VFX – A New Frontier: The Impact of Innovative Technology on Visual Effects

Chabanova, Anastasia

VFX – A New Frontier: The Impact of Innovative Technology on Visual Effects

Anastasia Chabanova

Westminster School of Media and Communications

University of Westminster

This dissertation is submitted for the degree of
Doctor of Philosophy

University of Westminster October, 2022

Abstract

Although Visual Effects (VFX) are an increasingly important element of the media content demanded by audiences, of media production (filmmaking and storytelling) and of the media industries, VFX remains a relatively under-research area within academic media or film studies. Innovations in technology are instrumental to the continuous developments in VFX technology, enabling the evolution of storytelling techniques and expanding the boundaries of VFX content and the VFX industries. In particular, a new wave of cutting-edge technologies have contributed to a period of extensive technical and organisational changes in the VFX industry. The implementation of these technologies is occurring during a period of growth in demand for VFX content, ever hight standards of quality (in particular the realism of VFX effects) and resulting demand for VFX workers. Supplying this demand for both greater quantity and quality of VFX content has increased the pressure for VFX production to be as efficient as possible. This has brought pressure on production budgets (to produce more and better content from the same or even diminishing resources) and production timeframes ("turnaround times"). One result of all these changes is that VFX workers now confront a multitude of new challenges.

This study investigates the new technology which is driving or enabling these changes and in particular focuses on the impact of implementing these technologies on VFX production (the VFX workflow). The study collects evidence to show how these new technologies, combined with the broader changes in the industry, are impacting VFX production and labour.

The thesis approaches this research task by use economic and sociological theories of technology, innovation, and production/labour to provide a conceptual framework to use in understanding how these changes are impacting the products produced by the industry and the work experience of VFX professionals.

The next step is to fill in the gaps in knowledge resulting from the relatively under-researched nature of VFX production withing academic media and film studies. The thesis provides a detailed account of the emergence and growth of “the VFX industry”, including historical and current product and process innovations. Rather than defining the object of study in relation to content genres or types of business, the study defines the industry in terms of workers using a common set of tools. This section of the thesis explores the economic and cultural causes of changes in the industry and maps out the qualitative changes in the creativity, job satisfaction and job security/precarity of VFX labour.

The collection of primary data through interviews with industry professionals provides the unique contribution of this study, setting out how VFX work is changing in different content genres, types of business and production roles, at different hierarchical levels.

This study contributes to the field by addressing the need for academic and empirical research in this neglected area of study. The thesis contributes original knowledge on the impact of current technological innovations by providing research based on primary data collected from interviews with the VFX workers impacted by the implementation of the technologies. Potential policy and practical applications of this research include assisting industry professionals in deconstructing the marketing “hype” around these cutting-edge technologies and outlining uncertainties and implications of these technologies, helping them in the complex decision making of evaluating and implementing current innovative technology

Table of Contents

Word Count: 68,435

List of Tables and Figures

Abbreviations

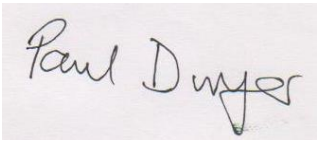
2D	Two-dimensional
3D	Three-dimensional
5G	Fifth Generation
AI	Artificial Intelligence
AR	Augmented Reality
BAFTA	British Academy of Film and Television Arts
BBC	British Broadcasting Corporation
BFI	British Film Institute
COO	Chief Operating Officer
COVID-19	Coronavirus Disease 2019
CG	Computer Generated or Computer Graphics
CGI	Computer Generated Imagery
CPU	Central Processing Unit
Dept	Department
DoP	Director of Photography
DSM	Documentary Search Method
DVD	Digital Versatile Disk
FTR	Film Tax Relief
FX	Effects
GAN	Generative Adversarial Network
GPU	Graphics Processing Unit
HD	High Definition
HoD	Head of the Department
IT	Information Technology
LA	Los Angeles
LED	Light-emitting Diode
LiDAR	Light Detection and Ranging
ML	Machine Learning
MR	Mixed Reality
NFT	Non-fungible Token
PEC	Political Economy of Communications
PDG	Procedural Dependency Graph
PIS	Participant Information Sheets
Previs/Pre-vis	Previsualisation
RTE	Real-time Engine
RQ	Research Questions
Sci-Fi	Science Fiction
SFX	Special Effects
TCE	Transaction Cost Economics
TD	Technical Director
TV	Television
UK	United Kingdom
US	United States
VES	Visual Effects Society
VFX	Visual Effects
VoD	Video on Demand
VPN	Virtual Private Network
VR	Virtual Reality

Author's Declaration

I hereby declare that all the material contained in this thesis is the result of my own work and investigations, except where otherwise identified by references. No portion of the work referred to in this thesis has been nor will it be submitted in whole or in part in support of an application for the award for another degree or qualification of University of Westminster or any other university or other institute of learning other than that of a Doctor of Philosophy at the University of Westminster.

Signed:  **ANASTASIA CHABANOVA**

[RESEARCHER]

Signed:  **Dr PAUL DWYER**

[DIRECTOR OF STUDIES]

Date: **01 / 06 / 22**

Introduction

Origins of Thesis

This thesis builds on, and is grounded in, my ongoing professional interest and experience in innovative ways of filmmaking and the possibilities of new storytelling techniques that arise as new technologies become available. The VFX industry is currently undergoing profound technical and organisational changes (Kaufman, 2019; Kaufman, 2020; Failes, 2020g; Visual Effects Society, 2020) and this research aims to address the need for academic studies in this area.

The first step in this process is to "demystify" the world of VFX. The world of film and tv has a large number of technical or industry terms. Film and TV studies academics have continued to help wider audiences understand these terms (Bordwell *et al.* 1985). The VFX sector uses all of the more general film and TV terminology but introduces a further range of terms specific to VFX content and production processes (Turnock, 2014). The interviews and documentary research for this study involves many of these terms and also a range of technical terms taken from the worlds of computing and IT or from the combination of these processes with film, TV and VFX. To try to help a wider audience understand all this, this thesis includes a detailed glossary (p229-234) with explanations of the terms used and sometime also the relationships between them.

The next step is in mapping out the scale and significance of VFX industry. The demand for VFX is growing, even films that would not be considered as heavy use VFX films have visual effects (Wright, 2011). VFX today takes up to 30-40% of the total production budget of many feature films and TV productions (Rüling and Duymedjian, 2014; Sanson and Curtin, 2017). VFX productions involve large workforces in various locations and significant numbers of artists (Samaras and Johnston, 2018). Next, the study tries to demystify the key processes involved in VFX production. Academic and industry

literature is reviewed to tell the historical evolution of processes like rendering, rotoscoping, Computer Generated Imagery (CGI) production etc. This section describes the VFX pipeline and the tasks of VFX workers. The industry term "pipeline" generally refers to the workflow/all stages of VFX production (Fitzgerald, 2018; Lee, 2019). To start to analyse how technology may be impacting these "traditional" VFX processes and pipeline, current technical literature is reviewed to identify the technologies industry professionals believe are having most impact on VFX production. These technologies include Artificial Intelligence (AI), Machine Learning (ML), Real-time technology, Virtual production, Cloud-based technology etc. All these technologies are explained, and the literature is reviewed to identify where industry professionals believe the technologies will have most impact on the processes and pipeline of VFX production.

Studying technical literature identifies a kind of "technical determinism". Industry journals seem to assume that because a technology exists it will inevitably have a big impact on the industry. So, the next step in the study is to try to understand the forces that might be driving implementation of technologies, and those that might mean companies don't or can't use them. The literature review covers economic pressures to adopt. The pressure for VFX production to be as efficient as possible means decreased budgets and turnaround times (Allison et. al; Sanson and Curtin, 2016; Heusser, 2013; MovieLabs, 2019; Venkatasawmy, 2016), which raises pipeline and data management challenges (Chung, 2011). But the literature review also identifies the important cultural forces which are driving companies to adopt new technology. The ambition to achieve more realistic and seamless visual effects continues to grow (Giralt, 2017; Samaras and Johnston, 2018), increasing the pressure to follow the highest quality and seamless reality standards in VFX.

The final step is to show what it means for VFX workers to be involved in these changes in their work. Here it is important to use academic literature review to understand research on creativity, job satisfaction and job security/precarity (Hesmondhalgh and Baker, 2008). The data collection section of this study tries to discover exactly which technologies are being adopted and where in the VFX production pipeline they are having an impact. Using a qualitative methodology, this research focuses on exploring how the innovative technologies identified are/are not impacting VFX production. The aim of this part of the research is to contribute to the academic and professional literature in the field

by providing insight into how the current technological innovations in video production may be driving changes in the VFX pipeline and the tasks of VFX workers. Having identified these key changes, the research aims to explore whether and how these changes have brought qualitative changes to the creativity, job satisfaction and job security of VFX workers.

The purpose of this thesis is to use cultural, economic, and sociological theories to enable a better understanding of how these changes are impacting the products produced by the industry and the work experience of VFX professionals. Finally, in setting out a programme for study in an area largely neglected by academic research, this thesis will conclude with recommendations for future research in the area of VFX production.

Research Questions

In researching the topic of VFX production this study has focused on trying to explain the likely impacts technologies developed in the last 5-10 years are now having on the performance of various stages of VFX production, and on specific VFX roles. The data collection focused on a crucial time period (from October 2020 to September 2022) when additional pressures towards digitisation, generated by the COVID-19 pandemic, further accelerated changes which had already been taking place over a longer time-period (since early 2000s).

This research aims to answer the following research questions (RQs):

1. Which new technologies are having the greatest impact on the VFX pipeline and what stages of VFX production pipeline (e.g., previs, rotoscoping, rendering) are most impacted?

2. What are the causes (e.g., the need to reduce time and cost) that drive the adoption of these new technologies in the VFX pipeline?

3. How do VFX workers feel new technologies changed the nature of their work, and with what consequences on conditions for creativity, job satisfaction and job security or precarity?

Research Aims and Objectives

Constant developments in technology create the possibility for filmmakers to push creative boundaries and create new ways of storytelling (Allison et al., 2016; Krotoski, 2011; Alexander, 2017; Murphy, 2018; Digital Storytellers, 2019; Summerfield, 2019). In the last decades of the twentieth century, visual effects have gained importance due to innovations in digital technologies, enabling VFX producers to create new ways of digital filmmaking (Allison et al., 2016). This change is reconstructing the VFX process and reformulating the abilities of VFX production (Dinur, 2017).

To give an introduction to the technical language and basic tasks involved in VFX, this section describes the basic products and processes involved. The basic products of VFX production are moving images (such as objects, characters, environments, and even entire scenes). The distinction between other forms of film and video production is that VFX products are not now normally possible to create physically with live-action capture using a camera. The majority of VFX products are digitally created, manipulated or enhanced (Finance and Zwerman, 2015; Okun et al., 2015). These images can be either two dimensions (2D), which is used to create elements such as matte paintings, and three dimensions (3D), which is used to create more complex elements such as objects or characters.

The VFX production process is described in detail in Chapter 1 (see p25), the overall production process is referred to as the workflow and is managed by a pipeline (see p28). The diagram below shows the main VFX tasks and roles involved.

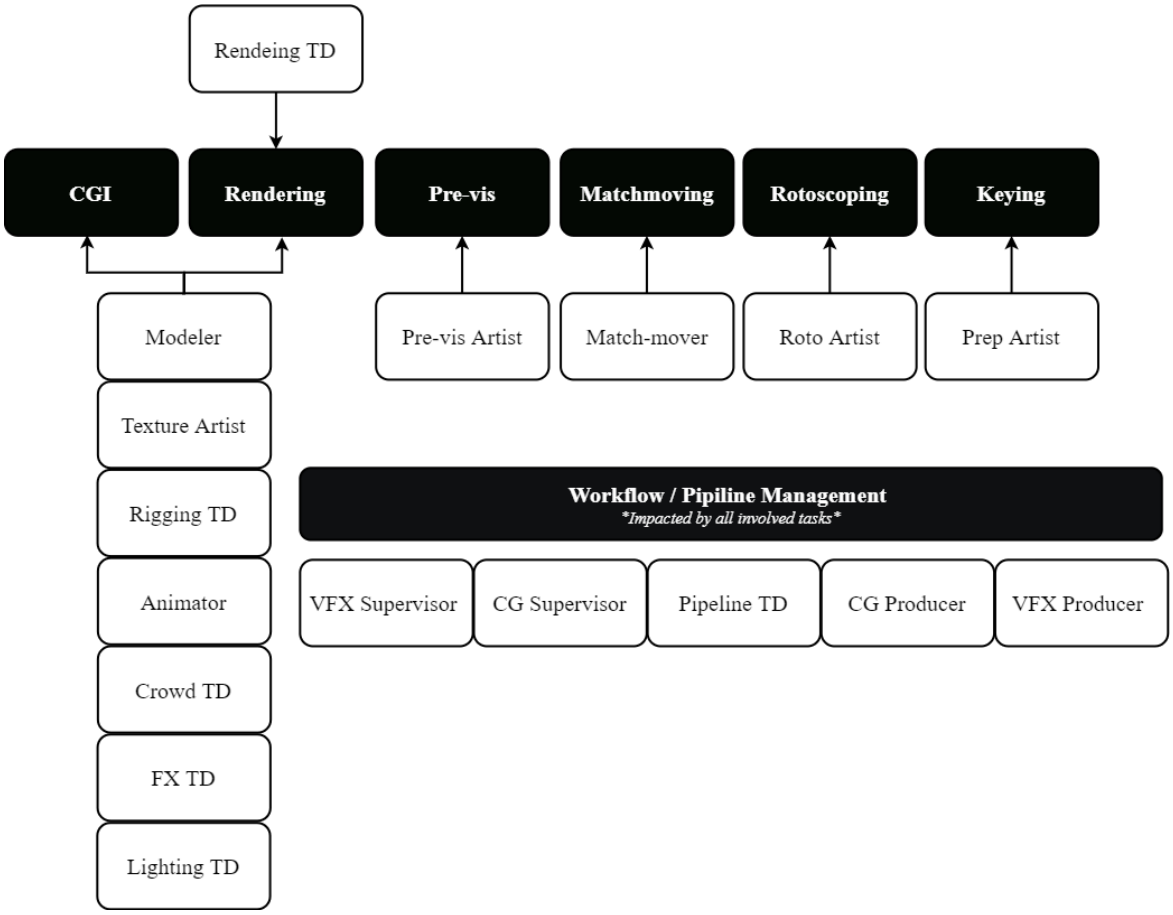


Figure 1: Main VFX Tasks & Roles

Sources: (Chung, 2011; Dinur, 2017; Dobbert, 2012; Dunlop, 2014; Finance & Zwerman, 2010; Lee, 2019; Pluralsight, 2015; Scalfari, 2019; Zamanian, 2016)

The aim of this study is to discover how far new technologies are changing these individual tasks and also the overall production process and its relation to the other stages of film and tv production. The first step, as Chapter 1 outlines (see pp19-28, pp39-52) more specifically, is to research industry reports and some academic studies to identify the VFX tasks whose characteristics mean they are most likely to be impacted by current innovations in technology. These can be briefly introduced here:

- **Pipeline Management –** *Cloud-based* (see p48) technology allows all production data (e.g., scripts, live footage, VFX assets) to be stored in the cloud and run-on cloud based virtual workstations rather than on-premise workstations, which would fundamentally change VFX production workflows (Dunlop, 2014; MovieLabs, 2019). This technology has the potential to increase IT security level

(MovieLabs, 2019) and enable remote work from any location in the world (Dunlop, 2014; MovieLabs, 2019). Additionally, *AI* and *ML* (see p41) technology is being implemented for automating some aspects of pipeline management (Failes, 2019a). These technologies have the potential to increase efficiency and productivity of pipeline management.

- **Pre-visualisation** (previs or pre-vis) **-** *Virtual Production* (see p51) technology (being developed by companies such as Ncam) allows live visualisation of CG VFX shots on set in real-time while filming (The Focus, 2019; Ncam, no date). *Real-time* rendering tools and virtual production techniques allow pre-vis studios to plan content creation more precisely by creating a single integrated workflow (Failes, 2020b). Similarly, *Mixed Reality (MR)* (see p52) technology (e.g., Microsoft and HoloLens) allows for the previsualisation and interaction with the VFX context of the location, where the camera is used to view the real set and virtual CG extensions at the same time (Dinur, 2017). Furthermore, *Augmented Reality (AR)* (see p52) technology also provides an interactive approach for pre-vis (Kadner, 2018). These technologies have the potential to increase efficiency and reduce risk of waste of this stage of VFX production.

- **Rendering -** the literature suggests that *Real-time* technology (see p45) is likely to speed up the process of rendering (McCullaugh, 2020; MovieLabs, 2019; Failes, 2017; Failes, 2020b), suggesting that this technology has the potential to increase efficiency and reduce the risk of waste. Further impacts of real-time technology on this process are described below under CGI.

- **Rotoscoping –** *AI* (including *ML*) technology is having a significant impact on rotoscoping (Xu et al, 2017) by automating some aspects of this process (Failes, 2019a), enabling semi-automated rotoscoping, which may reduce the time and money spent on this task (Sidhu, 2015). Similarly, *Lightfield Cinematography* (see p50) technology is being developed with the aim of using lightfield cameras equipped with pixel-accurate depth mapping to allow easier rotoscoping (Dinur, 2017). These technologies have the potential to reduce the time and costs of rotoscoping.

- **Keying –** the pixel-accurate depth mapping of *Lightfield Cinematography* has the potential use of reducing time and cost of this process by allowing easier and more detailed extraction of elements (Dinus, 2017; Failes, 2019b) and has the potential to replace the use of greenscreens (Dinur, 2017; Foster, 2017). Reviews of current research on technological innovations in VFX show that *AI* (including *ML*) also has a significant impact on the process of keying (Lutz, Amplianitis and Smolić, 2018). Furthermore, *Nano Technology* (being developed by companies such as Surrey NanoSystems) uses super-black coating that absorbs almost all incident light (Dinur, 2017; Surrey NanoSystems, no date), which can be used on 3D objects (to easily separate them the rest of the scene) or can replace use of a green screen (by allowing extraction derived from luminosity). These technologies have the potential to make the keying process more precise and less time-consuming, increasing efficiency and reducing the risk of waste in the process.

- **Match-moving –** the autonomous and simple functionality of *AI* has the potential to impact the match-moving (or motion tracking) by use of *ML* for face recognition and automatic tracking (Anderson, no date), which could increase efficiency and decrease costs.

- **CGI** - *Real-time* rendering and *AI* technologies (e.g., AI-based tools such as Headshot, which generates a digital human by analysing a photo) have the potential to increase flexibility and allow faster CG creation with automation, potentially also increasing efficiency and reducing the risk of waste in the film production process (Failes, 2019a; Failes, 2020a). Furthermore, authors have noted the potential of Real-time rendering to speed up the interdependent tasks of creative collaboration between VFX artists and filmmakers by increasing flexibility in enabling real-time compositing of CG (McCullaugh, 2020; MovieLabs, 2019; Failes, 2017; Failes, 2020b). There is also some suggestion of convergence as technology, used in the gaming industry, is increasingly becoming higher quality and has the potential to soon be used for VFX creation in film and TV (Dinur, 2017). Epic Games, a video games and software developer, is currently developing and experimenting with this technology to try to increase flexibility (enabling CG elements to be composited in real-time against live action footage) in creating CG environments and characters (Failes, 2017). Furthermore,

Epic Games recently acquired 3Lateral, the leader in CG character tools, which enabled the company to incorporate a game engine (Unreal Engine) to create real-time photoreal CG humans using a live actor performance (Failes, 2020a). This technique has been used in TV, film, and commercials; examples include CG Alita's use of Rosa Salazar's performance for Alita: Battle Angel, the CG creation of the "young" Anthony Hopkins in Westworld, and the CG Elton John in the 2019 John Lewis commercial (Failes, 2019c; Sarto, 2019). Digital Domaine, a VFX studio, used real-time digital human technology to create a real-time Pikachu and a real-time digital version of Martin Luther King Jr. (Failes, 2020a). Furthermore, Reallusion (animation software) created a tool called iClone, that includes a real-time technology Motion Live plugin, which reduces the time it takes to create and capture CG characters by allowing VFX artists and animators to input actors into characters (Failes, 2020c).

Research Aims

The set-out research questions of this study aim to:

- Highlight the importance of VFX in video production today. VFX has helped dramatically change the video production landscape; a development that should be the forefront of film innovation and academic research to further improve the process. Video production, more specifically the VFX sector, should no longer be a 'neglected area of academic study'.
- Explain the historical and current circumstances of how different stages of VFX production have emerged and changed, decomposed into sub-tasks and their relationship to product and process innovation. Furthermore, explore how VFX roles emerged and integrated.
- Identify current technological innovations in video production, explore how they are driving the VFX pipeline to change and collect evidence to answer the question of how these technologies are impacting VFX production.
- Explain how current technological innovations are impacting (and may impact in the future) the creativity, job satisfaction and job security or precarity of VFX workers.
- Set a foundation for further research by identifying a gap in the knowledge and a range of challenges VFX industry and workers are facing today.

Research Objectives

1. Mapping the Changes in VFX Production

Digitisation has had a huge impact on the VFX industry, and new technologies currently being introduced to the industry have the potential to make dramatic changes to the process of VFX production. This research mainly focuses on UK based VFX houses and freelancers to explore and evaluate the impact of innovative technologies on the video post-production process of VFX. The research will outline how the implementation of new technology has changed the performance of individual VFX production stages and the relationship between phases of both VFX production and entire video production process. Thus, the research will examine the extent to which new technologies listed previously, are:

- Impacting the performance of some VFX tasks, which unfolds by process innovation.
- Changing the relationship between different stages of VFX production, which develops by process innovation.
- Creating new VFX tasks, which evolves by product and process innovation.

2. Explaining Changes in VFX Production

The section above has very briefly outlined how current innovations in technologies have the potential to change the performance of some tasks, the relationship between different stages of VFX production, and creativity, job satisfaction and job security/precarity of VFX workers. While the literature review describes what changes may happen, some of the industry literature (e.g., Brown, 2019; Failes, 2019a; Failes, 2020a; Hatch, 2020; Kaufman, 2020; Wolfe, 2019a) seems to assume that changes will happen simply because new technology exists. This research starts from the view that existence of technology does not inevitably cause changes to happen. This view is deterministic, and instead, it is important to understand why technology is sometimes implemented and sometimes is not. To identify how previous academics have described and explained the causes of product and process changes in film and video production, this study reviewed literature relating to the following concepts: product and process innovation, creative labour, and innovative technology. The explanatory variables reviewed in this study explain why workflow may

change, include the following factors: the economic and marketing strategies used, the economic impact of innovative technologies, the product, process, and range of technological innovations involved in production.

3. Collecting Empirical Data to Map Changes and Test the Theoretical Framework

The methodology chapter (see p100) describes how the theoretical framework will be used to identify relevant data to collect, which can then establish how far some stages of VFX production are significantly changing as a result of the implementation of new technologies. Specifically, the methodology section will outline how the research process will collect data to illustrate changes in:

- The way these stages are defined and completed.
- The way new technologies are integrated into the workflow.
- How the workers are affected by these changes.

Original Contribution to Knowledge

Video production is a relatively neglected area of study in the media studies field (Garnham, 2011, Mayer et al. 2009). Within this small field, post-production, and academic studies of VFX production are very rare (Abouaf, 2000; Ceccarelli, 2017; Chung, 2011; de Bruin, 2019; Giralt, 2017; Jones, 2015; Kapler, 2002; Mohr and Carter, 2016; Morgan, 2020; Samaras and Johnston, 2018; Venkatasawmy, 2012). As a result, this thesis will be pioneering in its attempt to contribute to this small field and provide original knowledge by:

- Providing a detailed study of VFX production sector, an area of the industry currently neglected within academic literature.
- Provide a history of product and process innovation in VFX production, including current changes in technology.
- Providing original knowledge of how current technological innovations are changing the VFX production process. This will include identifying the potential these innovative technologies have to improve the quality and creativity of the

VFX production process, as well as critically evaluating negative impacts on quality and creativity.

- Exploring how the implementation of new technology is impacting labour by identifying qualitative changes in the creativity, job satisfaction and job security of VFX workers.
- Identifying the broader economic and cultural factors likely to be the causes of changes in the VFX production process.
- Raise the awareness of the importance of the VFX industry as a field of study and in particular the role of new technologies in changing the way VFX workers produce work.
- Influence policy and practice in the field: real world applications of this research may include industry professionals evaluating the use of current innovative technologies for improvement of the VFX production process. For example, to reduce time and increase cost efficiency, but perhaps more importantly, to improve creativity, jobs satisfaction and job security of VFX workers.

Research Methodology Overview

Underlying Research Philosophy

The philosophical assumptions underlying this study come from two perspectives – interpretivism (of hermeneutic in nature) and social constructionism. An interpretive approach helps to understand influences and impacts of technological trajectories (Deetz, 1996), gives insight of the process of influence (Walsham, 1993) and explanation (Burrell and Morgan, 1979). The social constructivism approach extends this by providing knowledge within the social-cultural context. By using both subjective and objective views of reality, this research will give unique individual insight and explanation.

Ethics

As a standard principle of research conduct (Eysenbach and Till, 2001), PIS forms were given to each participant and a consent form was signed prior to each interview. For remote interviews, the use of camera or audio only interviews were discussed and agreed with participants prior to each interview. Furthermore, in cases where the participant wished to retract any information given during the interview, the researcher complied to avoid any complications and to avoid any loss of trust (Morse and Field, 1995).

Sampling

This study used the purposive sampling method amplified by snowball sampling where the researcher got suggestions for other participants from the selected participants. Purposive sampling for this research consists of VFX freelancers and in-house workers, which include personal connections, recommendations from personal connections and researched freelancers who have been involved in VFX heavy productions. The VFX roles that have been identified as potentially being impacted include supervisory and specific tasks orientated jobs. Generic data and an overview of impacts was gathered from the supervisor-based roles, which includes information about VFX production management, and all tasks identified. However, data concerning job satisfaction was gathered from individuals who carry out those specific tasks.

Data Collection and Analysis

Because the area of study is cutting edge technologies and new forms of content and production practices, there is not really any discussion of the key aspects of this study in academic literature. Researching the main technologies and likely areas of impact could only be done through research of technical literature, industry conferences, manufacturers reports and online discussions. Documentary research method (DSM) of all of these forms of secondary data was necessary to identify and evaluate the capabilities of the new technologies and their impact on VFX, as the first step in refining the research questions, identifying population to collect data from and developing a survey and interview questionnaires. DSM for this study involved conducting detailed studies of various industry sources including articles from industry technical journals (such as *VFX Voice*

and *VFXWorld*), technology manufacturers white paper reports (e.g., by MovieLabs and Escape Technology), industry reports (e.g., by BFI and VES) and a wide range of online sources. This data gathered by this method is not presented in the data chapters of this thesis because it was used to help "demystify" VFX, to frame the research questions, to describe the technologies to be studied, to develop the research methodology and to explain the relationships between current developments and the historical development of the VFX production process. The results of documentary study form part of the introduction, literature review and methodology chapters.

Due to COVID-19, one-to-one interviews were carried out remotely over Zoom. The synchronous method was used to conduct interviews in real-time and audio recording, with informed consent of participants. Providing in-depth qualitative data, which included insights into film professional's opinions and beliefs on current and future predictions. This research included data collection by semi-structured interviews based on predetermined but open-ended key questions as guided conversation, which allowed the researcher to get answers to desired questions without limiting the participants in their answers. When formulating the key questions as an interview guide the researcher made sure that subsequent questions did not force or lead the participant to give a particular answer (Bryman, 2004; Drury, 2011). The analysis and coding process involved the researcher going through interview answers and classifying some answers into categories, which helped identify main themes from the interview data gathered in this study.

A Novel Approach to Data Collection: Industry Report – "VFX: A New Frontier"

As this research includes interviews with VFX industry professionals, who are creative and visual people, it makes it naturally difficult to get them excited about a research project that is mostly presented in a written form. Furthermore, due to the pandemic, taking part in a research project would not be their priority. As a result of low response rate, the researcher was required to explore alternative approaches and consequently *VFX: A New Frontier* was created. A website and an industry report were established as a way to deal with the initial low response rate resulting from the impact of the pandemic on the industry. This addition to the methodology has showed a significant impact on the response rate. This is further explained in the methodology chapter (see p70).

Organisation of the Thesis

The thesis is divided into seven chapters. The Introduction Chapter outlines research aims and objectives followed by research questions. An overview of research methodology is provided, and the chapter concludes with contributions to knowledge. Chapter 1 provides a rationale for the research and a review of relevant empirical, professional, and theoretical literature. The literature review describes and explains the emergence of visual effects and its production process, economic and social explanations of innovation in the industry. Furthermore, the chapter introduces discussing the production studies in relation to VFX production. The theoretical literature on film and new media, political economy and organisation and flexible specialisation is reviewed to try to identify how academic authors discuss the main forces and causal factors which influence film and tv production in general.

Description and explanation of the chosen methodology (the adoption of qualitative interviews, sampling, and details data collection) is presented in Chapter 2, describing the aims and the process of identifying and accessing interviewees by using an innovative approach during COVID-19. The overall aims of the research are restated, and ethical considerations are also highlighted in this chapter. Chapter 3 draws on methodology described in Chapter 2 to describe the process of data collection methods for this study, outlining the interview design and structure, sampling, process of collection and ethics and consent.

Consequently, Chapter 4 then sets out the empirical findings of the research and uses the theoretical perspective developed in Chapter 1 to give a detailed analysis of the data. The data analysis chapter specifies objectives and processes of analysis, summarises the findings and, outlines the adoption, implementation, and impacts of the new VFX technology. This is followed by the Discussion Chapter, which draws further on the theoretical perspective outlined in Chapter 1. This chapter starts to identify how cultural influences on production, such as the new standards of quality which become demanded and acceptable to audiences, can drive implementation of technology. The chapter also refers to economic theories to show how productivity is important in implementation.

Looking at creativity, job satisfaction and job security, the chapter tries to identify if tasks are less creative or more creative or more routine or more skilled. Theories of flexible specialisation and precarity are relevant to understand what may be driving VFX producers to implement technology in these ways. This chapter provides a detailed discussion of the interviews to identify the findings in relation to the research questions including not only the evidence of changes in VFX production and VFX workers jobs, but also trying to understand why these changes are happening by exploring their relevance to the wider literature in the field.

The final chapter concludes the thesis by providing a synthesis of the main findings, input for contribution to field, strengths and limitations and recommendations for future research. Ultimately, this research aims to highlight the importance of VFX and understand how and why its process is changing due to impact from new technology. This study consists of 20 in depth interviews with industry professionals, the data is analysed where most significant innovative technologies used in VFX today are identified, their potential impact on VFX production and labour is evaluated and the causes of those impacts are explored.

Chapter I: Literature Review

This chapter outlines and discusses main contributors to this field of study, highlighting VFX as neglected area of study and its importance in today's video production. The chapter starts by reviewing literature on the history of VFX, providing a historical and technical account of how different stages of VFX production emerged. The literature review outlines the history of technological innovations in VFX by opening a discussion on product and process innovations. Continuing the discussion of innovations in VFX, a range of technical literature (journal articles and industry reports) have been reviewed to identify current technologies most likely to impact the VFX workflow. Economic and social causes of innovation in VFX is discussed and the impacts of new technology on creative labour is explained. After the review of various theories and main literature, the state argument and the gap in the knowledge is presented.

Conceptual Framework

As noted above, to identify how previous academics have described and explained the causes of product and process changes in VFX, this study reviewed literature relating to the following concepts: product and process innovation, creative labour, and innovative technology. To explain the causes of changes in the VFX workflow, the study has identified the following explanatory variables: the economic and marketing strategies used, the economic impact of innovative technologies, the product, process, and range of technological innovations involved in VFX production.

The review of academic literature outlines existing knowledge about film and tv production. The idea is to create a conceptual framework to understand what forces are involved in changes in production and what impacts the changes have. The main literature looks at the cultural reasons why film and TV content changes and why new techniques and technologies are used to create them. The main literature reviewed here is about film

and TV styles and effects (Bordwell et al., 1985; Lotz, 2007; The next area of important literature is in political economy and organisation. This explains economic forces and marketing strategies which impact production– key areas are media economics (Doyle, 2002), vertical integration and disintegration (Porter, 1985) and flexible specialisation, (Storper 1993). Understanding technological forces for change is covered in academic studies of innovation (Manovich, 2002, Christensen, 2013). Changes in production involves study of subjects like the production workflow, division of labour, task decomposition, cycle time, task variability and task interdependence (Thompson, 1967; Taylor, 1914; Staiger, 1979). Studies of impacts of changes in production on jobs of media workers identify aspects if creative labour – creativity, job satisfaction, security and precarity (Banks 2007, 2014; Sanson and Curtin, 2017; Staiger, 1985)

Literature review is concerned with general studies of media and production, with little reference to VFX and so this chapter outlines the opportunities available for delivery of original contribution to this small and relatively neglected area of study:

VFX producers create a range of "products" which are video "effects", which can enhance what can be achieved by film and video recording. In that way, VFX is no different to any other aspect of media production. There have been many studies of the range of styles and effects created by media producers in the production process (e.g., Bordwell et al., 1985) and a few studies that explore discussions between industry and academic researchers (e.g., Hill et al., 2017). However, academic studies of the styles, techniques and workflow of visual effects are relatively rare (Abouaf, 2000; Ceccarelli, 2017; Chung, 2011; de Bruin, 2019; Giralt, 2017; Jones, 2015; Kapler, 2002; Mohr and Carter, 2016; Morgan, 2020; Venkatasawmy, 2012).

This gap is becoming more important as, the VFX industry is a growing section of the media industries, providing content for a range of platforms including film, TV, and games. But compared to studies of the film, TV and news industries, studies of the VFX industry are rare. Even where there are studies of VFX the focus is mainly on aesthetics or cultural aspects, not on production. Within the range of media studies, the area of 'production studies', even studies of the production of film, TV and video is a neglected area of study in the media studies field (Garnham, 2011). Existing studies of production tend to focus specific areas such as scriptwriting (Conor, 2014; Maras, 2009) or on the relationship between the production process and the ideological content of the film or TV

series produced (Mayer et al. 2009). Within this small field of 'production studies', academic studies of post-production and VFX production are very rare.

Some of the key contributors on the subject of VFX, innovations in technology and its impact on the industry, are technical publications such as *VFX Voice* and *VFXWorld*, which include research interviews with industry professionals. Furthermore, books by various industry professionals and academics, such as Rickitt (2006), Dinur (2019) and Ryan (2017), provide historical accounts of causes of product innovations and process developments in VFX and some outline the future impacts of technological innovations, some even mention specific technologies that may have the most impact on VFX. RQ3 is explored in the review of the literature dealing with creativity and organisation theory, for example Staiger (1979; 1985) and Banks (2010). Studies on VFX labour are rare, however there are a few accounts of the impact of organisation and management in VFX on creativity (Spelthann and Haunschild, 2011).

Most current literature on VFX provides accounts on current technological innovations and prospects, such as academic papers by research teams that are developing and/or applying various innovative technologies for VFX. For example, Adobe's research team and Beckman Institute for Advanced Science and Technology and University of Illinois, created an AI based tool that automates the extraction of backgrounds based on deep learning techniques (Xu et al, 2017).

Similarly, researchers at Trinity College Dublin, used AI to create a generative adversarial network (GAN) for natural image matting, which extracts very detailed elements (such as hair) without the use of green screen (Lutz, Amplianitis and Smolić, 2018). Another example is, Carnegie Mellon University in collaboration with DeepMotion, created real-time ML tool that enables animated characters in video games to perform a physical skill by using deep reinforcement learning and motion capture data (Spice, 2018).

Although some of these recent studies identify new innovations related to VFX and provide general descriptions of the impacts they are having or will have on the VFX pipeline and specific tasks, none of them provide detailed description and explanation of:

- how and why exactly these technologies impact VFX – for example, some say ‘reduce cost’ or ‘less time-consuming’ but give no further detail, measurement or substantial evidence of these effects is provided
- how they impact labour – no information on job satisfaction and security or changes in level of creativity is given

Some writers, who focus on technological innovation, do not assume technology will cause inevitable changes in VFX production (e.g., Manovich, 2001, 2005), but suggest that technological innovations emerge and succeed due to the needs for improvements in either the process or the technology, or both (Bordwell et al., 1985). Some writers see VFX production in terms of the “convergence” of computer, digital, film and video technologies. Digitalisation has changed the way academics view media studies. For example, with digitalisation and emergence of on-demand platforms, television has become digital media (Bennett, 2008). Bennett and Strange (2011) suggest a new approach to study contemporary media due to digitalisation. Within the field of media studies, which is continuously being impact by new technology, academics have not studied the video post-production process in detail (McClean, 2007; Turnock, 2012, 2015; Wright, 2011). As VFX is now a very computer-based process, writers on “new media” theory (Manovich, 2001, 2005) review the similarities of cinema and computer products and processes, suggesting that the histories of cinema and computing are entwined. Manovich (2001, 2005) suggests that computerisation affects the process of video production, and developments in computer technology cause innovation in video production.

Technical changes continue to allow production companies to create new techniques of digital filmmaking. Some of the literature, particularly in field of film theory, explains the historical development of visual effects in terms of product innovation (e.g., Allison et. al, 2016; Bordwell et al., 1985). Since the earliest days of cinema, constant developments in technology have allowed filmmakers to push creative boundaries and create new ways of storytelling (Allison et. al; Bordwell et al., 1985). The literature review identifies how the demand for improvements in the quality “product” (the VFX required for final movies or TV shows) influence the implementation of new technologies.

This research provides a foundation to be able to explain the significance of contemporary changes following the implementation of new technologies by putting them into the broader context of the historical development of VFX production, and the historical development of the film, TV, and post-production industry. The historical literature has been referenced with details of the film industry's timeline of development through the history of VFX and its increasing influence on the film industry. The research and analysis aim to include both the past and current developments taking place within the video production market. This will allow me to establish the nature of current innovations and future possibilities for the industry.

There is media production literature which focuses on the use of technology to improve production process. For example, Bordwell (1988) suggests that innovations in technology improve production efficiency by either decreasing the cost or the time of a particular task, which in turn is often achieved because the technology makes the results of production tasks more predictable (there is less 'task variability'), or by eliminating certain problems in the production process. Here, focus is on how pressure to improve cost efficiency interacted with technical developments to bring changes in the performance of a VFX task through the implementation of a different technology.

Writers in the field of political economy and organisation theory have analysed production processes in terms of how these technologies impacted labour and how the division of labour could affect both production innovation and efficiencies. Division of labour through task decomposition to increase efficiency is another important topic reviewed in economic literature in this area, which is studied in order to explore whether this process has been important in the historical changes in VFX production. The division of labour technique was first identified by Smith (1776), and it was used to improve specialisation by replacing craft production, (often involving production of the whole product by a craft worker), with manufacturing production, where the craft process would be broken down and decomposed into smaller tasks and carried out by separate specialised workers. Smith **(**1776) concluded that this specialisation resulted in increased output and a reduction in costs per unit when compared with the craft process, which led to increased profits.

The specialisation method was systematised in manufacturing by Taylor (1914), who introduced the concept of specialist routine tasks enabling the replacement of highly skilled labour by machines, or less skilled labour and improved industrial efficiency. Taylor focused on measuring the time and motions of workers to try to find the most efficient way of completing a task. For example, by reducing the number or increasing the efficiency of the worker's motions in performing a task, Taylor could reduce the overall time it took to complete the task. The idea of "cycle time" has become used by operations managers in working out how to measure improvements in production tasks (Mahadevan, 2015).

In media production terms like "turnaround time" are often used to talk about this type of measure of efficiency, additionally there are also measures such as the number of script pages filmed per day (Dwyer 2019). For VFX producers, turnaround or cycle time are likely to mean the time it takes to complete the whole process (e.g., production of a sequence or a whole film) or it could be the time to complete a particular VFX task (e.g., rendering a certain type of object).

One example where division of labour has not progressed so much is the distinction between pre-production (design) and production. In media this division is nowhere near as clear as in manufacturing. Empirical accounts of Film and TV production show that scripts are continually changed in production (Conor, 2014; Field, 2005; Snyder, 2005). This means the shooting script may only be a loose guide to the placement of cameras, people, and props, on set or on location. The design process continues in post-production, as directors and editors may make extensive changes to the script or what was intended on set when they start to assemble the elements of the film. Problems or opportunities identified during the editing process may lead to the process starting again (to a limited extent) with new elements being scripted (pre-production) and filmed (production). Thompson (1967) describes such types of production processes as interdependent.

This literature will be used to establish a theoretical and conceptual framework linking the identified new technologies with the various stages of VFX production, as a basis for explaining in detail the impacts these technologies are having on different VFX tasks. The diagram below shows the different stages of the VFX workflow, which is illustrated as an 'ideal type' of VFX production. Weber (1911) pioneered the use of ideal types as

academic constructs useful in comparing theoretical understanding with real-world data. Thus the actual workflows discussed in this thesis will differ from this ideal type, depending on the various factors identified in the literature review, including product genres and company/business types (see pages 92-95).

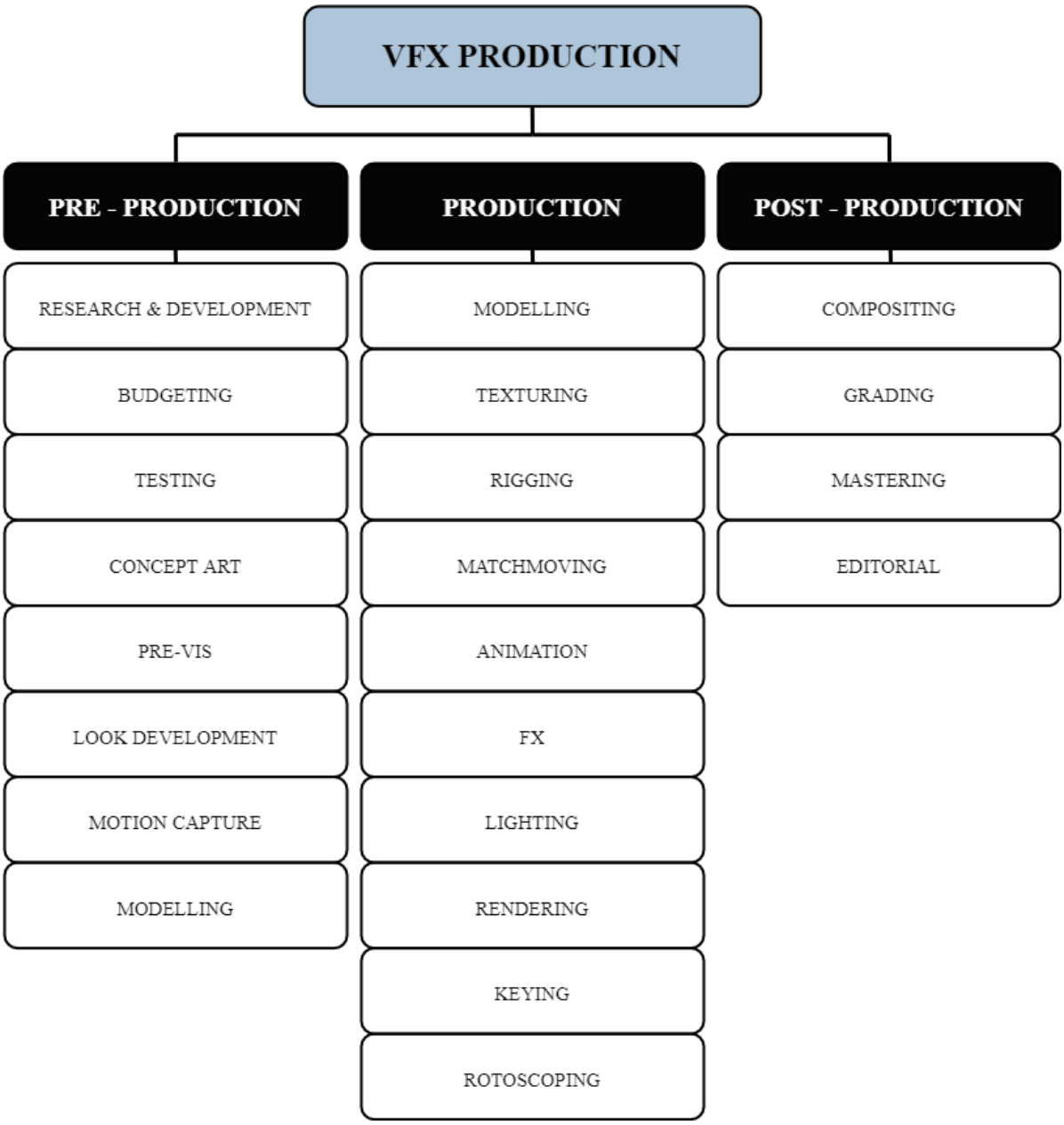


Figure 2: VFX Production Workflow

Sources: (Dinur, 2017; Dobbert, 2012; Dunlop, 2014; Finance and Zwerman, 2015; Fitzgerald, 2018; Lee, 2019; Spelthann and Haunschild, 2011; Zamanian, 2016; Zwerman and Okun, 2014)

The research explores impacts of changes in VFX production workflow caused by new technology on creativity, job satisfaction and security of VFX labour. The literature

review looks at authors such as Staiger (1979, 1985) who argued that media production becomes heavily standardised and routinised. This industrialisation limits creativity and innovation and can cause alienation. Staiger (1979) applied Marxist economic theory to argue that film production is based on routine tasks and is subject to overall changes across all economic sectors which replace craft processes with manufacturing style processes, and therefore causing 'alienation' of the worker and limiting creativity and innovation. Others such as Banks (2010) emphasise on continuing craft satisfaction from creative work. Banks (2010) looked at creative labour work conditions and environment. and its effects on creativity and quality of work and argued media production remained a craft process and could not be replaced by a manufacturing type process.

The next section of the literature review chapter sets out a theoretical framework to explain how the implementation of current innovative technologies is changing VFX production and why some technologies are not implemented. The research will also use the literature review to establish a theoretical framework to identify how implementation of the technology has affected cost and time efficiencies of VFX production, and creativity, job satisfaction and job security of VFX labour. These changes will be related to broader economic factors effecting the industry, along with cultural changes expressed in economic terms as consumer behaviour and the level of demand for VFX.

The Rise and Evolution of VFX

To address RQ2, the development of the key tasks of the VFX workflow and the emergence of associated production roles are identified in this chapter. The historical emergence of the main visual effects which will be researched are described in this section.

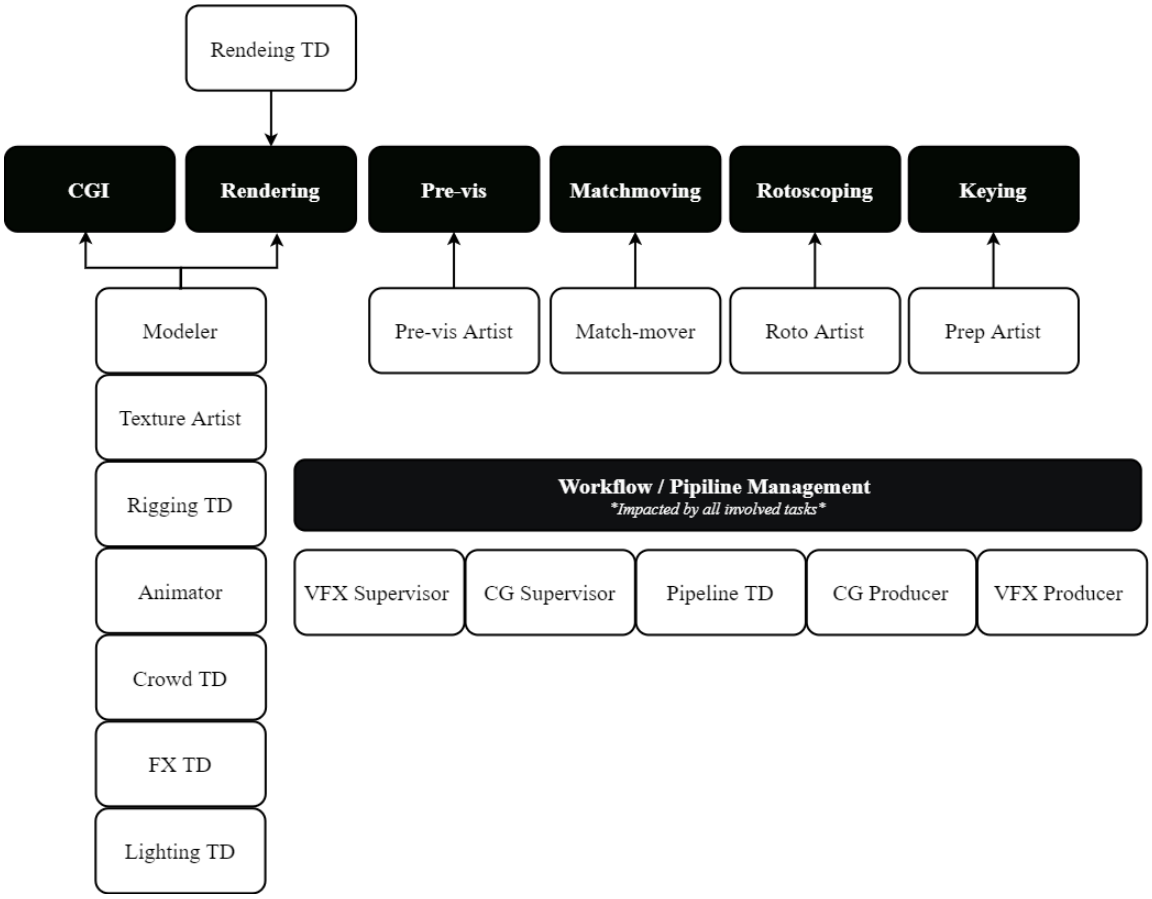


Figure 3: Main VFX Tasks & Roles

Sources: (Chung, 2011; Dinur, 2017; Dobbert, 2012; Dunlop, 2014; Finance & Zwerman, 2010; Lee, 2019; Pluralsight, 2015; Scalfari, 2019; Zamanian, 2016)

The diagram above illustrates the main VFX tasks, stages and interdependencies in the modern VFX production workflow and the jobs associated with them. The following sections explain evolution of this workflow, but for reference the main tasks are described below.

Previsualisation or often referred to as ‘previs’ (or ‘pre-vis), is a process of creating moving storyboards in 3D which show the desired CG shot concept with details

(movement, speed, time, proportions and sizes of CG elements) which is then used by the production team and the VFX supervisor as a reference on set when filming these shots (Desowitz, 2003; Finance & Zwerman, 2010; Okun et al., 2015; Spohr, 2019; Arundale & Trieu, 2015; Sawicki, 2011; Pardeshi and Karbhari, 2019).

CGI or often referred to as 'CG' is any image that is created or manipulated by a computer (Finance & Zwerman, 2010; Okun et al., 2015; Dinur, 2017; Pardeshi and Karbhari, 2019). There are three main artistic jobs (animator, modeler and texture artist) associated with creating and animating the main CG characters and objects and a range of technical and artistic roles involved in creating realistic effects.

There are a number of tasks which are connected to the process of combining live footage with CG animated or other VFX footage in a production:

Rotoscoping, also referred to as 'rotoing' or 'roto', is a process of tracing and contouring elements and their movement frame by frame, so they can be isolated and separated from the live footage (Fielding, 1985; Okun et al., 2015; Dinur, 2017; Spohr, 2019; Arundale & Trieu, 2015; Sawicki, 2011; Turnock, 2015).

Matchmoving or as it is often referred to as 'camera tracking' or '3D layout', is the "building block in today's modern CGI shot production" (Okun et al., 2015, p 689). It's a process of breaking down the live footage and creating a 3D scene that replicates the movement of the real camera which can then be used for animators to add effects (Dobbert, 2012; Okun et al.,2015; Finance & Zwerman, 2010). Matchmovers use matchmoving software, such as SynthEyes, which places tracking points to follow the movement and creates a digital camera which replicated the motions in the live footage (Mattingly, 2011; Okun et al.,2015). Although such software does help the matchmoving process by using measurement data such as LiDAR scans (also called '3D scans', which are used to create digital 3D representation of a real object) to assist mathematical camera movement, it is not an automated task as it still requires a lot of manual work from match-movers and animators usually start work simultaneously to add visual effects into real live footage shots (Dobbert, 2012). Previsualisation for these shots also planned in advance by the VFX team to help achieve the desired final outcome (Keil and Whissel, 2016).

Keying (or extracting a 'key') is a process of removing elements or objects from a scene. Green (or blue) screens are used to make extraction of elements easier by separating layers and creating a garbage matte, which is a term referred to the element that is being extracted (Mattingly, 2011; Okun et al., 2015; Dinur, 2017; Sawicki, 2011). Matte painting is used to create or replace a background and/or foregrounds (for example clouds) and produce a photorealistic scene (Okun et al., 2015; Finance & Zwerman, 2010; Dinur, 2017; Spohr, 2019). This process starts when a 3D scene is rendered through the digital camera and matte painters use the frame of this render to create a matte painting which is then inserted into the frame (Dobbert, 2012). This process has become a significant part of pre-production and previsualization to help achieve the desired outcome (Okun et al., 2015). Matte painting enabled filmmakers to tell stories in settings that would otherwise be impossible to film by creating abstract or inaccessible locations (Okun et al., 2015; Finance & Zwerman, 2010; Spohr, 2019). Although matte painting was originally done manually as a physical form of art (Fielding, 1985), CGI enabled matte painters to shift their work into the digital form and simultaneously increasing the control and freedom the artists have over creating and manipulating elements of this process (Keil and Whissel, 2016; Okun et al., 2015; Finance & Zwerman, 2010; Sawicki, 2011).

Rendering: Once the earlier stages of modeling, animation, texturing and lighting is completed, rendering is a downstream task which is a process of combining all elements of a CGI shot to create the final image by creating a 2D image from the 3D scene (Finance & Zwerman, 2010; Okun et al., 2015; Dinur, 2017; Spohr, 2019). Therefore, this process impacts other stages of VFX production, such as CGI.

In addition to specialised roles involved in the stages listed above, supervision and coordination of performance of VFX tasks involves several more jobs. The first is more to do with coordination with production and preproduction, which is done by the VFX Supervisor. Then, managing the production of CG elements, which is done by Computer Graphics Supervisor (CG Supervisor). Planning and budgeting the production of all the needed VFX elements is the responsible VFX producer and ensuring the technical operations and efficiency of the whole process is responsible Pipeline technical director.

VFX Workflow and Pipeline

A VFX workflow refers to every stage of VFX production. Organising the workflow requires expertise in every individual stage of the process, which is managed by a pipeline. A VFX pipeline is a process that breaks down all stages of the workflow in most efficient way. The VFX pipeline holds the whole VFX production together and ideally needs to be as flexible as possible to allow changes to be made throughout the process (Dunlop, 2014). Depending on the complexity and the size of a project, VFX production can be carried out in various VFX houses around the world (Pratt, Gill and Spelthann, 2007).

Culture and Technology: The Historical Development of VFX Techniques

Various VFX techniques emerged through process of technical development, alongside the emergence of film, animation, TV, and video game industries. During a very rapid development of technologies, since the early days of cinema, audiences immediately became fascinated with the imagery used and were naturally eager for further innovations. Innovations in Special Effects (SFX) by experimental filmmakers encouraged filmmakers to change their way of storytelling by adopting various techniques to achieve complex artificial imagery (Turnock, 2014). Griffiths (2010) suggests that the enticement of VFX today did not occur due to this experimentation period of SFX, but rather that the fascination started much earlier during medieval ages when the art in that era also pushed boundaries of reality.

SFX techniques were originally not separated from the core techniques of film production. Film pioneers like Méliès and Porter developed effects techniques alongside the development of the earliest methods of filmmaking (Bordwell et al., 1985). However, as the range of filmmaking techniques developed, SFX and later VFX became a specialist area of filmmaking, contained within a specialist department. Academic studies of filmmaking tended to focus on the 'production' area of directing film and TV and not the 'post-production' area which VFX became part of. In the pre-digital days, there was not a clear differentiation between SFX and VFX. However, they are now clearly defined as

two separate crafts and are often used together to magnify the desired effect. While SFX are real physical effects captured on camera, VFX are digitally generated artificial effects and enhancements, which are often used to re-create or enhance special effects and plays an important role to ensure that the visual effects look as authentic and smooth as possible (Giralt, 2017; Dinur, 2017; McClean, 2007; Okun et al., 2015; Pardeshi and Karbhari, 2019; Prince, 2011). SFX are still used to this day to both help achieve the desired effect and by creating cost effective options for these effects (Okun et al., 2015).

SFX divides into mechanical effects and optical effects (Fielding, 1985; Okun et al., 2015). Mechanical effects (or often referred to in the industry as 'practical' physical effects) are created live on set (North et al., 2015; Okun et al., 2015). They are usually considered part of the production process. These might include mechanised props, scenery, scale models, animatronics, prosthetic makeup, pyrotechnics, and atmospheric effects such as creating a certain type of weather or explosions. Optical effects are either created in-camera or in post-production, including the use of green screens (Fielding, 1985; Okun et al., 2015). They may take place as part of production or post-production. These SFX techniques are often used integrated with VFX to increase the effect of the action (Pardeshi and Karbhari, 2019; Okun et al., 2015).

