Visual Storytelling with Amarna3D

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Abstract

This thesis examines the process required to develop an immersive storytelling experience in a virtual reality environment based on archaeological and historical evidence. Rather than investigate a single building or small settlement this thesis investigates the issues facing the reconstruction of a large-scale environment. Whilst this is predominately a hardware and software issue that is continually evolving through emerging technologies, the content development must be carefully considered.

The focus of this thesis is a 3D reconstruction of the ancient Egyptian city at Amarna, known as Akhetaten; the short-lived capital of Egypt between 1347 and 1332 BCE. This was a time of great religious and political upheaval known as the Amarna Period and the city itself was the backdrop to many events played out during that time.

The Amarna3D Project was started in 2000 to develop a 3D visualisation of the city and has been repurposed many times for several different outputs since then. However, it was never designed as an interactive 3D environment. To take it forward a new reconstruction will be required, one in which the viewer can move freely throughout and the original Amarna3D model will be used to inform its development. The design will require direction from the archaeological material available to maintain historical integrity and visual accuracy.

This body of work is therefore an archaeo-developer's journey towards the creation of a historically accurate interactive visualisation of Amarna where its stories can be acted out. The research looks at the unique characteristics of this specific site and refrains from developing a general framework for the design and development of a wider range of archaeological sites.

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Preface

My career in the games industry began in the late 1980's where I started out as a generalist. I was involved in design, programming, and art creation, mainly on a freelance basis. I have worked on projects for Activision, Ocean, Infogrames, Atari, SEGA, Nintendo, EA, Microsoft, Sony, amongst others. I have gained experience in developing content for all the main game consoles ranging from arcades through to the present-day PlayStation and Xbox a journey which has seen many technological advancements in computing hardware and software. As roles within the developer studios became more specialised, I focused on the art pipeline as a 3D artist. My experience in design, programming, and art creation allowed me to function as a conduit between the three areas and led me to become one of the first technical artists in the industry.

In 2000 I left the commercial sector and took up a post as lecturer at Teesside University where I was responsible in developing the undergraduate and postgraduate games degree programmes. As part of this provision, I designed the first undergraduate degree in computer games art. The academic department grew over the years which enabled Teesside to provide a wide range of courses delivered to a large cohort who would go on to become employed in all the major games development companies.

My interests have always revolved around the 3D reconstruction of historical sites in antiquity which led me to leave Teesside to study formally for a degree in archaeology at Leicester in 2015 so that I would gain a deeper understanding of the subject. It is my belief that any future 3D reconstructions I develop will benefit as a result.

The Amarna3D Project is a model of the 18th Dynasty Ancient Egyptian City of Akhetaten at the modern-day site of Amarna, Egypt. Its initial construction was in 2000 and has since been used in a range of media including documentaries, magazines, and books. Whilst the model has been updated in part over the years, it has now reached a point where a fresh start is required to reflect the changes in technology and allow for it to be developed as a base for interactive storytelling.

Acknowledgements

2020 has been a difficult year for everyone due to COVID-19. For me there has been many highs and lows and working on this thesis has not been without issue. I did not have the time on campus to engage in general conversation about my research with other students and researchers in the way I had hoped but I was extremely fortunate to have travelled to Amarna before the lockdown.

Throughout my time working on this thesis, I have been helped and guided by my supervisor Dr Colleen Morgan, without whom I could not have continued as I have. Colleen has been a mentor, therapist, and friend in equal measure, and I will be in her debt for a long time to come.

My thanks go to Ryan Lay from BetaJester for the initial guidance and support files relating to Unity3D.

I would also like to thank Prof. Barry Kemp who has willingly donated his time and resources to help me with my research and, by inviting me to be part of the Amarna Project team, validated my decision to move into archaeology from games development. I would also like to thank the Amarna Project team, Miriam Bertram, Anna Hodgkinson, Scott Allan, Fabien Balestra, Marzia Cavriani, Juan Friedrichs, Tim Hagedorn, Sue Kelly, Margaret Serpico, Julia Vilaró and Alexandra Winkels, who not only made me so welcome but were happy to help answer any questions I had. A special mention to Dr Anna Hodgkinson who shared her data with me including the Amarna GIS files derived from the Kemp & Garfi surveys. I am also extremely grateful to Gwil Owen for the inclusion of a range of photos from his photographic archive.

On a personal level, I could not have accomplished anything without the love and support of my wife Dawn who has continued to put me first even when it has been difficult to do so. My time at Amarna was particularly traumatic for her as I narrowly missed lockdown in Egypt due to the global COVID pandemic.

Lastly, I would like to thank my mother Joan, who's regular telephone conversations have had me repeatedly attempt to explain what I am doing (no bad thing!).

Declaration

I declare that this thesis is a presentation of original work and I am the sole author. This work has not previously been presented for an award at this, or any other, University. All sources are acknowledged as References.

All images/models are the authors own unless otherwise stated.

1 Interactive Storytelling

1.1 Introduction

An emerging challenge within archaeology is to engage in digital visual storytelling. By reconstructing archaeological sites as interactive environments it is possible that the wider public can gain a deeper understanding of the past and the lives of the people who lived through it. The use of 3D capture technologies has enabled archaeologists to showcase their work but much of this has been on a modest scale. In general, 3D reconstructions are limited in size to houses, small forts, castles, and potentially a hamlet or village which may or may not incorporate interior spaces for exploration. The scale of reconstruction could be a result of financial constraints, timescales, or hardware and software limitations. This thesis looks at the issues surrounding the construction of a large-scale archaeological reconstruction of the ancient Egyptian city at Amarna, focusing on the 3D visual/narrative design process. The research looks at the unique characteristics of this specific site and refrains from developing a general framework for the design and development of a wider range of archaeological sites.

The development of an immersive visual storytelling experience delivered through a game engine requires a large interdisciplinary development team. So, for the purpose of this thesis the research was restricted to the specialist areas of art and design and not computer coding; looking at how archaeology can be used to inform the design. The VR design project has been titled AmarnaXR to differentiate it from the older long running digital model titled Amarna3D shown in Figure 1.

Figure 1, the Amarna3D model 2020

Amarna3D is an immensely detailed and archaeologically rich virtual recreation of the main city complex of the ancient Egyptian city of Akhetaten (modern day Amarna), birthplace of Tutankhamun and short-lived capital city of Egypt (1353-1336 BCE). The city has a fascinating history and is also the location where the famous bust of Nefertiti was discovered. Created initially as an independent research project, it was further enhanced by data from the official findings of the Egypt Exploration Society and the present-day Amarna expedition team.

Although the model of Amarna is extensively realised, it remains an environment relatively empty of people and stories. This thesis explores modes of storytelling using the existing Amarna3D models. This is an ideal case study exploring how existing archaeological models may be enhanced or translated into more interactive storytelling environments such as the proposed AmarnaXR design. The primary research questions are:

1) How can storytelling be introduced to VR reconstructions of archaeological sites?

2) Can reconstructions of archaeological sites be repurposed for storytelling?

3) Can future virtual reconstructions of archaeological sites incorporate elements that make them more suited for repurposing by the creative digital industry?

The thesis begins by looking at how archaeologists are exploring the physical and digital connections to games through the emerging field of archaeogaming. This comparatively new area of digital archaeology covers a range of gaming technologies however there is relatively little current research being done around the development of 3D modelling, virtual archaeological environments and visual storytelling methods relating to the heritage sector. The overview of archaeogaming is followed by an outline of the development of virtual reality and interactive storytelling. This sets the stage for the case study.

Chapter 2 takes the fundamentals of gameplay and storytelling explored in the first chapter and looks at how they can feed into the design of AmarnaXR, beginning with the development of the Amarna period as a storyworld. This chapter seeks to pull together all the relevant research material available for study when developing a visualisation of the site. It includes a review of the appropriate archaeological resources together with an exploration of the site of Amarna as a visual tour using the physical models and illustrations which have been developed by others. This gives an understanding of the site in terms of its history, geography, size and layout, flora, and fauna, all of which would need to be represented within the game engine. The chapter concludes with an account of the authors visit to Amarna as a member of the expedition team where he was tasked to capture several areas as 3D

models using photogrammetry. Spending time with the team allowed the author an opportunity to discuss potential narratives and gain a better insight into the location.

