

An Exploration of Virtual Reality Technologies for Museums

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Abstract

The Cryolo 1.0 is a practice-led research project that explores the processes and challenges of different virtual reality (VR) related technologies in the context of bringing static museum exhibits “to life”. It consists of producing four different applications that can be experienced on different platforms, such as a 3DoF VR video/application and an Augmented Reality (AR) application for mobile devices, a 6DoF VR application for VR devices such as the HTC Vive, and a Mixed Reality application suitable for a HoloLens or a MagicLeap. For the production of all these applications, various software and hardware were used in creating the 3D exhibit and developing a working production pipeline. All the technical and infrastructure challenges experienced as part of this study will be discussed.

Considering the rapid advancement in new technologies, museums have become a place for entertainment and displaying interactive creative applications in addition to promoting culture and educating people. In this context, museums all over the world already started embracing various new technologies available in the market to enhance their visitors’ museum experience and attracting larger audiences.

Each of these above-mentioned technologies has its own strengths and weakness in terms of implementation within the museum environment. When assessing the suitability of these four applications in comparison to each other, a BYOD (bring your own device) strategy fits very well to address/satisfy a maximum number of visitors to the museum, i.e., that museum content which could be installed on or viewed through a mobile/tablet device could suitably be put into action by considering all the requirements of the museum. Those platforms that require expensive hardware, such as HoloLens, as well as those applications whose usage is limited to the single visitor, such as VR Interactive Apps; or those whose hardware requires a lot of maintenance by museum staff, might not be efficient to be used in the museum. This research aims to introduce strategies and techniques that will support the Galleries, Libraries, Archives, Museums (GLAM) sector wanting to create an enhanced experience for their visitors. The trial and error following the production of these projects is documented throughout the exegesis. The result of this research was the successful implementation of a 3DoF VR application at Auckland Domain Museum.

Table of Contents

ABSTRACT	II
TABLE OF CONTENTS	III
LIST OF FIGURES	V
LIST OF TABLES	X
ATTESTATION OF AUTHORSHIP	XI
ACKNOWLEDGEMENTS	XII
TECHNICAL TERMS	XIII
1. INTRODUCTION	1
2. LITERATURE REVIEW	5
2.1. MUSEUMS — NEW TECHNOLOGY ADAPTATION	5
2.2. DEFINITIONS	6
2.3. AUGMENTED REALITY IN MUSEUMS	8
2.4. VIRTUAL REALITY IN MUSEUMS	16
2.5. MIXED REALITY IN MUSEUMS	18
3. METHODOLOGIES AND DATA (BLOG)	23
4. CONTENT DEVELOPMENT WORKFLOW	25
4.1. PREPRODUCTION	26
4.1.1. Character Development Preproduction	26
4.1.2. Environment Preproduction	30
4.2. PRODUCTION	31
4.2.1. Environment Acquisition	32
4.2.1.1. Insta 360 Shooting Process	32
4.2.1.2. Lidar Laser Scanning Process	34
4.2.2. HighRes Pipeline	35
4.2.2.1. Character Modelling Process	37
4.2.2.2. Character Rigging Process	41
4.2.2.3. Character Texturing Process	42
4.2.2.4. Character Animation Process	45
4.2.2.5. Character Lighting Process	47
4.2.2.6. Character Rendering Process	48
4.2.3. LowRes Pipeline	52
4.2.3.1. Low-Poly Modelling Process	52

4.2.3.2.	Low-Poly Rigging Process.....	53
4.2.3.3.	Low-Poly Texturing Process	54
4.2.3.4.	Low-Poly Animations Process	55
4.3.	POSTPRODUCTION	57
4.3.1.	Environment Development.....	57
4.3.1.1.	360 Stereo Image Stitching Process.....	58
4.3.1.2.	Creating HDRI Images	61
4.3.1.3.	Skeleton Removal Process	63
4.3.1.4.	Tripod Removal Process.....	63
4.3.1.5.	Matchmoving / CG camera Generation Process.....	64
4.3.1.6.	Lidar Point Cloud Data Post-Processing	67
4.3.2.	Movie Postproduction	69
4.3.2.1.	Stereo Compositing Process	69
4.3.2.2.	Editing Process.....	75
5.	APP DEVELOPMENT WORKFLOW	80
5.1.	3DoF VR — GOOGLE CARDBOARD APPLICATION DEVELOPMENT.....	80
5.2.	6DoF VR — HTC VIVE APPLICATION DEVELOPMENT	84
5.3.	MR — MICROSOFT HOLOLENS APPLICATION DEVELOPMENT	91
5.4.	AR — ANDROID MOBILE APPLICATION DEVELOPMENT.....	97
6.	DISCUSSION	102
6.1.	WHAT HAS BEEN DONE? ANALYSING RESEARCH	102
6.2.	IMPLEMENTATIONS	104
6.3.	INFORMAL FEEDBACK FROM THE MUSEUM	105
7.	CONCLUSION AND FUTURE WORK.....	107
7.1.	CONCLUSION	107
7.2.	FUTURE WORK	107
	APPENDIX	110
	REFERENCES.....	112

List of Figures

*Disclaimer: “The readers know that unless otherwise stated, photos/images and screenshots have been taken by the author of this thesis”

Figure 1: Cryolophosaurus output in 3DoF VR, 6DoF VR, MR, AR platforms	1
Figure 2: At ROM People reaction to life-size Dinosaur (Manager, 2016)	2
Figure 3: AR Technology use case through image trigger method (Producer, 2012)	2
Figure 4: 3DoF VR technology setup at the Auckland Museum by using Oculus Rift	3
Figure 5: Implementation of AR technology at Auckland Museum	3
Figure 6: XR – Extended Reality: Umbrella term for all other realities (Virtual,Mixed,Augmented,)	4
Figure 7: Communication issues chart in AR tour guide (Hammady, Ma, & Temple, 2016)	10
Figure 8: Horus AR game interface (Hammady et al., 2016).....	11
Figure 9: Interface of AR mobile game created by Rubino (Rubino, 2013).....	11
Figure 10: The museum app can be used in the middle of the city (Irimi,2014).....	12
Figure 11: People are able to see the history of a certain spot (Zhang,2010).....	13
Figure 12: UAR can be used around the city (Architectuur.ORG, 1999).....	13
Figure 13: Point the mobile device at this marker image (Piper, 2013).	14
Figure 14: AR technology implementation at ROM (Meldmedia Inc, 2013).....	15
Figure 15: Adding artistic content to the gallery area (Thiel, 2010). “We AR in MOMA” ...	15
Figure 16: Creative content in the gallery area (Thiel, 2010).....	15
Figure 17: VR film festival at the Museum (Nafarrete, 2016).	17
Figure 18: One of the 3DoF VR Films (Nafarrete,2016).....	17
Figure 19: At home using Google Cardboard & mobile VR app (eye, (n.d))	17
Figure 20: Eye Museum’ mobile VR app (eye, (n.d)).....	17
Figure 21: HoloLens and Skype in a tablet collaboration process (Chen, Lee, Swift, & Tang, 2015)	19
Figure 22: View of the real world (Chen, Lee, Swift, & Tang, 2015)	19
Figure 23: View from HoloLens (Chen, Lee, Swift, & Tang, 2015).	19
Figure 24: View from the companion device (Chen, Lee, Swift, & Tang, 2015).....	19
Figure 25: User virtual objects interaction with Holomuse application (Pollalis et al. 2017)	21

Figure 26: Bringing Cryolophosaurus to life in different platforms: Overall development workflow	25
Figure 27: Location of the Cryolophosaurus skeleton at the Origin Gallery	27
Figure 28: Information at the Auckland Museum	29
Figure 29: Information at the Auckland Museum	29
Figure 30: Museum cryolophosaurus Skeleton	29
Figure 31: Online reference image (Ilustraciencia,2018)	29
Figure 32: Clay Sculpt	29
Figure 33: 360 Stereo Shoot with Insta 360 Camera.....	31
Figure 34: Lidar shoot with Faro device	31
Figure 35: Content development Production workflow	32
Figure 36: Insta 360 Pro Camera.....	33
Figure 37: Setting up the came with the Mobile Application	33
Figure 38: Output from Insta 360 Camera with 6 stereo images from 6 fisheye lenses	33
Figure 39: HDRI image creation with different exposure settings.....	34
Figure 40: Faro Focus3D Laser Scanner	35
Figure 41: Faro mobile screen interface.....	35
Figure 42: Reference image for modelling (PopCultMedia, (n.d)).....	37
Figure 43: Normal – Followed reference	38
Figure 44: Lizard look mainly at the lower jaw.....	38
Figure 45: High-poly base mesh (150658 polygons)	38
Figure 46: Importance of Topology in character movements.....	39
Figure 47: Importance of Topology in Texturing UV layout process	39
Figure 48: Cryolophosaurus body Base mesh - ZBrush.....	40
Figure 49: Cryolophosaurus body high-poly mesh – ZBrush.....	40
Figure 50: Added details to each part of the model	40
Figure 51: Cryolophosaurus Rig Model.....	41
Figure 52: Texture reference for major parts.....	42
Figure 53: Reference for colours, patterns and spikes	42
Figure 54: Substance painter software for the base layer	43
Figure 55: Mari software for creating high-resolution textures.....	43
Figure 56: Texture nodes set up in Maya	43
Figure 57: UDMI method for creating hi-resolution textures	43
Figure 58: High detail textures for each part	44
Figure 59: Different colour variation textures.....	45
Figure 60: Lidar scanning process	46

Figure 61: Key movement of the character interaction with the environment.....	46
Figure 62: Light sources from 360 Live action Image.....	47
Figure 63: CG lighting test to match with 360 live action Image	47
Figure 64: Shadow reference at Origins Gallery.....	47
Figure 65: 3D Cryolophosaurus CG lighting test render	48
Figure 66: Different render passes output.....	49
Figure 67: Cryolophosaurus shadow pass output	50
Figure 68: Reference shoot for reflection at the origin gallery	50
Figure 69: Cryolophosaurus Reflection Pass	50
Figure 70: Renderpasses setup in Maya.....	50
Figure 71: Deadline rendering software	50
Figure 72: Unexpected render problems during the production.....	51
Figure 73: Low-poly model with proper topology (27041 Polygons)	52
Figure 74: Cryolophosaurus 3D skeleton model	53
Figure 75: Reference Image followed for creating a 3D skeleton	53
Figure 76: Cryolophosaurus low-poly model rig	53
Figure 77: Single UV set layout.....	54
Figure 78: Optimised Texture in 1 UVset - Color Map.....	54
Figure 79: Bump Map	54
Figure 80: Specular Map.....	54
Figure 81: Low-poly Cryolophosaurus with Textures applied	55
Figure 82: Low-poly animations (A), (B), (C) & (D).....	56
Figure 83: High-poly rig animation (Movie pipeline animation) with low-poly rig	56
Figure 84: Postproduction workflow	57
Figure 85: Six Output images from six lenses of Insta 360 Camera	58
Figure 86: Mistika VR – Stitching process.....	59
Figure 87: 360 Mono Images from Mistika VR	59
Figure 88: Anaglyph Image output from Mistika VR which need still fixing	59
Figure 89: Stereo images with ghosting effects and mismatching camera images.....	60
Figure 90: Insta 360 Stitcher software for stitching six raw images	60
Figure 91: Stitching six raw images of a different location.....	60
Figure 92: Final output stereo images from Insta 360 stitcher	60
Figure 93: Final HDRI Images for 7 locations (A), (B), (C), (D), (E), (F), (G)	62
Figure 94: Resulted in black unwanted data generated during HDRI image creation by multiple lighting exposers.....	62
Figure 95: With Cryolophosaurus Skeleton BG	63

Figure 96: Without Cyolophosaurus Skeleton BG	63
Figure 97: Final equirectangular 360 Stereo BG Images from Insta 360 stitcher with tripod	63
Figure 98: Cube format image with a tripod	64
Figure 99: Cube format image without tripod	64
Figure 100: Final equirectangular stereo 360 BG Images without tripod	64
Figure 101: 360 Stereo Image Matchmoving testing with PF tracking software.....	65
Figure 102: PF tracking software tried to track by using the 360-stereo video.....	65
Figure 103: Maya camera Centre point.....	66
Figure 104: Live action camera centre point	66
Figure 105: Reference of tiles that are visible in the nadir of the BG for finding the centre of the tripod	66
Figure 106: Final CG camera created manually to match with a live-action camera.....	67
Figure 107: Problems of mismatching the CG camera with a live-action camera	67
Figure 108: Point cloud data using Autodesk Recap software.....	68
Figure 109: 3D mesh output from Autodesk Recap.....	68
Figure 110: Lidar point cloud data using Reality Capture software.....	69
Figure 111: 3D mesh output from Reality Capture.	69
Figure 112: Reflection pass adding to BG glass panels	70
Figure 113: Nuke stereo compositing workflow with nodes and node groups.....	71
Figure 114: Compositing colour corrected Cryolo render with BG	72
Figure 115: Shadow Pass Pipeline	72
Figure 116: Left eye - Right eye workflow in Nuke software	72
Figure 117: Rotoscoping the Cryolo Render to reveal pillar in front as if Cryolo walking behind the pillars.....	73
Figure 118: Anaglyph Format BG	73
Figure 119: Composite with left and right eye - side by side format	74
Figure 120: Final stereo composite with left and right eye - over and under format.....	74
Figure 121: Premiere pro editing process	75
Figure 122: Red arrows indicating added TV footage and names of exhibits shows at Intro location BG	76
Figure 123: Final output over under 360 stereo format	77
Figure 124: Pillar roto is missing in one eye render in different positions of the video	77
Figure 125: Missing frames issue from one of the eyes at different positions.....	78
Figure 126: Cryolophosaurus Roto issues	78
Figure 127: Cryolo – 360 mono composition final output in closeup.....	79

Figure 128: Cryolo – 360 stereo composition final output in closeup.....	79
Figure 129: 3DoF VR Production outline.....	80
Figure 130: 360 video applied as render texture in skybox environment inside the Unity project window.....	82
Figure 131: Menu interactions start / pause/ Restart through Gaze	82
Figure 132: Vibration script window	83
Figure 133: Installed Android App.....	83
Figure 134: 6DoF VR production workflow.....	84
Figure 135: Hi-Res Lidar mesh	85
Figure 136: Low-Res Lidar Mesh	85
Figure 137: Matterport Photogrammetry mesh.....	86
Figure 138: Matterport mesh with high-poly Cryolophosaurus.....	86
Figure 139: Matterport mesh with low-poly character	87
Figure 140: Low-poly Cryolo distorted mesh.....	87
Figure 141: Low-poly Cyolo Model Texture stretching issues	87
Figure 142: 6DoF VR Working Prototype.....	88
Figure 143: Customization of inbuild code to fit the specific requirement	89
Figure 144: Light setup in Cryolo 6DoF VR Unity project	90
Figure 145: Cryolo position mismatch with 3D Origins gallery mesh	90
Figure 146: Cryolo animation test using Microsoft HoloLens at AUT office space.....	91
Figure 147: Mixed Reality Production pipeline	92
Figure 148: Cryolophosaurus character interaction with HoloLens.....	93
Figure 149: MRTK Unity plugin.....	93
Figure 150: MRTK build window options.....	94
Figure 151: Unity build setting options	95
Figure 152: Emulator mode	95
Figure 153: Observation of Cryolo character from multiple perspectives.....	96
Figure 154: Demonstration of occlusion by a real-world object	96
Figure 155: Augmented Reality production pipeline	97
Figure 156: Customization of high-poly model into low-poly model.....	98
Figure 157: Image-based AR application display through web camera.....	99
Figure 158: Installed Cryolo AR application on Android mobile.....	99
Figure 159: Cryolo AR trigger target image.....	99
Figure 160: Vuforia development portal shows the rating of the target image	100
Figure 161: Cryolo AR Application Prototype.....	101
Figure 162: Museum puzzle game app concept.....	108

Figure 163: Aim to implement HoloLens collaborative experiences in the Museum environment (Schulte, (2016))..... 109

List of Tables

Table 1: Movie and Game pipeline differences 36

Table 2: List of hardware used to capture the 3D environment and 360 environment footage 110

Table 3: List of the software used for environment post-processing, in building the Cryolophosaurus character and for application development..... 111

Attestation of Authorship

“I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.”

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Technical Terms

AR – Augmented Reality

DoF – Degree of freedom

MR – Mixed Reality

Polycount – Number of polygons or triangles

Polygonal Mesh – A configuration of polygons or triangles that defines the shape of a digital asset

Polygon/Poly – A closed, two-dimensional flat shape, which has straight sides and multiple angles

Rigging – The process sitting between modelling and animation stage where the joints and controls were created to fit the 3D model and bind joints with 3D mesh to create a required movement

Skinning – Part of the rigging process in which the mesh is bound with joints

Topology – In this research, a process of reorganising the flow of polygons, which helps for the position of joints for proper movement of the character and UV unwrapping for proper texturing

UDIM – An advanced method for creating UV maps for very large and detailed textures

UVs – U and V are the coordinates in 2D space assigned for texturing a 3D model.

VR – Virtual Reality

XR – Extended Reality, a universal group that comprises all the different forms of computer modified reality, containing AR, VR and MR.

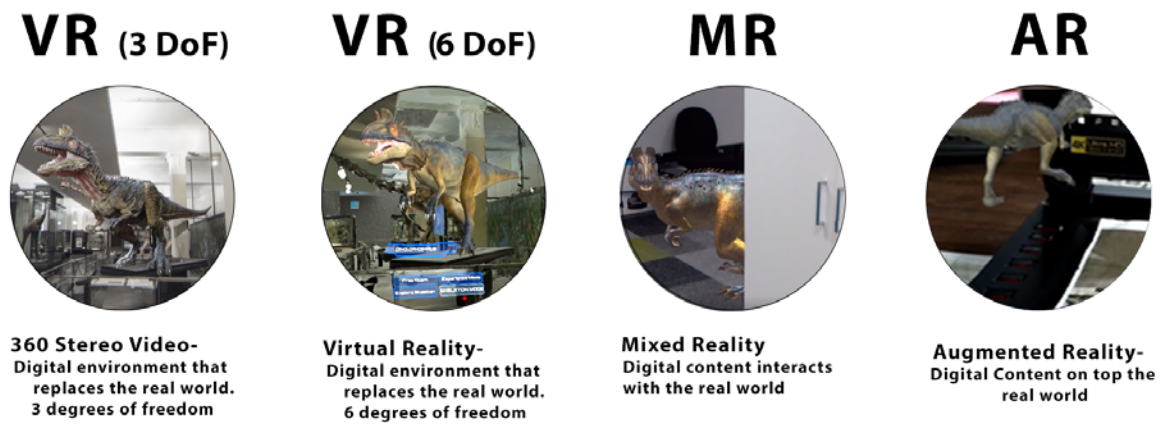


Figure 1: *Cryolophosaurus* output in 3DoF VR, 6DoF VR, MR, AR platforms

1. Introduction

I have loved museums since childhood and have always wanted to know more about the history, culture and evolution contained within them. This is especially true of the dinosaur section. I was always curious to know more about how these animals might have lived, how big they might have grown and what their individual characteristics may have been. For me, personally, there was never enough information available related to these animals, and what there was, was presented in a manner that meant that I could not easily grasp the content. Also, considering the exhibitions were always static, the overall effect was a generally boring and unsatisfying museum experience. I wished there was some device that existed, which could take me to their era and with it, be able to play with them and learn more about them.

Thanks to developments in AR/VR/MR technologies over the years—which have exponentially increased access to an almost unlimited array of content/stories via different devices—all of my childhood dreams have started to come true. Nowadays, if we look at most of the museums in the world, they have started exploring new technologies and started implementing these technologies into their galleries to create an enhanced visitor experience (Wojciechowski, Walczak, White, & Cellary, 2004). They are becoming a place where people can educate themselves in an interactive/intuitive manner, becoming entertainment places in line with other mainstream entertainment, such as TV and movie theatres etc.

In the context of the modern transmedia storytelling concept; in that we switch between multiple devices—mobile phones to tablets to TVs to laptops to PCs—for accessing the same content from multiple perspectives, it has become mandatory for any content to be

made available through multiple devices in order to get peoples' attention, to take the audience through an emotional journey and reach the maximum number of users (Pratten, 2011; K. T. Smith, 2011)

If we consider the remit of museums globally, they really were left with no option but to adopt these new technologies to enhance the visitor experience (Markovic, 2018). On the positive side, this gave museums the opportunity to engage young generations who are tech-savvy, attract them to the museum, and educate them about history and culture. So that these young generation people can understand the history in a better way, learn from it and build the future on top of it. By considering the habit of people using multi-device daily in their life, it will be a great advantage for the museum if they could demonstrate their museum displays using multiple platforms so that the visitors can understand the artefact in multiple perspectives and understand the context of the artefact in a better way. In the end, that would likely result in an enhanced museum experience (Pratten, 2011).

Let's look at some examples such as the 'Ultimate Dinosaurs' AR app used at the Royal Ontario Museum. Designed for a dinosaur fossil exhibition, it works with markers placed around the museum gallery to add dinosaur skins and bring southern dinosaurs to life as seen in Figure 2 and Figure 3.

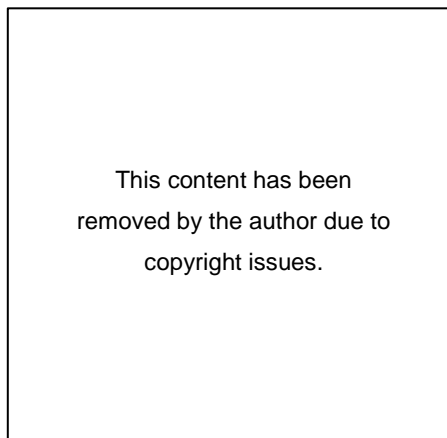


Figure 2: At ROM People reaction to life-size Dinosaur (Manager, 2016)

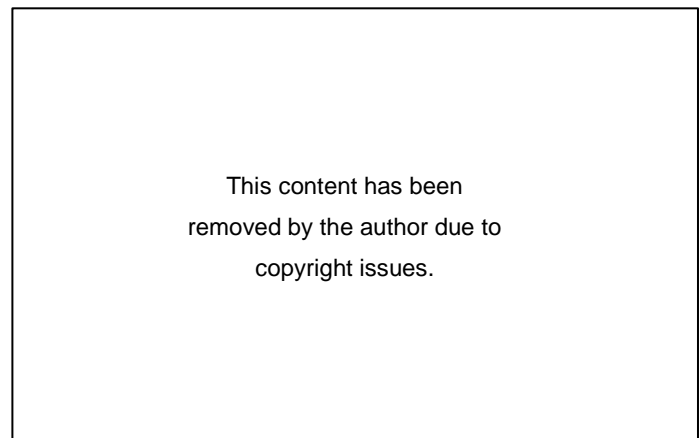


Figure 3: AR Technology use case through image trigger method (Producer, 2012)

Moreover, Auckland War Memorial Museum also started using VR technology to demonstrate the steps involved in the usage of artillery during the World War I to the public (Auckland Museum, 2017) as seen in Figure 4. In that 2D animation, the content was used to provide information about the artillery usage steps.



(A) 3DoF VR setup

(B) Its real Usage – visitor context

Figure 4: 3DoF VR technology setup at the Auckland Museum by using Oculus Rift

In addition, the museum also made AR technology available to children, who were given an AR-enabled drawing of an animal to colour in. Then, by using an AR camera, a coloured, 3D animation of the drawing can be displayed on the wall (see Figure 5).



(A) Fixed AR camera & drawing paper (B) Its display projection on to the wall

Figure 5: Implementation of AR technology at Auckland Museum

Augmented Reality merges digital content with real objects through tracking targets that the AR software recognises. Once the software sees the target tracker it can place the digital objects in the correct locations for the viewer to give the illusion that the reality has been augmented with digital content. To use a term from movie production, AR is camera tracking/match moving in real-time.

Many museums around the world have started using these new technologies, I will be discussing these in detail in the literature review section.

This document is an implementation exploration of new technologies in the museum context. I have taken a museum display object, a Cryolophosaurus (Dinosaur) skeleton that comes to life as a part of my research. I will be using the same dinosaur in multiple platforms to explore how it will fit and how assets can be reused in each individual platform in order to create an enhanced visitor experience. The research questions that are underpinning my journey are: What are the associated workflows for creating 3DoF VR, 6DoF VR, MR and AR applications? How much overlap exists in those workflows? What are advantages/disadvantages of those applications in the context of a museum?

As per the current trend in the market, these technologies have become mainstream. So, to represent all these technologies as an overall category, a new term has evolved called “XR”. There seem to be several definitions of the “X”: One of those definition is “Cross Reality” which defines “a form of “mixed reality environment that comes from the fusion (union) of ... ubiquitous sensor/actuator networks and shared online virtual worlds” (“X Reality (XR),” 2019, para. 1). Another one is “Extended Reality” which defines “a term referring to all real-and-virtual combined environments and human-machine interactions generated by computer technology and wearables. It includes representative forms such as augmented reality (AR), augmented virtuality (AV) and virtual reality (VR)” (“Extended reality,” 2018, para. 1). However, in the context of my work, I am going to use a third definition of “XR” as an overarching term, stating that the “X” is basically a placeholder for V/M/A as shown in Figure 6 (Irvine, 2017).



Figure 6: XR – Extended Reality: Umbrella term for all other realities (Virtual, Mixed, Augmented,)

2. Literature Review

2.1. Museums — New Technology Adaptation

The primary role of the museum is to collect objects, preserve them, research them and present them to the audience for education and entertainment. However, in this competitive world, the presentation has become an essential role of the museum in reaching people. In today's world, innovation and how museums exhibit objects in order to attract larger audiences, have become a significant role in the museum. In addition to engaging an audience, allowing interaction with objects and permitting customisation to the user are some of the main strategies a museum can employ to allow the viewer an enhanced experience (Macedonia, 2003).

Implications of digital technology continue to change every facet of human existence and culture, including museums. Museums across the world are incorporating new technologies into exhibition displays in order to augment the visitor experience. Considering the various options people have when spending their free time, museums have a huge task ahead of them to continue attracting an audience, due to people racing between numerous forms of entertainment (Macedonia, 2003)

However, Macedonia (2003) also noted that there are drastic advancements in the technology, software and hardware industries across the world, and museums are working hard to implement these currently existing technologies. These technological developments are empowering museum staff to apply new ideas and techniques to display their objects creatively and competently to museum visitors.

The role of museums has been changing over time. Museums are not only a place to promote culture and educate people but also a place for entertainment, creativity and interaction with new technologies. Museums are revisiting and intensifying their role in order to attract larger audiences by applying these technologies, as seen in Macedonia's (2003) research study.

Numerous studies (e.g., Macedonia,2003; Pedersen, Gale & Mirza-Babaei, 2016; Pollalis, Fahnbulleh, Tynes & Shaer, 2017; Yim et al., 2016) discovered that XR technologies are useful in improving the audience experience in the museum space. Considering these newly evolving technologies and the number of implementation options, new situations are coming into view for the museums, and they need stay on top of things in order to find out which technology best suits their demands.

Based on the above studies, it is evident that each technology has its pros and cons when executed in the museum space. In this context, I will be looking at applications of XR technologies in museum spaces and exploring the advantages/disadvantages and associated workflows for XR application/content development.

In the following review, I offer key definitions and look at each technology policy in turn. Based on this, I offer exploration of the creative technologies in a museum environment to bring the static artefact-based display to life. But before I do this, I would like to clarify the names and definitions of those technologies.

2.2. Definitions

It is essential to elucidate exactly what the three terms: Augmented Reality (AR), Virtual reality (VR) and Mixed Reality (MR) actually mean. As it stands, there has always been a lot of confusion around these technologies. To make these definitions clear, I am referring to an article from the Medium website (Thibault, 2018) and Allen's studies (Allen, 2016), as it describes each technology clearly, compares them and discusses the misconceptions about 360 videos vs VR and AR vs MR and so that we may understand them better from the practical application viewpoint.

Augmented Reality (AR) is defined in Allen's study as "an experience in which a virtual world is superimposed over the physical world in such a way as to allow both to be visible at the same time " (Allen, 2016, p. 2). In a similar way, Thibault states that AR is done by adding any virtual elements to our environments. The author further clarifies that in AR technology, virtual objects and the real environment do not react to each other (Thibault, 2018). As an example, a virtual object would not be obstructed by the real object in front of it, as seen in Figure 1, where the dinosaur was not obstructed by the laptop screen.

With respect to MR – Allen explains it as "an umbrella term that covers both "augmented reality" and "augmented virtuality" (Allen, 2016, p. 3). Alternatively, Thibault explains MR as an overlay of synthetic content on the real world that is anchored to and interacts with the real world (Thibault, 2018).

To use the example from the previous definition of AR, in contrast, a virtual object can be obstructed by real objects e.g. a wall, table etc. shown in Figure 154 (A) & (B), where the Cryolophosaurus (virtual object) is obstructed by the cupboard (real-world object).

If we look at these two definitions, we see that the industry publication emphasises the virtual and real-world interaction. I agree that this interaction plays a pivotal role to distinguish AR and MR clearly from each other. There is also an often-cited definition of "MR" in the paper

by Milgram et al. from 1994. However, the topic of this paper was purely display technologies and did not consider spatial awareness of MR devices as we are using them today, e.g., in the form of a HoloLens or MagicLeap. The authors do not at all hint to the physical interaction of virtual content to the real world, which is why I do not consider their definition of "MR" as pivotal to contemporary MR devices.

In the above descriptions of MR, Allen's study states AR as an integral part of MR and does not explain the term "augmented virtuality" in any depth. Thibault it highlights the interaction between the synthetic and the real world. It seems as if lately, the terms "AR" and "MR" are being used interchangeably. There is certainly some connection in the execution of these technologies, such as both having virtual items overlapped on the real world. Nevertheless, MR is an extended version of AR.

When it comes to a definition of VR, Allen's article states VR as something that "transports the viewer, regarding sight and sound, into a virtual space, resulting in full immersion" (Allen, 2016, p. 4). Whereas, Thibault describes VR as "a three dimensional, computer-generated environment, which feels realistic to you"(Thibault, 2018).

When we compare both definitions, Allen focuses on "immersion" as the main idea in VR, whereas Thibault puts emphasis on realism. Thibault further explains that VR does not feel real if does not have interaction to it and further states that VR should have a "sense of depth in what you see and allow a Degree of Freedom (DoF) in which you can move " (Thibault, 2018). Considering both authors' statements, it is evident that VR should have immersion, a sense of depth, interaction and a degree of movement.

When we come to the fourth category—3DoF VR (360 stereo video). It is not so much a technology, but specific content developed through a custom-designed camera rig or 360 cameras available in the market by shooting a real environment location. Even though It allows three rotational degrees of freedom, the viewer cannot move around and pick up objects and cannot do interactions which are possible through 6DoF VR. By considering these points 360 videos cannot be considered as real VR and it's just another content (Thibault, 2018).

In contrast, when we consider the advancement in 360 video technologies, that is, the ease in creating stereo video content and when this content integrates with CG Stereo, we can create realistic 360 stereo content. By considering the three rotational degrees of freedom and sense of depth, when the user accesses this live action & CG integrated video through HMDs, they can have a full-immersion experience. By considering these few extra factors,

like accessing the 360-stereo content through HMD with small interactions which have 3 rotational DOF, I am considering 360 stereo videos as 3DoF VR and Real 6DoF VR as an extended version of 3DoF which incorporates interaction in addition to immersion. In principle, 3DoF VR is like 6DoF VR without the translational freedom. It can however still have the interaction (e.g., control through gaze and one-button-tap, or gaze and time fuse mechanisms). 3DoF VR is often confused with 360-degree video, because that is a kind of content that is well suited for this technology. Whereas, if we access through 360 video content through a mobile or desktop, it can be considered as just video content. All the further developments of this thesis will be based on the considerations of above-mentioned definitions

2.3. Augmented Reality in Museums

There are four types of AR applications:

Marker/Image based AR: This type uses the camera of AR devices to detect one or more specific markers. Their position and orientation are calculated based on their appearance to the camera, and that information is used to adjust the overlaid CG content on the screen. An AR-enabled device is triggered when it encounters a marker and the overlaid CG content is then displayed on screen. I have utilised this type of AR application as a part of this thesis. I will explain thoroughly in further sections. In this marker can be an image, an object, a text, a logo, etc. (Singh, 2018).

Markerless AR: In contrast to the previous principle, this kind of AR uses the device's GPS, digital compass, velocity meter and accelerometer to overlay digital content on their screen. Some examples are: Google Map AR, Pokémon Go AR. In these applications, information and characters will pop up on the device screen on the basis of GPS location (Singh, 2018).

Projection based AR: For this kind of AR, light will be projected on to the surface of the real object and make it interactive by human touch with the help of sensors. Example project a keyboard on your desk, it can interactive (Singh, 2018).

Superimposition based AR: In this type, object recognition plays a major role. The augmented image can substitute the original image either incompletely or completely. It can be used in military filed to view the target in multiple perspectives (Singh, 2018).

AR Guided Tours

The study by Hammady, Ma & Temple (2016) explains that AR technology can be extended towards mass communication and can even be used in museum games. Applying AR in

these areas is a strategic move when striving to engage the museum's audience. In this study, the authors focused on a "roadmap for communication" model for effective execution of AR guided tours in the museum. This implementation is an effective approach to communicating with many visitors. The communication between the content creator (curator) and the digital content developer is very crucial in delivering the right content at the right time (Hammady, Ma, & Temple, 2016).

There are a few factors that could affect this communication process. The authors explain that there could be internal and external factors contributing to the disturbances. An overload of visitors using the AR guide application and inadequate lighting hindering the visual tracking are two examples of external factors that could affect the communication (Hammady, Ma, & Temple, 2016). I am also building a mobile AR application, utilising visual image tracking to trigger the application. The process of building the AR application will be explained in section 5.4.

Internal factors could be based on practicality, the usability of the system. It is divided into three categories; 'Tracking Technologies', 'Interaction and UI' and 'Display Techniques'. Magnetic fields could disturb the tracking, plus vision-based tracking could be a problem if the marker is blocked.

In the further AR application development in 5.4 AR section, the image which I will be used for tracking making sure it has enough tracking points and no blockage to it during the implementation stage.

Moreover, fast motion causes an AR system to lose tracking, and it could take some time to recover the tracking. When it comes to 'Interaction and UI', clarity of the textures is important to run the system. In this same category, if the museum is crowded then it will affect the interaction system. The third category - 'Display Techniques' - can be further divided into 'See-through HMD', 'Projection-based Display' and 'Handheld Devices'. 'See-through HMD' needs user feedback to identify an agreeable level. Head-mounted projection display (HMPD) deals with many optics and can cause a decrease in the illumination of the image. This HMPD does not support mobility. With handheld devices such as PDAs, phones and tablets, there could be drawbacks such as small screens and small keypads. Compared to HMD, these handheld devices have low-quality displays. Furthermore, carrying the devices around and aiming the camera at the museum artefact, with arms raised during the whole museum journey could be a big concern for visitors. Therefore, using handheld devices for the AR tour could result in fatigue and may not be suitable for long museum visits (Hammady, Ma, & Temple, 2016). As I am going to develop an AR mobile handheld

application for only one museum artefact, so fatigue might not be an issue in this current stage. But later if I get a chance to develop an application which spans several exhibits, fatigue might become an issue.