VFX is the process of manipulating the imagery used in filmmaking to enhance or fabricate live-action shots. Unlike early uses of analogue SFX to create creatures which lacked detail and did not allow for smooth integration with background (Prince, 2011), creating them digitally with VFX allows to create a dynamic and seamless image (Pardeshi and Karbhari, 2019; Melki, 2019). VFX production consists of creating or modifying shots on a computer and integrating them with live action footage (Goulekas, 2001). Compared to SFX, which originated in the first days of filmmaking, VFX is a relatively young industry which uses technology to digitally create or manipulate moving images (Scott, 1998). The VFX sector emerged when film post-production, including special and optical effects, became digital and created new opportunities for filmmakers (Spelthann and Haunschild, 2011). Today, most types of video production (Film, TV, Commercials, Music Videos, and other types of video productions) contain VFX (Spelthann and Haunschild, 2011). This ranges from complex and expensive CGI production down to very small tasks like removing certain unwanted element from the footage. For example, *Terminator 2* (1991) had only 54 VFX shots but 23 years later

Captain America (2014) had over 2,500 VFX shots. This dramatic increase displays how much the industry has been impacted by the VFX in such little time (Arundale and Trieu, 2014). And an increase in VFX shots isn't only seen in Science Fiction (Sci-Fi) genre. The audience's demand for high-quality productions with engaging and realistic VFX increased and studios are including more VFX shots into films (Global Animation & VFX: Strategies, Trends & Opportunities Report). This increasing demand for perfection in this industry means that there is a demand for VFX to evolve more, not just in terms of quality but efficiency too.

There has always been an element of "fix it in post" thinking in film and TV production (James, 2009). This illustrates the interdependencies of production tasks and post-production. Some of this goes back to Griffith. If there are mistakes made in using the continuity editing system in filming scenes or sequences, then sometimes VFX can help correct these problems without having to go back to re-shoot. *Fix-it shots* are where VFX is often used to fix elements in the footage, whether it is removing certain objects, modifying mistakes in an object, split screens, enhancing prosthetics or makeup, stabilizing the camera, fixing strobing lights, or retiming actions (Dinur, 2017). However, new technologies may change this concept of "fixing it in post" to *"we can fix it before the shoot"* (MovieLabs, 2019, p46).

VFX can also be used to add elements to filmed footage. *Screen inserts* are where VFX producers make digital fill-in for any screens in the frame. For example, if it wasn't possible to have a desired image on an iPhone screen during filming, this can be digitally inserted in post-production (Dinur, 2017). Adding bits of elements to the background, to create *set extensions*, or as a complete replacement of background is a great tool to create extraordinary visuals without greatly increasing production costs (Dinur, 2017). A similar role is played by c*rowd simulation* which can reduce production costs as it allows the creation of a large amount of CGI characters to be placed in frame instead of extras (Dinur, 2017). Finally, VFX can replace many of the practical SFX, which previously was performed on set. Examples would be *action elements* such as flashes, explosions, and blood, can be created digitally. This can reduce cost and increase the control of a desired effect (Dinur, 2017).

Turnock (2014) argues that experimental filmmakers had a significant impact on film production by providing technological and conceptual foundations for creating highly advanced imagery. “Trick photography” (R. Rickitt, 2006, p10) allowed the expansion of creativity by immersing the audiences in a fantasy world. There were many contributors that influenced the development of ‘trick films’, which is a term that was used for modern day VFX (Balla, 2017; North et al., 2015). Filmmakers such as Robert Paul, Cecil Hepworth and Alfred Clarke, created their own new cameras and/or techniques of filmmaking to improve and innovate SFX (Rickitt, 2006).

Georges Méliès had one of the biggest influences on SFX by creating innovative set designs and illusions using cinematic tricks such as stop-action, fast and slow motion, split-screen, and double exposure. Another significant influencer of SFX and editing techniques was Edwin S. Porter, who used various camera shifting techniques such as moving landscapes to change the background in *The Great Train Robbery*. Furthermore, Porter’s technique of tinting several frames a certain colour, for example, red to simulate a firing gun to amplify the effect, was later used by Alfred Hitchcock in *Spellbound* (Rickitt, 2006).

Filmmakers such as Méliès, Porter and Griffith contributed to advancements in technology and reforming the narrative styles of filmmaking (Gaudreault, 1987). Méliès and Porter, among other early film pioneers, used a split-screen technique to block out parts of the frame, allowing other elements to be photographed later, on the unexposed area of the film. However, a more improved method that allowed actors to move around the frame freely, was created by photographing the desired background and shooting foreground against a black backdrop separately. Combining the two elements successfully meant that the background image would need to have an unexposed area that was an exact match to the foreground. As the foreground usually consisted of moving actors, this was challenging to achieve but resulted in the development of travelling mattes, which allowed such effect (Fielding, 1985; Rickitt, 2006; Turnock, 2014).

Innovation in technology allowed filmmakers to produce digital mattes, which are computer-generated. From the double exposure technique by George Albert Smith and matte technique used by Méliès *The Man with the Rubber Head* (1901) which was also used by Porter for *The Great Train Robbery* (1903) and ultimately lead to the huge

success of the project (Kumar, 2021). To invention of Kinemacolor, the first colour film process, was created by George Albert Smith in 1908 (Kumar, 2021). To Frank William's travelling matte technique, to Walt Disney's using a white backdrop to integrate actors with cartoon characters in *Alice Comedies*, the blue screen method was developed by Linwood Dunn in 1930s and a first time a blue screen was used was by Larry Butler for *The Thief of Bagdad* (1940), winning Academy Awards for Best Special Effects that year. Blue or green screens are used in the background for colour matting, which allows to easily separate the foreground from the background. The computer software, which is used now, can then easily identify the background colour, and automatically create a digital matte by removing that colour.

However, for more complex footage or when unable to rely on a green screen, rotoscoping allows more creative freedom by manually outlining the shape and separating an element which allows for elements to be added, taken out, colour corrected (Fielding, 1985; Rickitt, 2006; Bratt, 2011). Rotoscoping technique was first established by animator Max Fleischer, who created the rotoscope, which was used to project live-action images onto a glass panel to be traced over (Bratt, 2011; North et al., 2015).

This technique was first used in the *Out of the Inkwell* (1918-1927) and became very popular among other producers, it was used for many famous productions such as *Snow White and the Seven Dwarfs* (1937), *Princess of Iron Fan* (1941) and dance movements in various *Betty Boop* cartoons (1932-1933). This device has since been replaced by computers. Rotoscoping and green screen techniques are used to separate certain elements from the scene to then be able to alter them. Although rotoscoping is a very time-consuming method, it is sometimes the only option when the use of green screen isn't possible. The Rotoscoping technique is easier and faster to use on objects with a defined shape, such as buildings but is unreliable for complex tasks such as the clearer separation for objects with less defined edges, such as hair.

The green screen extraction process (or keying) although necessary, can raise some complications, especially when the desired background is custom and bespoke. To achieve a good quality background, it will need to match the foreground. This requires planning to produce a scene with similar lighting. This will help blend the two creating "colour spill", a term used to describe the error when background colour reflects or spills

onto the subject in the foreground. A green spill can sometimes be unavoidable in places, but usually can be easily removed by digital tools. When the edges of a subject aren't well defined, for example, hair, what often results are very sharp edges which stand out. This can be fixed with a method called Light Wrap, which blends keyed out green screen footage with the background, creating smoother integration and adding realism to the scene (Dinur, 2017).

Matte artists began to use computers for altering matte oil and acrylic paintings. Further development of technology allowed matte paintings to be created, or in other words, painted entirely within the computer. Most commonly, digital matte painting consists of manipulating elements of the footage and creating digital matte layers. Originally, digital matte painting allowed the creation of 2D extensions of elements in a shot, such as buildings, however, the camera had to stay in a locked position throughout the shot. Further developments in technology led to the use of 3D digital set extensions, this allowed the camera to move around freely (North et al., 2015; Rickitt, 2006). Norman O. Dawn created the glass shot, where a sheet of glass, with detailed paintings, would be positioned in front of the camera to create or alter scenery. Dawn further improved this by developing an in-camera matte shot technique, which enabled the film to be combined with paintings (Fielding, 1985; Rickitt, 2006). In 1916, cameraman Frank Williams created a new method of filming, Actors were placed in front of a black background which allowed Williams to film a different background in its place. This began the development of travelling matte photography, which is widely used today for special and visual effects (Fielding, 1985; Rickitt, 2006).

When productions were carried out in studios, the use of various backgrounds for special effects had become problematic. However, it resulted in the first practical effect tool of rear projection, which would allow backgrounds to be projected onto a background screen behind the actors and therefore becoming a more efficient tool over other techniques (Fielding, 1985; North et al., 2015; Rickitt, 2006; Turnock, 2012; Turnock, 2015). Although it became a widely used tool for special effects, it still did not provide the seamless realism effect that was desired (Turnock, 2012; Turnock, 2015).

The rise of colour film also presented its challenges for special effects technicians. This led to a development in a new projection system in the 1940s by Paramount, where they

investigated how to sharpen images projected on backgrounds when produced in colour (Rickitt, 2006). The innovation of technology and camera tools to improve quality of image began in the 1950s, following the rise of television ownership and the establishment of cinema. By the 1960s the demand for television grew higher than cinema, which led to further use and development of special effects to gain back the audience (Rickitt, 2006).

In 1907, Griffith revolutionised the process of production by innovating the use of continuity editing. This created a set of "rules" for production and post-production which covered camera placement and movement, shot composition and lighting. Continuity just means that if you want to edit together two shots which have been taken from different perspectives (different places or angles) then the rule is that any object (or person or character) in the first shot must appear to (to the audience) be in the same position in the second shot. If a producer breaks this rule (either by moving an object or moving the camera too far) then the audience will notice the edit because it will stand out as a "jump" cut. To the audience, the person nor object seems to "jump" from one place to another. This system created some logical relationships between the tasks of production (taking the shots) and post-production (editing them). In most simple terms, shooting (production) has to come before editing can happen. So editing is in post-production. But also, it means if director does not follow rules of continuity in taking the shots, it may not be possible to edit the shots without a "jump cut". Although "jump cut" was used as style feature in most cases audiences see this as distracting and low quality (Coleman and Friedberg, 2016). Sometimes it's possible to "fix it in post" but otherwise the scenes have to be reshot, which can be very expensive (James, 2009). If the filming process has not been carefully planned and directed, then editors may receive the "rushes" and find the two shots cannot be edited together without creating this "jump". Even in major Hollywood feature films, it has been the case that resolving this problem has required the filming task be repeated to follow the continuity rule. This is a very expensive process, because filming is expensive, and calling the actors and the crew back to the same set or location to re-shoot a specific scene costs a lot for a short amount of film time. This is what makes post-production tasks dependent on the filming production task, this is just one example of how tasks in post-production can be dependent on tasks in production (Thompson,1967).

Griffith used a range of editing techniques, the fade-in and fade-out, iris-in and iris-out (Gunning, 1994). Digital editing technique was first established in the late 80s and allowed video productions to use negative celluloid film. This scanned the developed footage ready for transferring onto a computer for a digital edit. The digital intermediate process technique allowed the entire film to be edited solely by using a computer. This became widely used, especially for films that contained a large number of visual effects (Rickitt, 2006). In 1980s and 1990s, the rise of digital production and use of computers (e.g., first Avid machines) for digital editing created a new editing task of online editing. Offline editing might use analogue material (such as film) or low-resolution video. Online editing would produce the final, high resolution digital version. In VFX production, some tasks which used computer power (rendering) were performed offline and others could be done in "real time". This created a dependency between tasks as some offline tasks would be time consuming and they would have to be completed first before the next tasks could take place. Tasks with a short "cycle time" are described as "online" as they can either be completed in real time or would not be time consuming for the computer to process and the next tasks could take place. Other tasks require a large amount of computer power (such as rendering), which could take several hours or even days to process, making these tasks have long "cycle times". Due to the inefficiency of this, the workflow would implement these tasks "offline". Offline tasks can be automated and completed by the computer, which would allow VFX artists move onto alternative tasks which were not inter-dependent on completion of the offline task.

One of the first and one of most influential product innovations in the film industry was the creation of sound (Chapain and Stryjakiewicz, 2017), which transformed the film production process and had a huge impact on the whole film industry. Turnock (2014) argues that the advancements in SFX in the late 1970s was as significant as the introduction of sound to the contribution of technological and conceptual innovations in filmmaking. Perhaps this began with Stanley Kubrick's *2001: A Space Odyssey* (1968). Although the film did not have any major actors and was an unusual 141-minute length film, it was a huge success partly because it showed some of the most impressive special effects of that era. These were created by technological innovations, exclusively for this film, such as the front projection, which displayed a clearer background; a mechanically repeatable camera control, an early version of motion control which photographed the spacecraft model; and the 'slit scan' animation method, all contributed to the production

of the famous 'Stargate' sequence (Fielding, 1985; Rickitt, 2006; Turnock, 2015). Similarly, George Lucas's *Star Wars* (1977) heavily relied on special effects and also created new technologies, such as computer-linked camera control system, which allowed to record and repeat the exact movements of a camera, to integrate separately filmed scenes of spaceship movements and background elements (Rickitt, 2006; Ryu, 2007).

The audience's demand for sophisticated special effects was one of the biggest influences in the rise of movie budgets in the 1980s. The creation of DVD in 1996 was the most rapid consumer adoption of any new technology yet. Production of behind the scenes, especially the explanations to the making of special effects became very popular and increased the demand for SFX used in films (Rickitt, 2006). VFX technology improvements in the 90s resulted in the development of fast scanning and recording technology that allowed film images to be converted into digital images, which allowed further manipulation of images by use of computers and then recording back onto film. James Cameron's *Terminator 2: Judgement Day* (1991) showed digitally created characters and Steven Spielberg's *Jurassic World* (1993) displayed computer-generated images of dinosaurs, which showed a high level of sophistication and quality of new technologies (Rickitt, 2006; Abbott, 2006).

Digitalisation and VFX

There has always been demand for creation of the illusion of 3D images. Robert Baker's large scale paintings in the 1790s led to 360 panoramic paintings, which were installed at many different exhibitions and were very popular in the 1800s. The first 3D image created was probably produced by Wheatstone's stereoscope, created in 1838, which was a device that allowed to view different perspectives from each eye. Brewster further developed this device into a handheld lenticular stereoscope, presented at the Great Exhibition in 1851. The first mass produced 3D image viewer available to the public was the Holmes stereoscope produced in 1861. In the 20th century the first head-mounted stereoscope 'The View-Master', which was first introduced in 1939, was created by William Gruber (Tricart, 2017).

The introduction of CGI led to a new visual effect - *digital set extensions*, which are created with matchmoving that shows highly accurate movements of the camera by using detailed geometry and exact positioning, allowing the created 3D set extensions to be virtually filmed within a computer (Dobbert, 2006; Rickitt, 2006; Wright, 2011). These exact movements are then combined with the live-action footage. Furthermore, this approach allows more freedom when manipulating the set in various ways such as adding painted lighting effects to match the texture of 3D models to the real sets to help them blend in (Rickitt, 2006; Wright, 2011). This innovation allowed for a more cost-effective way to add complex and sophisticated set extensions to a scene that may not be possible to create physically in camera due to the cost or due to the level of complexity or unrealism (Wright, 2011).

There are two types of 3D modelling, technical and organic. Technical modelling includes objects such as vehicles and spaceships, and organic modelling includes human and creatures (Dinur, 2017). The process of creating elements in 3D is very time consuming and costly, however, there are several alternatives. For example, already created licensed models can be purchased and be more cost and time efficient. 3D scanning (create digital models from real objects) can be less time-consuming; however, it may not be cost-effective (Dinur, 2017).

Movement of 3D objects is created using dynamic simulations, which simulates movement of physical environments, such as tsunamis or collapsing buildings. Dynamic simulation in VFX becomes easier, reducing amount of time and budget in post-production when part of the shot is done practically on set with the use of SFX. Rigid-body simulations allow objects to keep their shape or separate into smaller pieces while moving, which is usually used for destruction effects. Cloth simulations add extra elements to an object, such as stretchiness, bend resistance and springiness. Fluid simulations are used to create effects such as smoke and water. Real footage of smoke and water can be used if camera movement does not prevent the use of 2D elements and if there isn't specific interference with CG elements. Particle systems are created to control various objects' behaviours and interactions with each other or with other objects. Crowd simulation uses particle systems, physical simulation and AI, which allow animators to control CG characters' behaviour (Dinur, 2017).

Creation of moving, live objects such as humans and creatures is more complex. Initially this was done through manual processes of drawing images on cells or creating practical objects and characters and generating moving images through stop motion techniques. Stop motion animators create artificial motion blur to generate an image of smooth movements. This was originally achieved manually and therefore was very time-consuming. Digital tools contribute to creating computer-generated animations and help reduce the sophisticated, time-consuming demands of stop-motion productions (Rickitt, 2006).

The final digital model of the character shows its outer shape, which is then used for character rigging. Rigging is a process of creating a control mechanism that allows animators to bring the CGI creatures to life by using the bone structure to enable realistic and accurate movement (Jones, 2013). During this process, character riggers would create a digital skeleton structure that will allow the creation of movements, followed by creating muscles and skin. Riggers would also create automated movements for the character, for example, a realistic breathing cycle. The final step of creating a digital character is texturing that adds colour and detail to the exterior of the model (Rickitt, 2006).

Usually, the role of the artists for this process is referred to as a ‘Rigger’, however as described previously, the VFX industry has different titles for same roles, some productions may refer to them as ‘Setup Artists’, ‘Technical Animators’, ‘Technical Artists’, ‘Animation TDs’, ‘Character TDs’ or ‘Creature TDs’ (Jones, 2013). Once digital riggers have finished the final design of the character, they hand it over to animators who create the motion (Rickitt, 2006). Animators are equipped with specialised software to create positions which create and complete any notable gaps in the motion of the character. They begin by creating different motions and actions, which would then build up into complex movement sequences (Rickitt, 2006).

While the motions of computer-generated creatures are usually created by animators, the motion-capture method is used to create complex and natural motion. Motion-capture is achieved by placing an actor in a motion-capture suit with markers and capturing the movement from various angles, which is then used on the computer-generated characters (Rickitt, 2006). The layout stage of the VFX is essentially blocking and positioning of all

elements in the created virtual environment. This is crucial when a VFX shot mostly consists of CG elements and animation as it will influence further VFX work (Dinur, 2017).

Virtual camera is a digital CG camera, which allows to generate and enhance shots in a way that cannot be achieved with a real camera (McClean, 2007). The virtual camera is the viewpoint that the computer will produce. Digital artists determine the type of lens, number of frames and use a virtual camera to mimic the movements and techniques of a real camera. Virtual cameras allow complete freedom of movement, which helps to produce perfectly choreographed compositions. However, sometimes digital effects need to be combined with real footage, which means that the virtual camera needs to follow the exact movements of the real camera. To achieve this, a 3D camera match moving technique is used. The SFX supervisor would need to be on set to accurately measure the positions of each subject, camera, and markers, usually by using laser equipment. This creates very precise results and accurate movement sequences (North et al., 2015; Rickitt, 2006).

Culture and Technology: Trends and Innovations in VFX Today

Academic studies, industry reports and industry magazines show that there are three most important trends today in VFX that drive change in the workflow (Giralt, 2017; Failes, 2017-2020; MovieLabs, 2019; McCullaugh, 2020; Kaufman, 2019-2020; Okun et al., 2015; Öhrström et al., 2018; Pardeshi and Karbhari, 2019; Samaras and Johnston, 2018). The three trends are briefly described below.

Previs Becoming Crucial

With continues grow of demand of VFX shots, previsualisation is becoming increasingly more important. Previs enables better understanding of VFX tasks. Essentially, it can provide more detail than a traditional static storyboard and this makes the director's desired outcome clear. Using previs provides the entire production a very detailed and clear vision of the project and what is required (Baumgartner, 2003; Pardeshi and

Karbhari, 2019). New technology is expected to be implemented into the VFX pipeline to evolve and improve this process. New approaches to this process, such as on-set previsualisation, which creates real-time visualisation, allows to preview and define VFX elements on set. This removes elements of uncertainty about the task and so can increase efficiency and productivity of the VFX post-production process (Briand et al., 2014; Baumgartner, 2003).

Achieving Authentic Realism and Seamlessness

Digital visual effects enhance the level of realism that traditional SFX could not achieve (McClean, 2007; North et al., 2015; Prince, 2011). But in addition, VFX is increasingly able to provide more realistic, seamless effects of motion and other complex aspects of reality (Dinur, 2017; Finance & Zwerman, 2010; Giralt, 2017; Jones, 2013; MovieLabs, 2019; Okun et al., 2015; Prince, 2011; Spohr, 2019; Wright, 2011; Pardeshi and Karbhari, 2019; Power, 2009). Although combining various techniques such as motion capture help achieve seamlessness (North et al., 2015; Power, 2009), the cultural demand for more realistic and seamless visual effects continues to grow (Giralt, 2017; Samaras and Johnston, 2018). Innovations in technology may be essential to achieve increasing standards of seamless reality in visual effects (Giralt, 2017; Rüling and Duymedjian, 2014).

Pressures to Increase Efficiency and Productivity

The cultural pressures for VFX to create the illusion of reality have an impact on the economics of VFX production. The growth of VFX across many genres means that, on average, VFX today takes up to 30-40% of the total production budget of a film or TV series (Rüling and Duymedjian, 2014; Sanson and Curtin, 2017). Costs are also related to complexities of managing VFX productions involving large workforces in various locations and significant number of artists (Samaras and Johnston, 2018).

The growth of demand for VFX is also occurring at a.time many productions are facing decreased budgets and turnaround times, increasing the pressure for VFX production to be as efficient and productive as possible (Sanson and Curtin, 2016; Heusser, 2013; MovieLabs, 2019; Venkatasawmy, 2016). All of this raises pipeline and data management

challenges (Chung, 2011). In response, cloud-based (MovieLabs, 2019; Öhrström et al., 2018) and Real-time technology (Dunlop, 2014; Failes, 2020b; MovieLabs, 2019; Pardeshi and Karbhari, 2019) are being implemented into VFX pipelines to help tackle these challenges.

Most Significant New Technologies in VFX Today

Media production industries today are faced with challenges that are caused by an increase in demand and simultaneously reduced turnaround times and tight budgets (MovieLabs, 2019; Venkatasawmy, 2016). New technologies have the potential to tackle these challenges, however this can only be achieved by applying appropriate technologies based on the type of production (MovieLabs, 2019). Complex VFX productions can include a team of up to 100 people working on various complicated processes and carrying out very specialised tasks. Innovations in technology have the potential to automate various routine VFX tasks, possibly increasing efficiency and decreasing costs of VFX production. This would impact process of VFX and interdependence between production and post-production, including the work processes of each VFX role.

As new technologies arise and audiences continue to demand content that enhances the experience of storytelling, the entertainment industries face continuous changes, which make it hard to predict the foreseeable future (MovieLabs, 2019). Even with this uncertainty, VFX companies are investing into various new technology to try to improve the VFX process to meet these challenges (Dodgson et al., 2010). This expectation asserts the importance of impacts new technologies will have on the VFX industry. The most significant new technologies that are having an impact are described below.

Artificial Intelligence and Machine Learning

AI and ML (subset of AI) is increasingly gaining importance and influence (Roettgers, 2018) and reshaping the media and entertainment industry (Zoodikers, 2018). To explain algorithms, Harari (2016), relates it to human emotions, which can be considered as "biochemical algorithms" (Harari, 2016, p 83). Harari (2016) describes an algorithm as a "methodical set of steps that can be used to make calculations, resolve problems and reach

decisions" (Harari, 2016, p 83). More complicated algorithms can estimate probabilities by including many different variables in the calculation. During the agricultural revolution, farmers used their brain as data-processing to develop organisations (Harari, 2016, p 156), today, humans have AI to assist them with data-processing.

The increase in VFX shots being added in productions and shorter production turnaround times raise challenges for VFX workers required to meet increasingly higher expectation at faster pace and AI technology has potential to assist achieve these growing demands (MovieLabs, 2019). AI, ML and deep learning (subset of ML) offer software solutions for VFX, computer graphics and animation by use of automation. Deep learning processes could aid in developing detailed 3D objects based on training data (Failes, 2019a). The use of AI and ML tools to automate parts of the VFX process have been used in productions such as Avengers Endgame, where Josh Brolin's performance was rendered into the character Thanos and in Solo: A Star Wars Story, where Harrison Ford is showed as a younger version of himself from previous Star Wars films (Pennington, 2019).

Industry professionals express their excitement around AI technology as it can automate mundane tasks in post-production and decrease costs and time (Brown, 2019; Dams, 2018). Furthermore, industry professionals suggests that ML and AI will have a significant impact on the creative by automating repetitive tasks and therefore allowing artist to focus on the creative input (McCullaugh, 2020). AI has the potential to execute many mundane or repetitive tasks and speeding up the VFX process by "animating background VFX characters, doing first-pass colour grades with various looks for directors to pick from, and automating rotoscoping, background removal, and "world building" that generates realistic 3D environments for directors to walk through and edit" (MovieLabs, 2019, p11).

Arraiy and Adobe are two examples of companies, who inspire to introduce AI to the world of post-production by using it to improve visual effects (Houser, 2018). To test the new digital effects technology created by Arraiy, visual effects filmmaker Stefan Avalos and his crew made a short film about self-driving cars and used the new visual effects technology to speed up the process that they would normally have to do by hand (Metz, 2018). Although the technology isn't sophisticated enough to be able to carry out all the work by itself, it is improving and the future ambition is to improve the technology to the

point where VFX can be instantly changed while filming on set, which will allow filmmakers to view the outcome and adjust they technique as necessary while they can still have the chance (Metz, 2018).

Furthermore, software that uses AI and ML, such as PDG (see p178), could be applied to improve the management aspect of VFX production. Project and personnel management on big production that involve large amounts of workers across many different departments of production and having up to hundreds of thousands VFX assets is becoming increasingly challenging to achieve and maintain (MovieLabs, 2019).

Although rotoscoping is a creative process which needs to be done by artists, AI and ML enable creation of tools which can make the process for efficient (Kaufman, 2020). AI-driven rotoscoping techniques are one of the focuses of Adobe's research, together with the Beckman Institute for Advanced Science and Technology and University of Illinois, they developed an AI based tool that automates the extraction of backgrounds based on deep learning techniques (Xu et al, 2017). Unlike other similar inventions, this tool aims to solve the problem of extraction when foreground and background colours are similar or include complex textures (Xu et al, 2017). The result of their research concluded that the created Deep Image Matting method performs better than those that only use colour as an element for extraction (Xu et al, 2017). Similarly, researchers at Trinity College used AI to create GAN for natural image matting, which enabled extraction of very detailed elements (such as hair) without the use of green screen (Lutz, Amplianitis and Smolić, 2018). OpenFX created a plugin called Rotobot, which is being used to improve rotoscoping by use of ML to extract multiple elements from a sequence (Anderson, no date). Similarly, Arraiy uses ML to create a stronger matte around strands of hair to allow easier and more precise background extraction (Anderson, no date).

Flame software uses ML and AI driven extraction to create a precise depth map, which allows VFX artists to create a more realistic image of elements such as fog (Anderson, no date). Carnegie Mellon University, in collaboration with DeepMotion, created a real-time ML tool that enables animated characters in video games to perform a physical skill by using deep reinforcement learning and motion capture data (Spice, 2018). This particular project was used to create realistic dribbling movement in basketball; however, it has potential to be used for skilled movements in animation. Stephen Regelous, a digital

artist, created an innovative software 'Massive' with AI, which was used to create photo-realistic crowds in Peter Jackson's *Hobbit* trilogy, which uses a wide range of movements by real actors and applies its large library to create characters with realistic movements, authentic aesthetics, and reactions (Miles, 2004).

Researchers from the School of Interactive Arts and Technology at Simon Fraser University suggest that the increase of interactive content has resulted in need for automated emotion and facial recognition (Alemi and Pasquier, 2019). Furthermore, they suggest that ML and motion capture data have been used as prominent tools to aid automatic generation of movement animation (Alemi and Pasquier, 2019). Alemi and Pasquier (2019) argue that advances in this field will provide a "less expensive, faster, and more flexible way to create movement animation content both in offline and interactive scenarios" (Alemi and Pasquier, 2019, p 48). Researchers at the University of California acknowledged that animation based on motion capture produces natural behaviours and movements, however creation of motion capture is a highly expensive and time-consuming process and proposed a method that generates motion capture data from videos, for example from YouTube, by use of reinforcement learning technique (Peng et al., 2018). Peng et al. (2018) suggest that this method has the potential to enable faster and easier generation of desired movements and behaviours. Researchers at Leibniz University of Hannover and the Max Planck Institute for Intelligent Systems created a method of generating accurate human 3D poses by using footage from a handheld moving camera and a device attached to the body that that measures movement, which could aid in identification and tracking of human subjects in cluttered and challenging scenes (Marcard et al., 2018).

AI-based tool Headshot, which generates a digital human by analysing a photo, has the potential to increase efficiency and reduce the risk of waste in the film production process by increasing flexibility and allowing faster CG creation (Failes, 2020a). Character Thanos in *Avengers: Infinity War* was created by Digital Domain by use of ML, which included facial capture training data, to transform an actor's face onto the character (Failes, 2019a). Productions such as *Avengers: Endgame, Captain Marvel, The Irishman* and *Terminator: Dark Fate* used digital de-aging and aging visual effects to create younger or older versions of actors, which includes making a CG version of actors. Deep fakes (use of AI and ML to transfer an actor's face onto another actor's performance) lack

resolution and precision quality required for VFX, however some have considered it might have potential in the future to be used in VFX (Failes, 2020f). Deep fakes were used in a music video for Charlie XCX and Troye Sivan, where the singers' faces were transferred onto multiple famous scenes from films and other music videos (Andreson, no date).

Real-time Technology

Real-time rendering with complete ray tracing (a rendering technique that generates a CGI image by tracing the path of light of a scene that results in producing high quality visual realism) of complex VFX shots is still unachievable today (MovieLabs, 2019). Offline renders of complex scenes can take hours or even days to complete and result in high costs up to 30% of the budget on high end productions (MovieLabs, 2019). Real-time rendering approach can help achieve better quality at minor costs (Yamaguchi et al., 2020). Furthermore, real-time technology can help achieve efficiency and reduce cycle time of traditional repetitive rendering process of rendering (rendering, receiving feedback and repeating this process numerous times) allowing artists more time to focus on the creative work (Op. cit. 2019).

As noted, some writers have argued convergence of computer and media industries is driving change (Manovich, 2015). Although new VFX technologies are also researched by some visual effects companies, the video and computer games sector is also driving development of new technologies. A key development seems to be the Unreal Engine to transform the process of rendering. Pre-rendered CG characters have their limitations. For example, CG versions of actors such as Wolverine in *Logan* and Rachel in *Blade Runner 2049*, raise the debate whether they are believable enough to be seen as human (Failes, 2019c), however innovations in technology show a promising improvement. Epic Games, a video games and software developer, is developing and experimenting with real-time rendering technology as they strongly believe that it can increase flexibility in creating CG environments and characters (Failes, 2017). Furthermore, Epic Games' game engine, Unreal Engine, recently acquired 3Lateral, the leader in CG character tools, which is used to create real-time photoreal CG humans based off from a live actor performance (Failes, 2020a). This has been used in TV, film, and commercials; for example, CG Alita based off Rosa Salazar's performance for *Alita: Battle Angel*, young CG Anthony

Hopkins in *Westworld* and Elton John in a last year's John Lewis commercial (Failes, 2019c; Sarto, 2019). Digital Domaine, a VFX studio, real-time digital human technology has been used to create a real-time Pikachu and real-time digital version of Martin Luther King Jr. (Failes, 2020a). The short film *The Heretic* created by Unity featured two realistic digital human characters and real-time technology allowed artists to change and manipulate them in real-time. Using real-time technology on these characters gives artists more creative freedom (Efremov and Lazar, 2019). CG elements also have importance in health and safety procedures, for example the creation of the Kikimora creature in *The Witcher* included the use of a practical prosthetic suit but also had to include CG due to safety and physical limitations (Failes, 2020e).

VFX is increasingly shifting from post-production only into production and even pre-production, as new technologies allow processes such as previs enable flexibility in decisions, reducing financial risks (McCullaugh, 2020). Kim Libreri, CTO of Epic Games, adds that as real-time technology is enabling integration of post-production with production by allowing digital elements to be updated in real-time on set during a live action shoot, this process of virtual production "brings a level of creative freedom and spontaneity to the set" (cited in McCullaugh, 2020). Adam Myhill, Creative Director at M&E Innovation Group, Unity Technologies, supports that real-time is the future of VFX, because it enables filmmakers to test out ideas faster and creativity is "longer limited by your stage in development" (cited in McCullaugh, 2020). As technology develops, we should expect to see the quality gap between real-time and non-real time renders will eventually disappear (Dinur, 2017). Real-time technologies are likely to have a significant impact on the VFX industry and have the potential to improve predictability and quality (Failes, 2020c). There is an important interdependence between other VFX tasks and rendering. This is because even the smallest changes to some aspects of VFX production in VFX require a 're-render'. Not only does this take time and expense it also means a time difference between making a change and seeing the results. New technologies can remove this cost but also the delays in the creative process. Real-time rendering at quality needed for film and tv VFX is likely to be a huge time-saver by speeding up the CG process such as modelling and animation, and adjustments in shaders, textures, and lighting. It can also speed up the creative process between VFX artists and filmmakers. Furthermore, it could contribute to a more interactive collaboration (Dinur, 2017).

Real-time rendering is often used in virtual production (see p51) to advance and speed up the processes of previs, set-scouting, live motion capture, compositing on set, in-camera VFX and final frame rendering (Failes, 2020c). This allows for faster feedback and flexibility during pre-production, resulting in instant decision making and reducing errors during shooting, which usually have to be "fixed in post" (Failes, 2020c). Using real-time technology for on-set previsualisation allows to preview and define VFX elements in real time on set, which increases efficiency and productivity (Briand et al., 2014; Dunlop, 2014). Chris Ferriter, CEO of Halon Entertainment, suggests that it is the interactivity aspect of real-time technology that will have the most impact as it enables scouting of virtual sets and multi-user collaborations with use of virtual cameras. (cited in McCullaugh, 2020). Furthermore, Ferriter acknowledges that "we're quickly approaching a day where the visual quality of real-time rendering will match the quality levels that you would expect from a traditional VFX finals pipeline" (cited in McCullaugh, 2020). Real-time rendering can increase flexibility by enabling visualisation and adjustment of virtual elements in real-time, which reduces time and costs (McCullaugh, 2020). At the moment, previs studios are expected to quickly respond to last minute changes in scripts, which need to be reflected in previs and postvisualisation animatics, and often in technical schematics, which show how shots are filmed (Dunlop, 2014; Failes, 2020b). Real-time rendering tools and virtual production techniques can allow previs studios to create more precise planning content (Dunlop, 2014; Failes, 2020b; Pardeshi and Karbhari, 2019).

Epic Games use real-time technologies to enable in-camera VFX during filming (Failes, 2020c; Wolfe, 2017). The use of LED wall panels produce imagery which blends in and allows real-time manipulation of background, lighting and other elements (Failes, 2020c). Chaos Group, creator of a CG rendering software V-Ray, is currently developing real-time ray tracer to allow exploring of V-Ray scenes in real-time and speed up the process (Failes, 2020c; Wolfe, 2019b). Glassbox's tools such as DragonFly and BeeHive allow to visualise virtual performance on a virtual set and enable collaboration with virtual art department and sets in real-time (Failes, 2020c; Wolfe, 2019a). Reallusion's iClone uses real-time and reduces time it takes to create and capture CG characters by allowing VFX artists and animators to input actors into characters (Failes, 2020c).

Steve May, Chief Creative Officer at Pixar Animation Studios, strongly suggests that "the technological ability to produce high quality CG content in real-time will have a dramatic impact on our creative process" as it will enable flexibility for creative decisions and "will result in a significant change to traditional production pipelines, artist tools and job descriptions" (cited in McCullaugh, 2020). Furthermore, real-time technology can be expected to have a significant impact on the balance between pre-production, production, and post-production process as it creates new opportunities that can improve and evolve the process of filmmaking. MovieLabs, a technology research group run by Paramount Pictures, Sony Pictures Entertainment, Universal Studios, Walt Disney Pictures and Television and Warner Bros. Entertainment published a white paper that describes the future vision for media production and suggests that "by 2030, new technologies, especially real-time photorealistic graphics, will create a more iterative creative process" (MovieLabs, 2019, p9). It is suggested that currently more specialised and separate phases of early production will become less specialised, previsualisation will become vital and be used to create all visuals except the live action and physical actors would be able to interact in real time with digital assets and virtual characters.

The VFX pipelines continuously change as new technology is integrated to ensure the pipeline is as efficient and cost-effective as possible (Dodgson et al., 2010; Dunlop, 2014). Integrating photorealistic real-time engine (RTE) pipelines into the workflow may allow previsualisation with quality high enough that seamlessly merges the live and digital environments enabling more freedom for artists making creative decision during the entire production process, including pre-production, production, and post-production (MovieLabs, 2019). Instead of using offline render farms (on-site computer systems which render CGI images, which require technical engineers to operate), which make the process of rendering time consuming and expensive, real-time engines will likely increase efficiency of VFX production enabling artists to render in real time (MovieLabs, 2019).

Cloud-based Technology

When production moved from analogue to digital workflows, many aspects of production remained the same, however data storage process changed from moving, replicating, and editing videotapes to using hard drives and digital editing (MovieLabs, 2019). However, even in this digital era, the constant moving and replication of digital data between

different production departments is time consuming and increases the risk of data being misplaced, leaked or corrupted by human error (MovieLabs, 2019). Managing the pipeline across different physical locations is challenging and these risks only increase as the size and complexity of data continues to increase, which reinforces the urgency to improve and evolve this process by increasing IT security and distribution flexibility (Chung, 2011; MovieLabs, 2019; Öhrström et al., 2018).

The cloud is a digital data storage system accessible by the internet that can be used to manage and traffic data on-demand and off-premises and provides solutions to the many challenges of managing the pipeline across different physical locations (Öhrström et al., 2018). Cloud based technology is likely to be increasingly integrated into the workflows with all production data (scripts, live footage, VFX assets, etc.) being stored in the cloud and run on cloud based virtual workstations rather than on-premise workstations, which would fundamentally change production workflows (Dunlop, 2014; MovieLabs, 2019). Some of the biggest advantages that cloud based workstations may bring are higher IT security level and eradicating the need to constantly be moving, replicating, and storing data between different companies involved in production, which will enable artists to keep full control over their assets (MovieLabs, 2019). Further development in cybersecurity unique to this specific industry that revolves around a very flexible production process are expected to have a significant impact on improving the production process, including VFX production (MovieLabs, 2019). Using cloud storage instead of local storage systems would allow VFX workers to work directly in the cloud, which would allow immediate viewing and feedback from other departments (Dunlop, 2014; MovieLabs, 2019). Moreover, being able to upload footage to the cloud directly from the camera on set and giving VFX workers immediate access will reduce the traditional delays between production and post-production and enable the VFX process to start promptly after filming (MovieLabs, 2019). Furthermore, integrating cloud-based technology into the VFX pipeline enables remote work from any location in the world (Dunlop, 2014; MovieLabs, 2019). The bandwidth power required to achieve is still an obstacle today, however the advantages and potential of this technology will encourage studios to continue to pressure the development of cloud-based technology (Dunlop, 2014; MovieLabs, 2019). The continued increase of Wi-Fi speed and the predicted increase of 5G speed enhances the chances of this being achieved in the near future.

When it comes to intellectual property and future revenue, the process of archiving and preserving data is crucial (Dodgson et al., 2010; MovieLabs, 2019). Archiving is an expensive process and cloud-based technology has the potential to eliminate the use of hardware for archiving, making the process more cost-effective and allowing easier access and management of archives by storing it "online" (Dunlop, 2014; MovieLabs, 2019). To integrate such technology into workflows would be hugely beneficial once it has developed further and makes it possible to encourage companies to trust in it when concerns such as IT security are raised (Dunlop, 2014; MovieLabs, 2019).

Lightfield Cinematography

Light fields technologies are being developed to achieve better methods of capturing and processing light data, which involves the amount of light flowing in every direction through every point in space (Cook, 2018; Dinur, 2017). One of the most significant innovative technologies that will have an impact on VFX is lightfield cameras with pixel-accurate depth mapping, which include multiple lenses and capture detailed light data than a normal single camera (Failes, 2019b). If every pixel was to have depth information on top of colour and light, it will provide a function for separating elements in the footage based on their distance, which will save time and money for rotoscoping and/or extraction and eliminate the need for green screens on set.

Furthermore, it would create a 3D representation of every element in the frame, simplifying camera tracking as there will no longer be a need for 3D tracking to manually measure the distances between elements in the 3D space. It will make depth-based compositing easier when elements need to be placed in a specific correct position within the 3D space or when elements need to develop within distance, for example when fog needs to intensify with distance. It will give the DoP the freedom to play around with the focus in post and apply depth-based filter effects or colour grading. If pixels have spatial and directional information, it will make it easier to retime shots and apply very accurate motion blur or perform 3D stabilisation on camera movement (Dinur, 2017). Lytro is one of the companies developing such technology.

Virtual Production

New technologies are also impacting stages of image creation further up the production process, creating changes in the balance between 'practical' creation of images by recording real events on camera and 'post-production' work of creating or altering these images via VFX. One important area is Virtual Production technology, which allows live visualisation of CG VFX shots on set in real-time while filming (Dunlop, 2014; The Focus, 2019; NCAM, no date). Similarly, MR technology (such as Microsoft and HoloLens) allows for the previsualisation and interaction with the VFX context of the location, where the camera is used to view the real set and virtual CG extensions at the same time (Dinur, 2017).

Virtual production enables flexibility and reduces limitations between VFX in pre-production, production, and post-production, speeding up the process (Dunlop, 2014; Kaufman, 2020). Industry professionals suggest although virtual production requires significant amount of planning and pre-production, it does increase flexibility of previsualization and modification of virtual elements due to real time rending, making the process faster and more cost effective (McCullaugh, 2020). Furthermore, it creates a more integrated collaboration between crew members (McCullaugh, 2020). Virtual location scouting tools, such as Magnopus's VR Scout, are used to scout virtual locations (Kaufman, 2020) and allow real-time collaboration between different heads of the departments (HoDs) such as Art director, director and DP (Dunlop, 2014; Failes, 2020c). This allows creative and production decisions to be made without risking financial consequences (McCullaugh, 2020).

Virtual production is enables VFX process to be part of production, rather than only post-production, by allowing different departments to visualise and manipulate the digital environment and characters composited with physical set and actors in real-time (Dunlop, 2014; Kaufman, 2020). Industry professionals suggest that real-time and Virtual Production is now the bridge between pre-production, production and postproduction (McCullaugh, 2020).

Nano Technology

Surrey NanoSystems created a coating that absorbs almost all incident light and holds the Guinness record for darkest man-made substance, which does not reflect any light or shows any surface. When applied onto a 3D object, it makes the object look perfectly flat and matte black with no visible surface detail at all. Some suggest applying replacing green screens with this technology to allow more precise extraction (Dinur, 2017).

Virtual, Mixed and Augmented Reality

Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR) are affecting video games, advertising and entertainment industries (Kadner, 2018). From the literature, it is hard to tell if VR is expected to have any effect on VFX, although some argue it might show an interesting dynamic in the near future. Techniques used for VFX apply to VR, only on a much bigger scale. As VR shows a 360-degree view, when shooting for VR, the set must be built for the 360-degree view and the action must happen simultaneously all around the multi-camera rig. VR content such as films, tv and music videos are already being produced *Star Wars: Episode 1* was the first film to be digitally projected in the cinema. History shows that various new technologies challenge this practice, such as DVD, home cinema systems and portable devices such as laptops, phones and tablets.

Many writers argue that AR is not likely to have a massive impact on VFX as it doesn't contribute to creative visuals (Dinur, 2017). However, some suggest that AR applications could be used in previs, such as Apple's ARKit, which include techniques such as tracking and moving the CG in perspective to match the camera view (Kadner, 2018). MR technology has the potential to impact VFX as devices such as Microsoft's Hololens can perform real-time 3D tracking of the viewer's environment, which enables integration of CG elements with the actual surroundings in real-time (Dinur, 2017).

Changes in the VFX Workflow

Enabling the development of complexity and quantity of VFX content has required of the rigorous video production process to evolve. Video production consists of five main stages: development, pre-production, production, post-production, and distribution (Patz, 2010). Each stage consists of multiple phases and responsibilities. Although VFX takes place in the post-production stage of video production (see Figure 4), several aspects of VFX production need to be considered during pre-production, production and post-production of video production. The role of VFX during pre-production, production and post-production of video production is described below.

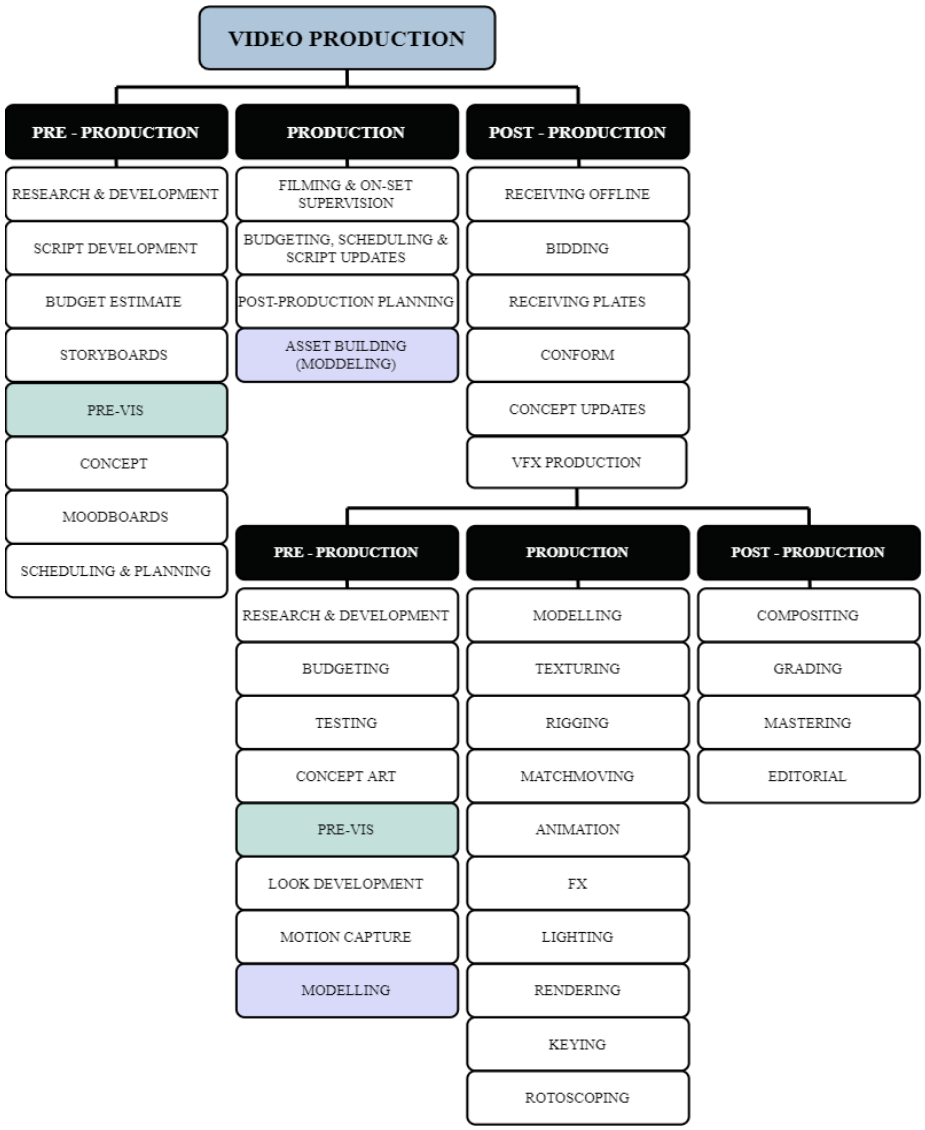


Figure 4: Video Production Workflow

Sources: (Cleve, 2012; Chung, 2011; Dinur, 2017; Dobbert, 2012; Dunlop, 2014; Finance and Zwerman, 2015; Fitzgerald, 2018; Honthaner, 2013; Lee, 2019; Spelthann and Haunschild, 2011; Wales, 2017; Zamanian, 2016; Zwerman and Okun, 2014)

Pre-production

The largest amount of VFX work is carried out during post-production, however it requires attention and careful planning during pre-production to successfully achieve the desired outcome. Many factors of VFX are impacted by the way the shot is carried out during production and if these tasks are not planned correctly, the tasks in post-production are affected, which could result in not being able to create the desired effects. The high risk of "fixing it in post" concept highlights the importance of the pre-production process (DeLouise, 2016).

There are several steps that can be taken during pre-production to increase control over the outcome. The process of managing the VFX production workflow starts right at the beginning of the project during the pre-production stage. The VFX supervisor can be hired to take control of creative and technical aspects of VFX. In pre-production, highly trusted specialists and senior VFX professionals are involved, who advise about the potential of VFX technology, the aesthetic of VFX shots and costs (Spelthann and Haunschild, 2011). A VFX shots breakdown, which is based on the information provided by the script and allows to assess the number of VFX shots and the level of complexity. Technical location scouts also allow the VFX supervisor to identify potential complications to come up with solutions before beginning their work (Dinur, 2017).

Concept art, such as the development of CG character looks also starts during pre-production. Concept artists are used when elements need to be created originally and from scratch, commonly in film genres such as fantasy and Sci-Fi (Dinur, 2017). Storyboard artists also produce a vital tool for the VFX team, their storyboards provide a very clear reference for the VFX team to design an appropriate strategy. Similarly, previs artists creating moving storyboards in 3D, which show the desired CG shot concept with details (Dunlop, 2014; Finance & Zwerman, 2010; Okun et al., 2015; Dinur, 2017; Spohr, 2019; Arundale & Trieu, 2015; Sawicki, 2011; Pardeshi and Karbhari, 2019). There are many other elements of VFX that require preparation such as camera tracking (or 3D tracking), which is a vital tool as it gives VFX artists exact positions and depth measurements, allowing them to match the created 3D environment to the real set. Precautionary steps can be taken during pre-production to achieve accurate camera tracking (Dinur, 2017) as it requires detailed information about the scene being filmed and the camera being used.

The VFX workflow requires a high level of coordination due to the complexity and the VFX supervisory team must work in a disciplinary fashion by reporting the progress on the daily basis (Samaras and Johnston, 2018; Spelthann and Haunschild, 2011). Communication of technical requirements and logistics before the shoot is valuable and important to get right as it will affect most of the elements of production (DeLouise, 2016). VFX production meetings during pre-production are vital as face-to-face discussions allow deeper detail of planning the VFX process.

Budgeting and scheduling ensure a smooth process and avoids any financial problems after production (Arundale & Trieu, 2014). Storyboards and VFX shot lists are used to estimate the time and budget required to achieve VFX shots. Considering time, costs and expectations for post-production is essential to ensure that the post house can deliver what the production requires (Cartwright, 2012).

Production

During the shooting stage of production, the VFX supervisor is usually accompanied by the VFX producer on set. They make sure that the VFX elements that require shooting on set are done appropriately and in the most efficient manner. VFX supervisor is on set during production to advise on how to shoot the VFX shots correctly in order to then digitally manipulate them in post-production (Spelthann and Haunschild, 2011). For example, motion-capture requires placing an actor in a motion-capture suit with markers (Rickitt, 2006).

VFX heavy productions include at least one VFX data wrangler, who collects necessary information from the set. This can include taking stills from different angles, close-ups of various physical elements and textures on set, camera details and slate information. Additionally, sometimes 3D scanning and photogrammetry are used to create digital copies of actors and props (Dinur, 2017).

Post-production

The VFX workflow takes place during the post-production process. During this process, the VFX and editing teams work closely together, due to the continues backs and forth

communications (Dinur, 2017). The VFX process in post-production starts once certain scenes or parts of scenes have been edited, as it is more time-efficient to integrate the VFX into the edit before picture lock (Ryan, 2017). During post-production, the raw takes are edited to form a coherent storyline and a rough-cut gives the VFX artists a clear view of VFX work required. As the editing process determines which planned VFX shots should and should not be used, there is an opportunity for any new unplanned ideas to be established. The final edits of VFX shots are assembled into sequences and sent to the VFX house (Spelthann and Haunschild, 2011).

Mapping Changes in the VFX Production Workflow

The VFX production workflow has evolved from the very simple, complete task of pioneers such as Méliès to today's pattern of specialisation and division of labour. Several people are now needed to specialise in individual tasks to get them done to the right level of quality and on time. VFX production consists of multiple organisational layers involved in all phases of production: pre-production, production, and post-production (Spelthann and Haunschild, 2011). In film pre-production, production and post-production are the three phases which are self-explanatory. However, during TV productions, for example, those phases overlap as pre-production for the second episode could be happening during production of episode 1. This overlap can also be seen in the VFX workflow.

While Figure 1 in the literature review chapter (see p25) showcase the most common VFX workflow, there is not one typical structure as each production is unique (Dunlop, 2014). Moreover, job titles and responsibilities may vary depending on the company and the production. Furthermore, as new technologies are introduced and advance, VFX pipelines constantly readjust to enable integration of these technologies into the workflow (MovieLabs, 2019).

Workers involved in VFX production can be divided into five teams: supervisory, pre-production, asset based, shot based and post-production. Each team has several roles. The responsibilities of each role are described in the table below. However, it is important to note again that workflows differ from the 'ideal type' depending on content types produced, business types, size of organisation, level of technology. Larger, more

technologically sophisticated businesses producing high quality (realistic, graphics heavy) content, will tend to have a greater division of labour and more specialist roles, such as 'Software Artists' who specialise in specific software such as Flame or Nuke. At the other end of the scale companies may have less specialisation and workflows may also include 'VFX' Generalists who have a wide range of skills in various stages of the workflow.

Supervisory Team	
VFX Supervisor	responsible for making sure all technical requirements are met on set when VFX shots are being filmed
CG Supervisor	responsible for planning and ensuring that the technical aspects of the VFX are executed properly
CG Producer	ensures that the VFX team meets all requirements set by the Director and/or client
VFX Producer	manages the progress of VFX shots on set, making sure all requirements and expectations from Director and/or client are met
Technical Team	
Pipeline TD	designs and develops custom tools to for all VFX departments to ensure pipeline runs smoothly and efficiently
Assistant TD	identifies any technical issues artists in each department may have and assists in solving them with TDs
Creature TD	develops tools and provides technical support for artists who create characters, such as Texture Artists
Lighting TD	develops tools and provides technical support for Lighting Artists
FX TD	develops tools and provides technical support for FX Artists
Rendering TD	provides technical support to ensure all final renders are executed correctly
Pre-Production Team	
Data Capture TD	collects data on set that is needed by VFX team (e.g., position of cameras, lens type, textures of set design and props etc.)
Pre-vis Artist	creates a rough 3D version of storyboards ('animatics')

Layout TD	determines the positions and movements of the virtual camera and 3D assets by using storyboards or pre-vis as a reference
Concept Artist	works closely with a Director to create 2D art of the intended look and feel of CG characters and environments
Asset Based	
Modeler	creates 3D assets (e.g., characters, props or environments)
Texture Artist	creates flat colour and texture for 3D assets
Rigging TD	creates a skeleton for 3D characters
Animator	creates movement of 3D characters
Shot Based	
Roto Artist	creates mattes to isolate objects, this is where the process of rotoscoping happens
Matte Painter	creates landscape and background elements
Environment Artist	creates a 3D (CG) world based on concept art
Match-mover	creates a 3D environment that replicates the perspective of the 2D live footage environment, which can then be used by animators
Crowd TD	creates and animates background characters
Lighting Artist	replicates the lighting from live footage for CG elements
FX Artist	creates simulations of elements (e.g., water, fire explosions, smoke, dust particles)
Post-Production Team	
Prep Artist	cleans up 2D shots from unwanted objects in a shot, this is where the process of keying happens
Compositor	responsible for assembling the final shot by combining final layers/renders from other departments

Table 1: VFX Roles & Responsibilities

Sources: (Chung, 2011; Dinur, 2017; Dobbert, 2012; Dunlop, 2014; Finance & Zwerman, 2010; Lee, 2019; Pluralsight, 2015; Scalfari, 2019; Screenskills, 2020; Zamanian, 2016)

Having described the existing VFX workflow and roles, it is now possible to start to identify how the new technologies described in the literature review may impact

individual tasks, the relationships between those tasks, the overall shape of the VFX production process and the creativity, job satisfaction and job security of VFX production workers.

A range of technical literature has been reviewed to identify the initial list of technologies most likely to impact the VFX workflow. These include AI and ML, which can execute many mundane or repetitive tasks and therefore increase efficiency. For example, animating background VFX characters and automating rotoscoping. Furthermore, pipeline management software that uses AI and ML could be applied to improve the management aspect of VFX production.

Real-time and cloud-based technologies are predicted to significantly change and evolve pre-production, production, and post-production workflows by enabling real-time feedback. Real-time technology is likely to have a significant impact by achieving efficiency and reducing cycle time of traditional repetitive rendering process, allowing artists more time to focus on the creative work. Real-time rendering and virtual production allow pre-visualisation studios to plan content creation more precisely by creating a single integrated workflow. Furthermore, it could contribute to a more interactive collaboration. RTE pipelines allow previsualisation with quality high, allowing more freedom for artists making creative decision by enabling artists to render in real time. Cloud-based technology allows management of data on-demand and off-premises, allowing managing the pipeline across different physical locations. Furthermore, it enabled higher IT security levels.