Chapter 3 is a review of the history of the Amarna3D model. This covers a range of Amarna related visualisations which have been created since the project began in 2000. The model has been repurposed several times over its lifetime, however it has many flaws, in particular its unsuitability for viewing in first person perspective leading to the realisation that a new version of the model is required to allow for greater visual accuracy and as a base for interactive storytelling. The original Amarna3D project can therefore be considered an earlier prototype which will inform the development of AmarnaXR.

Chapter 4 investigates a potential narrative, the story of Ranefer, and the locations required to facilitate its translation into a virtual experience. This ultimately informs the design and construction process and identifies the required resources and workload for projects of this kind.

Chapter 5 reports several observations based on the material gathered and some construction experiments conducted during the research period. Due to the sheer scale of this project additional modelling was kept to the minimum required to illustrate the topics for discussion.

Chapter 6 looks at what has been learned from the Amarna3D model and the issues surrounding the use of archaeological sites in VR reconstructions aimed at storytelling with a bias towards large scale sites. The thesis concludes with a summary and recommendations for future work.

1.2 Archaeogaming

Archaeologists have embraced the use of 3D modelling and virtual reality to "test scientific questions, communicate impressions of the past to others, and invite outside participation in the construction of the past" (Morgan 2009, 471). The term virtual archaeology was introduced in 1990 (Reilly 1991) to encompass the use of computers in simulating excavations, modelling archaeological contexts, and reconstructing historical structures as 3D visualisations. In 1997 the first collection of 3D computer generated archaeological visualisations listing 50 locations was published (Forte and Siliotti 1997). In the same year the historical strategy game *Age of Empires* (Ensemble Studios 1997) was released building on earlier historically themed strategy games such as *Civilisation* (Sid Meier 1991) and *The Seven Cities of Gold* (Ozark Softscape 1984).

The development of video games with well-defined civilisations has prompted some archaeologists and heritage specialists to study how virtual archaeology and computer gaming can be used together within an emerging research area termed Archaeogaming. Archaeogaming has been broadly defined by Andrew Reinhard as "the archaeology both in and of digital games" (2018, 2). This is a simplification of the many and varied ways in which archaeological methods and analysis can be used in connection with both digital and physical game constructs. Reinhard expands further on this by dividing Archaeogaming into several research areas as shown in Table 1.

One area of archaeogaming views the physical game package, that is the storage media, manual, and box, as a physical artefact. It explores the personal and commercial history of hardware and software, its distribution methods, change of ownership, and support communities (Reinhard 2018, 3). A notable example of this was the excavation in 2014 of the Atari video game burial in Alamogordo, New Mexico where in 1983 Atari, Inc. buried millions of copies of E.T.: The Extra-Terrestrial in a landfill (Reinhard 2018, 23–29). Archaeogaming takes the traditional archaeological methods used to study a site in the physical world and transfers them to the digital environment. An example of which was the examination of the hardware components and digital file structures located on data storage devices, such as hard drives and USB memory sticks, as archaeological sites (Moshenska 2014; Perry and Morgan 2015). This excavation explored a potential recording strategy for media archaeology projects whilst revealing issues surrounding the [dis]connection between hardware and software within the same artefact.

ARCHAEOGAMING	Real-world Archaeology of Video Game Hardware and Software	Atari burial ground
		History of use and object biography
		Conservation and preservation
		Establishing chronology and typology of games
		Gaming spaces - arcages
		History of personal or commercial use
		Archiving and game history
		Version control patches and damnatio memoriae
	Videogame or Virtual World as Archaeological Site	Tool definition and creation for in-world archaeology
		Application of real-world methods to virtual spaces
		Glitches as artefacts
		Game as artefact or the space between the hardware and the illusion of a world in game
		In-world garbology
		Survey landscape underwater exoarchaeology
	Philosophy	Quantum entanglement in video games
		Perception
		Complexity and chaos and algorithms
		Deism and world-building
	Reception	Archaeologists as playable characters
		Archaeologists as non-playable characters or AI
		In-world looting and or auctioning of in-game inventory
		Public perception of archaeology and archaeologists
		Developer perception and promotion of archaeology and archaeologists
		In-game depictions or reenactments of real-world historical events
	Game Development	Archaeological consulting with studios
		Archaeologists as game makers
		Developer influence and design choices
		Games as archaeology teaching tools
		Augmented reality for play tourism or education
		3D modelling and space-creation or recreations of antiquity both real or imagined
		Lore and lore communities
		Code source as epigraphy and palaeography
	Machine Created Culture	Virtual ethnography
		Procedurally generated environments and artefacts
	The Archaeology of [game title]	Minecraft
		Elder Scrolls
		World of Warcraft
		Fallout
		Mass Effect
		etc.
	Material Culture	Real and virtual commerce economics and numismatics
		Real-world manifestation of virtual world artifacts
		Cosplay and game-derived experimental archaeology
		In-world museums
		Real-world museums

Table 1, Archaeogaming research areas (after Reinhard 2018, 4)

Archaeogaming also involves treating established built environments within games as archaeological sites by exploring the cultures, histories, and lore created by the developers; including how they have grown, changed, and adapted through serialisation (Reinhard 2018, 88). Reinhard explains that historical games interpret past civilizations and places, shaping them into what works for the purpose of audience engagement, as similar to how archaeologists have interpreted the past from the material

recovered from the archaeological record (Reinhard 2018, 6). However, the motives are quite different in that game designers are working towards commercial success whilst the archaeologists are looking to increase knowledge. Developers aim to utilise public interest in historic periods and events to sell a product. To succeed they must develop an engaging story and associated gameplay; modifying history as required (Copplestone 2017a). Interestingly, as game designer's mashup more of the past they begin to create unique civilisations which are in turn of interest to archaeogamers (Mol *et al.* (Eds) 2017; Reinhard 2018, 197). With established game-worlds, archaeogaming also examines the physical manufacture and sale of digital artefacts in the form of in-game clothing, armour, and weaponry through real-world marketplaces creating a physical archaeological record mirroring the digital one (Reinhard 2018, 162). Here experimental archaeology through cosplay can be extended further by taste and smell through the interpretation of in-game food into real-world cookbooks (Monroe-Cassel 2016, 2019, 2020; Rosenthal 2018, 2020) albeit limited in the game-world cooking methods (Reinhard 2018, 179).

The construction of digital models of archaeological sites is a natural extension of illustrations and physical models which have been created by archaeologists. However, the development of virtual sites that can be interacted with is a complex process and one in which few archaeologists have been able to have autonomy over. The use of the online virtual world Second Life (Linden Lab 2003) has allowed archaeologists to bypass much of the software development and focus on content creation. This can be seen in the development of Çatalhöyük which was a "multivocal experiment in building, re-building, and representing the past and present realities of the physical site" (Morgan 2009, 468). The relatively limited construction tools within Second Life means that the resulting accuracy of the structures cannot compete with dedicated 3D modelling software but it still allows the archaeologist to make interpretive decisions which can be fed into more detailed reconstructions later (Morgan 2009, 476). Second Life includes the option to allow others to modify content within the environment enabling a collaborative approach to understand the site. This allows the archaeologists to think about the many ways archaeological data can be interpreted and communicated to a wider audience (Morgan 2009, 481). This thesis is focused on the archaeogaming area surrounding game development and the 3D recreations of antiquity both real and imagined, and in doing so touches on depictions of real-world historical events. Archaeologists as game developers is of great interest in that it affords the archaeologist an opportunity to not only disseminate one possible narrative but engage others in the exploration of multiple narratives through gameplay design (Copplestone 2017b). The dissemination of archaeological material through video games rather than the traditional publications (Mol et al. 2017, 12) is an intriguing possibility but one which would require overcoming the fluidic and transient nature of gaming technology as an archival system.