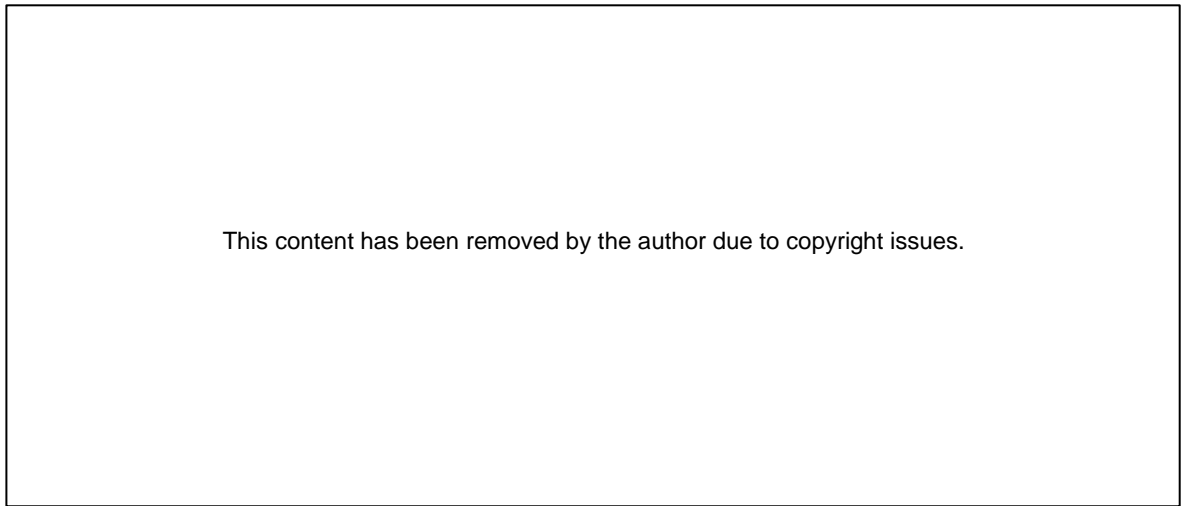


Figure 7: Communication issues chart in AR tour guide (Hammady, Ma, & Temple, 2016)

AR Gamification

The Hammady review also discussed the combination of gamification and AR technology. Through this gamification technique, not only can museum staff engage visitors, but they can also educate them in history and culture. The study authors used the game 'Horus' as an example, which was utilised in an Egyptian Museum in Cairo. This game was developed to educate people about the stories of Egyptian deities Osiris, Seth and Isis. The AR and gamification combination not only engaged visitors within the museum environment but also outside the museum.

The author surmised that after playing this game, the story of Egyptian culture and its lessons would stick with visitors (Hammady et al., 2016).

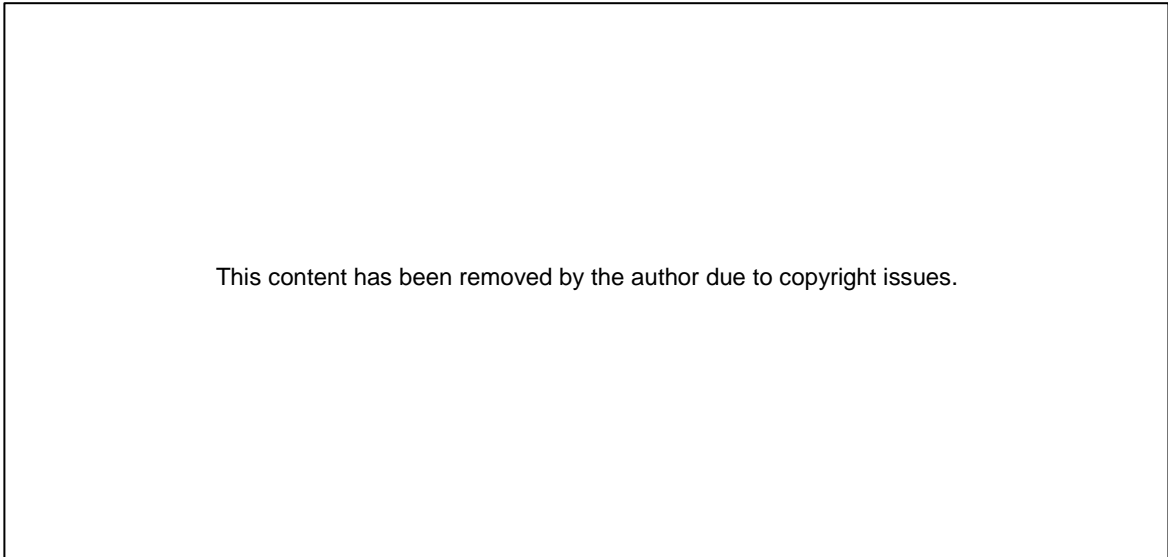


Figure 8: Horus AR game interface (Hammady et al., 2016)

Similarly, the AR mobile game/application created by Rubino (2013) showed that most museum visitors felt interested, satisfied and motivated, enjoying the AR game they played at the museum (Rubino, 2013).

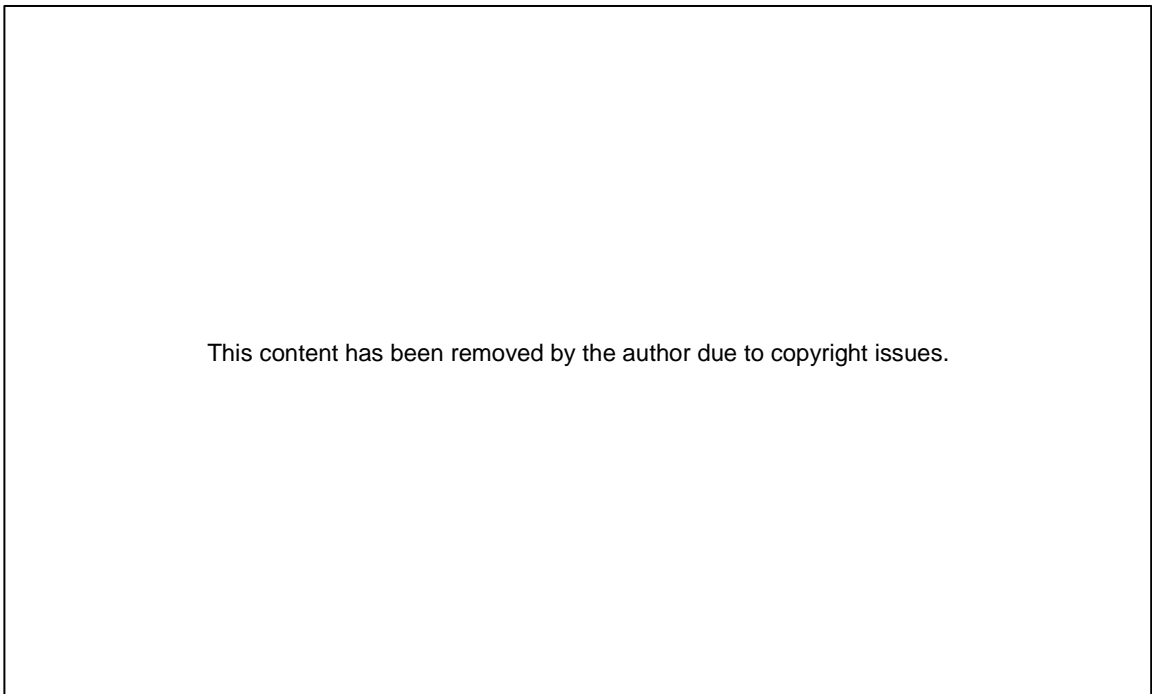


Figure 9: Interface of AR mobile game created by Rubino (Rubino, 2013)

Shelley Mannion, the Digital Learning Manager at the British Museum, wrote that they had developed four categories to incorporate the AR projects into the museum. These are “outdoor guides and explorers”, “interpretive mediation”, “new media art and sculpture” and “virtual exhibitions”. She considers the “StreetMuseum” iPhone app as an example of

“outdoor guides and explorers”, where people have the ability to expand beyond the museum’s physical walls. When away from the museum, out in the city streets, the museum’s smartphone app, using GPS, will show users the actual source of where a museum’s exhibit came from. It displays a historic photograph of the spot on the smartphone, temporarily hiding the current physical object and allows the exploration of history around the city environment (Mannion, 2011).

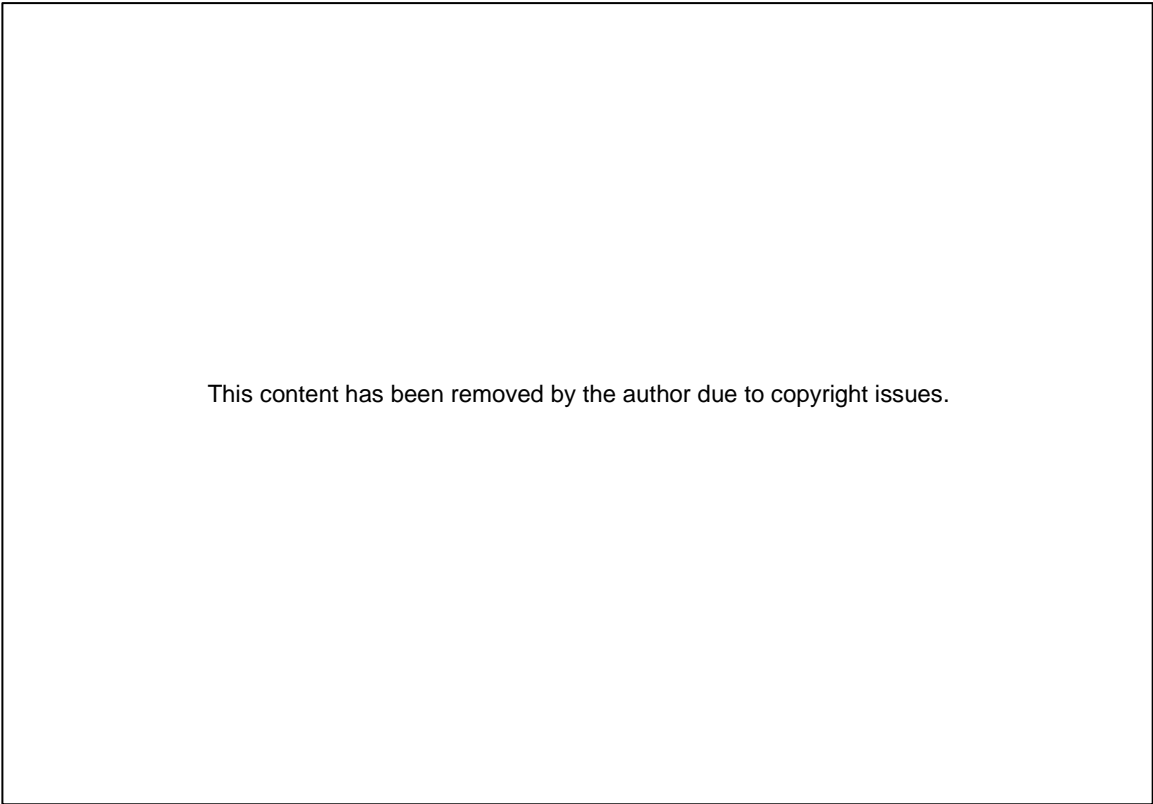


Figure 10: The museum app can be used in the middle of the city (Irimi,2014)

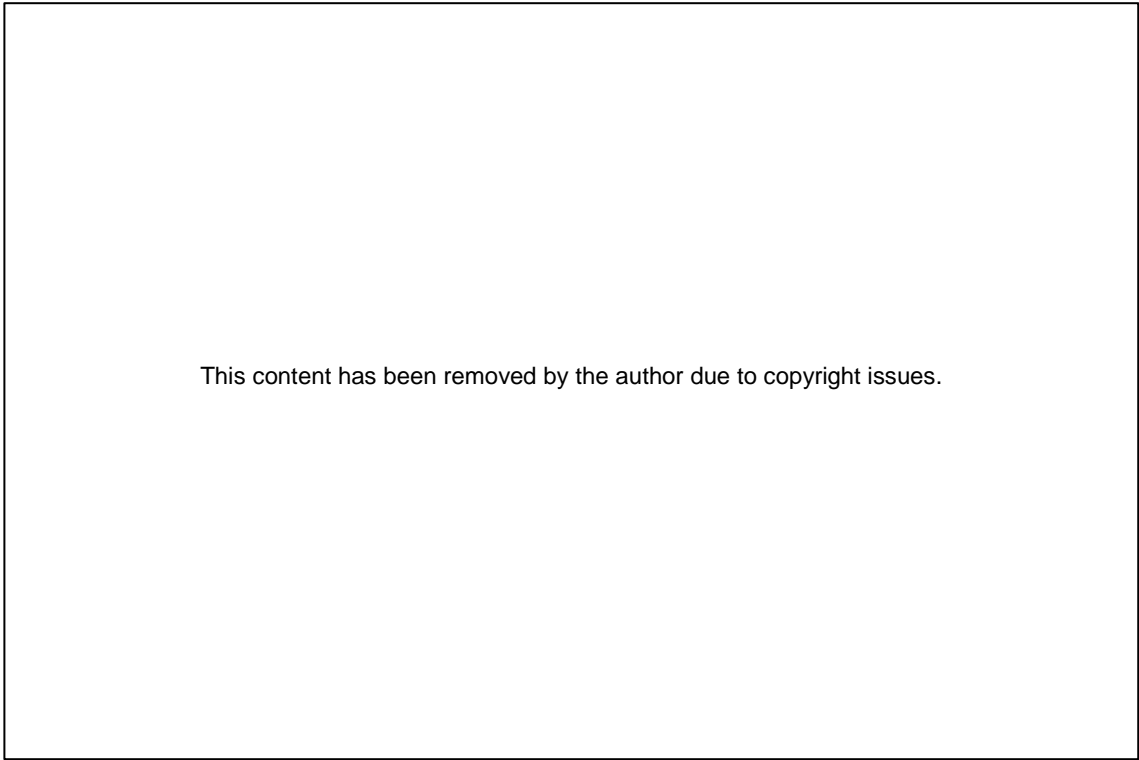
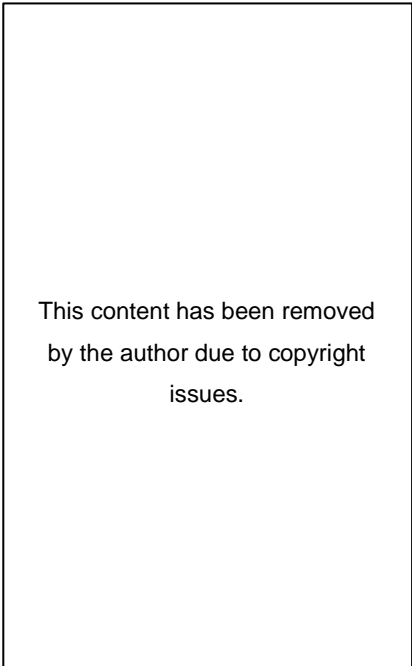
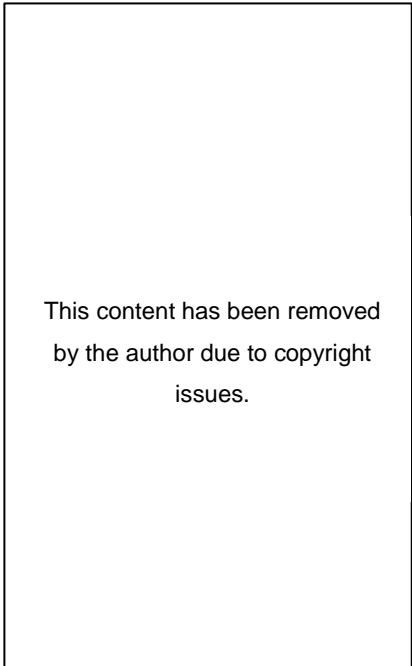


Figure 11: People are able to see the history of a certain spot (Zhang,2010).

This app is similar to the Urban Augmented Reality (UAR) app developed by Nederlands Architecture Institute (NAI), through which people can see and experience the built environment of the past, present and future (Ouwkerk, 2011).



(A) underground display of city centre

(B) underground car park view

Figure 12: UAR can be used around the city (Architectuur.ORG, 1999)

These types of AR mobile applications work based on GPS (Global Positioning System). The benefit of this type of application lies in allowing people to explore the city's past and present and even offering the ability to compare current locations around the city with historic images. The downside is that people need to have smartphones with internet connections to use it and be willing to download applications (Ouwerkerk, 2011).

The next category is "Interpretive Mediation". This type of AR application is designed for use within the museum's galleries when the user is looking at the exhibits via the museum's smartphone app. It augments the exhibit with information the user might find useful. As the apps mature, the kind of information that can be augmented can make a lasting impression on the user, and it permits the interaction with museum objects. The 'Ultimate Dinosaurs' app used at the Royal Ontario Museum is an example of this category. Designed for a dinosaur fossil exhibition, it works with markers placed around the museum gallery to add dinosaur skins and bring southern dinosaurs to life.

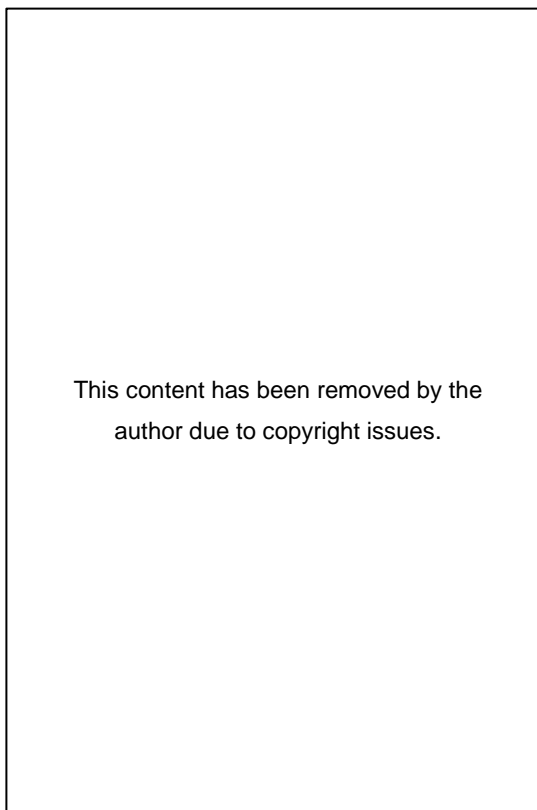
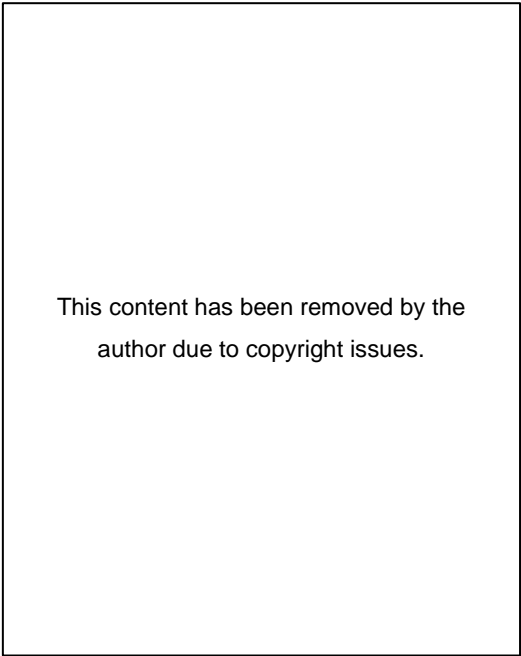
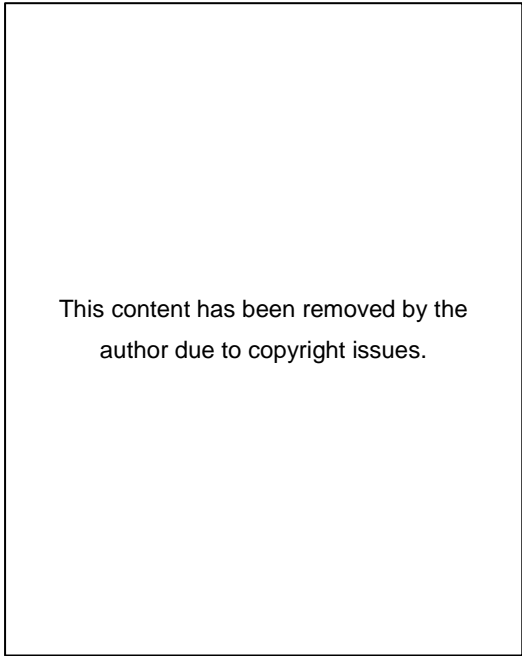


Figure 13: Point the mobile device at this marker image (Piper, 2013).



(A) People taking photos with a virtual dinosaur (B) Virtual dinosaur coming out of a poster at the bus stop

Figure 14: AR technology implementation at ROM (Meldmedia Inc, 2013)

Mannion did not thoroughly differentiate between the last two categories, “new media art and sculpture” and “virtual exhibitions”. She describes them as content that is created by people’s participation/contribution to building the AR application. For this category, she referred to the 2010 ‘We AR in MOMA’ app (Thiel, 2010) used in the New York City-based museum. Groups of people using their creativity created content using AR application to add synthetic content to the museum area, playing the role of the curator as well as an artist.

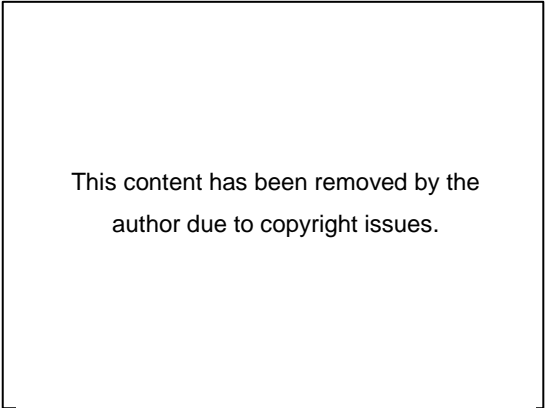
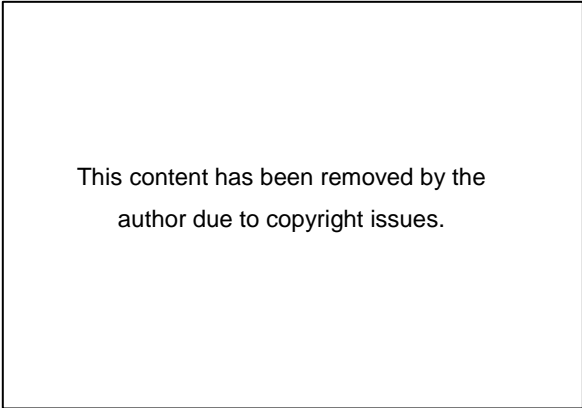


Figure 15: Adding artistic content to the gallery area (Thiel, 2010). “We AR in MOMA”

Figure 16: Creative content in the gallery area (Thiel, 2010).

All the above studies and applications emphasise how the visitor's interactivity with the objects and information on their mobile screen, helps to engage, educate and entertain them and offer a better experience. On handheld mobiles and tablets, AR is able to be seen on-screen with virtual elements added as overlays on the physical world. Whereas head-mounted devices (HMD) can offer an immersive experience with the object and the physical world.

On the other hand, the studies mentioned above do not explain the real size depth and real-time interaction of museum objects with the physical world. These are the primary qualities that help the viewer feel that displays exist physically. AR applications on handheld devices will not provide an immersive experience, as they cannot create real size depth, they have small screen size and need to point at the object always to see the virtual objects. This could create fatigue, as discussed earlier. By taking the drawbacks mentioned above into account, AR's application into the museum space would not create a fully immersive feeling with the object. The strength of virtual reality (VR) will be discussed in the next section.

2.4. Virtual Reality in Museums

The Macedonia (2003) study states that visitor participation and interaction with the artefacts within an immersive environment is always an enjoyable experience for the visitors. The study conducted a demonstration in an archaeological exhibition, in which the audience was allowed to experience the virtual archaeological dig with an immersive atmosphere, allowing the visitors to participate in the virtual digging site. It allows the user to brush away and dig to find the artefacts (Macedonia, 2003). In this VR method, the writer describes how the audience is completely immersed in a virtual world throughout their partaking. The museum exhibitors use HMD gear similar to HTC Vive, through which viewers have an immersive experience in the virtual world. The VR technology also permits the visitor to interact with museum objects, analogous to the AR method, but within a virtual space (Macedonia, 2003).

Similarly, another study (Styliani, Fotis, Kostas & Petros, 2009) explains VR as a simulation of a fantasy world or the real world which can be felt visually and offers the illusion of realism. In recent years, the cost of building VR experiences has dropped considerably. The main factor is prices for hardware as prices for consumer-grade VR hardware has fallen. In the VR platform, users get immersed in a wholly artificial creation.

Tracking and sensing technologies are needed to create strong immersive content. Also, high immersion VR content could involve physical sets, gloves and magnetic trackers (Styliani et al., 2009). By involving all of these physical objects, it is possible to create a completely immersive experience to the museum visitors. However, this could restrict the

free movements of the participant and could involve too much time setting the whole process up.

Furthermore, in Allen's thesis study, it states that usage of virtual reality outstripped augmented reality in 2015, and that trend seems to be continuing, although usage of AR through handheld devices is still prominent in the museum environment. For this, one of the reasons could be that "wearable augmented reality HMD is still in the development stage and wearable virtual reality devices are only beginning to enter the consumer market" (Allen, 2016, p. 22). "Eye Museum" in the Netherlands and "New Museum" in New York both hosted VR film festivals by using Samsung Gear VR devices.

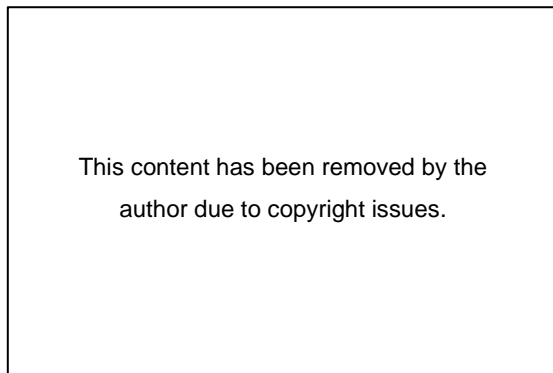


Figure 17: VR film festival at the Museum (Nafarrete, 2016). Figure 18: One of the 3DoF VR Films (Nafarrete, 2016).

"Eye Museum" allows visitors to experience VR tours and VR films through a mobile VR app.

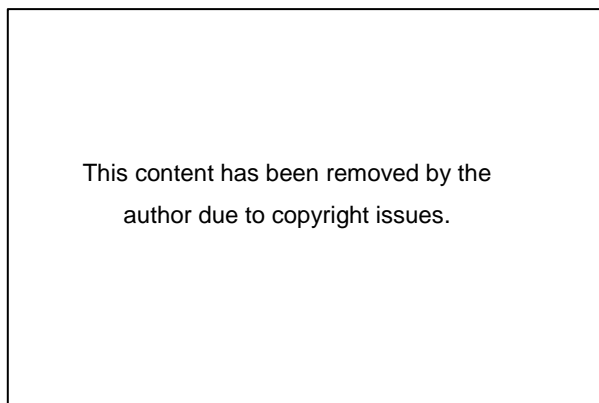


Figure 19: At home using Google Cardboard & mobile VR app (eye, n.d) Figure 20: Eye Museum's mobile VR app (eye, n.d)

Authors divide VR experiences into two categories based on the interactivity they offer to museum visitors. One is "VR films" –(3DoF VR) and the other is 6DoF VR. "VR films" are like a typical movie; the user is led through a story that is set in a 360-degree environment. Gabo Arora's "Clouds Over Sidra" is such a film about the real-life of Sidra, a young Syrian

refugee, narrated in her own voice. Visitors will experience the film in an immersive way with three rotational degrees of freedom.

In contrast, '6 DOF VR' are experiences wherein participants decide where they look and where they move, i.e., users have the choice to direct themselves and find the unknown treasure of the surroundings. Char Davies' "Osmose and Ephémère" VR creation falls into this second category. The third category is VR games; although there is not enough indication of its usage in the museum sector. It is also stated that Google Cardboard is the affordable HMD with which visitors can be inside the museum galleries though they are physically at home or some other place. These VR experiences come under the 3DoF VR category (Allen, 2016, p. 22).

In general, when comparing the possibilities of VR and AR, one could summarise it as follows: Augmented reality can turn any place into a gallery, virtual reality allows its participants to exist in any space imaginable.

However, VR technology does not allow the viewer to interact with the physical world, and the viewer might not comprehend the museum object in a real-world context, i.e., simultaneously seeing the real world. As discussed in Styliani's study, VR technology can be fully immersive but needs a lot of hardware setup. It is also a time-consuming process and restricts the free movement of the visitor (Styliani et al., 2009). In this VR usage, there is never any interaction between the viewer and the physical world; instead, the viewer is transported into an entirely new, different world. In VR technology, it is not possible to make the visitor feel like the object is present in the real world, as it does not allow the physical world to interact with the object i.e. interaction between the real world and virtual world at the same time. The immersive experience of the object coming to life in its actual physical context is feasible using Mixed Reality technology, which is the focus of the next section.

2.5. Mixed Reality in Museums

In our daily routine, we work together and share our daily experiences. Working collectively and sharing is the way of our lives. Because MR maintains the view of the physical world, including the people around the user, collaboration and collective experiences are possible.

In Styliani's study, it explains MR as "a combination of VR, AR and the real environment... objects are presented together on a single display" (Styliani et al., 2009, p. 4). The author uses the S.H.A.P.E. (Situating Hybrid Assemblies in Public Environments) project to explain enhanced interpersonal interaction in public places such as galleries and museums. MR is AR with spatial awareness, an extension of AR that allows public interaction.

As there is little evidence of implementation of Mixed Reality technology in the museum environment, I assume that is because the technology is fairly new. I am considering utilising the Microsoft HoloLens, which was introduced around 2016, in the museum context.

In Chen's (2015) study, the possibility is discussed of using HoloLens and Skype in an advanced collaboration method. Traditionally, HMD collaboration allows two or more HMD users, whereas this new collaboration concept allows a single HMD user, and additional companions can join in remotely through Skype-enabled devices such as mobile, tablet or PC. In the traditional HMD collaboration, all the participants need to have their own HMD, which could be a costly process (Chen, Lee, Swift, & Tang, 2015). However, implementation of this Skype collaboration process is possible in a museum, when one person drives the exploration of the museum and rest of the participants to join in with an inexpensive device that runs the Skype application, such as a smartphone. The participants can view what the HoloLens user sees and start interacting by using annotations which are instantly applied to the view of the HoloLens user.

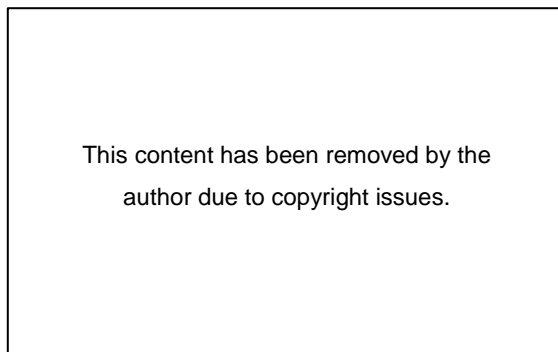


Figure 21: HoloLens and Skype in a tablet collaboration process (Chen, Lee, Swift, & Tang, 2015)

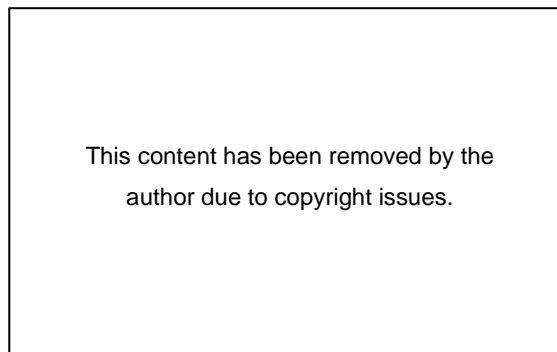


Figure 22: View of the real world (Chen, Lee, Swift, & Tang, 2015)



Figure 23: View from HoloLens (Chen, Lee, Swift, & Tang, 2015).

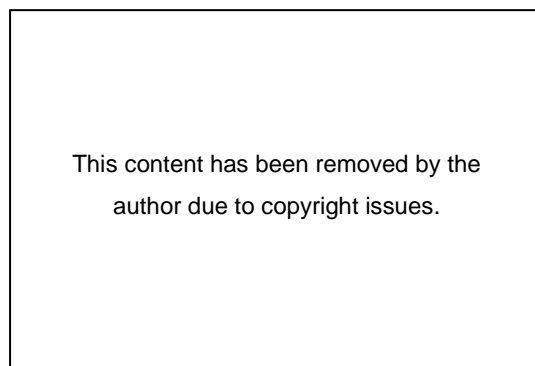


Figure 24: View from the companion device (Chen, Lee, Swift, & Tang, 2015).

Similarly, the study by Yim et al. (2016) explains the benefits of Mixed Reality over Augmented Reality and Virtual Reality. Similar to AR technology, in this MR process, virtual

objects are overlaid onto the physical world (Pedersen et al., 2016; Pollalis et al., 2017). However, in MR, additional to the overlap, virtual items can act together with the physical world in real time i.e., seeing virtual objects and real objects simultaneously, which is not feasible with the VR technology. Moreover, MR permits multiple users to interact collectively with the same object in real time. From a museum perspective, this collaborative feature lets multiple viewers have the immersive experience of the same kind around the same object at the same time (Yim et al., 2016).

Also, the sharing option allows the user to share his or her encounter with his or her friends who can access the data seen or recorded by HoloLens from different locations with their smartphone or PC. The personalisation feature in the HoloLens application makes it feasible for an in-detail analysis of an object.

Furthermore, the Pollalis et al. (2017) study shows how a viewer's interaction with exhibits can play a critical role in keeping them occupied. In this study, they built an MR application called HoloMuse, just like the TombSeer application which enables the user to pick up, rotate, scale and alter the museum 3D artefact using in-air gestures. This study was conducted with the intention of finding out the impact of the HoloMuse application on learning and engagement on art history and archaeology students.

The authors say that those AR applications that use tablets and phones often divert user's attention from the original artefact and its context. The interactions with the artefacts were limited comparing to HMD such as viewing will be virtual object overlaid on the original artefact only and on-screen touch gesture manipulation of the virtual object. In contrast, through HMD such as HoloLens, possibility that the virtual object can be viewed through any angle in a room scale size and interact it a natural way, can be picked up, rotate, placed anywhere within the environment without holding any device. In addition, can be scaled, modify otherwise not always feasible in the real world. By these types of the original artefact, active interaction and cautious investigation of the 3D artefacts will lead to new educational methods to museum and archaeology. Already existing AR mobile applications such as ArteMuse, ArtLinks and Imprints, enabled the visitors to spend more time with the artefact and allowed personalisation, sharing of exhibits. Overall the visitors had enhanced the experience in the museum. However, to date, there is an absence of significant research on how MR applications influence visitor engagement (Pollalis et al., 2017).

In evaluation part of the HoloMuse application, there were no substantial difficulties, but there were complications in composing definite motions, so users need much practice in

dealing with such type of gestures. These issues solved by introducing a tutorial in the HoloLens platform (Pollalis et al., 2017).