Virtual Production technology allows real time visualisation of VFX shots, allowing different departments to visualise and manipulate the digital environment and characters composited with physical set and actors in real-time. Similarly, MR technology allows for the previsualisation and interaction real set and virtual CG extensions at the same time. Lightfield cinematography technology can be used to make the process of rotoscoping and keying more time and cost-efficient. Similarly, Nano Technology has the potential to replace green screens and allow more precise extraction by reducing the risk of spills.

Literature review suggests that the identified technologies will impact the following tasks (for roles involved see Figure 3, p25) of VFX:

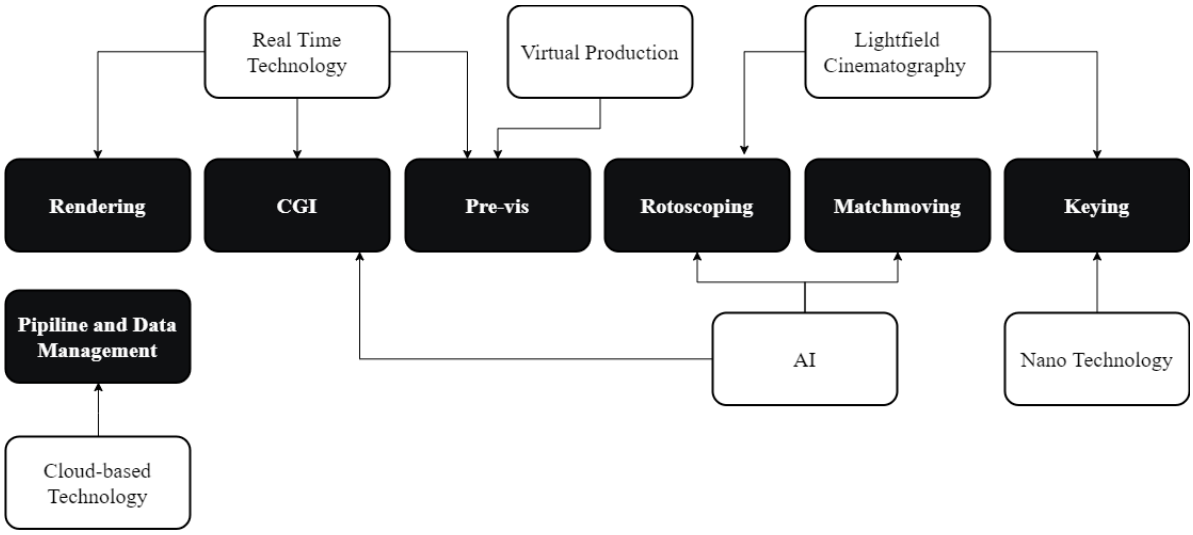


Figure 5: VFX Tasks & Technologies

Source: Author

Cultural and Economic Pressures for Innovation

Although cultural interests of audiences and producers have been important in historical use of technology to develop VFX techniques, sometimes industry literature is written as if all new technologies are going to have a dramatic effect on the industry (Failes, 2020d; Failes, 2020g; Foster, 2017; Kaufman, 2020; Okun et al., 2015; Pardeshi and Karbhari, 2019). This is known as technological determinism (Mcluhan, 1964). Many academics have criticized this approach. For example, they highlight the importance of economic factors in understanding changes in the media industries (Havens and Lotz, 2017). There is a lack of academic research on business models in the VFX industry and therefore the understanding of how this continuously changing industry responds to new challenges that come when new technology is introduced is limited (Kawashima, 2020). This section identifies key economic factors causing changes in the structure of the VFX industry and the influencing application of technology either to develop new VFX products or to transform the VFX production process.

The lack of academic study of VFX contrasts with the growing cultural and economic importance of this sector within the media industries. The VFX industry doubled in size

between 2008 and 2017 (BFI, 2019). In this period, turnover showed significant increases with 123% increase of film and video distribution and 113% increase of film and video production, including post-production (BFI, 2019). Since 1994, the highest number of feature films produced in the UK reached 376 in 2010 (Statista, 2017). The number rapidly increased from 200 in 2016 to 294 in 2017 and the box office revenue in the UK has been steadily growing since 2001 (Statista, 2017).

Gross value added of film post-production in the UK increased from £729 million in 2013 to £1,857 billion in 2017 (BFI,2019). Number of post-production companies in the UK increased by 18.3% from 2014 to 2018, making a total of 2,915 in 2018 (BFI, 2019). Turnover of post-production companies in the UK increased by 32.7% from 2014 to 2018, resulting in £1.8 billion in 2018 (BFI, 2019). In 2018, the global animation market (which includes visual effects in films) was worth £206 billion (Watson, 2020) and industry revenue of motion picture, video and tv post-production in the UK amounted to almost £1.3 billion (Huhn, 2020). The most successful films in the UK in 2019, by box office revenue, all included high VFX content, such as *Avengers: Endgame*, *Joker*, *Star Wars: The Rise of Skywalker*, *Captain Marvel*, *Spiderman: Far From Home*, *Jumanji: The Next Level* and *Rocketman* (Johnson, 2020). The increasing popularity of animated genre resulted in success of the industry market in 2019 (Mintel, 2019). The growth in demand and success of VFX heavy productions show the significant impact of VFX on the film industry.

The changes discussed in this thesis are part of broader changes in the industry. In 2017, United Kingdom (UK) was the 4th largest film producer worldwide and had box office revenue of £1.35 billion (Statista, 2018). UK government creative industries policies during the 80s and 90s helped support the development of a cluster of VFX industry businesses in London. Since 1925, the UK Government has protected its film industry with various cultural policies, which regulate the influence of the US film industry (Chapain and Stryjakiewicz, 2017). Such policies include the creation of quotas on the distribution of UK films and the use of various tax incentives for UK film productions, which have resulted in an increase of co-production (Chapain and Stryjakiewicz, 2017, p 79). These policies have experienced variation over the years due to the UK Government's changes of view on the influence and impact of the UK film industry in regard to the British economy (Chapain and Stryjakiewicz, 2017). Government's

introduction to the deregulatory policy during the multi-channel transition stage resulted in the significant expansion of development and clusters in the creative industries (Lotz, 2007).

Before 1980s, UK Film industry regulations protected productions from US influence and supported foreign investments. In 1927 a new act The Cinematograph Films enforced a 7.5% of British films screened in UK cinemas, which was then increased to 20% in 1935. In 1947, the 'Dalton Duty' act required a 75% tax on US films in order to further encourage UK productions and increase the US dominance. The 1957 Eady Tax enabled US companies to qualify their productions as British although the finance came from the US, which resulted significant decrease of UK productions during the 1950-60s. However, the lowest rates of UK productions were in the 1980s, when in the year of 1980 only 31 films were made and even decreased as low as 24 in 1981. This led to elimination of the Eady Tax in 1984 and the UK film production rates started to increase again in 1992 due to the tax incentive that allowed over £15m budget films to withdraw expenditure over three years after completing production, which encouraged US investment. In 1997, another tax incentive allowed 100% write-off of costs after completing production, which was aimed to encourage low budget UK productions, however, was also used by abroad US productions (Pratt and Gornostaeva, 2009)

Due to economic success in the creative industries, the UK Government continues to support them by dedicated tax relief to support high-end television productions (Gov UK, 2017). For example, for *Game of Thrones* and *The Crown* productions, which rapidly expanded their worth up to £1.5 billion since the scheme was introduced in 2013 (Gov UK, 2017). The growth of the VFX sector has been impacted by government policies designed to support digital industries. Since 2010, the UK's world leading digital industries sector increased its contribution to the UK economy by 23.3% in 2016; and keeps growing at an increase by 5.8% between 2015 and 2016 (Gov UK, 2017). The Government published its Digital Strategy in 2017 to grow the UK's place in the world's digital market (Gov UK, 2017). The Government's dedicated budget in 2017 accounted more than £500 million of investment in technologies, including AI, 5G and full fibre broadband (Gov UK, 2017). To grow its position in the global market and to expand global audiences, the UK Government continued its support by introducing the Industrial Strategy in 2017, which consisted of investment for immersive technologies, such as

virtual and augmented reality with £33 million from the Industrial Strategy Challenge Fund (Gov UK, 2017). The UK Government invested £780 billion in innovations to encourage creations of new "technologies of tomorrow" (Gov UK, 2018). To support and encourage the growth of creative industries, the UK Government is investing £33 million in new products and services that exploit immersive technologies, such as VR, AR and MR with the new Audience of the Future funding programme, which will run through 2018 and 2019 (UK Research and Innovation, 2018). Digital Catapult is amongst investors into UK immersive industry and is providing its immersive labs to help UK businesses to develop immersive technologies to help UK increase its market share (Bickerton, 2017). Therefore, further growth and development of innovations and artificial intelligence in the UK can be expected.

Decreases in tax on creative (and related IT) production, available government subsidies and funding and other regulatory measures enabled VFX production in London to become more cost effective than in some other locations (Newsinger, 2012). This created an option for producers to locate their content production in London rather than going to Hollywood, for example. As London grew as a centre of VFX production and related software development, providing and infrastructure which supported the digitisation of VFX content production. London developed a VFX labour force with a good level of technical skill and knowledge of the technologies emerging from the software industry that during the same period.

In the 90s and 2000s the Labour government's creative industries policy supported the IT and software industry as much as the creative industries (Garnham 2005). It's important to note that many have been critical of ideas of creative industries and their economic contribution as ideology designed to get factorable subsidy or regulations (Garnham, 2005). Garnham (p15, 2005) argues that: "the term "creative industries" can only be understood in the context of information society policy. It draws its political and ideological power from the prestige and economic importance attached to concepts of innovation, information, information workers and the impact of information and communication technologies drawn from information society theory. This sustains the unjustified claim of the cultural sector as a key economic growth sector within the global economy and creates a coalition of disparate interests around the extension of intellectual

property rights". However, as the creative industries have become more dependent on computing, that distinction between computing and software industries cannot be made.

While regulation and industrial policy can create conditions for industry growth (the "supply side"), industry growth also depends on demand for the product. Economics has an extensive impact on the developments and changes in the video production industry. When new technologies are established and new possibilities are revealed, economics influence the likelihood of their success. Initial research suggests a significant increase in demand for VFX film production has been driven by audience demand for particular types of viewing experience (Pennington, 2019). In 2018, BFI Screen Business report underlined increasing audience expectations for better VFX due to innovations in technologies. Furthermore, BFI audience research report showed that blockbusters with big budget visual effects are the most often watched type of film.

This growth in demand can be traced via genres. Partly the growth in demand for VFX reflects a growth in demand for animated films, which include visual effects. The size of the global streaming market for animation and VFX content was £2.8 billion in 2019 and is growing at an annual rate of 8% (Global Animation & VFX: Strategies, Trends & Opportunities Report). Action and animation genres increasingly include VFX (especially CGI). In 2018, the most successful film genres in the UK and Ireland ranked by box office revenue, ranked by box office gross were: "action" at £361.3 million and "animation" at £242.2 million (Statista, 2020). Action/adventure was the highest selling genre of films sold on video in 2018, accounting for 24.1% of sales revenue, followed by Sci-Fi and animation films which accounted for 16% and 12% of film on video retail sales revenue (Statista, 2020). In 2018, highest number of films released in the UK and Ireland were of action genre at 77 releases and animation at 46 (BFI, 2019).

The increase in growth of digital technology innovation in the film industry has had a huge impact on the market, enough for the BFI to recognise how critical it is and add a separate VFX sector in their film tax relief report (FTR). FTR report states that since 2007, the production expenditure in the UK Film market has seen a steady growth, from £850.9 to £1.72 billion in 2016. An estimated amount of £510.7m was spent on VFX in the UK and this sector of the market has generated 17,940 FTE jobs in 2016 (BFI, 2018).

While demand and policy enable an understanding of the growth and development of the industry, writers in the political economy of communications (PEC) field suggest alternatives to the ideas of conventional economics, such as the assumption that all firms compete to maximise profits. Academic study of PEC emphasises the relationship between political and economic forces in shaping media production (Wasko et al. 2011).

Since the 1960s, cultural industries, which include advertising, art, television, radio, film, fashion, graphic design, music and software production; experienced an increase in work activity and employment (Banks, 2007). During this cultural and creative age, some governments begun to support and encourage cultural industries, by promoting and investing in cultural production and allowing individuals and institutions to grow and embrace this new creative age (Banks, 2007). Governments and economic development agencies encourage growth in cultural industries and inspire workers to become self-sufficient, cultural, creative and knowledgeable (Banks, 2007). Craft production allows freedom in innovation and creativity to generate new and unique products and the Government's role in this is to encourage creativity without suffocating it (Banks, 2007).

Economic theory suggests that changes in industry may be driven by the desire of firms to maximise profits, and to try to do this by capturing a stable share of the market (Doyle, 2002). Neoclassical economics suggests that a company will keep expanding production of products as long as it is making profit on each product, however this only applies to homogenous products and video production products do not fit into that category. Although video production is highly expensive process, distribution of video products at large amounts is low cost. Media Economics studies analyse theoretical and practical economic practices of all types of media, including the film and TV organisations, and play an important role in understanding of how the industry operates as most decisions are influenced by resource and financial factors (Doyle, 2002). Thus, for example, competitive pressures mean VFX companies need to adapt to cost-effective, efficient, and flexible pipelines (Pennington, 2019; Wasko et al., 2011). Producers also respond to opportunities created due to the increase in demand for VFX film production. As the process heavily relies on digital and mechanical technology, this research aims to provide answers and evidence to the question of how automated digital technology impacts VFX production. Physical content distribution achieved economies of scale, however

digitalization and emergence of on-demand platforms not only caused changes in distribution, but also in production and consumption (Kawashima, 2020).

As an industrial economist, Porter (1985) suggested that a company could differentiate from competitors and gain market share with vertical integration by lowering costs of products or horizontal integration by buying competitors, launching new products or by producing higher quality products. Porter's concept of product differentiation may not apply to video production products as each product produced is individual. Therefore, companies have a higher demand for products overall.

Market control strategies, such as increasing the number of recognisable elements from other products, help reduce that risk (Dwyer, 2019). The pattern in consumption establishes different degrees of differentiation between the products to reduce financial risk. Berlyne (1974) suggested that consumption of experience products follow a U-shape, where audiences are least satisfied with products that are either too similar or too different and most satisfied by a new product that includes familiar elements. New innovations by a particular company or individual in the market result in adaptation to those innovations, which allows the competitors to sustain their position in the market (Leovaridis & Bahn, 2017).

Product differentiation strategy is often used in the US film industry as it is aimed to enable companies to sustain or even increase their place in the market (Bordwell, 1988). High budget productions often use talent, such as an A-list actor, to differentiate their product from competitors. Low budget productions use an influencer strategy. Furthermore, aggregation strategy is used by companies such as Netflix to gain market share and become the main VoD platform (Dwyer, 2019).

Although the UK is one of the main film producers in the world, United States (US) has remained as the main competitor and is increasingly growing its market share in the industry. The US film industry development history shows that high-cost levels were reduced by integration into large producing studios and concentrating most of the industry in Los Angeles since 1920's (Chapain and Stryjakiewicz, 2017). Today, US is the leading and by far the biggest film market in the world.

US and UK film industries are significantly different when it comes to the infrastructure. The US film industry, which is built on a small number of large film studios and is based on the integration between production and global distribution allowing the US film industry to become profitable and the dominant global market sharer. In economics, this structure of an industry can be a "barrier to entry" because it can mean it is hard for new firms to start up. The UK film industry does not seem to have had so many barriers to entry and developed a larger number of smaller production companies, focusing on the development of cultural and creative aspects of film production (Chapain and Stryjakiewicz, 2017). The number of film and video production companies in the UK has grown from 8,000 in 2008 to over 14,000 in 2018 (Statista, 2019).

One of the reasons for the US remaining the top competitor in the industry is their flexible production management and innovative financial system, which allows the US to dominate the global film industry market with their influential and vital technological developments (Chapain and Stryjakiewicz, 2017). Technological innovations have had a huge influence on the US film industry as improvements in various elements of filmmaking, such as SFX, for example, continue to impact US productions and set certain expectations of Hollywood films. Innovations in technology have been a part of the Hollywood business strategy to develop story-telling techniques and dominate the global film market. The American Society of Cinematographers, the Society of Motion Picture Engineers, and the Academy of Motion Picture Arts and Sciences were the most influential groups that encouraged technological innovation in the US film industry, which showed most impact between the 1930s and 1940s (Bordwell, 1988).

However, these broad industry statistics conceal problems defining the VFX industry as an object of study. Because cultural study of the VFX industry is rare, there is no commonly accepted definition of which content genres should or should not be included within the VFX industry. The content genres or cultural products that VFX producers work on vary across a wide range from Film, to TV, to games, to advertising etc. When breaking down a film, for example, the same process applies to other media products, but they have a different structure. For example, a news article or a long running TV series or a documentary, all require this kind of breakdown, but use a different template. In language theory they are called coherence structures because they aren't just any

template, but they are templates that are used to understand what someone wants to communicate.

The limited number of economic studies of the VFX industry means there is no common definition of the industry according to business types. The VFX industry consists of a multiplicity of business types: big companies that work on high end productions, medium to small sized companies that work on smaller projects. As companies diversify into related areas such as games production, using business types is equally problematic. Even specialist VFX houses tend not to produce content for a single platform. Instead, they all produce work for different platforms, such as Film, TV, games, and digital advertising. For example, big production companies that produce work for high end projects will break things down by using a Hollywood feature film template, which is hugely different from a TV advert or other forms of medium, as it is a different product and a different coherent structure, which requires a different way of communicating meaning. These companies don't just vary in terms of the size, but they also vary in terms of breaking down entirely different types of products, these differences then influence the changes in the production processes of these different businesses.

VFX and its technologies and techniques are being used to do essentially different jobs to make different cultural products as a result, in developing a methodology for selecting companies and individuals for data collection, this thesis contributes a novel definition of the VFX industry which is particularly useful in studying new technologies. Rather than content genre or business type, the definition of the object of study used in this research focuses on the tools used in VFX production. This is based on an analysis which reveals that beneath the surface diversity of the VFX industry, lies a common set of tools.

COVID-19 Impact on the VFX Industry

This research has occurred at the same time as the industry has experienced profound changes resulting from the pandemic. Particularly in relation to digitisation, the pandemic has been a significant driver of change. It is therefore important to recognise that some of the changes in VFX production may have been accelerated (or constrained) by the effects of the pandemic. Equally, other changes may result directly from the pandemic itself.

The constrictions of COVID-19 have impacted the VFX industry by accelerating digitisation. Before the COVID-19 pandemic, 46% of the VFX industry did not have technology that would allow their workers to work remotely from home, due to the expensive and sophisticated technology setups required for most VFX work. The majority of VFX workers are required to work in the office due to security, technical and economic reasons. However, the industry adapted to the changes quickly by transferring the usual setups to worker's homes by remote display tools, which allowed the display of secure office workstations to be transferred to a home computer screen over an encrypted data stream (The VES Technology Committee, 2020). Due to many VFX companies having clients from all over the world who need connect with the VFX team, working remotely was beneficial as everyone was able to work from home at the same time (Escape Technology, 2020). Furthermore, this allows flexibility in electrical requirements and reduction of physical labour of moving the workstations (The VES Technology Committee, 2020). The VFX workflows have evolved to ensure productivity maintains despite the disruptions and changes. Some of the advantages of remote work observed included improved and more productive time management since everyone involved in VFX production was able to work remotely at a time most suitable for them. For example, not having to wait around in meeting rooms for client's notes and not sitting around waiting for renders to complete (The VES Technology Committee, 2020).

Digital content and data security is essential in VFX work and to ensure that the remote-access setups had met all the required security needs, VPN technology was used to encrypt all data shared between workers and their company's datacenter (The VES Technology Committee, 2020). Using VPN allows a secure connection from a remote machine to the VFX worker's company's network. However, the disadvantage of using home internet connection is the limit of the size of files that can be downloaded, which can increase the time it takes to download the files. Furthermore, by using home internet the downloads take longer due to the large files and the data is also being distributed, which decreases security. However, another method that enables remote working which is more secure is streaming pixels. This method uses the process of sharing pixels rather than data, which allows the remote setup to mirror the office screens without downloading projects or files by decoding an encrypted stream of pixels (Escape Technology, 2020).

VFX production includes regular meetings with teams and clients, which are essential in order to discuss creative decisions and execute the project with good communication (Escape Technology, 2020). Screen shares and synced playback have been the main tools that helped VFX workers communicate (Chung, 2020). Platforms such as Slack, Google Hangouts and Zoom have played a huge importance in achieving efficient communication (Escape Technology, 2020).

The COVID restrictions created a new demand for digital methods to support remote working by teams across all sectors of the economy. VFX workers had to find new ways of working that would be possible remotely. Solutions included using cloud-based workstations with superfast processors able to support graphics heavy sequences. The proliferation of internet, online learning and new technologies enabled workers to integrate new technologies when during this period the industry was put in a position that these technologies which lay dormant or were being used individually started being used together. This period of time, although challenging, encouraged workers to think out of the box to create solutions raised by remote working. It pushed for everyone to use technologies even more, for example, although the cloud was already being used as a method to store data, it became massively important during this time as restrictions further forced this technology into being used and it became the only option. It enabled people to innovate with these technologies, in a way it did to various different technologies in various different industries, but especially in VFX there was an increased demand to develop and integrate these technologies into the workflow.

Impact of Innovation on VFX Production

The review of cultural and economic literature above has described the growth of demand for film and TV "products" including VFX and the development of companies and techniques to produce this content. The next section in the literature review focuses on how to explain how these changes impact the VFX production process by using the flexible specialisation theory of innovation to explain the pressures to introduce new technologies (for product variety or production efficiencies) to analyse the implementation of new technologies in the VFX workflow. This theory provides a range

of concepts (including outsourcing, use of freelancers, general vs specialist skills, job security and precarity) useful in describing and explaining changes in the work VFX producers do.

Writers in the field of political economy and organisation theory have analysed the forces that affect production processes in most industries, such as division of labour, industry structure and government policy (Staiger, 1979). This type of approach looks at how these technologies impacted labour and how the division of labour could affect both production innovation and efficiencies. The division of labour technique was used to improve specialisation by replacing craft production, (often involving production of the whole product by a craft worker), with manufacturing production, where the craft process would be broken down and decomposed into smaller tasks and carried out by separate specialised workers. Smith (1776) concluded that this specialisation resulted with increased output and a reduction in costs per unit when compared with the craft process. Smith's (1776) analysis of how the division of labour is used by manufacturers to achieve economies of specialisation was influential. The specialisation method was systematised in manufacturing by Frederick Taylor (1914) who created a model of task decomposition, which consisted of breaking down the work into smaller tasks and allowing specialisation of labour, therefore increasing efficiency. Taylor introduced the concept of specialist routine tasks enabling the replacement of highly skilled labour by machines or less skilled labour and improved industrial efficiency. Henry Ford used this model to develop a system of mass production (Storper, 1989). In 1913, Ford established the first assembly line in his factory, which relied on standardisation of parts and the change of the production process. The production process was simple, repetitive and sequential, which allowed easy replacement of workers as they did not require full knowledge of the process. Some writers argue Ford's approach can be seen in cinema in the division of labour (Manovich, 2002). The economic pressures for specialisation help in understanding how the overall shape of the traditional workflow of VFX (shown in the diagram on p25) has been developed. Here we can see that production workflow happens by the work of supervisors integrating the work of specialists in particular VFX tasks.

Outsourcing and Media Production

The video production market is hard to analyse by using traditional economic theories as every product produced is essentially a new innovation. Each video production is a new intangible product, which comes at a greater financial risk than most products of other industries. Industrial economists suggest that if a company attains a significant portion of market share, it can achieve economies of scale, allowing determination of prices for labour or technology. Another way to achieve this is through vertical integration, where the supply of production inputs, production process and distribution are combined, making the company more independent and achieving higher efficiency (Porter 1985).

Economists such as Caves (2000) have used economic theory to explain the decisions to disintegrate US feature film and UK TV production to independent production companies. Caves rejects the neoclassical approach and uses transaction cost economics (TCE) as it underlines that the decision-making process in production is more sophisticated and cannot be based on price due to the productivity uncertainties.

TCE allows to think of production as a series of transactions between workers and a various stage of the production process, rather than prices. In some cases, these transactions (production activities such as script writing, storyboarding, budgeting, editing, etc.) stay internal to the company, however TCE suggests that in most cases market transactions would be the most efficient way of allocating resources, as Williamson (1985) suggests, the reason why organisations would choose to organise the production themselves is to make the transactions more cost effective on the market. TCE suggests this is because businesses have limited knowledge about supplier or a complex production process. It may be difficult to differentiate what the supplier must provide and what the company is responsible for. To reduce this risk, companies may choose to produce everything in house where producers and managers have control over workers.

TCE theorists suggest that vertical integration is used to reduce the level of uncertainties in production. If a producer faces difficulties in defining performance that is expected of supplier in a contract (e.g., levels of creative or technical quality), they may hire workers on long-term contracts, so the project can be done in house enabling higher level of control (Dwyer, 2019). In an alternative case, if a producer has a high knowledge about

both the production process and the supplier, the risks would be limited and therefore it would be easier to outsource (Dwyer, 2019). Creative production can be interpreted as ‘simple creativity’ when a single worker (or artist) is used and ‘complex creativity’ when teams (or groups) of specialists are used (Caves, 2000). Outsourcing talent by contracting rather than brining talent in house allows to “generate word of mouth and network effects to increase audiences for a hit product” (Dwyer, 2019, p15).

Theory of Flexible Specialisation

However, identifying and explaining changes in film and TV production is challenging. In manufacturing various stages happen in discrete time periods: the product is designed, then it is produced, then it is distributed and then it is used or consumed. Production studies of film and TV production (Mayer et. al., 2009) show that scripts are continually changed in production and a shooting script may only be a loose guide to the placement of cameras, people and props on set or on location. The design process continues in post-production, as directors and editors may make extensive changes to the script or what was intended on set when they start to assemble the elements of the film. However, every time a new film is produced that design changes throughout the production process, an example of this process. Problems or opportunities identified during the editing process led to the process starting again with new elements being scripted (pre-production) and filmed (production).

Film and TV production film production is recorded, design (pre-production), production, post-production, distribution, and consumption happen at different times or can be intertwined (Dwyer, 2019). Unlike in other industries where a new design of a product is created and then produced in large amounts without any further changes to the design once it has been created, in the film industry, the film production process involves the creation of a new film, which is the design of a product. When TV was first established, video could not be recorded, therefore the design could happen first and production, distribution and consumption all happened at the same time as it was recorded live. The distinction between pre-production (design) and production in Film and TV is nowhere near as clear as in manufacturing (Dwyer, 2019). This seems also to be true in VFX production, instead of very efficient mass production of identical products, in VFX

production, each production produces an entirely new and unique product resulting in inefficiencies in some aspects of this creative process (MovieLabs, 2019).

In organisation theory this type of production is described as 'task interdependence,' (Thompson, 1967). A typical media example of this interdependence is when problems or opportunities identified during the editing process led to the process starting again (to a limited extent) with new elements being scripted (pre-production) and filmed (production). This the makes concept of waste is significantly important when it comes to process innovation in manufacturing and can also be applied to film in a means of time when extra filming days are recurred due to human error, which leads to decrease of time and money in production.

First introduced by Piore and Sabel (1984), flexible specialisation theory attempts to explain these types of flexible production by identifying patterns in the way companies adapt to changes in their markets, in innovative and flexible ways (Essletzbichler, 2003; Fitzgerald et al., 2021; Hirst and Zeitlin, 1997; Locke and Romis, 2007; Piore and Sabel, 1984; Press, 2008; Storper, 1993; Subesh and Panayiotopoulos, 1996). The theory is drawn upon the theory of mass production, which suggests that vertical integration produces economies of scale and increases productivity by having higher control over worker's performance. Flexible specialisation theory suggests that vertical disintegration occurred due to historic transition and although it accepts the Fordist mode of production, it argues that it lacks flexibility due to its dependence on standardised products and inability to produce new products in order to achieve specific demands or adapt to changes.

This theory suggests that new digital technologies helped reduce uncertainty and risk when buying production inputs. Disintegrating in a flexible way by outsourcing rather than being limited by what is provided in house, companies can achieve rapid production innovation and respond more rapidly to changes and demands (Dwyer, 2019).

Academic writers such as Tempest (2003) and Starkey et al. (2000) have highlighted the advantages of "functional flexibility". Such as the fluid environment which allows to hire a successful production team and providing opportunities for managers, in house teams and freelancers to learn across all divisions and from each other. Others, such as Arnold

and Bongiovi (2013) argue that the theory overemphasises how much disintegration of production has been driven by need to become for flexible than Taylorist or Fordist mass production specialisms to achieve product innovation. Suggesting that worker specialisms have remained, functional flexibility has been limited and outsourcing has not predominantly been driven by demand for innovation by finding new inputs from suppliers. Disintegration reduces financial risk of uncertainty by outsourcing and achieving numerical flexibility reduces fixed costs by reducing permanent workforce (Dwyer, 2019). Due to the high rate of failure of media products, numerical flexibility, which can be gained by vertical disintegration with outsourcing and reducing permanent workforce, is a vital tool to reduce fixed costs and allow businesses to release staff without cost redundancies (Dwyer, 2019). Over time as new technology emerged, they led to disintegration of many elements of production and increased process efficiency. However, introduction of new technology can also eliminate elements. For example, when the introductions of computers completely eliminated typesetting (Dwyer, 2019).

Since the internet, this flexible model of production and innovation has expanded even further. A model of open innovation, introduced by Von Hippel (2005), suggests that digital technology has reduced transaction costs to such extent where businesses can disintegrate production tasks to a wide market of freelancers. While specialisation can explain the overall shape of the traditional VFX workflow (see p25), TCE may be useful in explaining outsourcing (vertical disintegration) and flexible specialisation and the two forms of flexibility may be useful in explaining using freelancers: numerical (e.g., numerical flexibility) and changes to VFX tasks (functional flexibility).

Theories of Innovation

Another way researchers have explained changes in media production use theories of product and process innovation. This is particularly in the field of film theory, which explains the historical development in production in terms of product and process innovation.

For example, David Bordwell (1985) examined the development of narrative storytelling where the use of technology improved the quality of storytelling techniques. Others focus more on technological innovation as playing a crucial role in the changes of film production, for example Lev Manovich (2002) suggests that computerisation and visual effects redefined cinema. Dave Allen (2005), in *On Hollywood*, agrees that computerisation has improved efficiency of every aspect of production making the process less time-consuming and more convenient, furthermore creating new ways of storytelling. Some focus more on technological innovations occurring and succeeding due to the needs for improvements in either the process or the technology or both, such as David Bordwell (1985). Technological innovations have an impact on film styles and aesthetics, which creates soft innovations, such as the invention of new film genres (Chapain and Stryjakiewicz, 2017). Miles and Green (2008) suggest that the launch of a new film is considered a soft innovation (cited in Leovaridis and Bahn, 2017, p 161)

Different aspects of change include direction, function, timing, and causation, which can also be applied to the changes in the production process due to product or process innovation. Although the innovations in technology are allowing filmmakers to improve the ability to create worlds that replicate reality, they also provide new ways of storytelling. Regarding Hollywood, any stylistic changes are due to innovations that were encouraged by business strategies (Bordwell, 1988).

In Clayton M. Christensen's (1997) book *Innovator's Dilemma*, he discusses companies' ability to maintain their place in the market during times of technological changes and innovations. Although these changes occur in all industries, the Film & TV industry experiences a more significant impact as technological changes are critical in productions. His research suggests that although listening to customers is an important part of a successful business, there are times when companies invested in innovations that their customers were seeking, however as a result lost their market share. Christensen refers to such technology innovations as 'disruptive technologies' as they encourage a decrease in performance of a specific product and therefore lead to unsuccessful investments. The technology S-curve framework theory implies that early stages of a particular technology will show steady progress in performance improvements, however, it will rapidly increase as the technology becomes more familiar, until it starts to reach its limits, which is when more work and time will be put into further improvements. This framework was designed

to predict an impact on existing technology when new technology is developed. Christensen acknowledges that to succeed in investments and be able to adjust to new industry trends, companies need to recognise uncertainty in the future of their market. He suggests that a particular market might be seeking further technological improvements at a time when that technology isn't able to satisfy that need and therefore companies must recognise this issue and not let it led to investments in innovations that aren't necessary at that particular moment in time (Christensen, 2013).

One factor influencing if industries adopt innovations may be the "clustering" of the industry (Scott, 2004). The film industry is one of the most clustered of the creative industries (Chapain and Stryjakiewicz, 2017). There has been a lot of research of characteristics, roles and functions of different film clusters due to the history of specialisation on various film processes of particular cities, most famously in Los Angeles, Hollywood (Chapain and Stryjakiewicz, 2017). Some research suggests that clustering supports innovation in the film industry. By looking at industry clustering, we can analyse product and process innovations in particular specialist clusters. While some clusters such as Los Angeles may specialise in many different aspects of filmmaking, some such as London, mostly specialise in digital special effects and animation (Chapain and Stryjakiewicz, 2017).

Chapain and Stryjakiewicz looked at how clustering impacts creative industries innovation performance and assessing the nature of the innovation dynamic within the Soho cluster in London. Largest number of firms, employment and more than 80% of the film industry turnover is located in London, where Soho is considered the heart of the film industry since 1920s when Wardour Street received investment from the US based film production companies in order for them to expand and secure themselves in the UK (Chapain and Stryjakiewicz, 2017). The Soho cluster started to expand and develop with the support from many various higher education institutions, national public bodies and the London Development Agency. When researching the Soho cluster, Chapain and Stryjakiewicz's results showed that the main reason for most firms to be located in Soho is the fact that it is essential to be located in Soho if you want to be considered as a key player in the film industry due to the status attached to Soho as the historical heart of the industry. Soho based post-production companies are globally recognised as leaders in software and solutions for VFX and hold the most prestigious awards, such as Oscar for

Best Visual Effects, BAFTA Awards and Primetime Emmy Awards (Chapain and Stryjakiewicz, 2017).

Current innovations in digital technologies have impacted many processes of film production, distribution, and consumption (Chapain & Stachowiak, 2017). Since VFX is a big part of both Film and TV, this section covers product innovations in both sectors, although Film workers would've used different products to TV workers. The film industry has experienced a huge number of products, processes, organisational and soft innovations throughout history (Chapain and Stryjakiewicz, 2017). Companies have used product and process innovations to decrease costs of production and increase profits, which evolve production practice and establish new roles (Dwyer, 2019).

For example, digital distribution of films and TV series with online streaming platforms such as Netflix or the evolvement and increased efficiency of the continuity script with digital editing and post-production. Pratt and Gornostaeva's study (2009) on the impact of digitisation in the film & TV industry on innovation, where innovation is explored in technology, regulation, organisation and location, concluded that as the industry is at the forefront of innovation in new digital technologies, this encourages impact on the organisation of production.

Digital technologies are improving various film production processes by making them more efficient (Chapain and Stachowiak, 2017). For example, VoD platforms use algorithms to gather huge amounts of data and learn from user behaviour and improve the ability to match content by learning and classifying preferences of VoD users, allowing platforms such as Netflix to recommend personalised content (Cocorocchia et al., 2018). Innovations in technology reinforce constant reconstruction and recent analyses of technological developments reconsider the idea of cinematic technologies merely as technical (Bennett et al, 2008). However, Bennett et al suggest that film technology is not solely technical and materialistic, they embrace technology as practice and process, furthermore they expand the conception of technology and its impact on cinema (Bennett et al, 2008).

In the 1920-30s technology was considered as "cinematic notions", however, the relationship between technology and production significantly changed in the digital era

(Turquety, 2014, pp 50-51). Innovations in technology are transforming film production processes, which has impacted the traditional perspectives of realism and formalism in film theory since the early 1980s when special effects were introduced to the feature films production world (Prince, 1996). Due to technology innovations increase and the impact new technologies have on the process of filmmaking, film can now first and foremost be seen as technological (Bennett et al, 2008).

Innovations in ways that films are produced, distributed, marketed, and exhibited can be considered as organisational innovations, which mostly occur in the pre-production process innovations, such as financing (Chapain and Stryjakiewicz, 2017). They also occur in management and coordination production processes on larger film sets by development and improvement of creative leadership, team culture and management of film crews (Chapain and Stryjakiewicz, 2017). With the development of branding techniques, marketing has also been a huge part of organisational innovations in the film industry (Chapain and Stryjakiewicz, 2017). Organisational innovations also include film policies, which are discussed in more detail later.

The influence of product innovation allows companies to gain market shares by introducing new technologies. For example, Apple comes up with various technological innovations to differentiate and compete against their competitors. When all new technologies compete against each other, regulations determine one dominant design which becomes the preferred technology that is used by everyone (for example iPhone or Alexa mini), which means all other technologies aren't used anymore.

Industry life-cycle theory suggests that experimentation and product innovations slow down or stop when a dominant design gains legitimacy. Companies create barriers to new entrants (e.g., vertical integration) market control (Klepper, 1997). Secure market share and a dominant design, which is accepted as legitimate by producers, audiences, and regulators, enable to make efficiencies in the workflow. Although every product is different when it comes to the media industries, producers are able to follow the dominant design more routinely, which reduces variability in the tasks of each producer in the workflow and increases work efficiency. However, new technological discontinuities may enable new entrants. When the media industries are disrupted by

technological discontinuity and radical changes in technologies occur, this may impact the dominant design.

The historical emergence of the main VFX which will be influenced, changed, or added to by the emergence of innovations in VFX can be explored and explained by the life-cycle model (Klepper, 1997; Dwyer, 2019). In the case of CGI, technological change may have produced improvements in the quality of the product, however, may have disrupted the stability of the dominant design by creating a radically new challenges for producers to solve. For example, where does CGI improve the story and audience experience and where does it cause audiences to stop the suspension of disbelief necessary for drama. This may have reduced the efficiency of production because integrating CGI production process into feature films or TV drama workflows may have increased the variability of tasks and could, for example, lead to time being wasted in producing CGI sequences which don't improve the audience experience and may end up being cut from the project (Klepper, 1997; Dwyer, 2019)

This model can also be used to determine at what stage or stages of the industry life-cycle is VFX production. Some elements of the dominant design may be being disrupted by radically new technological innovations which may offer improvements in the quality of the product but may also create new problems for producers to solve. This may be increasing the variability of tasks in the workflow and therefore reducing efficiency. However, other technologies may be fewer radical innovations. For example, pre-visualisation technology may create opportunities to innovate the dominant design, but it may also just be used to reduce the variability of tasks. If live action directors are able to have more information about how the CGI will work, the technology may solve problems for them, for example how to direct actor's movements, which may increase efficiencies by reducing the number and variety of takes a director uses.

Before pre-visualisation, they may have done many takes for "safety" to cover them for variations in how the CGI would eventually turn out, however pre-visualisation enabled them to have more certainty that the live action they have filmed will definitely enable continuity of action with the planned CGI and so they may need fewer takes, and this will reduce the time and cost of each scene.

Industry professionals describe changes and impacts of product and process innovations in the entertainment industry as the Butterfly Effect, where new technologies and the smallest changes hugely impact the VFX industry (McCullaugh, 2020). When new technology and products arise, it takes time and investment into getting VFX artists to learn how to use new tools, however it can also improve the process of VFX by developing new skills and ways of creating VFX elements (Failes, 2020d).

Impacts of Innovation on Creative Labour

Many studies on organisational creativity provide knowledge and different perspectives on creativity and innovativeness in organisations (Davis and Scase, 2000; Sutton, 2001; Bilton and Leary, 2002; Styhre and Sundgren, 2005; Bilton, 2007). The ideas of specialisation, flexibility and process innovation in the previous section explained how companies try to improve efficiency in all types of production and even creative production. Film and TV productions demand high level of creativity and flexibility and at the moment there is an opportunity for process innovation, which can increase efficiency and reduce production costs (Ouyang et al., 2008). Some academics suggest that a certain amount of freedom in organisation and management increases creative freedom by allowing VFX workers to experiment (Bilton & Leary, 2002; Spelthann and Haunschild, 2011). Stark (1999) suggests that hierarchy organisation is a multi-layered structure of overlapping but also conflicting individual organisational forms.

Mark Banks suggests that artistic labour cannot be "standardised or mechanised without compromising effectivity", standardisation means restricting task variability and this becomes uneconomic if it reduces demand for the product (becomes lower quality than competition). New technologies might be able to provide substitutes for repetitive and routine tasks and therefore may help VFX artists to focus more on creative tasks, however this may also lead to certain changes in labour used for those VFX tasks. Banks (2010) looked at creative labour work conditions and environment and its effects on creativity and quality of work and argued media production remained a craft process and could not be replaced by a manufacturing type process.

Project management is a typical technique used in media production to try to improve efficiency. Johannes Lehner (2007) looked at the impact of classical theatre staging models on project management in development. He compared project manager roles in industrial development projects to the role of the director in theatre, as both are responsible for the outcome of the project or production. The process, use of tools and responsibilities of project management depends on the scale of a project. The bigger the scale and the sophistication of the project, the more coordination, planning and organisation it will require. The planning process becomes very crucial when a project is ambiguous. Leadership plays an important role in project management as it directly impacts the possibility of success or failure. Lack of coordination and support from leaders lead to product development delays. Communication between everyone involved in the project is essential for the outcome as it is carried out through trial and learning. Lehner also mentions an interesting insight about theatre productions building marking strategies around crises during production to increase awareness and get media attention for the production. This also relates to many film productions. Lehner relates the acting process to team building and resource planning processes, as they require the identification of the division of tasks between the team members. Rehearsals are linked to the implementation phase in project management, and the premiere of a film, where filmmakers can determine audience and critics reaction to their work, can be related to some companies that launch their final product through events (Lehner, 2009).

Business Process Management is a business improvement method which uses technology that encourages reduction of costs (Champy and Hammer, 2001). It means companies look at the processes they use and "reengineer". Sometimes this just means getting rid of a process, or it can mean "decoupling" so two processes which were dependent on each other can happen more independently (Champy and Hammer, 200). There hasn't been too much re-engineering in video production. Although the innovations technology are developing fast, most film production processes are still carried out in a traditional way, for example the various required documentation (such as call sheets) used on the daily basis on set is still paper-based and usually distributed to cast and crew manually (Ouyang et al., 2008). During production, documentation associated with various roles is recorded (for example, the camera assistant documents technical camera details of each shot on a sheet and the sound recordist completes a document with information of all dialogue and effects recorded on set), which are then used to create a daily progress report (Ouyang et

al., 2008). Traditionally and even most of the time today, these documents are paper-based and involves a manual process (Ouyang et al., 2008). Ouyang et al. (2008) applied this technology to process innovation for film production by automating the daily documentation and therefore reducing costs, errors and time spent when it is done manually. The results showed that this technology reduced data redundancy, improved data accuracy and suggested that the earlier this method is introduced in production the more efficiency is gained (Ouyang et al., 2008).

Before the evolution of the continuity script, productions wasted valuable time and mistakes were easily made. The development of the continuity script increased efficiency and reduced the time wasted (Dwyer, 2019). Similarly, real-time technology has the potential to increase efficiency and decrease time spent on various VFX tasks by faster and automated rendering. “Right first time” process used in the car industry in 1970s was used to increase efficiency and decrease number of mistakes made due to the substantial number of faults that occurred in the cars that were being developed. “Just in time system” was also created to boost efficiency, so that unfinished parts weren’t lying around and not sold. Similarly, the VFX process can also use this type of process (Womack et al., 2007). By reducing time of each task, VFX production will develop process efficiency.

Dwyer (2019) explains the theory of media production in the concept of three resources of production – land, labour and capital, and proposes the concept of substitution for one of these resources. Economists suggest that media production is labour heavy due to limited amounts of substitutions. This economic theory suggests that as AI becomes more acceptable, it will start impacting human employment as machines are able to substitute for complex tasks (Harari, 2016). This potential to substitute complex human tasks is what means AI could have a significant impact on VFX production and could potentially reduce job security of some VFX workers.

Job Satisfaction, Security and Precarity

Some writers have argued that changes to improve efficiency have a tendency to remove creativity and job satisfaction work creative work, in the interests of efficiency and management control. New technology might encourage excitement, however, for some,

it does raise concerns about losing jobs and a decrease in income and opportunities (Leopoldseder, 2017). As described above, some aspects of specialisation, division of labour and task decomposition associated with mass production can be applied to media production. The labour process theory of the organisation of work suggests that capitalism causes changes in efficiency. Staiger (1979, 1985) looked at the relationship between quasi-monopolies and the labour process of media production and argues that media production consists of standardised productions and routine tasks, which limits freedom of creativity and innovation. Staiger (1979, 1985) applied Marxist economic theory to argue that film production is based on routine tasks and is subject to overall changes across all economic sectors which replace craft processes with manufacturing style processes, and therefore causing 'alienation' of the worker and limiting creativity and innovation. She described industrialisation and alienation, arguing that the heavily standardised and routinised media production limits creativity and innovation. Even in areas where throughout the history of media production, technologies could not be substituted by labour, it may now be that this type of work could be performed by new innovative technologies. Many suggest that autonomy can significantly increase the job satisfaction in creative workers (Bilton and Leary, 2002; Scott, 1995; von Rimscha, 2015). This attests that new technology could impact labour in a positive way, however there are also accounts that suggest the contrary. Many academics have analysed the impact of digitalisation on labour, resulting in exploitation and unpaid labour (Bennett and Strange, 2015; Fast et al., 2016; Palm, 2011; Scholz, 2013; Terranova, 2000).

Ursell (2000) notes the changes in TV work and employment in the UK during decades leading up to 2000s, such as the decrease in permanent staff, increase in casualisation of labour, higher difficulty of entering the industry, decrease in reward and support, decrease in earnings and the progressive decline in working terms and conditions. This increase of exploitation of labour, degradation of working terms and conditions and "precarity" of job status can be explained by Marxist of capitalism responding to decreased profits. However, it can also be explained as the majority of the film and TV industry consists of freelance workers, they organise their own labour markets (Ursell, 2000). Ursell (2000) attempts to explain these changes by observing that freelance labour becoming the majority of TV workers (who organise and maintain their own labour markers) and that many work either within very limited employment relation or none at all.

Factory-style production may negatively impact creativity, however automation may support creativity(Banks, 2007). New technologies may be able to provide substitutes for repetitive and routine tasks and therefore may help VFX artists to focus more on creative tasks. Perrow (1969) suggests that automation is usually more possible with more routine, repetitive tasks. Blair (2001) explores the labour process and market in the UK Film industry and underlines those debates around the future of work and non-standard forms of employment only focus on flexible specialisation framework to understand industrial organisation and labour market operation lack depth as they do not factor in any other impacts of a very complex labour market. Blair (2001) highlights the importance of labour market movements between different work groups and working with different individuals when analysing the labour market in the film industry. The entrance into the film industry is strongly influenced by personal connections within the industry and labour constantly needs to re-secure work and maintain their positions within the groups and contacts (Blair, 2001). This flexible labour market causes uncertainty of freelancers working in the industry, however by building and maintaining a set of long term and stable relationships in the labour market reduces that uncertainty (Blair, 2003). In his book, Banks refers to Tim Dant, who questions faults in general critical theories as they do not look at work as a specific part of life or provide comprehensive empirical data which examines organisation at work (Banks, 2007, p 25). Furthermore, Banks refers to Herbert Marcuse, who explored alienation in labour and whose observations showed that work has a negative impact on all human faculties, forces satisfaction and that industrial production ingrains a drugging rhythm, however, were not supported by substantial empirical data (Banks, 2007, p 25).

Job satisfaction is an important aspect for producers today due to the increasingly longer work hours and shorter turnaround times, which increase productivity pressures (Sanson and Curtin, 2016; Heusser, 2013; Venkatasawmy, 2016). The precarious conditions of VFX workers who work long hours with low pay and uncertainty of job security are partly due to the lack of union representation for VFX workers and the pressures of workers to create additional content (such as for social media) when working on the agreed VFX for a project (Sanson and Curtin, 2016). Writers like Hesmondhalgh, Miège and Ryan suggest that cultural workers cannot be completely alienated as craft production encourages spiritual, emotional or artistic connection with their work (Banks, 2007). Hesmondhalgh and Baker's research looked into three conditions of creative labour: pay,

working hours and unions; insecurity and uncertainty; socialising, networking and isolation within three different cultural industries: Music, TV and Magazines. Research on artistic labour suggests that artists take on multiple jobs; there is an increase of self-employment (freelance workers) and short-term contracts dominate the sector; work is irregular; career expectations are unclear; earnings are unequal; artists are younger than other workers; and the workforce appears to be growing (Hesmondhalgh and Baker, 2011). Freelancers experience isolation and alienation due to short-term contracts, which lead to lack of motivation and constant need to maintain contacts (Hesmondhalgh and Baker, 2011). Furthermore, freelancers have very limited financial and psychological support from unions, which decreases the quality of working life (Hesmondhalgh, 2010). Freelancers show more uncertainty than in house staff (Dex et al, 2000), which suggests for further studying of the quality of working life and the policies in the creative industries.

The element of volunteering as a way to enhance employability can been linked to Foucauldian theory and Hesmondhalgh and Baker argue this needs to be addressed more seriously. Due to increasing competition and fear of replaceability, young starting freelancers often work for free or for very low wages, as well as work in all stages of production, in order to gain a place in the highly competitive industry (Hesmondhalgh and Baker, 2011). However, in many cases, this can result in continuing to work for free, expenses only or for ridiculously low pay for many years, without any significant career change. Hesmondhalgh and Baker's research findings confirmed that, in television, contracted working hours have extended over the years, however the crew isn't receiving payments for the extra hours of work. Although according to their research, the crew can refuse working extra hours without pay, Banks underlines that it is important to be flexible and taking on more work if you plan to be successful in the industry (Banks, 2007). Lehner also mentions the similarity between project managers in industrial development initiating high-risk projects in order to progress in their careers, and theatre directors selecting plays only for personal satisfaction rather than basing their decision on criteria that a particular theatre or audience needs (Lehner, 2009). This can also be related to filmmakers, especially freelancers, who take on high-risk or low-pay projects simply to increase their portfolio and gain a certain status in the very competitive industry (Hesmondhalgh and Baker, 2011).

Spelthann and Haunschild (2011) offers a different perspective to this field by looking at organisational creativity in VFX production in terms of hierarchies due to many roles in VFX are unranked (non-hierarchical) and the different workflows involved overlap. The developments in SFX production had an impact on labour creating a new workforce (Turnock, 2014) and then led to the digitalization of VFX and division of labour. the production tasks which once were completed by a single production worker became 'decomposed' into more specific tasks with specialised equipment and specialised workers who can be more efficient and/or achieve higher quality because of that process of specialisation which Adam Smith (1776) described. The process of task decomposition improves the quality of decision making and achieves simplification and mechanical aggregation effect (Lee and Siemsen, 2017). Simplification suggests making judgements on aspects of a complex task rather than on the whole task (Henrion et al., 1993). Mechanical aggregation suggests that the decision can be made once judgements on all aspects are put together (Einhorn, 1972). This process often follows from organisational structure (Lee and Siemsen, 2017) and is used to "divide and conquer" (Raiffa, 1968, p271) by breaking down complex tasks into smaller / simpler ones.

Spelthann and Haunschild (2011, p102) qualitative empirical study of organisational creativity in VFX production in hierarchies affirms that "analytically distinct organizational layers (networks, firms, projects, etc.) more or less collapse into an indistinguishable organizational ecology of practice, which is governed by ambiguity, latency, organizational redundancy and rivalry between incompatible organizing principles rather than transaction efficiency or trust". As VFX production in a one-off project, personal networks "endure current collaboration and provide a forum for building up reputation, signalling skills and market value, and thus communicate important recruitment information for subsequent collaboration" (Spelthann and Haunschild, 2011, p103).

Some researchers divide the industry into two distinct types of organisations, VFX facilities and VFX studios (Spelthann and Haunschild, 2011). VFX facilities are usually "matrix-structured, multi-project-based firms, whose departments provide the technological infrastructure, but also an internal labour market from which the projects can draw resources" (Spelthann and Haunschild, 2011, p104). They work as a service company for productions and on a smaller scale projects such as music videos or

commercials, VFX suites and labour in VFX facilities can even be booked by the hour (Spelthann and Haunschild, 2011). However, VFX studio companies can be characterised as "administrative shells" (Spelthann and Haunschild, 2011, p104) that work on a project-by-project basis and use the same few VFX supervisors, who are allocated by film production companies and subcontract work to VFX facilities.

Although most theorist of business administration suggest that no redundancy and organisational slack encourage optimal efficiency (Landau, 1969), Penrose (1959) was the first to suggest that in fact it is essential in order to increase reliability (Landau, 1969; Spelthann and Haunschild, 2011). The uncertainty of the requirements of each VFX project makes it difficult to foresee whether new skills and training may be needed, which makes learning-on-the-job the main strategy for VFX labour over the course of their careers (DeFillippi and Arthur, 1998). However, learning and experimentation usually takes places outside the working hours since during the project, the VFX worker is required to complete all the required work (Spelthann and Haunschild, 2011). Therefore, it can be observed that this project-based organisation provides organisational slack and opportunities for off-the-job learning, which encourage creativity (Spelthann and Haunschild, 2011). Other sources of creativity and inspiration that can be seen as organisational slack and redundancy, include VFX workers socialising in creative places in London such as Soho house (Pratt, 2002; Grabher, 2002; Spelthann and Haunschild, 2011).

Spelthann and Haunschild (2011) argue that "the diversity of organizational forms and practices constitutes a potential for organizational creativity that gets activated through a particular organization of diversity, which is characterized by multilayeredness, duplication, overlap, incongruence, redundancy, organizational slack, rivalry and latency". The study shows that management in the creative industries is not simple and clearly structured, but an entanglement of multi-layered practices.

Hesmondhalgh and Baker (2011) attempted to evaluate creative workers' accounts of their own creative labour by adding the concepts of autonomy and "good work" to their definition of creative labour: "Cultural-industry organisations also tend to be structured in such a way that some workers are able to gain high levels of autonomy, in both senses analysed in this book: workplace autonomy and creative autonomy. This means that they

have the possibility of shaping outcomes, and producing good work in the sense of work that contributes to the common good" (Hesmondhalgh and Baker, 2011 p222)

There are problems with a definition which seems to reduce creativity to the concept of autonomy. This is evident when Hesmondhalgh and Baker make a distinction between two types of autonomy. Some workers have "aesthetic or artistic" autonomy, such as creative artists, and others have "professional" autonomy, such as journalists (Hesmondhalgh and Baker, 2011, p 62). In many ways, this simply replaces the problem of how to define and analyse "creative labour" with the question of how to define "aesthetic or artistic" labour.

However, the concept of autonomy can be useful in analysing how far VFX workers see autonomy as essential to their idea of creative work. Autonomy relates to the ideas of authority and "power", which are also explored by Hesmondhalgh and Baker (2011). This enables an analysis the politics of creative work; the idea that power structures in organisations may influence who has autonomy in their work and whose work is routine. This allows them to suggest that access to creative work may follow a hierarchy in creative organisations. They emphasise the need to analyse the forms of structural causality that influence creative workers' conditions and experiences, and which result in profound inequalities of access and reward.

This idea of hierarchies of power relates to the discussion of division of labour and Taylorism (above) whereby managers are able to decide which workers have autonomy (for example managers themselves) and which perform routine tasks in a workflow controller by managers. Hesmondhalgh and Baker follow the discussion outlined there when they note that "within the cultural industries themselves, there is a division of labour, with some people taking on more of the creative, demanding, challenging but also rewarding work, especially that around symbol-making and craft skills, and others involved in 'humdrum' (Caves, 2000) routine tasks." (Hesmondhalgh and Baker, 2011, p 233). They contrast autonomy with powerlessness and suggest that "there is a strong tendency for creative workers to occupy the lower-authority, higher-skilled locations here: i.e., experts and skilled workers with little or no supervisory or managerial powers" Hesmondhalgh and Baker's (2011, p 68).

Hesmondhalgh and Baker expand the concept of precarity to create a broader concept of "good work" They note, as Murdock (2000) suggests a division in creative organisations "between groups with relatively secure conditions of employment or their own successful businesses and those operating in conditions of permanent insecurity and independence" (quoted in Hesmondhalgh and Baker, 2011, p 69).

They use this concept to differentiate between work which may technically be creative, but which comes at a cost, particularly in terms of job precarity. Hesmondhalgh and Baker suggest that an ideology of creativity conceals work, which is not really "good work" as in creative organisations: "many workers tolerate poor pay, long hours, and difficult conditions in order merely to gain jobs with very poor levels of security and protection. In other words, to achieve the possibility of self-realisation through creative work seems to require what some recent critics have called self-exploitation" (Hesmondhalgh and Baker, 2011, p 221). They suggest that creative workers may not always be fully aware of their own conditions and experiences, whether the processes are really creative while working long hours on very short-term contracts and having an uncertain future. They conclude that creative work may not be "good work" due factors such as low security, high precarity and poor work-life balance.

However, Hesmondhalgh and Baker also suggest that, even under these conditions of precarity, creative work may still be better work than factory work, for example. This is because creative workers generally have much more autonomy and control over how they complete tasks than factory workers (e.g., Taylorism/Fordism). They suggest that it is important to consider creative workers' positive experiences and to not dismiss these accounts of job satisfaction through (precarious) creative works as simply the product of ideology, "false consciousness" or disciplinary discourses. On the face of it then, the cultural industries provide significant opportunities for good work" (Hesmondhalgh and Baker, 2011, p 222).