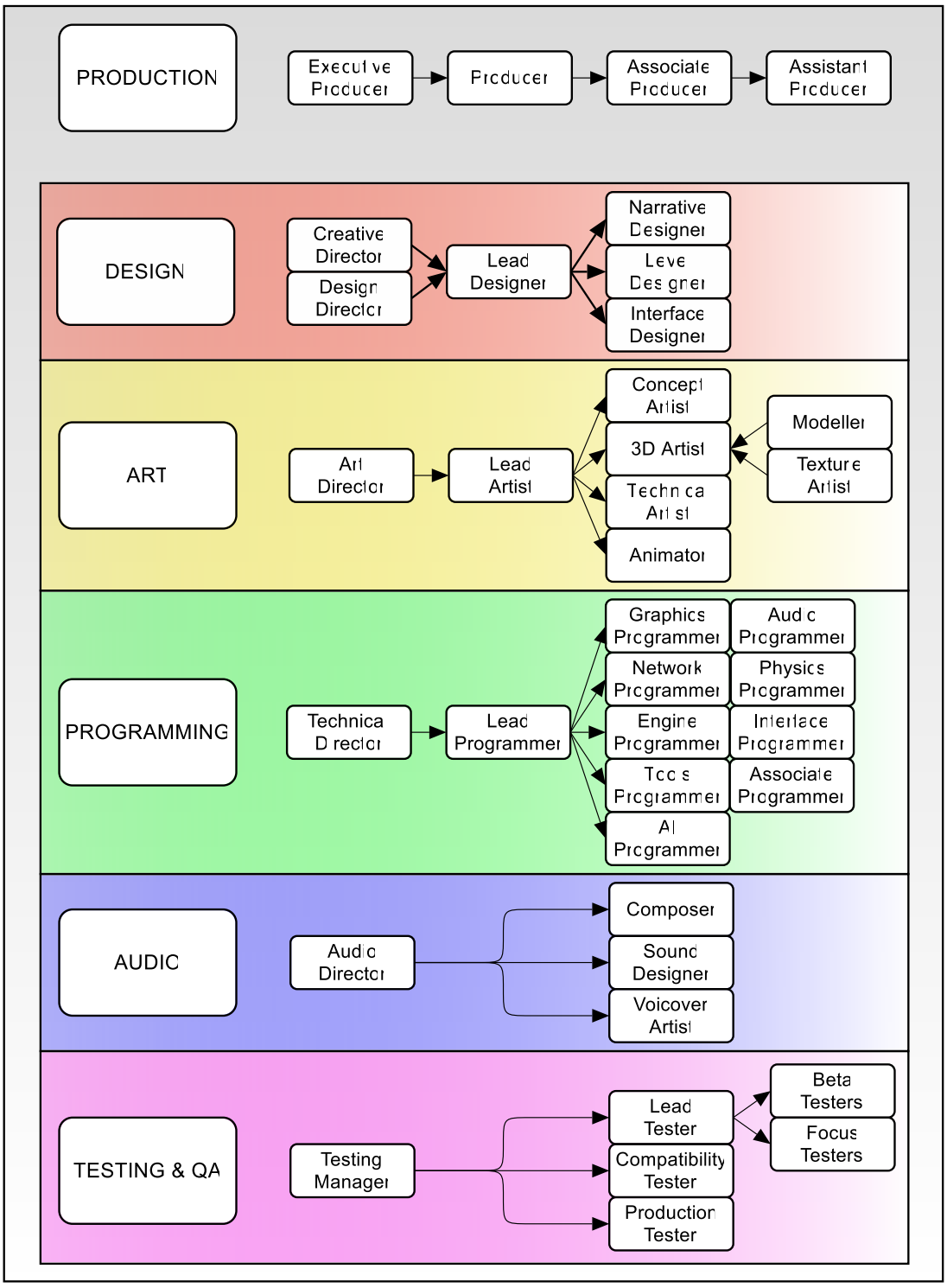


Figure 2, a typical organisational structure of a medium sized modern game development studio

Some games allow for user input to modify the environment, player avatar, or non-player characters through the use of game editor software supplied by the publisher, a notable example is the Unreal Editor (Epic Games 2020a). The editor became fundamental to the establishment of the 'modding' community who used it to develop their own alternative versions of published games. Other

publishers have followed suit by making game editors (Crytek GmbH 2020; Unity Technologies 2020) available free to the general public for use in developing their own games or virtual reality experiences.

In the early years of games development, it was entirely possible for one person with enough technical skill to create a complete game in isolation. These games have grown from text-based adventures through scrolling bitmap graphics to immense 3D environments with visuals that can rival some film sets. As games have increased in their complexity so too have the skills required to build them. Developers require a specialist team with expertise in design, art, programming, audio, and testing all working under the guidance of the Producer to create a publishable game. Figure 2 presents the typical roles found within a medium sized games development studio derived from multiple sources (Mitchell 2012; Novak 2012; Rogers 2010). Of the roles presented, it is the artists and designer's roles which are of most relevance to this thesis, with the artists responsible for the construction of the visual assets and the designers responsible for the story, gameplay, and level assembly.

Whilst the production pipeline and software development tools have been refined over the years the demand for higher quality visuals and detailed open world environments has led to much larger development teams, particularly within the art department where the main content is created. Ubisoft's Assassins Creed franchise is well known for its detailed historical visuals and open world. The Assassin's Creed: Origins Discovery Tour game mode (Ubisoft 2018) allows the player to wander around ancient Egypt without having to complete quests (Figure 3). Whilst the historical, archaeological, and geographical accuracy is flawed in parts, the ancient Egyptian world has so much detail that it creates an immersive quality that is currently unmatched, and with the stand-alone educational version it is a useful tool in academia (UdeMNouvelles 2018).

It has been argued that the increased detail within the environments can affect the story and level design (Reinhard 2018, 191) however the development pipeline ensures that designers and artists work in parallel. The artists are free to develop photorealistic assets whilst the designers use whitebox or block out techniques to develop the gameplay. Whiteboxing uses low resolution or primitive geometry as temporary assets to construct the game level within the level editor. These are replaced with the finished art assets when they are complete. In some cases, art assets from a previous game can be used as a stand in for more complex level design. It is not the detail required of the assets but the scale of the game world that is an issue. Raphael Lacoste, Art Director on Assassin's Creed: Origins (ACO), spoke about the asset development at the 2017 Montreal International Game Summit (MIGS 17). He was interviewed by GamesBeat where he disclosed that the ACO team was around 1000 people with 300 of those working on the artwork. At the 2018 Games Developers Conference Jean Guesdon, franchise head for Assassin's Creed, presented the development timeline chart (Figure 4)

for the Assassin's Creed series showing a four-year development period for ACO spanning three studios. For the Discovery Tour, work continued through to 2018 with assistance from additional Ubisoft studios worldwide. With this size of development team and production timeframe it is no wonder that the ACO open world is so detailed, but at this scale few developers can compete. In 2019 Assassin's Creed franchise recorded over 100 million unique users (Ubisoft 2020).

Figure 3, poster artwork for Assassin's Creed: Origins Discovery Tour (Ubisoft 2018)

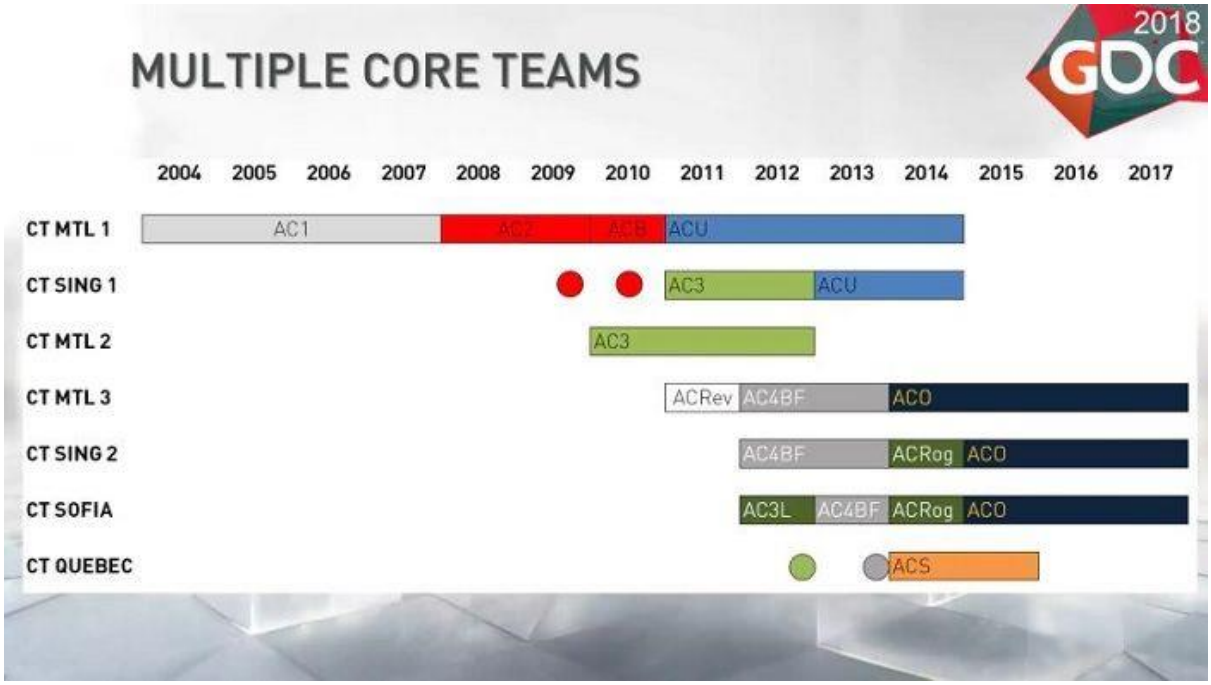


Figure 4, Assassin's Creed chart detailing series development (Ubisoft, GDC 2018)

The Assassin's Creed franchise is not only a commercial success but also a success in delivering large historical sites to the general population. These open world environments are a very credible virtual

reality experience and whilst their narratives may be fanciful, they prove the potential of the technology for storytelling. The next section explores the history of virtual reality and leads into gameplay and storytelling.