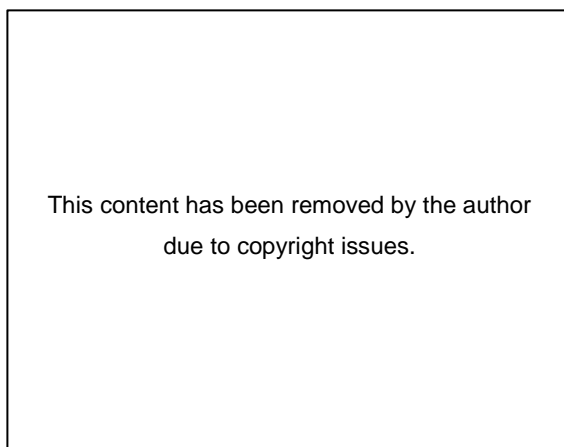


Figure 25: User virtual objects interaction with HoloMuse application (Pollalis et al. 2017)

However, the goal of these two applications TombSeer and HoloMuse is similar, i.e., to make an application that connects history and reality. These applications will give me an idea of HoloLens usage in the museum perspective and the issues which I need to go through while I am working on the Cryolophosaurus MR application. The type of natural gesture interactions which were discussed above will be helpful in my MR research, as I am also going to use HoloLens as part of MR research and the user will be interacting with the Cryolophosaurus object using natural gestures such as pinch to move it. I will be experimenting with these types of gestures and interactions and discuss them in detail in section 5.3.

In the context of implementing the MR application in a museum environment, there are many advantages of it, such as the possibility of interactions with the object as natural as we use in our day-to-do life such as gaze, hand gesture and voice. Additionally, if the museum doesn't have enough room to display their artefacts and exhibits, with the help of HoloLens Holograms museums can provide hidden secrets about the past and deliver great information about artefacts to more visitors, especially to the younger generation. Also, once a particular hologram deploys in a particular position of the museum, all the visitors can experience that hologram in that same position where it got deployed and if they leave the room and come back, it would still be there. It is also possible to make them follow the visitors to whichever galleries they visit. Holograms support 3D spatial sound, so that sounds seem like they are coming directly from the hologram, even if it's out of sight. MR applications

can be a tour guide for visitors. Considering all these benefits visitors can have a new and exciting experience in the museum.

However, as museum staff can deal with up to thousands of visitors per day, the maintenance of the devices will be a great challenge. Current devices on the market are fairly fragile and complex to use, whereas devices for frequent use by museum visitors need to be robust and simplistic. The hardware purchasing cost, their maintenance cost and the cost involved in building the applications also need to consider.

3. Methodologies and Data (Blog)

In order to come to a comparative conclusion within the proposed research, I chose a practice-based approach. The strategy is a creative practice-based methodology, with data collection through documentation and reflective journaling of the project.

Candy's report (2006) explains that new knowledge can be gained through original investigations with the help of practice and its outcomes. This new knowledge and the innovations surrounding it may be exhibited through creative outcomes such as images, models, digital media and exhibitions (Candy, 2006). This philosophy perfectly matches what I am trying to achieve and will help me to find an answer to my research questions (see page 4). This type of research or study requires that practical work is done, and through an evolution process, new concepts and methods are generated in the search for original knowledge.

Through the creative practice-based methodology I have used in my study, I developed new perceptions and understanding through purposeful questions. I documented my process, with all progress and mistakes readily made available online throughout my research journey. Reflective journals have been used to find new ideas, get a better understanding of the techniques used during the development stage and tried new ideas in further stages of the development process. The purpose of "practice by reflection" is to use conclusions to improve practice and to perceive "best practice" (Niedderer & Roworth-Stokes, 2007). For validation, experts from the museum staff acted as project advisors. Frequent feedback sessions were conducted with their help to get input and suggestions for accurate representation in the final exhibition. For data collection, online reference images, videos and audio, plus materials given by the museum curator were used. The self-reflective material was included online, along with visual documentation of the process. The whole process was practical and iterative, with a large problem-solving factor, making sure all the feedback from museum managers was implemented successfully and creatively, to bring the museum display to life. In the end, four systems were compared in the context of technical challenges and expert's opinion for implementation at the museum.

All these development workflows can be further applied to any other artefact of the museum. For example, using these technologies we can bring the Moa or the Huia "back to life", moving around in the fauna section of the museum via MR technology, or ancient sharks swimming around the marine section. They would appear in their real environment through VR technologies and augmented with educational information using AR technologies. That

way, visitors can understand, learn and experience the museum displays in a different perspective in multiple platforms.

By following these workflows, several experiences can be created in an innovative way to facilitate the enhanced experience in the museum environment, and by doing so, fulfil the actual purpose of the museum.

4. Content Development workflow

After going through all the theoretical foundations considered in this literature review section, the next stage is the development of the practical workflow. The aim is to create 4 applications - one for each of the XR technologies presented in Chapter 2. For AR, MR, and 6DoF VR, this involves the creation of 3D models and animations that are used "directly" in the application. For 3DoF VR, I am developing a 360-degree stereo movie, which involves the creation of rendered footage of those 3D models ("indirect" use).

In building these four different application pipelines, the understanding of hardware, its limitations, functionalities of various software used for integrations and building the CG character for those four different platforms, plays a major role. Figure 26 provides an overview of the workflow and pipelines.

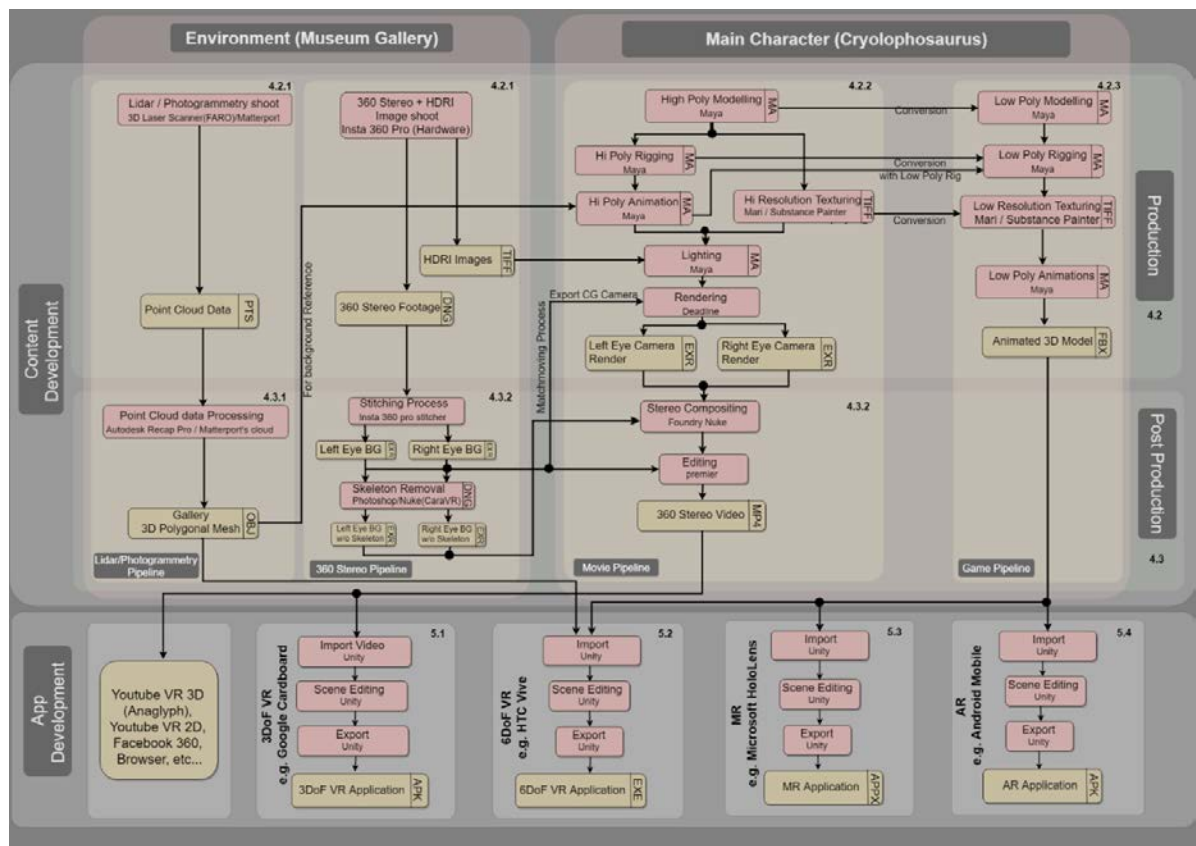


Figure 26: Bringing Cryolophosaurus to life in different platforms: Overall development workflow

I have divided this chapter into three major sections: Preproduction (Section 4.1), Production (Section 4.2) and Post-production (Section 4.3).

Section 4.1 explains the pre-production process involved in building background environment and character development where research focused on finding the best ways

to capture the environment and appropriate approach for building a realistic character. Section 4.2 describes the steps involved in building the CG environment for the sake of creating the 6DoF VR application as well as a background reference for animating the Cryolophosaurus in that environment. In the same section, I will be discussing the process of shooting 360 stereo footage to be used in developing the 3DoF VR application. In addition, section 4.2 also involves building a high poly Cryolophosaurus character as well as the low poly version of it. In section 4.3, I will describe the postproduction process about how the high poly Cryolophosaurus character, and 360 stereo environment integrates to build the 360-stereo video for the 3DoF VR application. In addition, section 4.3 discusses the process involved in converting point cloud data into a 3D mesh environment which will be further used for developing the 6DoF VR application and the challenges involved during the process. I start discussing major sections which explain the content development in detail.

4.1. Preproduction

As a part of this thesis research, the main goal is to bring one of the museum's displays, the Cryolophosaurus character, to life in four different platforms 3DoF VR, 6DoF VR, MR and AR. Considering the nature of these different technologies, the two VR applications (3DoF, 6DoF) need a background environment, while AR and MR are dependent on real environments. So, I will start explaining the steps followed in character development preproduction first then environment preproduction process in detail in the next sections.

4.1.1. Character Development Preproduction

I had visited Auckland War Memorial Museum many times before having this idea of creating an application that would bring exhibits to life. With my passion for dinosaurs, I visited the museum's Origins Gallery and found the Cryolophosaurus skeleton display. I have chosen this display out of another ten major displays that exist in the gallery because of its location within the context of the gallery (shown in Figure 27). From this position, animating the character will be easy and can create an interesting story with the animation in order to make an exciting experience to the visitors.

As a part of this, the main challenge is to tell an interesting story of the subject within the Origin gallery of the museum, making it come to life from the existing skeleton, roaming within that environment and going back to become a skeleton again. When considering the characteristics of the subject—it is an animal, a carnivore, huge in size, with sharp teeth etc.—the story needs to match the traits of the subject. In this context, the subject comes to life in a museum environment which has pillars, TV screens, other exhibits, etc. So, the story

is built based on understanding the characteristics of the subject, the limited space/props available in the background and especially considering the viewer who is watching the subject from a fixed position (3DoF VR) in mind. First, to establish the wildness of subject, it was animated to attack the TV screen as it sees some movement happening on the screen, then walk around the pillars observing all the existing displays. Meanwhile it feels that someone is watching it, then comes closer to the camera (viewer) and realises no one is there then going back to become a skeleton again.

This story was devised to create some interest in the subject by utilising its traits—including a bit of scariness—from the viewer perspective. People can stand near this installation and use their mobile along with Google Cardboard or any other VR headset, they can view the 360 VR story in 3D. One of the considerations when choosing this exhibit was to reach a broad range of museum visitors, as there is enough setup space to demonstrate the artefact to the public at this Cryolophosaurus skeleton location.

For the building of the Cryolophosaurus character, I researched its history, its shape, skin pattern and possible behaviours by watching related movies and analysing the information at the museum (shown in Figure 29, Figure 30 and Figure 31), so that I could represent the final output as realistically as possible.



Figure 27: Location of the Cryolophosaurus skeleton at the Origin Gallery

Next, I started collecting information about the Cryolophosaurus from resources such as academic journals (Zimmerman, 2000), online articles (Museum, 2017), online images (see Figure 31) and information provided at the Auckland Museum (see Figure 28, Figure 29 & Figure 30). Information about its appearance helped me during the 3D modelling stage, and to get a better understanding of its head shape and volume, I sculpted it in clay (see Figure

32). The gathered information was also included in the 3DoF VR voiceover and texts in the 6DoFVR and AR applications.

The Cryolophosaurus existed during the Mesozoic era, which was divided into three different time periods:

1. The Triassic Period – 245 Million Years Ago to 205 Million Years Ago
2. The Jurassic Period – 205 Million Years Ago to 140 Million Years Ago
3. The Cretaceous Period – 140 Million Years Ago – 65 Million Years Ago

Dinosaurs are divided mainly into two groups as per their bone structure: saurischian ("lizard hipped") and ornithischian ("bird hipped"). The saurischian group is further divided into two subgroups: theropods (two legged) who are also carnivorous (meat eaters) and sauropods (four legged) who are herbivorous (plant eaters). Considering the information provided by Zimmerman, Cryolophosaurus belongs to Jurassic period, theropods family and saurischian category which based on the lizard-hipped. The Cryolophosaurus is also called "frozen (cold) crested lizard" (Zimmerman, 2000).

Cryolophosaurus signifies the largest genus theropod known from the early Jurassic period of Antarctica, i.e. 188 million years ago. Cryolophosaurus is distinguished by a unique cranial crest, produced mainly by the lacrimals (part of eye socket bones). This distinguishes it from all other theropods. It is estimated to measure 6.5m in body length and 465 kg in weight. Its fossil was discovered on Mt. Kirkpatrick, Antarctica, by Palaeontologist Dr William Hammer in 1991 and the first carnivorous dinosaur to be found in Antarctica (N. D. Smith, Makovicky, Hammer, & Currie, 2007).

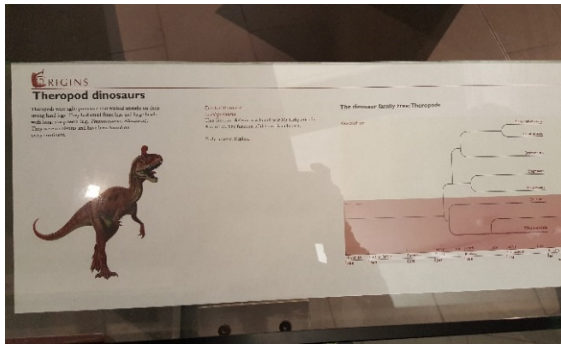


Figure 28: Information at the Auckland Museum

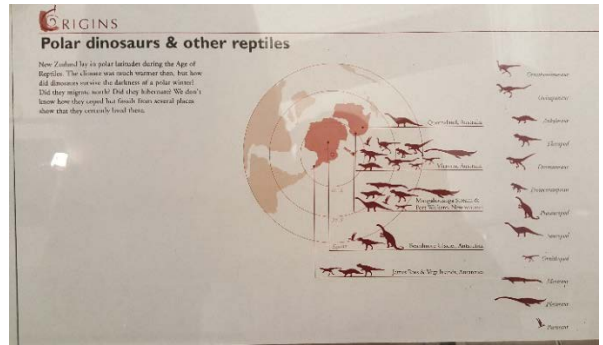


Figure 29: Information at the Auckland Museum



Figure 30: Museum Cryolophosaurus Skeleton

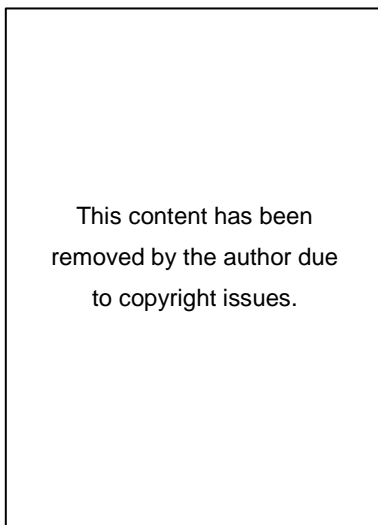


Figure 31: Online reference image (Illustraciencia,2018)



Figure 32: Clay Sculpt

4.1.2.Environment Preproduction

For the two VR applications, two different types of background environment are needed. One is the stereo image environment for creating the 3DoF VR application, the other one is a 3D environment for developing the 6DoF VR application. Creating these two types of environments required two different approaches and needed two different types of equipment to capture the environment. A specialised 360-degree camera (Insta 360) was used to capture stereo image footage, whereas a laser scanner (Faro Focus 3D) was used to capture point cloud data of the gallery space.

In the context of launching these products to the public, I visited the museum to find out if there were any previous installation at Auckland museum to take reference from. As seen in Figure 4, the Auckland Museum VR installation setup was done in a corner using an Oculus Rift, which is demonstrating the usage of artillery in World War II. This installation is which is independent of any physical museum artefact. The HMD was connected via a wire and the CPU was is fixed inside a wooden box.

When it comes to demonstrating the Cryolophosaurus skeleton coming to life, the position of the 360 camera is important as it is the point of view from which the visitor will experience the scene. In addition, camera position needs to be exported as a CG camera into Maya software for the story animation and rendering phase (see section 4.3.1.5). The camera position of the camera needs to be chosen so that the 3D character has enough space to move around in the origin gallery, interact with the camera in an extremely close position and in the end go back to origin position to become a skeleton again. All this story experience can happen in an immersive manner if the museum installs a VR device similar to the Oculus Rift installation mention above or on a 2D screen if they install a tablet device. By considering all these requirements, the 360-camera position was fixed (shown in Figure 33) during this process. The height was chosen to be that of an average standing person. That way, a visitor putting on the headset which would be installed in the same position, would experience a seamless "transition" to the virtual space.

When it came to lidar shooting, the position of the device was not as considered, as the purpose of the shoot was to create a 3D environment. To create point cloud data, the device needs to be positioned in several locations to cover a maximum of surfaces and to generate enough overlapping data for the reconstruction process. Figure 34 shows the lidar shoot from one position. Considering the restriction in shooting time extra precautions were taken to make sure most of the available time is used for shooting only.



Figure 33: 360 Stereo Shoot with Insta 360 Camera



Figure 34: Lidar shoot with Faro device

4.2. Production

The production stage focused on two major parts. Firstly, capture the environment as per the requirements for creating VR applications and, secondly, build a Cryolophosaurus character that can fit into four different platform pipelines. Considering this direction, the production stage was divided into three sections (shown in Figure 35).

Section 4.2.1 explains the process of Environment “Capture/acquisition”. Section 4.2.2 describes all the production stages involved and implemented in building the high-res character, such as modelling, texturing, rigging, animation, lighting and rendering sections. Lastly, section 4.2.3, the low-res pipeline, gives details about the steps followed in creating a low-poly character.

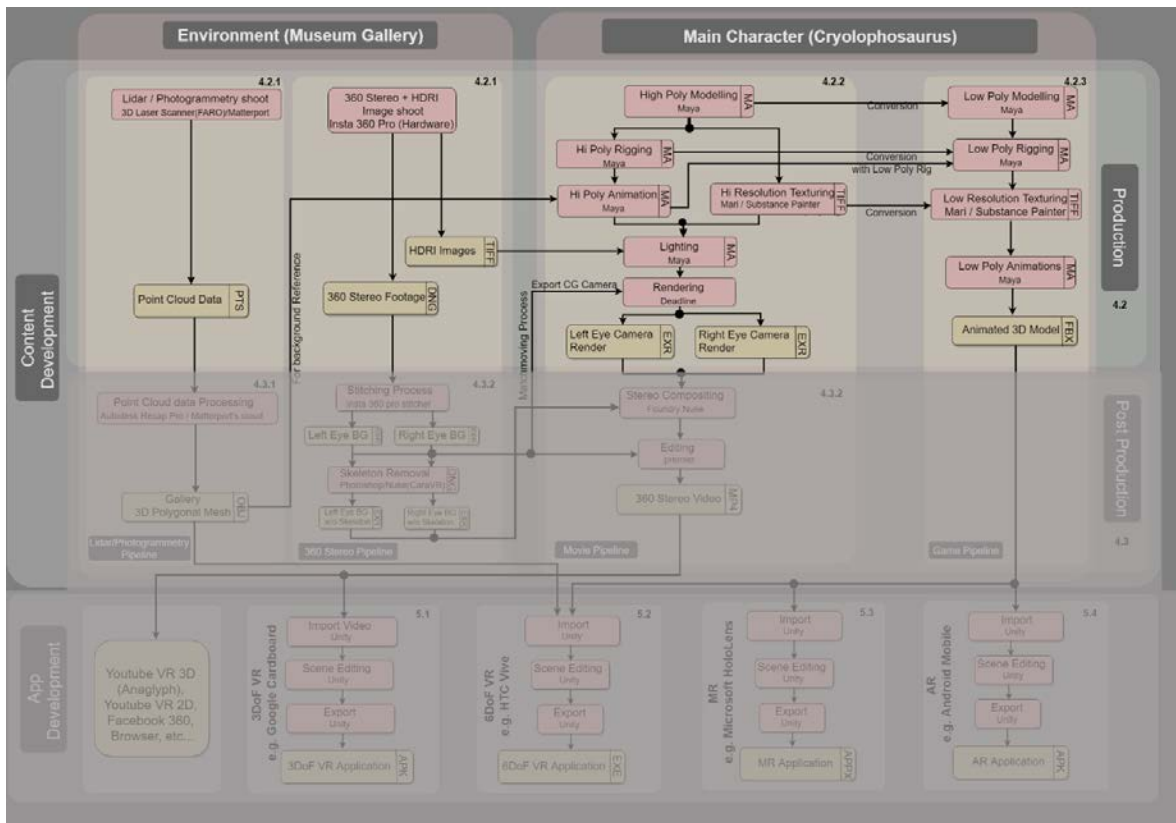


Figure 35: Content development Production workflow

4.2.1. Environment Acquisition

As per the requirement of 3DoF VR and 6DoF VR technologies, two types of environments were needed: one was the stereo 360-degree image, the other one was a 3D environment. The following two subsections describe the acquisition process of those using a 360-degree stereo camera (Subsection 4.2.1.1) and a Lidar laser scanner (Subsection 4.2.1.2).

4.2.1.1. Insta 360 Shooting Process

The purpose of the shoot with Insta 360 Pro Camera shown in Figure 36 was to create stereo background (BG) images in multiple locations to use them in CG character integration for creating the 3DoF VR application. Another target was to develop HDRI images in multiple locations to use them in Maya software as an image-based lighting (IBL) for creating appropriate CG character lighting, which in turn was needed to match with the BG as part of the 3DoF VR application development process.

Despite all the preparations (as mentioned in section 4.1.2), there were a few challenges during capturing time. For example, for the 360 shoot, the centre position of the tripod plays a major role as this live-action-camera position will be used to create the CG camera with the positions of both needing to match for CG character integration with live action footage.

Other challenges included a limited two-hour time window from 8am–10am for the shoot due to museum opening times, staff availability, and security issues for the shoot, i.e. making sure there were no people at the Origins Gallery at the time of the shoot. Lastly, there were technical issues—camera operation using an application with appropriate settings (shown in Figure 37 and Figure 39). Due to all these reasons, it took me three visits to gather all the required materials.



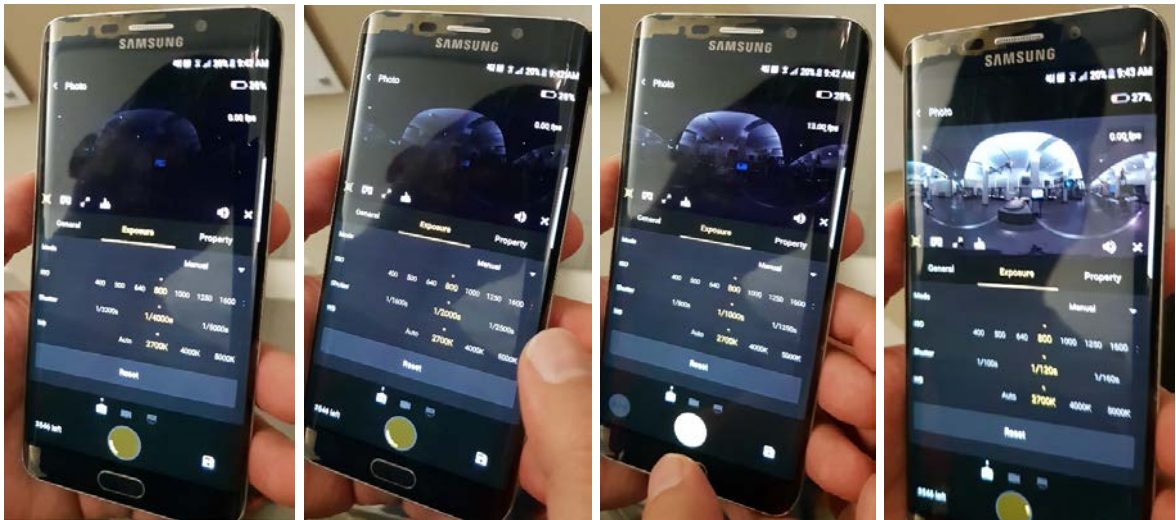
Figure 36: Insta 360 Pro Camera



Figure 37: Setting up the came with the Mobile Application



Figure 38: Output from Insta 360 Camera with 6 stereo images from 6 fisheye lenses



(A) 1/4000s shutter speed (B) 1/2000s shutter speed (C) 1/1000s shutter speed (D) 1/120s shutter speed

Figure 39: HDR image creation with different exposure settings

4.2.1.2. Lidar Laser Scanning Process

The Faro Focus 3D is a high-speed laser scanner used to capture point clouds of three-dimensional images of complex environments in a matter of few minutes. The resulting dataset is a combination of millions of points in 3D space known as point cloud that provides an exact digital reproduction of the physical world. I used the Faro Focus3D device shown in Figure 40 which is a small-scale hand-held device that has a touchscreen interface and also works with a mobile app for its operation shown in Figure 41. The converted digital data can be used in Virtual Reality production (Faro Focus 3D, 2013).

Even though it only takes few minutes to capture one location, complex environments require a number of scans, which adds up to the overall capture time of several hours which is not ideal in a commercial or industrial environment. The post-production work to manage a large number of data points requires specialist software and high-end hardware systems (Faro Focus 3D, 2013).

The purpose of laser scanning was to capture the Origins Gallery point cloud data, convert into the 3D mesh and use it in the virtual reality production. Due to the limited access time to the location, I was not able to cover sufficient positions and captured only two-point clouds.

Since I only captured the data at two spots, this resulted in a poor quality of the point cloud data which in turn resulted in a poor 3D mesh and low-quality textures. The process of converting point cloud data into 3D mesh will be explained in the postproduction section.



Figure 40: Faro Focus3D Laser Scanner

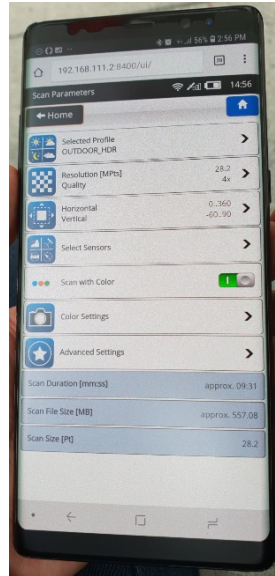


Figure 41: Faro mobile screen interface

4.2.2. HighRes Pipeline

Before describing in detail the CG production process, I would like to point out the reason for the two major modelling workflows in this phase. Applications for AR, MR, and 6DoF VR run in real-time and therefore need to work with simplified 3D models. The workflow for this kind of content is similar to that used in the gaming industry.

In contrast, the 360-degree movie for the 3DoF VR application can be rendered "offline" and therefore allows for higher quality and complexity of the 3D models. This offline workflow is similar to industrial CG movie production. The main differences between those two workflows are highlighted in the following table:

	Movie production	Game production
Model	High polycount (millions)	Low polycount (thousands)
Textures	Multiple of 4K & 8K	Only 4K and below
UVs	Multiple UDIM ¹	Single UDIM
Rigging	More controls	Fewer controls
Materials	Complex	Simplified
Final Quality	High	Low to medium
Camera	Fixed camera (to view)	Full control on the camera (play)
Experience	watch the story from one angle	Interactive, user can drive the story
Performance	Hardware independent	Hardware dependent
Render	Pre-rendered (slow)	Real-time (faster)

Table 1: Movie and Game pipeline differences

CG Character development was a very complex process, as it was aimed at the high-quality output for a 360-stereo environment. 360 stereo image and video formats are not as common as other existing file formats such as png, jpg and mp4. The 360 stereo video production is still in its infancy and there are no established best practices to follow. Considering this situation, there were some challenges in each stage to fulfil the requirements of 360 stereo production. In the modelling stage, developing a highly detailed CG character dealing with 64.5 million polygons was a big task. It needed high-specification hardware to render such a large mesh. I will explain the handling of this big task in detail in the below sections.

Once I had finalised the character and gathered all the information needed for the development of the 3D character in CG preproduction stage, I moved on to the CG production stage, which is made up of six sub-stages (shown in Figure 35):

4.2.2.1: Modelling: Development of a high-poly model

4.2.2.2: Rigging: Rig the 3D models of the high-poly model

4.2.2.3: Texturing: Build in the textures for the high-poly model

4.2.2.4: Animation: Animating the 3D character in the museum environment to make the visitor feel that it is alive and moving around them.

¹ Seymour, M. (2014). *UDIM UV mapping*. Retrieved January 5, 2019, from <https://www.fxguide.com/featured/udim-uv-mapping/>

4.2.2.5: Lighting: A process that involves matching the lighting of the character with live action footage.

4.2.2.6: Rendering: Combining all the above stages for final compositing.

These stages are similar to 3D film production. In most of these stages, I have used industry-standard 3D software “Autodesk Maya” (Autodesk, 2019). For texturing “Foundry Mari” (Foundry, n.d), “Allegorithmic substance-painter” (Substance by Adobe, 2019) and for rendering “Thinkbox Deadline” (Deadline, 2019) software were used. Alternative software, such as 3DS Max or Blender can be used, instead of Maya. Similarly, Photoshop or ZBrush can be used for texturing. Backburner can be used as an alternative for Deadline network rendering software.

4.2.2.1. Character Modelling Process



Figure 42: Reference image for modelling (PopCultMedia, (n.d))

I started modelling the Cryolophosaurus 3D Character based on the image shown in Figure 42 as well as by referencing the museum exhibit, along with the theoretical knowledge of museum curators.

Some creative freedom was taken to make the Cryolophosaurus as interesting as possible. One example of this is the lizard-like look of the face due to the name Cryolophosaurus meaning “frozen-crested lizard”. At first, I followed the reference image while modelling (shown in Figure 43), then later modified its lower jaw more towards a lizard-look to match its face to its name “frozen-crested lizard” (shown in Figure 44).

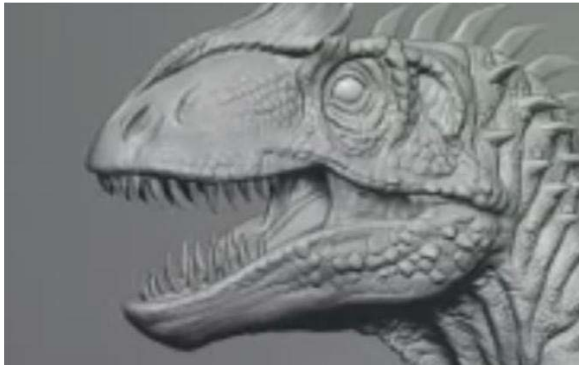


Figure 43: Normal – Followed reference

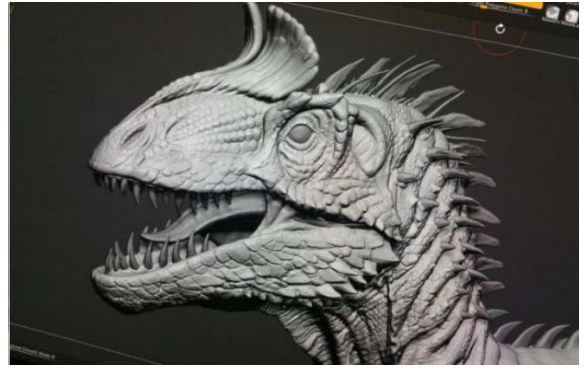
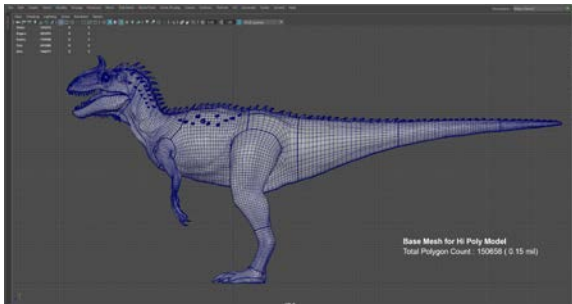
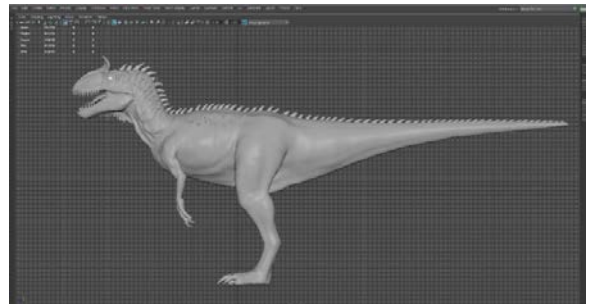


Figure 44: Lizard look mainly at the lower jaw

In generating the highly detailed 3D model, I followed the general “movie 3D production pipeline”. The key points to consider in the modelling process were: the number of polygons the character is made up of, and the topology of the model (shown in Figure 45). Those aspects must be suitable for the further pipeline, i.e., the edge loops of the whole 3D character need to be fit for the rigging process as well as the texturing process (shown in Figure 46 and Figure 47 with red outline) (Danan, 2016).



(A) Edge loop display on



(B) Basic lambert material

Figure 45: High-poly base mesh (150658 polygons)

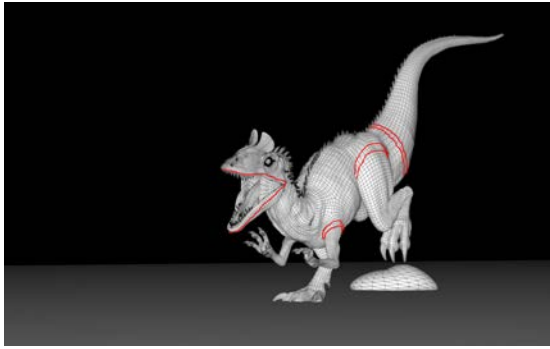


Figure 46: Importance of Topology in character movements

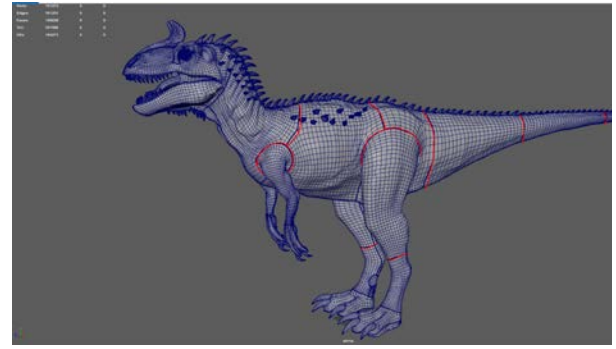


Figure 47: Importance of Topology in Texturing UV layout process

Once the base mesh with 150658 polygons shown in Figure 45 (A) & (B) was created by using Maya software with proper edge flow then this base 3d model was taken further into ZBrush software for adding high details to the character to create a realistic Cryolophosaurus creature.