Finally, Hesmondhalgh and Baker extend the analysis of creative organisations to include workers not usually included in the academic study of cultural production. They emphasise the point that "someone has to clear up after musicians and producers have used a recording studio" (Hesmondhalgh and Baker, 2011, p 233) and conclude that "the

cultural industries provide some great jobs as well as some awful jobs" (Hesmondhalgh and Baker, 2011, p 234).

Hesmondhalgh and Baker's (2011, p 39) table below helpfully summarises main concepts and relevant literature analysing creative work and job security or precarity.

Table 2.1 Conceptualising good and bad work

	Good work	*Bad work*
Process	Good wages, working hours, high levels of safety	Poor wages, working hours and levels of safety
	Autonomy	Powerlessness
	Interest, involvement	Boredom
	Sociality	Isolation
	Self-esteem	Low self-esteem and shame
	Self-realisation	Frustrated development
	Work–life balance	Overwork
	Security	Risk
Product	Excellent products	Low-quality products
	Products that contribute to the common good	Products that fail to contribute to the well-being of others

Figure 6: 'A Model of Good and Bad Work' by Hesmondhalgh and Baker

Source: (Hesmondhalgh and Baker, 2011, p39)

This thesis integrates Hesmondhalgh and Baker's distinction between creative products and creative processes (Figure 6) and uses the idea of "excellent products" or "high quality" products to analyse both the competitive pressures influencing the introduction of new technology and the interview evidence collected for this study where VFX workers communicate about creativity of the product. Because of the diversity of the content genres and business types in the VFX industry outlined above, we may expect VFX workers to adopt a hierarchy of excellence or product quality and variety, with Hollywood features (such as the successful "Marvel Universe" series) at the top, for example, and low-cost online advertising productions (such as animated TikTok videos) at the bottom.

The thesis also adopts Hesmondhalgh and Baker's use of the concept of hierarchy to analyse the politics of work in VFX production houses, and the access to good work. This enables the study to explore how far, even within the hierarchy of creative workers, there

are precarity concerns, for example if some VFX workers do not feel as secure in their job as workers at the top of the hierarchy.

Hierarchy of VFX Workers

Some literature suggests that a lack of organisation increases creativity and innovation in hierarchies (Bilton and Leary, 2002; Florida, 2002). Others suggest that it is the flexibility and multiplicity of forms of organisation in VFX production, with overlap between different VFX roles and tasks, which may encourage creativity and innovation, allowing workers to gain knowledge and experience of areas of VFX work that aren't included in their specific job description (Manning, 2008; Spelthann and Haunschild, 2011).

The first researcher to develop a detailed study of hierarchy was Weber (1911) who was the first to use the idea of bureaucracy. He did not imply that every company is the same, a hierarchical bureaucracy, but suggested that by studying a wide range of them researchers can illustrate variations from an 'ideal type'. From this, we may expect that the hierarchy in every VFX company will be different from the 'ideal type' that Weber illustrated, but that we can use this approach to create an example of what the ideal type of VFX hierarchy may be.

This is approach was used by ScreenSkills (2020) in developing a hierarchical diagram which illustrates the different types of roles in the VFX workflow, their hierarchy and whether they fall under managerial, creative or technical umbrella (Figure 7).

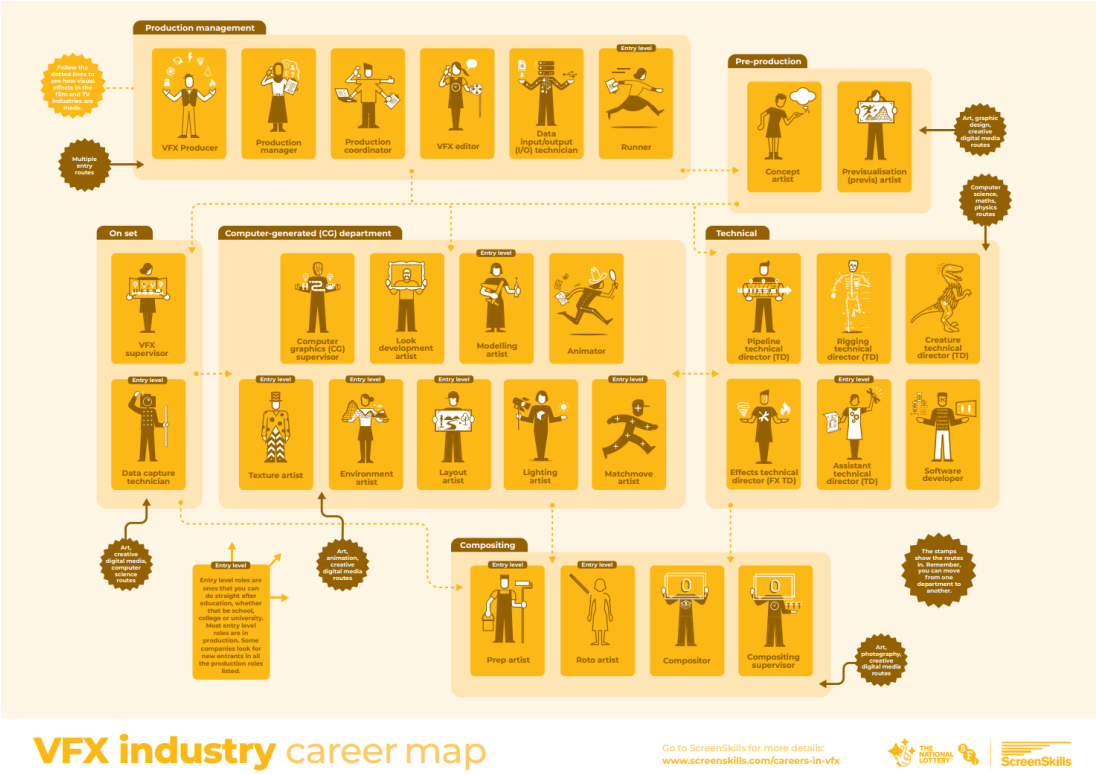


Figure 7: ScreenSkills VFX Industry Career Map

Source: (Screenskills, 2020)

Based on the Screenskills map, and the industry literature relating to VFX houses, including their company websites, the hierarchical structure below represents an 'ideal type' of the hierarchy which can be compared with the real authority structures found in the organisations studied for this research. Alongside the VFX workflow diagram, This hierarchy diagram thus provides the basis for determining the sample of VFX workers to be interviewed for data collection, to ensure that the study is able to represent the impacts of technology implementation on a range of VFX workers.

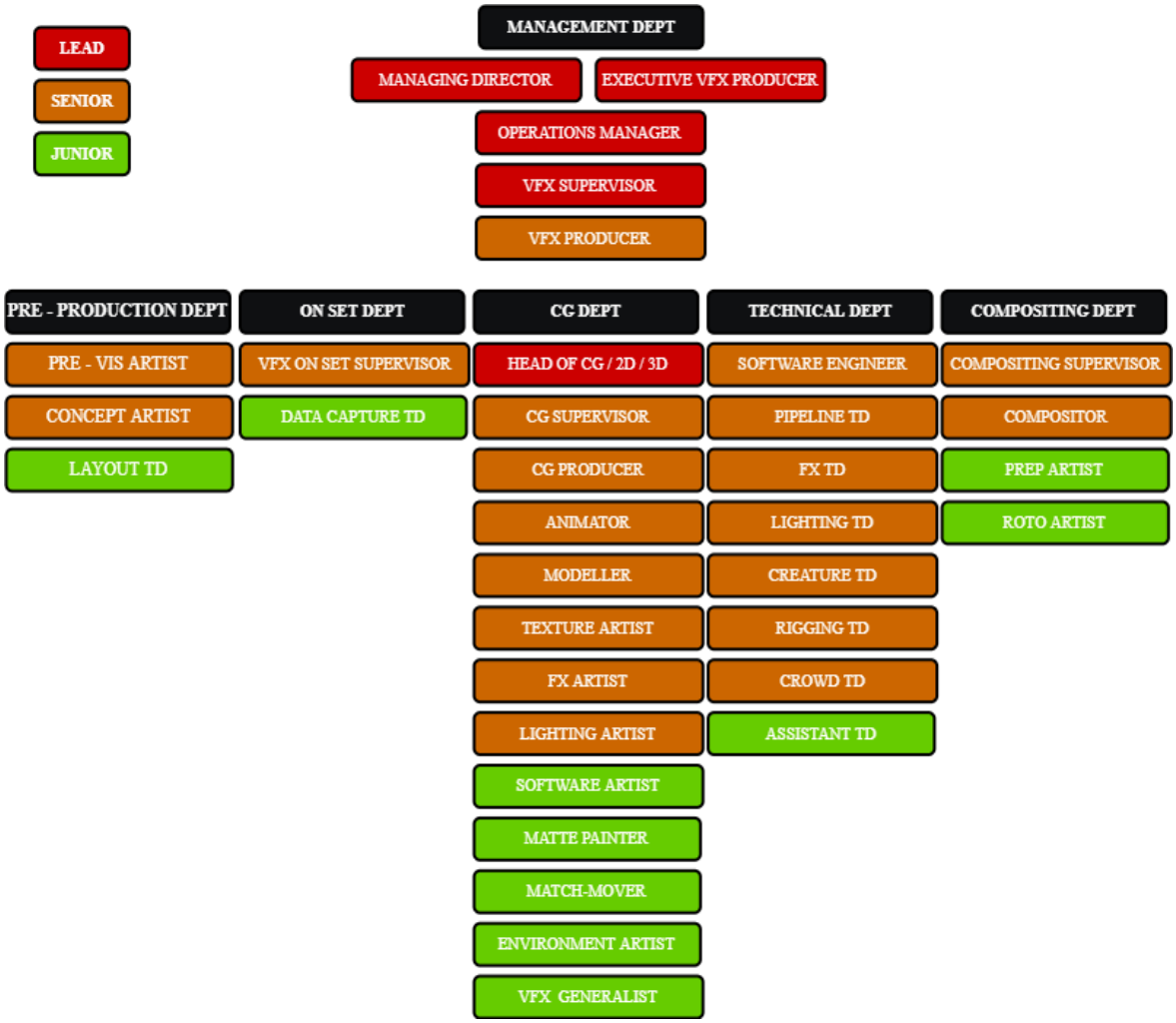


Figure 8: Hierarchy of VFX Workers

Sources: (Chung, 2011; Dinur, 2017; Dobbert, 2012; Dunlop, 2014; Finance & Zwerman, 2010; Lee, 2019; Pluralsight, 2015; Scalfari, 2019; Screenskills, 2020; Zamanian, 2016)

Therefore, based on studying a variety of organisational structures in different VFX companies, which are all different, Figure 8 is the suggested 'ideal type' of VFX hierarchy, which helps give some understanding and map the interviewees of this research.

Since Weber's work appeared, many studies have identified the range of factors which mean an organisation structure may be different from the ideal type. Child and Mansfield (1972) suggest that some of the aspects of the hierarchy (e.g., the number of levels of management, the degree of specialisation of roles, the formalisation of the type of role)

reflect the size and scale of the organisation. This research suggest that it also holds true for VFX production houses, that larger organisations tend to be more formal, structured and hierarchical and smaller houses more flexible. Although hierarchies may be different in each VFX production and studio, the diagram below shows an exemplar of hierarchy of VFX workers, which includes lead, senior and junior roles. Lead roles oversee the project and make final decisions. Senior roles have the power to make their own decisions in the project, however they can be overpowered by the leads. Junior roles work independently, however are also overpowered by seniors and leads. In some cases, some of the roles illustrated above (Figure 8) may be categorised as mid or mid-senior (or mid-junior).

A second factor affecting the nature of the hierarchy concerns the power and skill level of its workers. Mintzberg (1979) suggest that professional organisations (such as hospitals) are less bureaucratic than the ideal type, because they include highly trained professionals with high control over their work and thus a high degree of autonomy.
The high level of autonomy for professionals in professional organisations suggested by Mintzberg (1979) is similar to what is going on in media production organisational structures.

Technology and Division of Labour: Creative vs Routine Tasks

As well as organisational size and the power and skills of the workforce, many studies suggest that technology is an important factor influencing the degree of hierarchy and structure within organisations (Thompson, 1967; Perrow, 1970; Woodward, 1965). These studies found that levels and types of technology implemented influence aspects such as the number of the hierarchy levels (Woodward, 1958; 1965; Udy, 1959; Zwerman, 1970). As Scott puts it: “To focus on the technology of an organization is to view the organization as a mechanism for transforming inputs into outputs.” (1975, p5).

As the section discussing the VFX workflow noted above, the way VFX is produced is changing partly because the technology is changing. This section reviews the discussion so far to show how the implementation of technology may impact VFX production roles,

not only at different stages of the production workflow, but also at different points in the organisational hierarchy.

Some of the technologies studies in this research have the potential to enable new creative tasks. For example, using Unreal Engine requires a whole new skill set and has create a whole separate category of jobs for artists who specialise in that technology. As it allows artists to create narrative animation on their own from scratch, it can be assumed that this technology has create a new set of creative tasks, which you wouldn't have been able to do before. AI can also be used for creative tasks by generating 'original' content based on a data set of the desired visuals.

However, most of the new technology seems to eliminate or reduce the amount of routine tasks or reduce the time it takes to complete them. For example, Runway that uses ML for rotoscoping, automates the process, which allows artists to complete this routine task faster. Routine tasks such as rotoscoping, can be increased in efficiency by using technology such as ML. Real-time rendering technology eliminates the routine task of manual rendering that's required throughout all processes of VFX production (e.g., CGI, animation, 3D modelling, rigging etc) which also increases efficacy. Reducing the amount of time spent on routine tasks gives artists more time to focus on creative tasks. Creative tasks such as animation and CGI are improved by the drive of efficiency when technologies such as real-time rending and AI (including ML) are being implemented into their workflow as they reduce the routine tasks artists have to complete and instead gives them time to focus on the creative aspect.

The Conceptual Framework for this Thesis

The above review of the literature has established a conceptual framework which can be used to try to understand the role of technologies in VFX. The literature review suggests that product market innovations (CGI features and CGI TV series) and the resulting growth of demand for VFX production has led to a search within the VFX industry to apply new technologies which can deliver the VFX techniques which give a competitive advantage to certain products, or which can reduce the costs or time taken to produce those effects. The application of these has the potential to change both the performance

of some VFX tasks, the relationship between tasks and the jobs and job satisfaction of VFX labour.

The industry and technical literature reviewed for this thesis suggests that, to meet demand, the VFX industry is searching for cost-effective, efficient, and flexible production processes (usually referred to as “pipelines” or “workflows”). It is argued that new technologies are not just being used to innovate in the products (enable new types of film, TV, and video to be produced) but also to achieve efficiencies and flexibility in the process of producing those products. This literature suggests that the industry is focusing its attempts to achieve these efficiencies and this flexibility through application of a range of digital and mechanical technologies. The most significant technologies identified from the literature review are:

- Artificial Intelligence (including Machine Learning)
- Real-time Technology
- Cloud-based Technology
- Virtual Production
- Lightfield Cinematography
- Nano Technology

This research explores the implementation of these technologies and in some cases some technologies have been implemented earlier on and some are only just starting to be implemented. However, this research explores the impacts of at all these technologies as a whole, over the period of time around COVID. Thus the VFX workflow diagram illustrates a stage before the year 2020. This research focuses on changes that have occurred since 2020 where all these new technologies have been implemented together.

The literature does suggest that there may be delays between the development of these technologies and their implementation. When new technology and products arise, it takes time and investment into getting VFX artists to learn how to use new tools, however it can also improve the process of VFX by developing new skills and ways of creating VFX elements. These innovations in technology have the potential to change the performance of VFX tasks and the relationship between tasks and jobs, furthermore, impact labour involved in carrying out these tasks. This is summarised in the diagram below.

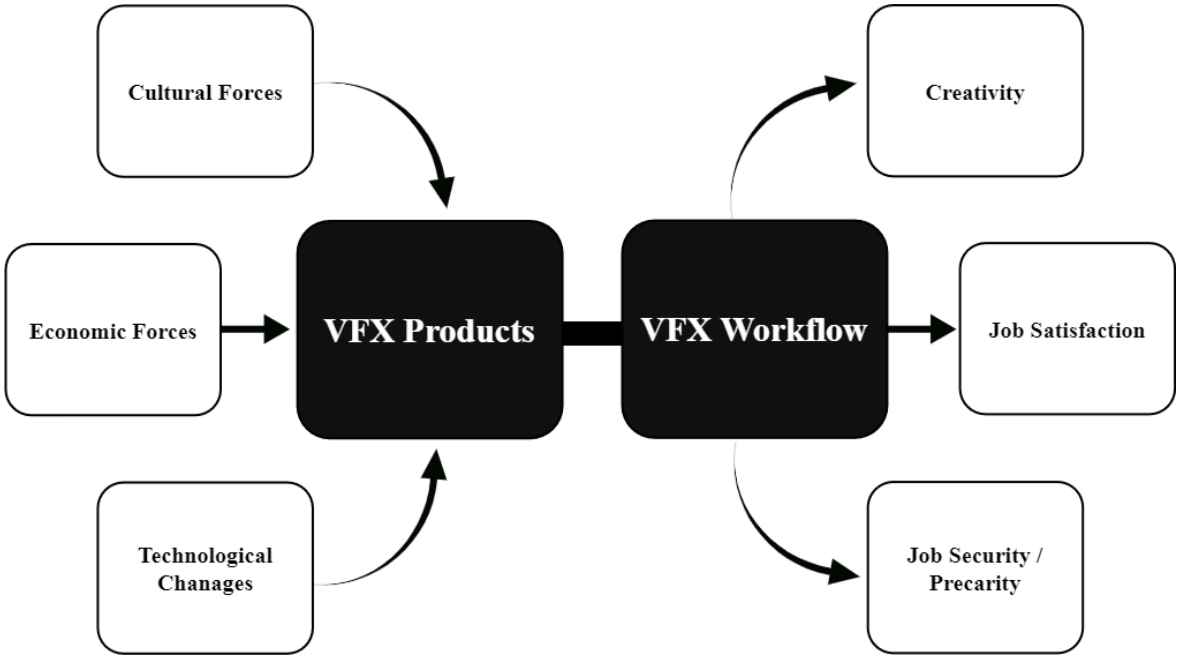


Figure 9: Conceptual Framework

Source: Author

So far, a range of technical literature has been reviewed to identify the initial list of technologies most likely to impact the VFX workflow and to describe the tasks involved in VFX production in detail. However, there are strong tendencies in the technical and industry literature to assume all the things that are possible will actually happen in reality. Many of these writers talk about a technology that "will" have a specific impact on some aspect of VFX production. They don't always explain why they are so confident of this and seem to assume that because something is possible it will be inevitable. This technology determinism is part of what this research is trying to examine (Wielgosz, 2017). The data collection will try to find out the impacts that are happening or the ones which are in the process of happening. This means when technology does or does not have an impact, is something to understand and explain.

Chapter II: Methodology

This chapter will begin by outlining an overview and rationale for the choice of methods used in the methodology of this study. The methods used to identify, and access interviewees will then follow. A discussion of the adaption of methodology for this research due to restrictions and complications faced during the COVID-19 pandemic will be provided.

Methodology Overview

Research Philosophy

Burrell and Morgan (1979) propose that "all theories of organisation are based upon a philosophy of science and a theory of society" and state that all social studies approach their research with "assumptions about the nature of the social world and the way in which it may be investigated" (Burrell and Morgan, 1979, p1). These assumptions are based on ideas about what knowledge can be gained through research and how the data can be sorted as true or false. Ontological assumptions are based on the "essence of the phenomena under investigation" which may include looking at whether the reality of the subject being investigated is external to the individual and is objective or whether it is created in the individual's consciousness or mind. Epistemological assumptions determine whether knowledge can be acquired through research or whether it has to be experienced. Human nature assumptions determine the relationship between human beings and their environment and aim to identify perspectives of human beings responding in a mechanistic or deterministic fashion to situations that occur in their

external world. Their experiences are viewed as products of the environment conditioned by external circumstances.

All three of these assumptions directly affect methodological assumptions as each one has significant importance in what way the social world is researched. Methodologies can view the social world as external to the individual or as a subjective reality. Subjective views allow to develop an understanding about how individuals create, modify and interpret the world they are in (Burrell and Morgan, 1979).

Interpretivist research philosophy is based on naturalistic approach of data collection, such as interviews, and allows to gain in-depth research (Collins, 2010; Myers, 2008). There are several variations of interpretivism, such as phenomenology, which is a philosophy of experience and is applied in research to understand experience of specific phenomena (Cimino and Leijenhorst, 2019; Littlejohn and Foss, 2009). This research uses the interpretivism philosophy by emphasizing on qualitative analysis and interpreting and integrating the interviewees opinions into the study. Furthermore, this research focuses on phenomenology by developing an understanding through direct experience the interviewees have had of the phenomena. Adopting such an approach would assist with identifying how and why the innovative technologies listed previously are impacting the VFX workflow and would allow to explore how the professionals working in those roles feel about it. To gain the desired knowledge, this research provides qualitative data with the use of one-to-one interview methodology technique described below.

Research Methods

VFX has dramatically changed the video production landscape, a development that should be at the forefront of academic research to further improve the process and should no longer be a 'neglected area of academic study'. Therefore, this study aims to highlight the importance of VFX in video production today and set a foundation for further research by identifying a gap in the knowledge and a range of challenges VFX industry and workers are facing today. This study aims to explain the historical and current circumstances of how different stages of VFX production have emerged and changed, decomposed into sub-tasks and their relationship to product and process innovation. Furthermore, to explore how VFX roles emerged and integrated. This study aims to

identify current technological innovations in video production, explore how they are driving the VFX pipeline to change and collect evidence to answer the question of how these technologies are impacting VFX production and impacting (and may impact in the future) the creativity, job satisfaction and job security or precarity of VFX workers.
In the early stages of this research, it was proposed to compare interview evidence against an online questionnaire (see p213). The questionnaire included open-ended, dichotomous and multichoice questions. This method was chosen because it helps to collect data on participants' attitudes and experiences (Bell, 1999) and allows the participants to take part in the research at a convenient time for them (Gilbert, 2001). A questionnaire was created and displayed on the website, which was created for this research. However, the response rate was so low that it was decided that this method would not be able to generate useful data for the study. As noted below, the problem of initially low responses to requests for interviews was resolved through an innovative research methodology and this provided the main primary evidence and data for the study.

Documentary research method (DSM) is the analysis of written documents with information on the phenomenon being studied (Bailey 1994). In this study, DSM was used because, as mentioned previously, academic studies on VFX are rare. Therefore, to be able to identify and evaluate the capabilities of the new technologies and their impact on VFX, it was necessary to conduct detailed studies of various industry sources. The broad data needed to describe the economic, cultural and technological changes occurring in VFX industry was gathered from industry reports by industry bodies like British Film Institute (BFI) and Visual Effects Society (VES). This included reports like Global Animation & VFX: Strategies, Trends & Opportunities Report. Data to help identification of the technologies which are emerging and having impacts, to identify the population involved in this process and to design the survey and research questions came first from documentary study of a large number of industry technical journal articles (from publication such as *VFX Voice* and *VFXWorld)*. More detailed data about the capabilities of different technologies was researched from technology manufacturers white paper reports (such as MovieLabs, Escape Technology, Adobe etc.). This method was used as initial research discussed in the literature review chapter. Moreover, this method was used to help identify the interviewees and structure the interviews by helping to identify key questions. To gain knowledge and provide in-depth insight into how new technology is being used and impacting VFX, this study implements qualitative research method by

conducting detailed interviews. The data from industry professionals in this study provide insight of trends and new technology in VFX today and how they impact VFX production. As stated in the literature review chapter (see pp41-52), initial research suggests that the following innovations in technology are having the most impact on VFX production:

- Artificial Intelligence (including Machine Learning)
- Real-time Technology
- Cloud-based Technology
- Virtual Production
- Lightfield Cinematography
- Nano Technology

There are many debates around AI technology, for example:

- Ethical and Social: dangers of moral outsourcing as AI lacks human judgment and compassion, many argue that intersection of AI and body-mind augmentations is a threat to human dignity.
- Privacy: concerns over machine learning and AI use in big data raising privacy and cybersecurity risks.
- Philosophical: intelligence is a manifestation of rational action, neuroscience believes that human brain can be said to be similar to computers, however others argue that Ai can only be used for problem-solving skills and cannot replace human intelligence.
- Economic: debates on whether AI has negative or positive impact on employment/labour – concerns over computerization reducing demand for those forms of labour that rely on pattern recognition.
- Political: issues of AI being used in the form of bots to manipulate public opinion during elections.

However, the level of AI used in technology specifically for VFX production, does not raise any of the issues above, apart from the economic issues mentioned above. For purposes of this research, AI technology is being referred to the use of it by implementing machine learning techniques to analyse existing data to automate routine tasks that are

usually carried out manually, such as face recognition, automatic tracking, and automation of backgrounds extraction.

Interviews have become the main method in social science research as they provide in-depth knowledge (Rapley, 2001). Structured interviews are based on the same script for each interview with predetermined questions, which allows for clear comparison between transcripts, however, decreases freedom in participant's answers (Punch, 2005). In unstructured interviews, questions are asked spontaneously based on the interviewee's answers, which does not allow for in-depth analysis (Bryman, 2004). Semi-structured interviews meet in the middle of these two approaches to produce the desired data collection (Dunn, 2000). Predetermined but open-ended questions give researchers more control and does not limit the participant's answers, similar to closed questions in structured interviews (Ayres, 2008). Face-to-face interviews raise some challenges caused by time, financial and geographical limitations (Cater, 2011).

Today's technology allows a computer to be used as a methodological tool for research (Bolderston, 2012). Although the use of a web camera may provide a similar experience as an in-person interview and therefore help identify nonverbal and social cues (Stewart and Williams, 2005; Sullivan, 2012), it does not show the participants body language due to a close-up image of their face only (Cater, 2011). Technological disruptions such as delays or poor video and audio quality may cause conversational turn-taking (Markham, 2004; Fielding, 2010; King and Horrocks, 2010). Due to COVID-19, one-to-one interviews were carried out remotely over Zoom. Online platforms such as Zoom offers researchers today a new method to collect qualitative data and increases chances of accessibility of participants (Deakin and Wakefield, 2013).

During the pandemic and lockdowns, many productions were cancelled or paused and many VFX freelancers and companies were out of work, which made accessibility of participants easier. However, although some interviewees were easier to access due to being at home, some were hard to approach through their company due to them being on furlough. This problem was solved by contacting them directly via linked-in.

Due to the gap of knowledge in the subject and the complexity and detail of data needed to gather further insight into VFX production, this research consists of one-to-one semi-

structured remote interviews based on predetermined but open-ended key questions as guided conversation, which allowed to get answers to desired questions without limiting the participants in their answers. When formulating the key questions (see p208) as an interview guide, subsequent questions were structured in a way that did not force or lead the participant to give a particular answer (Bryman, 2004; Drury, 2011).

Identifying and Accessing Interviewees

This study aims to provide an understanding of the VFX industry and its variation, as mentioned in the Literature Review Chapter, and reasons why new technologies are adopted, which is why the study was conducted in London. Historical causes to why London provides a good sample of the VFX industry is explained in the Literature Review Chapter (pages 60-68). The sample of interviews in this chapter is taken from this part of the VFX industry, which is different from Hollywood or anywhere else in the world. It is important to acknowledge that London VFX industry is big and complex, but also different from everywhere else.

The data collection for this research was conducted by interviews with VFX workers in the London cluster of the industry. As noted in the literature review chapter, the workers and businesses located in London provide the largest and most diverse sample of workers and businesses in the VFX industry to study. The value of this sample is that it enables collection of data from across the region range of content genres, business types and VFX production roles in the UK. No other UK location would be able to represent the full range of changes in the UK VFX industry This explains the sample of interviewees included in this study, which all come from different sized companies and work on different types of projects. Although all the work they produce is done in the UK, however many of the projects may be distributed and even ‘produced’ (filmed or executed, or financed by, or belong to) in other countries, for example USA.

Literature review chapter (see pp41-52) suggests that identified technologies above are impacting various stages of VFX workflow and therefore may impact different VFX tasks and roles, which are involved in those stages. The table below (see Table 2) illustrates which tasks and roles may be directly impacted by new technologies; however, it is

important to acknowledge that managerial roles may also be impacted in general. Although VFX and CG Supervisors and Producers will not be impacted directly by the identified technologies, they may be impacted by the changes these technologies may cause in the VFX workflow. Similarly, Pipeline TDs may not be impacted by some of these technologies directly, however any changes in the workflow will impact pipeline development and management. Furthermore, as some VFX tasks depend on each other or done at the same time, changes in the nature of work of any task will simultaneously impact all other tasks and roles involved in VFX production.

VFX Task	Technology	VFX Roles
Rendering	• Real-time Technology	• Modelers • Texture Artists • Rigging TDs • Animators • Crowd TDs • FX TDs • Lighting TDs • Rendering TDs
CGI	• Real-time Technology • AI	• Modelers • Texture Artists • Rigging TDs • Animators • Lighting Artist • FX Artist • Environment TDs • Crowd TDs • FX TDs • Lighting TDs • Creature TDs
Rotoscoping	• Lightfield Cinematography • AI	• Roto Artists
Keying	• Lightfield Cinematography • Nano Technology	• Prep Artist
Matchmoving	• AI	• Match-movers

Pre-vis	• Real-time Technology • Virtual Production	• Pre-vis Artist
Pipeline Management	• Cloud-based Technology	• Pipeline TDs

Table 2: VFX Tasks & Roles Potentially Impacted

Source: Author

Access to collect this data has been gained by approaching VFX houses and freelancers who are currently working in the industry within the roles listed above by using purposive and snowball sampling methods. Purposive sampling is usually the preferred participant selection process in qualitative research as it involves selecting the most representative participants for the aim of the research (Bolderston, 2012) and is often amplified by snowball sampling where current participants identify other potential participants (Bolderston, 2012).

Purposive sampling for this research consists of VFX freelancers and in-house workers, which include personal connections, recommendations from personal connections and researched freelancers who have been involved in VFX heavy productions. LinkedIn was another way of contacting industry professionals. The roles listed above include supervisory and specifically task orientated roles. Generic data and an overview of impacts was gathered from the supervisor-based roles, which includes information about all tasks identified. However, data concerning job satisfaction was gathered from specific task-oriented roles.

Morse (1994) suggests at least 6 and Creswell (1998) suggests at least 5 to 25 interviews when collecting qualitative data for phenomenological studies, which is when interviewees describe their experience of a certain phenomenon. Based on this, this research consists of 20 in depth interviews with industry professionals.

It is important to remember that the interviews came from VFX workers in different types of companies. As the literature review explained, VFX production does not change as a result of technological determinism. This is because not all technology impacts VFX producers the same way. Early evidence from the interviews confirmed this. For example,

different choices have been made between big studios and small commercial producers. This is also the same for VFX production workers. Not everyone in VFX production is impacted by these technologies, even though they may know about impacts on other workers or companies. The data collected confirmed this. Some of the interviews described general changes in the VFX workflow they had seen, but express that these changes did not impact their specific work directly or had not impacted them yet. Other interviewees were knowledgeable about the changes in the VFX workflow and the impact on their work, however they communicate their lack of control in the decision-making process of implementing new technology. These interviews were used to understand the broader picture. But during the interview process it was possible to find interviewees who are involved in decisions about implementation of technology or who are experiencing the impacts of technology on their work already. These interviews were very important in explaining the detailed aspects of why technologies are being used and what impacts they are having.

As noted in the literature review, this study adopts Hesmondhalgh and Baker's (2008) concept of "excellent products" (see p91) to help capture the way product quality and variety are important in the implementation of new technologies in VFX. The sampling this includes interviewees from both high and lower quality products to analyse how implementation of new technology impacts the work of VFX workers across the range of product genres, and to help understand how these workers discuss the creativity of the product.

To make sure the evidence presented is most clear and reliable, data analysis chapter only uses quotes from the interviewees who either were being directly impacted in their work or who were decision-makers in deciding if, where and how they should implement new technology.

An Innovative Approach during COVID-19

This research focuses on changes happening to the 'ideal type' VFX workflow (see p23) and across 'the ideal type' hierarchy (see p94) in the period 2020-22. As well as explaining the changes which have already occurred, the interviewees of this study discuss the trajectory change that they believe is happening and which may carry on for a number of years. With new technologies coming out and getting adopted some parts of the workflow are changing into a different direction, perhaps not a radically different direction, but they may vary around the direction they are going in. As stated in Literature Review Chapter, COVID has significantly changed the adoption of technology in the VFX workflow (see p68) and it is important to focus on this period, because observing changes and getting the feedback from interviews was a crucial turning point. The assumption might be that this is a crucial time to study VFX technologies because the difference between pre-COVID and post-COVID is going to be significant, and this research included observing these changes as they were happening and the data from interviews suggests that nothing will go back to pre-COVID way. The same reasons that made it a crucial period to study the industry, also made it difficult to research due to people being busy and unreachable during this time.

As the VFX industry is relatively small, technically complex, and therefore very exclusive, it is hard to gain access to professionals unless there are personal connections. The lockdown conditions during this research made access to these professionals even harder, resulting in low response rate. Taking a proactive approach in adjusting to the low response rate due to pandemic, it was crucial to implement a different and more appealing way of initiating a conversation with industry professionals and interest them in taking part in this research. The methods used to tackle this challenge are listed below.

VFX: A New Frontier – The Website

A website for the research project was created in order to make the project look professional and legitimate, as well as a tool to attract the right type of people for the interviews. As VFX professionals are very visual and creative people, it was essential to create visual materials that represent this project.

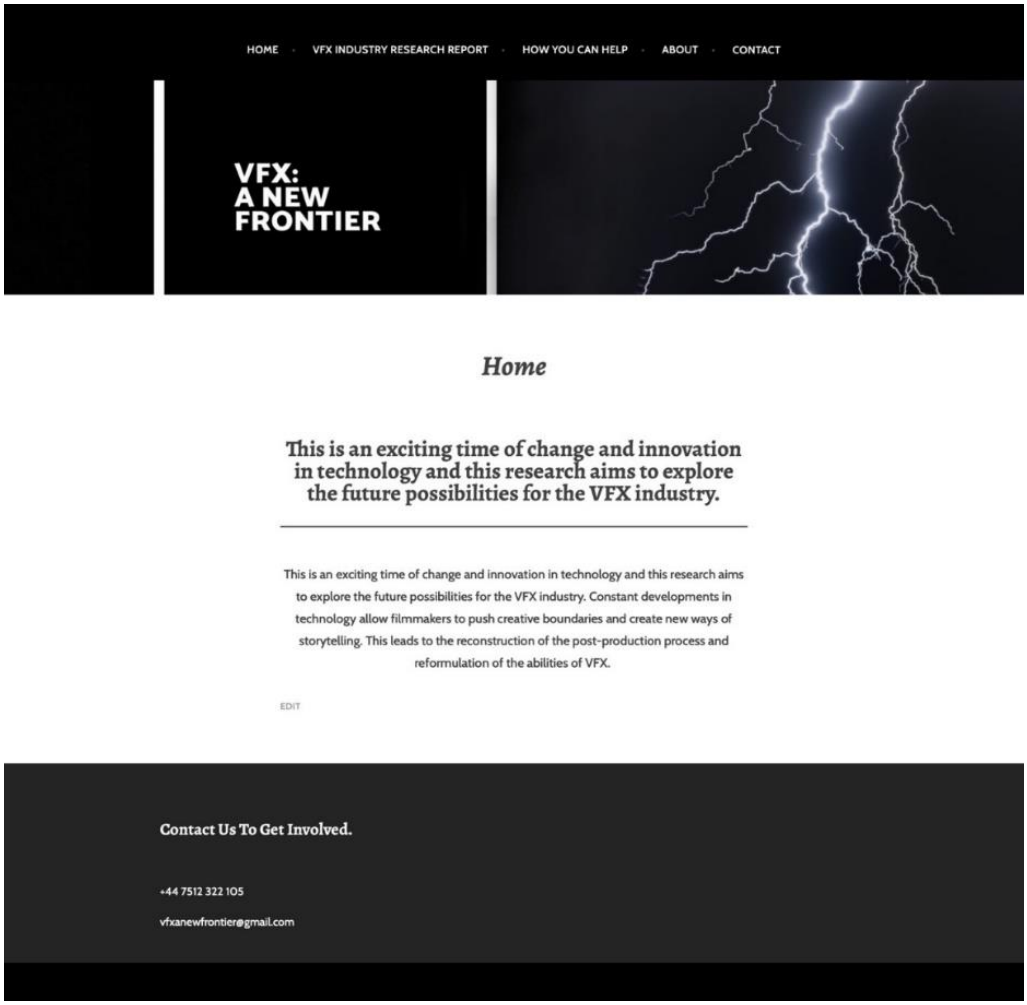


Figure 10: 'VFX – A New Frontier' Website

Source: (WordPress, 2021)

VFX: A New Frontier – Infographic Pitch

An infographic pitch that summarises the objectives of this research was created and sent out to industry professionals when approaching them for interviews.

Figure 11: 'VFX – A New Frontier' Infographic Pitch

Source: Author

Chapter III: Data Collection

This chapter will begin by outlining an overview of the design and structure of interviews. Followed by information about the sampling. Subsequently, specific details will then be provided about the process of data collection. Finally, details regarding ethical and consent approval will be outlined.

Interview Design and Structure

Spelthann and Haunschild (2011) case study of qualitative interviews with VFX artists, technicians, producers and supervisors in London and Los Angeles was inspired by traditional approaches to qualitative organisational research suggested by Yin (2003). The research first identified the roles and workflows involved in VFX production and then carried our interviews to gain knowledge and understanding project organisation, labour market institutions and the workers roles in various organisational concepts. This study applies the same method to obtain detailed data.

One-to-one semi-structured remote interviews allowed the researcher to provide an extensive and detailed in-depth data, providing more valuable insight. The synchronous method was used to conduct interviews in real-time, which has the potential to mirror techniques and methodological approaches usually used in face-to-face interviews. This also allowed the discussion between researcher and participant to flow naturally (Hooley et al., 2012; Stewart and Williams, 2005).

Audio recorded interviews, with informed consent of participants, reduced the risk of mistakes made by memory and allow thorough and repeated examination of answers. This provided in-depth qualitative data, which included insights into film professional's opinions and beliefs on current and future predictions.

Semi-structured interviews based on predetermined but open-ended key questions as guided conversation allowed to get answers to desired questions without limiting the participants in their answers. The key questions were personalised to each VFX role, task, and technology that it may impact. The researcher expected most answers from interviews to concern aspects such as product quality, ability to do new effects, the time is takes to produce an effect, the cost of producing work (in terms of either time or amount of people, or cost of technology), job satisfaction of people engaged in producing that task and level of creativity experienced by that person. All this data relates to this study's research questions and develops the answers to the questions that are listed in the Appendices on page 208.

Operationalising 'Creativity'

When using words such as 'creativity' during interviews, the researcher had to find ways to operationalise the concept. There are many examples of literature that's attempted to define creativity (without much success), the researcher has drawn on economic literature (research on how efficiencies are achieved in production) and sociology of work/organisations literature (which studies changes in the work people do – e.g., the amount of variability in their tasks and the relationship between these changes and the ways workers feel about their work – e.g., job satisfaction and alienation). Dwyer connects these ideas and concludes that "creativity is crucial in realising each new individually differentiated variant", so the worker, through "trial, error and discourse" produces their "interpretation" in "every task" by "exercising creativity in the way they apply the skills and knowledge routines they possess" (Dwyer, 2019, p197). As noted, Hesmondhalgh and Baker (2008, 2011) emphasise the importance of autonomy in understanding creative work (see pp88-92) and this concept is used in the interviews an analysis to see how far VFX workers see autonomy as essential to their idea of creative work.

Therefore, for the purpose of this study, the researcher defines it by:

- level of skill – specialised skills being applied when carrying out a task
- variation of task – extent of control or repetition
- efficiency – lower cost and job satisfaction

Furthermore, Hesmondhalgh and Baker's (2011) concepts of "good work" and their emphasis on the different experiences of workers at different points in the hierarchy relate to the research question around job satisfaction and interview statements are analysed to establish the extent to which they find their jobs satisfying as opposed to frustrating.

Access and the Position of Researcher

The problem of access limits the scope of any research and accessing Hollywood companies is significantly more challenging than to access smaller companies or independent filmmakers (Mayer, 2008; Ortner, 2009). During this study, the researcher encountered this problem initially in getting interviewees to respond to the invitation to be interviewed for the research. As Mayer (2008) and Ortner (2009) suggest, in resolving this problem it is essential to get the interviewees to have an interest in the research. This is reflected in this study with the development of the Infographic Pitch and Industry Report, which helped interviewees understand how this research could also be valuable to them. The problem of access also influenced the balance of the sample of interviewees, reflecting the fact that accessing freelancers working for smaller companies was significantly easier than artists working on major Hollywood productions in-house. The result of sampling used in this study supports Mayer's (2008) and Ortner's (2009) view that it is easier gain access to workers lower down the hierarchy than those at the top, as the majority of the sample of this study are junior artists.

When researchers compare their own status with that of their interviewees, sometimes the researcher has a similar knowledge bases as the interviewees, which some describe as "studying sideways, and sometimes the researcher would be at an advantage or a disadvantage - "studying up" or "studying down" (Mayer, 2008; Ortner, 2009). Mayer (2008) and Ortner (2009) point out that more senior people attempt to influence the research. To some extent, the researcher may have been in less of a strong position to challenge their opinions than a junior freelancer, for example. Access issues and the hierarchical power structure have an influence on this type of research in ways that other researchers have noted are very common limitations on media research, which focuses on practitioners rather than texts or audiences. Even a second attempt to gain access to interviewees for this research did not produce very good results, further illustrating the

importance of these power relations in the types of knowledge produced by this type of media research.

The researcher had a similar knowledge bases as the majority of interviewees. However, some of the technical knowledge of the Senior ranked interviews may have outweighed the researcher's.

Sampling

As described in Chapter 1, VFX workflow and roles vary depending on the company and production, the interviews in this study give detailed qualitative data that include discussions of all aspects of VFX production as the interviewees work on most VFX tasks despite their job titles. Due to high competition between VFX houses, the interviewees of this study preferred to keep their and their companies' names anonymous.

As Hesmondhalgh and Baker (2011) suggest that autonomy also relates to the idea of authority and contrast autonomy with powerlessness, the interviews are chosen based on their position in the hierarchy. This helps to establish a correlation between VFX workers who suggest that their creativity is increasing and how high they are in the hierarchy. All interviewees in this study are based in London and are in a different positions of 'power' in the hierarchy (see pages 92-95). Leads are highted in red, seniors are highlighted in yellow and juniors are highlighted in green. To keep their anonymity, each interviewee, their job title, type of VFX tasks they execute, description of company and type of work they produce is listed below.

Role	VFX Tasks	Company/Products/Sector
Interviewee 1: COO of VFX stock footage company and VFX Generalist	• Rotoscoping • Rendering • CGI • Matchmoving • Keying	• In-house (over 7 years of experience) • Medium size company (over 7 years) • Online service - large library of stock footage elements for professional VFX • Create their own custom VFX assets, which can be purchased online
Interviewee 2: VFX Generalist	• Rotoscoping • Highly experienced with Unreal Engine	• Freelancer (over 10 years of experience) • Works on independent projects as well as being hired by companies • Produces VFX for social media and commercial content
Interviewee 3: Operating Manager	(Highly experienced) • Workflow and Pipeline management • Knowledgeable about all stages of VFX and roles • Investment decisions on new technology/software	• In-house (over 10 years of experience) • Medium size independent VFX studio (over 10 years) • Produces complex VFX for commercial content
Interviewee 4: CG Pipeline TD	• Pipeline development • Knowledgeable about Rotoscoping	• In-house (over 10 years of experience) • Medium size independent VFX studio (over 15 years) • Produces high end VFX for big film and TV productions

Interviewee 5: VFX Software Engineer and Architect	(Highly experienced) • Pipeline development • Pipeline tool development • Knowledgeable about Rendering, Rotoscoping and CGI	• In-house (over 15 years of experience) • Large BAFTA and Oscar winning VFX studio (over 35 years) • Produces highly complex VFX for commercials, film, and TV
Interviewee 6: VFX Generalist	• Rotoscoping • Rendering • CGI • Keying	• Freelancer (over 10 years of experience) • Works on independent projects as well as being hired by companies • Produces VFX for commercials, film, and TV
Interviewee 7: VFX Generalist	• Pre-vis • Rendering • Rotoscoping • CGI • Keying	• Freelancer (over 15 years of experience) • Works on independent projects as well as being hired by companies • Produces VFX for commercials
Interviewee 8: VFX Generalist	• Pre-vis • Rendering • Rotoscoping • CGI • Keying	• In-house (under 5 years of experience) • Small VFX company (over 5 years) • Works on independent projects as well as being hired by companies • Produces VFX content for commercials and music videos
Interviewee 9: VFX Generalist	• Rendering • Rotoscoping • CGI • Keying	• Freelancer (over 15 years of experience) • Works on independent projects as well as being hired by companies • Produces VFX for commercials, film, and TV

Interviewee 10: VFX Generalist	• Rendering • Rotoscoping • CGI • Keying	• Freelancer (over 10 years of experience) • Works on independent projects as well as being hired by companies • Produces VFX for commercials, film, and TV
Interviewee 11: VFX Generalist	• Rendering • Rotoscoping • CGI • Keying	• Freelancer (over 8 years of experience) • Works on independent projects as well as being hired by companies • Produces VFX for commercials, film, and TV
Interviewee 12: VFX Generalist	• Rendering • Rotoscoping • CGI • Keying	• Freelancer (over 5 years of experience) • Works on independent projects as well as being hired by companies • Produces VFX for commercials and music videos
Interviewee 13: Flame Artist	• Rendering • Rotoscoping • CGI • Keying	• Freelancer (over 15 years of experience) • Works for various companies • Produces VFX for commercials, film, and TV. Specialising in VFX software - Flame
Interviewee 14: VFX Supervisor	• Knowledgeable about all stages of VFX and roles	• Freelancer (over 10 years of experience) • Works for various companies • Supervises on VFX heavy production sets for commercials, film, and TV

Interviewee 15: VFX Supervisor	• Knowledgeable about all stages of VFX and roles	• Freelancer (over 5 years of experience) • Works for various companies • Supervises on VFX heavy production sets for commercials, film, and TV

Table 3: List of Interviewees

Source: Author

A second wave of interviewees was conducted to ensure the research has a good representation of the positions in the ideal type VFX organisation hierarchy, which includes generalists in junior roles and those who work on big projects. Although all interviewees in the second wave of interviews have more years of experience in the broader industry than stated below, their years of experience specifically in the VFX sector (this number is stated in the table below) is significantly less than this, due to the new technology they have implemented, which caused them either to change their careers paths or got them into a new job.

Interviewee 16: VFX Generalist	• Highly experienced with Unreal Engine, VR, AR and MR • Rendering • CGI	• Freelancer (under 5 years of experience) • Works on independent projects as well as being hired by companies • Creates content (animated videos and cinematic trailers) using Unreal Engine for games and films • Has over 5 years of experience working on immersive projects using VR, AR and MR

Interviewee 17: VFX Generalist	• Designs VFX Assets • CGI	• Freelancer (under 5 years of experience) • Creates content for advertising companies and brands • Creates VFX assets
Interviewee 18: VFX Generalist	• Rotoscoping • Matchmoving • Works on applying AI, ML & Real-time Rendering tools into the VFX workflow	• In-house (under 5 years of experience) • Medium size company (over 5 years)
Interviewee 19: VFX Generalist	• Rendering • CGI • Highly experienced 3D motion designer	• Freelancer (around 10 years of experience) • Creates content for animation, film, TV, commercials, and music videos
Interviewee 20: VFX Generalist	• Highly experienced with Unreal Engine • Rotoscoping • CGI	• In-house (under 5 years of experience) • Small-Medium VFX House (over 5 years) • Produces VFX for commercials, games, and film

Table 4: List of Interviewees

Source: Author

In smaller companies, artists given the general title **'VFX Generalist'** may be carrying out a broader variety of tasks usually in response to the needs of specific productions. Specialisation of VFX production in large VFX houses means VFX artists that work in-house are usually given specific job titles depending on the VFX tasks they work on, such as:

- 'Texture Artist' (responsible for the creation of textures, colours and organic surface qualities required for computer-generated creatures and hard-surface models used in production)

- ‘Lighting Artist’ (responsible for the lighting and rendering of elements required to complete visual effects shots)
- ‘Paint and Roto Artist’ (working closely with Compositors to help them integrate all elements of an image, including CG and live action, to create film visual effects shots)
- ‘Rigging Artist’ (working closely with the CG Supervisor and the Rigging Supervisor, the Rigger will be responsible for building robust and efficient rigs and working with the CG team to implement and support these rigs)
- Specific to software being used such as ‘Nuke Artist’ or ‘Flame Artist’ (having in-depth knowledge of node-based digital compositing and visual effects software ‘Nuke’ or ‘Flame’).

Freelance VFX Generalists that work for various VFX companies and independent film productions. Their job varies depending on the project. When hired by a company to work among a team of VFX artists they may be given a specific role or task such as rotoscoping or pre-vis, however when hired by an independent production they may be expected to produce the entire VFX content needed for that production, which may include all aspects of VFX such as pre-vis, rendering, rotoscoping, CGI and extraction of elements.

VFX Supervisors are responsible for meeting all technical requirements on set and reporting the progress on the daily basis (Samaras and Johnston, 2018; Spelthann and Haunschild, 2011). They use the prepared pre-vis tools as reference on set to ensure the process is done accordingly and resolve any problems that may occur on set (Desowitz, 2003; Finance & Zwerman, 2010; Okun et al., 2015; Spohr, 2019; Arundale & Trieu, 2015; Sawicki, 2011; Pardeshi and Karbhari, 2019).

Operating Manager – this position requires assuring a smooth running of the VFX house with ongoing projects along with the responsibility of maintaining good performance of operations within the studio. This position also requires an operational vision on the short and long term, therefore providing a daily support to current productions as well as planning for future productions and what changes / implementations they may require. Operating Managers are required to be highly experienced with workflow/pipeline management and therefore are highly knowledgeable with every aspect of VFX production.

Pipeline TDs make sure a VFX project runs smoothly by identifying and fixing problems as they arise and make sure each department has the software tools that they need to complete their part of the project to their best. Pipeline TDs are highly nondelegable about VFX production pipelines and all the roles. They communicate with VFX artists across the team to understand their needs and work closely with engineers, who design and test any new software. As mentioned previously, different companies have different requirements and expectations for each role. In this case, this specific interviewee, although there is no official job title 'CG Pipeline TD' they have been responsible for creating a new CG pipeline for their company, which included creating a customised pipeline to suit their needs and increase efficiency.

VFX Software Engineers design, author, maintain and refactor VFX systems to meet all requirements. They are highly knowledgeable on VFX workflow, pipeline and tools development. They are required to work in software languages or tech stacks specific to any particular project as well as being responsible to understand the business and wider industry as they may be encouraged to propose new and innovative solutions for any problems that arise or to improve the workflow. The interviewee in this study has designed and architected large production pipelines and tools systems.

Process of Collection; Structured Interviews

Video conference interviews were conducted over Zoom. Interviews lasted between 45 to 90 minutes, some lasted longer than others because they expressed direct impacted on their work or were decision-makers in implementation of new technology. Therefore, more data was collected. Participants were firstly asked to describe their professional experience in VFX, current job and company (or different productions and companies if freelancing). The participants were then asked key questions and subsequently follow up questions based on their role. In cases where interviewees were more generalist and had experience in multiple roles despite their job title, the researcher asked key questions based on technology the participants would bring up during the interview despite what role the key question was targeting.

Ethics and Consent

Ethics approval for this research was granted by the University of Westminster in April 2020 (application ID: ETH1819-1180). As a standard principle of research conduct (Eysenbach and Till, 2001), PIS form has been given to each participant and a consent form has been signed prior to each interview. Due to interviews being remote, the use of camera and audio was discussed and agreed with the participants prior to each interview. At the beginning of each interview, the researcher briefly discussed the study and provided participants the opportunity to ask any further questions or raise any concerns. All participants were then informed that they could withdraw at any time during the interview.

Chapter IV: Data Analysis

The literature review (pages 41-52) demonstrated that there are various innovative technologies being established now that are or may have a significant impact on the VFX process. This chapter will examine these impacts in further detail by drawing on insight from interviews conducted with employees at various VFX houses and freelance VFX artists.

Objectives and Process of Analysis

Analysis and coding of qualitative data from the interviews reduces the amount of data by identifying and categorising it into different themes or elements, which can then be analysed across all transcripts to identify recurrences and correlations between codes (Bryman, 2016). Semi-structured interviews analysis includes the process of coding, where each code represents an individual element of information gathered during the interviews (Miles and Huberman, 1994). One of the biggest advantages of a remote interview over platforms such as Zoom is the fact that the interview can be audio and/or video recorded and then transcribed, making data collection and analysis easier (Cater, 2011). The interviews in this study were transcribed with Descript software which uses an AI powered speaker detection and this data was then analysed, categorised, and interpreted individual responses manually by the researcher. Due to the complexity and technicality of interview data, the transcripts were also carefully checked manually by the researcher and an open coding method was used, as it assists to identify and conceptualise data and phenomenon in qualitative research analysis (Flick, 2018; Strauss, 1987; Strauss and Corbin, 1990). The open coding process involved the researcher going through interview answers and classifying data into categories by describing them in short sentences, for examples answers that apply to category “cost effectiveness” or “time saving” or “quality of work produced”, which were then further described and expanded with relevant concepts. Direct quotes from the interviews were drawn upon in each category.

Summary of Findings

The interviews involved in this research cover the key points of interest relevant to the discussion of the questions raised by the literature. The key themes from the interviews are outlined below and further details are given in the Discussion & Conclusion chapter.

The data collected in this study confirms that integration of automated tools has become the ‘bread and butter’ of today’s VFX, which confirmed hypothesised uses of innovative technologies as already being widely applied into the pipeline in complex productions as well as being encouraged for any VFX work. The evidence presented in this study suggests that Real-time technology, AI (including ML), Cloud-based technology and Virtual production are having the most impact on the VFX pipeline. More specifically, the following stages of the pipeline: previs, rendering, CGI and rotoscoping stages of VFX production. Additionally, on pipeline management and data security and management.

This research suggests that the causes of changes are due to the fast-growing demand of content and the continues increase of quality and realism standards for VFX. Additionally, due to the need to increase productivity and efficiency to meet these demands and standards. Furthermore, data shows there is pressure to automate routine tasks and eliminate some very technical tasks and allow artists to focus their time on the creative process.

The evidence presented in this study suggests that new technology changes the nature of artists work, level of creativity and job satisfaction. Interview evidence shows that technology that automates routine and mundane tasks, such as ML, significantly increases job satisfaction and allows to focus more time on the creative process. Innovative technology that uses real-time and virtual production also increases the level of creative freedom as it increases flexibility and allows for more interactive approach of VFX production. Moreover, cloud-based technology and ML significantly change the process of pipeline management, making the VFX process more efficient and increases productivity, which in turn increases job satisfaction as it enabled workers to focus on creative work.

Themes from Interviews

The literature review section described the historical, technical, and economic influences on the development of the modern VFX workflow (shown in Chapter 1 on pages 25-81). This section presents the data collected from the interviews with production workers describing the changes that they see concerning the adoption of new technologies, and the exploitation of their potential. The chapter uses the theoretical framework presented in the literature review chapter (particularly the ideas of specialisation, vertical integration and dis-integration and flexible production) to explain why these changes are occurring and to evaluate their significance for the VFX industry and for VFX production workers (particularly their job security and job satisfaction). The data from interviews is represented and categorised into themes below.