1.3 Virtual Reality

The term virtual reality (VR) was made popular by Jaron Lanier in the 1980's when he set up VPL Research with Thomas Zimmerman to develop VR goggles and the data glove for commercial use (Bosworth and Sarah 2019, 1). However, the road to modern virtual reality has been a long one beginning with the pinhole and camera obscura (Latin "dark chamber"). The optical effect of the pinhole and camera obscura can be traced back to the 4th century BCE in the Chinese Mohist text *MoJing* (Needham 2004, 98) although the earliest scientific work with the camera obscura is attributed to the great Arab physicist Ibn al-Haytham at the start of the 11th century CE (Sarton 1927, 721). The camera obscura was a dark room which permitted light to enter through a pinhole projecting an inverted image of the exterior onto the wall within. Later use of mirrors and lenses allowed the projected image orientation to be corrected and re-projected to a different plane within the room. The effect of the camera obscura was to bring the outside, inside, and alter the scale if desired. Between the 16th century and the mid-19th century it was used for popular entertainment, scientific enquiry, and artistic practice (Crary 1990, 29). The projected image could be used as a drawing aid to create a permanent and accurate copy of the exterior view. By rotating the camera obscura, it was possible to create a panoramic representation and with the invention of portable booths different locations could be explored.

In 1787 the artist Robert Barker patented a method for minimising the perspective problems inherent in painting 360-degree panoramas and in 1791 presented, "Panorama of London from the Albion Mill, Southwark" to the public (Byerly 2012, 36; Bosworth and Sarah 2019, 1). To see the new panoramas correctly a large viewing platform was required, prompting a new type of building, the rotunda. The Panorama in the Strand (1802-1831), and the Rotunda in Leicester Square (1823-1861) were two such buildings, the interior workings of which can be seen in Figure 5. Panoramas took the viewer to places they would normally not be able to visit, creating a form of virtual tourism and with the depiction of national and international events brought a narrative element to this new immersive experience. The use of a rolling canvas introduced moving panoramas and the feeling of traveling through a scene. One very popular method was the unrolling of a canvas showing the world's capital cities as if viewed from a balloon. This 'balloon-eye view' was the forerunner of today's 'flythrough' view, popular with many modern virtual reality simulations. River journeys and boat journeys were popular from the early 1820s through to 1900, sometimes with actors narrating the scenes on view (Altick 1978, 203). The

most impressive was Banvard's Panorama of the Mississippi exhibited in England in 1848 and reviewed by Dickens in the *Examiner*, who was impressed with its length at three miles (Slater 1996, 135).

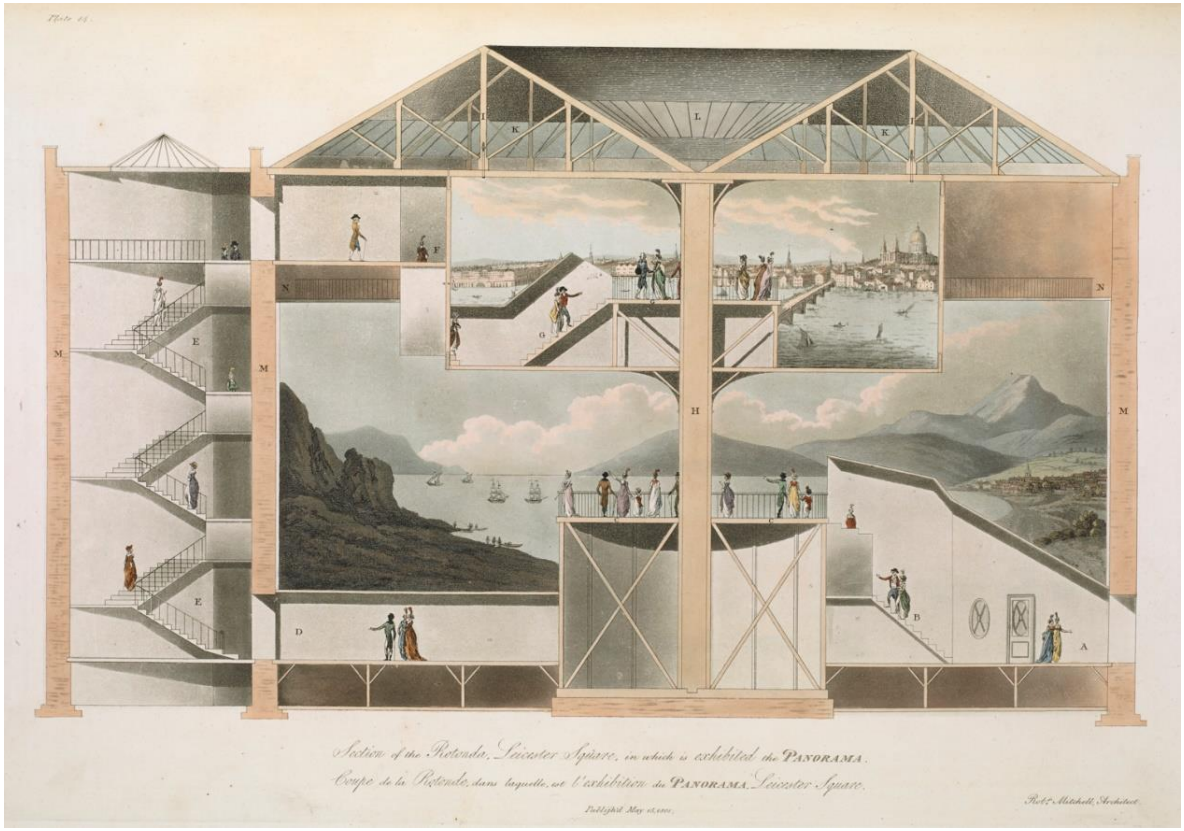


Figure 5, section of the Rotunda, Leicester Square (Mitchell 1801)

1.3.1 The Head Mounted Viewer

With the advent of photography, the quality and accuracy of panoramas increased, and the viewing technology started to shrink to accommodate the size restrictions in developing photographs. The invention of the stereoscope in the 1830s, was able to take advantage of stereo pair photographs (stereographs) and with the later replacement of the mirrors with lenses in 1849 by David Brewster, the modern 3D viewer was born. The stereoscope has continued through to the present in various forms such as the View-Master in 1939, Google Cardboard in 2014 which is used in combination with a mobile phone to display stereo images in 3D, and Oculus Rift introduced in 2016 (see Figure 6). The modern head mounted display (HMD) includes motion and rotation sensors which record the translation, or sliding motion, through the three axes giving a total of six degrees of freedom (6DoF), see Figure 7. The HMD is connected to a computer which generates the immersive visuals and the addition of 3D positional sound further enhances the immersion by bringing audio cues typically found in the real world. To interact with the environment the user can trigger events through either looking at an object or signpost using a crosshair view or through the manipulation of hand-held joystick and button controllers. Hand-held controllers normally include similar positional and rotational sensors

found in the HMD allowing for enhanced freedom of movement when manipulating objects or features within the environment.