ZBrush modelling Process

In order to add details to the 3D character, there are two main software tools in the market; one is Pixologic ZBrush and the other is Autodesk Mudbox. Having an industry background, I chose ZBrush, which has extra tools for creating a highly detailed character and is capable of handling high poly count meshes. The high-resolution mesh is needed because in the 360-degree video there are extreme close-up shots and the 360-video has a planned resolution of 4K.

As I was aiming to create a realistic/believable character the body base mesh which was 150,658 polygons in ZBrush subdivided to became 40.403 million polygons and the whole high-polygon model ended up becoming 64.5 million (shown in Figure 48 and Figure 49), adding extra details to each part of the model (shown in Figure 50 (A), (B), (C) &(D)).

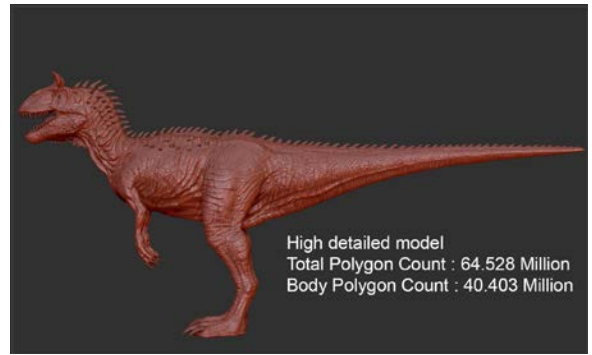
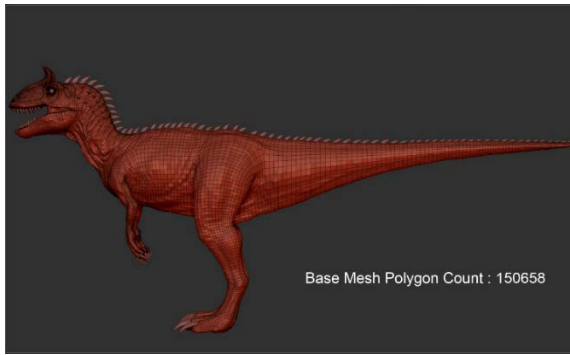


Figure 48: Cryolophosaurus body Base mesh - ZBrush

Figure 49: Cryolophosaurus body high-poly mesh - ZBrush

Processing such a high polycount mesh requires high-spec computers with sufficient RAM (Minimum 32GB) and high-performance 3D graphics card (e.g., Nvidia 1080). This whole modelling process is typical industry-practice level.



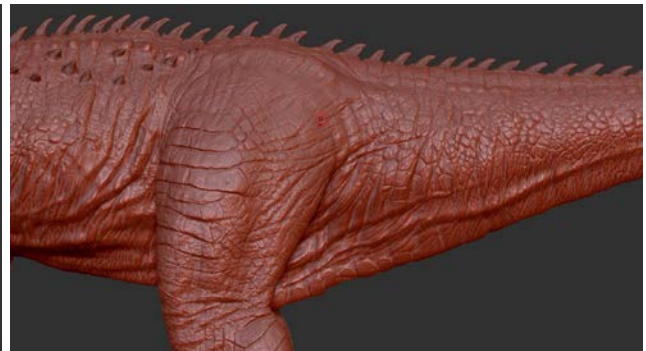
(A) Head details



(B) Hand details



(C) Feet details



(D) Body details

Figure 50: Added details to each part of the model

4.2.2.2. Character Rigging Process

The rigging stage is a crucial step in the animation pipeline. To create realistic dinosaur (Cryolophosaurus) movements, the character rig needs to have a lot of advanced controls, so that during the animation stage no limitations in creating extreme poses and subtle secondary movements—such as neck and thigh muscle movements—are experienced. Rigging is the process that sits between the modelling and animation stage, making sure the mesh is deforming as per the movements needed without distorting it unrealistically. Creating a high-standard rig requires a lot of back and forth between testing and refining until you have a rig that can fulfil the required movements in the animation process. The Cryolophosaurus rig model is shown in Figure 51.

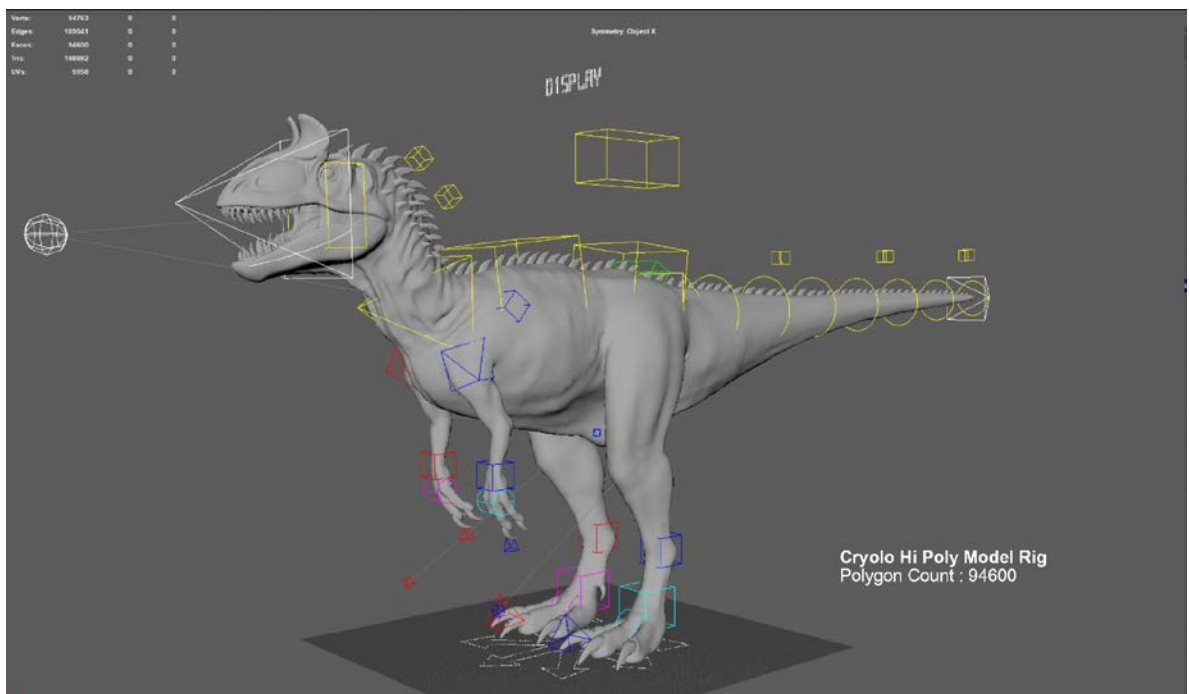


Figure 51: Cryolophosaurus Rig Model



Figure 54: Substance painter software for the base layer



Figure 55: Mari software for creating high-resolution textures



Figure 56: Texture nodes set up in Maya

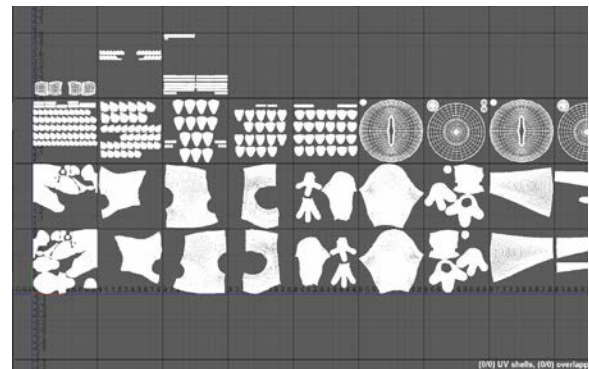


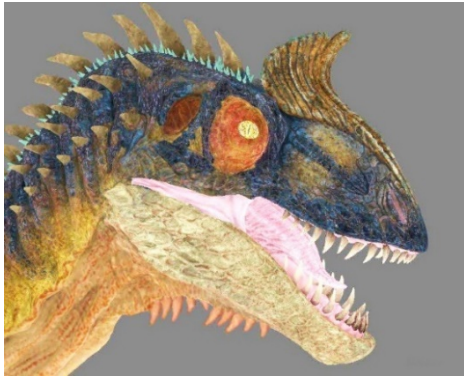
Figure 57: UDMI method for creating hi-resolution textures

For this project, a body 3D mesh of nineteen UDIM sets was created. Following this UDIM method for creating UVs and by using Mari, I created all the required textures and texture nodes in Maya such as a colour map, bump map, displacement map and specular map.

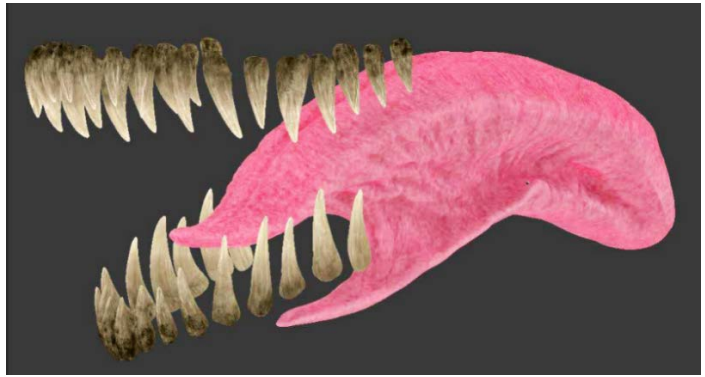
While using Mari and Substance Painter for creating textures, I found some technical differences in both of them. Mari supports a lot of data and comes with a lot of advanced features specially designed for creating high-resolution textures. It is mainly used in VFX feature film production, where the high level of resolution required for extreme close-up shots is needed. It is very good at dealing with texture seams of different UV sets. It needs a high performance PC/hardware to be able to deal with multiple UDIMS and painting highly detailed textures.

In contrast, Substance Painter is targeted for creating textures easily, and comes with a large set of presets called "smart materials" that can easily be adjusted and customised through parameters. I used Substance Painter mainly for the gaming pipeline. Texturing at seams with different UV sets is an issue. So considering these above differences between Mari and Substance Painter, Mari is more suitable for the 360 stereo pipeline for creating high resolution detailed textures. Few parts of the Cryolophosaurus textures (shown in

Figure 58 (A), (B),(C) and (D)) and for different colour variations (shown in Figure 59 (A),(B),(C)& (D)).



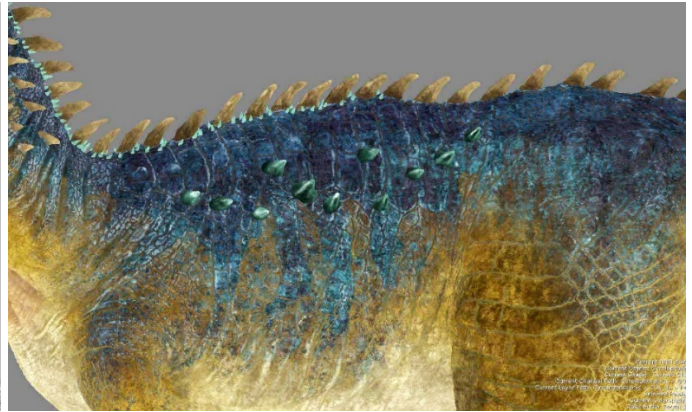
(A) Closeup textures for Eyes



(B) Teeth and tongue

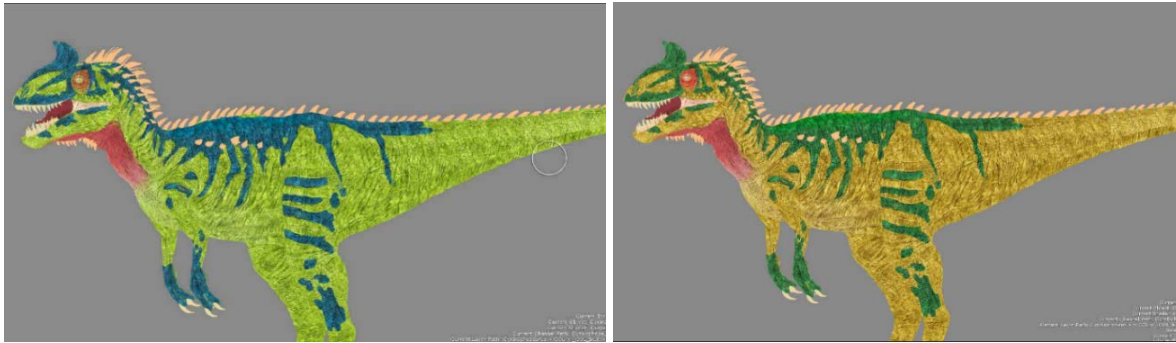


(C) Nails and feet



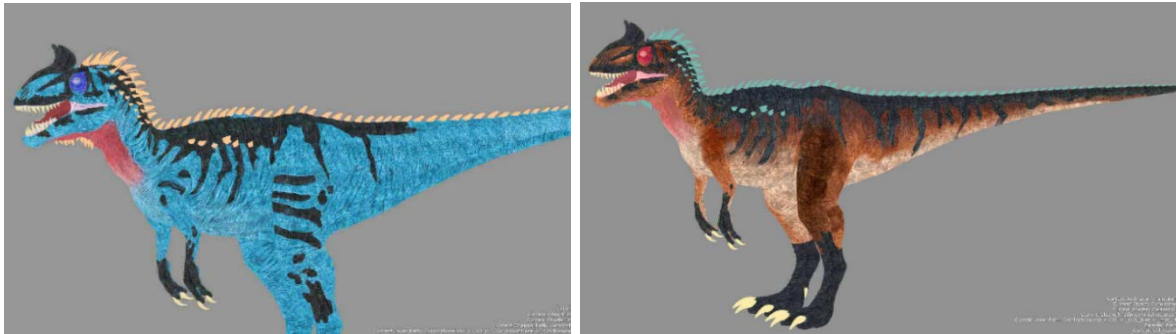
(D) Body and spikes

Figure 58: High detail textures for each part



A) Green

(B) Yellow



(C) Blue

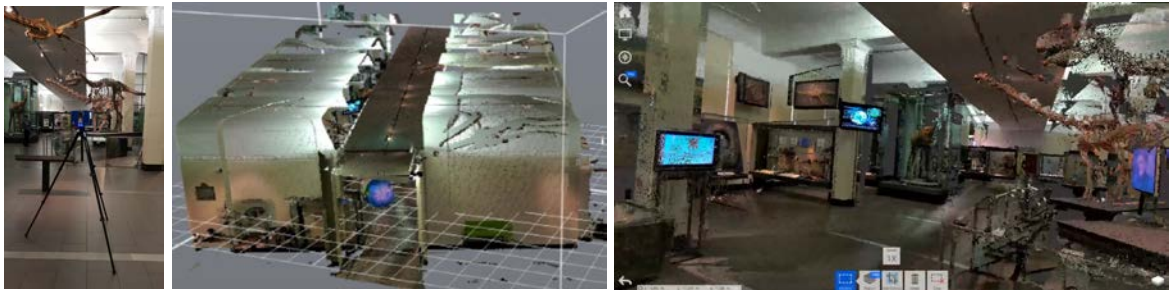
(D) Brown

Figure 59: Different colour variation textures

4.2.2.4. Character Animation Process

The next stage is to animate the 3D Cryolophosaurus character. There were a few challenges I needed to address in order to create realistic, believable animation. First, the artistic challenge, i.e. creating a believable, realistic and convincing movement within the Origins Gallery environment and, second, how to create those movements technically. To the artistic challenge, I studied a lot of dinosaur films and documentaries to observe dinosaur movements such as roaring, walking and jumping etc. To address the technical challenge, I used the 3D mesh created via the lidar scanning process (shown in Figure 60 (A), (B) and (C)). As explained at the beginning of the animation process, how the story was developed and Cryolophosaurus animation was planned considering the museum background, this CG environment supported the implementation of that story. For example, the BG was used as a reference for avoiding mesh penetration through ground/walls/ columns/ shelves etc. as well as helped in accurate foot placement on the ground to create believable animation. These details are important to support the illusion that this character really exists in that environment. In addition, this CG environment helped in creating accurate reflections, lighting and shadows, the process of which I will discuss in further sections. The detailed CG environment building process will be discussed in section 4.2.1 & section 4.3.1.6. So,

by using all these strategies I was able to fulfil the challenge mentioned above. Figure 61 shows one of the key movements of the Cryolophosaurus interaction with the CG environment created through lidar shoot.



(A) Lidar shoot (B) Point cloud mesh

(C) Autodesk Recap software for converting 3d Mesh

Figure 60: Lidar scanning process

This environment 3D mesh was able to help in matching the position and size of the Cryolophosaurus character with a skeleton position and its size. The volume of the 3D mesh helped in animating the character as per the length and width of the gallery. Props, which are the parts of the environment such as the TV and the rock, helped to pose the 3D character so as to perfectly match its interactions (shown in Figure 61). This same animation was used in three applications—360 Stereo, VR and MR—to compare the applications in building their production pipeline, technical challenges while implementing their production.

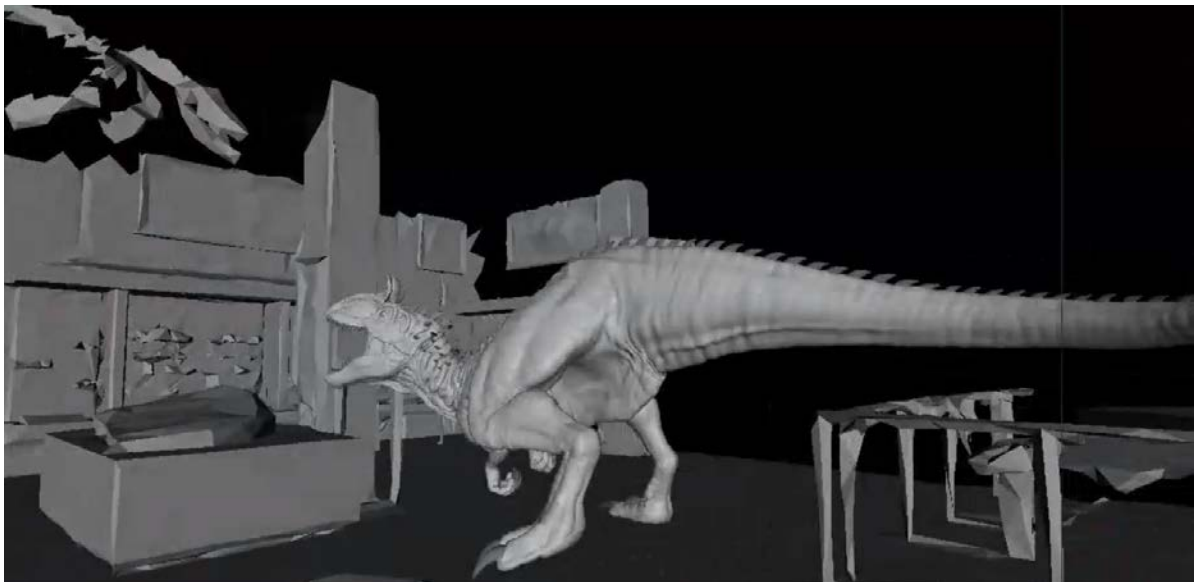


Figure 61: Key movement of the character interaction with the environment.

4.2.2.5. Character Lighting Process

A subpart of the production stage is lighting the 3D character as a part of 360 VR application production pipeline. The main target of this lighting stage is to match the CG character lighting with 360 stereo live footage, the creation of which I will be discussing further in sections 4.3.1.1, 4.3.1.3 and 4.3.1.4. CG character lighting matching with live action indoor origin gallery lighting was achieved through HDRI images created with live action footage explained in section 4.3.1.2 combined with customized CG lights in Maya software.

In this lighting stage, HDRI images from the environment shoot were imported into Maya software and used as a light source reference (shown in Figure 62) to support overall scene lighting (shown in Figure 63). So, the combination of HDRI image as a light source and custom created CG lights helped in matching the CG lighting with 360 live action image. A lighting reference shoot at the Origins Gallery taken as a shadow reference (shown in Figure 64(A) and (B) for creating realistic shadows that perfectly match with live action footage. Applying all these strategies, along with importing all the high-resolution textures, I could set up the CG lighting scene for rendering (shown in Figure 65), which I will be discussing in the next section.



Figure 62: Light sources from 360 Live action Image

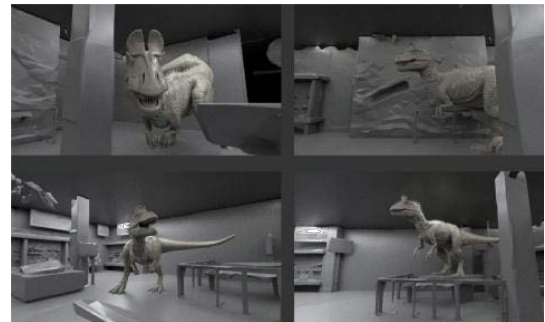


Figure 63: CG lighting test to match with 360 live action Image



(A) Position 1



(B) Position 2

Figure 64: Shadow reference at Origins Gallery



Figure 65: 3D Cryolophosaurus CG lighting test render

4.2.2.6. Character Rendering Process

By far the largest task in this whole CG production pipeline was rendering the high-polygon model with high-resolution textures in 360 stereo format. This was possible only with an advanced network rendering software like Deadline. Without Deadline, which manages a cluster of computers serving as a "render farm".

The scene was rendered with a Maya Stereo camera—which needs to be generated in 360 stereo format—which is perfect for matching with a live-action camera. So that when CG rendered images combine with live action footage they need to integrate smoothly, the final output needs to be realistic and the viewer feels that the character really exists in that environment. This CG camera generation process will be discussed in section 4.3.1.5.

During rendering, I set up different rendered passes in the Maya software using “Arnold Render Engine” (shown in Figure 70). Each rendering pass allows you to modify a single attribute, thus greatly saving rerendering time by avoiding the need to re-render images. For example, if I needed to adjust the specularity of the character to match with background

lighting, by just manipulating only the specular pass, the character lighting can be fixed. This manipulation won't disturb the other attributes of the character.

Different render passes generated through the rendering process are shown in Figure 66. The shadow pass is shown in Figure 66 and is a result of the reference shoot at the Origins Gallery described in the previous subsection. Similarly, following a reflection reference shoot (shown in Figure 68), I created a reflection pass output (shown in Figure 69).



(A) SS pass

(B) Direct SS pass



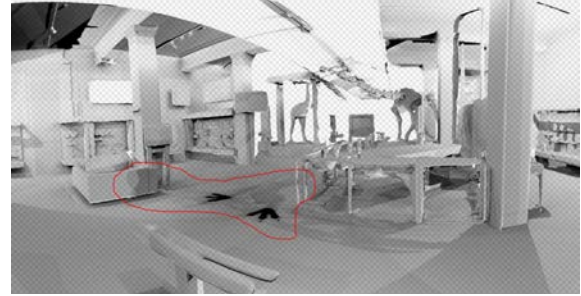
(C) Indirect Specular pass

(D) Direct Specular pass

Figure 66: Different render passes output



(A) Shadow pass with environment hidden



(B) Shadow pass in the environment context

Figure 67: Cryolophosaurus shadow pass output



Figure 68: Reference shoot for reflection at the origin gallery



Figure 69: Cryolophosaurus Reflection Pass

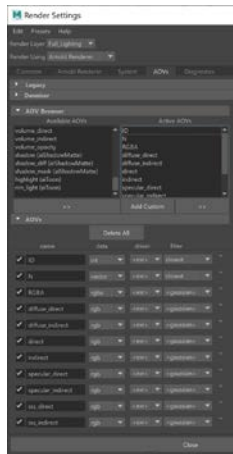


Figure 70: Render pass setup in Maya

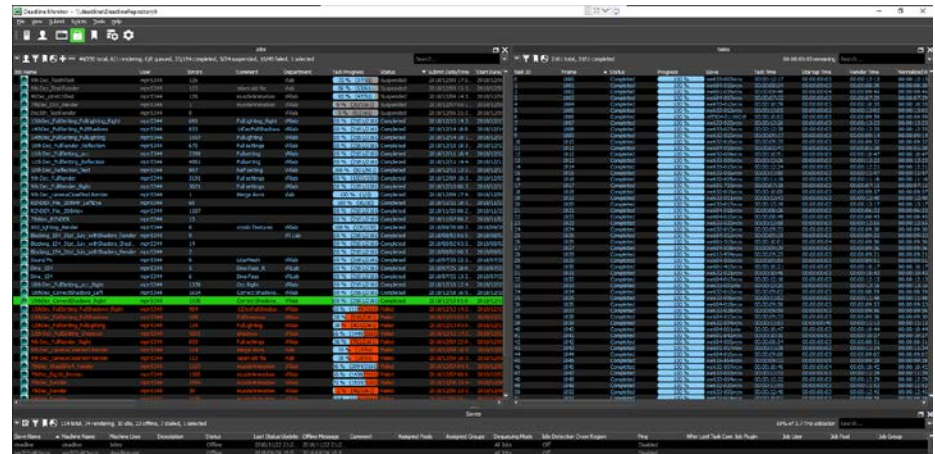


Figure 71: Deadline rendering software

The next challenge was rendering the animated Maya scene to get a highly detailed, believable-quality rendering with 4K resolution. When rendering 3160 frames of animation with a 4k resolution with 360 VR format, with two cameras, one for the left eye and one for the right eye, at minimum two minutes per frame, the total render time with one PC was around five days for one camera. By adding in a second camera, the total hours became 10

days. Any small errors in the rendering process would further extend the render time period significantly. To overcome this render time issue, I used Deadline (shown in Figure 71) a parallel network rendering software. This reduced the overall rendering time from five days to one day per camera by using around 70 computers. Before finalising the render setup, I carried out some low-quality, fast rendering to get some quick results to test the rest of the pipeline and for optimized render settings.

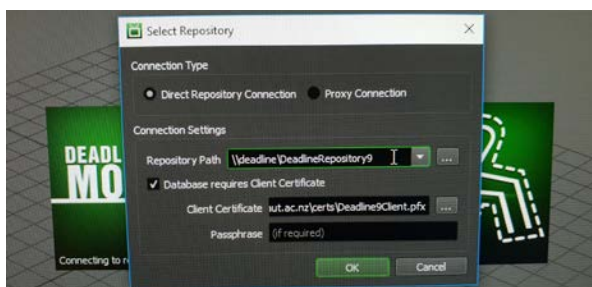
During this rendering process, there were many unexpected problems, such as character rig issues, missing frames, mesh distortion, mesh penetration with a camera, texture problems and render engine problems etc. (shown in Figure 72 (A),(B),(C) and (D)).



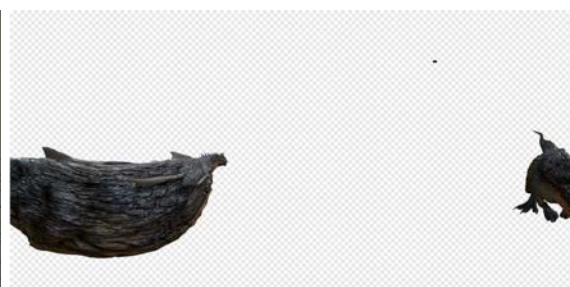
(A) Displacement map error



(B) Camera Penetration



(C) Deadline repository error



(D) Mesh distortion

Figure 72: Unexpected render problems during the production

By following all these above-mentioned strategies in each stage, I managed to get CG stereo footage, which was further merged with stereo Live action stereo footage. This process, which will be explained in section 4.3.2 (shown in Figure 129), is used for developing the 3DoF VR application. In the next section, I will be discussing the building of the low-poly model, the creation of its textures and rigging of it, which is an optimization process for making the Cryolophosaurus 3D character suitable for the AR, VR, MR production pipeline.

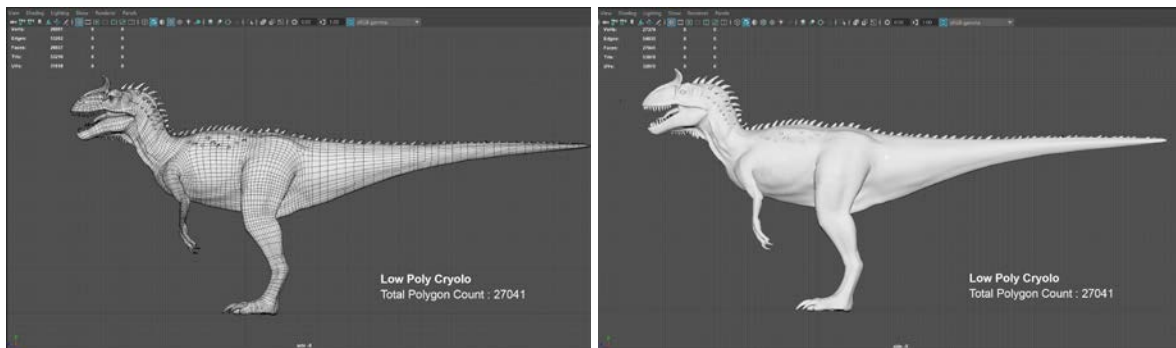
4.2.3. LowRes Pipeline

This section will be describing the general game pipeline procedures for creating assets that are of lower resolution to allow XR applications to run smoothly at high frame rates. As part of the game pipeline, this section is subdivided in to four sections.

1. Low-Poly Modelling
2. Low-Poly Rigging
3. Low-Poly Texturing
4. Low-Poly Animations

4.2.3.1. Low-Poly Modelling Process

After successfully completing the high-poly model (see section 4.2.2.1) , it is possible to create a low-poly version of the model as part of the optimisation workflow for assets that can be used in real-time AR, MR, and 6 DoF VR applications.. The topology of the low-poly model is also very important to fit into further production process such as rigging and texturing, a similar process that is followed in high-poly production also. The low-poly “Game production pipeline” model is mainly about creating a model where all the details come through textures instead of from the 3D mesh.



(A) Edge loop display on

(B) Basic lambert material

Figure 73: Low-poly model with proper topology (27041 Polygons)

The base mesh used for creating the high-polygon model was also used as a base for creating the low-poly model. In the process of poly reduction, special care was taken to keep the key edges and maintain the proper topology to use in the further production pipeline. In this low-poly optimisation process, the base mesh consists of 150,658 polygons (shown in Figure 45) was reduced down to 27,041 (shown in Figure 73) keeping the appropriate edge loop. I followed a general modelling process to create a 3D Cryolophosaurus skeleton model (shown in Figure 74) to match the pose of real skeleton located in the museum (shown in

Figure 75) to use it in the 6DoF VR production. Once the required models were created, I moved onto the rigging process.

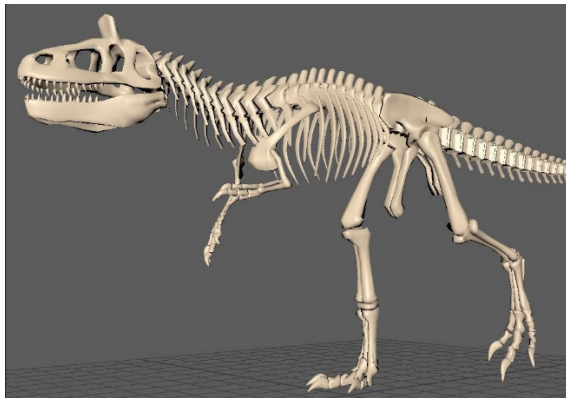


Figure 74: Cryolophosaurus 3D skeleton model



Figure 75: Reference Image followed for creating a 3D skeleton

4.2.3.2. Low-Poly Rigging Process

After successfully completing the rig for the high-poly model (shown in Figure 51), the rigging of the low-poly model becomes an easier task because the existing high-poly mesh, rigging joints and controls can be re-used by fitting them to the low-poly mesh and re-skinning its mesh (shown in Figure 76).

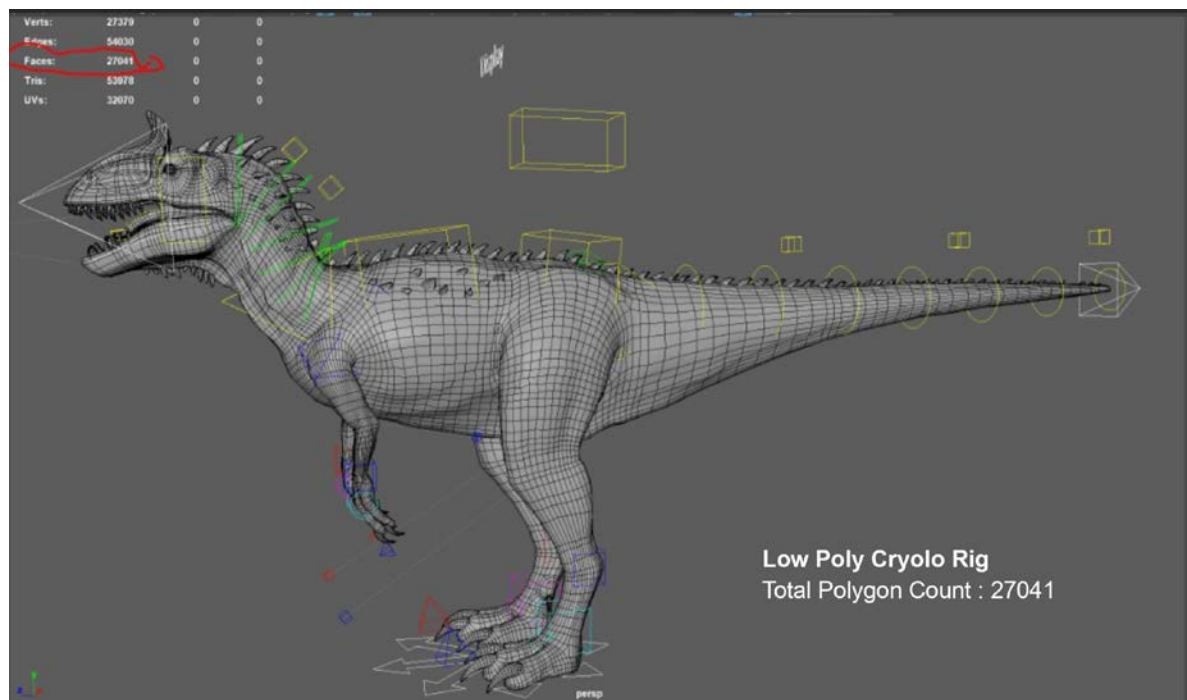


Figure 76: Cryolophosaurus low-poly model rig

4.2.3.3. Low-Poly Texturing Process

In contrast, to the multiple UDIM sets used in the high-resolution texturing pipeline (shown in Figure 57) only a single UDIM set is used in the low-poly texturing pipeline shown below images. As Unity software supports a maximum of 8k (or 4k depending on the target hardware) resolution textures and a single UV set for providing better performance in the final applications, I followed these technical limitations in this project. As a first step I reduced 19 UDIM sets into a single UDIM set (shown in Figure 77) and used already created high-resolution textures of the high poly model, converted to low-resolution textures to fit the single UDIM set (shown in Figure 78, Figure 79 and Figure 80). The final output of the low-poly model with textures applied is (shown in Figure 81). So, the process for creating low-poly textures has become easy as I used already existing textures of the high-poly model and adapted them to the limitations of Unity software.