Increase in Quality and Realism Standards

The interviews for this research confirm that the VFX product market is changing and the demand for high quality and high level of realism of VFX is getting higher. Interviewees mention productions such as *The Mandalorian*, which has pushed the boundaries of CGI and established a new standard. The other lead company over the past two decades, Marvel Studios, was also referenced by as a key driver in adoption of technologies and changes to the workflow:

"People are scrambling to hire unreal developers and people that have that sort of experience. So that's been quite a change that was maybe a bit of tempering of the excitements around us. You look at the Mandalorian videos and kind of go, 'that's incredible'"

- Interviewee 4 | CG Pipeline TD

"Filmmaking is becoming increasing more complex as the stories people are telling are becoming more abstract. Basing their stories in abstract worlds such as Dr Strange is going to further drive the convergence of real time VFX and traditional offline VFX in order to achieve these desired visuals"

- Interviewee 5 | VFX Software engineer and architect

"MetaHuman Creator has built-in guardrails to ensure physical realism. I think the realism offered with MetaHumans will become accepted as a new standard for CG humans and will be commonplace in the types of films that are produced"
- Interviewee 2 | VFX Generalist

"…with the level of realism that the MetaHumans are bringing is amazing"
- Interviewee 6 | VFX Generalist

Many interviews also referred to certain technologies as very important in helping companies achieve this increase in quality demand. For example, Unreal engine's real-time technology:

"We're partnering with a real-time VFX company to bring in their specialisation so that we can actually build out products for unreal engine that are based off of our products, so they're going to look a lot more realistic with a 100% loophole, so it's not obvious that it's going to cut back to the beginning of the animation"
- Interviewee 1 | COO of VFX stock footage company and VFX Generalist

The interviews also show that production companies are making use of the new technologies to diversify and innovate in the range of VFX content they produce, possibly establishing new genres and new standards. For example, one interviewee mentions Dreams (a video game creation system), in the past this process would've involved rendering time and couldn't be done in real-time:

"Professional CG films and games can be created in real-time, directly on a video game console"
- Interviewee 2 | VFX Generalist

As realism standards are being increased, achieving and pushing those boundaries may depend on the power of technology available to artists, rather than the level of their skills:

"I think that in movies, we lived through a pretty big chunk of poor VFX, not from lack of skills of people, but because of the limit in terms of technology. There are so many

examples of movies where scenes were ruined by bad VFX. Now we are coming out of that phase"

- Interviewee 17 | VFX Generalist

Achieving realism may not always necessarily mean achieving the exact replica of real people or real-world objects and environments:

"It's definitely increasing expectations on artists. But I think the big change was the adoption of physically based rendering. If you look at Pixar, they are adopting physically based rending workflows, even though the characters don't have realistic proportions or you might have landscapes that you've never seen in real life, but light still follows the same laws, so you're able to model things like the Fresnel effect and all these things that contribute to a realistic image and make it believable. That's something that's just become very common now, with things like Substance Designer you can produce really realistic materials, I am astonished by how far computer graphics has come and it reminds me how much more I need to learn"

- Interviewee 18 | VFX Generalist

Furthermore, the demand of achieving realism in VFX may not be present in every industry that uses VFX to create content, for example advertising:

"If you are doing the next Godzilla movie, you want to make it look real, you want to terrify people"

- Interviewee 17 | VFX Generalist

"For my content, it's more about how to style it, rather than how to make it look real. My aim is present something that will be attractive to clients, not to trick you into thinking it's real"

- Interviewee 17 | VFX Generalist

"In my experience, every time when I tried to push the boundaries of hyper-realism, those were the ones that performed the worst"

- Interviewee 17 | VFX Generalist

"It is something that we all want to do, but it depends on what scale you are competing on. I would say for feature films it makes more sense, because everyone can specialise and so you do get a more photorealistic result, but in my shoes, as a generalist the level of realism even in films from back in the 90s a lot of the time the level of VFX is still above what we can do as solo artists. That's why I think I've seen a lot of generalist artists move away from photorealistic results and try to create unique styles that nobody else does, focusing on the story or emotional impact or much softer skills like taste or colour theory"

- Interviewee 19 | VFX Generalist

However, this might depend on the type of product being advertised and therefore in some areas of advertising that demand for realism may still exist:

"…it's specific to the content."

- Interviewee 17 | VFX Generalist

Increase in Demand

Many of the interviews emphasized that the changes in the product market are not simply affecting the quality standards required in VFX production, but also creating a demand for an increase in the volume of VFX production which has not existed before in the industry. Increasing demand drives a demand for improvements in productivity and economies of scale. Interviews suggest that the introduction of new technologies could increase productivity so the production sector could increase volume of output production:

"There's such a high demand for new content and the turnaround time, being able to cut down on that as much as possible, I think is going to be great"

- Interviewee 8 | VFX Generalist

Interviewees pointed to rise of streaming companies as creating new markets for VFX content and brought a demand to increase the volume of output from the industry:

"There's a higher demand for content now than ever. Everything is just coming together perfectly. You see what all of the big streaming companies have been doing now, or I guess specifically HBO Max releasing all of their theatrical releases at home, is trying to get as much content there as possible"

- Interviewee 2 | VFX Generalist

Factors Influencing Investment Decisions

One of the most important findings from the interviews is identifying which VFX companies are adopting new technologies. The literature review identified technology determinism as a problem in some industry studies of impact of technology. The interviews in this study show that the technologies identified are not being adopted by all VFX producers.

Some interviewees emphasise that some smaller studios or companies may not be implementing some of the new technology at all, for example due to the cost of investment. Not choosing to invest into certain types of innovative technology, such as virtual production, may also be due to the fact that some smaller companies have no use in it because of the type of content they are required to create for their productions.

For example, simple VFX content for a less complicated project may only require traditional simple VFX (such as keying and other non-complex VFX work), which can be done in a 'traditional' way without further assistance or any new technology:

"Virtual production, AI, those sorts of things. It's not necessarily stuff that we are emphasising from at the moment"

- Interviewee 4 | CG Pipeline TD

"Virtual production obviously has become pretty big over the last year or so. I do still think it's probably more the domain of the biggest studio that can afford to invest in the software resource to integrate that pipeline or all the new virtual production focused pipeline"

- Interviewee 4 | CG Pipeline TD

"We could invest a lot of money. We could invest time and energy into all of the dimensions, whether it's technology or staff, but ultimately what is the most applicable use of this technology? What is the application for someone who is not a studio, but is ultimately creating six 60 seconds of commercial? If we build it, will the agencies recognise workflow adjustment that they will have to make and how can we influence that conversation? Because for the same challenges that we would have, an advertising agency doesn't really think about our production in those terms, so that's the biggest challenge in adopting new technologies"

- Interviewee 3 | Operating Manager

Some interviewees point out that not investing into a specific new technology may also be due to the fact that their individual challenges would not get fixed by it. Therefore, the decision of making a high-cost investment outweighs the need to rather save those finances to invest into more urgent things that would fix their challenges (such as more staff):

"We run the company over with the long view, but obviously being very sensitive towards making careful decisions, as well as why there's strong evidence based on this as well. So that influences our ability to invest in things like unreal engine and these sorts of flash word technologies. We were very much focused on doing the best thing for the challenges that we faced as a studio, not just doing things for the sake of doing them and where we can make strategic decisions that are going to impact our bottom line and improve our commercial performance. That's where we focus. It's not just doing things for doing things sake of doing them"

- Interviewee 3 | Operating Manager

Interviews reveal that although technology such as virtual production brings a lot of new ways of achieving desired VFX shots, it also comes with its own challenges. Smaller companies may not have the access to enough staff or have enough time to deal with those challenges, which again discourages some companies to invest into certain technologies due to their own priorities as a business:

"Although virtual production brings a lot of new ways of achieving desired VFX shots, it also comes with its own challenges"

- Interviewee 4 | CG Pipeline TD

"Virtual production obviously has become pretty big over the last year or so. I do still think it's probably more the domain of the biggest studio that can afford to invest in the software resource to integrate that pipeline or all the new virtual production focused pipeline"

- Interviewee 4 | CG Pipeline TD

Pressures for Future Investment

Interviews suggest that the pressure to adopt the technologies exist and will continue over time. All the tools that an artist needs for high-end VFX projects are already available to them, however as technology becomes more democratised and these tools increase in quality and efficiency, it will increase the pressure to invest:

"Ten years ago, you had to build all of your own high-end simulation software as you couldn't buy it. Now you can buy a lot of it and that's going to be a continuing trend"

- Interviewee 5 | VFX Software engineer and architect

"Off the shelf tools will allow artists to iterate more quickly, see the results instantly"

- Interviewee 5 | VFX Software engineer and architect

Interviewees suggest that specifically technology that uses real-time and virtual production will increasingly pressure the VFX industry to integrate these technologies into the workflow:

"Real time VFX is huge without a doubt. Unreal is where I think a lot of it is. I think they're going to be the catalyst for everyone to really push the industry forward"

- Interviewee 2 | VFX Generalist

Interviews support the continued trend of outsourcing and dis-integration of production even by the biggest production houses. Pressures to invest into cloud-based technology increases as:

"One of the biggest challenges in high-end projects is coming up with a system to get thousands of people to work effectively together. Allowing VFX workers to collaborate and work together remotely by providing a remote system that work efficiently will be a key change"

- Interviewee 4 | CG Pipeline TD

"Cloud based security and a distributed remote workforce will allow for much wider ecosystem in the VFX industry. Furthermore, with easy access to high-end tools allows for much more effective distributed workforce, since VFX workers come into the workplace already skilled and having had access to the tools that they require"

- Interviewee 5 | VFX Software engineer and architect

Automation and Scaling Improving Productivity and Efficiency

All the interviews in this study highlight the importance of automation and scaling as it improves productivity and efficiency along with increasing creative freedom. This interview confirms that today, a majorly automated VFX pipeline is required to make profit and that new technologies are being used to automate existing tasks within the workflow:

"Automation and scaling is the cornerstone of any pipeline and has become the bread and butter of today"

- Interviewee 5 | VFX Software engineer and architect

Automation tools are used to eliminate routine tasks and therefore improving efficiency and productivity:

"I really do think that the synthetic VFX is going to be a really important thing. AI generating a lot of things, doing a lot of the tedious work of whether it's 3d modelling etc. I think that that's going to be a massive game changer"
- Interviewee 2 | VFX Generalist

"Rotoscoping is a really tedious thing nobody likes to do. I was rotoscoping something the other day and I was using the roto brush that's now in After Effects. It is a more recent tool and it's definitely a lot easier, but it just still takes time. What Runway ML can do by speeding that process up is incredible"

- Interviewee 8 | VFX Generalist

Artificially creating more variants of footage that has already been filmed will increase productivity by generating more outputs and assets from the same inputs:

"…feeding the computer with stock footage of real effects that have been filmed in the past"

- Interviewee 1 | COO of VFX stock footage company and VFX Generalist

However, interviews suggest that when deciding on real or synthetic images, the level of quality and type of production are considered:

"That might depend on what product you are aiming for, whether it is a social media ad or a blockbuster film that will be shown on iMax screens"
- Interviewee 2 | VFX Generalist

"Different choices will be made between big studios and small commercial producers"
- Interviewee 3 | Operating Manager

Data from interviews highlights the importance of further improving the rotoscoping process to eliminate routine tasks:

"If you are roto scoping, for example, they go and shoot these plates, they send them to us and then you individually cut out each one of the characters so that you can figure out what goes in front of what goes behind the character. That's something that always struck

me, you can't just attach something to the camera to get that sort of data. But I know that there are some research projects at the moment to use deep learning techniques to do that sort of work, where you can feed the postage and it'll draw the outlines around all of the characters in the shop"

- Interviewee 4 | CG Pipeline TD

The interview above suggests that the process of rotoscoping has remained the same, close to the traditional process as described in the literature review, however other interviewees pointed out that most roto artists are increasingly using machine learning to speed up the process:

"Most Roto artists use software that implements machine learning or includes machine learning into their custom pipeline in order this has become unavoidable in high-end VFX heavy productions"

- Interviewee 5 | VFX Software engineer and architect

"…a transition of going further into physics space rendering instead, where the focus became on making the simulation of the render, the lights and the surfaces look physically accurate"

- Interviewee 5 | VFX Software engineer and architect

Interviewees pointed out the efficiency gains when using real-time based pipeline for rigging that uses ML, which have resulted:

"What used to take half an hour to calculate on a machine can now run at 90 frames per second"

- Interviewee 5 | VFX Software engineer and architect

One interviewee suggested that software, which uses AR and real-time technology, has the potential to automate the process of matchmoving and improve the process of previs:

"…it's called CamTrackAR. And it utilizes LiDAR, volumetrically through LiDAR capture depth information, so you can composite without having to actually track a scene, because all of that information is stored within the phone"

- Interviewee 2 | VFX Generalist

This interviewee suggests using ML and real-time technology to increase efficiency of the process of rigging:

""...it's about making artists go faster, taking something that was traditionally offline and making it real time. Simulate a rig in a machine learning domain instead of building everything from scratch in game, running the simulation inside the real time world and then suddenly get a result – that is far, far better than doing the whole thing in game. It also means that this is a way transition from having 10 years' worth of a really complex system to having to rebuild that inside of Unreal Engine or Unity, and then convert that into a real time representation. Machine learning allows us to keep these existing workflows that have been fine tuned for a long time that are very, very complex and apply them in other domains"

- Interviewee 5 | VFX Software engineer and architect

This interview suggested that adapting autonomy driven software written from scratch or open source have helped improve efficiency and pipeline management:

"A lot of the big things that we've done to improve our efficiency are very much autonomy driven software, like from scratch written or open source. We've come up with something open source and built on top of that and that kind of spans from editorial. So not offline editorial, but online editorial, the way we've changed it is we've made the scope of who run the editorial process a lot, a lot wider"

- Interviewee 3 | Operating Manager

PDG (Procedural Dependency Graph) is a procedural architecture designed which allows producers to use ML to synthesise or augment lots of data. Interviewee 4 described this as *"it makes life better for artists"* and added:

"I really liked the idea of picking up PDG for the sort of thing where in theory, if a lead on a show needs to change something about the way the pipeline works for their show, or they need to know a bit about how you use Houdini and then they can open up these graphs and say 'okay, at this point where it's rendering the work that I've done, I actually wanted to do it from a different camera, or I want to overlay some information onto the

daily about how many polygons are in the shelves' or something like that. That's something that people will be able to add by themselves, so it becomes more integrated in a way. I didn't want people to be reliant on software reasons. Also, essentially, I didn't want assets to have to stay, I really want the pipelines to do this for me. I wanted to empower assists and leads and supervisors to go in and make the changes to the pipeline that they needed to make. I think PDG is going to change the game for us in that way. I'm sure there are other studios that have done similar things"

- Interviewee 4 | CG Pipeline TD

Automation and Scaling Increasing Creative Freedom

Interviews pointed out the importance of the impacts new technology has on the creative process:

"I think the technology allows you to be more creative because it gives you more options or different ways of doing things"

- Interviewee 4 | CG Pipeline TD

As described above, automation and scaling have a significate impact on increasing efficiency and productivity of VFX production. However, some interviewees also point out that it can also have a significant impact on the creative process.

Interviewees believe that automation and scaling will continue to drive the change of the VFX artists process from being very technical to becoming very creative and artistic:

"As VFX artists spend less time on repetitive tasks this frees up workers to spend more time on the creative tasks which can improve the quality of the final product"

- Interviewee 1 | COO of VFX stock footage company and VFX Generalist

"Automation is not a way of getting rid of artists, but rather a way of getting to focus on the creative process. Five-ten years ago, being an artist was a very technical job and the

more good tools artists have, the more those tools become democratised and as a result artists can focus more on the creative process"

- Interviewee 5 | VFX Software engineer and architect

"A layout artist could use machine learning to make layouts of a scene, which will allow them to assemble the scene by focusing on the creative rather than spending a lot of timing moving 3D objects around, which would make the iteration speed of this much more rapid. Machine learning will be used as a tool to speed manual cycles up and allow more room for creativity and originality"

- Interviewee 7 | VFX Generalist

The interviews showed that integrating automation tools into the workflow can be more time consuming than doing those tasks manually, the level of benefit depends on what the artist is trying to achieve:

"Using Machine Learning is a slow process, but once you have your data set, it will save a tonne of money on labour in the long run, and it will save a lot of time and costs"

- Interviewee 20 | VFX Generalist

"…the amount of time it takes them to generate that sort of system is often way more time consuming than to just do it manually and put in the hard labour. I reach for whatever makes sense for me and my workflow, sometimes it's reaching for a plug in that does it automatically really well, other times I want to do it manually"

- Interviewee 19 | VFX Generalist

For example, training AI for pattern recognition can sometimes be more time consuming than doing it manually, however, as Interviewee 18 suggests, it depends on what type of pattern you need it to detect and the length of footage you want to feed it:

"…using Machine Learning to detect species of animals for example, if it's a short clip it might be faster to do scroll through it yourself and make a note of what happens in a scene, but once you start automating things and deploying things at scale, it quickly

becomes inefficient to do that, which is why Machine Learning has become particularly interesting"

- Interviewee 18 | VFX Generalist

"...sometimes I do things manually, because you can't easily automate animation to a specific rhythm of music you want for example. In that aspect, sometimes full manual is better, it creates a more custom look. More authentic and higher quality."

- Interviewee 19 | VFX Generalist

As Interviewee 18 gave an example above, using traditional computer algorithms to detect patterns of animals would prove difficult, as writing a mathematical function that reflects an animal's appearance is problematic. You could for example use patterns of animal's stripes or spots, however not the whole animal form and therefore the chances of patterns to misclassified are high. This is where ML can help:

"Machine Leaning has been shown to be very effective at noticing things that humans can't always notice, so it's really useful at identifying things that aren't immediately obvious that traditional computer algorithms have a hard time dealing with"

- Interviewee 18 | VFX Generalist

It can eliminate or reduce the time artists spend on routine tasks:

"AI and Machine Learning are really useful for things that can be a massive pain in VFX workflow, so rotoscoping is one. Rotoscoping manually is a massive pain, so if I can get a computer to do a reasonable job of it – I'm happy. Same thing with depth estimation, if you can get a mono camera and you don't have to buy a stereo or a depth camera, and you can estimate to a reasonable degree of reliability the depth of a scene – that's something that's very useful"

- Interviewee 18 | VFX Generalist

"...not having to do those mundane tasks frees up time for creativity, I want to be doing more high end or more complex tasks, when looking at the technology - I always look for something that is low effort and high reward"

- Interviewee 19 | VFX Generalist

However, eliminating or reducing certain routine tasks, does not necessarily mean artists would eliminate manual control altogether:

"It's definitely changing things and people have to be really fast paced to keep up. For example, a texture artist will probably have to learn some sort of AI tool I think, because it can just be much faster I think, it can produce a larger variety of things. But I think a lot of those skills will still be useful, there are times where you want to have that manual control, you want to have really fine control over what your 3D models and your textures are doing. So those skills are still useful, but people will; have to learn these other tools as well. ML is realty useful in producing something really rough, really quickly and then you can improve on that"

- Interviewee 20 | VFX Generalist

It can, however, speed up the process:

"I use a software with ML for camera tracking, but some of these automated tools still require manual intervention, but it's a good rough first pass. It definitely speeds up the process"

- Interviewee 18 | VFX Generalist

It can also be used to create a foundation for artists:

"ML is a really fast way of producing a pitch deck during the concept stage"

- Interviewee 20 | VFX Generalist

"The way I'm seeing it right now is I think AI is useful for look development, creating moodboards or different iterations on a composition, which can then be used to create something more authentic and original based on that. It can be a really good assist"

- Interviewee 19 | VFX Generalist

Furthermore, technology such as AI, can sometimes also be used for creative tasks:

"It's a real mix, I think there's an explosion of people using AI to create artwork and that has raised some ethical issues, I think some artists think they might be out of work because

of that. There's also a question of, these AI systems have to be trained on something and the artists whose work is used to pull data from to generate the artwork - I doubt those artists have been involved in that process or maybe even aware that their artwork has been used. So that opens up a lot of questions on copywriting, plagiarism, compensation and things like that"

- Interviewee 18 | VFX Generalist

Although it cannot always be used for creative tasks, it can be used as a tool to increase the time artists can reserve for creative tasks:

"It frees you up to focus on other things, so if you have a pipeline which will automate a lot of these tasks for you and you can put as minimal effort as possible to get the finish result, not cutting corners, but just from an efficiency point of view, it gives you more headspace to do other things and explore possibilities, it lets you iterate on things faster and it's just a better workflow overall if you can take advantage of the technology"

- Interviewee 18 | VFX Generalist

"AI is very useful in motion capture, the traditional motion capture workflow is relatively concrete, but if you can get one or two cameras and you can determine where someone is in 3D with all the correct joint rotations – that is an incredibly powerful thing"

- Interviewee 18 | VFX Generalist

Interviewees also suggest that AI and ML have the potential to improve the process of CG creation by providing different variants of content that has been filmed in camera:

"AI and ML, I think is one of the things that's going to be really powerful in the future as well. For example, fire and real explosions are not super easy to film, they are complex and pretty expensive. But then you have CG simulation side that has a lot of benefits, but the biggest downside is it's not real. I think that there are some very natural progressions, very natural segues for being able to, for instance, feed a machine learning model a set of a hundred, a set of 200 explosions that are specific type and generate new content based off of that just to add more variations. If we're able to film 25 things and we're able to get 50 or 75 out of that entire clip set because of generated variants, I think that

would be really helpful and really beneficial in a lot of ways. I think there's a lot of opportunities for possibilities within that area"

- Interviewee 1 | COO of VFX stock footage company and VFX Generalist

Software that uses AI (including ML) technology also has the potential to improve the process of 3D modelling:

"Runway ML is incredible, not only does it handle incredibly tedious tasks like rotoscoping, but it also allows for synthetic image creation based on datasets. So if you need a nature scene or a cityscape, but you want it fully customised with the look and feel you want and you don't want to have to pay royalties on the image. The one step the use of ML would really bring it into the world of VFX and just make it a tremendous advantage would be in terms of creating 3d models. If you feed it five different cars or even images of cars and I could easily see it turning into a 3d model that's fully textured and you're able to just take that in, texture it more if you want to make adjustments, but that's your custom image. I'm sure they're going to be there eventually. You can feed it your own custom images and it will allow you to create a fully synthetic, but still believable image. You may have seen the images of people who don't actually exist – it's that same type of thing. I don't think they're into 3D modeling yet, but once that technology reaches the ability to create 3D models, it will be invaluable to VFX"

- Interviewee 8 | VFX Artist

"I think in the near future AI will be able to create a full 3D environment or model for us, so it's going to start automating a lot of these processes. We've already seen rotoscoping started to get automated, so anything tedious like modelling for example, if we can get AI to do that – it would be significant"

- Interviewee 19 | VFX Generalist

Artistic Process Shifts from Technical to Creative

Another significant change caused by new technology is the shift of the artistic process from being very technical to more creative. Further developments in technology that uses ML has the potential to make some aspects of the VFX process simpler and less technical

for artists, shifting the process from being very technical to becoming very creative and artistic:

"Runway, a ML technology, is able to kind of iterate faster and an interesting thing. This is just my perspective, they were kind of working in a couple of different areas, but then they shifted gears to video tools. I think that's another reason why they're not as popular or well-known, because they were kind of working across some different industries. And then once they swapped over to video tools, everybody that I know kind of stood up and looked over that way. The best part about that platform is that they are connecting the complexities of machine learning technology. With the common knowledge of the creative aspect, you know, so if I'm an editor, I don't really care as much about learning Python and trying to do all of these different things. If I'm an editor and I want an object to be removed, I want to click it and I want it to be removed. But I think that platform brings those two worlds together so well and naturally and all that to say, like they're still in beta of some of their video tools, so I think this is really just the beginning"

- Interviewee 1 | COO of VFX stock footage company and VFX Generalist

"A layout artist could use machine learning to make layouts of a scene, which will allow them to assemble the scene by focusing of the creative rather than spending a lot of timing moving 3D objects around, which would make the iteration speed of this much more rapid. Machine learning will be used as a tool to speed manual cycles up and allow more room for creativity and originality"

- Interviewee 7 | CG Pipeline TD

This interview confirmed that the task of lighting a scene was dependent on the prior task of rendering, however machine learning has changed that:

"The lighting artists are no longer placing the lights into the shot to make it look real, but rather building a version of reality that is accurate. Lighting is now a process where you effectively have tools that are producing exactly the right image. For example, being able to place the sun in the scene which imitates the same time of the day and has the same layers of sky and overcast – the image would looking exactly like the image that was shot through the camera"

- Interviewee 5 | VFX Software engineer and architect

Making new technology easier to use in terms of technical aspect could significantly improve artists' experience:

"...that should be the goal. It is possible for software to be just as deep and complex without having an extremely hard to use interface"

- Interviewee 19 | VFX Generalist

Some new technology, such as Unreal Engine, enables artists to tell their stories in a visual way, which may not have been possible for them to create before:

"I think for people like me that have stories to tell, that are then just able to turn themselves to a new kind of technology, it closes the gap a little bit"

- Interviewee 20 | VFX Generalist

As Interviewee 20 suggests, new technology such as Unreal Engine has "closed the gap" between creative and technical aspect of animation by giving the tools artists need to create their own animations without the manual skill of drawing for example:

"For me personally, up until the point of me learning Unreal, I never thought that I could do animation. I can't draw and that was just so far outside of what I thought I could be doing or would ever do, so for me personally, it's closed the gap a little bit"

- Interviewee 16 | VFX Generalist

"I would love to learn how to draw, but it isn't necessary"

- Interviewee 19 | VFX Generalist

"...AI can close that gap – it can draw for you and create moodboards or storyboards for you, we can see technology rapidly evolving and that can often replace the need to hire a designer or someone to do the storyboards or concept art for example. But it depends on the level of quality you are looking for, if you want it to be extremely custom, beautifully crafted and completely unique – then you probably do want to work with humans, you want better experts at their craft and that just elevates the project"

- Interviewee 19 | VFX Generalist

"I'm not a tech guy at all, but I can create without learning the technical stuff"

- Interviewee 17 | VFX Generalist

However, that does not mean that those traditional skill sets are no longer required or not valued:

"The more of these things you do learn, the more it will pay back into your work"

- Interviewee 20 | VFX Generalist

"The best artists out there, including the best 3D artists out there that I now of, also know how to create beautiful forms, how to model, how to draw. You can use technology as a crutch to get you somewhere faster, but ultimately the end result might not be as high quality if you took the time to learn those skills yourself and combine everything together"

- Interviewee 19 | VFX Generalist

"Being a traditional artist in many ways is just as technical, just in a different way, you have to know anatomy and all these other disciplines"

- Interviewee 20 | VFX Generalist

New technology such as Unreal Engine that eliminates manual skills traditionally used by animators enabled artists to create work that has the potential to match the level of a high end production, which involves massive crew numbers, is backed up by high finances and needs months of work hours:

"…for instance, even with live action, because Unreal can be used with live action, it's making me think even if I was to use Unreal in a live action project, how could I do it to eliminate these huge costs that need a whole different production house just to do the VFX on a live action. But now we can do it in real time. I could potentially have an actor in front of an LED screen and be moving lights and effects within Unreal Engine and see what it looks like in real time through the camera. That's something that I wouldn't be doing in my career at this point. It might have been 10 years once I'm finally on a Marvel film and it's exciting that I could potentially be doing that now. Not necessarily just myself, because even filmmaking is a team effort, but it could be a very skeleton crew that

is doing this and still making it look like something that's come out of a major blockbuster Hollywood production and being able to still own it – you own it"

- Interviewee 16 | VFX Generalist

The interviews also suggest that the new technologies have enabled a significant improvement in the quality of the lighting process by driving the process to be more creative:

"The lighting artists process became not about trying to make the VFX look real, but rather about trying to capture the performance and be creative"

- Interviewee 5 | VFX Software engineer and architect

Furthermore, the same change has been seen in process of rigging and creature creation:

"Similarly with rigging and creatures, where the process of rigging 10 years ago used to be trying to build a character that looks real. Now, you build a skeleton base, you add muscles, you put on layers of fat, you put the skin on, and then the animator that doesn't have to worry about how realistic the creature's parts should look. Animator can now simply move the skeleton of the hand and the physical simulation takes care of it. The artistic process shifted from being very technical to very creative"

- Interviewee 5 | VFX Software engineer and architect

Implementing ML technology into VFX pipeline management has a siginifciant impact on the artists. Interviewee 4 described it as *"it makes life better for artists"* and added:

"I wanted to empower assists and leads and supervisors to go in and make the changes to the pipeline that they needed to make"

- Interviewee 4 | CG Pipeline TD

Several interviewees saw this process as one of liberating producers from routine and repetitive tasks:

"It has also helped to shift the process of VFX artists from very technical to creative. Looking back to 10 years ago"

- Interviewee 7 | VFX Generalist

"It is used as a tool in VFX which allows to build tools that speed up the process"

- Interviewee 8 | VFX Generalist

"…enables creatives to make the changes directly themselves"

- Interviewee 4 | CG Pipeline TD

Prominence of Cloud-based and Real-time Technologies

Interviewees suggest that further developments in cloud-based technology will improve the process for VFX artists:

"Cloud computing in general is growing so much. Before, people had a barrier to entry with VFX, not only did you need to probably pay a lot of money to go to universities that could give you access to a nice computer that would have the software you needed, but now you can use something like shadow cloud computing or for example when Amazon announced that they are building servers specifically for the VFX industry so people will be able to just rent a machine to do the work they need to do"

- Interviewee 8 | VFX Generalist

"One of the biggest challenges in high-end projects is coming up with a system to get thousands of people to work effectively together. Allowing VFX workers to collaborate and work together remotely by providing a remote system that work efficiently will be a key change"

- Interviewee 4 | CG Pipeline TD

"5G is *going to be a big component in that as well as far as accessibility being able to harness the cloud out in the field and while you're working. I think that's going to be huge."*

- Interviewee 6 | VFX Generalist

"Cloud-based workstations now allow anyone to rent a high-end PC that's capable of studio-quality VFX. Once a massive barrier to anyone interested in learning VFX on their own, people have historically relied on universities or VFX schools to have access to the tools they need to learn their craft. Now, they can do this from the comfort of their own home for a very minimal cost, and on an as-needed basis. MetaHuman Creator is also cloud-based. What's great about it is it has built-in guardrails to ensure physical realism. It's still got some quirks as it just launched, but as it becomes easier to use and widely adopted, I think it will be the catalyst that gets a lot more people interested in virtual production. I also think the realism offered with MetaHumans will become accepted as a new standard for CG humans and will be commonplace in the types of films that are produced."

- Interviewee 2 | VFX Generalist

In addition, interviewees in this study point out the potential of combining ML with cloud-based technology:

"When talking about the cloud and accessibility when it comes to VFX, Runway ML is a perfect example of what's possible when you combine cloud-powered VFX production along with machine learning and AI"

- Interviewee 8 | VFX Generalist

There are some interesting elements in the process of this change. One is the seemingly an important question of IT security:

"Security has been dominating a lot of the direction of the media industry. VFX workers are forced to work in the confined environments in the office due to strict security restrictions. Cloud based security and a distributed remote workforce will allow for much wider ecosystem in the VFX industry. Furthermore, with easy access to high-end tools allows for much more effective distributed workforce, since VFX workers come into the workplace already skilled and having had access to the tools that they require"

- Interviewee 5 | VFX Software engineer and architect

The emergence of GPU (Graphics Processing Unit) significantly impacted the work of artists, making the process faster and enabling artists to spend more time on the creative than when they used CPU (Central Processing Unit):

"Around 2013 the first GPU render engines that were accessible to people, before then I was using psychical render or CPU based renders and those are extremely slow, especially when you are working with 3D, they were super slow to work with and you would have to wait 30 minutes for your render to finish and if you see your shit and don't like the lighting for example, you would have to change it and then have to wait another 30 minutes to see if it's improved. And at some point you just get exhausted and think to yourself 'well that's good enough', so that really gets in the way of the creative process. So when GPU engines came out, like Octane for example, it was a total game changer because it's an order of magnitude faster, about 10 times faster than your average CPU engine and for the same price. That allowed me to be more creative and was one of the biggest leaps"

- Interviewee 19 | VFX Generalist

In more recent years, real-time rendering technology has improved that process even further:

"Real-time rendering is used in game engines like Unreal Engine, but off-line render engines are also developing their own versions of that as well, so Octane for example has one that's been in development for about 15 years and is about to be released. These off-line rendering engines are fast, but they are not real-time. That immediate feedback and being able to work in that final context of what the final image is going to look like, seeing all the lighting and texturing right there in front of you makes a massive difference"

- Interviewee 19 | VFX Generalist

Integrating real-time rendering into the workflow enabled artists to focus more on the creative tasks:

"…when I'm creating cinematics, real-time definitely helps, the rest of it is just figuring out how to make the character walk or how to animate the camera. The Unreal films or

cinematics that I see, lack the film language. I feel like that's a strength that I'm just adding to Unreal, so if it wasn't in real-time, I probably would struggle a lot"

- Interviewee 16 | VFX Generalist

"At the moment I'm using 3ds Max for rendering, which I personally don't like that much, I generally prefer real-time, I like having that really fast iteration, you just can't do that with traditional rending, it just takes a long time"

- Interviewee 20 | VFX Generalist

"With real-time rendering, it's an entirely different experience having something that responds to you and something that's almost intelligent. Real-time rendering and ML are incredible, there just weren't ways of doing this stuff before"

- Interviewee 18 | VFX Generalist

Interviews suggest that real-time technology could be highly beneficial to VFX production. This interview suggest that real-time technology is likely to be a significant factor in reducing cycle time:

"VFX artists today, if they want to make changes artistically, they have to wait a couple of hours to see the results, as you have to simulate and calculate before any changes can be made. However, if machine learning and real time can be used to make those processes immediate, that would significantly change the whole process and make it much more efficient and therefore driving that shift into creativity"

- Interviewee 5 | VFX Software engineer and architect

One interviewee suggested that software, which uses AR and real-time technology, has the potential to automate the process of matchmoving:

"…it's called CamTrackAR. And it utilizes LiDAR, volumetrically through LiDAR capture depth information, so you can composite without having to actually track a scene, because all of that information is stored within the phone"

- Interviewee 2 | VFX Generalist

This interviewee states that ML combined with real-time allows to create a rig with an assistance of machine learning and then transferring it into the game instead of creating it from scratch:

"This allows for simulation of a rig in a machine learning domain instead of building everything from scratch in game for example. This different approach of running the simulation inside the real time world allows to see results much faster than doing the whole thing in game. This transition from having 10 years worth of a really complex system to not having to rebuild that inside of unreal engine or unity for example, but convert that into a real time representation. Machine learning allows artists to keep these existing workflows that have been fine tuned for a long time that are very, very complex and apply them in other domains"

- Interviewee 5 | VFX Software engineer and architect

Relationship between Pre-production, Production and Post-production

Many academic literature on film and tv assume that VFX production happens in the 'post-production' stage (James, 2009). However, interviews in this study confirm that new technology is continuing to cause changes in the relationships between pre-production, production and post-production process. For example, virtual production:

"There is huge value in that when rather than being on the set in Morocco for eight months, you might as well be on X street and building your environments for two months, it's a totally different way of thinking"

- Interviewee 7 | VFX Generalist

Some interviews point out that this shift may give productions an opportunity for more cost-effective methods:

"...it's fascinating how post-production is now becoming production, so I feel like it's going to speed that production, which therefore makes stuff cheaper to make"

- Interviewee 16 | VFX Generalist

This interview suggested that technology that uses automation will allow VFX to further contribute to tasks which were previously the specialist responsibility of pre-production or production workers:

"I think automation will bring that perfect storm for visual effects to kind of take-over by eliminating those barriers of the technical work upfront to create things"

- Interviewee 1 | COO of VFX stock footage company and VFX Generalist

This interview confirms the many limitations and uncertainties about the changes in the VFX workflow that will impact production and pre-production:

"But there are so many things you have to take in. What camera angles you can cover because of how many assets you've built and you can't just drop them at perfect 360 degree CG Iceland. You have agreed with the production ahead of time. We are going to build all of this stuff to a standard, and that will hold up in camera. And we're only going to bolt these camera angles and it doesn't really give the directs and freedoms, just swing the camera around because why did we bui'd all that stuff behind and looking at us? You've got the issues of you can't get too close to the LED panels because you might not make out basically the individual pixels funnels. I think a lot of people were very excited and then kind of quickly realised there were going to be a lot of drawbacks to that, about how much extra planning you had to do up and how much money you had to invest in to getting that sort of workflow up and running."

- Interviewee 4 | CG Pipeline TD

'Democratisation' and Job Satisfaction

Every time a new technology in introduced, there is a period of disruption when advantages and disadvantages, opportunities and limitations of the new technology are evaluated:

"Every new technology that comes along, it's super disruptive, there are positives and negatives. Everything rapidly changes when these things happen. With any new technology we want to see what it can do for us and how it can improve our lives and of course with those improvements we are all aware of the dystopian possibilities and we want to limit those"

- Interviewee 19 | VFX Generalist

With the amount of new technology coming out is making artists have to act fast to learn new skills to keep up:

"I have to go back to basics and learn a lot at the moment to try to keep up"

- Interviewee 20 | VFX Generalist

As new technologies arise, they require a new set of skills to be learnt and therefore creating new jobs:

"…it is creating more creative and technical jobs"

- Interviewee 16 | VFX Generalist

"There's such a surplus of jobs, for 3D, for design – we are needing media more and more as we become more of a digital society"

- Interviewee 19 | VFX Generalist

Furthermore, learning these new skills enables artists to use the new technology to its fullest potential and therefore creating new ways of creating content:

"If you don't know how it works, you don't know what the limit is and you don't know how to push that limit"

- Interviewee 17 | VFX Generalist

Much software is available to artists free of charge, such as Unreal Engine, Runway ML, Blender, for example:

"The fact that the software is free is mind blowing"

- Interviewee 20 | VFX Generalist

"I don't understand how a software like that is open source"

- Interviewee 17 | VFX Generalist

It also enables artists to have more freedom over their work as they have more options:

"Flexibility is something everybody should have. Now that the technology is more accessible, you get that flexibility"

- Interviewee 17 | VFX Generalist

It seems that with fully animated content, the artists get divided into two groups, those who create the assets (the base) and those who then combine various assets together and create the final product. Some artists do both and have even more control over their intent content. For example, Interviewee 17 essentially designs assets that Interviewee 16 could buy to create content:

"I use blender for auto visualisation and designing objects. I design versions of objects that do not exist"

- Interviewee 17 | VFX Generalist

"I decided not to invest into a very high-performance computer, because I work with a team of people who take my designs to then create animations on their workstations"

- Interviewee 17 | VFX Generalist

Democratisation of technology increases the variety and number of already produced assets artists have access to. Even if artists aren't able to create specific assets themselves, there are massive libraries of already made assets available to them, which some artists use as a base for their inspiration for ideas:

"…my only limit is what I could do or what I can find on the marketplace. When I find stuff on the marketplace – then the story comes around that…"

- Interviewee 16 | VFX Generalist

“I personally never learnt how to model very well ,because I’ve always had access to stock 3D websites and I’ve been able to create whatever I wanted practically that way and if I needed something very custom specific, then I would hire a modeller”

- Interviewee 19 | VFX Generalist

Furthermore, combining Unreal Engine technology with motion capture technology allows artists to become more creative as it increases their freedom and enables them to create any asset their desire. Some companies buy motion capture suits and have them available to their freelance artists they hire on projects. This eliminates the cost an artist would have to make to purchase their own suit, however the company would then have some power over their projects:

“I have two mocap suits myself and that just opens up the possibilities even more”

- Interviewee 20 | VFX Generalist

Within Unreal Engine, it cost the artists around £200-300 to buy assets and 3 weeks to create a 30 second sci-fi clip. In addition to the time lag, producing, rather than outsourcing, would have cost a significant amount more and would’ve required a large production crew if it was animated traditionally:

“I'm currently limited to the stuff that I can buy. But, when adding a motion capture suit, that limit goes away. That's one step forward to be even more creative and work with real actors in a VR or animated setting. It's really exciting”

- Interviewee 16 | VFX Generalist

Making these software applications available to artists enabled them to create content, which might otherwise be impossible for them to make, either due to eliminating a certain skillset required to make such content the traditional way, the cost of an established high end software or technology required, because new technology provides better quality, or because the new technology enabled a whole new separate way of creating content.

"It wouldn't be possible to create my content without these technologies, my career jumped when I started to use Blender, because it's easier and faster. It gives out a more satisfying result every time"

- Interviewee 17 | VFX Generalist

"Democratisation of creative tools has been going on for a while, I remember using Blender probably around 15 years ago, but it's all just exploded recently, because you can do so much more in there now than you used to be able to and it's got Real-time Rendering too. Free tools can be very powerful, but I think there will always be a niche of high end paid professionals tools that will do things that the free ones never can. A lot of tools are free and available now, but it still takes a long time to learn how to use them and to be really skilled at this stuff it can take years. I think the there's a lower barrier to entry, but it takes a while to develop these sort of skills and I think that will be the case for a while. I think it's getting easier to make stuff, but there are still some very skilled people out there who really know their stuff and are able to make things faster and higher quality."

- Interviewee 18 | VFX Generalist

"…it is creating this atmosphere of democratisation, where poets are often better at handling AI than someone like me for example, but my whole career I've seen technology evolving and that's never scared me because as an artist you have to be constantly learning and constantly keeping up with what the newest software is and the technology. It's always a partnership between artists and technology"

- Interviewee 19 | VFX Generalist

For example, Unreal Engine enabled artists to create content when they have financial limits as the software is free and available for their use at their own workstations:

"…where I'm still struggling to get funding for certain projects, Unreal Engine, where it stands right now, is giving me the tool to execute it anyway"

- Interviewee 16 | VFX Generalist

New technology being easily accessible to artists allows them to get their content out at their own convenient time and without constrains that employees might put on them:

"Unreal Engine allows me to just content regardless of wherever I'm getting paid or not. I can be in my back office at four o'clock in the morning, so it's the access - that's what this new technology is doing for me personally, it's enabling me to get stories out"

- Interviewee 16 | VFX Generalist

As Interviewee 16 suggests, the democratisation of technology such as Unreal Engine enabled artists to achieve work, which would have in the past taken much longer and would have involved a large number of artists:

"For me personally, it's given me a piece of software that is free to use. I won't owe them a thing unless my project goes off and gets a million dollars. With this kind of technology, I'm able to get my creative ideas out where it's just me. Ten years ago, this would've been impossible, you would need a whole production and an animation house to do what I've done in a month, for instance"

- Interviewee 16 | VFX Generalist

However, some high end productions might still choose more established technologies:

"There's probably more competition than there used to be. I don't think that the entry level easy to use free stuff, like Runway for rotoscoping for example, is necessarily going to replace the more established tools. I think some houses would still want people who know how to use their traditional tools, there are big render farms and workflows that are built around traditional tools that aren't necessarily in place in some of the newer tools"

- Interviewee 18 | VFX Generalist

As new technologies arise, it takes time for them to develop enough for artists to start to utilise them over their preferred already established technology:

"User experience in Blender is a nightmare. In some softwares, anything that is Adobe or Cinema 4D for example, you can guess shortcuts blindfolded, but in Blender nothing makes sense. But it's still such a wonderful software and it's free"

- Interviewee 17 | VFX Generalist

Good user experience does not only influence the job satisfaction of workers and has potential to decrease time spent on certain tasks as Interviewee 17 suggests, but it also allows artists to focus on creative tasks when the technical aspects are easier to navigate:

"It's important for software to be user friendly, so you can just be creative and artistic. Some software, like Maya, 3Ds Max or Houdini, it gets so much in the way that it's hard to be creative sometimes. You get into this very technical mindset, so it's hard to create art"

- Interviewee 19 | VFX Generalist

It can also influence artists to choose other software with better user experience, which may impact the quality of their work, but software that is easier to use in terms of technical skill may increase job satisfaction, which could outweigh some artists choice between quality and job satisfaction:

"I tried using Nuke, but I can get a close enough result in After Effects. Although Nuke can maybe give me that extra 10 %, but is it worth it for me to spend years learning that?"

- Interviewee 20 | VFX Generalist

The hardware and software producers are very entwined in their work and need constant communication to make sure the updates match accordingly in order for both to work at best abilities:

"…video graphics cards that haven't updated their drivers to match Unreal Engine's updates. These are kind of issues when we are always on the cutting edge of technology and it's broken"

- Interviewee 16 | VFX Generalist

Furthermore, interviewees expressed the significance of an increase in importance and use of game engines to create VFX rather than VFX specific software:

"If I was talking to myself a few years ago, my advice would be to learn game engines, because if you are processing in openFrameworks for example, you can't do some of the stuff that you can do in game engines"

- Interviewee 18 | VFX Generalist

Some interviews show that the VFX production workers will become more multi-skilled, 'generalists' rather than focused specialists:

"And if you're going into the big studios and the big Hollywood. VFX houses, that's probably still going to be how they're going to work for a long time. I don't see that really changing in the near future, but I definitely see a huge democratisation happening where it's going to be more about knowing which tools to use, knowing how to use those tools to accomplish what they want."

- Interviewee 8 | VFX Generalist

"…that's already happening, especially the developers that I've come across, we all do a little bit of everything and I found that in filmmaking as well, I don't think you can be a standalone thing, because the amount of things that I'm doing right now is just mind boggling"

- Interviewee 20 | VFX Generalist

"I think you'll have problems if you are trying to specialise now when the world is kind of moving forward from that. So specifically, within VFX, you won't be out of work if you can do multiple things. Houses will hire somebody that can do five things, rather than one person who could do one thing"

- Interviewee 16 | VFX Generalist

"I wouldn't want to be a specialist, there is much less creative freedom in that…"

- Interviewee 20 | VFX Generalist

"It's also a question of time, do I have the time to learn modelling, to take 6 months off and to learn how to do sculpting and modelling? Not necessarily, so if you are a generalist – you'll probably have to take some shortcuts. As much as we all want to, we can't take

5 years off to do a crash course in every single discipline. We kind of have to pick and choose our battles"

- Interviewee 19 | VFX Generalist

However, when new technologies arise, it also creates an opportunity for those who want to get into the industry to specialise in a specific new technology:

"It's a nice time to get into the industry because there's only a handful of people, probably globally, that can actually work out how to do this stuff or make it look a certain way. For the indie creators, I think you'll just have a bigger impact"

- Interviewee 16 | VFX Generalist

Although the interviews show that many artists are choosing to become generalists as new technologies emerge, this does not necessarily decrease the need for specialists:

"…but I think for feature films that are massive, like Marvel, you can't have a team of just generalists, you have to have the best people in world for those specific text, because they are so cutting edge and have thousands of artist on those films, so it makes perfect sense that everybody is a specialist"

- Interviewee 19 | VFX Generalist

"I am a generalist, but I know where my limits are and I know that I'm not going to get into the whole field of audio for example, so I hire someone who is an expert to do that for me and it's amazing to collaborate"

- Interviewee 19 | VFX Generalist

"Some people like to be really really good at one thing, but if you're going to do that, you have to be extremely good at it, very fast and really get your name out there. It's very competitive. If you're a generalist you won't short of work, because you can do lots of stuff, but you won't be as good as someone who specialises. But if you specialise too much, maybe the technology changes and you're out of a job of you don't keep up. If you are a generalist, you also don't want to spread yourself too thin, it's also really hard to be good at ten different things, you jump between things and it takes time to get back into

it. It takes time and constant effort to keep your skills sharp and that's something that's really hard"

- Interviewee 18 | VFX Generalist

"There's probably more competition than there used to be. I don't think that the entry level easy to use free stuff, like Runway for rotoscoping for example, is necessarily going to replace the more established tools. I think some houses would still want people who know how to use their traditional tools, there are big render farms and workflows that are built around traditional tools that aren't necessarily in place in some of the newer tools"

- Interviewee 18 | VFX Generalist

Some point out that as new technologies emerge, there is an increase in demand for specialist workers. For example, the introduction of Unreal Engine has sparked an interest 'unreal developers' who specialise in that technology:

"People are scrambling to hire unreal developers and people that have that sort of experience. So that's been quite a change that was maybe a bit of tempering of the excitements around us. You look at the Mandalorian videos and kind of go, 'that's incredible'."

- Interviewee 4 | CG Pipeline TD

Some artists believe that it should be encouraged to have a balance between generalist and specialist skills:

"I've always been a generalist and I get into specialist practises sometimes depending on a project. For example, I had a project that required me to dive deep into character animation, which is a very specialised skill, but it was something I had to learn to make that project the way it needs to be. I think generalists have a superpower in knowing they can learn anything and the more you learn, those other fields influence how you work in your favourite specialised field. You can kind of be both, be a generalist and specialise in camera movement and lighting for example. Having your own artist style is also a form

of specialism. Or if you are able to produce a whole short film yourself and you know the entire workflow and you can do everything – then you are a specialist at that"

- Interviewee 19 | VFX Generalist

New technology and shifts in the VFX workflow show how VFX production as a whole can change, as tasks change, the traditional division of labour between job roles can change. The interviews suggest some job roles which may be particularly impacted by these changes. They also identify some skilled work which is being automated. The advice to become a generalist rather than a specialist suggests that some roles may be, perhaps temporarily or perhaps permanently, deskilled. Some VFX workers may find themselves losing their jobs because their specialism has been replaced:

"Anyone that is interested in visual effects could go ahead now start building their own company where they're working for, doing freelance work that maybe has a focus on visual effects, instead of wanting to go work on this big Hollywood movie. Virtual production especially will have a huge advantage"

- Interviewee 6 | VFX Generalist

Interviews also show that many VFX houses starting to hire more tool builders who can create custom solutions. One interviewee identified a:

"…*preference for people that are tool builders. They are driven by building things that everyone can use and that is another huge benefit to our ongoing effort of efficiency, effectiveness and quality. And now if someone builds a suite of destruction savings for a project spending that way, we can use that and then it's kind of building the next thing."*

- Interviewee 3 | Operating Manager

Interviews suggest technology that uses elements of AI and ML, can decrease the amount of time needed to complete certain tasks and impact the way certain tasks are carried out with the assistance of automating tools. However, this does not just impact costs, but also job satisfaction. Some of the VFX artists interviewed said the find rotoscoping less job satisfying than other tasks due to the amount of repetitive tasks it requires and so reducing the time spent on these tasks also improves job satisfaction:

"Rotoscoping is a very tedious process and can take hours"

- Interviewee 8 | VFX Generalist

"Machine learning software can help reduce that time as a lot of it is very repetitive"

- Interviewee 7 | VFX Generalist

"Rotoscoping is a really tedious thing nobody likes to do. I was rotoscoping something the other day and I was using the roto brush that's now in After Effects. It is a more recent tool and it's definitely a lot easier, but it just still takes time. What Runway ML can do by speeding that process up is incredible"

- Interviewee 6 | VFX Generalist

Moreover, implementing ML technology into VFX pipeline management has a siginifciant impact on the artists. Interviewee 4 described it as *"it makes life better for artists"* and added:

"I wanted to empower assists and leads and supervisors to go in and make the changes to the pipeline that they needed to make"

- Interviewee 4 | CG Pipeline TD

Interviews suggest that there will be a continues trend of technology democratisation:

"In terms of the democratisation of the filmmaking industry when DSLRs really kind of hit that boom maybe about a decade ago, everyone was then making independent films and now we see the industry again getting into that sort of space."

- Interviewee 2 | VFX Generalist

Some interviewees from this study suggest that in the next 10 years we will see an emerging digital marketplace as the digital world becomes increasingly important and 3D tools become more democratised:

"Your presence in the digital world is as important as the presence in your physical world. The beauty of the digital world is the manufacturing cost is zero"

- Interviewee 5 | VFX Software engineer and architect

"…we are going to see this emerging marketplace where people are going to start buying and selling in this digital world and the need for 3D assets is going to increase because of this metaverse and NFTs becoming popular"

- Interviewee 5 | VFX Software engineer and architect

"Creating NFTs is another place where VFX artists can work. Depending on the project, some of these projects have a lot of money and they can hire full, studios to do work or several VFX artists can jump on board. It's another place where content is starting to get developed and in the metaverse, which is where all our digital stuff is"

- Interviewee 19 | VFX Generalist

Moreover, interviews suggest that further democratisation of technology will have a significant impact on job satisfaction:

"… people have historically relied on universities or VFX schools to have access to the tools they need to learn their craft. Now, they can do this from the comfort of their own home for a very minimal cost, and on an as-needed basis"

- Interviewee 2 | VFX Generalist

"Five-ten years ago, being an artist was a very technical job and the more good tools artists have, the more those tools become democratized and as a result artists can focus more on the creative process"

- Interviewee 5 | VFX Software engineer and architect

However, some point out that AI is being used to automate routine tasks, which may impact job security and precarity levels of some VFX workers as the technology gets developed further and is implemented more:

"So many artists are upset that AI is going to steal their jobs and automate us out. A lot of people who are technicians and have worked their whole lives at rotoscoping for example. Many of us have known for years that it's less safe to be a technician rather

than an artist or someone who is making a lot of creative decisions. If you are a technician solely it is easier to get put out of a job"

- Interviewee 19 | VFX Generalist

Furthermore, interviews suggest that new technology could also have broader impacts on the industry as a whole:

"Just as before, when you would have to create a movie, you know, you would have a huge crew, even just doing a regular commercial shoot. You would need a crew of five to ten people on set the thing, but we've seen everything technology shrinks down and then it becomes one or two people can go out to shoot a commercial, it's pretty remarkable. And I think it's going to be the same way with visual effects. So I think we're not going to see, VFX studios go away, maybe becoming more vast, so they don't really need as many people working there, because I think AI is going to augment a lot of that"

- Interviewee 2 | VFX Generalist

Discussion

The discussion chapter identifies the key findings of the study, in terms of existing changes and patterns of change over time and uses the conceptual framework in the literature review to try to explain why and how new technology is being adopted in some companies, and for some tasks, and also why it is not being implemented in other places. This section also uses literature review to identify how the evidence in the interviews helps answer the research questions about the creativity and job satisfaction of VFX workers and also their job security or precarity.

Increase in Demand and Standards

As the literature review (pp 60-**Error! Bookmark not defined.**) explained, in the past two decades there has been significant growth in the size of the VFX production industry in response to increasing demand for VFX elements to be included in a range of media product types including feature films, TV series, games and advertising. The interview sections confirmed that one of the biggest driving the changes and growth of the VFX industry is the increasing demand for VFX elements in productions. The interviewees for this study also stated that high demand for content and higher expectation for VFX could be driving all the new products for VFX to emerge (Interviewees 2 and 8, p128). Similarly, to experimental filmmaking having pressure on mainstream filmmakers such as George Lucas to adopt cutting-edge techniques into their films (Turnock, 2014), these advancements in technology today create new expectations for VFX production.

In the interviews an important factor encouraging adoption is the role of lead companies like Lucas Films and Marvel Studios in establishing a standard of quality which is putting pressure on other companies to eventually have to follow (Interviewees 4 and 5, p125). Many interviews referred to the importance of *The Mandalorian (*e.g., Interviewee 4, p125) in setting this new standard of quality in VFX for TV and film. In establishing an industry standard, *The Mandalorian* may have changed the nature of the product market for TV series with CGI and so established a new standard for CGI. Marvel Studios

productions were also mentioned by interviewees in regard to setting higher standards for VFX and encouraging the use of real-time technology in order to achieve the desired complex VFX shots (Interviewee 5, p125).

Epic Games is another company that is driving the changes in the VFX industry, pushing the boundaries of what can be achieved with VFX, increasing the quality and realism standards and enabling easier access and creation of high end VFX. Unreal engine's MetaHuman allows to create high quality digital humans as well as making the process much easier and simpler with the use of real-time technology, by including a full facial and body rig and using data from real-world scans (Unreal Engine, no date). It enables the rendering process to happen in real time, compared to the traditional rendering process described in chapter 1 (see p27) and provides physical realism. This drives change because audiences and commissioners of VFX content start to expect this as the standard for CG humans (Interviewees 2 and 6, p126). As lead companies establish a standard for the level of realism of computer animation, so audiences and commissioners will come to expect this of all producers, gaining legitimacy when the VFX industry accepts it as the new standard. Some interviewees point out that achieving realism is difficult due to lack of development in technology rather than the skills of artists (Interviewee 17, p126). Although the desire to achieve realism depends on the type of product, for example some artists creating content for advertising of products that do not yet exist may not want them to look 'realistic' and their focus is on making the image stylistic rather than realistic (Interviewee 17 and 19, p127). Furthermore, the term 'realism' may also depend on what exactly the artists is trying to achieve, for example it may mean achieving a realistic look rather than realistic proportions of a character (Interviewee 18, p127).

The data from interviews suggest that companies are using new technologies to diversify and innovate in the range of VFX content they produce, possibly establishing new genres and new standards. For example, a video game creation system and service *Dreams* developed by Media Molecule and published by Sony Interactive Entertainment enabled to create content in real-time directly on a video game console (Interviewee 2, p126). This change in the technology has the potential to make VFX content re-purpose-able across a range of platforms in a way which has not been possible before. The literature review chapter described this kind of change as horizontal integration, where a company which had previously specialised in one area (such as games production) is able to enter a related

markets (such as film and TV). This part of the interviews may be explained as an example of "flexible specialisation" where changes in production are driven by product innovation across an industry, where an industry is moving from a focus on producing a single type or small range of products to a broader range of different types of product or content (see literature review p73).

Increasing Demand Drives Productivity and Economies of Scale

Data from interviews shows that the changes in the product market are not only increasing the quality standards, but also increasing the demand for VFX production as whole, and new technology is created to increase productivity and efficiency to meet those demands (Interviewee 2 and 8, p128). The literature review chapter (p28) explained some of the methods media production companies use to increase the volume of content they are able to produce by achieving efficiencies in the performance of certain production tasks. The chapter explained the idea of cycle time (the time taken to complete a specific sequence of production activities) to help explain what producers mean by phrases like "turnaround time" (see literature review p35).

The idea of cycle time (the time taken to complete a specific sequence of production activities) helps understand what VFX producers mean by "turnaround time". A cycle could be the time to complete a particular VFX task (e.g., rendering a certain type of object) or it could be time to complete a whole production. The data chapter showed that in VFX production a 'cycle' could be the time it takes to complete a particular VFX task (e.g., rendering a certain type of object) or it could be the time it takes to complete a whole process (e.g., production of a sequence or a whole film). Reducing the time it takes to complete a cycle means taking less time to complete one or more actions. This could mean an increase in productivity.

Factors Influencing Investment Decisions

Interviews gave various reasons behind decisions companies make when choosing whether to invest into certain new technology. Some companies choose not to invest in particular technologies because of their cost (Interviewee 3, p130); some companies have

other priorities before investing into new technology, due to their individual challenges not being able to get fixed by the new technology (Interviewee 3 and 4, p130); some companies decide that although technology such as virtual production brings a lot of new ways of achieving desired VFX shots, it also comes with its own challenges (Interviewee 4, p131).