Figure 6, the evolution of stereo head mounted displays: (1) Brewster Stereoscope (CC BY-SA), (2) Sawyer's View-Master (CC-0), (3) Google Cardboard (CC-0), (4) Oculus Rift (CC-0)

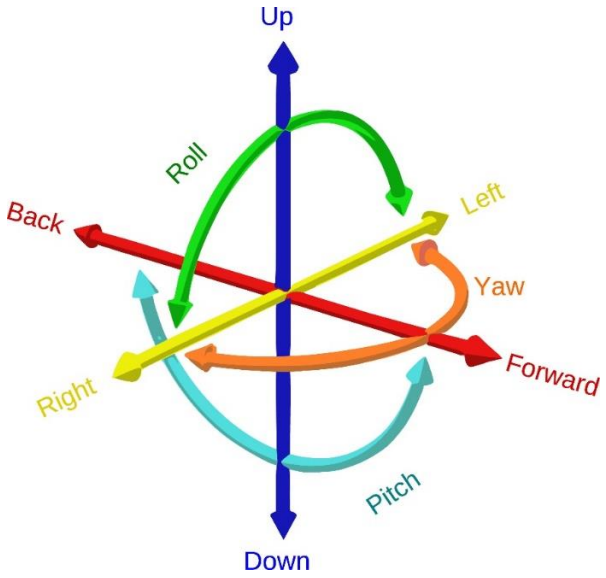


Figure 7, six degrees of freedom (CC BY-SA)

A VR environment is a method of transporting the player into a place they would not normally have physical access to. This allows experiences to be based on geographical locations, fictional locations, off-world locations, or scale-based from sub-atomic to galactic in size. VR can also be used to transport

the player through time to different periods. Whilst VR places the user inside a virtual world Augmented Reality (AR) brings artificial elements into the real world. The AR environment uses video cameras to stream the player's point of view and augments this with visual, auditory, or haptic data feedback accurately positioned in real-world 3D space. This is achieved through the implementation of additional processing using a combination of GPS, object, and pattern recognition to accurately register the position of the digital augmentation in real-time. In its simplest form it can be a live information feed over a video or TV broadcast. In the game industry it can be used to bring a battle into your living room, hunt monsters in the street, or run away from zombies while out for a jog. With coded targets, books come alive in your hands allowing the reader an opportunity to interact with the characters themselves.

1.4 Gameplay and Storytelling

The craft of storytelling has taken many forms throughout history including word of mouth, the written page, theatre, and film. Stories are generally a linear construct albeit sometimes told outside of chronological order. A good story must be "credible, coherent, and dramatically meaningful" (Adams 2010, 158). They are typically a passive experience being entirely controlled by the author who takes us on one path through the story from beginning to end.

In 1938, Dutch Anthropologist Johan Huizinga described gameplay as a non-serious and utterly absorbing activity conducted outside ordinary life which proceeds according to a set of rules. He adds that it is not associated with any material interest or profit and that it creates its own social groups separate from the outside world within its own boundaries of space and time (Huizinga 1964, 13). However, game historian David Parlett sees gameplay as two distinct forms namely formal and informal (Parlett 1999, 3). Parlett describes informal play as that of children and puppies playing around or schoolchildren acting out the exploits of their heroes and heroines in an impromptu way. Whereas formal gameplay is based on ends and means. The ends constitute a goal to be achieved by either an individual or team-based contest. The means are the tools required to win the contest within the boundaries of a set of rules. Once the objective is won the game has concluded and play ceases.

Games have numerous possibilities which are actively navigated through by the player. With a range of choices available, the player can create their own stories using the numerous interactions they have experienced within the game. This means that each time the game is played the experience will be slightly different. It is the games designer, who engineers the range of possibilities for the player, but it is the player who chooses the path. Creating an immersive experience is the very heart of game design revolving around gameplay.

1.4.1 Game Mechanics

The rules of gameplay are the mechanics of the game and are designed to enable player actions or restrict them (Domsch 2013, 16). Some games will begin with simple game mechanics and introduce more complex ones as the game progresses to challenge the player and maintain interest. Being able to maintain the interest of the player is fundamental to the success of a game, make it too easy and the player becomes bored, make it too difficult and they give up.

The primary game mechanic is that of space and how it is traversed by the player (Schell 2019, 130–135). Real-world mechanics follow the physical laws found in the real-world such as gravity and solid matter which would restrict the player from walking through walls or being able to fly. Real-world mechanics enable the player to walk, run, climb, swim, and manipulate objects. The advantage of real-world mechanics is that they are already known to the player having experienced them in real life.

Game mechanics can be implemented in a way which enables narrative events to take place and a story to be told which creates empathy and an emotional connection between the player and the characters within the game. This can be seen in the popular game series Left 4 Dead (Valve 2008, 2009) and The Last of Us (Naughty Dog 2013, 2014, 2020) where players become invested in the wellbeing and safety of the characters beyond that normally found in action adventure games (Dubbelman 2016). Storytelling mechanics include player and non-player character interaction in the form of physical contact, dialog, and progression. The mechanics of progression involve exploring the game space, gain abilities and skill, collect objects, discover clues, and experience cut-scenes triggered at certain locations tied to the plot (Adams and Dormans 2012, 31).

Building economies is inherent in simulation and strategy games and revolves around in-game resource management. Civilization and SimCity involve constructing buildings which establish economic relationships with each other depending on their type and location (Adams and Dormans 2012, 197). Player mismanagement, natural disaster, or aggression can impact the economy. Economy can be used as a narrative event at a character level to enable plot progression through trade or skills.

1.4.2 The Backstory / Storyworld

“Worlds can exist without stories, but stories cannot exist without a world” (Wolf 2012, 29). The storyworld of a video game is the fictional world in which the structure of the game and its rules as well as the actions of the player within it are given meaning (Domsch 2013, 27). It is the environment in which the story takes place but does not limit itself to just the present game. It sets the rules of the world so that all stories are developed from a common foundation and have a coherent structure. This world establishes what society looks like and the languages used. It describes how this world began and what events shaped it including any belief system (Berger 2020, 116). It explains what type of

environments are present, the climate, and what nature looks like, in short, its whole ecosystem (Wolf 2012, 30). By developing a solid storyworld each story or plot line reinforces the next bringing it to life and enabling the player to become deeply immersed in the place and time. The storyworld is the primary blueprint from which all related stories are developed from (Nitsche 2008, 243).

By imagining the storyworld as a planet then stories can be thought of as the countries on it, they can have their own individuality but must not deviate from the established storyworld. A story is constructed from specific events which, when connected, form the plot. The plot is the linear path or journey taken by the player through the game. The plot structure will have a beginning, middle, and end (Heussner et al. 2015, 121). The beginning will setup any goals the player must achieve and why. The middle forms most of the time within the story and revolves around the movement from one event to the next. For the story to work it needs to have an emotional resonance with the player such as conflict, humour, or loss. Events should escalate to push the plot forward and, as the player nears the end of the game, they should feel a sense of evolution has taken place in their characters outlook and situation when compared with the beginning. How the story and plot are conveyed to the player forms the narrative structure constructed from interactions, dialogue choices, visual events, art style, tone, and music. It is important to note that whilst the plot takes a linear path through the story the interactive nature of games can affect how this path is structured with regards to gameplay.

1.4.3 The Interactive Story

Interactive stories include three kinds of events: player events which are under the control of the player, in-game events which are initiated and controlled by the game mechanics, and narrative events which are fixed to the plotline within the story (Adams 2010, 159–160).

1.4.4 Linear Gameplay Stories

Linear gameplay moves the story along by interspersing player control with animated cut sequences (Figure 8). This is a popular method used by many games but can break the players immersion when their character is taken control of by the game engine and acts in a way which may not have represented their style of gameplay up to that point. In other words, the player may be less competent during the interactive parts than that portrayed by the cut sequence giving the sense of a split personality. By taking away control from the player there is also the possibility that the player fails to reconnect with the game character after the cut sequence. However, it is an effective way of balancing the advancement of the storyline whilst allowing for the player to spend time immersed in each event. Cut sequences can help to impart additional information needed to complete the next challenge and consolidating an event before moving on. They are also a way of changing the perspective from the

players point of view or show a parallel event taking place. Regarding the plot they can also be used as a retrospective piece allowing the player to remember a moment (Salen and Zimmerman 2004, 31).