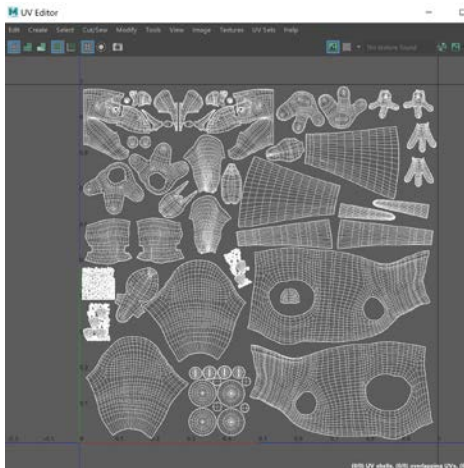


Figure 77: Single UV set layout



Figure 78: Optimised Texture in 1 UVset - Color Map

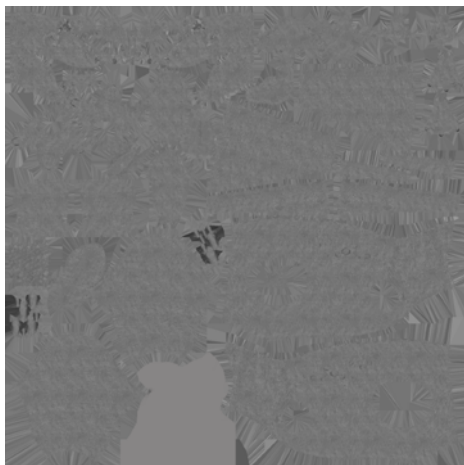


Figure 79: Bump Map

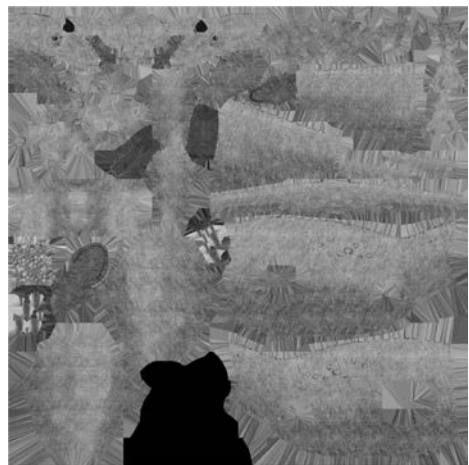


Figure 80: Specular Map

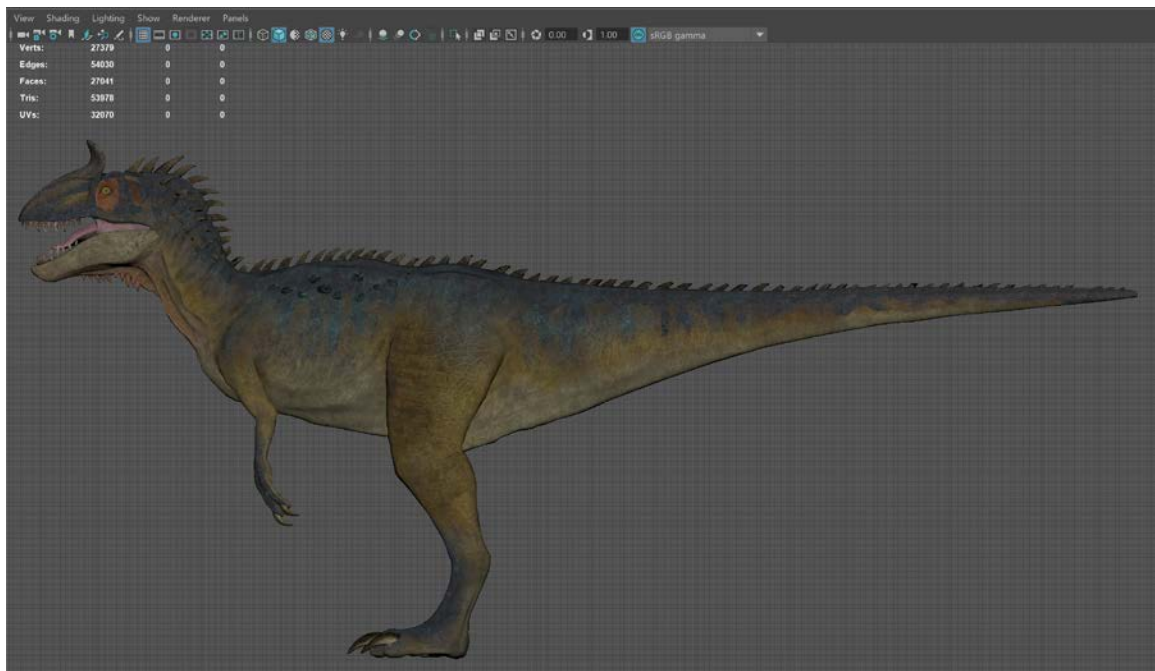
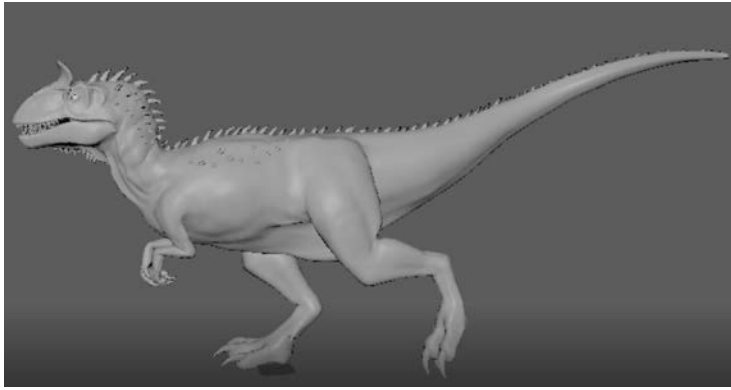


Figure 81: Low-poly Cryolophosaurus with Textures applied

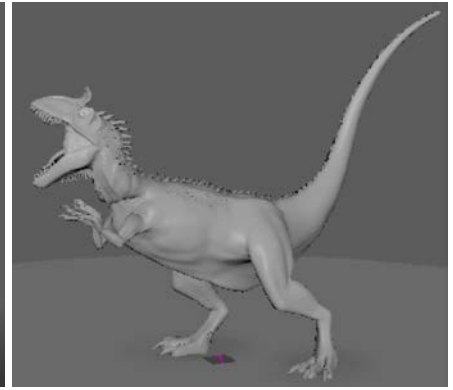
4.2.3.4. Low-Poly Animations Process

When it came to create Cryolophosaurus animations for each XR application, most of the animations for the movie pipeline could be re-used. However, during the development of the AR and MR application, I realised that a new set of animations needed to be created. While the 3DoF and 6DoF VR applications were developed in the context of the Origins Gallery exhibition environment and therefore are adjusted to take aspects like columns and pedestals into account, the AR and MR applications needed a set of animations that is independent of such context.

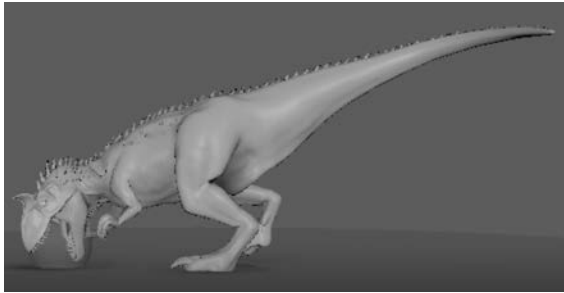
Considering this issue, I created an extra animation specially for AR applications such as Cryolophosaurus walk, Cryolophosaurus Roar, Cryolophosaurus Eat and Cryolophosaurus Run (shown in Figure 82 (A), (B), (C) and (D)). That way, the AR application can be interactive and educational to the visitors. These animations can also be used in the 6DoF VR and MR pipeline. Implementation of all these animations in the real productions will be explained in detail in the App development workflow section 5.3 and 5.4.



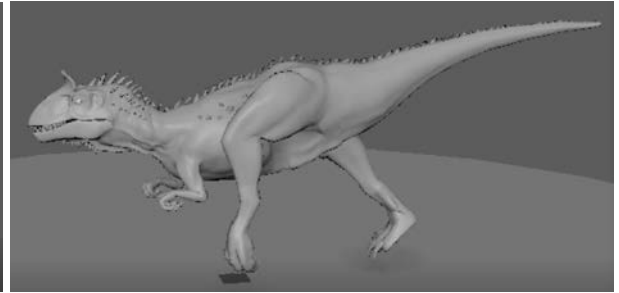
(A) *Cryolophosaurus Walk*



(B) *Cryolophosaurus Roar*



(C) *Cryolophosaurus Eat*



(D) *Cryolophosaurus Run*

Figure 82: Low-poly animations (A), (B), (C) & (D)



Figure 83: High-poly rig animation (Movie pipeline animation) with low-poly rig

4.3. Postproduction

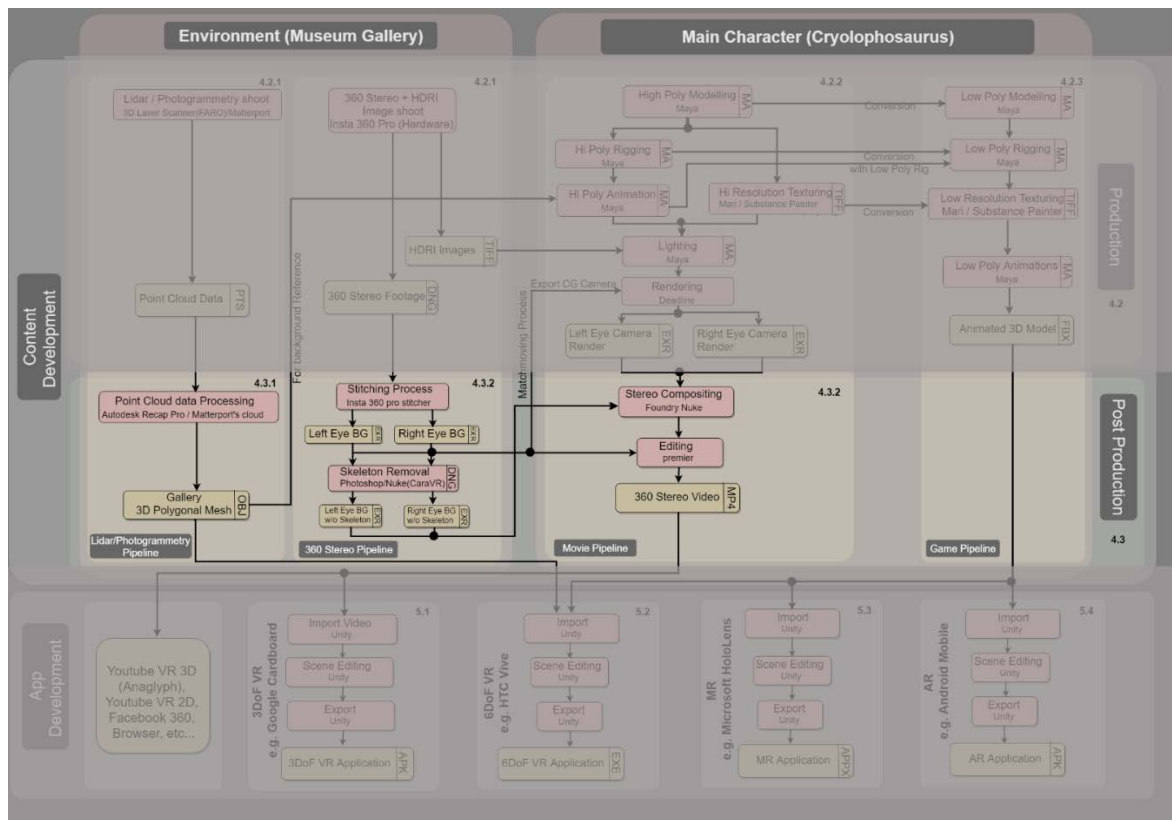


Figure 84: Postproduction workflow

At the end of the Production phase, I have acquired the background footage and a 3D environment scan and created the 3D high- and low-poly models of the Cryolophosaurus. The next major step is postproduction which will generate a 360-degree movie and a 3D environment mesh. Those assets, together with the low-poly 3D model will be used in the creation of the actual XR applications. Postproduction is a complex process especially for Environment development shown in Figure 85. For a detailed explanation, I have divided this section into two subsections

1. Environment Development
2. Movie Postproduction

4.3.1. Environment Development

In this section, the complex process of generating a 3D environment out of the captured data such as point clouds and 360-degree stereo footage will be explained. This section further separated into the following six subsections:

1. 360 Stereo Image Stitching Process

2. Creating HDRI Images
3. Skeleton Removal Process
4. Tripod Removal Process
5. Matchmoving / CG Camera creation Process
6. Lidar point cloud data post-processing

4.3.1.1. 360 Stereo Image Stitching Process

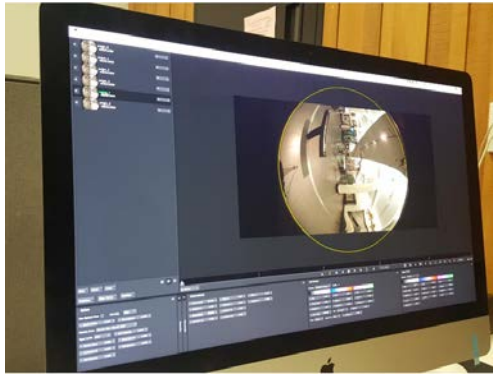
The images captured by the Insta 360 camera during the production stage need to be stitched into a seamless 360-degree stereo image. There is only a limited range of software that is capable of this task. I started experimenting with Mistika VR and Insta 360 Stitcher.

I Imported the six-individual fish-eye images (shown in Figure 85) from Insta 360 into Mistika VR. Then, I used the built-in Insta 360 camera presets available in Mistika VR, followed the Mistika VR stitching process (shown in Figure 86) and produced seamless mono 360 images (shown in Figure 87). However, when trying to create a stereo 360 image, Mistika VR failed to produce a seamless stitch (shown in Figure 88) with issues such as ghosting and mismatch (shown in Figure 89).

The best alternative post-production software for a complete 360 stereo workflow is to use Cara VR and Ocula plugin for Nuke software by Foundry. However, this comes with a high price tag. The only alternative for stitching was to use the Insta 360's proprietary software called Insta360 Stitcher. With Insta360 Stitcher software I was able to produce a seamless 360 image at a resolution of 4K, which met the required standard. Since it was proprietary software the process of stitching stereo images was very easy using the built-in options (shown in Figure 90) for stitching one location footages. The same process can be used to stitch multiple location images (shown in Figure 91). The final output stereo images can be seen in Figure 92.



Figure 85: Six Output images from six lenses of Insta 360 Camera



(A) Image from one lens



(B) Final 360 Image after stitching six images from each lens

Figure 86: Mistika VR – Stitching process



(A) Left Eye



(B) Right Eye

Figure 87: 360 Mono Images from Mistika VR

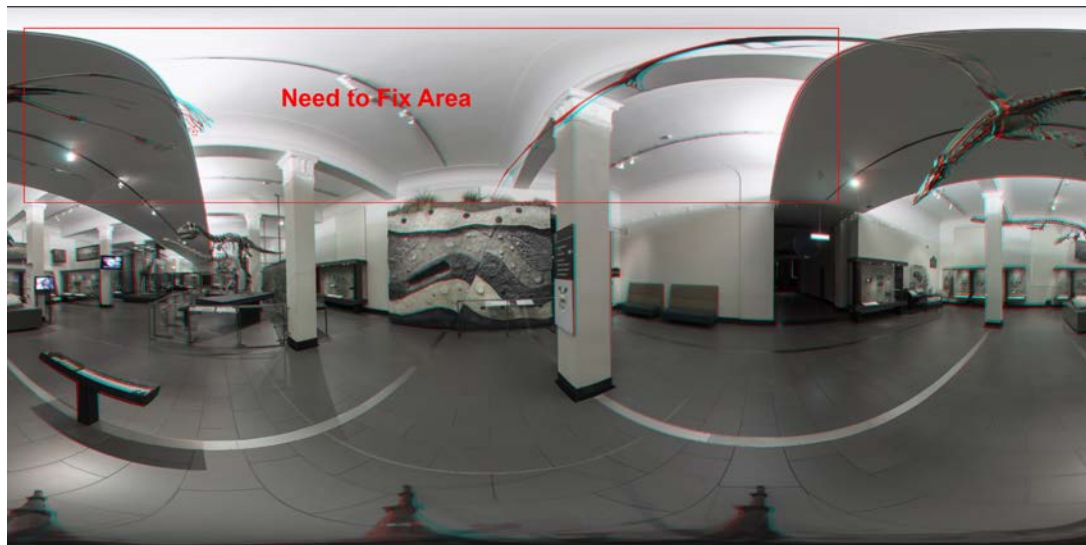
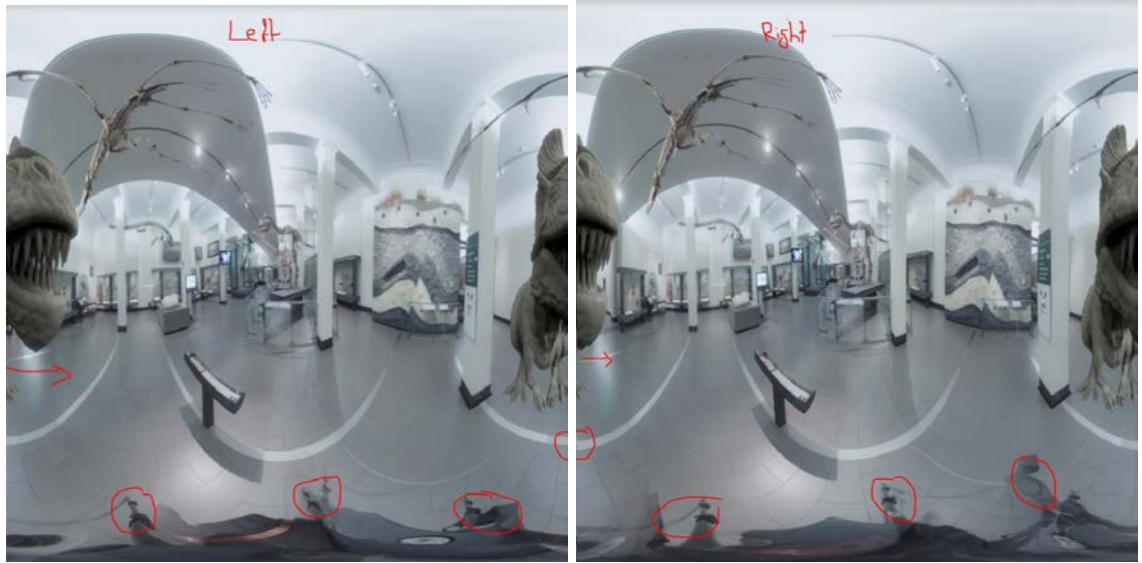


Figure 88: Anaglyph Image output from Mistika VR which need still fixing



(A) Left eye

(R) Right eye

Figure 89: Stereo images with ghosting effects and mismatching camera images

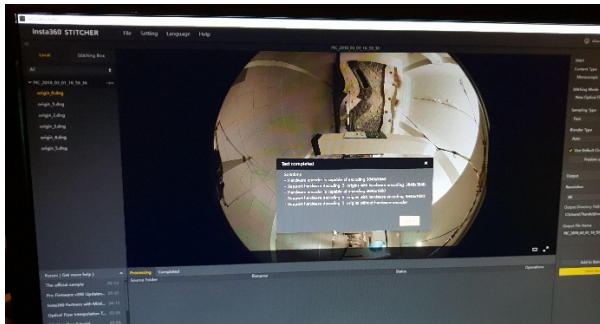


Figure 90: Insta 360 Stitcher software for stitching six raw images



Figure 91: Stitching six raw images of a different location



(A) Left Eye 360 mono image



(B) Right Eye 360 mono image

Figure 92: Final output stereo images from Insta 360 stitcher

4.3.1.2. Creating HDRI Images

Using Insta 360, I captured at each spot a series of 11 exposures in intervals of 2 stops: -8, -6, -4, -2, 0, +2, +4, +6, +8. I scoped out the Origins Gallery and around Cryolophosaurus, seven spots were chosen around the pillars based on the Cryolo's walking animation. Since Insta 360 has six lenses, each exposure has six individual images which will be combined into a full 360 image. The total number of raw images in .dng format at each spot, therefore, is 6 lenses x 11 exposures = 66 images. These are later stitched to create 11 individual 360 images of multiple exposures. These 11 images are merged together to create an HDRI image. So, at seven spots there should be seven HDRIs, which resulted in a total of $7 \times 6 \times 11 = 462$ individual images.

While processing these HDRI images, I noticed, for a 360 mono image the resulting HDRI worked really well for Image Based Lighting (IBL) in Maya software in order to create realistic character lighting, matching the Origins Gallery environment (shown in Figure 93 (A),(B),(C),(D),(E),(F) and (G)).

However, there was a problem while using HDRI's for stereo images. The left eye HDRI image and right eye HDRI images have different colour and exposure values which created a ghosting and uneven colour contrasts (shown in Figure 94), which meant I couldn't use an HDRI image from the 11 exposures.

To overcome this, I took the mid exposed image, adjusted highlights and shadows and used some of the missing information from under-exposed images to create the final stereo images to be used in as a BG for creating the 3DoF VR Application (shown in Figure 97).



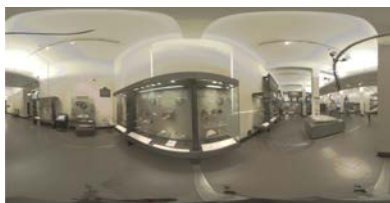
(A) Location 1



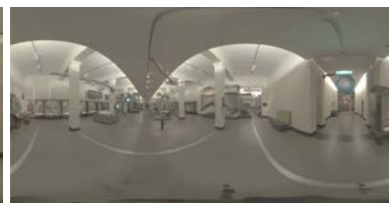
(B) Location 2



(C) Location 3



(D) Location 4



(E) Location 5



(F) Location 6



(G) Main Location 7

Figure 93: Final HDRI Images for 7 locations (A), (B), (C), (D), (E), (F), (G)



Figure 94: Resulted in black unwanted data generated during HDRI image creation by multiple lighting exposers

4.3.1.3. Skeleton Removal Process



Figure 95: With Cryolophosaurus Skeleton BG



Figure 96: Without Cryolophosaurus Skeleton BG

I created two environments: one with the skeleton (shown in Figure 95) and one without the skeleton (shown in Figure 96). Without a skeleton, the BG is used in the Nuke compositing process and the BG with the skeleton was used in the editing process (shown in Figure 84). Photoshop was used in this skeleton removal process. Advanced software such as Nuke and Mistika VR also can be used for this process.

4.3.1.4. Tripod Removal Process

During the photoshoot, because of the nature of 360 capturing, the tripod (or any other form of camera mount) cannot be hidden. Usually, this will be removed in image editing during the post-processing. As part of this process, both left eye and right eye equi-rectangular images (shown in Figure 97) are converted into cube format (shown in Figure 98) and the nadir photo containing the tripod is removed by retouching the image using photo editing software such as photoshop (shown in Figure 99). Finally, after removing the tripod, the cube format is converted back into equirectangular images as seen in Figure 100.



(A) Left eye



(B) Right eye

Figure 97: Final equirectangular 360 Stereo BG Images from Insta 360 stitcher with tripod

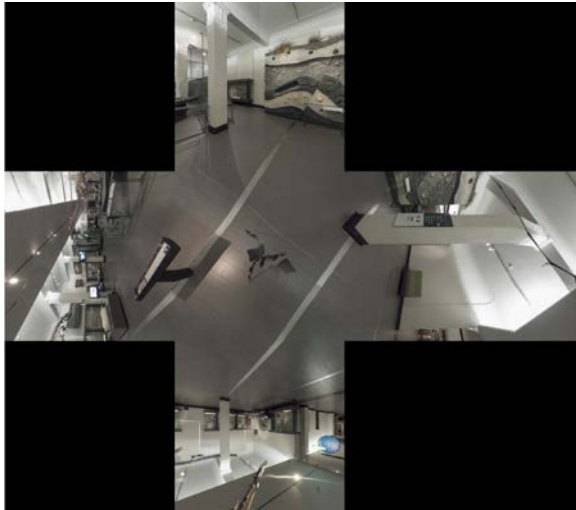


Figure 98: Cube format image with a tripod

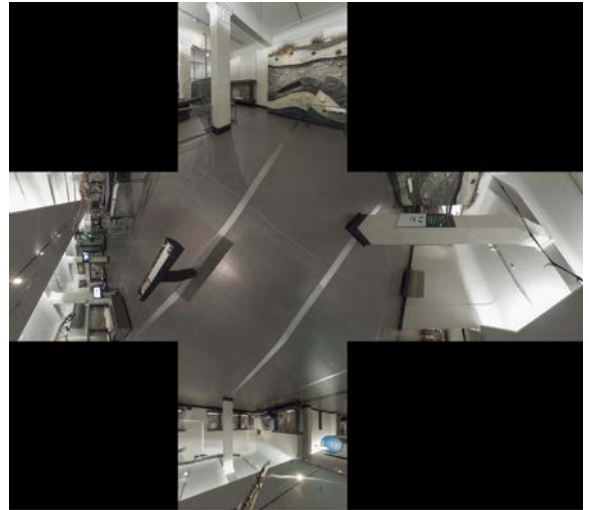
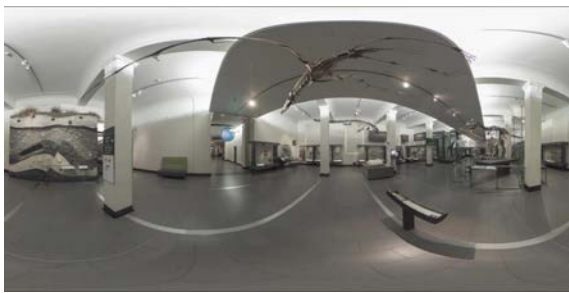
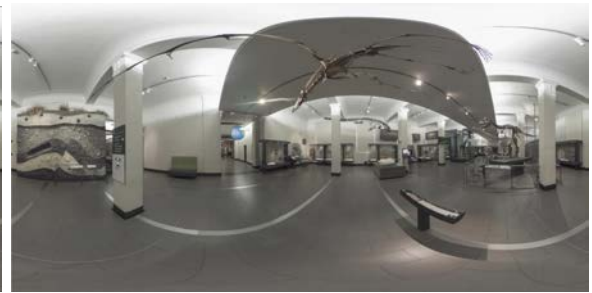


Figure 99: Cube format image without tripod



(A) Left eye



(B) Right eye

Figure 100: Final equirectangular stereo 360 BG Images without tripod

4.3.1.5. Matchmoving / CG camera Generation Process

After having finished the 360 stereo images, the next stage is the match moving process. As a part of this process, I need to work with camera tracking software to create a CG camera perfectly matched to the live-action camera, so that both are in sync and give a real feel when viewed in the virtual space. While shooting the live action, I failed to note down the measurements of the camera position and the height with respect to the surrounding environment. This turned out to be a big issue while doing a match move in the post-processing.

In order to accomplish seamless match moving, I experimented with different software, including PF tracker (shown in Figure 101). While trying this software, I found that it does not have a matchmoving feature to deal with 360 mono/stereo images. I also tried the 360 Stereo Video format to do the match move (shown in Figure 102) but to no avail. This is

because the 360 format is a new and evolving format and support in software is not yet widespread.



Figure 101: 360 Stereo Image Matchmoving testing with PF tracking software



(A) 360 Stereo video footage

(B) Closeup view of PF tracking points with rotoscoping the person

Figure 102: PF tracking software tried to track by using the 360-stereo video

With no other option on the table, I had to match the CG camera position manually. I achieved this by aligning the position and height values of the live-action camera with a CG camera. For height of the live-action camera, I took the references to the centre point of live action Cryolophosaurus footage (shown in Figure 103) and matched with the CG camera in Maya software (shown in Figure 104).

For a centre point of the live action camera, I took the reference of tiles that are visible in the nadir of the BG (shown in Figure 105) and matched the same centre point in Maya Camera (shown Figure 106).

During this manual match moving process, I encountered multiple issues where the Cryolo was flying or going through the walls (shown in Figure 107).

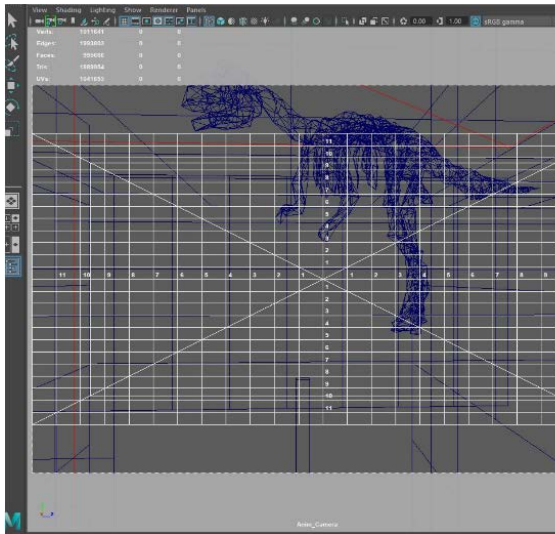


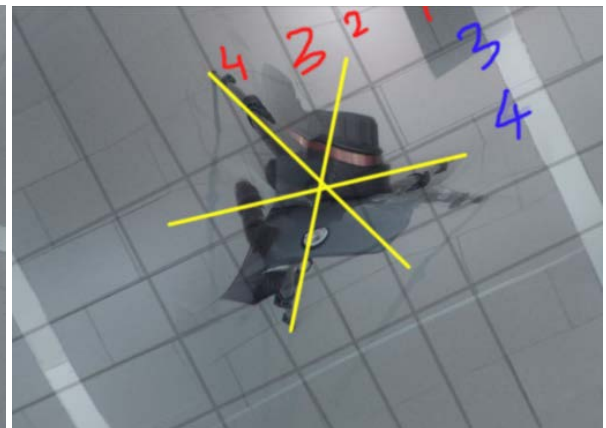
Figure 103: Maya camera centre point



Figure 104: Live action camera centre point



(A) Reference points for each tile



(B) Centre point of the tripod

Figure 105: Reference of tiles that are visible in the nadir of the BG for finding the centre of the tripod



Figure 106: Final CG camera created manually to match with a live-action camera



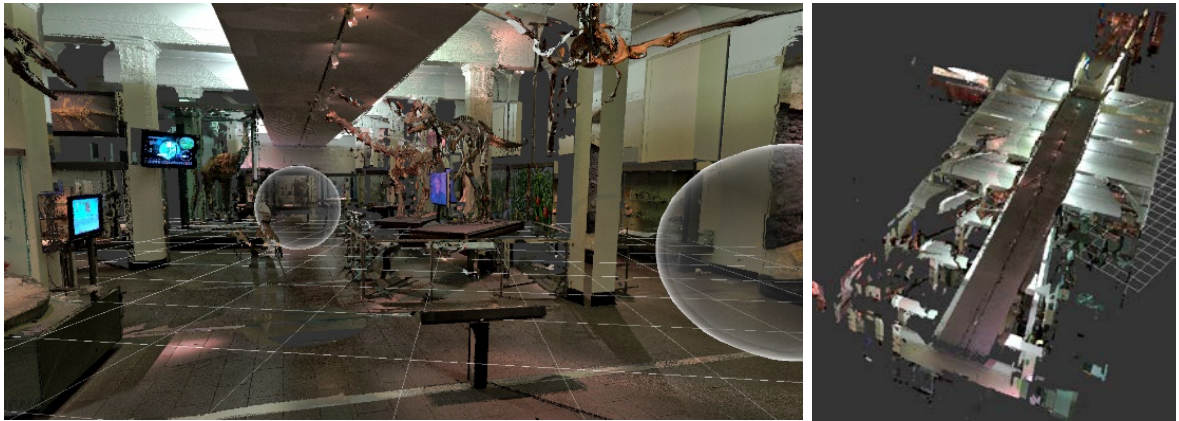
(A) Cryolo render is not aligning with BG Cryolo skeleton (B) Cryolo animation not matching with the floor

Figure 107: Problems of mismatching the CG camera with a live-action camera

4.3.1.6. Lidar Point Cloud Data Post-Processing

After capturing the two positions in the Origins Gallery using the Faro Focus 3D Laser Scanner, I imported the LIDAR PTS format data into Autodesk Recap software (shown in Figure 108) and Reality Capture software (shown in Figure 110) for processing in order to test which of those two products would produce the best quality 3D mesh. Reality Capture resulted in a poor quality 3D mesh, as it was only able to generate overall boundaries and failed to provide a detailed mesh of the interior artefacts (shown in Figure 111). However, Autodesk Recap was able to produce an acceptable 3D mesh, although, there were a lot of missing textures and the quality was poor (shown in Figure 109). This 3D mesh was used as a reference for animating Cryolophosarus within the Origins Gallery.

The whole purpose of using the LIDAR scan and the resulting mesh, was to use them in the 6DoF VR production, however, since the resulting mesh was of low quality, I had to go for other options such as Matterport 3D Mesh, which was provided by Auckland Museum. This mesh was created by photogrammetry using the Matterport 3D device. Comparing the Matterport 3D mesh with the Faro Focus 3D mesh, I was able to see Matterport's 3D Scan and mesh has a better quality of scan, textures, and coverage with multiple scans. This led me to choose Matterport to mesh over to Faro Focus 3D for creating the 6 DoF VR application, which I will be discussing in section 5.2.