The theory of flexible specialisation stated in the literature review chapter outlined that for VFX producers to have this kind of product innovation they need flexible types of production. But some interviewees stated product innovation, improved quality and flexible production will mainly be only for the large VFX producers. This is because some technologies are very expensive to acquire limiting to larger VFX companies which have the budget and the volume of production to be able to buy them. In contrast to some technologies making VFX more accessible to people, some technology, for example virtual production, remain being only accessible to bigger studios that can afford to invest into the software resource and integrate a virtual production pipeline (Interviewee 4, p129).

The literature review chapter showed how the structure of VFX industry has in the past been determined by the cost of the technology required to produce the content demanded by the film, TV, and games industries. The high cost of some technologies can only be covered if the company has a certain volume or level of production. In this case the cost of technologies can be recouped relatively quickly, over a large number of productions. But this high cost of some technologies makes a "barrier to entry" to smaller operators who cannot either raise the investment fund because they are not sure they will have the number of productions and so receive the money they need to pay it back.

The literature review chapter showed that some industry and technical writers are actually 'technologically determinist' because it implies that once a technology exists, it will inevitably be used in practice (e.g., Brown, 2019; Failes, 2019a; Failes, 2020a; Hatch, 2020; Kaufman, 2020; Wolfe, 2019a). The evidence in the data chapters does not support technology determinist explanation. For example, some VFX artists / houses are not investing into some of the new technologies as they do not tackle the challenges they are facing now. Current challenges include faster turnaround times due to the increase in the demand for content, but also the increase in demand for higher quality product. Literature

review chapter covered media economics theories (Doyle, 2002) that show how media production houses are in some ways like most businesses, so they are looking to reduce costs to compete for business and make a profit. However, some may companies have decided at the moment that the costs of investment in the technology are too much considering the returns (e.g., of either reduced production costs or improved quality).

The literature review chapter described the growth of VFX production in the UK, and the growth of VFX production companies working on Hollywood blockbusters as well as others working in TV, advertising, and games. The chapter described a general type of production workflow but also described how specialisation in larger production houses would produce specific types of VFX artists jobs where smaller companies may have less specialised workflow. The data collection chapter showed how the sampling technique resulted in interviewees from different types of companies producing different types of VFX outputs. The evidence of the interview shows that these differences help explain why some production companies have chosen not to invest in the new technologies. Budgets and quality standards of online advertising and simple TV commercials have not changed significantly, and at present there does not seem to be a change in demand that requires more complex VFX elements. For an advertising company, selling low-cost media products, spending a lot on CGI represents a big risk, if clients aren't prepared to pay extra or to commit to a production much further in advance (Interviewee 3, p130).

For high-cost markets, such as movies and games, the cost of new technology is smaller as a percentage of the cost of each project. Profit margins may be bigger too, so company can pass on this cost to their clients over several projects. If the cost of each project/product is low (e.g., production of online advertising) then company would need to be sure they could sell a very large number/volume of them to be confident they could cover the cost of investment in new technology.

The interviews for this study do show that some of the predictions of writers on new technology in the VFX industry (see literature review chapter pages 41-52) are not happening. Several interviewees, especially companies that mostly produce short VFX sequences for commercials (Interviewee 3, p130), simply said that the technologies are not affecting them yet. The interviews show that even where changes are happening there

is a lot of uncertainty about which changes will become permanent and be established and which are experiments which will not be carried on.

Pressures for Future Adoption of Technology Do Exist

While it is not "inevitable" technology will be adopted, this research provides evidence pressure to adopt the technologies exist and will continue over time. Even the artists/production houses who have chosen not to invest now, do state it will be only a matter of time before they do start to adopt these technologies. Most of the interviewees in this position believed that real-time and virtual production will have a huge impact on the industry, especially once it's been further developed.

There is some evidence that new technologies may be applied even by small producers and freelancers. This could be a significant change and increase in flexibility for production in the VFX industry and it may mean "barriers to entry" have been lower and so VFX production is more democratic. The interviews described evidence of how in the last 10 years, the technology in media production has become more democratised. Ten years ago, VFX artists had to build high-end simulation software themselves in the studio from scratch as it wasn't available to purchase. Now any artist can use software such as Houdini and Maya that have all the tools they need already. The next 10 years will also see democratisation. All the tools that an artist needs for high-end VFX projects are already available to them, however these tools will get higher quality and start to work faster. These off the shelf tools will "allow artists to iterate more quickly, see the results instantly" (Interviewee 5, p131). Some companies are investing less and less into in-house built technology for this reason. It may be that if the cost of other technologies limits adoption to larger, well financed companies at the present, the role of technology manufacturers in bringing forward further technological developments will improve the cost-benefit ratios associated with adopting these technologies, making this a realistic investment for smaller producers.

And further into the future, interviewees identified a logic which supports a trend to outsourcing or other forms of dis-integration of production even by the biggest production

houses (p132). IT security is one element in the process of this change as due to strict security regulations many VFX productions are forced to be done in office, however cloud-based security will allow for remote workforce and easy access to high-end VFX tools which will make the VFX production process more efficient and also allow companies to outsource production to many countries in the world (Interviewee 5, p132). Being able to harness the cloud while on set can significantly increase flexibility in VFX artists' work. Some interviewees suggest that cloud-based technology allows easier access to high quality VFX at minimal costs and combining cloud-powered VFX production along with machine learning and AI could have some potential. Cloud-based technology, such as MetaHuman Creator by Unreal Engine, allow easier access to high quality VFX at minimal costs. Runway ML is a perfect example of the potential improvements in VFX production which possible when cloud powered VFX production is combined along with ML and AI.

The data chapters suggest that just as when most successful technologies enter the market, we see a democratisation of the filmmaking industry, with new technology coming out for the VFX industry, we will start to see the same. Most interviewees expect we will see vertical disintegration in the industry, reduced costs of production allow new entrants, new small firms to enter the market.

Some of the interviewees identified this change compared with the changes which happened in the film and TV industry in the late 20th and early 21st century (Interviewee 2, p162). Interviewee 2 suggests new technologies coming out for the VFX industry will start to have the same impacts on VFX production as new camera technologies did on independent film and video production in the 2000s. In that case, technology reduced the amount of crew needed, replacing labour or automating tasks. This vertical disintegration in the industry was described by one interviewee as "democratisation' (Interviewee 2, p162).The interview suggests that AI and ML technologies has the potential to do for VFX artists what DSLR technology did for camera operators and Directors of Photography. Following the example of filmmaking, this "democratisation" could also have broader impacts on the industry as the reduced costs of production allows "new entrants", new small firms who can enter the market. These firms can innovate new types of VFX products, or they can give flexibility to large companies through allowing them to do greater outsourcing to small companies.

It could be that the VFX industry has a choice between control by big producers or "democratisation". But it could also be both options are possible. For cost reasons, at the blockbuster end of the industry, innovation in very high quality VFX production is still likely to be driven by large producers who have the resources to fund this. But the theory of flexible specialisation says that product innovation can come about as new technologies enable the creation of product market "niches". In this case, new, small production houses can compete with big producers because they specialize in a particular type of production work or tasks. If both options are possible, flexible specialisation theory would explain this, because it would mean large companies are not able to develop the degree of product innovation and diversification they need on their own. Instead, they will require to develop greater flexibility in their work processes, including outsourcing to small specialist producers.

The data collected for this study suggests virtual production will allow VFX work to become more accessible and increase flexibility creating vertical dis-integration. This technology could make it more cost-effective for a company to work with a market of suppliers rather than do all of these workflow tasks in-house as they can get the same level of quality and control from freelancers, as they could if there were supervising the work in house (Interviewee 6, p161).

Automation and Scaling Improving Productivity and Efficiency

While interviewees were excited to talk about the changes in quality which new technologies can help with, and about changes to the VFX production workflow described in Chapter 1 (these are described below) it is clear that meeting demand for an increase in output by increasing productivity and efficiency of existing VFX workflow is a very important priority for companies that introduce these new technologies.

Today, in VFX, a majorly automated pipeline is required in order to make profit. This has become the "bread and butter" (Interviewee 5, p132) of today's VFX industry. This means new technologies are being used to automate existing tasks within the production process outlined in the workflow outlined in Chapter 1 (p25).

Chapter 1 (pp 32-32) described the historical development of rotoscoping and the workflow diagram on page 25 showed the important role rotoscoping has in the workflow. The evidence of this study is that new technology is enabling replacement of some of the manual tasks involved in rotoscoping with automation. For example, some VFX artists / houses have integrated various technologies that use automated tools such as AI and Machine Learning to help with rotoscoping (Interviewee 1, p142; Interviewee 5, p134; Interviewee 6, p162; Interviewee 7, p162; Interviewee 8, p133, Interviewee 18, p138). Furthermore, Interviewee 18 points out that these technologies have potential to assist in automating the task of depth estimation (p138).

Technology that uses AI and ML, such as Runway ML, which is used for rotoscoping, makes tasks easier and less complicated for VFX workers (Interviewee 1, p142). Removing complex steps from the process reduces "cycle time" (see literature review p35) also allows workers to get the task done faster and has the potential for cost-efficiencies. It also allows more room for creativity as artists spend less time on repetitive tasks (Interviewee 18, p140). For example, using software with ML technology for camera tracking speeds up the process significantly (Interviewee 18, p139). However, as Interviewee 20 suggests (p139) eliminating or reducing routine tasks with new technologies does not necessarily mean artists eliminate manual control over those tasks completely. More task variability is starting to give VFX workers more opportunity to develop their own creative ways to carry out a task. This follows a pattern in other areas of the workflow, where automation is removing some of the repetitive tasks and enabling VFX workers to concentrate on variable or creative tasks. However, some interviewees pointed out that in some cases implementing automation tools may take longer than completing the tasks manually (Interviewees 18, 19 and 20, p137). There is evidence that making these processes quicker and less tedious can in practice make work more job satisfying (Interviewee 6, p162; Interviewee 19, p138). Furthermore, Software that use real-time technology, such as CamTrackAR, have the potential to automate the traditionally manual process of matchmoving (see literature review, p26) and increase precision and efficiency of previs (Interviewee 2, p134). Some interviewees suggests that automation tools can be used in creative tasks to create a foundation for artists to then work on manually (Interviewee 19 and 20, p139).

Although the interviewees did not say their creativity or job satisfaction was being negatively impacted, this may be because this study is still a small sample. Literature review showed that in other industries automation, like Fordism, can make job satisfaction lower. As stated in theoretical framework in the literature review, works such as Perrow (1969), suggest that automation is usually more possible with more routine, repetitive tasks. This may be used by VFX companies to increase productivity of existing workers as smaller cycle times mean more content produced for same cost. By simplifying these tasks, the technology also means production workers who aren't specialists in this field, or aren't as familiar with this process, to still be able to get the job done. This also creates possible efficiency through "deskilling". Companies could cut costs further by employing less skilled and cheaper workers to do this work or could replace some roles with technology. This is area for future research to discover if VFX producers get to do more creative work or just do more repetitive tasks or replaced by machines. Furthermore, Interviewee 18 points out some ethical issues when using technology such as AI as a creative tool rather than as an automation tool (p139).

But automation does not always mean creativity is impacted negatively. Literature review covered theory of flexible specialisation (see p73). In this case, the development of new customised processes may be because the type of product being produced is required to be more varied and so workflows change, and workers have more variable tasks to do. Driver of change in VFX have been described as demand for new content, from simple online content commercials to high production value computer games. VFX production is also impacted by the product market, for example as budgets for certain types of products rising or falling due to changes in demand for those products.

Technology Increasing Creative Freedom

The literature review described and explained the development of the modern VFX workflow (p28) as a process of economic, creative, technical, and technological change. Over time this has altered the nature of VFX tasks and the relationships (see "interdependencies", p25) between tasks. The VFX workflow has not stayed the same. There have been changes over time in the relationships between production and post-

production, between routine and creative or editorial tasks and between technical tasks and creative tasks.

The evidence of this study is that new technologies are not simply automating the routine tasks in the existing VFX workflow but enabling further changes in the way the VFX workflow is put together. The interviews showed that automation and productivity ('scaling') are not new things in designing VFX production. They are "cornerstones" of VFX workflow so it is predictable that VFX houses would use new technologies in this way (Interviewee 5, p132). However, many interviewees argued that companies are also using the automation potential of the technology to try to improve quality of output. The link with automation seems to be that VFX houses are trying to achieve the "cornerstone" objectives of increasing productivity and scaling the output they can get from the workflow and at the same time trying to increase quality of product by liberating creative workers from routine or repetitive tasks (Interviewee 1, p136; Interviewee 3, p135; Interviewee 5, p134 and p136; Interviewee 7, p137). But the interviewees also state that the impact on creativity is not just in reducing repetitive tasks through automation. VFX technologies are not simply being used to automate and simplify the existing VFX workflow tasks identified in chapter 1. The interviews say that these technologies are being adopted because of they can enable VFX workers to take on new tasks, for example working in real-time in Unreal Engine (Interviewee 4, p160).

Some of the most interesting examples given in the interviews talk about the possibility to make fundamental changes to the processes of video, film and TV production and post-production. The literature review chapter described the relationships (see "interdependencies", p25) between tasks in VFX production. This showed that in traditional VFX workflow many tasks in post-production are dependent on tasks in production. The chapter literature review explained how some of these interdependencies happened in historical development of VFX workflow (p28). One reason for dependencies comes from the rules of continuity in film production which have lasted since the earliest years of the film industry (see "jump cuts" in literature review chapter, p82). Now VFX technology allows editors and post-production workers to "remove" objects showing in a frame and potentially to move them elsewhere in the frame. This means that editor can correct the "jump cut" problem without the director having to re-shoot the scene. Two important tasks which have been inter-dependent since start of

cinema might not be dependent in future. In the literature review chapter this was called “de-coupling” as this is a common way of trying to improve efficiency or quality in workflows in other industries outside the media (see “business process management” in literature review, p82). As Interviewee 1 (p142) suggest, software that uses ML such as Runway, enables fundamental change in rules of continuity, as it allows to “remove” objects. This means a task of editing is “decoupled” from a task of production and can reduce costs of re-shooting.

Interviewees also talked about process of changing the relationship between production and post-production in examples such as substituting practical effects (effects created in the filming process on set or on location) with VFX effects. One way this happens is new technology that uses deep learning techniques to automatically process the footage, enables automatically capturing information that you have to go and generate by hand. For rotoscoping, for example, instead of individually cutting out each character in order to figure out what goes in front or behind each character the software can analyse this task and generate a solution (Interviewee 4, p133).

Another example of interdependencies is in post-production process itself. Chapter 1 explained the difference between “on line” and “off line” tasks in post-production (see “offline editing”, p35). Some interviewees stated that the automation and better processing power of VFX technologies is basically changing the tasks which are online and those which are still offline. For example, real-time based pipelines that use ML to transition traditional offline processes to online (many producers call this “real time” because it means the VFX producer does not have to wait very long for the task to be completed). Interviewees pointed out the efficiency and quality gains (Interviewee 5, p134) by allowing for fully simulated rigs to be used in previs and virtual production workflows, which reduces the cycle time and at the same time enabling creative workers to do new things. The potential of reducing the cycle time of creative tasks, such that they become “real time”, is likely to be a significant factor in the future application of these technologies because it enables VFX production to more closely match the natural (“real time”) processes of human creativity (Interviewee 5, p149).

One explains that, for example, creating a rig in a ML and real-time powered software, instead of creating it from scratch in a game engine, allows artists to apply existing

reliable workflows that are very complex (Interviewee 5, p135). Using these technologies can help improve the already established and very complicated VFX process by applying ML and real-time assistance tools, which will increase efficiency.

Artistic Process Shifts from Technical to Creative

The VFX workflow described in Chapter 1 (p25) showed that task dependencies can affect the quality, as well as the efficiency of VFX production. One example of this occurs when creative tasks are dependent on technical/developer tasks. This was true in one of the companies (Interviewee 4, p133) where the interviewee described the task interdependencies of the rotoscoping process at their VFX house, which closely approximated to the description of this process in the literature review on page 26.

However, other interviewees pointed out that VFX producers are increasingly using machine learning to speed up the rotoscoping process (Interviewee 5, p134). This is due to time limitations on projects, not using machine learning to aid in rotoscoping would drastically increase the amount of time an artist would spend on this particular task and with current complexity and time restrains on productions – artists are required to work as efficiently as possible.

Chapter 1 described the process of creating photorealistic environments. The chapter showed that reproducing, in animation, the light effects produced by natural or electric lighting was a complex task similar to the manual craft process of lighting a set in film production. Each time the task is performed is a bespoke solution involving some degree of trial-and-error in more or less randomly placing lights until the artist achieves the desired effect.

The interviews confirmed the problem with this process of adding light to an animated scene, essentially the task of lighting a scene was dependent on the prior task of rendering. Once the render had been done, there was a separate stage of making the simulation of the render so that the lights and the surfaces look “physically accurate” (Interviewee 5, p134). Machine learning has enabled a change in these task dependencies so that lighting

and rendering can happen simultaneously and VFX is no longer replicating the analogue process of lighting a set (Interviewee 5, p142).

Whilst, clearly the lighting process could only be described as creative, the interviews suggest that the new technologies have enabled a significant improvement in the quality of this aspect of VFX production by replacing one creative process with a superior creative process, which allows artists to focus on capturing the "performance and be creative" (Interviewee 5, p145). Similarly, as Chapter 1 described the processes of simulating a rig (see p38). ML combined with real-time technology allows to create a rig with an assistance of machine learning and then transferring it into the game instead of creating it from scratch (Interviewee 5, p145). Integrating real-time rendering into the workflow enabled artists to focus more on the creative tasks as it enabled artists to work in real-time by eliminating manual rendering and reducing the time of this process (Interviewees 16, 18 and 20, p148).

PDG (Procedural Dependency Graph) is a procedural software that uses ML to help manage VFX pipeline workflows. Software that uses ML, such as PDG, are used for automation to effectively reduce manual cycles and work of pipeline management. Due to extremely tight turnaround times today there is an increasing importance of assuring that the VFX pipeline runs as efficiently and smooth as possible, which can be achieved by using innovative technology. PDG allows producers to analyse Film, TV, Games, Advertising and VR content production pipelines and then to distribute tasks and manage dependencies to automate tasks and to increase the scale of production output. When created CGI environments, all steps that are included in this process have a specific order and must be carried out as fast as efficiently as possible. One implication of the technology is in enabling changes to the interdependencies between creative and technical tasks. PDG automates mundane pipeline tasks using a network of nodes that describe each of these steps, which would traditionally be done manually. This dependency created a delay similar to the "off line"/"on line" distinction described above. This dependency could impact on efficiency, for example if the developer took considerable time to implement the task. It could also impact quality if the developer did not necessarily interpret the request as the creative had expected. PDG improves the process of task and project management by distributing tasks and managing dependencies. As Interviewee 7 suggests (p146), implementation of ML technology is likely to continue the trend of

shifting the VFX process from very technical to becoming more creative. Interviewee 19 points out the importance of making new technologies easy to use and requiring minimal technical knowledge to increase user experience satisfaction, which would also shift the artistic process from being very technical to more creative and may increase job satisfaction (p143).

The literature review chapter explained how producers could achieve efficiencies by economies of scale. The interview evidence suggests that, at least in larger VFX houses, PDG is being used to increase the scale of production. From the perspective of the company, there is a clear cost/productivity driver for this change. The new process reduces the overall time taken to produce an asset (its "cycle time"), because it reduces time creatives spend waiting for developers to make changes and decreasing the overall amount of time it takes to make these kinds of changes.

There may also be a quality reason for companies to introduce this change. In the past, the process involved creatives briefing developers on the changes they wanted. The creatives would not then see the final changes until the work had been completed and they could see whether the brief had been followed and whether the changes made had produced the desired effect. If the changes had only been partially successful, for example, there would be a cost and time pressure to accept the loss in quality, rather than repeat the process.

The introduction of PDG changes the process from a sequential process, with built in delays, to a "real time" process where creatives can make changes, assess effects, and if necessary, quickly and easily repeat the process with slight modifications until the desired quality is achieved. In this way, the technology appears to support the 'natural' creative process better than the existing workflow. One interviewee described this as "it makes life better for artists". Several interviewees saw this process as one of liberating producers from routine and repetitive tasks and "allowing artists to focus on the creative process" (Interviewee 5, p136; Interviewee 1, p136; Interviewee 7, p137).

These interviews also provide evidence that the implementation of this technology is not simply to automate routine tasks. It is also changing the balance between tasks performed by "technical" workers (for example, writing computer code) and creative workers. This

represents a fundamental change to the workflow described in Chapter 1 and a significant change in the VFX production process This research suggests the application of technology is changing the interdependencies between creative and developer tasks.

Some new technologies “close the gap” between creative and technical and also traditional and digital creative processes (Interviewees 19 and 20, p143). For example, Unreal Engine enables artists to create animation without the manual skill of drawing (Interviewee 16, p143). It also allows an individual artist to create work which they have complete control over that would traditionally involve a large crew and would be time consuming and high cost (Interviewee 16, p144). However, some interviewees pointed out quality concerns when using such technologies instead of traditional artists (Interviewee 19 and 20, p144).

As with all the technologies studied for this thesis, the changes in production are still at a very early stage. But there is clearly the potential for a significant change in the balance between creative/editorial and technical/production control of tasks. The literature review chapter described how such changes have affected other media industries, including the moment that technology enabled journalists to typeset and format their own articles, rather than printers and typesetters doing this.

Open-Source and Creativity as a Driving Factor

There is evidence that the changes in VFX production are not simply a response by producers to technological potentials and possibilities created by manufacturers. Alongside this process, there appears to be an organic process with producers seeking out potential to improve the quality of the content they produce.

VFX houses not only implement technology, but also develop their own solutions to create autonomy driven software. Machine learning seems to be the most useful and widely used tool to increase efficiency and improve job satisfaction by decreasing the amount of tedious repetitive tasks. This suggests that in this case, quality is what is driving the changes. Interviews suggested that enabling these changes and adapting autonomy driven software written from scratch or open source have helped improve the

creative/editorial process by improving efficiency (Interviewee 3, p135). This is not the case of responding to manufacturers coming up with pre-designed 'solution', but rather producers themselves identifying ways to find technologies to improve the VFX process.

This research suggests that further development and implementation of open-source self-made solutions and implementation of autonomy driven software may lead to further changes in the production processes. For example, interviewees suggested it may further change the balance between offline and online processes and change the nature of online editorial (Interviewee 3, p135; Interviewee 5, p135).

Authenticity of 'Real' vs CG Generated Images

The literature review chapter explained the changing role of filming real events for use in animation compared to artificially creating images through manual drawing or computer animation. Furthermore, the growing standards of the level of realism expected from visual effects is increasing (see p40). The evidence of this study is that the new technologies are changing the cost and quality calculations VFX producers make in deciding whether to use 'real' or computer-generated images.

For example, creating VFX images of fire and explosions is difficult to film and so is expensive. AI and ML has the potential to decrease these costs by feeding the computer with stock footage of real effects that have been filmed in the past. Artificially creating more variants of footage that has already been filmed will increase productivity by generating more outputs and assets from the same inputs (Interviewee 1, p133 and p140).

Another example would be rotoscoping. Technologies such as Runway ML, which uses AI and ML, can decrease the amount of time needed to complete this task by automating some of the process. However, this does not just impact costs, but also job satisfaction. Some of the VFX artists interviewed said the find rotoscoping less job satisfying than other tasks due to the amount of repetitive tasks it requires and so, reducing the time spent on these tasks also improves job satisfaction (Interviewee 1, p136; Interviewee 3, p135; Interviewee 5, p134 and p136; Interviewee 7, p137).

There are a range of impacts on quality, which appear partly to depend on which sector of the industry, and which type of VFX producer is implementing the technology. An example of this would be the use of "synthetic" rather than "real" footage to create scenes. Runway ML provides a synthetic image generator, which uses ML technology to create synthetic scenes based on the dataset given, providing a completely custom image. Virtual production also allows producers to create environments from the office rather than traveling to a film set. Clearly, the cost and time spent on this form of VFX production, in contrast to the cost of filming a real scene, is minimal.

This substitution of real images with and virtual raises questions in regard to quality of the finished product in both cases. Respondents suggested that the potential use real footage rather than CG created elements will generally increase the quality of VFX. But the quality considerations of real versus synthetic elements were also related to the overall costs of production. The decision would relate to the level of quality required (Interviewees 2 and 3, p133).

Interviewees have described a process of experimentation and innovation where companies work out the perfect amount of real and artificially created elements to achieve the best outcome. However, overall, respondents suggested that the biggest deciding factor remains the quality when it comes to deciding how to create challenging scenes. In this case, producers describe quality as "the authenticity" of the images –how realistic the images look. In almost any production process, cost reduction is likely to have an impact on quality and therefore, the more important product quality is, in deciding sales/profits, the less likely producers are to compromise quality to reduce costs.

Relationship between Pre-production, Production and Post-production

The literature review chapter (p25) explained the interdependencies between tasks in the VFX workflow and tasks in pre-production and in production (the shooting of live action film, TV, video etc.). The interviews for this study suggest several changes may be occurring in the balance between these inter-dependent production processes. As Interviewee 7 (p150) suggests, virtual production may be one of the new technological developments that may drive the shift in balance of the production process as it allows to create environments from office rather than traveling. This substitution of real images with virtual raises questions in regard to quality of the finished product in both cases.

The literature review chapter also explained the theory of flexible specialisation and to some extent the changes in interdependencies described by interviewees may represent a further extension of "functional flexibility" (see p74). Interviewees suggested VFX production workers may increasingly be empowered to take on or contribute to tasks which were previously the specialist responsibility of pre-production or production workers (Interviewee 1, p151).

Automating tasks like rotoscoping could decrease crew numbers and allow more time for creativity. Furthermore, generalists may become multi-skilled, whereas multi-taskers and the specialists may be less able to take advantage of this breaking down of the technical barriers. One interviewee suggested that technology that uses AR and real-time technology has the potential to automate the process of matchmoving and improve the previs process for more precise and easier planning of VFX (Interviewee 2, p134). CamTrackAR simultaneously records the captured tracking data and live footage, automating the traditionally manual process of matchmoving (see literature review, p26). Additionally, this software has multiple previs tools that enable placing 3D assets into the scene in real-time, which can improve communication and planning processes between different production departments.

However, there are many limitations and uncertainties about how the 'new' VFX workflow will relate to production and pre-production. This is a period of experimentation and change where companies and their partners in production are exploring a range of new ways of combining and changing tasks to meet changing and growing demand in the various media markets (Interviewee 4, p151).

'Democratisation' Impact on Job Satisfaction and Security

There is an obvious relationship between automation and the number of jobs available. As seen in the interviews, technology reduces amount of crew needed, replacing labour or at the very least reducing time by automating tasks. The data chapters confirmed AI and ML has the potential to do this for VFX artists.

Some interviews talked about democratisation as allowing new companies and freelancers to enter VFX production. But it could also be the case, at least for some VFX workers, "democratisation" is what Ursell (2000) referred to as "casualisation" or "precarity". Flexible specialisation theory explains how producers can vertically dis-integrate the performance of some production tasks either by using casual or freelance labour or by 'outsourcing' the task to one of a number of supplier companies in the market (this is "numerical flexibility"). This type of flexibility involves reducing costs to enable companies to cope more effectively with peaks and valleys in demand, by replacing permanent staff and technologies, which represent a cost even when demand is low, with freelance or outsourced staff, who only incur costs when there is a demand for the work. The data chapter do suggest new technologies will allow companies to hire staff on a freelance or temporary basis and then let them go when they do not have a production in progress. This clearly may impact the employment position and job satisfaction of in-house production workers who may in the future lose their security of employment.

But 'flexible specialisation' can also mean functional flexibility, meaning producers gain more variety of skills so they can do more different tasks. The interviews stated, at least for creative VFX workers, there are four ways that the new technologies appears to have increased job satisfaction: automation of routine and repetitive tasks has given some creative workers extra time to work on creative tasks; the technology is enabling VFX producers to have more broad skills and not be so specialised in one task; the technology has also enabled creative workers to do completely new creative tasks which were not possible before.

One final way using new technology may have improved job satisfaction of creative workers is in use of technologies like PDG to enable creatives take over control of some tasks which were done by technical workers (such as developers) previously. This shows that the impacts on producers depends on what their role or tasks are in the workflow. As explained, this software takes control over this production task out of the hands of developers and puts it more in the hands of creatives. Because this is at the experimental stage, it is not yet possible to determine whether the impact of this is change will be to deskill the work of and maybe also make redundant, some of the developers. By contrast it adds technical skills to work of the creatives. This may change the level of job satisfaction of these two roles with creatives feeling more empowered and developers

limited to control of other elements of production. Similarly, to experimental filmmaking having an impact on film production by shifting the technological and conceptual expectation as well as creating a new workforce (Turnock, 2014), these new technological developments are likely to drive changes in the VFX workforce today as new developments in the workflow continue.

Furthermore, interviews showed that in-house workers in junior positions have less control over their creative work. For example, Interviewee 20 pointed out having to use a software that does not meet their requirements, when they would prefer to use software that includes real-time rendering, which would significantly impact their job satisfaction (p149). Freelance artists who have more control over their creative work seem to have higher job satisfaction as they have more power over their creative decisions.

This research did not interview the technical workers as it was beyond the scope of this study. It is possible to identify this as an area for future research to see, for example, if technical workers have suffered a decrease in job satisfaction as some of their work has been automated and taken over by creative workers. Another possibility is that this automation means that previously technical workers have been able to take on some new creative tasks and so in fact their job satisfaction has increased.

Specialist vs Generalist Skills

Flexible specialisation describes functional flexibility as method of achieving flexibility in production. This is the opposite of Adam Smith's specialisation process, because it is replacing specialist skilled work with multi-tasking, multi-skilled work, where production companies are able to adapt to the changing demands of audiences or commissioning companies ("the product market") by having a workforce which can switch between a range of tasks, or perform new tasks, as required. The progress of automation and of 'deskilling' of some technical roles does suggest changes in VFX workflow will remove some of traditional animation/VFX specialisms or reduce the demand for them. This would mean lower job security ("precarity") for these workers. It may mean reduced job satisfaction for some technical workers because their work will be done by creative and editorial workers. In this respect, the overall trend shown in the interviews would seem to be that the VFX production workers who continue to get work in the industry will be

those who become more multi-skilled, ‘generalists’ rather than focused specialists. This would support the idea that “functional flexibility” in production is increasing.

New technology and shifts in the VFX workflow show how VFX production as a whole can change, as tasks change, the traditional division of labour between job roles can change. The interviews suggest some job roles which may be particularly impacted by these changes. They also identify some skilled work which is being automated. An example of this trend towards developing multi-tasking, generalist VFX production workers is the pattern of VFX houses starting to hire more tool builders who can create custom solutions (Interviewee 3, p161).

The advice to become a generalist rather than a specialist suggests that some roles may be, perhaps temporarily or perhaps permanently, deskilled. Some VFX workers may find themselves losing their jobs because their specialism has been replaced (Interviewee 2, p164). But what appears seems like “casualisation” and loss of job security (‘precarity’) for some VFX producers, could also be, for other production workers, a lowering of ‘barriers to entry” to the industry. Recent graduates for example, might see the potential for freelance work as a way to gain experience and develop their professional profile. However, some interviews point out that as new technologies emerge, there is an increase in demand for specialist workers. For example, Interview 4 (p160) suggests that the introduction of Unreal Engine has sparked an interest in hiring ‘unreal developers’ who specialise in that technology. Furthermore, interviews suggest that although there are many advantages of becoming a generalist, this does not necessarily decrease the need for specialists (Interviewees 18 and 19, p159).

The interviews for this study have shown that VFX producers are finding opportunities to increase efficiency, effectiveness, and quality by making changes to the production workflow. One aspect of this is that some tasks are becoming, at least initially, less specialised. It is not clear if these changes will be permanent or are a temporary reaction as new technologies cause disruption in the industry and different types of producers change specific elements of production. It could be that in ten years’ time these changes become established and production roles become more specialised although in a different workflow from the one in existence before the changes.

Patterns of Potential Changes in the Future

Many of the interviewees talked about what changes they believe will happen in the near future. Although this evidence is not as reliable as the interviewees describing what has already happened, it is valuable in this research because it helps identify the patterns of change. Interviewees talked about a number of patterns of change in the future which they can describe already based on the changes they have seen.

As stated previously (see p184), interviews in this study suggest that in the future there will be a continued process of democratisation of technology, increase of remote workforce and implementation of cloud-based workstations and IT security systems. One of the drivers identified for this change was in terms of addressing the challenges presented in delivering high-end projects. As the production of these projects involves increasing scale and specialisation, there is a problem of coordinating this work – literally, in coming up with a system to get thousands of people to work effectively together. Interviewees suggested that allowing VFX workers to collaborate and work together remotely by providing a remote system that work efficiently will continue to be an important way to meet this challenge. This will also raise changes in security. At the moment, many VFX workers are forced to work in the confined environments in the office due to strict security restrictions. The evidence of this research is that further implementation of cloud-based security and a distributed remote workforce will allow for much wider ecosystem in the VFX industry. Democratisation, where there is easy access to high-end tools also allows for much more effective distributed workforce, since VFX workers can come into the workplace already skilled and having had access to the tools that are required for production (Interviewee 2, p163 and Interviewee 5, p163).

Although some literature (like Staiger, 1979) sees automation and creativity as opposites, most interviewees for this study seemed to think automation is supporting creativity. For example, application of machine learning can be used as a tool to speed manual cycles up and so allow more time in worker's day for creativity and originality. Interviewees from this study believe that machine learning will continue to drive the change of the VFX artists process from being very technical to becoming more creative and artistic. Many

VFX artists today, if they want to make changes artistically, they have to wait a couple of hours to see the results, as they have to simulate and calculate before any changes can be made. However, as machine learning and real time are used to make those processes quicker and even immediate, that significantly changes the whole process and make it much more efficient and therefore driving that shift into creativity (Interviewee 1, p136; Interviewee 3, p135; Interviewee 5, p134 and p136; Interviewee 7, p137). For example, a layout artist could use machine learning to make layouts of a scene, which will allow them to assemble the scene by focusing of the creative rather than spending a lot of timing moving 3D objects around, which would make the iteration speed of this much more rapid.

Interviews in this study suggest that the changes in the relationships between pre-production, production and post-production will continue. Furthermore, there that there will be further converging of real time and traditional offline VFX. The pattern of changes in the product market seem to suggest a continued direction in VFX production. Many interviewees talked about major producers, like Marvel Studios, setting standards which competitors have to try to match. Filmmaking is becoming increasing more complex as the stories people are telling are becoming more abstract. Basing their stories in abstract worlds such as *Dr Strange* is going to further drive the convergence of real time VFX and traditional offline VFX in order to achieve these desired visuals (Interviewee 5, p125).

For example, when using virtual production or LED walls, more and more of the media creation process will be applied before starting filming, as producers have to make all of the effects and assets work in advance. Furthermore, producers have to build something that allows visual effects, assets and technology to work both in real time, but also allows them to produce offline high-quality images at the end. Some interviewees of this study suggest that in five-ten years' time all film (not just conventional VFX genres) will have an element of real time, whether it's cameras scouting, pre or post vis tech service, or even using LED volumes, which provide the perfect image in camera. Despite this, some of the traditional patterns are also likely to continue. Interviewees believed, there will continue to be a "fix it in post" approach with an element of touch ups even when using real time, as it will not be sufficient to render all the necessary details. For example, digital doubles would have to be worked on in post-production.

Currently a lot of this technology is in its infancy, which means many processes have to be done twice at the moment. For example, when shooting LED volume shots and then anything that needs to be rendered, artists have to rebuild some elements and then do it again. To bridge this gap between real time and VFX would eliminate the need to do things multiple times (Interviewee 5, p149). Rather than a transformation overnight, this research suggests that there will be a combination of new and old approaches. The ability to go between the two worlds of a real-time and traditional offline VFX is likely to be a feature of VFX production in the next 5-10 years.

The VFX industry is not only impacted by the film, tv and other video content industries, it is also heavily involved in the gaming industry and other immersive industries that use technology such as AR (for example, in art exhibitions) or 3D holograms (for example, in live music concerts). As VFX is used in very innovative and experimental industries and projects, it is likely to have impacts from many different industries that have different demands from various markets.

Besides the innovations that are happening in the media industry that are driving all these changes, interviewees also spoke about factors outside of the industry that are increasing the value and volume of VFX content required and produced. For example, the metaverse and 3D becoming commoditised. With the increasing use and importance of social media platforms, the way people portray themselves online, their digital version, is becoming increasingly more important. A digital version of yourself is becoming increasingly as important as the physical version (Interviewee 5, p162).

The transactional economies in certain online game environments are becoming bigger in economic value (Antin, 2020; Holm and Mäkinen; 2018). Some interviewees from this study suggest that there is going to be an “emerging marketplace” in the near future, where there are going to be transactions of 3D elements (Interviewees 5 and 19, p163). In the metaverse you don’t produce anything physical, every single thing you produce can be unique. Interviewees in this study suggested that there will be a 3D version of the internet in the future, similarly to what is already happening in the gaming industry. For example, Epic Games are doing online concerts where sometimes 10 million people show up to watch a virtual concert with famous musicians, all in a 3D world.

This research suggests that metaverse will affect VFX production in different ways from the media economics. Unlike filmmaking, metaverse isn't about storytelling, but about having a space for a digital version of yourself. Software that use ML technology have an opportunity to transform the process of 3D modelling by applying the same principles of creating synthetic images into creating custom 3D models (Interviewees 8 and 19, p141). Further developing this idea is likely to bring more opportunities for new businesses and products to enter this market.

Conclusion

Summary

This research has addressed the following critical questions related to the study of VFX production:

1. Which new technologies are having the greatest impact on the VFX pipeline and what stages of VFX production pipeline (e.g., previs, rotoscoping, rendering) are most impacted?
2. What are the causes (e.g., the need to reduce time and cost) that drive the adoption of these new technologies in the VFX pipeline?
3. How do VFX workers feel new technologies changed the nature of their work, and with what consequences on conditions for creativity, job satisfaction and job security or precarity?

In relation to RQ1, the evidence presented in this study suggests that Real-time technology, AI (including ML), Cloud-based technology and Virtual production are having the most impact on the VFX pipeline. The evidence also showed where in the VFX production line these technologies are having the most impact. Real-time technology is impacting previs, rendering, CGI and rotoscoping stages of VFX production, as well as pipeline and data management. AI and ML are impacting rotoscoping and CGI, as well as pipeline management. Cloud-based technology is impacting previs, CGI and rotoscoping, as well as pipeline management, security, and data management. Virtual production is impacting previs, rendering and CGI.

This research suggests that the answer to RQ2 corresponds to the fast-growing demand of content and the continues increase of standards for VFX. The first cause of changes and implementation of new technology into the VFX pipeline is the need to achieve these high-quality standards. But the second driver is in the growth of the VFX industry and

the need for increasing quantity of VFX elements in film, TV, games, and other platforms. This second cause impacts the VFX production pipeline due to the need to increase productivity and efficiency to meet these high demands for content. The data from interviews in this study shows that the need to ensure the VFX pipeline runs as efficiently and smoothly as possible, as well as cost-efficient as possible, is ever growing in this industry. This second cause of change is important in creating the pressure to automate routine tasks and eliminate some very technical tasks. However, as the evidence collected for RQ3 shows, increases in efficiency does not mean jobs have become less creative. The pressure to compete in quality standards means that there is a need to automate some tasks to ensure artists can focus their time on the creative process.

This research shows that RQ3 is an important aspect of the changes in VFX production. The evidence presented in this study suggests that, in general, when new technology is being implemented into the VFX pipeline, it changes the nature of artists work, and in a lot of cases it increases the level of creativity and job satisfaction. Interview evidence described how technology such as ML that automates routine and mundane tasks significantly increases job satisfaction and allows to focus more time on the creative process. Innovative technology that uses real-time and virtual production also increases the level of creative freedom as it increases flexibility and allows for more interactive approach of VFX production. Moreover, cloud-based technology and ML significantly change the process of pipeline management, making the VFX process more efficient and increases productivity, which in turn increases job satisfaction as it enabled workers to focus on creative work.

The data in this research was gathered from across the range of the UK industry and includes a broad range of content genres and business types. By focusing on the common technologies, the study has been able to compare and contrast changes across this very diverse industry.

Cultural Influences on VFX Production

The themes in the first category suggested that quality, creative and technical standards set by major producers is a key driver in causing companies to implement changes in VFX production. Current changes do fit into the pattern of stylistic and technical

development of SFX and VFX over more than 100 years described in the literature review (see pp28-39). Compared to the earlier years of video production, significant new factor seems to be a clear growth in audience preference for VFX elements in film and video, and games.

This study has also supported the idea that there is now a broad audience and industry acceptance of new standards of quality of VFX especially e.g., in CGI humans in TV series like *The Mandalorian.* Some of this cultural influence on changes in VFX production is referred to by writers on VFX content like Turnock (2014).

Using the concept of "excellent products" from Hesmondhalgh and Baker (see "excellent products" in literature review p91) has enabled the study to describe the kinds of creative tasks enabled by the implementation of new technologies. Using this concept helps understand what VFX production workers mean when they use concepts such as realism or photorealism or when they refer to the Marvel aesthetic to describe the kinds of products they believe are excellent. The interview data then shows how VFX workers connect these concepts of excellent work to help them indicate the kinds of tasks they believe are 'creative'. For example, this study shows that artists consider it creative work when they use their knowledge and skill to create something unique and original. Many interviewees connect this to the idea of "autonomy" by referring to creative work in terms of completing manual tasks that they have high control over. Furthermore, this study shows that artists see new opportunities to be creative with new technologies and having more freedom and control allows them to be more creative. Data gathered in this study shows that new technologies enable artists to be more creative without having an extended amount of technical knowledge. Furthermore, some new technologies enable artists to be creative without having knowledge of the traditional creative process.

Applying concepts of "excellent products" and "good work" also helps illustrate how technology is eliminating some tasks and creating opportunities for this kind of creative work. For example, interviewees referred to being able to create animation in Unreal Engine without knowing the traditional craft. The data also shows that artists are using new technology as an assistance to eliminate or reduce routine tasks, which enabled them to spend more time on the creative tasks and increasing their job satisfaction.

The themes in the second category, cover the most likely patterns of potential changes in the future. This study shows that the drivers of change and implementation of new technology in VFX are not only from changing cultural styles and standards in traditional film and TV. The interviews showed increasing importance of the digital world and people's digital self, alongside the potential use of ML to create 3D models. This pattern of change is influencing the industry as a new digital marketplace emerges and increases the value and volume of VFX production required.

Determinism suggests that technology implementation is the same in all companies (McLuhan, 1964). However, this study shows that different VFX companies are responding to cultural influences such as continuously more complex storytelling demands. As a result, some VFX houses prefer building their own customised tools internally rather than using already made technology and software as they believe they are not developed enough yet to be invested in.

However, the study also showed that the changes in VFX production are at an early stage. Most of the technology that is covered in this research are at the experimentation stage (see "product innovation" in literature review pp75-79). Different companies are trying various approaches to using these technologies without knowing which they will end up keeping or dropping. For example, creating fire, hair and explosion assets is a complex task for animators due to the complexity of texture as well as movement as it is highly variable, detailed, and inter-related. It is therefore less complex to create and film these events in live action than to animate them. The technology creates an option to substitute complex animation of these events with the much simpler process of filming these events in live action. An aspect of these decisions that did not emerge in the literature review is the different strategies of large and small companies. The study shows that cultural variables may influence a company to focus on increasing quality (for example shooting these events specially and then using the technology to animate) rather than the company focusing on reducing production costs (for example using stock footage).
The variety and fast-paced change of new technology increases the level of uncertainty when companies are deciding to invest. However, this study shows the various options VFX producers identify and explore when they are trying to decide if and how they should implement the technologies.

Economic Influences on VFX Production

The literature review chapter described several economic forces which influence implementation of technology in media production; growth in VFX industry, product innovation and implementation of technology for quality improvement in different sectors, different strategies for process innovation and achievement of economies of scale, automation, productivity improvements or cost reduction. This study has shown how all these forces are continuing to be important in VFX producers' decisions about which technologies to use and which aspects of the VFX pipeline need to change.

The first is growth in VFX industry and the need to achieve improved productivity to meet increasing demand for VFX content. In describing the detailed changes to VFX production it becomes clear that the demand for an increase of productivity and efficiency of the existing VFX workflow is driving implementation of new technology and therefore also driving the changes in the process. Automation and use of AI (including ML) technology in software for rendering, rotoscoping, 3D modelling, and pipeline management is making a significant difference in efficiency and productivity. The evidence of this study suggests that many VFX artists and houses have integrated various technologies that use tools, such as AI (including ML) to automate tasks involved in rotoscoping, pipeline assisting software or their own custom-built pipelines. However, this is also an area where the strategies of different companies influence how they implement the technology. For example, some VFX houses have decided they can build their own more complex pipelines that use ML to its most potential whichever way they require it.

However, this study did not show that increased efficiency was in fact reducing the number of jobs and strongly impacting job security through unemployment of VFX workers. The evidence was that there is growing number workers in high-end VFX production. The use of technology is helping this because it means VFX companies can use technology to help source and manage these workers. This is shown in the pattern of remote workforce in VFX production which interviewees also sometimes called democratisation of production. The literature review chapter (see pp72-75) called this outsourcing or vertical disintegration in production, and there is evidence that this is happening in VFX and that this pattern is likely to increase. A similar pattern is of Cloud-

based technology being implemented into the VFX pipeline. This trend in using cloud-based storage and security systems can support the outsourcing pattern and so is also likely to continue to be improved and encouraged to be implemented.

Literature review chapter talked about specialisation of tasks and division of labour in development of the traditional VFX workflow (see 'division of labour' in literature review, pp70-71). The evidence of this research is that some of these impacts of technology have started to change relationships between pre-production, production, and post-production of VFX. For example, real-time and virtual production technology, allow previsualisation in real time and therefore creative decision could be made during the entire VFX production process (pre-production, production, and post-production).

The interviews suggest that pattern of changes in relationships between pre-production, production and post-production is likely to continue as technology that uses ML and real-time are being implemented into the pipeline. One interesting aspect of this seems to be pattern of implementation of ML continuing to drive the shift of artists process from technical to creative. As noted, this study did not interview the technical VFX workers, so it is impossible to say to what extent this impacts their job satisfaction and job security. Some interviews suggested that the difference in specialisation between technical and creative VFX workers may be decreasing and production houses are demanding more workers with "generalist" skills of both technical and creative.

There is some evidence that these changes may be caused by a growth in product innovation (new types and broader range of VFX produced) caused by the cultural influences discussed above. This product innovation may require greater flexibility in production. There does seem to be, among creative workers at least, a move from more specialist skills and tasks to more generalist skills, in particular, with some creative workers taking over some previously technical tasks or being encouraged to take on more technical work. This is some support for the idea that VFX industry is moving towards "flexible specialisation" identified in many media industries (see Storper, 1993) – technology enables product innovation and requires flexible skills (functional flexibility) and technology reduces 'barriers to entry' and enables small firms and even freelancers to compete with larger firms (interviewees called this trend "democratisation").

Economic Influences on Job Satisfaction and Job Security

This study has suggested that automation to improved productivity does not seem to be affecting how VFX workers feel about the creativity and job satisfaction of their work. This is because of the type of tasks which technology is being used to automate. For example, real-time technology reduces cycle time of rendering. Automation of these routine tasks seems to be driving increase in job satisfaction and allowing more time for creativity in other tasks rather than taking away creativity and giving it to the machine. Some aspects of flexibility may be affecting job security and job satisfaction (see Hesmondhalgh and Baker, 2008) as technology (especially cloud-based) means large VFX firms are able to outsource work to independent companies and freelancers anywhere in the world. But this might mean they do not need so many full time VFX workers employed as staff in the office – they might be able to take on workers just when they are needed. This type of flexibility is not so much needed for creating highest quality content but is more important for keeping costs low (see "numerical flexibility", p75). Academic studies identify this kind of flexibility with job "precarity" (Hesmondhalgh and Baker, 2008).

This study looked at the role of hierarchy to see how far this may influence which workers gain the opportunity to do creative work and which may have less autonomy and control over tasks. The interview data does not enable a clear conclusion about whether bigger VFX houses, with more formal hierarchies, are more likely than small houses, with more informal hierarchies, to have these differences in impacts on creative work. However the evidence presented in this study does suggest that hierarchy makes a significant difference between roles at different levels of the hierarchy on whether they have autonomy/creative work. This data gathered in this study also suggests that individuals that have a great deal of control over what technologies they implement also have significantly more control over their creative work. The evidence also suggests that VFX workers in this position have an increased job satisfaction.

Using Hesmondhalgh and Baker's concept of "good work" (see "good work" in literature review pp88-92) has helped analyse whether having a role at a particular level of the hierarchy makes a significant difference to whether they have "good" (secure) or "bad" (precarious) work. Data from this study does not show any significant correlation between

the level of hierarchy and job security or precarity, however this does not mean that it does not influence it. Data in this study shows that although freelancers are continuously faced with job security risks, the democratisation of technology and the increase of generalists also means that more opportunities for work are created.

The concept of "good work" also helps understand how VFX workers can express how much they value the creative work they do, may also point to the precarity of this work, and thus the extent to which their work may be creative but not (in Hesmondhalgh and Baker's terms) good. Data in this study shows that workers who have high control over their work and access to various new technologies have higher job satisfaction and express that these factors increase their creativity levels.

Cultural and Economic Influences on Creativity

Although lower job security may reduce job satisfaction, there is evidence that creative VFX workers generally are finding that impacts are mainly concentrated in routine tasks and that, cultural and economic pressure for high standards of VFX quality, means companies are expecting these VFX workers to spend more of their time generating creative outputs and less time on routine tasks. This means most creative VFX workers interviewed believed their creativity was not being impacted. As previously stated, this research did not include the technical, and it may be that their creativity and job satisfaction is being impacted, so this is an area for future research.

Future Patterns of Change

The trend of democratisation in the VFX industry, which emerges from the data gathered for this research, raises the question of whether democratisation is permanent or temporary. It is not clear if the current impacts and changes are a permanent new state of the industry and the production pipeline or if this is a stage of disruption, which may be followed by new, different paths of change. Furthermore, whether it is only a period of disruption or whether the VFX industry in this digital world is always going to be disruptive.

Contribution to field

This study provides a detailed academic study of an industry that is, relative to other aspects of film and tv production, a neglected area (Turnock, 2014). This study is also a type of research which is contributing to in the academic field, of media industry and production studies (Mayer et al. 2009) by focusing specifically on VFX production. The study has showed how academic theories discussing the cultural influences on media production (such as Bordwell et al., 1985) and social and economic theories about media production (such as Banks 2007; Mayer et al., 2009) can be used to analyse the reasons for changes in VFX production processes, tasks, workflow, and pipeline.

This study contributes to broader knowledge creativity, job satisfaction, and job security and precarity in media production (such as Hesmondhalgh and Baker, 2008) by providing knowledge about the specifics of how these subjects are being impacted in VFX production. This study also contributes to the qualitative methods of studying media production (Bruun, 2016). It also introduces a new and original innovative method to contribute to resolving a traditional problem of gaining access to interview media producers (Bruun, 2016). The study was able to increase the number of responses to requests for interview by using industry methods as ways of communicating the aims of with research such as creating a website and an infographic 'pitch'. It also encouraged VFX producers to respond by giving them something in return for participating.

This meant identifying how the aims of the research could also meet the needs of media producers being researched by producing and circulating an industry report to help them understand issues of implementation of technology, any obstacles and impacts on creativity and job security (see p214)

As well as this contribution to specific fields of academic literature, this study can have an impact by contributing to the industry understanding and implementation of new technology. As an outcome of this research, the industry report attached with this study (see pp214-228) provides a clear summary of the data gathered in this research, as well as providing various suggestions for challenges raised from the interviewees in this study. Reports from academic research can help outline uncertainties and implications VFX

companies would need to consider, which would help businesses deconstruct the excitement around cutting-edge technology and identify the issues. For example, this study has identified job satisfaction, creativity, and security as important issues, as well as costs, quality, and efficiency, in implementing technology. One issue identified is the impact of technology implementation on technical VFX workers, which is an area for further research.

Strengths and Limitations of the Study

This last section of the thesis summarises the strengths of this research, including its methodology, but also identifies the limitations. Because this is a study of an industry which is relatively neglected in academic literature, because it is a study of production rather than a content or audience analysis, and because it is a study of cutting-edge technologies, there are many problems faced by this kind of research which are not so great in other kinds of study. This means it is possible to identify many limitations with this research and also to identify many recommendations for ways further research could improve the information and understanding provided in this thesis.

This study provides knowledge of changes in the production process in a very specific industry, which hasn't been wholly studied or researched in great detail by academics. As the VFX industry is (still) relatively small, technically complex, and therefore very exclusive, it is hard to gain access to professionals unless there are personal connections. As a contribution to the field, the strengths of this research include providing original data and deep insight from industry professionals themselves. Evidence has been collected from industry professionals at the cutting-edge of the implementation of technology, VFX workers who could provide deep and extensive knowledge of the technology and how it is being used in VFX production.

A second strength is down to the innovative methodology used to collect this evidence. The lockdown conditions during this research made access to these professionals even harder. In response to this, various innovative methods were used in this study to gather interviewees. This is one of the biggest strengths of this study as it was targeting the right professionals by using familiar methods that would attract them and encourage trust in the researcher. By using the technique productions use to pitch projects (by creating a

treatment), the researcher created an Infographic Pitch for this research that resembled a treatment. This method was highly affective for these professionals, backed up by a website and a linked in page which were both focused solely on this specific research study. Furthermore, creating an industry report based on this research gave further reason for the interviewees to accept the offer of being part of it. All these innovative methods not only gained their trust, but also sparked an interest in them as they may also benefit from this research. The innovative methods in this study should be considered to be re-used and further improved in future research, as gathering data in this specific industry differs highly from any other academic field and it is important for the researcher to have a good understanding of the industry and its professionals when approaching them in the most effective way.

However, this study tackles the implementation of 'cutting-edge' new technologies as they are emerging now, and therefore it isn't something interviewees have had experience with for many years. This means implementation of cutting-edge technologies in VFX is a difficult topic to research compared with asking producers about other aspects of VFX production which are not changing so fast. This means that there are many aspects of the subject which are uncertain at the moment, and which could change depending on the different forces driving implementation of technology in VFX.

Limitations of this research include some aspects of methodology as the industry professionals interviewed in this study mostly work in the UK, and although London is considered to be the heart of the VFX industry, it would be insightful to get data from professionals based in other countries, especially the US as it contributes to the majority of high-end film, TV and games productions. Another aspect of the methodology that could be improved for future research is a larger sample and variety of job roles. A larger sample would provide more in-depth qualitative data and therefore would further contribute to the research. Having a larger variety of job titles would open opportunities to discover different areas of the VFX pipeline that might also be impacted, or it might help to detect which other areas of the pipeline might benefit from specific technology. In particular, the sampling did not include many technical VFX workers, who may be negatively impacted by the technology as technical tasks may be automated and creative VFX workers may be more in control of production, which may impact their job satisfaction.

Another limitation is regarding the type of companies / VFX houses the sampling is coming from. For further research into new technology, it would be recommended to sample from higher end VFX productions and large size companies as the interviews made it clear that only high budget productions are able to fully experience the new technology. However, when researching to detect what areas of the pipeline demand improvement, it would be recommended to broaden out the sample as those who do not have access to the expensive technology may provide other insight and ideas into various problem-solving solutions.

The interview technique where the researcher focused on key questions worked successfully in gathering data for this research. However, a limitation comes from the way the questions were developed in relationship to the job titles. This was based on the view that VFX production is specialised and VFX producers know most about one of the processes in the workflow. But during the interviews it became clear that in some cases VFX workers were more generalist and knew about more than one of the processes. Due to the variety of VFX tasks and technology each participant was knowledgeable with, the key questions should not have been based on the job title, but rather on the technology that specific participant was experienced in. This is because even if one of their jobs is as a roto artist, for example, they may still have experience with other parts of the pipeline such as CG, for example.

Therefore, basing the key questions on their experience with specific technology rather than limiting it to one role would be highly beneficial. Furthermore, aesthetic and quality questions about the impact of technology are another area which was not addressed in the study, however interviews in this study suggest that this is an important aspect of the many impacts.

In practice this limitation could be managed. The researcher asked key questions based on technology the participants would bring up during the interview despite what role the key question was targeting. This was more effective than limiting them to their job title, especially as it has been discovered during this research that the job title does not necessarily mean that the individual is limited to knowledge specifically in that role. On the contrary, this research shows that majority of VFX workers are highly versatile and

are usually knowledgeable in various roles and tasks due to the interdependent nature of the VFX process.

However, this limitation also helped deal with another limitation of the study. Although the methodology was successful in getting evidence from VFX workers who could help answer the research questions, there was still the problems of the pandemic and temporary shutdown of production. As a result, the researcher was unable to gather interviewees with all the job titles that were originally targeted (see p105). But as noted, this study shows that most VFX workers have experience in multiple areas of the pipeline and therefore were able to answer the research questions regarding various tasks even those that are not officially included in their job title.

Recommendations for further research

The previous section identified a number of limitations which happen with this kind of research. This section identifies how future researchers could overcome these limitations and help provide more generalisable evidence and deeper understanding of the research questions asked in this thesis.