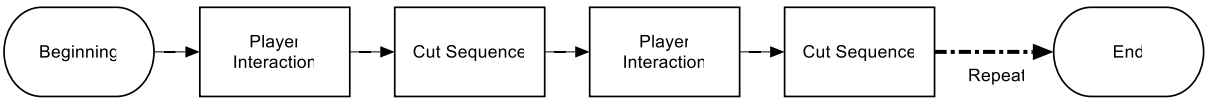


Figure 8, linear gameplay story sequence

1.4.5 Non-Linear Gameplay Stories

A non-linear story is chaotic and can result in an unwieldly story which fails to come to a satisfactory conclusion. By giving the player too much choice, the experience becomes fractured and the story is diluted and less coherent. The initial driving premise of the story may not be consolidated at the end leaving the player wondering what the point was. From a developer's point of view the work involved in creating more choices can rapidly get out of control adding to the complexity, development time, and ultimately making it financially non-viable. Schell discusses the scale of the problem by using a simple mathematical calculation where one unique event spawns three choices each leading to a unique event (Schell 2019, 267) see Figure 9. If those events also spawn three choices, then within ten iterations we must create 88,573 unique outcomes. This is calculated as 3^10 plus the sum of the previous choices and creates an ever-increasing diverging non-linear gameplay sequence. At twenty iterations we are talking 5,230,176,601 unique outcomes which is impossible unless accomplished procedurally. This is different to gameplay where individual events may have several tasks that can be completed out of sequence. One problem with a procedurally generated system could be the loss of a cohesive plot. If the story is based on historical events, then the artificial intelligence would need to ensure factual integrity and chronological accuracy.

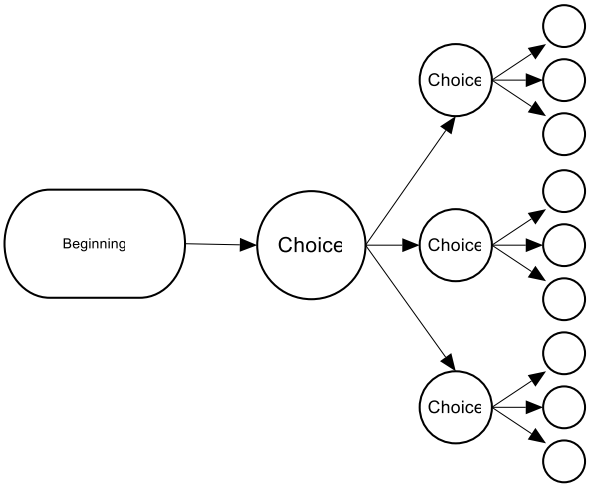


Figure 9, a diverging non-linear gameplay sequence

If the gameplay is a series of encapsulated events with their own beginning and end, then we only need to give variation within these two points. This is a convergent gameplay sequence guiding the players choices and giving the illusion of free will, whilst gently nudging the player towards a pre-determined event, see Figure 10. This may be a strain however in open world games where the player can move freely throughout the whole of the environment (Heussner et al. 2015, 121).

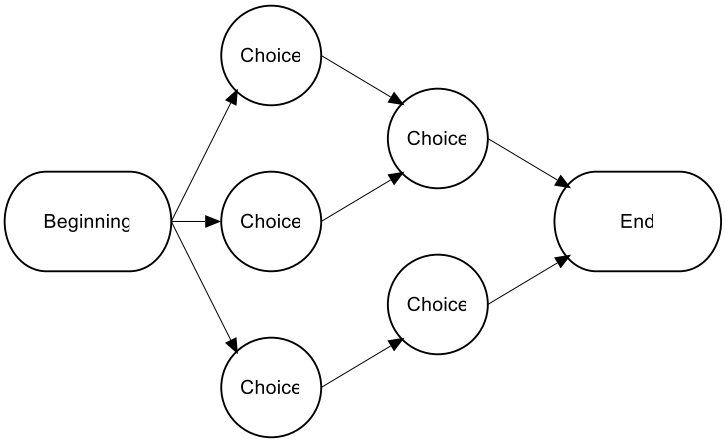


Figure 10, a converging non-linear gameplay sequence (after Schell 2019)

This chapter has presented an overview of how interactive stories can be developed within a gaming framework. However, before a story can be told the 3D environment has to be constructed and this is an extremely complex process. At the start of a project the 3D environment is an empty void within 3D space, and everything required to visualise it must be created by the artists. The story and 3D environment construction can be developed in parallel only if both are driven by the same storyworld concept.

In the game development industry artists are generally brought into a project with little prior knowledge of the historical period or geographic region. They would be required to conduct relevant research to enable the accurate reconstruction of digital assets. Whilst the Lead Designer will have provided a sizeable proportion of this through the initial storyworld research, particularly in the form of major plot assets, it is generally the artists responsibility to provide the additional infill assets within the environment.

For an accurate reconstruction of the city layout, its associated flora and fauna, the people, and their life events, it is necessary for the artists to become very familiar with the archaeology and geography of the site. This research can therefore become a weak point in terms of overall historical accuracy and depending on the scale of the project it may be prudent to gain the input of subject specialists at this stage.

The next chapter begins with the development of the AmarnaXR storyworld which would normally be undertaken by the designer. This serves to inform both the construction of all the interactive elements (3D assets) and any potential storylines. Much of the design process is a fact-finding exercise to see what resources are available and how they can be utilised within the AmarnaXR construction. This chapter will present the main archaeological resources available, a tour of Amarna in terms of the past and the present using visual interpretations developed throughout its excavation period, and finally the authors first-hand experience of the site which helped to gain an impression of the site in terms of atmosphere and potential storylines.

2 AmarnaXR Design

The development of an interactive experience based on the Amarna Period and the life of the inhabitants of the city at Amarna requires researching the history of the period and the physical evidence left behind. Initial design research is a broad range approach to collect all the potentially useful resource material together. The Design Team have the initial responsibility of gathering this together and making it available in an organised form for the other development teams. For AmarnaXR the starting point requires looking into the events of the Amarna Period with a view to creating a backstory in support of the development of the Storyworld.

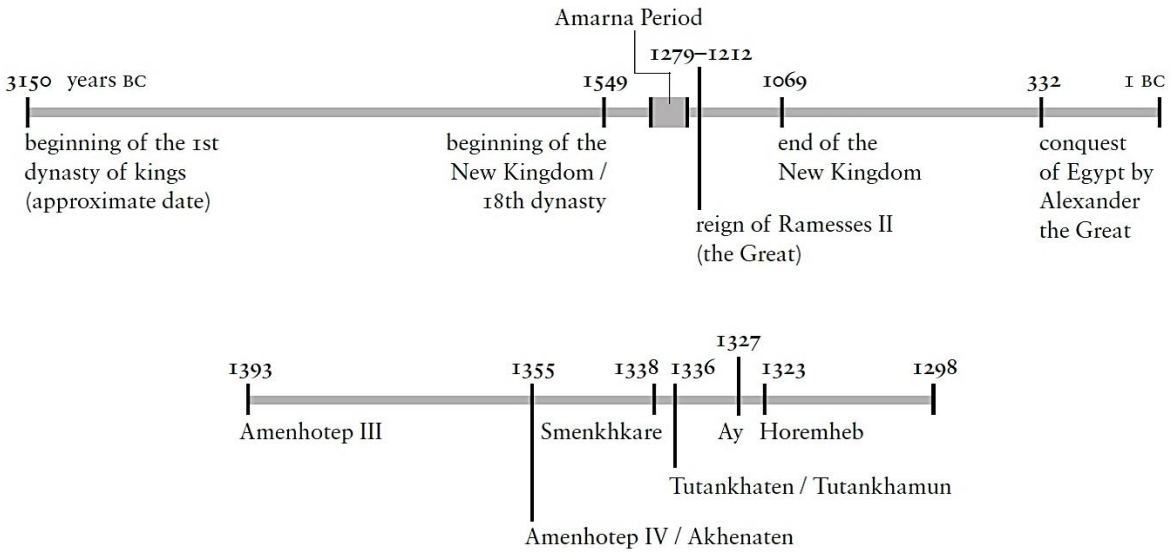


Figure 11, chronology of the Amarna Period (Kemp 2012, 304)

2.1 The Amarna Period as Storyworld

The Amarna Period took place at the end of the 18th Dynasty in Egypt between 1353-1322 BCE and refers to the reigns of pharaoh's Amenophis IV (Akhenaten), Nefernefruaten, Smenkhkare, and Tutankhamun, see Figure 11. The 18th Dynasty was a period which started the New Kingdom era and was also noted for the reign of Hatshepsut (c.1473-1458 BCE), the second confirmed female pharaoh. Under the reign of Amenophis III / Amenhotep III (c.1390-1353 BCE), Egypt saw unprecedented prosperity and reached the peak of its artistic and international power. Amenophis III embarked on many construction projects including the expansion of the temple of Karnak and the Colossi of Memnon built to guard the entrance to his mortuary temple the largest to have been built in Egypt (Kozloff 2012, 122–124). Before his death, Amenophis III had created more statues of himself than any other pharaoh totalling over 250 and was known as Amenhotep the Magnificent. However, at the time

of his death the Amun priesthood, the most powerful of the religious cults, had grown in wealth to a point where they were a religious and political power potentially rivalling that of pharaoh (Reeves 2019).