(A) Inside point cloud data showing scanned positions

(B) Exterior view of the point cloud data

Figure 108: Point cloud data using Autodesk Recap software



(A) 3D mesh generated from Recap without textures

(B) 3D mesh generated from Recap with textures

Figure 109: 3D mesh output from Autodesk Recap

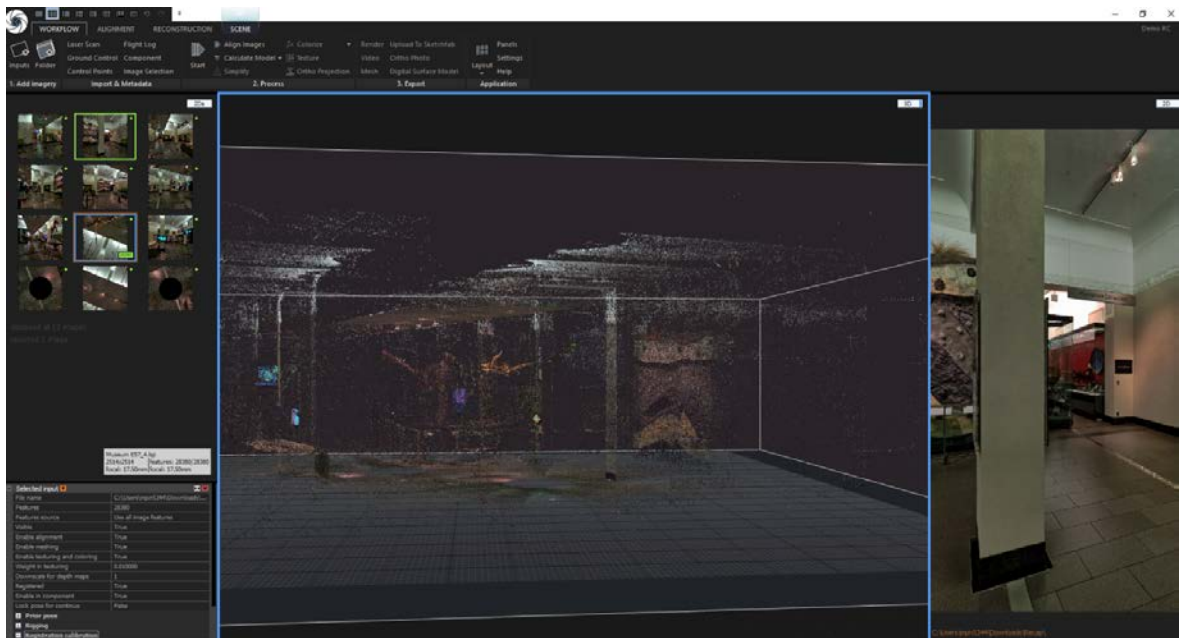
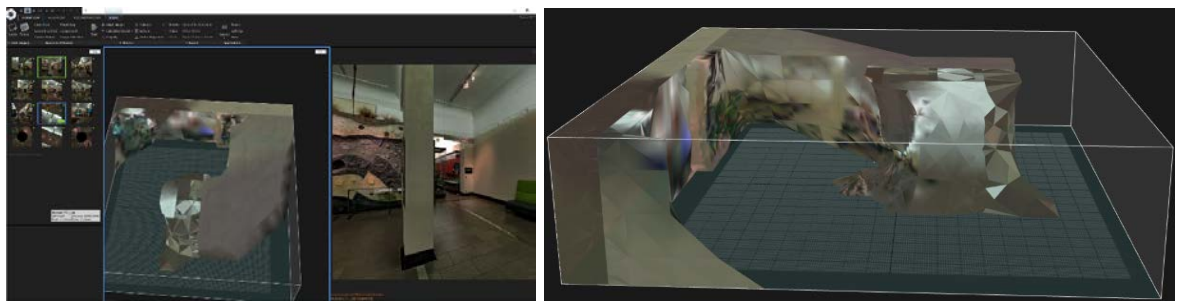


Figure 110: Lidar point cloud data using Reality Capture software



(A) Reality Capture processed 3D mesh output (B) 3D Mesh output closeup view

Figure 111: 3D mesh output from Reality Capture.

4.3.2. Movie Postproduction

In this postproduction section, tasks will be the same as general movie postproduction process, but the 360 stereo format will be used instead of general video formats. There are two main subsections I will be discussing:

1. Stereo Compositing Process
2. Editing Process

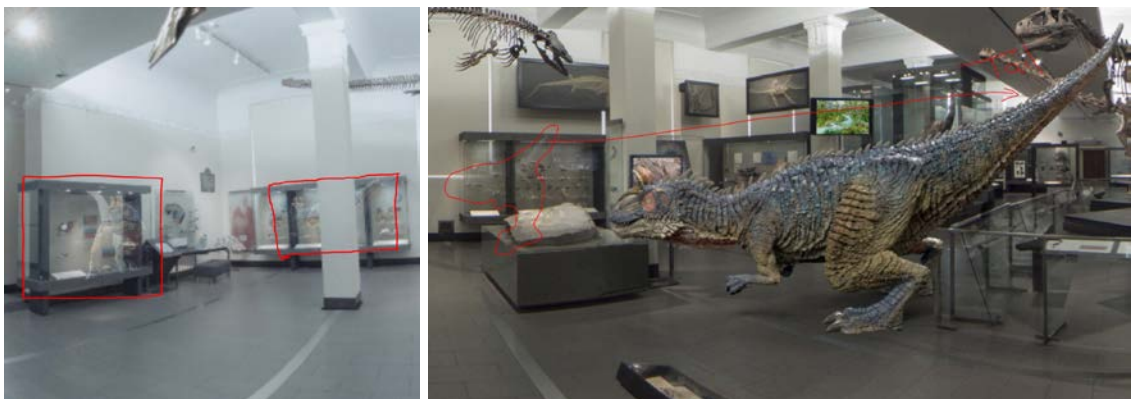
4.3.2.1. Stereo Compositing Process

The Cryolophosaurus stereo renders output from the character rendering process 4.2.2.6 and the Environment development tripod removal section 4.3.1.4 are taken as input for the

Stereo Compositing process (shown in Figure 84). The compositing tool used is Foundry Nuke with the left eye/right eye pipeline (shown in Figure 116). The whole stereo compositing process contains the following key layers: BG environment, TV Footages, Reflections, Shadows and Cryolo which are composed separately for Left Eye and Right Eye pipeline and merged together to create an over and under (top–bottom) output (shown in Figure 113). While compositing for Live preview, I created anaglyph format to view it on screen with red and cyan glasses (shown in Figure 118) and side-by-side format (shown in Figure 119) to use in an HMD such as the HTC Vive or the Oculus Rift.

Over and under (O/U), also known as top–bottom, is commonly used in videos. In videos, cameras mostly travel horizontally and the side-by-side (SBS) format (shown in Figure 119) can result in an uneven video, whereas O/U format videos appear softer and more comfortable to watch. I have used YouTube, which only supports O/U format and most of the HMDs have inbuilt YouTube 3D apps through which 360 3D/stereo videos are easily accessible for experience and testing.

With respect to character compositing, in Maya, I have rendered Cryolo in multiple passes to save re-rendering and post-production process time, such as SS pass, Direct SS pass, Reflection, Indirect Specular pass, Direct Specular pass (shown in Figure 66 (A) (B) (C) and (D)). These passes will help to control each attribute of the character. All these passes are merged together to get a colour corrected image (shown in Figure 114). Later, added reflection pass and shadow pass add a realistic look for the Cryolophosaurus to match with the environment. The reflections are displayed on the glass panels across the Origin Gallery's interiors (shown in Figure 112) and shadows are shown on the floor, walls and pillars (shown in Figure 115). The shadow even shows up on the left pillar base in the correct way due to the replicated geometry in Maya (shown in Figure 115 (B) and (C)).



(A) Cryolo reflection renders to side glass panels (B) Cryolo reflection renders on front glass panel

Figure 112: Reflection pass adding to BG glass panels

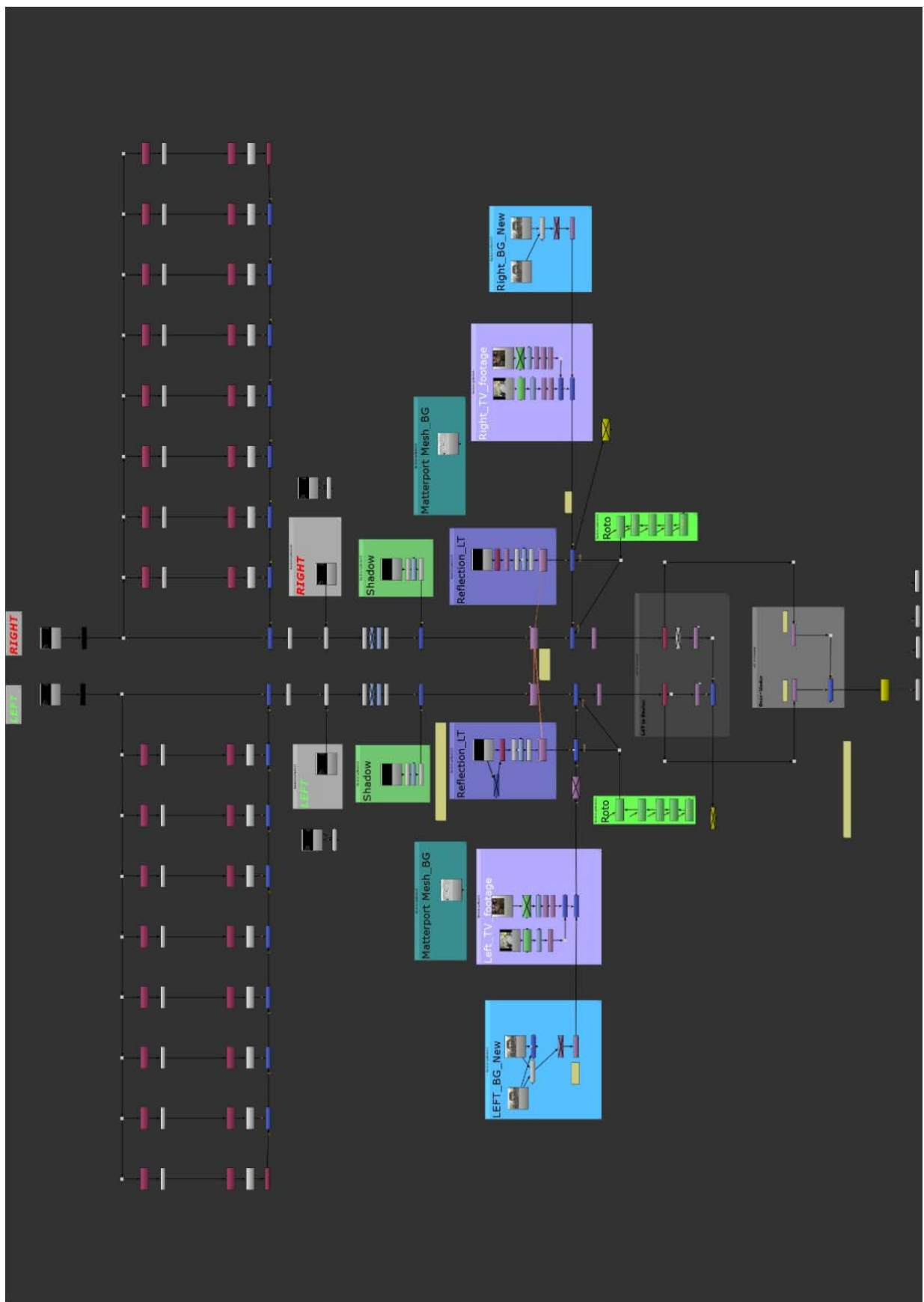


Figure 113: Nuke stereo compositing workflow with nodes and node groups



(A) Combing all the passes (B) Compositing with BG in closeup (C) Compositing with BG in full frame

Figure 114: Compositing colour corrected Cryolo render with BG



(A) Backplate (B) Backplate with shadow pass (C) Cryolo colour corrected pass with shadow

Figure 115: Shadow Pass Pipeline



Figure 116: Left eye - Right eye workflow in Nuke software

For the BG environment compositing, I merged BG with TV footage and performed Rotoscoping, which is the process of generating a mask or matte to cut off part of an image or video, so that it can change it or add it to another background. In this instance (shown in Figure 117) it looks as if Cryolophosaurus is walking behind the pillars. Finally, I performed colour correction on a character to match with the background environment. Both character and environment compositing are performed for the left and the right eye and then merged in order to give the stereoscopic output in O/U format (shown in Figure 120) to use across multiple platforms such as gear VR, HTC Vive, Facebook 360 and YouTube 360.



(A) Cryolo Render Before Roto in close up

(B) Cryolo Render after Roto in closeup

Figure 117: Rotoscoping the Cryolo Render to reveal pillar in front as if Cryolo walking behind the pillars



Figure 118: Anaglyph Format BG



Figure 119: Composite with left and right eye - side by side format

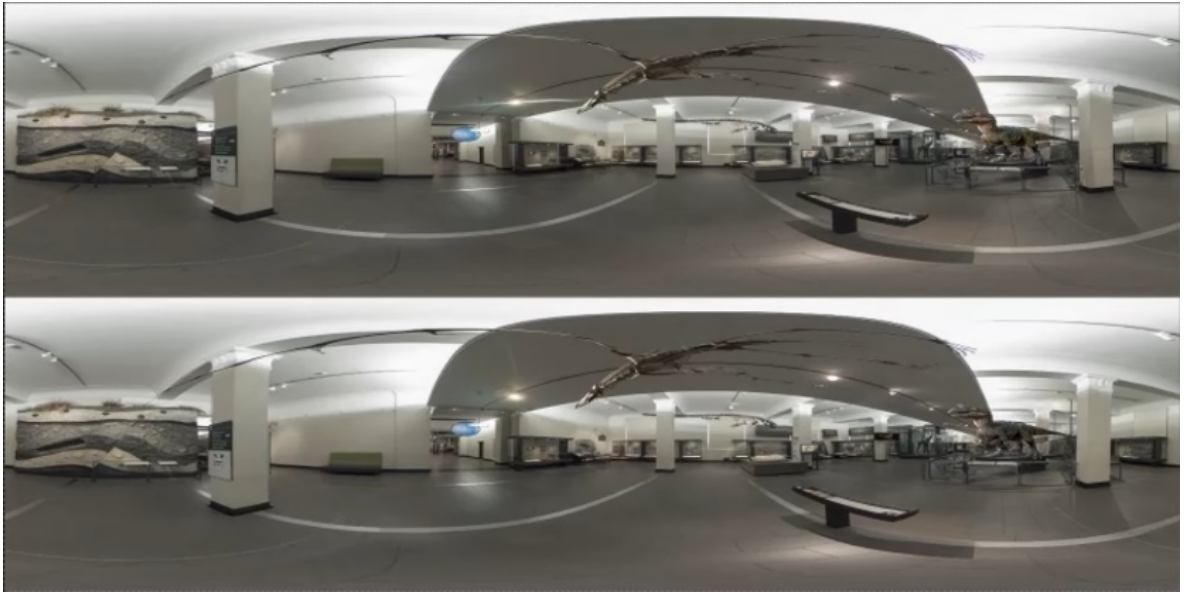


Figure 120: Final stereo composite with left and right eye - over and under format

4.3.2.2. Editing Process

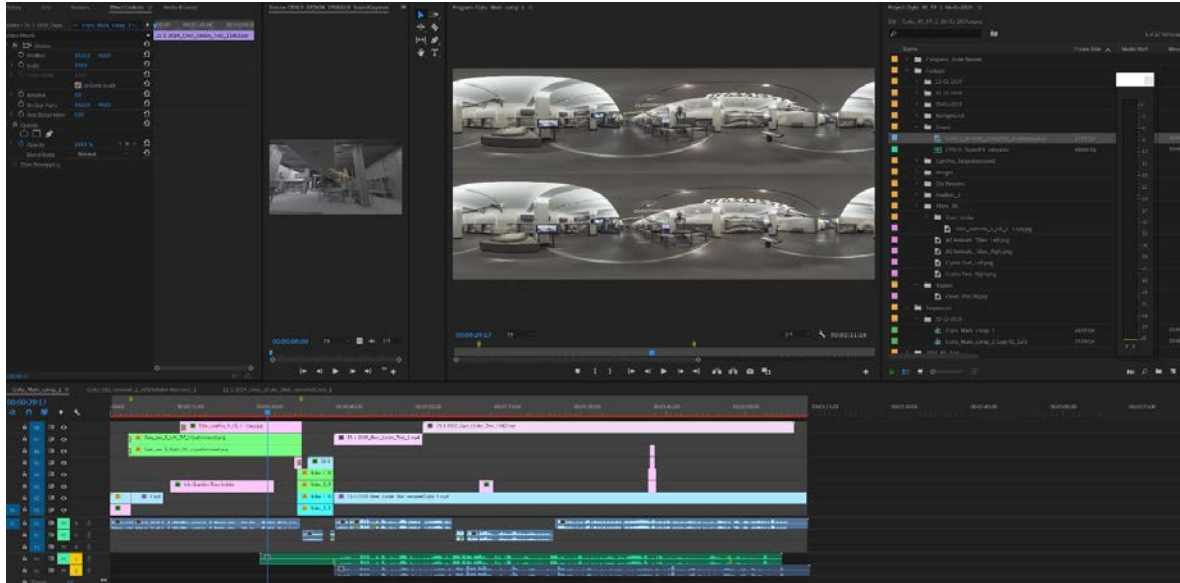
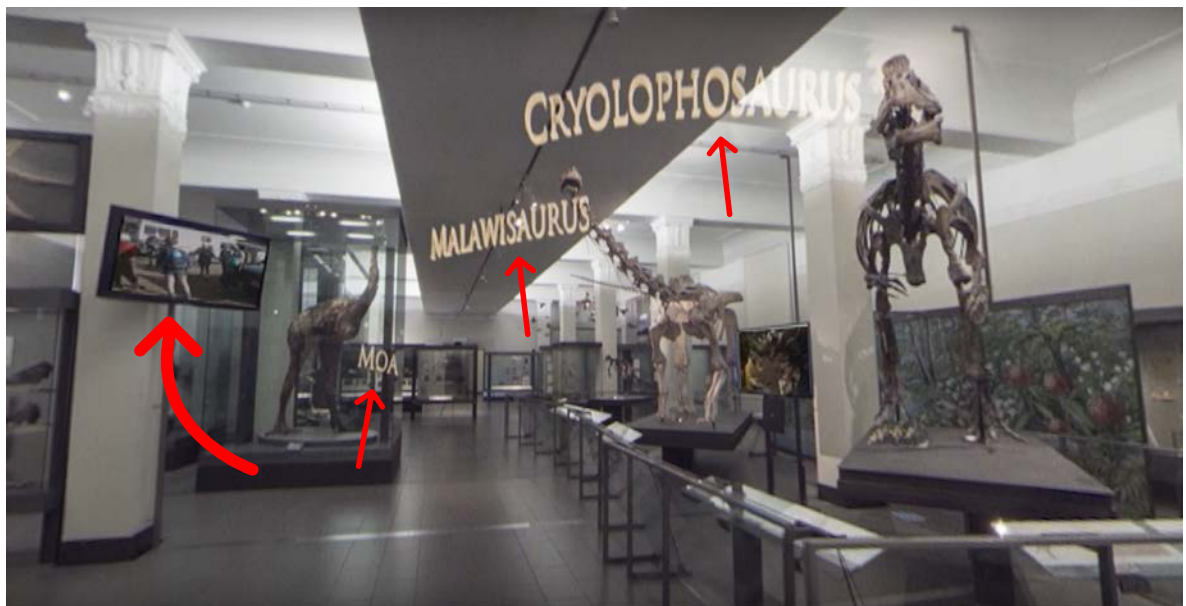


Figure 121: Premiere pro editing process

Editing is the final stage in the post-production process. I used Adobe Premiere Pro software for editing and the whole process was done in O/U format (shown in Figure 121). The result of the editing process is the final output video (MP4) which can be exported into Unity for Mobile app creation for viewing with google cardboard. This final 360 video output can be exported into social media platforms such as YouTube/ Facebook for general viewing in mono or stereo /anaglyph formats either through smartphones or tablets.

As per the storyline at the beginning of the video, an intro camera position stereo image was chosen within the Origins Gallery to show and explain other exhibits such as Moa, Malawisaurus etc. Since the intro part doesn't have any CG work, I imported a 360 stitched footage directly into Adobe Premiere Pro and added required titles around other exhibits using inbuilt 360 workflows. Then, I added TV footage onto the BG and manually moved them to create the stereo effect (shown in Figure 122).

For the audio editing, I used Adobe Audition software in order to edit, sync voiceover and sound effects using the reference proxy video from premiere pro. These audio files are individually exported to Premiere Pro for further process. After audio editing was completed, I added voice over and sound effects to the main timeline within Premier Pro for both camera positions explaining the characteristics of the other exhibits and Cryolophosaurus.



(A) BG in closeup



(B) BG in full frame

Figure 122: Red arrows indicating added TV footage and names of exhibits shows at Intro location BG

As the story switches from intro camera to main camera position, I used rotoscoping technique to reveal the Cryolophosaurus from skeleton BG. Once the dinosaur was revealed, the skeleton BG was hidden. For the main story and animation sequence, Nuke output imported onto Premier Pro timeline. As the story comes to end, the Cryolophosaurus completes its walk around the Origins Gallery, comes back to its original position and reverts back to the skeleton by unhiding the skeleton BG.

After the editing process is completed the entire sequence is exported as stereo 360 format (shown in Figure 123) for further process.



Figure 123: Final output over under 360 stereo format

During the compositing process, I came across a lot of unexpected issues after the final stereo render, for example, the Roto was missing in one eye footage shown in Figure 124 (A), (B), and (C)).



(A) Position one

(B) Position two

(c) Position three

Figure 124: Pillar roto is missing in one eye render in different positions of the video

Other issues were renders of the dinosaur missing for one eye at different positions (shown in Figure 125 (A), (B) and (C)).



(A) position one

(B) position two

(C) position three

Figure 125: Missing frames issue from one of the eyes at different positions

In addition, there was a need to perform extra roto to make sure the Cryolophosaurus render fits perfectly into the BG, i.e. the tail needs to go behind the pillars and nails need to go behind the base (shown in Figure 126).



(A) Cryolo tail go behind the pillar

(B) Cryolo nails need to go behind the base

(C) Cryolo Nails need to go behind the bar

Figure 126: Cryolophosaurus Roto issues

Despite all the compositing and editing challenges, the final result was to a believable product as per the plan at the beginning of the project, as seen in Cryolo – 360 mono composition final output (shown in Figure 127) and Cryolo - 360 stereo composition final output (shown in Figure 128).



Figure 127: Cryolo – 360 mono composition final output in closeup



Figure 128: Cryolo – 360 stereo composition final output in closeup

An example output 360 stereo video after final editing can be watched using this link:

<http://bit.ly/2lodXXe>

5. App Development Workflow

So far, I have covered the content development workflow in Section 4, explaining the development of background environment and high-poly, low-poly Cryolophosaurus character development, in this section, I will explain how the outputs from Section 4 will be used in building XR applications. In this context, this chapter is further divided into four subsections. Section 5.1 explains the process involved in developing 3DoF VR; Section 5.2 describes the steps followed to build the 6DoF VR application; Section 5.3 talks about MR application development and Section 5.4 describes the steps involved in building the AR application.

5.1. 3DoF VR — Google Cardboard Application Development

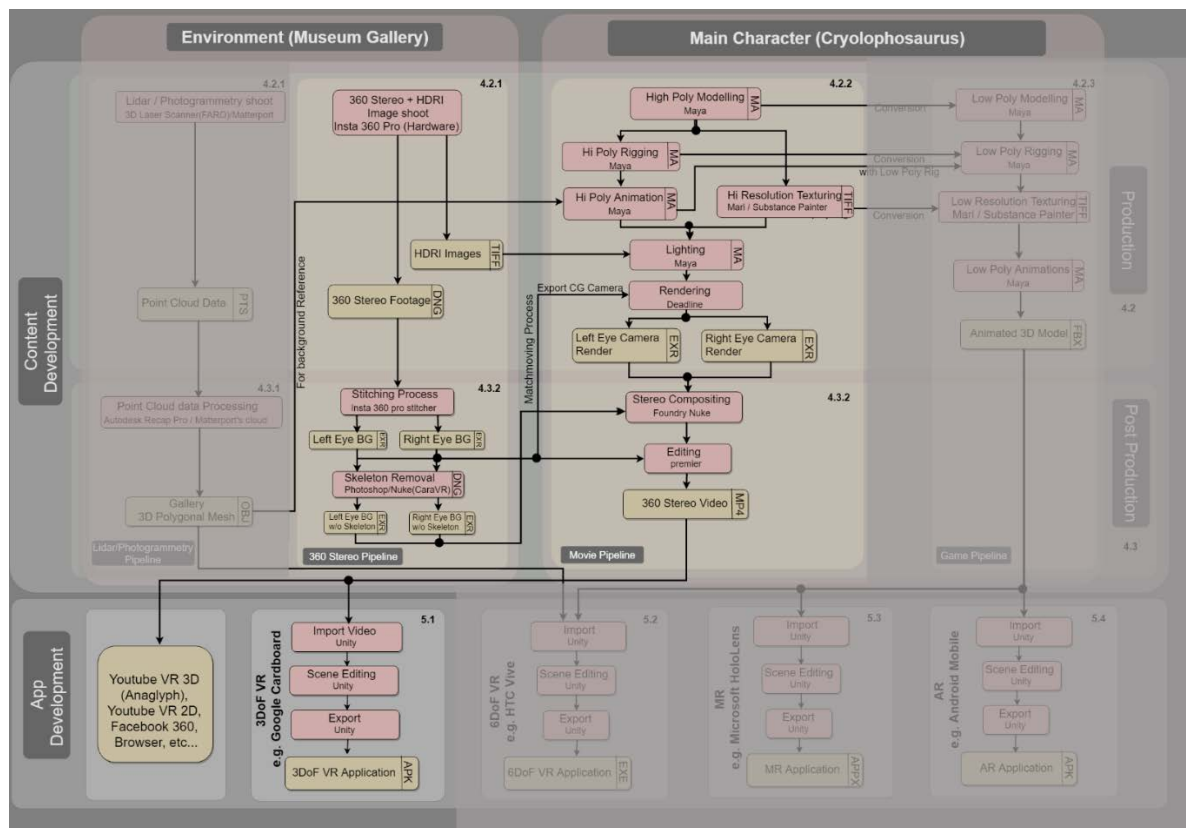


Figure 129: 3DoF VR Production outline

The main asset for 3DoF VR is the 360 video which can be played back with a variety of existing applications such as YouTube, YouTube VR, Facebook360, etc. However, I wanted to create a standalone application with additional features such as a gaze-controlled 3D playback menu and vibrotactile feedback. The Unity Engine is an authoring tool that allows to implement such features.

The above diagram (Figure 129) shows the major workflow of the 3DoF VR production pipeline where the 360 stereo output feeds into Unity software, for building an interactive 3DoF Android application. This application can be installed on Android mobiles and can be viewed through google cardboard or similar types of devices. In addition, the above diagram shows that the 360 stereo video can also be uploaded to social media platforms such as YouTube and Facebook. These YouTube video can be viewed as 2D format directly on PC or mobile or tablet screens where no further device is required. But when a person wants an immersive experience, the YouTube video can be changed to 3D format and an extra HMD is required.

This section explains the Unity software usage in building a 3DoF VR android application. As in this 3DoF VR application building process, the 360 stereo video is imported into Unity and applied as a render texture to the skybox material (shown in Figure 130). Required scripts were written for the menu interaction start/stop /pause functionality and gaze (shown in Figure 131). In addition, to improve the user experience while viewing through a mobile device, extra scripts were added in such a way that that mobile phone vibrates whenever a major action happens in the story, such as the Cryolophosaurus attacking the TV screen, jumping onto a pedestal, or roaring (shown in Figure 132). This script allows the playback of vibration patterns at certain times of the movie playback, e.g., the impact when the Cryolophosaurus jumps and lands on a platform.

Additional scripts and 3D texts provide a pause and play functionality during the experience to give control to the viewer with a simple touch gesture (shown in Figure 131(A),(B) and (C)). There is also a restart button at the end of the experience to replay (shown in Figure 131 (D)). In addition, spatialised audio as the dinosaur walks around the Origins Gallery provides 360 surround sound effects to the viewer. This was achieved by "animating" the position of the source of creature sound effects such as the roaring or footsteps in sync to the video using positional data from the creature animation stage (section 4.2.2.4). To maximise the effect of the spatial audio, even more, a spatialiser plugin was enabled. This plugin takes physiological features of the human ear and the process of audio perception into account and allows the user to hear sounds from "above", "below" and "behind".

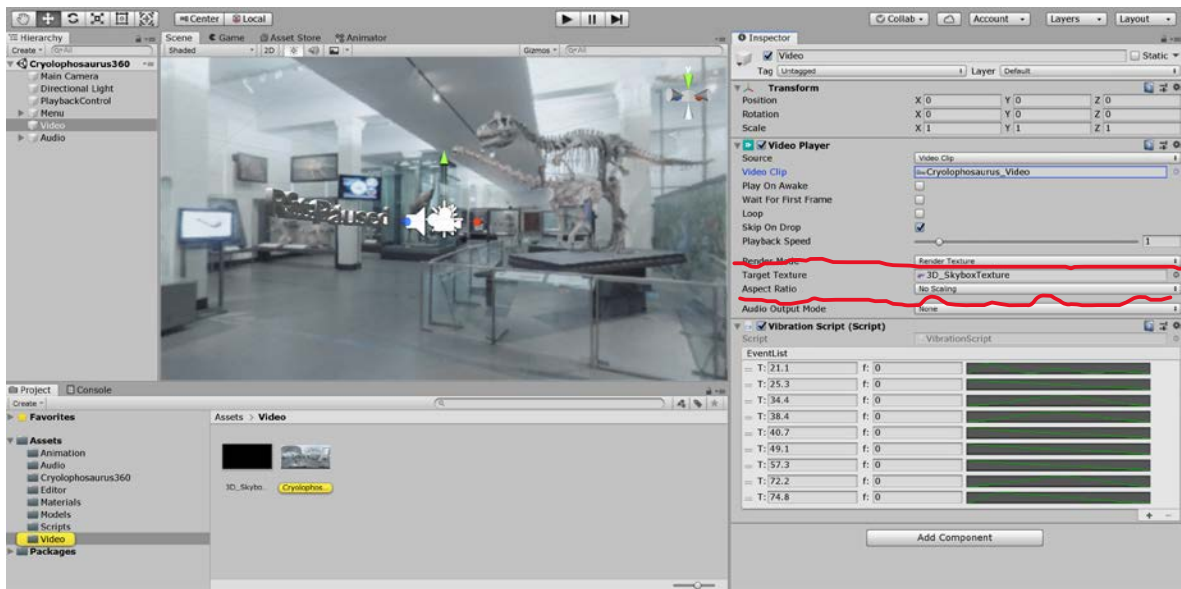


Figure 130: 360 video applied as render texture in skybox environment inside the Unity project window



(A) Start button to the begin the application

(B) Colour interaction for the trigger to start the application



(C) Pause button to pause the video when touching on the mobile screen

(D) Red Restart button for restarting the video

Figure 131: Menu interactions start / pause/ Restart through Gaze

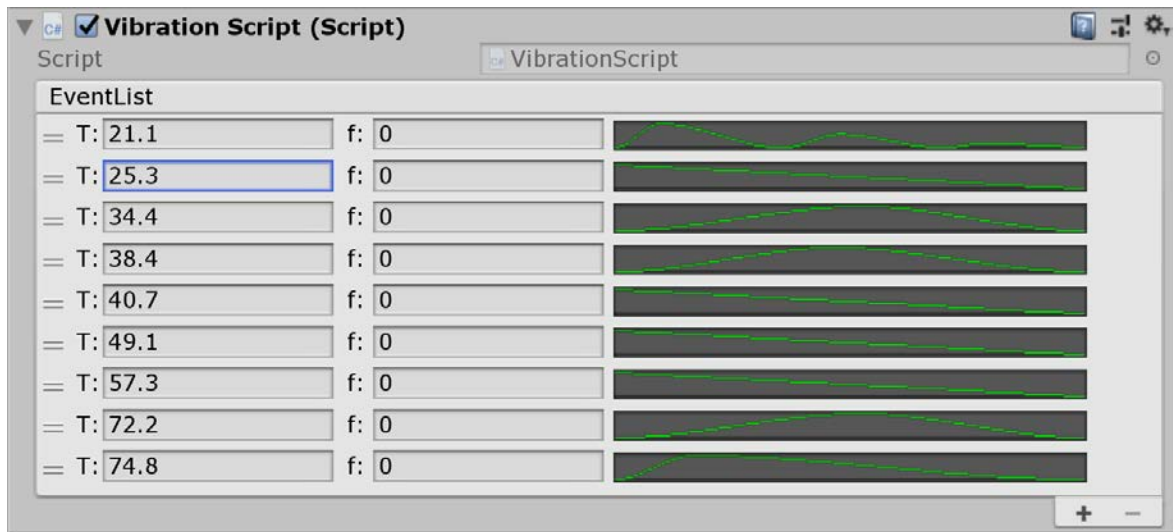


Figure 132: Vibration script window²

As a final step, Unity builds an “APK” file, which can be installed into any Android smartphone (shown in Figure 133). When the phone is inserted into Google Cardboard and viewed as HMD, the whole VR application can be experienced in an immersive way. The viewer can feel that they are standing in the Origins Gallery, experiencing the Cryolophosaurus come to life from its skeleton, walk around, go back to its original position and become a skeleton again. While watching the stereo video, voiceover provides additional information about the dinosaur.



Figure 133: Installed Android App

² T: denotes the timestamp for a vibration event in the video playback. f is the vibration frequency (not supported by majority of mobile phones yet), and the curve is the amplitude of the vibration signal over time.

5.2. 6DoF VR — HTC Vive Application Development

In this section, I describe the development of a 6 DoF VR application, ensuring that 3D content is suited for device such as HTC Vive or Oculus Rift.

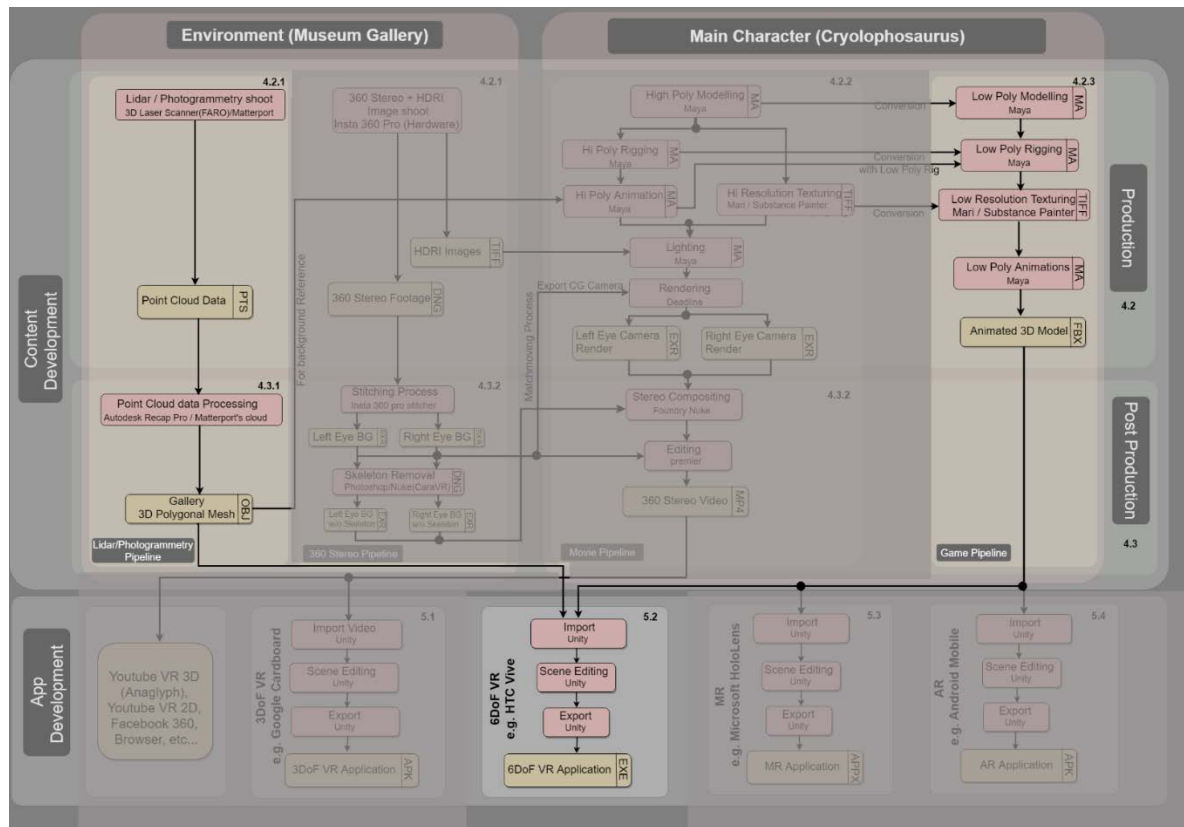


Figure 134: 6DoF VR production workflow

As a part of the VR pipeline, 3D content such as the low-poly 3D Cryolophosaurus model and animations from section 4.2.3.4 and the BG environment 3D mesh from lidar postproduction section 4.3.1.6 were imported into Unity. The number of polygons of the models mentioned in the previous section was actually the result of experimentation during this phase. For VR application optimized performance, the maximum polycount limit can go up to 1- 2 million triangles or vertices per each frame and need to use as limited textures as possible (Oculus, 2018).