This study answers RQ1 by providing data which shows that real-time, cloud-based, virtual production and AI (including ML) are among the new technologies that are having the most impact on the VFX pipeline. Furthermore, providing data that shows which aspects of the pipeline are most impacted: rendering, rotoscoping, CG, and engineering and management of the pipeline itself. Further research could be done to investigate this RQ by exploring other areas of the pipeline which are also highly impacted, such as pre-vis, as none of the participants of this study work on pre-production. However, as many of them mention, the pre-vis process has been highly impacted by new technology and many predict that it will continue to do so.

RQ2 of this study is answered with the data from interviews which shows that reasons behind these changes are either driven by the need to reduce cost and time as demand for VFX production grows and production process needs to be faster, or by the continuous

rising of the quality standards that require VFX to push boundaries to meet those high demands and expectations of both the audience and the market. Further research can be done to explore the potential of some of these technologies such as AI (including ML) to automate certain tasks, such as rotoscoping, and therefore eliminating certain routine tasks of the process. Similarly, further research can be done to explore different areas of VFX that still lacks high quality, for example MetaHumans creating realistic humans. However, most producers and even audiences still prefer 'real' images rather than CG created due to the lack of authenticity. Research into this specific area could help determine what exactly makes a CG created image 'authentic' and 'realistic' and which technology could help further advance this process to push those boundaries of quality and creativity. Further research into how new technology is impacting aesthetic and quality of VFX would be beneficial.

Further research could be done to answer RQ3 to determine how VFX workers feel specific technology introduced to their specific role impacts the nature of their work, level of creativity, job satisfaction and job security or precarity. This research provides insight into roto scoping, pipeline management and general impacts by professionals, however, to get a deeper understanding into each role further research would need to be conducted. For example, conducting research specifically on real-time technology and CG artists. This type of research would not only gain more knowledge of the specific VFX roles by exploring the possible causes of these impacts, but it also may help to discover ways to improve VFX workers job performance or satisfaction by using new technology. Furthermore, further research is needed to understand if more technical workers are negatively impacted. This study does not include many interviews with technical workers whose work is also being impacted and control sometime given to creative workers, which may impact their job satisfaction.

The innovative methods used in this study to gather participants would be hugely beneficial for any further research. One of the limitations of this is that, because it was not possible to get a high response rate to the survey, the evidence is based on a small sample of the population of VFX workers. A recommendation of this research is that future researchers could use the same methodology used in this study to gain responses from a bigger sample of VFX producers.

Another limitation of the research is that the evidence all comes from the UK VFX production industry. So, a recommendation of this research is that further research, based on survey questionnaire for example, could collect data from other countries that have a highly developed VFX industry or are increasingly developing a larger VFX market share. It would be interesting to have research to compare findings of this study with evidence of changes in other countries such as the US, Canada, New Zealand, Japan, and Singapore. Comparing these studies would give more insight of the entire VFX industry and reveal more trends or complications VFX workers are facing. Another limitation of this research is that it is based on VFX workers who producer content for film and TV productions, However the interviews have shown how other industries (such as video games and the emergence of the Metaverse) are having an impact on VFX producers. It is another recommendation that further research into VFX should also be extended to gather data from individuals that not only work in the film and TV industry, but also in the gaming industry. This research could help show how far gaming is reliant on VFX and how many innovations in technology specially for VFX are introduced within and for that industry.

Future research would not need to focus only on the job roles and technologies included in this study. For example, if there is further research into a specific new technology, which is (as proved in this study) usually only acquired by bigger companies or businesses that are highly focused on immersive and innovative projects due to not only the high cost of some of these technologies, but also the need for them as smaller companies produce simpler content that may not need any further assistance by technology. In contrast, if further research is focused on finding neglected areas of the VFX pipeline that is still seeing many problems such as no solutions for simple routine tasks (such as automatic extraction of certain elements in the scene), the sample should be broader and include all sizes of companies as well as freelancers. This would help provide more data into what problems different roles are facing and with further research would help provide solutions, which could even be divided into different cost categories and provide various solutions by using different technology to target the same problems but at different costs that would be within the different budget limits. Moreover, as many of the interviews from this study confirm the benefits of real-time technology, further research specifically in that technology could contribute to determining more ways this specific technology could improve the VFX process. The target sample in any further research in this area of

study should also be decided depending on these types of research questions, which will help determine the types of companies and roles of the individuals.

Finally, this research has identified new research questions which were not imagined at the start of the study. It would be valuable for further research could be done into specific questions and problems identified in this evidence gathered for this study. There are particular research questions around economic aspects of VFX production. As Interviewee 2 states, there is higher demand for content more than ever, and as Interviewee 8 confirms that this means the turnaround time needs to be cut down as much as possible. Moreover, as Interviewee 5 expresses that filmmaking is becoming increasingly more complex as the stories are becoming more abstract these further urges solutions for increasing efficiency. Further research into understanding the question of how efficiency is combined with creative storytelling and which companies are providing solutions to these questions would be highly beneficial. Another research question identified concerns "democratisation" of technology. As Interviewee 5 mentions the importance and benefits of the democratisation of VFX tools, further research could be done to determine which VFX tools are still missing that easy access. Data on this could encourage industry professionals to introduce more VFX tools. Research in this area would also benefit from looking at how far democratisation could also result in precarity of employment for some VFX workers as new freelance workers are able to enter the market.

A strong theme which emerged in this study relates to the growing challenge of managing large teams of VFX producers who may be spread around the world. As Interviewee 4 and 5 clearly state that one of the biggest challenges of today on high end projects is coming up with an effective system where thousands of VFX workers can work together effectively. Further research into exploring options and solutions for a remote VFX workforce could be highly beneficial to the industry, for example studies on cloud-based security systems could be the starting point to figuring out an effective solution to this problem. This is corroborated by Interviewee 5, when they acknowledge that automation and scaling has become the 'bread and butter' of the VFX industry today. However, as Interviewee 3 suggests that not all VFX workers are able to integrate certain technology that uses ML, for example, further research into cheaper solutions for freelancers and

smaller companies could be done to help provide other options that would help artists with routine tasks without having to invest into highly expensive software.

The question of creativity is a very complicated one which could be the focus of separate research on its own. As Interviewee 4 suggests, new technology allows artists to be more creative, further research into this area could help explore areas of VFX that could benefit from investing into new technologies to help artists jobs become less technical and more creative.

This study has also revealed the impact of technology on the skills VFX workers need. As many interviews from this study highlight the importance of VFX tools, and as Interviewee 3 confirms that the demand for tool builders is increasing. Further research could be done to explore the benefits of this job and discover which aspects individuals would need to focus their skills on.

The final research question this study has identified relates to the influence of changes in industries outside the film and tv industries. As Interviewee 5 suggests that 3D and specifically the metaverse may have a huge impact on the VFX industry and increase the demand for 3D assets. The final recommendation for further research, arising from this study, relates to the way VFX production now forms part of new media, entertainment and communication industries, which are only just beginning to emerge.

Appendices

Appendix I: Key Questions

Key Questions for all interviewees:

1. Question - Are there any new technologies that are having an impact on your job and if so, which would you identify as the most significant?

   Follow up - How exactly does X change the way you do your job?

2. Question - What do you think companies are they trying to achieve by implementing X into the workflow?

   Follow up – Do you think X improves the quality, efficiency or reduces costs of VFX production?

3. Question - How do you feel these impacts have changed the nature of your work, level of creativity, job satisfaction and job security (or precarity)?

4. Question – What's your experience of using Real-Time, Virtual Production, Lightfield Cinematography, AI, Nano and/or Cloud-based technologies? What task do you use X for?

   Follow ups - What affect have you found that X has on X task?

   - If it "improves" the X process, in what ways does it improve it?

   - How do you feel these impacts have changed the nature of your work, level of creativity, job satisfaction and job security (or precarity)?

Key Questions for Modelers, Texture Artists, Animators and Rigging, Crowd, FX, Lighting and Rendering TDs:

1. Question – What's your experience of using Real-time technology?

2. How does Real-time technology impact the process of rendering?

   Follow up - If it "improves" the rendering process, in what ways does it improve it?

3. Question – Does Real-time technology impact the quality or efficiency of rendering?

4. Question – How do you feel Real-time technology impacts the nature of your work, level of creativity, job satisfaction and job security (or precarity)?

Key Questions for Modelers, Texture Artists, Animators and Rigging, Crowd, FX and Lighting TDs:

1. Question – What's your experience of using Real-time and/or AI technologies?

2. How does Real-time and/or AI technologies impact the process of CGI?

   Follow up - If they "improve" the CGI process, in what ways do they improve it?

3. Question – Do Real-time and/or AI technologies impact the quality or efficiency of CGI creation?

4. Question – How do you feel Real-time and/or AI technologies impact the nature of your work, level of creativity, job satisfaction and job security (or precarity)?

Key Questions for Roto Artists:

1. Question – What's your experience of using Lightfield Cinematography and/or AI technologies?

2. How does Lightfield Cinematography and/or AI technologies impact the process of rotoscoping?

   Follow up - If they "improve" the rotoscoping process, in what ways do they improve it?

3. Question – Do Lightfield Cinematography and/or AI technologies impact the quality or efficiency of rotoscoping?

4. Question – How do you feel Lightfield Cinematography and/or AI technologies impact the nature of your work, level of creativity, job satisfaction and job security (or precarity)?

Key Questions for Prep Artists:

1. Question – What's your experience of using Lightfield Cinematography and/or Nano technologies?

2. How does Lightfield Cinematography and/or Nano technologies impact the process of keying?

   Follow up - If they "improve" the keying process, in what ways do they improve it?

3. Question – Do Lightfield Cinematography and/or Nano technologies impact the quality or efficiency of keying?

4. Question – How do you feel Lightfield Cinematography and/or Nano technologies impact the nature of your work, level of creativity, job satisfaction and job security (or precarity)?

Key Questions for Match-movers:

1. Question – What's your experience of using AI technology?

2. How does AI technology impact the process of matchmoving?

   Follow up - If it "improves" the matchmoving process, in what ways does it improve it?

3. Question – Does AI technology impact the quality or efficiency of matchmoving?

4. Question – How do you feel AI technology impacts the nature of your work, level of creativity, job satisfaction and job security (or precarity)?

Key Questions for Pre-vis Artists:

1. Question – What's your experience of using Real-time and/or Virtual Production technologies?

2. How does Real-time and/or Virtual Production technologies impact the process of pre-vis?

   Follow up - If they "improve" the pre-vis process, in what ways do they improve it?

3. Question – Do Real-time and/or Virtual Production technologies impact the quality or efficiency of pre-vis?

4. Question – How do you feel Real-time and/or Virtual Production technologies impact the nature of your work, level of creativity, job satisfaction and job security (or precarity)?

Key Questions for Pipeline TDs:

1. Question – What's your experience of using Cloud-based technology?

2. How does Cloud-based technology impact the pipeline management?

   Follow up - If it "improves" pipeline management, in what ways does it improve it?

3. Question – How do you feel Cloud-based technology impacts the nature of your work, level of creativity, job satisfaction and job security (or precarity)?

Key questions for VFX and CG Supervisors and Producers and Pipeline TDs:

1. Question – Have innovations in technology impacted the VFX production workflow?

   Follow up question - If so, which technologies have had the most impact and how exactly have they impacted the VFX production process?

   Follow up question - What do you think are the causes that drive the implementation of these technologies?

   Follow up - How do you feel these impacts have changed the nature of your work, level of creativity, job satisfaction and job security (or precarity)?

Appendix II: Questionnaire

1. Are you happy for your name and/or your company's name to be mentioned in the public report? (Yes / Just company's name / Just my name / No)
2. Your name (text box)
3. Job title (text box)
4. Company name (text box)
5. Your email (optional - for follow up questions)
6. Which innovations in technology have had the most impact on the VFX production workflow? (text box)
7. How are they changing the VFX production process? (text box)
8. Are new technologies impacting your job? (Yes/No)
    a. (If yes), which would you identify as the most important? (text box)
    b. How have they affected your work?
        i. level of creativity (increased/decreased)
        ii. job satisfaction (increased/decreased)
        iii. job security? (increased/decreased)
        iv. your earnings (increased/decreased)
9. Have you have had experience with **real-time technology**? (Yes/No)
    a. (If yes) what impacts has it had on:
        i. final quality (significant improvement, small improvement, no impact, small reduction, big reduction, don't know)
        ii. efficiency (significant improvement, small improvement, no impact, small reduction, big reduction, don't know)
        iii. your creativity (significant improvement, small improvement, no impact, small reduction, big reduction, don't know)
        iv. your job satisfaction (significant improvement, small improvement, no impact, small reduction, big reduction, don't know)

**Same questions as above about Virtual Production, Lightfield Cinematography, AI, Nano and Cloud-based technologies **

10. What do you think are the reasons studios are bringing in these technologies?
    a. to reduce time/cost of specific VFX tasks (Yes/No)
    b. to improve quality of VFX effects (Yes/No)
    c. Other (text box)

Appendix III: "VFX: A New Frontier" Industry Report

Industry Report

May, 2022

- **Impact of Innovative Technology on VFX**
- **Establishing New Standards for VFX**
- **Democratisation of Technology**
- **Automation and Scaling**
- **Shift from Technical to Creative**
- **Balance between Pre-production, Production and Post-production**

VFX: A NEW FRONTIER

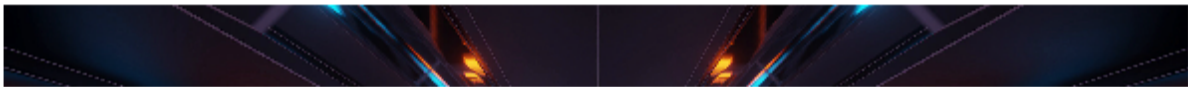
Research by Anastasia Chabanova

Report Overview

The VFX industry is currently undergoing profound technical and organisational changes (Kaufman, 2019; Kaufman, 2020; Failes, 2020; Visual Effects Society, 2020), the demand for VFX is growing and VFX productions involve large workforces with significant number of artists in various locations (Samaras and Johnston, 2018). Decreased budgets and turnaround times increase the pressure for VFX production to be as efficient and productive as possible (Sanson and Curtin, 2016; Heusser, 2013; MovieLabs, 2019; Venkatasawmy, 2016), which raises pipeline and data management challenges (Chung, 2011). Furthermore, the ambition to achieve more realistic and seamless visual effects continues to grow (Giralt, 2017; Samaras and Johnston, 2018), increasing quality and seamless reality standards of VFX.

This industry report provides a summary of data gathered from interviews with VFX industry professionals and proposes solutions to various problems raised by interviewees. It addresses most significant trends and new technology that drive change in the VFX workflow in respond to today's challenges and aims to help identify uncertainties and implications that should be considered before investing and implementing new technology into the pipeline. The report helps to deconstruct "the hype" around today's cutting-edge technology and considers underlying issues around job satisfaction and security, creativity, costs, quality and efficiency.

Contents



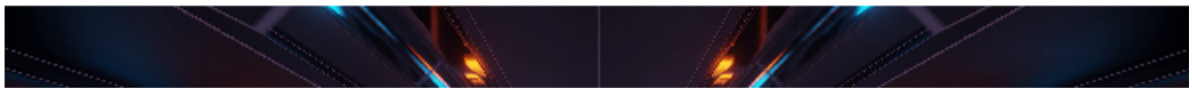
Increase in Demand and Standards for VFX

One of the biggest factors driving the changes and growth of the VFX industry is the increasing demand for VFX elements in productions. High demand for content and higher expectation for VFX seems to be driving all the new products for VFX to emerge. Similarly, to experimental filmmaking having pressure on mainstream filmmakers such as George Lucas to adopt cutting edge techniques into their films (Turnock, 2014), these advancements in technology today create new expectations for VFX production.

An important factor encouraging adoption is the role of lead companies like Lucas Films and Marvel Studios in establishing a standard of quality, which is putting pressure on other companies to eventually have to follow. The Mandalorian was an important production in setting this new standard of quality in VFX for TV and film. In establishing an industry standard, The Mandalorian may have changed the nature of the product market for TV series with CGI and so established a new standard for CGI. Marvel Studios productions were also mentioned by interviewees in regard to setting higher standards for VFX and encouraging the use of real-time technology in order to achieve the desired complex VFX shots.

Epic Games is another company that is driving the changes in the VFX industry, pushing the boundaries of what can be achieved with VFX, increasing the quality and realism standards and enabling easier access and creation of high end VFX. Unreal engine's MetaHuman allows to create high quality digital humans as well as making the process much easier and simpler with the use of real-time technology, by including a full facial and body rig and using data from real-world scans. This drives change because audiences and commissioners of VFX content start to expect this as the standard for CG humans. As lead companies establish a standard for the level of realism of computer animation, so audiences and commissioners will come to expect this of all producers, gaining legitimacy when the VFX industry accepts it as the new standard.

Companies are using new technologies to diversify and innovate in the range of VFX content they produce, possibly establishing new genres and new standards. For example, a video game creation system and service Dreams developed by Media Molecule and published by Sony Interactive Entertainment enabled to create content in real-time directly on a video game console. This change in the technology has the potential to make VFX content re-purpose-able across a range of platforms in a way which has not been possible before. Furthermore, the changes in the product market are not only increasing the quality standards, but also increasing the demand for VFX production as whole, and new technology is created to increase productivity and efficiency to meet those demands.



Who is Adopting New Technologies?

There are various reasons behind decisions companies make when choosing whether to invest into certain new technology. Some companies choose not to invest in particular technologies because of their high cost; some companies have other priorities before investing into new technology, due to their individual challenges not being able to get fixed by the new technology; some companies decide that although technology such as virtual production brings a lot of new ways of achieving desired VFX shots, it also comes with its own challenges.

However, product innovation, improved quality and flexible production will mainly be only for the large VFX producers. This is because some technologies are very expensive to acquire limiting to larger VFX companies which have the budget and the volume of production to be able to buy them. In contrast to some technologies making VFX more accessible to people, some technology, for example virtual production, remain being only accessible to bigger studios that can afford to invest into the software resource and integrate a virtual production pipeline.

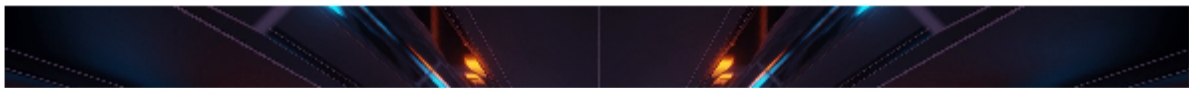
Historically, the structure of VFX industry has been determined by the cost of the technology required to produce the content demanded by the film, TV and games industries. The high cost of some technologies can only be covered if the company has a certain volume or level of production. In this case the cost of technologies can be recouped relatively quickly, over a large number of productions. But this high cost of some technologies makes a "barrier to entry" to smaller operators who cannot either raise the investment fund because they are not sure they will have the number of productions and so receive the money they need to pay it back.

Some VFX artists and houses are not investing into some of the new technologies as they don't tackle the challenges they are facing now. Current challenges include faster turnaround times due to the increase in the demand for content, but also the increase in demand for higher quality product. Some companies have decided that the costs of investment in the technology are too much considering the returns (e.g., of either reduced production costs or improved quality).

Budgets and quality standards of online advertising and simple TV commercials have not changed significantly, and at present there does not seem to be a change in demand that requires more complex VFX elements. For an advertising company, selling low-cost media products, spending a lot on CGI represents a big risk, if clients aren't prepared to pay extra or to commit to a production much further in advance.

For high-cost markets, such as movies and games, the cost of new technology is smaller as a percentage of the cost of each project. Profit margins may be bigger too, so company can pass on this cost to their clients over several projects. If the cost of each project/ product is low (e.g. production of online advertising) then company would need to be sure they could sell a very large number/volume of them to be confident they could cover the cost of investment in new technology.

However, even where changes are happening there is a lot of uncertainty about which changes will become permanent and be established and which are experiments which will not be carried on.



Pressures for Future Adoption of the Technology

While it is not "inevitable" technology will be adopted, the pressure to adopt new technologies exist and will continue over time. Even the artists and VFX houses who have chosen not to invest now, do state it will be only a matter of time before they do start to adopt these technologies. Real-time and virtual production will have a huge impact on the industry, especially once it's been further developed. There is some evidence that new technologies may be applied even by small producers and freelancers. This could be a significant change and increase in flexibility for production in the VFX industry and it may mean "barriers to entry" have been lower and so VFX production is more democratic.

In the last 10 years, the technology in media production has become more democratised. Ten years ago, VFX artists had to build high-end simulation software themselves in the studio from scratch as it wasn't available to purchase. Now any artist can use software, such as Houdini and Maya, that have all the tools they need already. The next 10 years will also see democratisation. All the tools that an artist needs for high-end VFX projects are already available to them, however these tools will get higher quality and start to work faster. These off the shelf tools will *"allow artists to iterate more quickly, see the results instantly"*. Some companies are investing less and less into in-house built technology for this reason.

It may be that if the cost of other technologies limits adoption to larger, well financed companies at the present, the role of technology manufacturers in bringing forward further technological developments will improve the cost-benefit ratios associated with adopting these technologies, making this a realistic investment for smaller producers. IT security is one element in the process of this change as due to strict security regulations many VFX productions are forced to be done in office, however cloud based security will allow for remote workforce and easy access to high-end VFX tools which will make the VFX production process more efficient and also allow companies to outsource production to many countries in the world.

How Are New Technologies Being Used?

Automation and Productivity Improvement & Cost reduction

Today, in VFX, a majorly automated pipeline is required in order to make profit. This has become the "bread and butter" of today's VFX industry. It is clear that meeting demand for an increase in output by increasing productivity and efficiency of existing VFX workflow is a very important priority for companies that introduce these new technologies.

New technology is enabling replacement of some of the manual tasks involved in rotoscoping with automation. Some VFX artists and houses have integrated various technologies that use automated tools such as AI and Machine Learning to help with rotoscoping, making the process quicker and less tedious. This, in practice, can make work more job satisfying. Technology that uses AI and/or ML, such as Runway ML, which is used for rotoscoping, makes tasks easier and less complicated for VFX workers, removing tedious steps from the process and allowing workers to get the task done faster. This opens up the potential for cost-efficiencies and allows more room for creativity as artists spend less time on repetitive tasks.

Improving Productivity and Efficiency - Increasing Creative Freedom

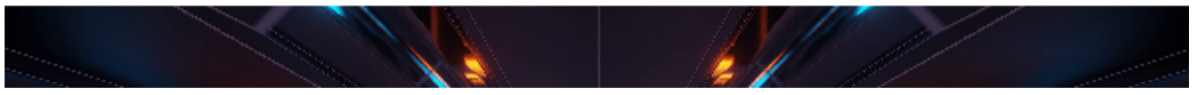
The VFX workflow has not stayed the same. There have been changes over time in the relationships between production and post-production, between routine and creative or editorial tasks and between technical tasks and creative tasks. New technologies are not simply automating the routine tasks in the existing VFX workflow, but enabling further changes in the way the VFX workflow is put together. Automation and productivity are not new things is designing VFX pipeline - they are "cornerstones" of VFX workflow. It is predictable that VFX houses would use new technologies in this way. However, many interviewees argued that companies are also using the automation potential of the technology to try to improve quality of output. The link with automation seems to be that VFX houses are trying to achieve the "cornerstone" objectives of increasing productivity and scaling the output they can get from the workflow and at the same time trying to increase quality of product by liberating creative workers from routine or repetitive tasks. Furthermore, adopting software that uses ML and real-time tools is likely to be a significant factor in the future application of these technologies as it enables VFX production to more closely match the natural ("real time") processes of human creativity.

A shift from control by technical workers to creative workers

VFX workers are increasingly using machine learning to speed up the rotoscoping process due to time limitations on projects where artists are required to work as efficiently as possible. New technology, such as ML, allows artists to focus on capturing the "performance and be creative". Animators now can solely focus on being creative as that very technical process has been improved by enabling riggers to texture artists to build a character that is created in a way that automatically creates realistic physical simulation.

Software that uses ML, such as PDG, are used for automation to effectively reduce manual cycles and work of pipeline management. Due to extremely tight turnaround times today there is an increasing importance of assuring that the VFX pipeline runs as efficiently and smooth as possible, which can be achieved by using innovative technology. PDG allows producers to analyse Film, TV, Games, Advertising and VR content production pipelines and then to distribute tasks and manage dependencies to automate tasks and to increase the scale of production output. When created CGI environments, all steps that are included in this process have a specific order and must be carried out as fast as efficiently as possible. One implication of the technology is in enabling changes to the interdependencies between creative and technical tasks. PDG automates mundane pipeline tasks using a network of nodes that describe each of these steps, which would traditionally be done manually. PDG improves the process of task and project management by distributing tasks and managing dependencies. Implementation of ML technology is likely to continue the trend of shifting the VFX process from very technical to becoming more creative.

In the past, the process involved creatives briefing developers on the changes they wanted. The creatives would not then see the final changes until the work had been completed and they could see whether the brief had been followed and whether the changes made had produced the desired effect. If the changes had only been partially successful, for example, there would be a cost and time pressure to accept the loss in quality, rather than repeat the process. The implementation of ML (either with software that uses ML or adding it to customised pipelines) changes the process from a sequential process, with built in delays, to a "real time" process where creatives can make changes, assess effects, and if necessary, quickly and easily repeat the process with slight modifications until the desired quality is achieved. In this way, the technology appears to support the 'natural' creative process better than the existing workflow. The implementation of this technology is not simply to automate routine tasks. It is also changing the balance between tasks performed by "technical" workers (writing computer code for example) and creative workers. There is a potential for a significant change in the balance between creative/editorial and technical/production control of tasks.



Open Source Technologies and Creative & Editorial as a driving factor

The changes in VFX production are not simply a response by producers to technological potentials and possibilities created by manufacturers. Alongside this process, there appears to be an organic process with producers seeking out potential to improve the quality of the content they produce. VFX houses not only implement technology, but also develop their own solutions to create autonomy driven software. Machine learning seems to be the most useful and widely used tool to increase efficiency and improve job satisfaction by decreasing the amount of tedious repetitive tasks. This suggests that in this case, quality is what is driving the changes. Enabling these changes and adapting autonomy driven software written from scratch or open source have helped improve the creative/editorial process by improving efficiency. This is not the case of responding to manufacturers coming up with pre-designed 'solution', but rather producers themselves identifying ways to find technologies to improve the VFX process. Further development and implementation of open source self-made solutions and implementation of autonomy driven software may lead to further changes in the production processes.

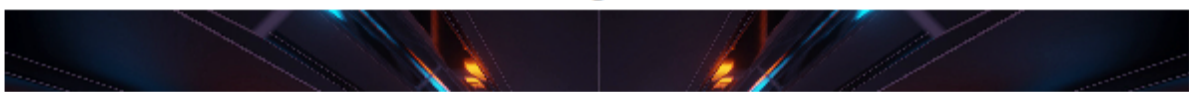
Authenticity of 'real' vs CG generated images

The growing standards of the level of realism expected from visual effects is increasing and new technologies are changing the cost and quality calculations VFX producers make in deciding whether to use 'real' or computer-generated images.

AI and ML has the potential to decrease these costs by feeding the computer with stock footage of real effects that have been filmed in the past. Artificially creating more variants of footage that has already been filmed will increase productivity by generating more outputs and assets from the same inputs. There are a range of impacts on quality, which appear partly to depend on which sector of the industry, and which type of VFX producer is implementing the technology. An example of this would be the use of "synthetic" rather than "real" footage to create scenes. Runway ML provides a synthetic image generator, which uses ML technology to create synthetic scenes based on the dataset given, providing a completely custom image. Virtual production also allows producers to create environments from the office rather than traveling to a film set. Clearly, the cost and time spent on this form of VFX production, in contrast to the cost of filming a real scene, is minimal.

This substitution of real images with and virtual raises questions in regard to quality of the finished product in both cases. The potential use real footage rather than CG created elements will generally increase the quality of VFX. But the quality considerations of real vs synthetic elements were also related to the overall costs of production. The decision would relate to the level of quality required.

There is a process of experimentation and innovation where companies work out the perfect amount of real and artificially created elements to achieve the best outcome. However, overall, the biggest deciding factor remains the quality when it comes to deciding how to create challenging scenes. In this case, producers describe quality as "the authenticity" of the images –how realistic the images look. In almost any production process, cost reduction is likely to have an impact on quality and therefore, the more important product quality is, in deciding sales/profits, the less likely producers are to compromise quality to reduce costs.



Balance between Pre-production, Production and Post-production

Several changes may be occurring in the balance between these inter-dependent production processes. Virtual production may be one of the new technological developments that may drive the shift in balance of the production process as it allows to create environments from office rather than traveling. This substitution of real images with virtual raises questions in regards to quality of the finished product in both cases.

It is important to remember that not all technology impacts VFX workers the same way. For example, different choices have been made between big studios and small commercial VFX houses. VFX workers may increasingly be empowered to take on or contribute to tasks which were previously the specialist responsibility of pre-production or production workers.

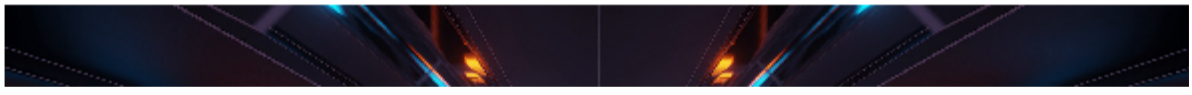
Software such as the CamTrack AR app have the potential to be used as a tool during pre-production for more precise and easier planning of VFX. However, there are many limitations and uncertainties about how the 'new' VFX workflow will relate to production and pre-production. This is a period of experimentation and change where companies and their partners in production are exploring a range of new ways of combining and changing tasks to meet changing and growing demand in the various media markets.

Democratisation and Job Satisfaction

There is an obvious relationship between automation and the number of jobs available. Democratisation as allowing new companies and freelancers to enter VFX production. New technologies will allow companies to hire staff on a freelance or temporary basis and then let them go when they do not have a production in progress. This clearly may impact the employment position and job satisfaction of in-house production workers who may in the future lose their security of employment.

At least for creative VFX workers, there are four ways that the new technologies appears to have increased job satisfaction: automation of routine and repetitive tasks has given some creative workers extra time to work on creative tasks; the technology is enabling VFX producers to have more broad skills and not be so specialised in one task; the technology has also enabled creative workers to do completely new creative tasks which were not possible before.

One final way using new technology may have improved job satisfaction of creative workers is in use of software like PDG to enable creatives take over control of some tasks which were done by technical workers (such as developers) previously. This shows that the impacts on producers depends on what their role or tasks are in the workflow. This software takes control over this production task out of the hands of developers and puts it more in the hands of creatives. Because this is at the experimental stage, it is not yet possible to determine whether the impact of this is change will be to deskill the work of and maybe also make redundant, some of the developers. By contrast it adds technical skills to work of the creatives. This may change the level of job satisfaction of these two roles with creatives feeling more empowered and developers limited to control of other elements of production.



Similarly to experimental filmmaking having an impact on film production by shifting the technological and conceptual expectation as well as creating a new workforce (Turnock, 2014), these new technological developments are likely to drive changes in the VFX workforce today as new developments in the workflow continue.

The overall trend would seem to be that the VFX production workers who continue to get work in the industry will be those who become more multi-skilled, 'generalists' rather than focused specialists. New technology and shifts in the VFX workflow show how VFX production as a whole can change, as tasks change, the traditional division of labour between job roles can change. An example of this trend towards developing multi-tasking, generalist VFX production workers is the pattern of VFX houses starting to hire more tool builders who can create custom solutions. The advice to become a generalist rather than a specialist suggests that some roles may be, perhaps temporarily or perhaps permanently, deskilled. Recent graduates for example, might see the potential for freelance work as a way to gain experience and develop their professional profile.

VFX producers are finding opportunities to increase efficiency, effectiveness, and quality by making changes to the production workflow. One aspect of this is that some tasks are becoming, at least initially, less specialised. It is not clear if these changes will be permanent or are a temporary reaction as new technologies cause disruption in the industry and different types of producers change specific elements of production. It could be that in ten year's time these changes become established and production roles become more specialised although in a different workflow from the one in existence before the changes.

Future of VFX

Conventional media production – what will change

Continued democratisation of technology

In the future, there will be a continued process of democratisation. One of the drivers identified for this change was in terms of addressing the challenges presented in delivering high-end projects. As the production of these projects involves increasing scale and specialisation, there is a problem of coordinating this work – literally, in coming up with a system to get thousands people to work effectively together. Allowing VFX workers to collaborate and work together remotely by providing a remote system that work efficiently will continue to be an important way to meet this challenge. This will also raise changes in security. At the moment, many VFX workers are forced to work in the confined environments in the office due to strict security restrictions. The evidence of this research is that further implementation of cloud based security and a distributed remote workforce will allow for much wider ecosystem in the VFX industry. Democratisation, where there is easy access to high-end tools also allows for much more effective distributed workforce, since VFX workers can come into the workplace already skilled and having had access to the tools that are required for production.

Continued changes in balance of the production process

The pattern of changes in the product market seem to suggest a continued direction in VFX production. Major producers, like Marvel Studios, are setting standards which competitors have to try to match. Filmmaking is becoming increasing more complex as the stories people are telling are becoming more abstract. Basing their stories in abstract worlds such as Dr Strange is going to further drive the convergence of real time VFX and traditional offline VFX in order to achieve these desired visuals.

For example, when using virtual production or LED walls, more and more of the media creation process will be applied before starting filming, as producers have to make all of the effects and assets work in advance. Furthermore, producers have to build something that allows visual effects, assets and technology to work both in real-time, but also allows them to produce offline high quality images at the end. In the near future, we can expect all film (not just conventional VFX genres) will have an element of real-time, whether it's cameras scouting, pre or post vis, or even using LED volumes, which provide the perfect image in camera.

Currently a lot of this technology is in its infancy, which means many processes have to be done twice at the moment. For example when shooting LED volume shots and then anything that needs to be rendered, artists have to rebuild some elements and then do it again. To bridge this gap between real time and VFX would eliminate the need to do things multiple times. Rather than a transformation overnight, this research suggests that there will be a combination of new and old approaches. The ability to go between the two worlds of a real-time and traditional offline VFX is likely to be a feature of VFX production in the next 5-10 years.

Machine learning driving the shift from technical to creative

Although some literature (like Staiger, 1979) sees automation and creativity as opposites, some industry professionals seemed to think automation is supporting creativity. For example, application of machine learning can be used as a tool to speed manual cycles up and so allow more time in worker's day for creativity and originality. Machine learning will continue to drive the change of the VFX artists process from being very technical to becoming more creative and artistic. Many VFX artists today, if they want to make changes artistically, they have to wait a couple of hours to see the results, as they have to simulate and calculate before any changes can be made. However, as machine learning and real time are used to make those processes quicker and even immediate, that significantly changes the whole process and make it much more efficient and therefore driving that shift into creativity. For example, a layout artist could use machine learning to make layouts of a scene, which will allow them to assemble the scene by focusing of the creative rather than spending a lot of timing moving 3D objects around, which would make the iteration speed of this much more rapid.

Cloud-based technology potential

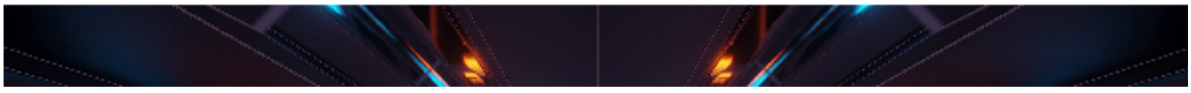
Being able to harness the cloud while on set can significantly increase flexibility in VFX artists work. Cloud-based technology allows easier access to high quality VFX at minimal costs and combining cloud-powered VFX production along with machine learning and AI could have some potential. Cloud-based technology, such as MetaHuman Creator by Unreal Engine, allow easier access to high quality VFX at minimal costs. Runway ML is a perfect example of the potential improvements in VFX production which possible when cloud-powered VFX production is combined along with machine learning and AI.

Influences from outside the industry

Besides the innovations that are happening in the media industry that are driving all these changes, there are factors outside of the industry that are increasing the value and volume of VFX content required and produced. The VFX industry is not only impacted by the film, tv and other video content industries, it is also heavily involved in the gaming industry and other immersive industries that use technology such as AR (for example in art exhibitions) or 3D holograms (for example in live music concerts). As VFX is used in very innovative and experimental industries and projects, it is likely to have impacts from many different industries that have different demands from various markets.

Furthermore, with the increasing use and importance of social media platforms, the way people portray themselves online, their digital version, is becoming increasingly more important. A digital version of yourself is becoming increasingly as important as the physical version. In the next 10 years we will see an emerging marketplace where people are going to start buying and selling in this digital world. The transactional economies in certain online game environments are becoming bigger in economic value than the output of many countries. NFTs allow people to create something digital that is unique and even big fashion companies are starting to invest in these start ups, because they see an opportunity to create a new market. As in the metaverse you don't produce anything physical, every single thing you produce can be unique. Many predict there will be a 3D version of the internet, similarly to what is already happening in the gaming industry. For example, Epic Games are doing online concerts where sometimes 10 million people show up to watch a virtual concert with famous musicians, all in a 3D world.

The metaverse will affect VFX production in different ways from the media economics. Unlike filmmaking, metaverse isn't about storytelling, but about having a space for a digital version of yourself. Software that use ML technology have an opportunity to transform the process of 3D modelling by applying the same principles of creating synthetic images into creating custom 3D models. Further developing this idea is likely to bring more opportunities for new businesses and products to enter this market.



References

Chung, H. J. (2011). Global Visual Effects Pipelines: An Interview with Hannes Ricklefs. Media Fields Journal, 2.

Failes, I. (2020g). New Tech in VFX: Fall Edition. VFX Voice.

Giralt, G. F. (2017). The Interchangeability of VFX and Live Action and Its Implications for Realism. Journal of film and video. 69 (1), 3–17.

Heusser, J. (2013). VFX in Los Angeles – 100 hour weeks & homeless. fxguide, 10 June.

Kaufman, D. (2019). Global VFX: State of the Industry 2019. VFX Voice, Spring 2019.

Kaufman, D. (2020). New Virtual Technologies Remake VFX's Future Pipeline. VFX Voice, Winter 2020, 18-28.

MovieLabs (2019). The Evolution of Media Creation: A 10-Year Vision for the Future of Media Production, Post and Creative Technologies. MovieLabs.

Samaras, E. and Johnston, A. (2018). Fleeting Film: Using Story to Seek Archival Permanence in the Transitory and Globalized Digital Visual Effects Industry. Preservation, digital technology & culture, 47 (1), 12–22.

Sanson, K. and Curtin, M. (2017). Voices of Labor Creativity, Craft, and Conflict in Global Hollywood. Berkeley, CA: University of California Press.

Staiger, J. (1979). Dividing Labour for Production Control. Cinema Journal, 18 (2), 16-25.

Turnock, J. (2014). The True Stars of Star Wars? Experimental Filmmakers in the 1970s and 1980s Special Effects Industry. Film history. 26 (4), 120–145. Sydney: Indiana University Press.

Venkatasawmy, R. (2016). Crisis in the Digital Visual Effects Industry and Hollywood Cinema. Film international (Göteborg, Sweden), 14 (1), 6–23

Visual Effects Society (2020). VFX in 2021: What Works, Who Works and What's Changing Forever. Vimeo.

Glossary

NUMERICAL

2D refers to a two-dimensional digital image, which is used in image creation and manipulation (e.g., 2D animation), and image output (e.g., compositing).

3D is often used as another term for CGI and refers to a three-dimensional digital image, which is used in image creation and manipulation (e.g., 3D animation), and image output (e.g., 3D compositing).

A

Artificial Intelligence (AI) refers to computer systems that perform tasks, which usually require human intelligence (e.g., visual perception, speech recognition, decision-making).

Animatics refers to animated storyboards or static storyboards with some animation.

Animation is a moving image that is created frame by frame.

Animator is an individual person responsible for producing animations.

Algorithm is a set of instructions, which is used to solve or accomplishing a particular task.

Augmented Reality (AR) is an interactive technology that combines real and virtual worlds enabling real-time interaction.

Asset refers to (1) created digital imagery, such as a character, an environment, or an object. (2) elements of the created imagery, such as models, animations, textures.

B

Blue screen is a material that is suspended behind an object, which can then be extracted.

C

Cinematographer is an individual who has a skill in capturing moving images on camera. **DoP**s are sometimes referred to as Cinematographers (see p230).

Cloud refers to internet accessible on-demand computer system resources (e.g., data storage platforms).

Compositing refers to combining all rendered VFX elements into the final image.

Computer Generated Imagery (CGI or CG) is imagery created or manipulated by a computer.

Computer Graphics (CG) is imagery created or manipulated by a computer.

Computer Graphics Supervisor (CG Supervisor) is an individual responsible for technical solutions and software selections on a project.

Concept Artist is an individual responsible for creating the intended look and feel of the characters and environments in a 2D form.

Continuity is the flow of action from one shot or scene to the next.

D

Depth of field is the range of foreground and background focus/distance.

Digital double is a digital representation of a character (actor).

Digitisation refers to digital representation.

Director is an individual responsible for overseeing the creative aspects of a project or production.

Director of Photography (DoP) or sometimes referred to as Cinematographer is responsible for visual interpretation of the script and manages the camera and lighting departments.

E

Editorial refers to the process of integrating and editing VFX shots into the project (e.g., a film).

Editing is a process of assembling shots and scenes.

Extraction refers to removal of elements.

F

Frame is a single image of a moving sequence.

G

Green screen is identical to use and concept to a **blue screen** (see p229).

K

Keying is a process of removing the blue/green screen from the shot.

L

LiDAR scanning (or 3D scanning) is a process of analysing and collecting data of the physical appearance (e.g., shape, measurements, colour) of real-world object and creating a digital 3D model replica.

Light field camera captures the angle of light (unlike traditional camera that only capture the intensity of light) and this data can be used for multiple purposes such as manipulating the depth of field.

Live action refers to capturing footage on set (usually with a traditional film or video camera).

M

Matchmoving is a process of duplicating live action camera movement in a CG environment.

Matte is an image used to control the transparency of another image.

Matte painting is a manually painted image, which is combined with live-action footage (used in earlier cinema to create elements of s scene such as mountains or buildings).

Metaverse refers to a virtual environment space where individuals can interact with one another in digital environments and represent themselves with digital avatars.

Machine Learning (ML) is a subset of AI, which uses algorithms to analyse and draw inferences from patterns in data.

Mixed Reality (MR) merges real and virtual worlds by combining elements of physical and virtual environments.

Motion capture is a technique of capturing live action performance for CG environment performance.

P

Pipeline refers to the process of managing and organising a workflow.

Pipeline TD (Technical Director) is an individual responsible for designing and developing custom tools for the pipeline.

Pre-production is the first stage of video (includes e.g., script development, casting, budgeting, previs) or VFX (includes e.g., previs, concept art) production.

Previsualisation (Pre-vis or Previs) is a process of visualising desired shots, sequences or entire scripts. Previs for VFX includes using 3D animation tools and a virtual environment. One use is to supplement or replace the traditional practice of setting out desired shots with a manually drawn storyboard.

Pre-vis Artist is an individual responsible for creating rough, greyscale 3D models and environments, to place in a scene in order to map out the general camera angles, layout and animation for a scene.

Production is a process of capturing or creating content.

Post-production is the last stage of video (includes e.g., editing, VFX, colour grading, audio mixing) or VFX (includes e.g., compositing, mastering) production.

Postvisualisation is a process of combining and assembling digital elements over edited footage to visualise and refine the desired VFX.

Producer is the administrative head of a project, who is responsible for budget, schedule, etc.

R

Rig is a virtual skeleton with animation controls.

Rigging is a process of creating a rig.

Rigging TD is an individual responsible for creating rigs for characters.

Real Time Engine (RTE) is a tool that's used to composite and render media elements (e.g., CG elements, audio, video) in real time.

Rendering is a process of creating a 2D image from a 3D data set.

Rotoscoping is a process of extracting elements from a moving image by tracing an element frame by frame and creating a matte or mask for extraction.

Rotoscoping Artist (Roto Artist) is an individual responsible for the process of rotoscoping.

S

Set refers to an environment where filmmaking takes place with artificially constructed scenery.

Shot is a continuous moving image sequence.

Spill refers to any contamination of an element by light reflected from the green (or blue) screen.

Special Effects (SFX) refers to effects that are created physically on set in front of the camera (sometimes referred to as "practical" effects).

Storyboard is a sequence of drawings that visualises the intended action of a scene or entire project.

T

Take refers to the process of capturing a shot.

Technical Director (TD) is an individual responsible for ensuring that the technical aspects are addressed.

Texture refers to creating flat colour and texture of assets.

Texture Artist is an individual responsible for creating textures for assets.

Tracking is a process of determining the movement of objects in a scene relative to the camera by analysing the captured footage of that scene.

Turnaround time refers to the amount of time scheduled to complete a process (arranged deadlines).

V

Virtual Production is a process of combining VFX elements with live action in real time.

Virtual Reality (VR) refers to simulated experience that allows users to experience and interact with a virtual environment.

Visual Effects (VFX) refers to assets generated by computer.

Visual Effects Supervisor (VFX Supervisor) is an individual responsible for technical requirements of VFX production on set.

W

Workflow refers to every stage of a production process.

List of References

Abbott, S. (2006). Final Frontiers: Computer-Generated Imagery and the Science Fiction Film. Science-fiction studies. 33 (1), 89–108. Available from https://www.jstor.org/stable/4241410 [Accessed 7 Jan 2020].

Abernathy, W. J. and Utterback, J. M. (1978). Patterns of Industrial Innovation. Technology review, 80 (7), 228-252. Available from https://www.academia.edu/23341473/Patterns_of_Industrial_Innovation [Accessed 7 December 2019].

Albert, T., Moehrle, M. G. and Meyer, S. (2015). Technology maturity assessment based on blog analysis. Technological Forecasting & Social Change, 92, 196–209. Available from https://doi.org/10.1016/j.techfore.2014.08.011 [Accessed 7 December 2019].

Alemi, O. and Pasquier, P. (2019). Machine Learning for Data-Driven Movement Generation: a Review of the State of the Art. ResearchGate, 20 March. Available from https://arxiv.org/pdf/1903.08356.pdf [Accessed 7 December 2019].

Alexander, B. (2017). The new digital storytelling: creating narratives with new media, 2nd ed. Santa Barbara: Praeger.

Allison, T., Dhir, M., Higgins, S., Keil, C., Keil, C., Monticone, P., North, D., Overpeck, D., Polan, D., Purse, L., Rogers, A., Turnock, J., Whissel, K., Whissel, K. and Wright, B. (2016). Editing and Special/Visual Effects. New Brunswick, NJ: Rutgers University Press. Available from https://doi.org/10.36019/9780813570839 [Accessed 7 December 2019].

Anderson, M. (no date). A comprehensive guide to the state-of-art in how AI is transforming the visual effects (VFX) industry. Ross Dawson. Available from https://rossdawson.com/futurist/implications-of-ai/comprehensive-guide-ai-artificial-intelligence-visual-effects-vfx/ [Accessed 6 March 2020].

Anderson, P. and Tushman, M. L. (1990). Technological Discontinuities and Dominant Designs: A Cyclical Model of Technological Change. Administrative Science Quarterly, 35(4), 604–633. Available from https://doi.org/10.2307/2393511 [Accessed 6 March 2020].

Antin, D. (2020). Why Online Gaming Matters to the Digital Economy: Economists study virtual game economies to learn about digital assets, the future of economic growth in the virtual world. Medium, 14 May. Available from https://medium.com/super-jump/why-online-gaming-matters-to-the-digital-economy-1e253c5de3b2 [Accessed 10 October 2020].

Arnold, D. and Bongiovi, J. R. (2013). Precarious, Informalizing, and Flexible Work. American Behavioural Scientist, 57 (3), 289-308. Available from https://pure.uva.nl/ws/files/2090049/136675_Arnold_and_Bongiovi_2013_Precarious_Informalizing_and_Flexible_Work.pdf [Accessed 12 May 2020].

Arundale, S. and Trieu, T. (2015) Modern Post: Workflows and Techniques for Digital Filmmakers. Oxford: Routledge. Available from https://ebookcentral.proquest.com/lib/westminster/detail.action?docID=1757878 [Accessed 5 Sep 2020].

Ayres, L. (2008). Semi-structured interview. Qualitative Research Methods, 811-812. Thousand Oaks: Sage Publications

Azad, S., Xu, J., Yu, H. and Li, B. (2017). AAAI Conference on Artificial Intelligence and Interactive Digital Entertainment. Available from https://aaai.org/ocs/index.php/AIIDE/AIIDE17/paper/view/15873/15158 [Accessed 5 October 2018].

Abouaf, J. (2000). Creating illusory realism through VFX. IEEE computer graphics and applications. 20 (4), 4–5. Available from https://doi.org/10.1109/MCG.2000.851741 [Accessed 5 October 2018].

Bailey, K. D. (1994). Methods of Social Research. New York: The Free Press.

Baillieu, B. and Goodchild, J. (2002). The British film business. Chichester: John Wiley & Sons Ltd.

Balla, G. (2016). The Director's Method in Contemporary Visual Effects Film : the Influence of Digital Effects on Film Directing. Available from https://etheses.whiterose.ac.uk/19071/ [Accessed 10 September 2019]

Bazalgette, P. (2017). Independent Review of the Creative Industries. London: Department for Digital, Culture, Media & Sport. Available from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/649980/Independent_Review_of_the_Creative_Industries.pdf [Accessed 10 September 2019]

Banks, M. (2007). The Politics of Cultural Work. Basingstoke: Palgrave Macmillan.

Banks, M. (2014). 'Being in the Zone' of Cultural Work. Journal of Current Cultural Research, 6 (1), 241-262. Available from http://www.cultureunbound.ep.liu.se/v6/a14/cu14v6a14.pdf [Accessed 5 October 2018].

Baumgartner, R. (2003). Beyond Words: Previs as a Design and Approval Tool for Directors. Animation World Network, 12 September. Available from https://www.awn.com/vfxworld/beyond-words-previs-design-and-approval-tool-directors [Accessed 5 October 2018].

Bellour, R. and Penley, C. (2000). The analysis of film. Bloomington: Indiana University Press.

Bellour, R. (2012). Between-the-images. Zurich: JRP/Ringier.

Bennett, B., Furstenau, M. and Mackenzie, A. (2008). Cinema and technology: cultures, theories, practices. Basingstoke: Palgrave Macmillan.

Bennett, J. (2008). Television Studies Goes Digital. *Cinema Journal*, *47*(3), 158–166. Available from https://doi.org/10.1353/cj.0.0019 [Accessed 10 October 2018].

Bennett, J. and Strange, N. (2011). *Television as digital media*. Durham, NC: Duke University Press.

Bennett, J. and Strange, N. (2015). Media Independence: Working with Freedom or Working for Free? New York: Routledge.

BFI (2018). Screen Business: How screen sector tax reliefs power economic growth across the UK. BFI, October 2018. Available from https://www.bfi.org.uk/sites/bfi.org.uk/files/downloads/screen-business-summary-report-2018-10-08.pdf pdf [Accessed 10 October 2018].

Bickerton, J. (2018) Tech experts predict rise of algorithms in production. Broadcast, 14 March. Available from https://search.proquest.com/docview/2014023543?accountid=14987 [Accessed 10 October 2018].

Bickerton, J. (2019). Challenges of the post boom. Broadcast, 2 September. Available from https://search.proquest.com/docview/2283332172/fulltext/3A69C16F6D544454PQ/1?accountid=14987 [Accessed October 10, 2019].

Bilton, C. (2007). Management and Creativity: From Creative Industries to Creative Management. Oxford: Blackwell Publishing.

Bilton, C. and Leary, R. (2002). What Can Managers Do for Creativity? Brokering Creativity in the Creative Industries. International Journal of Cultural Policy, 8 (1), 49–64. Available from https://doi.org/10.1080/10286630290032431 [Accessed October 10, 2019].

Blair, H. (2001) Work, Employment & Society, SAGE Publications, London, Vol.15, No. 1, pp. 149-169

Blair, H. (2003) Sociology, SAGE Publications, London, Volume 37(4), pp. 677–694

Bolderston, A. (2012). Conducting a Research Interview. Journal of Medical Imaging and Radiation Sciences, 43 (1), 66-76. Available from https://www.jmirs.org/article/S1939-8654(11)00132-9/pdf [Accessed October 22, 2018].

Bordwell, D. (2006). The Way Hollywood Tells It: Story and Style in Modern Movies. Berkeley, CA: University of California Press.

Bordwell, D. (2019). Reinventing Hollywood: how 1940s filmmakers changed movie storytelling. Chicago: The University of Chicago Press.

Bordwell, D., Staiger, J. and Thompson, K. (1988). The classical Hollywood cinema: film style and mode of production to 1960. London: Routledge.

Bordwell, D., Staiger, J. and Thompson, K. (2019). Classical Hollywood Cinema: Film Style and Mode of Production to 1960. London: Routledge.

Bowman, D. and Mcmahan, R. (2007). Virtual reality: How much immersion is enough? Computer, 40 (7), 36-43. Available from. https://ieeexplore-ieee-org.ezproxy.westminster.ac.uk/document/4287241 [Accessed 4 November 2018].

Bratt, B. (2011) Rotoscoping: Techniques and Tools for the Aspiring Artist. Saint Louis: Taylor & Francis Group. Available from https://ebookcentral.proquest.com/lib/westminster/detail.action?pq-origsite=primo&docID=645032 [Accessed 10 October 2019].

Briand, G., Badoglian, F., Szlapka, J. F., Lavalou, J. M., Nanofiller, M., Christie, M., Lvoff, J., Bertolino, P. and Guillou, E. (2014). On-set Previsualization for VFX Film Production. IBC2014 Conference. The Institution of Engineering and Technology. Available from https://digital-library.theiet.org/content/conferences/10.1049/ib.2014.0037 [Accessed 10 October 2019].

Brown, A. (2019). The Robots Are Coming. Animation World Network, 8 August. Available from https://www.awn.com/vfxworld/robots-are-coming [Accessed 5 October 2019].

Bruun, H. (2016). The qualitative interview in media production studies. In: *Advancing media production research*. London: Palgrave Macmillan, 131-146. Available from https://ebookcentral.proquest.com/lib/westminster/detail.action?docID=4096854 [Accessed 10 October 2019].

Bryman, A. (2004). Social research methods, 2nd ed. Oxford: Oxford University Press.

Bryman, A. (2004). Social research methods, 5th ed. Oxford: Oxford University Press.

Burrell, G. and Morgan, G. (1979). Social Paradigms and Organisational Analysis, 1st ed. London: Routledge.

Burrows, J. (2018). 'Certificated operators' versus 'handle-turners': the British film industry's first trade union. Journal of British Cinema and Television, 15 (1), 73-93. Availble from https://www.euppublishing.com/doi/abs/10.3366/jbctv.2018.0403 [Accessed 4 February2018].

Caldwell, J.T. (1995). Televisuality: Style, Crisis, and Authority in American Television.

Caldwell, J. (2000). Electronic Media and Technoculture. New Brunswick, NJ: Rutgers University Press. Available from https://www.fulcrum.org/concern/monographs/jw827c173 [Accessed 4 November 2018].

CAMEo (2018). Workforce Diversity in the UK Screen Sector: Evidence Review, CAMEo Research Institute: Leicester. Available from https://www2.bfi.org.uk/sites/bfi.org.uk/files/downloads/bfi-workforce-diversity-in-uk-screen-sector-evidence-review-2018-03.pdf [Accessed 10 October 2019].

Campagnolo, G.M., Giannatou, E., Franklin, M., Stewart, J., Williams, R. (2018). Revolution remixed? The emergence of Open Content Film-making as a viable component within the mainstream film industry. Information, Communication & Society. 1-18.

Cater, J. K. (2011). Skype a cost-effective method for qualitative research. Rehabilitation Counselors & Educators Journal, 4 (2) 10–17. Availble from https://www.academia.edu/540705/Skype_A_cost_effective_method_for_qualitative_research [Accessed October 22, 2018].

Caves, R. (2006). Organization of Arts and Entertainment Industries in Ginsberg, V. and Throsby, V. (Eds.). Handbook of the Economics of Art and Culture, 1, 533-566. Amsterdam: Elsevier. Available from https://www.sciencedirect.com/science/article/abs/pii/S1574067606010179?via%3Dihub [Accessed May 9, 2020].

Ceccarelli, N. (2017). Animation and informative films: Two early 'digital' films. Animation practice, process & production. 6 (1), 137–148. Available from https://doi.org/10.1386/ap3.6.1.137_1 [Accessed May 9, 2020].

Chapain, C. and Stachowiak, K. (2017). Innovation Dynamic in the Film Industry: The Case of the Soho Cluster in London. Creative Industries in Europe: Drivers of New Sectoral and Spatial Dynamics. 65-94.

Child, J. and Mansfield, R. (1972). TECHNOLOGY, SIZE, AND ORGANIZATION STRUCTURE. Sociology, 6(3), 369–393. Oxford: Sage Publications. Available from https://www.jstor.org/stable/42851250.

Christensen, M. C. (2013), The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail, Harvard Business Review Press, Boston. Available from https://ebookcentral.proquest.com/lib/westminster/reader.action?docID=5181800 [Accessed on 1 December 2018].

Christensen, M. C. and Rosenbloom, R. S. (1995). Explaining the attacker's advantage: Technological paradigms, organizational dynamics, and the value network. Research Policy, 24(2), 233–257. Available from https://doi.org/10.1016/0048-7333(93)00764-K [Accessed on 1 December 2018].