After the death of Amenophis III his son Amenophis IV became pharaoh and proclaimed that both his father and the sun-god Aten had become one; a move towards re-establishing the divinity of the pharaoh. This meant that the kingship past, present, and future were fused as one divine entity through the Aten (Reeves 2019). By elevating his father to that of a divine being and positioning himself as the sole earthly connection to him, Akhenaten was beginning a calculated move to ensure pharaoh was the supreme power throughout Egypt. By becoming the sole representative and 'high priest' of the Aten, the only way the people could connect with the Aten was through Akhenaten. To indorse this religious move, in year 5 of his reign, Amenophis IV changed his name from Amenophis, 'The god Amun is content', to Akhenaten, 'He who is effective on the Aten's behalf'.

To secure his new religion Akhenaten had to dismantle the power of the other religious sects and the most complete way of doing this was to abandon both Memphis, Egypt's administrative capital and Thebes, the religious centre. A new religious and administrative capital would be built at the mid-point between the two from which the pharaoh could rule under the one god, the Aten. The location of the new city was to be on virgin land, untouched and unoccupied, therefore politically neutral. The cliffs to the east of the chosen site included a small valley entrance gap which resembled the hieroglyph *akhet*, 'horizon', where the sun-god would be reborn at the start of each day. The 'Horizon of the Aten' or *Akhet-Aten* was the name given to the area within which was built the city.

The move to Akhetaten began with the marking of the boundary through a series of proclamations carved into rock-cut stelae as to the extents of and structures to be constructed within Akhetaten. The first of the stelae to be discovered in modern times was by Claude Sicard in 1714 and has been given the name stela A with the remaining stelae also following an alphabetic nomenclature. The total number of stelae found to-date is 15 and their locations are shown in Figure 12.

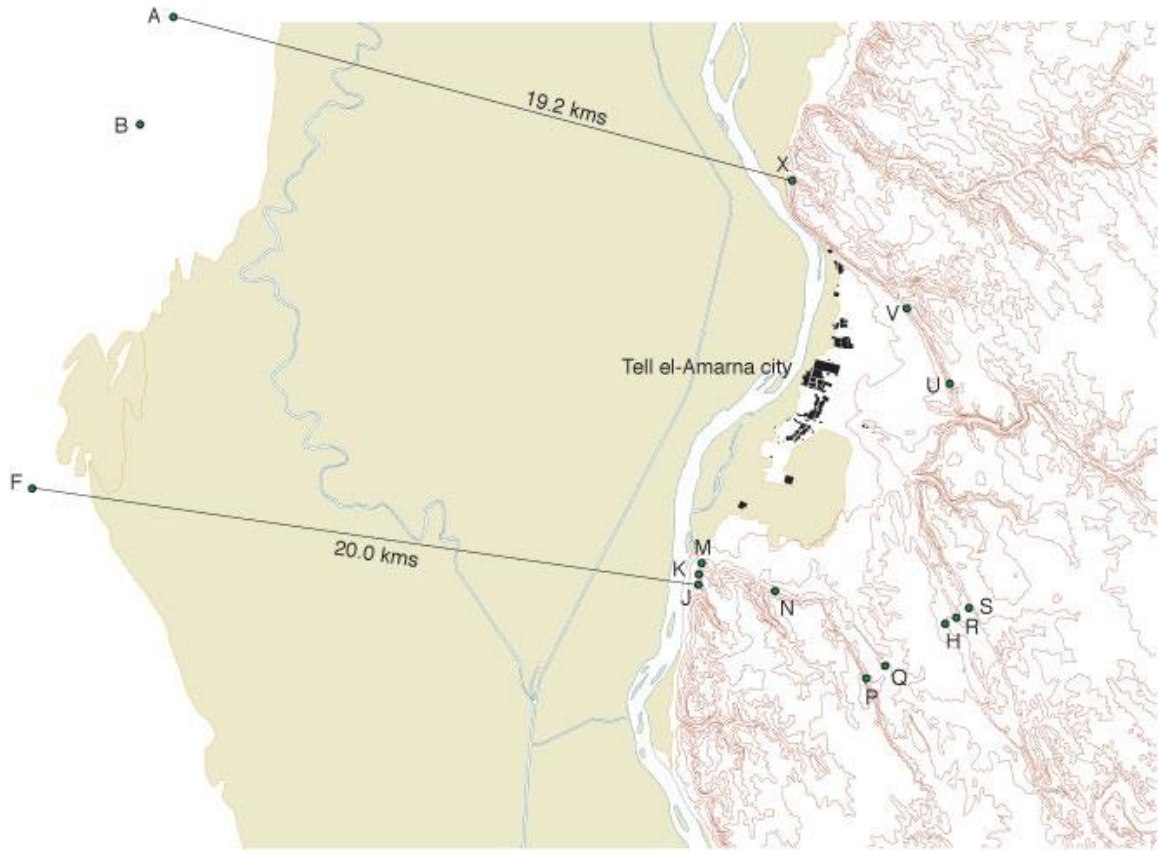


Figure 12, locations of the boundary stelae (Barry Kemp)

Akhenaten set out in his proclamation what structures would be built (Kemp 2017a) and these included the House of Aten, the Mansion of the Aten, the Sun Temple for Nefertiti, the House of Rejoicing (for jubilee festivals), the Pharaoh's Residence, and a residence for Nefertiti. In the cliffs he declared that his tomb and those of his wife Nefertiti and their daughter Meritaten would be constructed. Akhenaten also declared that a tomb for the Mnevis bull would be created, showing a tolerance to other religions which is slightly at odds with the general thinking regarding perceived fanatical monotheistic ideology. Within the northern cliff's, tombs for his high advisers and priests would be built and to the south, tombs for high officials.

The construction of Akhetaten began with the building of the first altar to the Aten which would later become the Small Aten Temple. To the north of this was constructed a small palace and beyond this a larger temple was begun which would become the Great Aten Temple. The North and South Palaces followed shortly after and in year 6 Akhenaten moved his whole court to Akhetaten.

The Aten was not represented as a statue to be worshiped within a dark chamber deep inside a temple. The temple architecture did not follow the enclosed structures normally found elsewhere in Egypt and were built as open-air constructs to allow direct access to the sun-god. This design was a continuation of the *Gem-pa-Aten* ('the Aten is found') temple structure constructed by Akhenaten at

Karnak a few years earlier (Montserrat 2000, 15). As the god was visible throughout the daylight hours, the Aten was presented as a solar disk with its rays stretching outwards terminating in hands which, in later versions, would each hold an *ankh*, the symbol for 'life'. The disc form of the Aten, along with the royal family worshiping it, decorated the temples and palaces throughout Akhetaten. The presence of the Aten is always shown as showering its rays of light only on the royal family and no one else, reaffirming the power of Akhenaten; a confusing situation given the sun-drenched nature of Egypt. The priestly hierarchy and daily routine of the old religion was streamlined (Teeter 2011, 193) and the Aten priesthood's primary function dealt with the daily offerings and acting as the servants of the god, which by default meant the pharaoh as the sole representative on earth.

Religion and politics have always brought about power struggles and bloodshed and, although we do not know the extent as to the dangers within the royal court, we can be confident that pharaoh would need to maintain a heightened state of security during the changes he was making. We also know that the idea of relocating the capital was not a new one for Egypt. The founder of the 12th Dynasty, Amenemhat I also known as Ammenemes I (1991-1962 BCE), had previously abandoned Thebes to establish a new capital named Amenemhat-itj-tawy (Itjtawy), in the Faiyum region. Unfortunately for Ammenemes I he was assassinated by his own guards while his son, Senusret I was on a campaign in Libya (Simpson (Ed) 2003a). The events are recorded in 'The Teaching of King Ammenemes I to His Son Sesostris' (Simpson (Ed) 2003b), written during the early Middle Kingdom (2040-1782 BCE) as is the first reported mention of the '*itn*', Aten as a deity. It is highly likely that Akhenaten was aware of the teaching of Ammenemes I, recorded in the 18th Dynasty 'Papyrus Millingen', as two ostraca have been discovered at Amarna which mention the text (Parkinson 2000).