I started with the high-res 3D environment exported model from Recap consisting of 3.37 million triangle mesh along with a 0.9 million triangle Cryolophosaurus character mesh. As a result, the final scene contained 4.2 million triangles (shown in Figure 135) in the Unity project. This did not result in a suitable framerate, so I tried 1.53 million triangles environment and 0.9 million triangles Cryolophosaurus next - again with an insufficient resulting framerate. By using the Matterport environment mesh with 0.1 million triangles, the

framerate was improving (shown in Figure 137). I then realised that the character polygon mesh is still high-res (shown in Figure 138). For further testing, I used the Matterport mesh and replaced the high-poly character with low-poly 26k poly mesh (shown in Figure 139). After trying all these above-mentioned combinations, the last combinations worked well for the smooth performance of the final VR application.

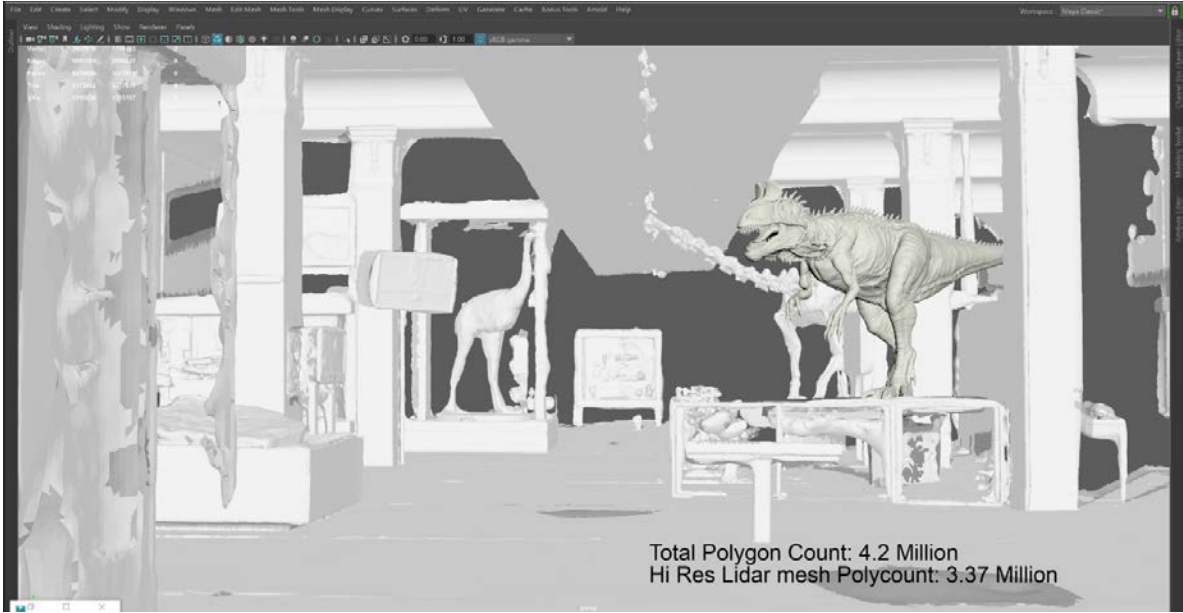


Figure 135: Hi-Res Lidar mesh

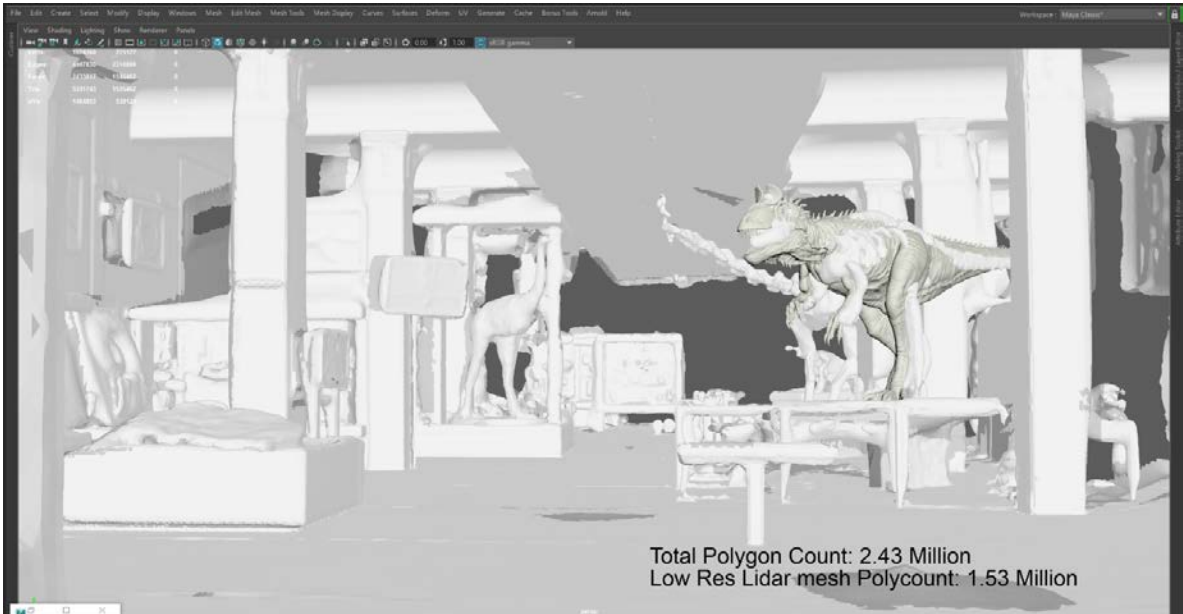


Figure 136: Low-Res Lidar Mesh

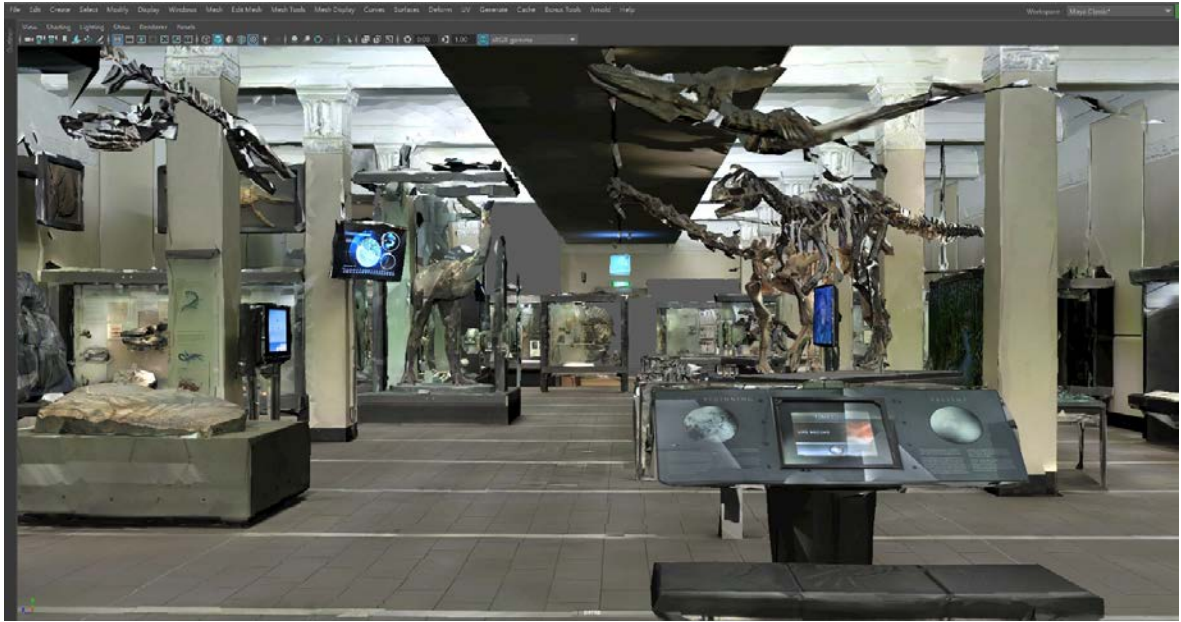


Figure 137: Matterport Photogrammetry mesh

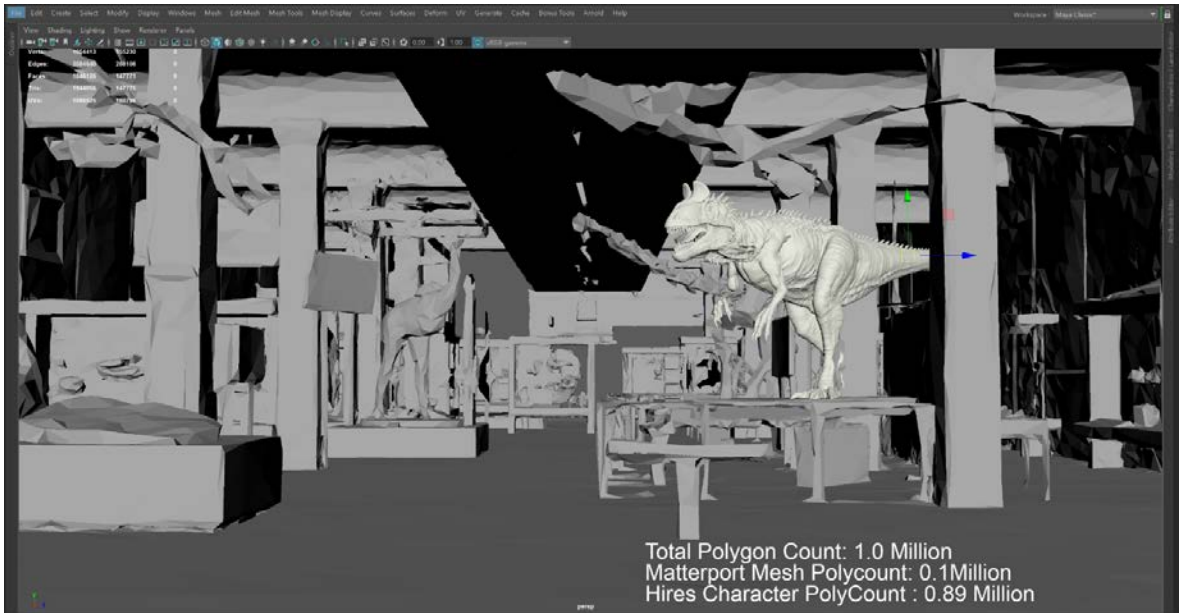


Figure 138: Matterport mesh with high-poly Cryolophosaurus

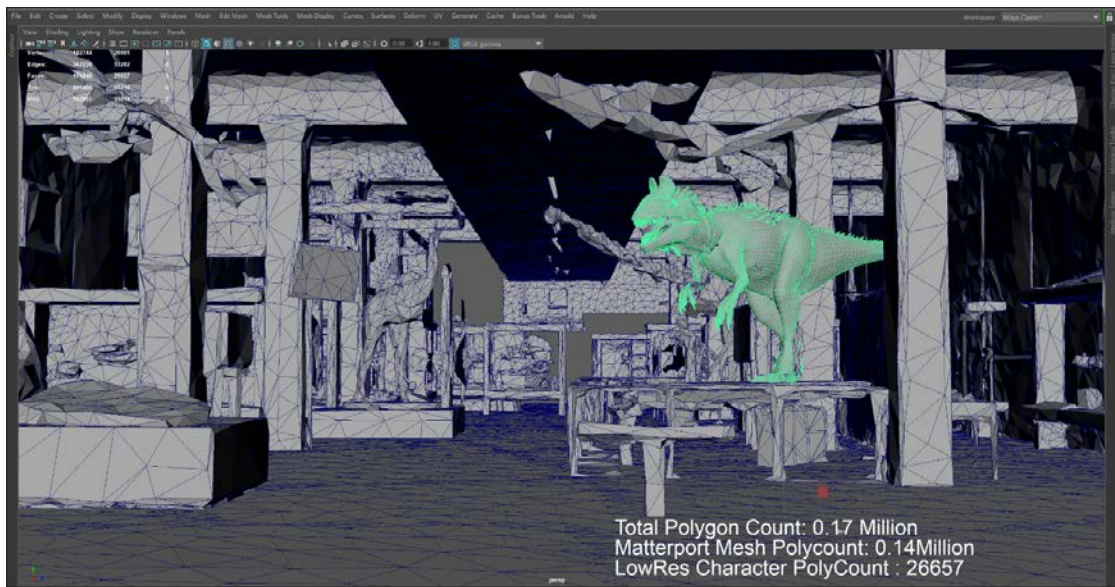
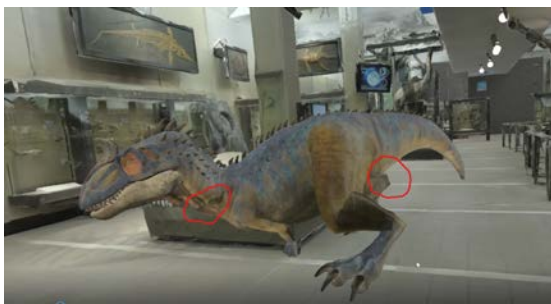


Figure 139: Matterport mesh with low-poly character

However, when I applied the high-poly animation, which was used in the 3DoF VR application to the low-poly rig, the overall animation was working smoothly, but in extreme poses, the Cryolophosaurus character mesh was distorted (shown in Figure 140 (A) and (B)) and the texture also was stretched (shown in Figure 141 (A) and (B)).

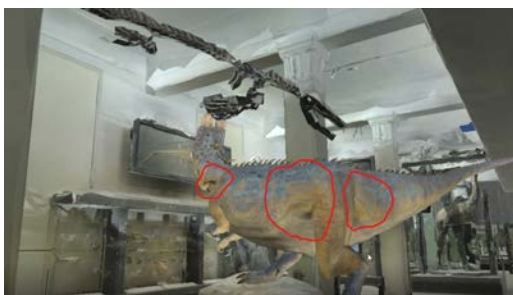


(A) distorted mesh at pose 01

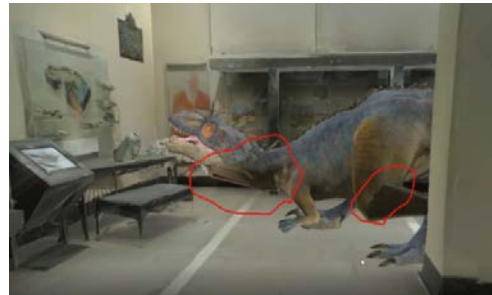


(B) distorted mesh at pose 02

Figure 140: Low-poly Cryolo distorted mesh



(C) Texture stretching at pose 03



(D) Texture stretching and mesh distortion in pose 04

Figure 141: Low-poly Cryolo Model Texture stretching issues

To fix this issue, I replaced the low-poly rig with a high-poly rig to see if there is any improvement in mesh distortion and texture stretching.

As a part of the Interactive VR process, the application was focused on implementing two functions; firstly, “Come Alive” and secondly, “Explore Skeleton” as seen in VR prototype Figure 142 (A). The main purpose of the “coming alive” function is to have the Cryolophosaurus step off the pedestal and roam around the gallery. This is the same animation that was used for the 3DoF VR movie (shown in Figure 142 (B) and (C)). The reason for “explore” function was to give the user the option to learn about the Cryolophosaurus skeleton e.g. point at bones and learn their names in an interactive manner (shown in Figure 142 (D), (E) and (F)).



(A) Default VR scene view with buttons & interactive Cryolo skeleton (B) Cryolo comes to life after pressing the “Come Alive” button



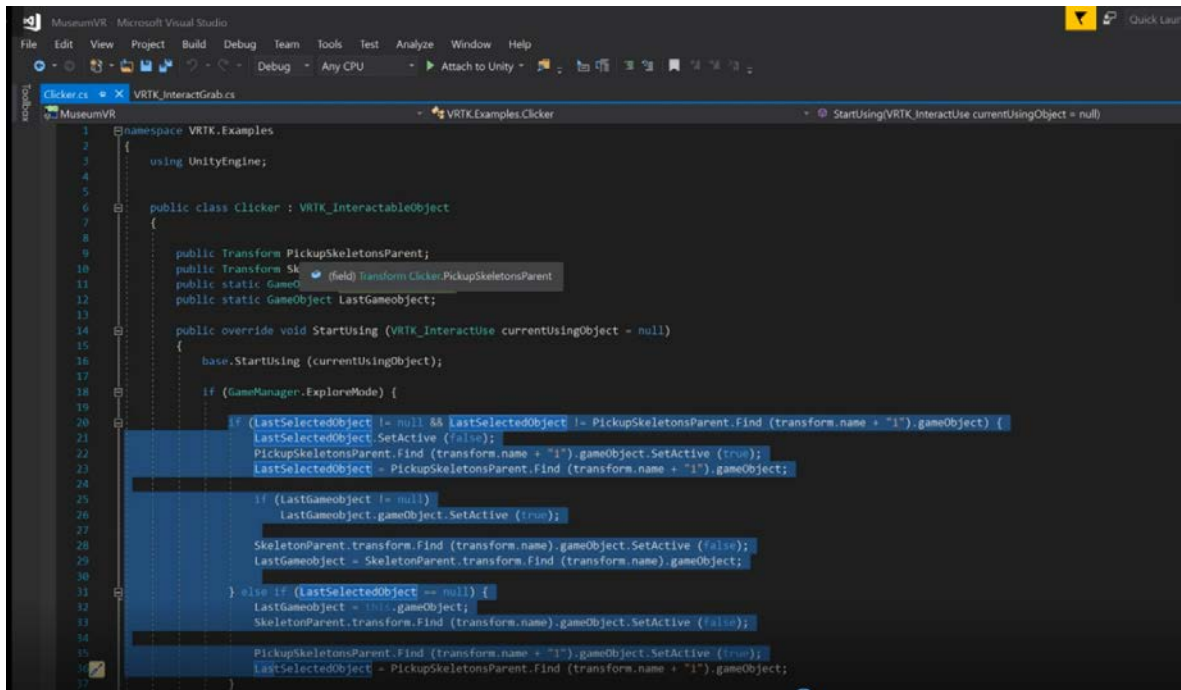
(C) Cryolo roaming around the Origin gallery (D) “Explore Skeleton” button interaction with Vive controller



(E) Information provided in “Explore mode” with Vive controller (F) Object interaction by using Vive controllers

Figure 142: 6DoF VR Working Prototype

To implement these functions in a Unity project, two main plugins were installed, VRTK (Virtual Reality Toolkit) and Steam VR. For the whole VR programming few of the inbuilt functions and classes of VRTK were used, however for customisation to a specific need, the inbuilt functions were modified as per the application requirement (shown in Figure 143). For example, in the explore mode, when the user points the controller at the skeleton, whichever bones are selected by the laser pointer, that bone's name will be projected on the left controller display (shown in Figure 142(E)).



```
1 namespace VRTK.Examples
2
3     using UnityEngine;
4
5
6     public class Clicker : VRTK_InteractableObject
7     {
8
9         public Transform PickupSkeletonsParent;
10        public Transform Sk (field) Transform Clicker.PickupSkeletonsParent
11        public static GameObject
12        public static GameObject LastGameObject;
13
14        public override void StartUsing (VRTK_InteractUse currentUsingObject = null)
15        {
16            base.StartUsing (currentUsingObject);
17
18            if (GameManager.ExploreMode) {
19
20                if (LastSelectedObject != null && LastSelectedObject != PickupSkeletonsParent.Find (transform.name + "1").gameObject) {
21                    LastSelectedObject.SetActive (false);
22                    PickupSkeletonsParent.Find (transform.name + "1").gameObject.SetActive (true);
23                    LastSelectedObject = PickupSkeletonsParent.Find (transform.name + "1").gameObject;
24
25                    if (LastGameObject != null)
26                        LastGameObject.gameObject.SetActive (true);
27
28                    SkeletonParent.transform.Find (transform.name).gameObject.SetActive (false);
29                    LastGameObject = SkeletonParent.transform.Find (transform.name).gameObject;
30
31                } else if (LastSelectedObject == null) {
32                    LastGameObject = null;
33                    SkeletonParent.transform.Find (transform.name).gameObject.SetActive (false);
34
35                    PickupSkeletonsParent.Find (transform.name + "1").gameObject.SetActive (true);
36                    LastSelectedObject = PickupSkeletonsParent.Find (transform.name + "1").gameObject;
37
38                }
39            }
40        }
41    }
42 }
```

Figure 143: Customization of inbuilt code to fit the specific requirement

Once all the code customisation was finished, I focused on how to improve the quality of the overall look of the application. Examples of appropriate lighting setup have been created to match the real environment lighting (shown in Figure 144).

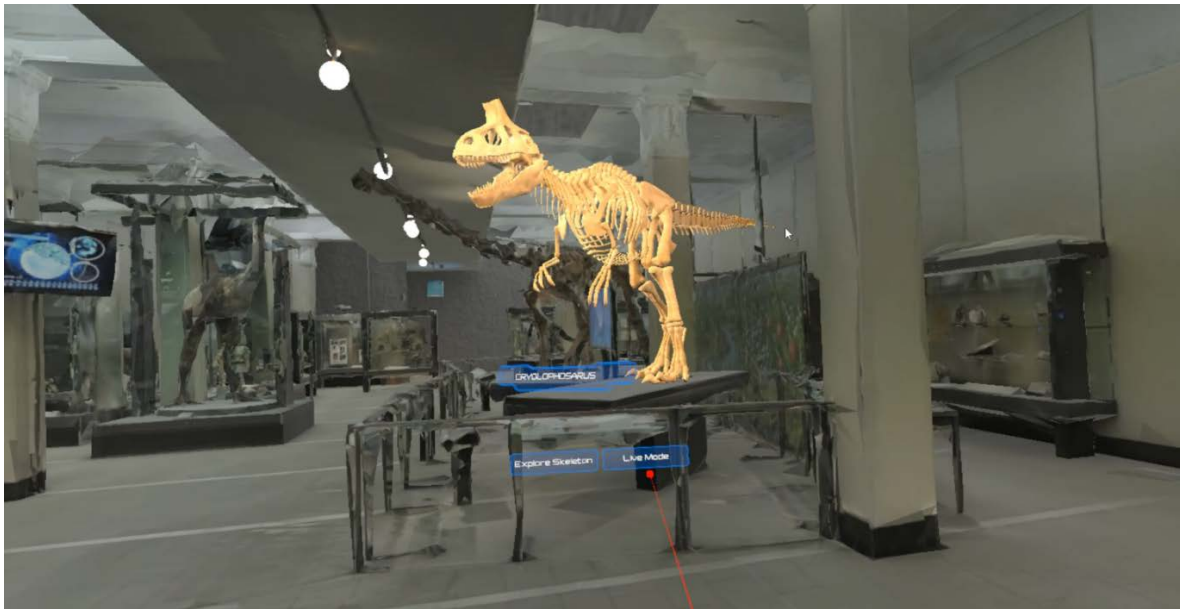


Figure 144: Light setup in Cryolo 6DoF VR Unity project



(A) Cryolo head penetration with TV object

(B) Cryolo tail penetration with the Glass object

Figure 145: Cryolo position mismatch with 3D Origins gallery mesh

There was an issue of matching the Cryolophosaurus animation with the position of the environmental objects (shown in Figure 145 (A) and (B)), especially when the Cryolophosaurus attacks the TV object shown in Figure 145 (A). The reason for this mismatch animation was because of using the different BG environment during the animation process and the actual environment used in the final application. During the animation process, the laser scanned 3D mesh was used whereas in the final application, the Matterport mesh was used. There was a small difference in the position of object creation while using these two different methods. In the end, I fixed this position issue by tweaking the Cryolophosaurus animation manually.

5.3. MR — Microsoft HoloLens Application Development

This section describes the integration of the 3D content into an MR application using the Microsoft HoloLens. “HoloLens is essentially a holographic computer built into a headset that allows you to see, hear and interact with holograms³ within an environment such as a living room or an office space” (trustedreviews, n.d. para. 5). This is an application more about importing the Cryolophosaurus animations into the HoloLens platform to make it seem like they really exist in our living environment (shown in Figure 146).



Figure 146: Cryolo animation test using Microsoft HoloLens at AUT office space

³ Microsoft calls it a "hologram", but it is not strictly speaking a physical hologram of a 3D object created by laser pattern interference (Kovach, 2015).

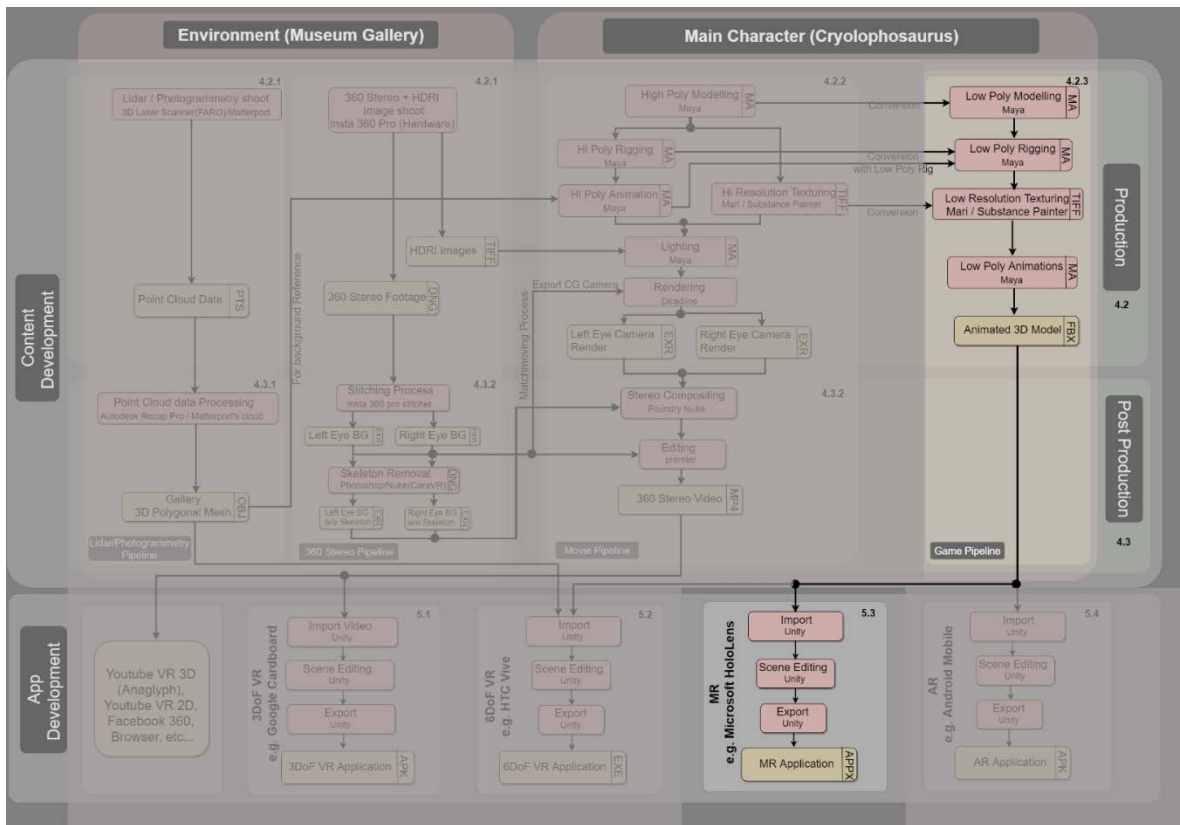
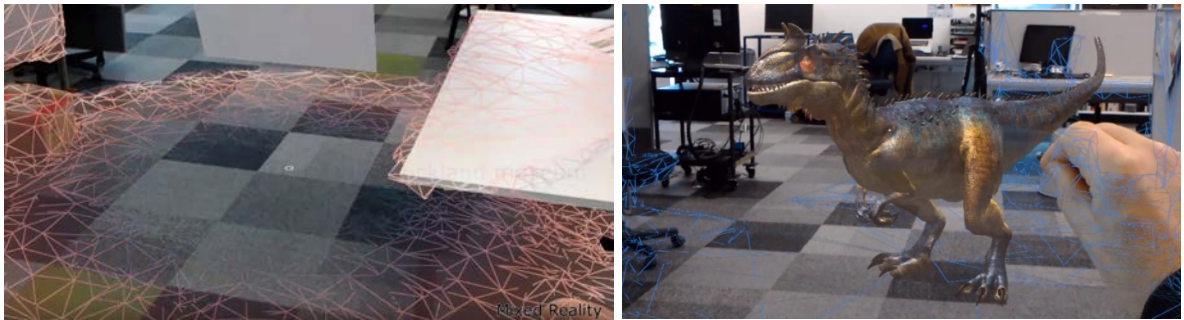


Figure 147: Mixed Reality Production pipeline

As mixed reality is still fairly new to the market, the development pipelines are not yet very stable and require a constant updating of firmware, engines and tools. At the time of writing, Unity had just recently integrated support for the MagicLeap into the main engine and thereby eliminated the need to download and install a specific custom version. Similar to the external VRTK plugin in Unity explained in section 5.2 for creating a VR application, for MR development it is necessary to install MRTK (Mixed Reality Toolkit) plugin in Unity (shown in Figure 149) to build HoloLens applications. Also, Microsoft had just released MRTK version 2, which is meant for the development of applications for the HoloLens 2 as well as for HoloLens 1, but that also required updates to the version of Windows 10 and the Windows SDK of the development machine. However, that SDK update was ahead of the Windows version running on the HoloLens, so it was necessary to juggle SDK version numbers and deleting advanced MRTK components to get a working application with advanced features of the MRTK 2 onto the HoloLens 1.

As a part of the pipeline (shown in Figure 147), low-poly model animations, which were developed in section 4.2.3.4, were imported to Unity in fbx format. The code mainly focused on hand gestures i.e. air tap for interaction with Cryolophosaurus character shown in (Figure 148 (A), (B), (C) and (D)). To run the application on the HoloLens, one has to build an “Appx”

file and deploy the application on the device using MRTK build window options (shown in Figure 150) and unity build setting options (shown in Figure 151).



(A) Environment Mesh Reconstruction

(B) Repositioning the Character by using the Air tap HoloLens Gesture



(C) Reposition Cryolo on top of the stool with reconstruction mesh

(D) Cryolo on top of the stool without reconstruction mesh

Figure 148: Cryolophosaurus character interaction with HoloLens

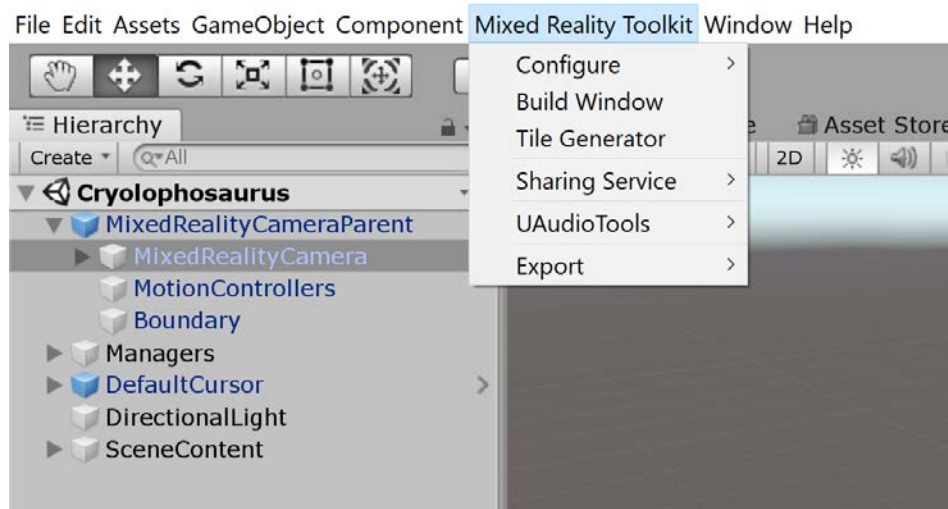


Figure 149: MRTK Unity plugin

There are three ways of running the HoloLens application. One way is through Emulator, if an actual device is not available (shown in Figure 152). The second, is accessing the project

remotely on the HoloLens through WiFi—without actually deploying on the device—for quick iteration called “remote machine”. Lastly, fully installing the whole application onto the HoloLens device, which may take around 5–10 min, or more, to deploy on to the HoloLens. For early rapid iteration, I had used remoting and only deploy finish stages to the actual device. Remoting also has the advantage that it uses the GPU power of the development machine, but has disadvantages due to delay, jitter, and bandwidth limitations of WiFi which causes image artefacts and a lagging experience.