Christie, I., Chateau, D. and Oever, A.v.d. (2014). Technē /Technology: researching cinema and media technologies: their development, use, and impact Amsterdam: Amsterdam University Press. Available from http://www.oapen.org/search?identifier=607770 [Accessed on 1 December 2018].

Chung, L. (2020). The effects of COVID-19 on the VFX industry. Post Magazine. Available from http://www.postmagazine.com/Publications/Post-Magazine/2020/July-August-2020/The-effects-of-COVID-19-on-the-VFX-industry.aspx [Accessed 5 September 2020]

Chung, H. J. (2011). Global Visual Effects Pipelines: An Interview with Hannes Ricklefs. Media Fields Journal, 2. Available from https://www.academia.edu/2057617/Global_Visual_Effects_Pipelines_An_Interview_with_Hannes_Ricklefs [Accessed 5 September 2020]

Cimino, A. and Leijenhorst, C. (2018). Phenomenology and Experience: New Perspectives. Boston: Brill. Available from https://ebookcentral.proquest.com/lib/westminster/detail.action?pq-origsite=primo&docID=5760789# [Accessed 5 September 2020]

Cleve, B. (2012). Film Production Management, 3rd ed. New York: Focal Press

Cocorocchia, C. et al. (2018). How do emerging technologies affect the creative economy? | McKinsey & Company. How do emerging technologies affect the creative economy? | McKinsey & Company. Available from: https://www.mckinsey.com/industries/media-and-entertainment/our-insights/how-do-emerging-technol ogies-affect-the-creative-economy [Accessed Oct 22, 2018].

Coleman, L.J. and Friedberg, D. (2016). JUMP•CUT: How to Jump•Start Your Career as a Film Editor, 1st ed. New York: Routledge. Available from https://doi.org/10.4324/9781315535418 [Accessed March 5, 2020].
Collins, H. (2018). Creative Research: The Theory and Practice of Research for the Creative Industries, 2nd ed. London: Bloomsbury Visual Arts. Available from http://dx.doi.org/10.5040/9781474247115 [Accessed March 5, 2020].

Conor, B. (2014). Screenwriting: Creative labor and professional practice. New York: Routledge. Available from https://doi.org/10.4324/9780203080771-9 [Accessed March 5, 2020].

Creswell, J. W. (1998). Qualitative inquiry and research design: Choosing among five traditions. Thousand Oaks, CA: Sage Publications.

Curtis, C., 2017. Baz: UK creative industries can be worth £130bn. Broadcast.

Dams, T. (2018). The shape of post-production in 2019. Broadcast, 28th November. Available from https://www.broadcastnow.co.uk/tech/the-shape-of-post-production-in-2019/5134861.article [Accessed December 4, 2018].

Dancyger, K. (2011). The technique of film and video editing: history, theory, and practice, 5th ed. Oxford: Focal Press.

Davis, H. and Scase, R. (2000) Managing Creativity: The Dynamics of Work and Organization. Open University Press, Buckingham.

Deakin, H. and Wakefield, K. (2013). Skype interviewing: Reflections of two PhD researchers. Qualitative Research, 14 (5), 603–616. Available from http://qrj.sagepub.com/content/early/2013/05/24/1468794113488126 [Accessed 15 September 2019].

Deetz, S. (1996). Describing Differences in Approaches to Organization Science: Rethinking Burrell and Morgan and Their Legacy. Organization Science, 7 (2), 191-207. Available from https://www.jstor.org/stable/2634981?sid=primo&seq=1#metadata_info_tab_contents [Accessed 18 December 2018]

de Bruyn, D. (2019). Paul Winkler: Migrating from analogue to digital practice. Animation practice, process & production. 8 (1), 107–122. Available from https://doi.org/10.1386/ap3_00007_1 [Accessed 10 Oct 2020]

DeFillippi, R.J. and Arthur, M.B. (1998) Paradox in Project-Based Enterprise: The Case of Film Making. California Management Review, 40, 125–38.

Desowitz, B. (2003). The Previs Gospel… According to McDowell and Frankel. Animation World Network, 26 September. Available from https://www.awn.com/vfxworld/previs-gospel-according-mcdowell-and-frankel [Accessed 5 October 2019].

Dex, S., Willis, J., Paterson, R., Sheppard, E. (2000). Freelance Workers and Contract Uncertainty: The Effects of Contractual Changes in the Television Industry. Work, Employment & Society. 14 (2), 283-305. Available from https://journals-sagepub-com.ezproxy.westminster.ac.uk/doi/abs/10.1177/09500170022118419 [Accessed 18 December 2018]

Di Sciascio, E., Donini, F.M., Mongiello, M. (2011). Structured Knowledge Representation for Image Retrieval. 16 Available from https://arxiv.org/abs/1109.1498 [Accessed 18 December 2018]

Digital Storytellers (2019). Top 5 Ways Storytelling Has Changed This Decade. Digital Storytellers. Available from https://www.digitalstorytellers.com.au/top-5-ways-storytelling-has-changed-this-decade/ [Accessed 19 December 2019]

Dinur, E. (2017). The Filmmaker's Guide to Visual Effects: The Art and Technique of VFX for Directors, Producers, Editors and Cinematographers. London: Routledge

Dobbert, T. (2006). Matchmoving: The Invisible Art of Camera Tracking. 1. Aufl. Alameda: Sybex. Available from: https://ebookcentral.proquest.com/lib/westminster/detail.action?docID=267271 [Accessed on Sep 5, 2020].

Dobbert, T. (2012) Matchmoving: The Invisible Art of Camera Tracking. 2. Aufl. Somerset: Sybex. Available from: https://ebookcentral.proquest.com/lib/westminster/detail.action?docID=1120249 [Accessed on Sep 5, 2020].

Dodgson, N., Patterson, J. and Willis, P. (2010). What's up Prof? Current Issues in the Visual Effects & Post-Production Industry. Leonardo (Oxford), 43(1), 92–93. Available from: https://doi.org/10.1162/leon.2010.43.1.92 [Accessed on Sep 5, 2020].

Doyle, G. (2002). Understanding Media Economics. London: SAGE Publications

Drury, R., Homewood, K. and Randall, S. (2011). Less is more: The potential of qualitative approaches in conservation research. Animal Conservation, 14, 18–24. Available from https://zslpublications.onlinelibrary.wiley.com/doi/full/10.1111/j.1469-1795.2010.00375.x Accessed October 22, 2018].

Dunlop, R. (2014). Production Pipeline Fundamentals for Film and Games. New York: Routledge.

Dunn, K. (2005). Qualitative Research Methods in Human Geography, 2nd ed. Oxford: Oxford University Press.

Dwyer, P. (2019). Understanding Media Production. London: Routledge.

Efremov, V. and Lazar, A. (2019). Real-time procedural VFX characters in unity's real-time short film "The Heretic." ACM SIGGRAPH 2019 Real-Time Live. ACM. pp. 1–1. Available from https://doi.org/10.1145/3306305.3332363x [Accessed 5 Sep, 2020].

Einhorn, H. (1972). Expert measurement and mechanical combination. Organization Behavior and Human Performance, 7(1), 86-106. Available from https://www.sciencedirect.com/science/article/abs/pii/0030507372900098 [Accessed 20 April 2020].

Escape Technology (2020). Going Remote: Covid-19 and the Impact of Remote Working in the VFX Industry. London: Escape Technology. Available from https://www.escape-technology.com/images/documents/Going-Remote_Remote-Working-Research-Report.pdf [Accessed 20 April 2020].

Essletzbichler, J. (2003) From mass production to flexible specialization: The sectoral and geographical work of contract work in US manufacturing, 1963-1997. *Regional Studies*, 37 (8), 753-771. Available from doi:10.1080/0034340032000128695 [Accessed October 22, 2018].

Eysenbach, G. and Till, J.E. (2001). Ethical issues in qualitative research on internet communities. BMJ, 323 (1103). Available from https://www.bmj.com/content/323/7321/1103 [Accessed October 22, 2018].

Failes, I. (2017). How Real-time Rendering Is Changing VFX And Animation Production. Cartoon Brew, 29 August. Available from https://www.cartoonbrew.com/tools/real-time-rendering-changing-vfx-animation-production-153091.html [Accessed 5 January 2020].

Failes, I. (2019a). The New Artificial Intelligence Frontier of VFX. VFX Voice, Spring 2019, 22-27. Available from https://www.vfxvoice.com/the-new-artificial-intelligence-frontier-of-vfx/ [Accessed 5 January 2020].

Failes, I. (2019b). Light Fields and the Future of VFX. VFX Voice, Fall 2019, 24-28. Available from https://www.vfxvoice.com/light-fields-and-the-future-of-vfx/ [Accessed 5 January 2020].

Failes, I. (2019c). Digital Actors: Are They Ready For Their CG Close-ups? Cartoon Brew, 2 August. Available from https://www.cartoonbrew.com/vfx/digital-actors-are-they-ready-for-their-cg-close-ups-169723.html [Accessed 5 January 2020].

Failes, I. (2020a). Real-Time CG Humans Hit the Big-Time. VFX Voice, Spring 2020, 10-15. Available from https://www.vfxvoice.com/real-time-cg-humans-hit-the-big-time/ [Accessed 8 April 2020].

Failes, I. (2020b). How Previs Has Gone Real-Time. VFX Voice, Spring 2020, 34-39. Available from https://www.vfxvoice.com/how-previs-has-gone-real-time/rd [Accessed 8 April 2020].

Failes, I. (2020c). For Companies at the Forefront, the Future is Real-Time. VFX Voice, Winter 2020, 46-50. Available from https://www.vfxvoice.com/for-companies-at-the-forefront-the-future-is-real-time/ [Accessed 8 April 2020].

Failes, I. (2020d). New VFX Tools, and How VFX Pros Are Using Them. VFX Voice, Spring 2020, 64-67. Available from https://www.vfxvoice.com/new-vfx-tools-and-how-vfx-pros-are-using-them/ [Accessed 8 April 2020].

Failes, I. (2020e). World-Building and Monster-Hunting with The Witcher. VFX Voice, Spring 2020, 70-81. Available from https://www.vfxvoice.com/world-building-and-monster-hunting-with-the-witcher/ [Accessed 8 April 2020].

Failes, I. (2020f). The Biggest VFX Trend – Making Actors Younger and Older. VFX Voice. Available from https://www.vfxvoice.com/the-biggest-vfx-trend-making-actors-younger-and-older/ [Accessed 8 April 2020].

Failes, I. (2020g). New Tech in VFX: Fall Edition. VFX Voice. Available from https://www.vfxvoice.com/new-tech-in-vfx-fall-edition/ [Accessed 8 April 2020].

Fast, K., Örnebring, H. and Karlsson, M. (2016). Metaphors of free labor: a typology of unpaid work in the media sector. Media, Culture & Society, 38(7), 963–978. Available from https://doi.org/10.1177/0163443716635861 [Accessed 6 March 2019].

Finance, C. and Zwerman, S. (2015). The Visual Effects Producer: understanding the art and business of VFX. 1st edition. Amsterdam: Elsevier/Focal Press. Available from https://learning.oreilly.com/library/view/the-visual-effects/9780240812632/?sso_link=yes&sso_link_from=university-of-westminster [Accessed 8 Sep 2020].

Field, S. (2005). Screenplay: the foundations of screenwriting. Revised ed. New York: Delta Publishing.

Fielding, N. (2010). Virtual fieldwork using access grid. Field Methods, 22 (3), 195–216. Availble from https://journals.sagepub.com/doi/10.1177/1525822X10374277 [Accessed October 22, 2018].

Fielding, R. (1985). The technique of special effects cinematography. 4th ed. London: Focal.

Fitzgerald, R. (2018). What is the Visual Effects pipeline? CG Spectrum. Available from: https://www.cgspectrum.com/blog/the-visual-effects-pipeline [Accessed 12 March 2020].

Fitzgerald, R., Dyerson, R. and Mishimagi, T. (2021). Strategic Transformation in Japan's SMEs, 1990–2008: Flexible Specialization, Industrial Restructuring, and Technological Change. *Enterprise & Society*, 1-36. Available from doi:10.1017/eso.2021.30 [Accessed 5 October 2021].

Flick, U. (2018). An introduction to qualitative research, 6th ed. Los Angeles: Sage.

Florida, R. (2002). The Rise of the Creative Class and How it's Transforming Work, Leisure, Community and Everyday Life. Basic Books, New York.

Foster, A. (2017). Could light field technology cut the cost of VFX? IBC, 11 May. Available from https://www.ibc.org/create-and-produce/could-light-field-technology-cut-the-cost-of-vfx/1936.article [Accessed 5 January 2020].

Garin, M. (2016). The Intermittence of Visual Motifs: A Quantitative Methodology for a History of Cinema Without Names. In: Cavallotti, D., Dotto, S., and Quaresima, L. (2016). A History of Cinema Without Names/2: Contexts and Practical Applications. MI, Italy: Mimesis International, pp 59-68

Garnham, N. (2005). From cultural to creative industries: An analysis of the implications of the “creative industries” approach to arts and media policy making in the United Kingdom. International Journal of Cultural Policy, 11(1), pp 15-29. Available from: https://www-tandfonline-com.uow.idm.oclc.org/doi/pdf/10.1080/10286630500067606?needAccess=true [Accessed on Dec 7, 2018].

Gaudreault, A. (1987). Theatricality, Narrativity, and Trickality: Reevaluating the Cinema of Georges Méliès. The journal of popular film and television. 15 (3), 110–119. Available from: https://doi.org/10.1080/01956051.1987.9944092 [Accessed on Jan 3, 2019].

Giralt, G. F. (2017). The Interchangeability of VFX and Live Action and Its Implications for Realism. Journal of film and video. 69 (1), 3–17. Available from: https://doi.org/10.5406/jfilmvideo.69.1.0003/ [Accessed on Dec 7, 2018].

Glisovic, S. et al. (2016). The problem of peer review in screen production: exploring issues and proposing solutions.

Goode, L. (2018). AI Made a Movie - and the Results are Horrifyingly Encouraging. Wired, 6 November. Available from: https://www.wired.com/story/ai-filmmaker-zone-out/ [Accessed on Dec 7, 2018].

Goulekas, K.E. (2001) Visual Effects in a Digital World. Morgan Kaufmann, San Francisco, CA.

Gov UK (2018). Billion-pound backing for British innovation. Available from: https://www.gov.uk/government/news/billion-pound-backing-for-british-innovation [Accessed on Oct 18, 2018].

Gov UK (2017). Creative industries’ record contribution to UK economy. Available from: https://www.gov.uk/government/news/creative-industries-record-contribution-to-uk-economy [Accessed on Oct 28, 2018].

Grabher, G. (2004) Temporary Architectures of Learning: Knowledge Governance in Project Ecologies. Organization Studies, 25, 1491–514.

Garnham, N. (2005). From cultural to creative industries: An analysis of the implications of the “creative industries” approach to arts and media policy making in the United Kingdom. International Journal of Cultural Policy: CP, 11(1), 15–29. Available from: https://doi.org/10.1080/10286630500067606 [Accessed on Oct 28, 2018].

Griffiths, A. (2010). Wonder, Magic and the Fantastical Margins: Medieval Visual Culture and Cinematic Special Effects. Journal of visual culture. 9 (2), 163–188. Available from: https://doi.org/10.1177/1470412910372757 [Accessed 16 September 2020]

Gunning, T. (1994). D.W. Griffith And The Origins Of American Narrative Film: The Early Years At Biograph. Chicago: University of Illinois Press.

Harari, Y.N.a. (2016). Homo deus: a brief history of tomorrow London: Harvill Secker.

Hatch, N. (2020). The critical importance of adopting virtual production. Post Magazine. Available from https://www.postmagazine.com/Publications/Post-Magazine/2020/May-June-2020/The-critical-importance-of-adopting-virtual-prod.aspx [Accessed 16 September 2020]

Havens, T. and Lotz, A. D. (2017). Understanding media industries. 2nd ed. New York: Oxford University Press.

Henrion, M., Fischer, G.W., Mullin, T. (1993). Divide and conquer? Effects of decomposition on the accuracy and calibration of subjective probability distributions. *Organizational Behavior and Human Decision Processes*, 55(2), 207–227. Available from https://www.sciencedirect.com/science/article/abs/pii/S0749597883710319 [Accessed 16 September 2020]

Hesmondhalgh, D. and Baker, S. (2011). Creative Labour: Media Work in Three Cultural Industries. London: Routledge.

Heusser, J. (2013). VFX in Los Angeles – 100 hour weeks & homeless. fxguide, 10 June. Available from https://www.fxguide.com/quicktakes/vfx-in-los-angeles-100-hour-weeks-homeless/ [Accessed 16 September 2020]

Hill, A., Steemers, J., Roscoe, J., Donovan, J. and Wood, D. (2017). Media Industries and Engagement: A Dialogue across Industry and Academia. Media industries, 4 (1). Available from https://doi.org/10.3998/mij.15031809.0004.108 [Accessed 16 September 2020]

Hirst, P. and Zeitlin, J. (1997). Flexible Specialization: Theory and Evidence in the Analysis of Industrial Change. In J. Hollingsworth & R. Boyer (Eds.), *Contemporary Capitalism: The Embeddedness of Institutions* (Cambridge Studies in Comparative Politics, pp. 220-239). Cambridge: Cambridge University Press. Available from doi:10.1017/CBO9781139174701.009 [Accessed 16 September 2020]

Holm, J. and Mäkinen, E. (2018). The Value of Currency in World of Warcraft. Journal of Internet Social Networking & Virtual Communities. Available from https://ibimapublishing.com/articles/JISNVC/2018/672253/ [Accessed 16 September 2020]

Holt, J., Perren, A. (2009). Media industries history, theory, and method. John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, United Kingdom

Honthaner, E. L. (2013). The Complete Film Production Handbook, 4th ed. New York: Routledge.

Hooley, T., Marriott, J. and Wellens, J. (2012). What is Online Research? London: Bloomsbury Academic. Available from https://www-bloomsburycollections-com.uow.idm.oclc.org/book/what-is-online-research-using-the-internet-for-social-science-research/ [Accessed September 23, 2018].

Houser, K. (2018). The Oscar for Best Visual Effects Goes To: AI Tomorrow's VFX artists might not be human. Futurism, 28 March. Available from https://futurism.com/polluted-cities-clean-air-status-symbol [Accessed 5 October 2018].

Huhn, P. (2020). Industry revenue of “motion picture, video and tv post-production” in the United Kingdom from 2012 to 2024. Statista, 10 February. Available from: https://www-statista-com.uow.idm.oclc.org/forecasts/397531/motion-picture-video-and-tv-post-production-revenue-in-the-united-kingdom [Accessed on January 7, 2020].

James, J. (2009). Fix it in post: solutions for postproduction problems. 1st ed. Amsterdam: Focal Press. Available from https://doi.org/10.4324/9780080928388 [Accessed 20 March 2020].

Jones, N. (2015). Variation within Stability: Digital 3D and Film Style. Cinema Journal, 55(1), 52–73. Available from https://doi.org/10.1353/cj.2015.0073 [Accessed 20 March 2020].

Jones, S. (2013). Digital creature rigging: the art and science of CG creature setup in 3ds max. 1st ed. New York: Focal Press. Available from https://doi.org/10.4324/9780240824062 [Accessed 25 Sep 2020].

Kadner, N. (2018). Buckle Up for AC Set Tour App. A Brief History of an iPhone App for American Cinematographer: Employing augmented reality, this new technique will further illustrate the collaborative creative approach of modern productions. ASC, 18 October. Available from https://ascmag.com/articles/buckle-up-for-ac-set-tour [Accessed 25 October 2018].

Kapler, A. (2002). Evolution of a VFX voxel tool. ACM SIGGRAPH 2002 Conference Abstracts and Applications. ACM. pp. 179–179. Available from https://doi.org/10.1145/1242073.1242192 [Accessed 25 October 2018].

Kaufman, D. (2019). Global VFX: State of the Industry 2019. VFX Voice, Spring 2019. Available from https://www.vfxvoice.com/global-vfx-state-of-the-industry-2019// [Accessed 8 April 2020].

Kaufman, D. (2020). New Virtual Technologies Remake VFX's Future Pipeline. VFX Voice, Winter 2020, 18-28. Available from https://www.vfxvoice.com/new-virtual-technologies-remake-vfxs-future-pipeline/ [Accessed 8 April 2020].

Kawashima, N. (2020). Changing Business Models in the Media Industries. Media industries, 7 (1). Available from: https://doi.org/10.3998/mij.15031809.0007.105 [Accessed on Dec 5, 2020].

Keil, C. and Whissel K. (2016) Editing and Special/Visual Effects. Vol. 6. New Brunswick: Rutgers University Press. Available from: https://ebookcentral.proquest.com/lib/westminster/detail.action?docID=4647677 [Accessed on Sep 5, 2020].

Kelion, L. (2019). CES 2019: Tech preview of the expo's hottest new gadgets. BBC, 5 January. Available https://www.bbc.co.uk/news/technology-46715334 [Accessed 9 January 2019].

Khalil, T. M. (2000). Management of Technology: The Key to Competitiveness and Wealth Creation. New York: McGraw-Hill.

King, N. and Horrocks, C. (2010). Interviews in Qualitative Research. Thousand Oaks: Sage Publications.

Klepper, S. (1997). Industry Life Cycles. Industrial and corporate change. 6 (1), 145–182. Available from https://doi.org/10.1093/icc/6.1.145 [Accessed 20 March 2020].
Krotoski, A. (2011). Storytelling: digital technology allows us to tell tales in innovative new ways. The Guardian. Available from https://www.theguardian.com/technology/2011/aug/07/digital-media-storytelling-internet [Accessed 10 September 2019]

Kumar, A. (2021). Beginning VFX with Autodesk Maya: Create Industry-Standard Visual Effects from Scratch. Berkeley, CA: Apress L. P. Available from https://learning.oreilly.com/library/view/beginning-vfx-with/9781484278574/?sso_link=yes&sso_link_from=university-of-westminster [Accessed 10 September 2019]

Landau, M. (1969) Redundancy, Rationality, and the Problem of Duplication and Overlap. Public Administration Review, July/August, 346–58.

Lee, T. (2019). Behind the Scenes: Understanding the VFX Pipeline. Academy of Animated Art. Available from: https://academyofanimatedart.com/behind-the-scenes-understanding-the-vfx-pipeline/ [Accessed 12 March 2020]

Lee, Y. S. and Siemsen, E. (2017). Task Decomposition and Newsvendor Decision Making. Management Science, 63(10), 3226-3245. Available from https://pubsonline-informs-org.uow.idm.oclc.org/doi/10.1287/mnsc.2016.2521 [Accessed 12 March 2021]

Lehner, J. M. (2009). The staging model: The contribution of classical theatre directors to project management in development contexts. International Journal of Project Management, 27(3), 195–205.

Leopoldseder, H., Schöpf, C., Stocker, G., Prix, A.E. (2017). CyberArts 2017 : international compendium : Prix Ars Electronica - computer animation/film/VFX - hybrid art - digital musics & sound art - u19 - create your world : STARTS Prize '17 - Grand Prize of the European Commission honoring innovation in technology, industry and society stimulated by the arts Berlin : Hatje Cantz Verlag GmbH.

Leovaridis, C. and Bahm, M., 2017. ASPECTS REGARDING VIRTUAL REALITY AS INNOVATION IN CREATIVE INDUSTRIES. Revista Romana de Sociologie, 28(3), pp. 157-172.

Littlejohn, S. W. and Foss, K. A. (2009). Encyclopedia of communication theory. London: SAGE Publications, Inc.

Locke, R. M. and Romis, M. (2007). Improving Work Conditions in a Global Supply Chain. MIT Sloan Management Review, 48, 54-62. Available from https://www.proquest.com/scholarly-journals/improving-work-conditions-global-supply-chain/docview/224963391/se-2 [Accessed 12 March 2021]

Lotz, A.D. (2007). The television will be revolutionized. New York; London: New York University Press.

Lotz, A.D., 1974- (2014). The television will be revolutionized, Second edition. New York : New York University Press.

Lutz, S., Amplianitis, K. and Smolić, A. (2018). AlphaGAN: Generative adversarial networks for natural image matting. Available from https://v-sense.scss.tcd.ie/wp-content/uploads/2018/07/AlphaGAN_arxiv.pdf [Accessed 7 December 2019].

Mahadevan, B. (2015). Operations management: theory and practice. 3rd ed. Delhi: Pearson. Available from https://learning.oreilly.com/library/view/operations-management-3rd/9789332541092/?sso_link=yes&sso_link_from=university-of-westminster [Accessed 20 March 2020].

Malik, S., Chapain, C., Comunian, R. (2017). Rethinking cultural diversity in the UK film sector: Practices in community filmmaking. Organization. 24 (3), 308-329.

Manning, S. (2008). Embedding Projects in Multiple Contexts – a Structuration Perspective. International Journal of Project Management, 26, 30–37.

Manovich, L. (2002). The language of new media, 1st MIT Press pbk. ed. Cambridge, Mass.: Cambridge, Mass. : MIT Press. Available from http://web.b.ebscohost.com.ezproxy.westminster.ac.uk/ehost/ebookviewer/ebook/bmxlYmtfXzEzODcwMl9fQU41?sid=e9cf976f-c379-46a2-9773-a47e8416d8a2@pdc-v-sessmgr01&vid=0&format=EB&rid=1 [Accessed 5 October 2018].

Maras, S. (2009). Screenwriting: history, theory and practice. London: Wallflower.

Marcard, T., Henschel, R., Black, M., Rosenhahn, B. and Pons-Moll, G. (2018). Recovering Accurate 3D Human Pose in the Wild Using IMUs and a Moving Camera. Lecture Notes in Computer Science, 11214, 614-631. Available from https://www.researchgate.net/publication/328113448_Recovering_Accurate_3D_Human_Pose_in_the_Wild_Using_IMUs_and_a_Moving_Camera_15th_European_Conference_Munich_Germany_September_8-14_2018_Proceedings_Part_X#fullTextFileContent [Accessed 7 December 2019].

Markham, A. N. (2004). The internet as research context. In: Seale, C., Gobo, G., Gubrium, J.F. and Silverman, D. (eds.). Qualitative Research Practice. London: Sage Publications, 328–44.
Markham, A. N. (2004). The internet as research context. In: Seale, C., Gobo, G., Gubrium, J.F. and Silverman, D. (eds.). Qualitative Research Practice. London: Sage Publications, 95–125.

Mattingly, D. B. (2011) The digital matte painting handbook. 1st ed. Indianapolis: Wiley Pub., Inc. Available from https://learning.oreilly.com/library/view/the-digital-matte/9781118078044/?sso_link=yes&sso_link_from=university-of-westminster [Accessed 8 Sep 2020].

Mayer, V. (2008). Studying up and F**cking up: Ethnographic Interviewing in Production Studies. Cinema Journal, 47(2), 141–148. Available from https://doi.org/10.1353/cj.2008.0007 [Accessed 8 Sep 2020].

McClean, S. T. (2007). Digital storytelling the narrative power of visual effects in film. Cambridge: MIT Press. Available from https://ebookcentral.proquest.com/lib/westminster/detail.action?docID=3339423 [Accessed 8 Sep 2020].

McLuhan, M. (1994). Understanding media: The extensions of man. Cambridge: MIT press.

McCullaugh, J. (2020). VFX Enters the Roaring ‘20s. VFX Voice, Winter 2020, 58-74. Available from https://www.vfxvoice.com/vfx-enters-the-roaring-20s/ [Accessed 8 April 2020].

McKinlay, A. and Quinn, B. (1999). Management, technology and work in commercial broadcasting, c. 1979-98. New Technology, Work and Employment, 14 (1), 2-17. Available from https://onlinelibrary-wiley-com.ezproxy.westminster.ac.uk/doi/epdf/10.1111/1468-005X.00049 [Accessed October 22, 2018].

Melki, H. (2019) An Investigation into the Creative Processes in Generating Believable Photorealistic Film Characters. Available from https://pure.ulster.ac.uk/en/studentTheses/an-investigation-into-the-creative-processes-in-generating-believ [Accessed 8 Sep 2020].

Metz, C. (2018). Palo Alto startup takes AI to the movies. SFGate, 31 March. Available from https://www.sfgate.com/business/article/Palo-Alto-startup-takes-AI-to-the-movies-12795286.php#photo-15316238 [Accessed 5 October 2018].

Miles, M. (2004). Where's massive? Metro: Media & Education Magazine, 139, 142-145. Available from https://search.proquest.com/docview/236454871?accountid=14987&rfr_id=info%3Axri%2Fsid%3Aprimo [Accessed 5 October 2018].

Miles, M. and Huberman, M. (1994). Qualitative data analysis: An expanded sourcebook. 2nd ed. Thousand Oaks: Sage Publications.

Minichiello, V., Aroni, R., Timewell, E., and Alexander, L. (1995). In-depth interviewing: Principles, techniques, analysis, 2nd ed. Melbourne: Longman.

Mintzberg, H. (1979). The structuring of organizations: a synthesis of the research. Englewood Cliffs: Prentice-Hall.

Mohr, S. and Carter, C. (2016). Adapting Practical Aesthetics to the performance animation process. Animation practice, process & production. 5 (1), 57–77. Available from https://doi.org/10.1386/ap3.5.1.57_1 [Accessed 5 October 2018].

Morgan, D. (2020). Towards a natural history of animated backgrounds. Screen. 61 (2), 296–305. Available from https://doi.org/10.1093/screen/hjaa028 [Accessed 10 Sep 2020].

Morse, J. M. (1994). Designing funded qualitative research. In Denizin, N. K. & Lincoln, Y. S., Handbook of qualitative research (2nd Ed). Thousand Oaks, CA: Sage.

Morse, J.M. and Field, P.A. (1995). Qualitative research Methods for Health Professionals, 2 nd ed. Thousand Oaks: Sage Publications.

MovieLabs (2019). The Evolution of Media Creation: A 10-Year Vision for the Future of Media Production, Post and Creative Technologies. MovieLabs. Available from https://movielabs.com/prodtech/ML_2030_Vision.pdf [Accessed 10 Sep 2020].

Murdock, G. (2000). Reconstructing the ruined tower: contemporary communications and questions of class. *Mass Media and Society*. London: Arnold.

Murphy, S. (2018). Technology and the Evolution of Storytelling. Medium. Available from https://medium.com/@shanemurphy_2728/technology-and-the-evolution-of-storytelling-90a533dc3037 [Accessed 16 September 2019]

Myers, M. D. (2009). Qualitative research in business & management. Los Angeles: SAGE.

NCAM (no date). Revolutionizing the way visual content is created. NCAM. Available from https://www.ncam-tech.com/products/ncam-reality/ [Accessed 11 December 2019].

North, D., Rehak, B. and Duffy, M. (2015). Special effects: new histories, theories, contexts. London: BFI.

Okun, Rafferty, K., Squires, S. and Zwerman, S. (2015). The VES handbook of visual effects: industry standard VFX practices and procedures. Second edition. Burlington, Mass: Focal Press. Available from https://learning.oreilly.com/library/view/the-ves-handbook/9781138012899/?sso_link=yes&sso_link_from=university-of-westminster [Accessed 8 Sep 2020].

Öhrström, M., Tomlinson, J., Cortes, R. and Goda, S. (2018). Cloud-based pipeline distribution for effective and secure remote workflows. Proceedings of the 8th Annual Digital Production Symposium, 1–8. Available from https://doi.org/10.1145/3233085.3233096 [Accessed 8 Sep 2020].

Ortner, S. B. (2009). Studying sideways: Ethnographic Access in Hollywood. In: Mayer, V., Banks, M. J. and Caldwell, J. T. (2009). Production Studies: Cultural Studies of Media Industries. London: Taylor and Francis, 175-189.

Palm, M. (2011). Labor's New Empire. The Journal of Communication Inquiry, 35(4), 433–438. Available from https://doi.org/10.1177/0196859911417182 [Accessed 6 March 2019].

Pardeshi, A. S. and Karbhari, V. B. (2019). Recent Trends in VFX (Virtual Effects) and SFX (Special Effects). IJERT, 8 (7), 882-884. Available from https://www.academia.edu/40045617/IJERT_Recent_Trends_in_VFX_Virtual_Effects_and_SFX_Special_Effects_ [Accessed 5 October 2018].

Pennington, A. (2016) Rise of the machines: AI for editing. Broadcast. Available from https://search.proquest.com/docview/1919404995?accountid=14987 [Accessed 5 October 2018].

Pennington, A. (2017) TV on fast track to the future. Broadcast. Available from https://search.proquest.com/docview/1976013910?accountid=14987 [Accessed 5 October 2018].

Pennington, A. (2019). How AI is reinventing visual effects. IBC, 4 July. Availble from https://www.ibc.org/create-and-produce/how-ai-is-reinventing-visual-effects/4060.article?adredir=1 [Accessed September 16, 2019].

Penrose, E. (1959) The Theory of the Growth of the Firm, 3rd edn. Oxford University Press, Oxford.

Perrow, C. (1967). A Framework for the Comparative Analysis of Organizations. American Sociological Review, 32 (2), 194-208

Perrow, C. (1970). Organizational Analysis: A Sociological View. Belmont: Wadsworth, p 192.

Petre, M. and Rugg, G. (2010) The Unwritten Rules of Phd Research. Open University Press; 2 edition, p 10.

Piore, M. J. and Sabel, C. F. (1984). The Second Industrial Divide. *Journal of Peace Research*, 24(2), pp. 206–206. Available from https://doi.org/10.1177/002234338702400213 [Accessed 10 September 2019]

Pluralsight (2014). Understanding Rotoscoping – The Process Every VFX Artist Should Know. Pluralsight. Available from https://www.pluralsight.com/blog/film-games/understanding-rotoscoping-process-every-vfx-artist-know [Accessed 10 September 2019]

Pluralsight (2015). VFX jobs and what they do. Pluralsight. Available from https://www.pluralsight.com/blog/career/vfx-jobs [Accessed 10 September 2019]
Power, P. (2009). Animated Expressions: Expressive Style in 3D Computer Graphic Narrative Animation. Animation: an interdisciplinary journal, 4 (2), 107–129. Available from https://doi.org/10.1177/1746847709104643 [Accessed 10 September 2019]

Press, K. (2008). Divide to conquer? Limits to the adaptability of disintegrated, flexible specialization clusters. *Journal of Economic Geography*, *8*(4), 565–580. Available from https://doi.org/10.1093/jeg/lbn012 [Accessed 12 October 2018].

Pratt, A.C., Gill, R. and Spelthann, V. (2007) Work and the City in the e-Society – A Critical Investigation of the Sociospatially Situated Character of Economic Production in the Digital Content Industries. Information, Communication & Society, 10, 922–42.

Pratt, A. C. and G. Gornostaeva (2009). The governance of innovation in the Film and Television industry: a case study of London, UK. Creativity, innovation and the cultural economy. A. C. Pratt and P. Jeffcutt. London, Routledge: 119-136. Available from

https://pdfs.semanticscholar.org/1c57/bb8de159073d52baaa3cb3bfa335ff2a89ee.pdf [Accessed 12 October 2018].

Prince, S. (1996). True Lies: Perceptual Realism, Digital Images, and Film Theory. Film Quarterly. 49 (3), 27-37. Available from https://search.proquest.com/docview/223097348?accountid=14987&rfr_id=info%3Axri%2Fsid%3Aprimo [Accessed 12 October 2018].

Prince, S. (2011). Digital Visual Effects in Cinema: The Seduction of Reality. Piscataway: Rutgers University Press. Available from https://ebookcentral.proquest.com/lib/westminster/detail.action?pq-origsite=primo&docID=861454 [Accessed 12 October 2018].

Punch, K. F. (2005). Introduction to social research: Quantitative and qualitative approaches, 2nd ed. London: Sage Publications.

Raiffa, H. (1968). Decision Analysis: Introductory Lectures on Choices Under Uncertainty, 1st ed. Reading, MA: Addison-Wesley.

Rickitt, R. (2006). Special Effects: The History and Technique. London: Aurum Press.

Rodowick, D.N. (2007). The virtual life of film Cambridge, Mass.: Cambridge, Mass. : Harvard University Press.

Rüling, C.-C. and Duymedjian, R. (2014). Digital bricolage: Resources and coordination in the production of digital visual effects. Technological Forecasting & Social Change, 83, 98–110. Available from https://doi.org/10.1016/j.techfore.2013.05.003 [Accessed 21 October 2018].

Ryan, B. (1992). Making Capital From Culture : The Corporate Form of Capitalist Cultural Production. Berlin : De Gruyter. Available from https://search.ebscohost.com/login.aspx?direct=true&db=e000tww&AN=560090&site=ehost-live&scope=site [Accessed 21 October 2018].

Ryan, M. A. (2017). Producer to Producer: A Step-by-Step Guide to Low-Budget Independent Film Producing, 2nd ed. London: Michael Wiese Productions.

Ryu, J. H. (2007). Reality and effect: A cultural history of visual effects. ProQuest Dissertations Publishing. Available from https://www.proquest.com/docview/304847807?pq-origsite=primo [Accessed 2 November 2018].

Salt, B. (2006). Moving into pictures: more on film history, style, and analysis. London: Starword.

Salt, B. (2009). Film style and technology: history and analysis. 3rd ed. London: Starword.

Samaras, E. and Johnston, A. (2018). Fleeting Film: Using Story to Seek Archival Permanence in the Transitory and Globalized Digital Visual Effects Industry. Preservation, digital technology & culture, 47 (1), 12–22. Available from https://doi.org/10.1515/pdtc-2018-0001 [Accessed 5 June 2019].

Sanghrajka, R., Hidalgo, D., Chen, P., & Kapadia, M. (2017). In AAAI Conference on Artificial Intelligence and Interactive Digital Entertainment. Available from https://aaai.org/ocs/index.php/AIIDE/AIIDE17/paper/view/15883/15202 [Accessed 2 November 2018].
Sanson, K. and Curtin, M. (2017). Voices of Labor Creativity, Craft, and Conflict in Global Hollywood. Berkeley, CA: University of California Press. Available from https://doi.org/10.1525/9780520968196 [Accessed 2 November 2018].

Sarto, D. (2019). Raphael Bob-Waksberg and Kate Purdy's 'Undone' Debuts on Amazon Prime. Animation World Network, 13 September. Available from https://www.awn.com/news/raphael-bob-waksberg-and-kate-purdys-undone-debuts-amazon-prime [Accessed 5 October 2019].

Sawicki, M. (2011) Filming the Fantastic: A Guide to Visual Effects Cinematography: A Guide to Visual Effects Cinematography. Oxford: Routledge. Available from

https://ebookcentral.proquest.com/lib/westminster/detail.action?pq-origsite=primo&docID=739038 [Accessed 15 September 2020].

Scalfari, S. (2019). Job Titles in 3D Animation & Visual Effects, And What They Actually Mean. The Rookies. Available from https://discover.therookies.co/2019/05/22/job-titles-in-3d-animation-visual-effects-and-what-they-actually-mean/ [Accessed 6 January 2020]

Scholz, T. (2013). Digital labor: The internet as playground and factory. London: Taylor & Francis Group. Available from https://doi.org/10.4324/9780203145791-17 [Accessed 6 March 2019].

Scott, A. (1998) Multimedia and Digital Visual Effects: An Emerging Local Labour Market. Monthly Labour Review, March, 30–38.

Scott, A. J. (2004). The Other Hollywood: the Organizational and Geographic Bases of Television-Program Production. Media, culture & society. 26 (2), 183–205. Available from https://doi.org/10.1177/0163443704039498 [Accessed 20 March 2020].

Scott, R. K. (1995). Creative Employees: A Challenge to Managers. Journal of Creative Behavior, 29. pp. 64–71. Available from https://doi.org/10.1002/j.2162-6057.1995.tb01424.x [Accessed 20 March 2020].

Scott, W. R. (1975). Organizational Structure. Annual Review of Sociology, 1(1), 1–20. Available from https://doi.org/10.1146/annurev.so.01.080175.000245 [Accessed 20 March 2020].

Scouten, C., 2017. Battle against piracy goes on. Broadcast.

Screenskills (2020). Careers in Visual Effects. Available from https://www.screenskills.com/media/3392/vfx-2020-web.pdf [Accessed 10 Decemberber 2020]

Shirvani, A., Ware, S., & Farrell, R. (2017). In AAAI Conference on Artificial Intelligence and Interactive Digital Entertainment. Retrieved from https://aaai.org/ocs/index.php/AIIDE/AIIDE17/paper/view/15836/15172 [Accessed 21 October 2018].

Sidhu, B. S. (2017). Light Field Capture – A Paradigm Shift for Cinematography, Visual effects and Live-Action Virtual reality? Medium, 4 December. Available from https://virtualrealitypop.com/light-field-capture-a-paradigm-shift-for-cinematography-visual-effects-and-live-action-vr-a946055adc8f [Accessed 5 January 2020].

Smith, A. (1776). The Wealth of Nations. London: Penguin

Smith, H. and Dean, R.T. (2009). Practice-led research, research-led practice in the creative arts Edinburgh: Edinburgh: Edinburgh University Press.

Snyder, B. (2005). Save the cat!: the last book on screenwriting you'll ever need. Studio City, Calif: Michael Wiese.

Spice, B., (2018). How a Computer Learns To Dribble: Practice, Practice, Practice: Deep reinforcement learning makes basketball video games look more realistic. Carnegie Mellon University. Available from https://www.cmu.edu/news/stories/archives/2018/august/computer-dribble.html [Accessed 15 September 2019].

Spohr, S. J. (2019) The guide to managing postproduction for film, TV, and digital distribution. New York: Routledge, Taylor & Francis Group. Available from https://learning.oreilly.com/library/view/the-guide-to/9781351056724/?sso_link=yes&sso_link_from=university-of-westminster [Accessed 15 September 2020].

Staiger, J. (1979). Dividing Labour for Production Control. Cinema Journal, 18 (2), 16-25. Available from https://www.jstor.org/stable/1225439 [Accessed 15 September 2019].
Staiger, J. (1985). The Politics of Film Canons. Cinema Journal, 24 (3), 4-23. Available from https://www.jstor.org/stable/1225428 [Accessed 15 September 2019].

Stark, D. (2009) The Sense of Dissonance: Accounts of Worth in Economic Life. Princeton University Press, Princeton, NJ.

Starkey, K. C., Barnatt, C. and Tempest, S. (2000). Beyond Networks and Hierarchies. Organization Science, 11(3), 299-305. Available from https://www.jstor.org/stable/2640263 [Accessed 12 May 2020].

Spelthann, V. and Haunschild, A. (2011). Organizational Creativity in Heterarchies: The Case of VFX Production. Creativity and Innovation Management (20), 100-107. Available from https://doi.org/10.1111/j.1467-8691.2011.00598.x [Accessed 12 May 2020].

Statista (2017). Film Industry in the United Kingdom: Statista Dossier. Available from: https://www.statista.com/study/21148/film-industry-in-the-united-kingdom-statista-dossier/ [Accessed on Oct 24, 2018].

Statista (2018). Leading film markets worldwide: gross box office revenue. Available from: https://www.statista.com/statistics/252730/leading-film-markets-worldwide--gross-box-office-revenue/ [Accessed on Oct 24, 2018].

Statista (2019). Film Industry in the United Kingdom (UK). Statista. Available from: https://www.statista.com/study/21148/film-industry-in-the-united-kingdom-statista-dossier/ [Accessed on January 7, 2020].

Styhre, A. and Sundgren, M. (2005) Managing Creativity in Organizations: Critique and Practices. Palgrave Macmillan, Basingstoke.

Stewart K., Williams M. Researching online populations: the use of online focus groups for social research. Qualitative Research, 5 (4) , 395–416. Available from https://journals.sagepub.com/doi/10.1177/1468794105056916 [Accessed 15 September 2019].

Storper, M. (1989). The transition to flexible specialisation in the US film industry: external economies, the division of labour, and the crossing of industrial divides. Cambridge journal of economics. 13 (2), 273–305. Available from https://www.jstor.org/stable/23598213 [Accessed 20 March 2020].

Strauss, A. L. (1987). Qualitative analysis for social scientists. Cambridge: Cambridge University Press. Available from https://doi.org/10.1017/CBO9780511557842 [Accessed 20 March 2020].

Strauss, A. L. and Corbin, J. M. (1990). Basics of qualitative research: grounded theory procedures and techniques. Newbury Park: Sage.

Subesh, K. D. and Panayiotopoulos, P. (1996). Flexible Specialisation: New Paradigm for Industrialisation for Developing Countries? *Economic and Political Weekly*, *31*(52), L57–L61. Available from http://www.jstor.org/stable/4404936 [Accessed 15 September 2019].

Sullivan, J. R. (2012). Skype: An appropriate method of data collection for qualitative interviews? The Hilltop Review. 6 (1), 54–60. Available from https://scholarworks.wmich.edu/cgi/viewcontent.cgi?article=1074&context=hilltopreview [Accessed 15 September 2019].

Summerfield, B. (2019). New Ways of Storytelling. Medium. Available from https://medium.com/@18039861/new-ways-of-storytelling-ca886251b26d [Accessed 6 March 2019]

Surrey NanoSystems (no date). About Vantablack: What is Vantablack? Surrey NanoSystems. Available from https://www.surreynanosystems.com/about/vantablack [Accessed 11 December 2019].

Sutton, R. (2001) The Weird Rules of Creativity. Harvard Business Review, 79, 94–103.

Squire, J.E. (2017). The movie business book, Fourth edition. New York, New York; London, England: Routledge.

Ouyang, C., Wang, K., ter Hofstede, A., la Rosa, M., Rosemann, M., Shortland, K. and Court, D. (2008). Camera, Set, Action: Process Innovation for Film and TV Production. C*ultural Science Journal,* 1(2). Available from https://doi.org/10.5334/csci.16 [Accessed 11 December 2020].

Johnson, J. (2020). Most successful films in the United Kingdom (UK) and Republic of Ireland in 2019, by box revenue. *Statista.* Available from https://www-statista-com.uow.idm.oclc.org/statistics/238237/most-successful-films-in-the-uk-and-ireland-by-box-office-revenue/ [Accessed on January 7, 2020].

Williamson, O. E. (1985). The Economic Institutions of Capitalism. New York: Free Press.

Watson, A. (2020). Size of the animation market worldwide from 2017 to 2020. *Statista.* Available from: https://www-statista-com.uow.idm.oclc.org/statistics/817601/worldwide-animation-market-size/ [Accessed on January 7, 2020].

Taylor, F. W. (1914). Scientific Management. New York: Harper & Row

Tempest, S (2003). Intergenerational Learning. Management Learning, 34(2), 181-200. Available from https://pure.uva.nl/ws/files/2090049/136675_Arnold_and_Bongiovi_2013_Precarious_Informalizing_and_Flexible_Work.pdf [Accessed 12 May 2020].

Terranova, T. (2000). Free labor: producing culture for the digital economy. Social Text, 18(2), 33–58. Available from http://web.mit.edu/schock/www/docs/18.2terranova.pdf [Accessed 6 March 2019].

The DV Show (2018). Artificial Intelligence and Video Production – Will it Replace Humans? The DV Show, 18 August. Available from [Accessed 5 October 2018].

The Filmmaking Research Network (no date). Assessment of Filmmaking As Research. What Should Filmmaking Researchers Consider When Submitting Their Work For Research Assessment? How Can You Make Explicit The Research Components Of Your Work? The Filmmaking Research Network. Available from http://filmmakingresearch.net/wp-content/uploads/2018/10/Assessment-of-Filmmaking-as-Research.pdf [Accessed 18 December 2018].

The Filmmaking Research Network (no date). Film Research In Ref Impact. How Film As Research Outputs Featured In Ref 2014. And What Lessons Can Be Learned To Create Strong Cases For 2021. The Filmmaking Research Network. Available from http://filmmakingresearch.net/wp-content/uploads/2018/10/Film-Research-in-REF-Impact.pdf [Accessed 18 December 2018].

The Filmmaking Research Network (no date). Researching Filmmaking Practices. Supporting Researchers To Reflect On Their Approaches. Research Insights Gained Through, For And About Filmmaking Ensure The Making Of The Film, That is The Filmmaking Practice, Is Central To The Research Enquiry. The Filmmaking Research Network. Available from http://filmmakingresearch.net/wp-content/uploads/2018/10/Researching-Filmmaking-Practices.pdf [Accessed 18 December 2018].

The Focus (2019). Virtual Production 101: How does it work, how can it revolutionise VFX? Medium, 18 October. Available from https://medium.com/@thefocus/virtual-production-101-how-does-it-work-how-can-it-revolutionise-vfx-1c7e80ade0f2 [Accessed 11 December 2019].

The VES Technology Committee (2020). Working from home: How the COVID-19 pandemic has impacted the VFX industry and will change it forever. VFX Voice. Available from https://www.vfxvoice.com/working-from-home-how-the-covid-19-pandemic-has-impacted-the-vfx-industry-and-will-change-it-forever/ [Accessed 5 November 2020]

Thompson, J. D. (1967). Organizations in Action. New York: McGraw-Hill

Thompson, K. (199). Storytelling in the new Hollywood: understanding classical narrative technique. Cambridge, Mass: Harvard University Press.

Thompson, K. (2003). Storytelling in film and television. Harvard University Press.

Tricart, C. (2018). Virtual reality filmmaking: techniques & best practices for VR filmmakers. London: Routledge.

Turnock, J. (2012) The Screen on the Set: The Problem of Classical-Studio Rear Projection. Cinema journal. 51 (2), 157–162. Available from: https://doi.org/10.1353/cj.2012.0000 [Accessed on Sep 20, 2019].

Turnock, J. (2014). The True Stars of Star Wars? Experimental Filmmakers in the 1970s and 1980s Special Effects Industry. Film history. 26 (4), 120–145. Sydney: Indiana University Press. Available from: https://doi.org/10.2979/filmhistory.26.4.120 [Accessed on Sep 20, 2019].

Turnock, J. (2015). Patient research on the slapstick lots: From trick men to special effects artists in silent Hollywood, Early Popular Visual Culture, 13:2, 152-173. Available from: http://dx.doi.org/10.1080/17460654.2015.1025531 [Accessed on Sep 20, 2019].

Turnock, J. A. (2015) Plastic reality: special effects, technology, and the emergence of 1970s blockbuster aesthetics. New York: Columbia University Press. Available from: https://ebookcentral.proquest.com/lib/westminster/detail.action?docID=1643205 [Accessed on Sep 5, 2020].

Turquety, B. (2014). Toward an Archaeology of the Cinema/Technology Relation: From Mechanization to "Digital Cinema". *Researching Cinema and Media Technologies – Their Development, Use, and Impact.* Amsterdam: Amsterdam University Press, 50–64. Available from: https://doi.org/10.25969/mediarep/13695 [Accessed on Sep 5, 2020].

Udy, S.H. (1959). Organizations in Action. New York: McGraw-Hill.

UK Research and Innovation (2018). Audience of the future. Available from: https://www.ukri.org/innovation/industrial-strategy-challenge-fund/audience-of-the-future/ [Accessed on Oct 18, 2018].

UK Screen Alliance (2019). Inclusion and Diversity in UK Visual Effects, Animation and Post-Production. UK Screen Alliance: London. Available from https://www.ukscreenalliance.co.uk/subpages/inclusion-and-diversity-in-the-uks-vfx-animation-and-post-production-sectors/ [Accessed 15 June 2020].

Unreal Engine (no date). MetaHuman Creator: High-fidelity digital humans made easy. Unreal Engine. Available from https://www.unrealengine.com/en-US/metahuman-creator [Accessed 15 June 2020].

Ursell G. Television production: issues of exploitation, commodification and subjectivity in UK television labour markets. Media, Culture & Society. 2000;22(6):805-825.

van den Oever, A. (2014). Techné/Technology: Researching Cinema and Media Technologies - their Development, Use, and Impact. Amsterdam: University Press.

Venkatasawmy, R. (2013). The digitization of cinematic visual effects: Hollywood's coming of age. Blue Ridge Summit: The Rowman & Littlefield Publishing Group. Available from https://ebookcentral.proquest.com/lib/westminster/detail.action?docID=1117135 [Accessed 12 May 2020].

Venkatasawmy, R. (2016). Crisis in the Digital Visual Effects Industry and Hollywood Cinema. Film international (Göteborg, Sweden), 14 (1), 6–23. Available from https://doi.org/10.1386/fiin.14.1.6_1 [Accessed 12 May 2020].

Visual Effects Society (2020). VFX in 2021: What Works, Who Works and What's Changing Forever. Vimeo. Available from: https://vimeo.com/488949607 [Accessed 10 February 2021]

Von Hippel, E. (2005). Democratizing Innovation. Chicago: MIT Press. Available from http://web.mit.edu/evhippel/www/books/DI/DemocInn.pdf [Accessed 12 May 2020].

von Rimscha, M. B. (2015). The Impact of Working Conditions and Personality Traits on the Job Satisfaction of Media Professionals. Media industries. Media Industries (Austin, Tex.), 2 (2). Available from https://doi.org/10.3998/mij.15031809.0002.202 [Accessed 12 May 2020].

Wales, L. M. (2017). The Complete Guide to Film and Digital Production, 3rd ed. New York: Routledge

Walsham, G. (1993). Decentralization of IS in developing countries: power to the people? Journal of Information Technology, 8 (2). Available from https://www.proquest.com/docview/901453621?accountid=14987&pq-origsite=primo [Accessed 22 February 2019]

Wasko, J., Murdock, G. and Sousa, H. (2011). The Handbook of Political Economy of Communications. Somerset: Wiley.

Wielgosz, M. (2017). Usefulness and Potential Benefits of Analyzing New Media from the Perspective of L. Manovich's Soft Technological Determinism – The Case of Instagram and Smartphone. Social Communication, Vol.3 (Issue 2), pp. 6-13. Available from https://doi.org/10.1515/sc-2017-0007 [Accessed 22 February 2019]

Williams, J. (2019). Personal flying go kart take off for manned flight over fields below. StoryTrender, 22 February. Available from http://www.storytrender.com/86962/personal-flying-go-kart-takes-off-for-manned-flight-over-fields-below/ [Accessed 22 February 2019]

Willis, D. A. (2017). New Products & Services, American Society of Cinematographers, Hollywood. American Cinematographer; Hollywood Vol. 98, Iss. 9, (Sep 2017): 110-118. Available from https://search.proquest.com/fiaf/docview/1986966805/BA804C4A4B9543EEPQ/6?accountid=14987 [Accessed 12 October 2018].

Woodward, J. (1958). Management and Technology. London: H.M.S.O.

Woodward, J. (1965). Industrial Organization: Theory and Practice. London: Oxford University Press.

Woodward, J. (1970). Industrial Organization: Behavior and Control. London: Oxford University Press.

Wolfe, J. (2017). Epic Games Releases Real-Time Compositing Tool Composure. Animation World Network, 22 August. Available from https://www.awn.com/news/epic-games-releases-real-time-compositing-tool-composure [Accessed 5 October 2019].

Wolfe, J. (2019a). Glassbox Technologies Launches with Real-Time Virtual Production Workflows. Animation World Network, 4 March. Available from https://www.awn.com/news/glassbox-technologies-launches-real-time-virtual-production-workflows [Accessed 5 October 2019].

Wolfe, J. (2019b). Chaos Group Shows Future of GPU Rendering and Real-Time Ray Tracing at GTC 2019. Animation World Network, 19 March. Available from https://www.awn.com/news/chaos-group-shows-future-gpu-rendering-and-real-time-ray-tracing-gtc-2019 [Accessed 5 October 2019].

Womack, J. P., Jones, D. T. and Roos, D. (2007). The machine that changed the world. New York: Free Press.

Wright, S. (2011). Compositing visual effects essentials for the aspiring artist. 2nd ed. Amsterdam: Elsevier/Focal Press. Available from https://learning.oreilly.com/library/view/compositing-visual-effects/9780240817811/?sso_link=yes&sso_link_from=university-of-westminster [Accessed 15 September 2019].

Xu, N., Price, B., Cohen, S. and Huang, T. (2017). Deep Image Matting. Available from https://arxiv.org/pdf/1703.03872.pdf [Accessed 15 September 2019].

Yamaguchi, t., Yatagawa, T., Tokuyoshi, Y. and Morishima, S. (2020). Real-time rendering of layered materials with anisotropic normal distributions. Computational Visual Media, 6(1), 29–36. Available from https://doi.org/10.1007/s41095-019-0154-z [Accessed 10 June 2020].

Yin, R. K. (2003). Case study research: design and methods, 3rd ed. Thousand Oaks: Sage Publications.

Young, J.C. et al. (2018). A methodological guide to using and reporting on interviews in conservation science research. Methods in Ecology and Evolution, 9 (1), 10-19. Availble from https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/2041-210X.12828#mee312828-bib-0013 [Accessed February 20, 2018].

Zamanian, K. (2016). How an Average VFX Pipeline Works. Premium Beat. Available from https://www.premiumbeat.com/blog/how-an-average-vfx-pipeline-works/ [Accessed 10 September 2019]

Zoodikers (2018). How AI is revolutionising the entertainment industry [forum post]. Zoodikers Consulting. Available from http://zoodikers.com/2018/03/ai-revolutionising-entertainment-industry/ [Accessed October 22, 2018].

Zwerman, S. and Okun, J. A. (2014). The VES Handbook of Visual Effects, 2nd ed. New York: Routledge.

Zwerman, W.L. (1970). New Perspectives on Organization Theory. Westport: Greenwood Publications Co.