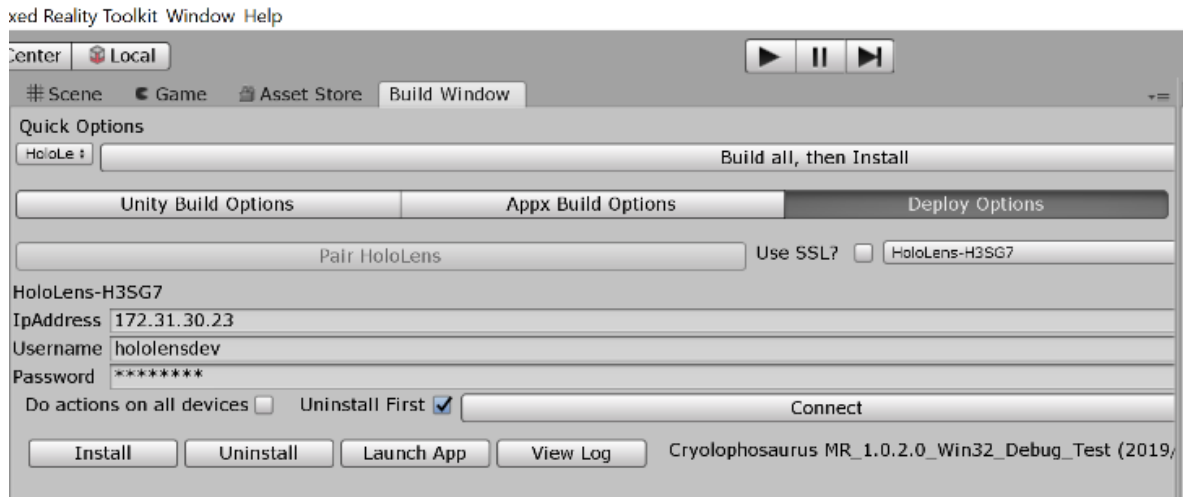


Figure 150: MRTK build window options

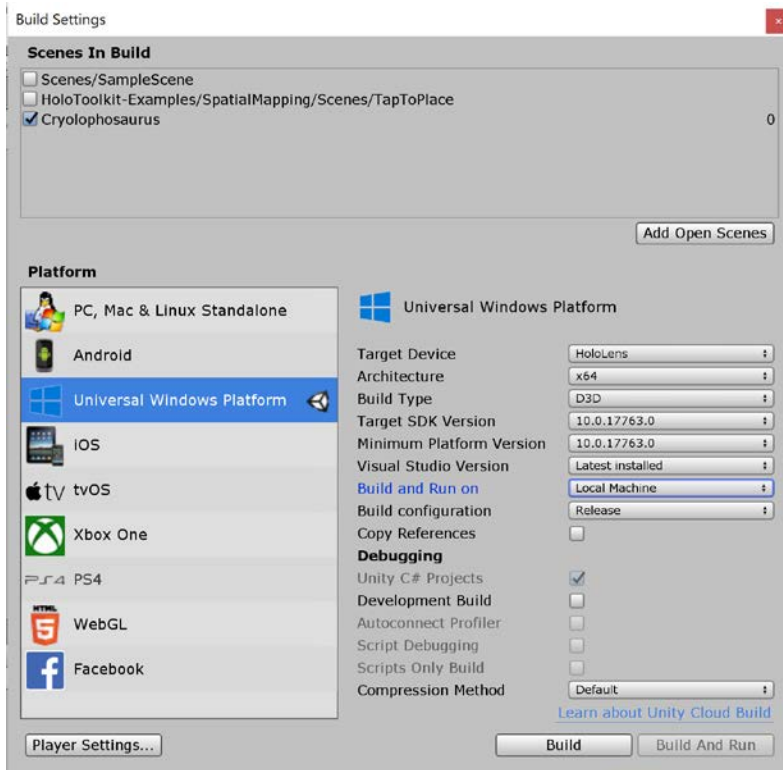


Figure 151: Unity build setting options

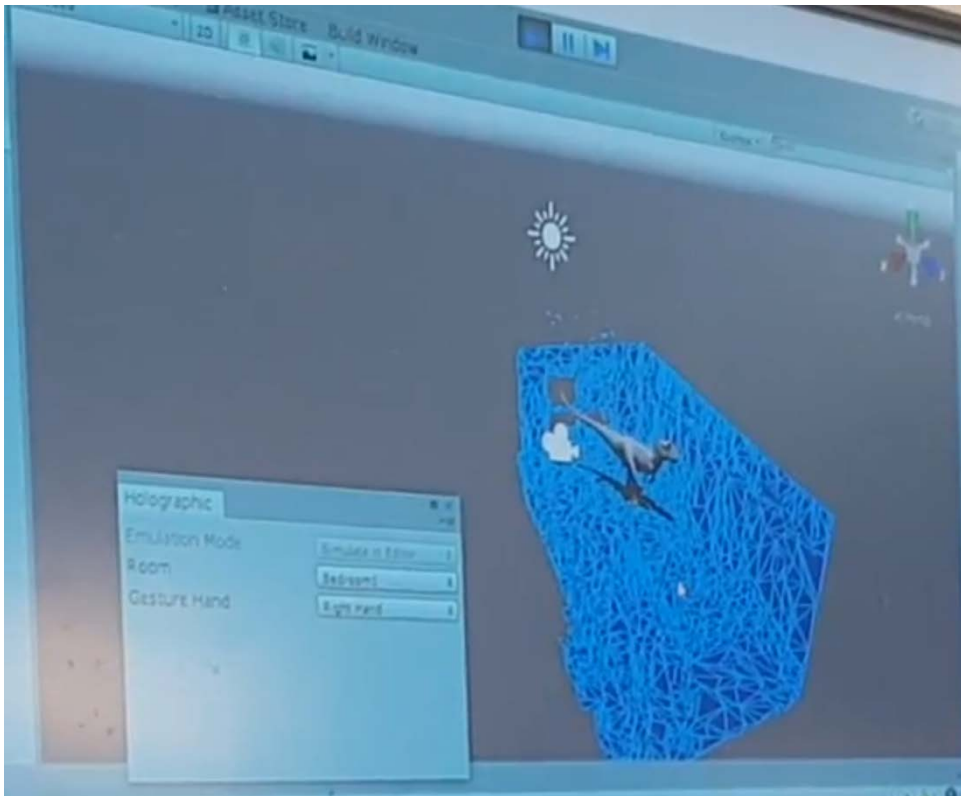


Figure 152: Emulator mode

One major advantage of MR applications is that a person can interact with the object, i.e. Cryolophosaurus character as if it really exists in the space around them. The character can be viewed in multiple perspectives as shown in below Figure 153. So, by using the MR application the user can observe and understand about the display/character in a better and intuitive way.



(A) Closeup view

(B) View from a different perspective

Figure 153: Observation of Cryolo character from multiple perspectives

An important feature of MR applications is the fact that holograms are occluded by real-world objects that are in front of them (see Figure 154). This is an important part of the development of an MR app. HoloLens and MagicLeap provide information about the physical surroundings (wall/table/floor/ceiling/etc.) in the form of a mesh. In some of the screenshots above, that mesh is rendered as wireframe, e.g., to assist with placing. To “naturally occlude” virtual objects, it is necessary to choose a special material (Spatial Occlusion) for rendering that does not actually show up on the display but modifies the depth buffer.

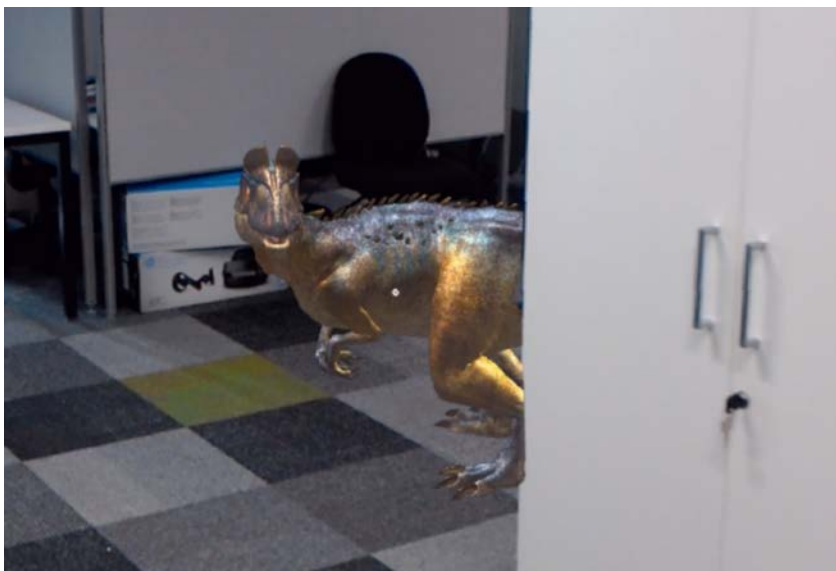


Figure 154: Demonstration of occlusion by a real-world object

One other thing worth noticing in MR production, is that it is impossible in current MR headsets to create a shadow. MR displays (HoloLens as well as MagicLeap) are additive displays, so they cannot make something darker. Black transparent pixels that would work in AR, don't do anything in current MR devices.

5.4. AR — Android Mobile Application Development

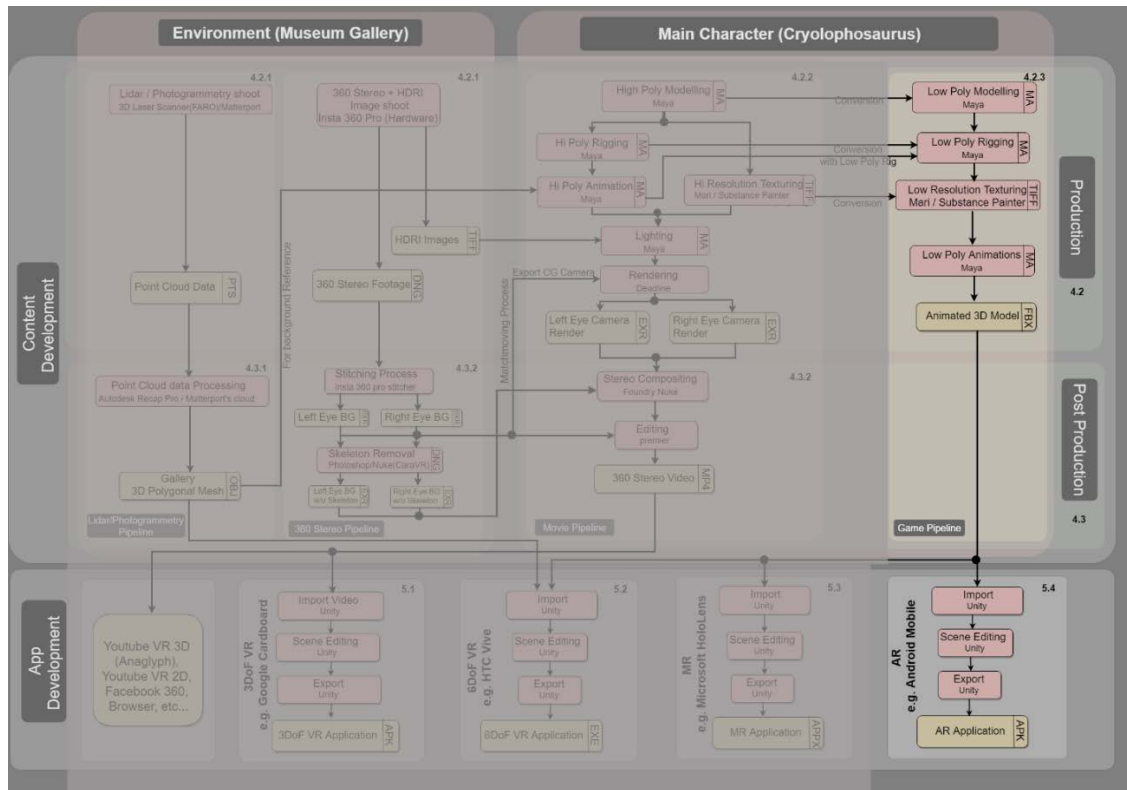
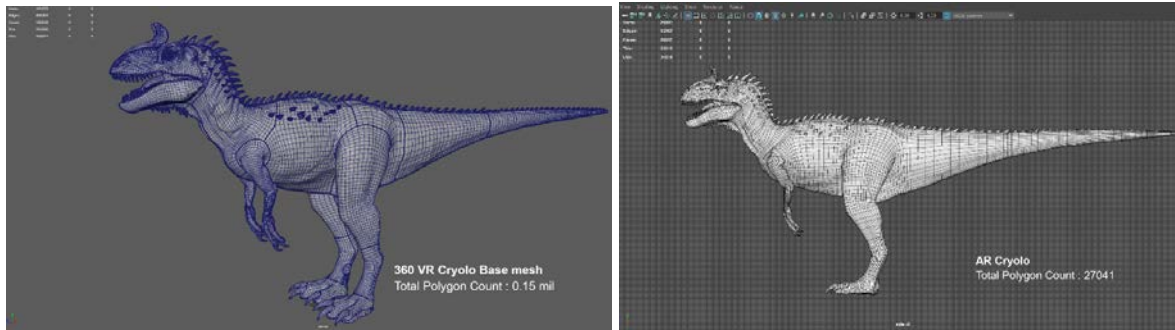


Figure 155: Augmented Reality production pipeline

In this section, I focus on building an AR application for an Android mobile device, taking into account the low processing power of these devices and the small screen size. Considering these restrictions, the CG section (shown in Figure 155) was aimed to create a low-poly Cryolophosaurus model from the high-poly model (shown in Figure 156 (A) and (B)), low-resolution Cryolophosaurus textures (shown in Figure 81), low-poly Rig (shown in Figure 76), animations (shown in Figure 82). All these low-poly FBX animations were imported into Unity to create the AR application.



(A) Base high-poly mesh for low-poly conversion

(B) Low-poly AR model with 27k polygons

Figure 156: Customization of high-poly model into low-poly model

Out of all the different types of AR (see section 2.3), I have chosen to create a marker-based application. As a trigger image template, I used the picture in Figure 159 and imported as a part of Unity Vuforia prefab inside Unity. Inside Unity, I assembled/programmed the scene using the Vuforia prefabs and Unity C#. In the end, I tested this AR application using the webcam (shown in Figure 157), once the results matched the requirements on the webcam, I exported an “apk” file and launched on an Android device (shown in Figure 158).

To run the AR application smoothly, as soon as the installed AR application is launched, the mobile camera opens automatically, point the mobile camera towards image target to trigger Cryolophosaurus animations and interact with the given menu buttons for running the further application (shown in Figure 161). The image target plays a major role in running the application. The image target must be unique, high-contrast and have sharp edges, so that the software can track the image easily. In addition, the image target should be unique to the location, no repeating patterns. In the Vuforia development portal shows the rating of the target image to show how much good quality the target image is for easy tracking for triggering the AR application (shown in Figure 160).

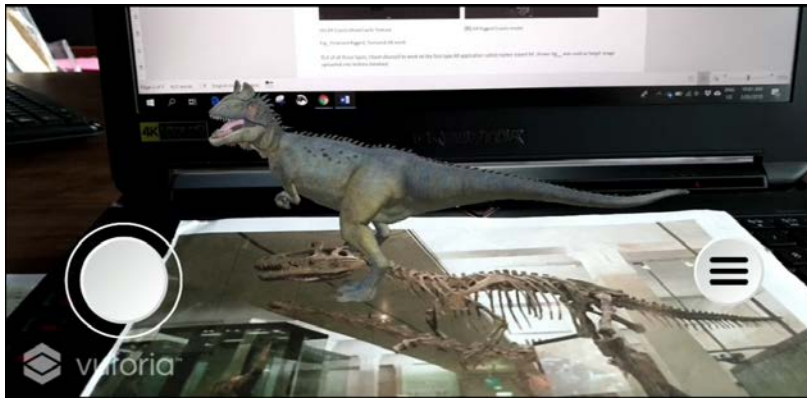


Figure 157: Image-based AR application display through web camera



Figure 158: Installed Cryolo AR application on Android mobile



Figure 159: Cryolo AR trigger target image

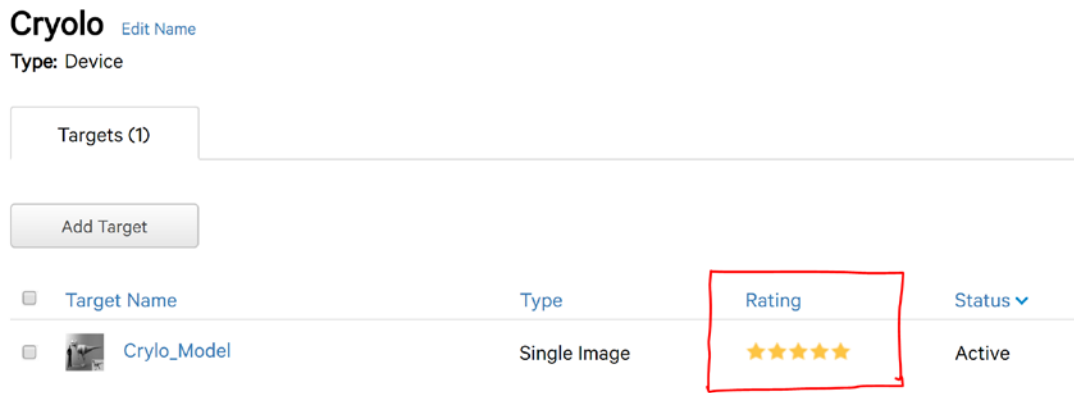
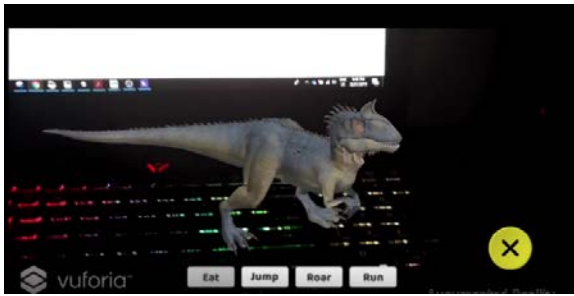


Figure 160: Vuforia development portal shows the rating of the target image

As a part of this AR application development, the main content was focused on interactive experiences and some learning elements. As seen in Figure 161, Cryolophosaurus AR application prototype, in the main screen left bottom side (shown in Figure 161 (A)) implemented a drive mode function where the user can control the Cryolophosaurus running animation like in a game mode. When the user touches the main menu right bottom side, there will be a submenu options “ Actions”, “Facts”, “Skeleton” (shown in Figure 161 (B)). With the “Actions” function (shown in Figure 161 (C) and (D)), the user can have interactive experiences, with the “Facts” function (shown in Figure 161 (G)), the user is able to display information about Cryolophosaurus. With the “skeleton“ function (shown in Figure 161 (H)) the user can learn more information about Cryolophosaurus skeleton parts. By considering the User Experience to make the application user-friendly implemented a two-finger gesture to make the character zoom in and zoom out (shown in Figure 161 (E) and (F)).



(A) left- Drive mode function Right - Main menu function (B) Right - Submenu functions



(C) Action - Submenu options



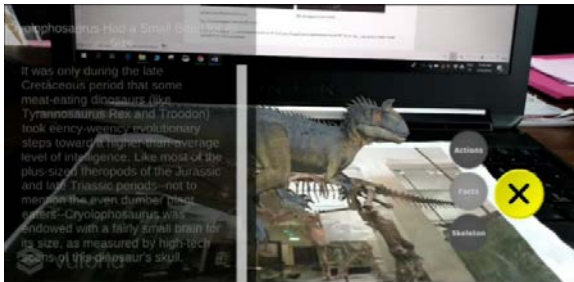
(D) Triggered actions as per the concern buttons



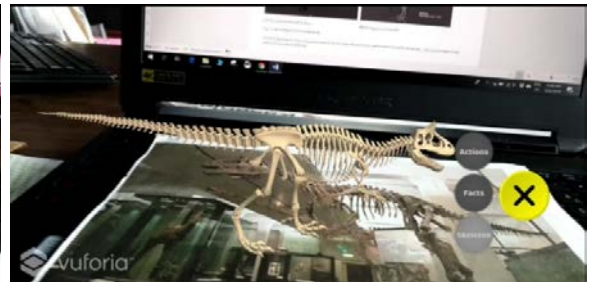
(E) Two fingers outward action for scale-up function



(F) Two fingers inward action for scale down function



(G) Cryolophosaurus fun facts button



(H) Skeleton explore button

Figure 161: Cryolo AR Application Prototype

6. Discussion

6.1. What has been done? Analysing research

Museums are a place of exploration, to know our past, history and culture. The current evolving technologies are enabling museums to provide this information in an interesting manner to provide an enhanced experience to visitors. In this context, I started to research the asset creation pipeline for four XR types, what is necessary and what can be “recycled”.

The research “comparison of virtual realities technologies in the museum”, a practice-based approach has led me to experiment with various software and hardware through this testing journey. This research focuses on building four type of XR applications 3DoF VR, 6DoF, MR, AR while developing I have gone through various technical and artistic challenges. Each application has its own challenges depending on the output requirements.

As part of the research test cases, I have decided to bring the Cryolophosaurus skeleton to life in various technological platforms. To make sure I am in the right direction in fulfilling the requirement of the museum, I have been in contact with the Auckland Museum staff throughout this journey.

The biggest challenge taken during this research was developing all these applications in such a way that they are ready to implement in real museum environment i.e. launching for museum visitors to enhance their experience. So, to implement in real environment first challenge was to build the environment, the Cryolophosaurus character and those need to feel that they are real to the visitors. While interacting with the applications, they must get the impression that this is the real creature that lived millions of years ago that they are interacting with, that they want to know more about it and enjoy its current presence.

Extra care was taken in building the creature, focusing on minute details such as overall shape, appearance, skin textures, volume, its movements / actions, followed lot of reference materials, 3d production best practices, applied technical skills and used concern software / hardware to fulfil all these requirements i.e. to bring the character to a realistic look.

When it comes to a realistic environment, the first thought came to build a forest to take the visitors into million years ago era so that the visitors can experience Cryolophosaurus in its real environment. However, the amount of time to build a realistic forest along with realistic Cryolophosaurus might not be possible to complete the research on time. So, decided to use existing Origins Gallery as an environment, which is a more feasible and better way to test all four applications for comparison purposes. So, to acquire the environment, I used

the lidar scan and photogrammetry to convert the Origins Gallery into digital for VR application and to compare this VR application with 360 Stereo Video (3DoF) did a 360 stereo shoot also within the same Origins Gallery.

In the next stage, out of four application development, 3DoF VR (360 stereo video) application content development was the most challenging process I have come across. Because firstly, the 360-video format is a still-evolving format, not fully established yet in the market, Secondly, working with the stereo format in addition to 360 formats made the production complex, as there is not much easily available software to work with this 360 stereo format such as for stitching and creating HDRI images. The production even got more complex after involving CG realistic Cryolophosaurus 360 stereo renders and compositing these 360 stereo renders with 360 stereo backgrounds. In this process, the biggest challenge was match moving, i.e. getting the CG camera to match with live action camera. Considering this evolving 360 stereo format I came across, there is no software exists in the market yet, which can generate CG camera. So, I have ended up doing match moving manually. When coming to stereo compositing, there is advanced software available in the market, which specially deals with stereo compositing such as Cara VR and Ocula plugin for Nuke software. However, because of price constraints, I was not able to use them, instead having to do compositing only with basic Nuke software. This process increased stereo compositing time and affected the overall quality of the final output. All these issues showed that these 360 Stereo video productions are a challenging application for development.

Issues during environment postproduction:

The result of Insta 360 three-time shoot turned out to be better than expected despite all the challenges in capturing the Origins Gallery environment. However, the captured data conversion to the required stereo image could have been better, for example, I was not able to create HDRI stereo BG image. This situation is because of non-availability of appropriate software in the market that deals with 360 stereo images. Even similar situation has come during the match moving process to create a CG camera from live action footage. The software available in the market is not ready yet to address match moving process with 360 stereo images. Hoping this 360 images/ video format will become a mainstream format in the near future.

When it comes to the result of Faro laser scan, it was not appropriate as required for the VR production pipeline. Moreover, there are few considerations what should be improved in capturing appropriate point cloud data. Firstly, there could have been more time to capture

the whole gallery from many different camera locations, minimum 15–20 positions. So, 8–10 hours of time required in order to shoot these many positions. Hope the museum staff and security will spare these many hours in the future shooting process. Secondly, the time for doing photogrammetry also helps a lot in building a required 3D mesh as the combination of photogrammetry with lidar scan can help in creating a high-quality 3D mesh with high-resolution texture output. In contrast to 360 stereo format, there is appropriate software available in the market to deal with point cloud data and hundreds of photos which are output from lidar scan and photogrammetry.

When coming to the rest of the XR applications' development, I have realised that they were not as complex as 360 stereo development. It's also not straightforward either, putting the models into Unity and making something work is easy, but making it so that interaction is intuitive *and* engaging will be a challenging process, specifically in terms of interaction principles. All these XR applications can be developed by general game production pipeline with Unity/unreal software by using its related plugins in that software such as for AR – Vuforia engine, MR – mixed reality toolkit (MRTK) and for VR – virtual reality toolkit (VRTK). As per the hardware concern, high processing power PCs are required for developing all these applications.

6.2. Implementations

Considering the output was developed for multiple platforms, there are a number of ways to implement in the museum environment for the public. Overall in this whole thesis, there are two major workflows which I have followed. One is the movie pipeline (non-interactive) and another is game pipeline (interactive).

The movie pipeline, which, as demonstrated, is to create a quality movie. It's a complex pipeline requiring a team of creative specialists to bring the creature to life. This pipeline can be useful for bringing the other artefacts/displays to life such as Moa, Malawisaurus etc in a movie format. All these movies can be demonstrated through devices where the visitors can easily have access to the content, such as mobile/tablets/PCs and even online (Web). This is one of the best approaches museums can adopt, so that information about the museum displays can be disseminated to the maximum number of people inside the museum and even outside the museum also. In addition, an extension pipeline, also demonstrated in this thesis, would enable this movie output to be converted to an interactive application, where

visitors can install the application on their mobile and experience the same movie in an interactive and immersive manner by utilising google cardboard or a similar device.

When it comes to the game pipeline, it is general game production that I followed for this thesis. Museums can adopt this game pipeline to engage, educate and entertain visitors in an interactive manner. In addition, this game pipeline enables museum staff, with the help of creative experts, to create multiple applications of a museum display, which can be accessed through multiple devices. The transmedia storytelling concept applied in this thesis—where visitors can access Cryolophosaurus content on multiple devices such as android mobile (AR), HTC Vive (6DoF VR), Microsoft HoloLens (MR). This type of transmedia approach/pipeline can enable museum staff to create innovative applications to engage and attract the maximum number of people, especially the younger generation who are tech savvy. In addition, by providing one display in multiple devices which can enable the visitors to better understand and experience the display in a different perspective of the same display.

So, in this context, Auckland War Memorial Museum, or any museum across New Zealand, can use these XR technologies to develop interesting, innovative and interactive applications designed to attract a greater number of visitors to the country and promote New Zealand culture to the world, as well as possibly contributing in a real way to the country's economy.

6.3. Informal feedback from the Museum

Since beginning this project, I have been talking with Auckland Museum digital managers and offering suggestions and feedback for developing XR applications for the museum.

Despite their busy schedule, they helped me out in 360 shoot inside the Origins Gallery. Once the 3DoF VR came to good shape, I have shown them the progress. They were very much impressed with the output, even agreed to launch the product to the public.

As per the feedback concern, they have asked to me to add titles to the displays and add one more 360 camera location at the beginning of the video so that visitors can understand about Cryolophosaurus in the context of other displays around it. After addressing their feedback, they were happy with the output and currently discussions are ongoing to launch the 3DoF VR application to the public as per the availability of resource at the museum.

Out of all four products, they preferred 3DoF VR video, as this product can be viewed on mobile, tablet, web or google cardboard and mobile i.e. BYOD (Bring your own device) concept. So that the product can easily reach a greater number of visitors with minimum

maintenance from the museum side. About the AR application, considering the museum visitors' requirements, they suggested me to convert the downloadable AR application to a web-based AR application, as people prefer not to download applications to their mobile or tablets.

As regards the MR application, they liked the HoloLens Cryolophosaurus prototype, but they may not be interested further to launch to the public as the maintenance of the device will be costly and allotment of dedicated staff to demonstrate to MR application to the visitors might not be feasible. Furthermore, because of the same reason, they prefer 3DoF VR, HTC Vive / Oculus Rift applications over 6DoF VR application.

7. Conclusion and Future Work

7.1. Conclusion

After experiencing many challenges during the development of these XR applications, I am feeling very positive about the output of this research, as Auckland War Memorial Museum agreed to launch the 3DoF VR application to the public. By implementing these XR applications, museums move beyond static displays to offer an experience where the Cryolophosaurus display, or any others, comes to life and people get an interesting, intuitive, interactive and immersive encounter. Because of this research, my childhood dream is no longer a dream but a reality. I am able to experience Cryolophosaurus in its life-size and learn about it interactively. This Cryolophosaurus production pipeline can be useful to bring other museum displays to life also and be used to create enhanced museum experiences for visitors.

3DoF VR can be possible with normal VR—but with the help of 360 stereo footage, the best quality output can be achieved and be easily accessible on mobile/tablet/HMD, hence the real implementation of this content will be feasible in the museum, instead of huge HTC Vive setup needed for running the VR application.

High-quality laser scanning needed to get high-quality output in the VR application. Buying a high-end laser scan such as Faro 3D will involve huge cost. When comes to 360 stereo shoot, the cost can come down drastically.

7.2. Future work

All applications developed as a part of this thesis have the scope to improve further when I consider implementing the user experience concept to make these existing applications intuitive to use. Currently, I have not focused much on the user experience.

As per the suggestions from the museum's Digital Manager about AR application, I would like to convert the Cryolophosaurus downloadable AR application to a web application so that visitors don't need to download an application but can just use the web link to experience the Cryolophosaurus AR content. In addition, the museum would like to do a user test with these XR applications with real visitors and get the feedback for further refinement. So, I will be focusing on those testing with real visitors in the near future.

The application content focused on interactive experiences and learning elements. A further focus will be on the improvement of applications considering user experience best practices,

so that the user will have the best experience while using this AR application in the museum environment. For example, implement SLAM (Simultaneous Localisation and Mapping) technology in the future application development, where the device will distinguish between walls and floors with the help of reference points of the physical world. By implementing this technology, 3D objects in the AR application can feel like they really exist in the real world instead of just being superimposed on it.

Museum Tour App concept (shown in Figure 162). This project is based on a puzzle game app and works on any mobile or tablet to engage the visitors in the museum and creatively educate them. Users solve the puzzle by visiting various exhibits across the museum. During their journey, visitors get a chance to explore museum exhibits through different platforms and at the same time get the answers or clues to solve the puzzle. In the end, once they solve the puzzle, they will be awarded points. These points allow the user to buy their favourite exhibit merchandise at museum gift shops.

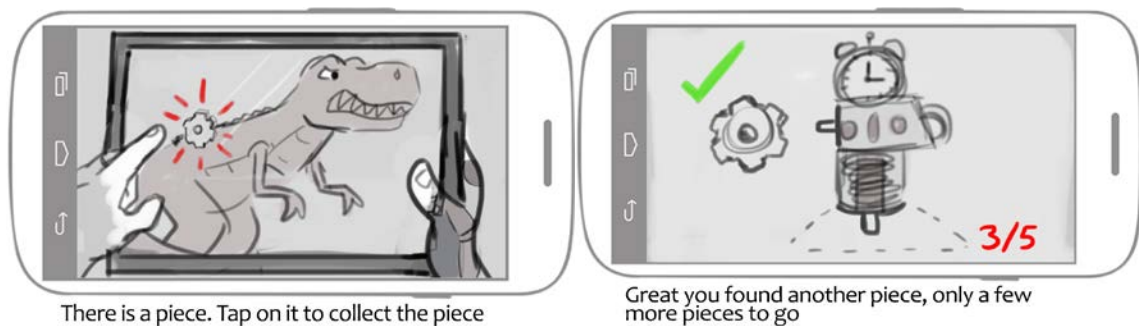


Figure 162: Museum puzzle game app concept

Considering the sharing option available in the HoloLens device, I would like to enable the sharing option in the current MR application (shown in Figure 163), so that in the museum context, visitors can share their experience in a collaborative manner, i.e. multiple people can see and share the experience at the same time. In addition, planning to implement voice input commands so that the interaction with the objects is similar to our daily conversations with our pets.

No doubt these XR technologies are very useful tools in the museum sector. With these applications, visitors are able to visualise the history (display) in a more accurate way, with a different perspective and in multiple platforms. However, to reach the maximum number of people with minimal maintenance, museums may prefer applications that can run on mobile/tablet and allows BYOD over other applications that involve more maintenance and a huge price.

If museums could afford to develop and maintain these types of XR applications, I am sure it will enhance the visitor experience. Then, not only will museums remain relevant in an increasingly technological world, they will continue to fulfil their mission and gain additional revenue at the same time.

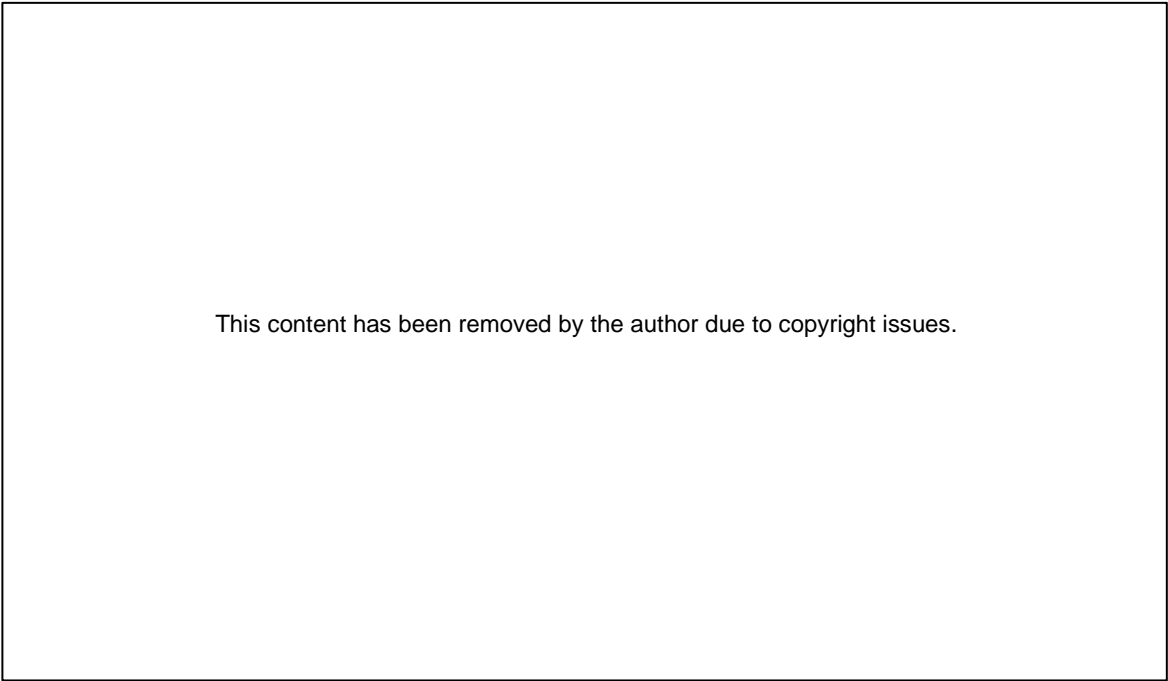


Figure 163: Aim to implement HoloLens collaborative experiences in the Museum environment (Schulte, (2016)).

Appendix

For the overall development workflow as seen in Figure 26, I have used a range of software and hardware. The selection of those was based on a combination of my prior industry experience and the resource availability at AUT.

With respect to hardware there are many alternative devices that can be used for specific tasks, a few of them I have mentioned in the following table.

Task	Hardware used	Alternative hardware
Stereo 360 Image shoot	Insta 360 Pro	DSLR Camera, Xiaomi MiJia 360 Sphere, Rylo, Insta360 One X, Vuze VR 3D 360
Mono 360 Image shoot	Insta 360 Pro	DSLR Camera, Ricoh Theta S, Samsung Gear 360, LG 360 Cam
HDRI Images shoot	Insta 360 Pro	DSLR Camera, Ricoh Theta S, Samsung Gear 360
Point Cloud Data and 3D Mesh of Location	Faro Focus 3D	Xbox connect sensor, Structural sensor, Matterport

Table 2: List of hardware used to capture the 3D environment and 360 environment footage

The software used is of an industry standard. However, there are many alternative software that perform similar tasks but might not fit into the current workflow and also do not have all the required features and are less efficient, some of these are mentioned in the below table.

Task	Software used	Alternative software
360 Image Stitching	Insta 360 Pro-Stitcher, Mistika VR	Kolor Autopano Pro, PTGui, KR Pano, Panoweaver
3D Mesh converting	Autodesk Recap Pro, Reality Capture	Agisoft Photoscan, Pix 4D
3D Modelling	Maya, ZBrush	Mudbox, 3DS Max, Blender, Modo
Texturing	Mari, Substance Painter	Photoshop, ZBrush, Mudbox
Rigging	Autodesk Maya	3DS Max, Blender
Animation	Autodesk Maya	3DS Max, Blender
Lighting	Autodesk Maya	3DS Max, Blender
Rendering	Autodesk Maya, Deadline	Autodesk Backburner, Render Pal
Programming	Unity	Unreal Engine

Table 3: List of the software used for environment post-processing, in building the Cryolophosaurus character and for application development

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