It is fair to say that Akhenaten's actions led to possibly the single biggest upheaval in ancient Egypt, affecting every level of society. The many gods to which the people relied on for daily assistance, had been demoted. The powerful cults of Amun, Horus, Isis, Osiris their statues, processions, rituals, and the offerings associated with them were suppressed. It is possible that the subjugation of these complex cults may have appealed in its simplicity to some Egyptians, but in doing so it also removed the infinite ways one could ask the gods for assistance and protection during daily life (Teeter 2011, 186). How did they react to the loss of a god which was powerful one day and not the next? Did this invalidate their previous prayers and offerings? The priests had lost their power and financial income, what were they to do? The temple support staff and craftsmen employed to produce objects necessary for worship were also out of work. The transition was not likely to be easy and resentment certainly built up however it is entirely plausible that Akhenaten did not enforce the sole worship of the Aten but rather promoted the Aten as the most powerful, to which all others were subservient

much in the way that Amun had been prior. Evidence of this can be seen at Amarna where the religion of the old gods continued albeit at a much less obvious way through private worship (Kemp 2012). Akhenaten may have been a religious fanatic, or he could have been a ruthless politician, but he must also have been aware of the fate of Ammenemes I and would need to ensure he did not succumb to the same fate. The overthrow of the Amun priesthood and the construction of Akhetaten was only part of his plan and it was his religious reforms that would ensure the loyalty of his subjects.

For a millennia people had believed that the darkness of night (and the afterlife) was inhabited by demons, gods, and all sorts of horrors which would devour all those who did not live their lives honourably. The fate of an individual had always been in their own hands and that by living a virtuous life they would be rewarded with a rich and good life in the hereafter. However, in the Amarna Period the realm of the dead was simply the absence of light (and life) from the Aten. It was Akhenaten, as the earthly representative of the Aten, who gave life after death and as such the safety of the eternal soul was not found through the good deeds you did in life but in your devout service to the pharaoh. This is evidenced in the tomb paintings which traditionally would have focused on the daily life and achievements of the deceased alongside their dutiful worship of the gods. In the Amarna tomb paintings, the occupant is relegated to a small figure and the focus is on the royal family worshipping the Aten and bestowing gifts to the deceased for loyal service. It was palace life and the processional activities of the royal family throughout the city which were made large, not the residence or accomplishments of the deceased. The tomb occupant no longer had any real control over their own eternal life, which was at the mercy of the pharaoh. Traditional belief also held that the *ba* (energy) of the deceased would leave the tomb at sunrise as a human-headed bird and re-join the living, free to go where it pleased and drink from the Nile. In the Amarna Period the *ba* was allowed to visit the city, mix with the living, enjoy the rays of the Aten, and eat the 'unused offerings of your father Aten' from the altars in the Great Aten Temple (Murnane 1995, 112). Akhenaten was not only the almighty power in life, but he was in complete control of the afterlife. The people had to pledge their loyalty or risk their very existence in eternity.

Between years 8 and 12 Akhenaten refocused his attention back to the cult of Amun who had continued to function albeit in a reduced capacity in opposition to the new religion. This time a true persecution was to take place as Akhenaten instigated a purge of the god Amun's name from all monuments. The fear was so great that the Egyptian people themselves ground out and removed the name of Amun from personal possessions to not be caught. Paranoia gripped the population; there was a real danger that watchful eyes were ready to inform on one another to the authorities (Reeves 2019, 152).

If Akhenaten was moving towards establishing total control of his people, the same cannot be said for the foreign powers. Akhenaten was so concerned with his domestic issues that he neglected his foreign affairs. The Amarna tablets show evidence of this as correspondence between Egypt and its foreign territories (Rainey 2015; Moran 1992; Mynářová 2007). This was most noticeable in year 12 when a revolt occurred in Nubia and Akhenaten ordered the King's son of Kush, Thutmose the Viceroy of Nubia, to deal with it. In the north towards Syria, vassal kings pleaded with Akhenaten for support to quell local fighting between countries for fear of losing their lands. However, in the same year 12 there is evidence of foreign dignitaries paying tribute to Akhenaten and Nefertiti, probably at the site of the Desert Altars, depicted in the tombs of Huya and Meryre II shown in Figure 13.

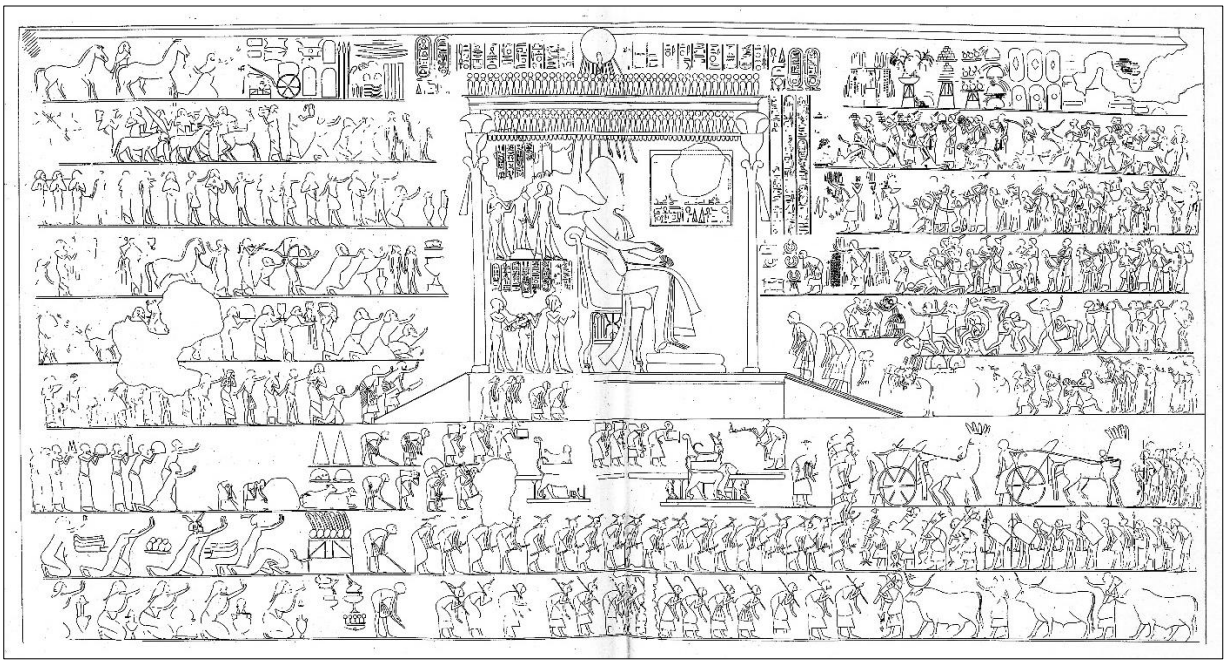


Figure 13, paying tribute to Akhenaten in year 12, tomb of Meryra II (de G. Davies 1905a, pl. XXXVII)

The period between year 12 and 14 brought sorrow to Akhenaten's' court in the death of Meketaten the second daughter of Akhenaten and Nefertiti, along with Kiya the secondary wife of Akhenaten, and Queen Tiye the mother of Akhenaten. In grief it may have been that Akhenaten decided to focus on a rebuild of the Great Aten Temple as there is evidence of the site being cleared in part and a rebuild having taken place at this time (Kemp 2014, 6).

The last few years of Akhenaten have caused much debate. Nefertiti may have ruled alongside him as coregent (alluded to in the tribute wall painting where she is sitting alongside her husband as an equal) or have fallen out of favour for possibly moving away from the Atenist religion back towards the old gods. In year 17 Akhenaten died and his successor was named as Neferneferuaten or Smenkhare. Scholars have argued whether this was a brother of Akhenaten, another son of his, or Queen Nefertiti

(Kemp 2012; Reeves 2019; Aldred 1968). However, within two years this king disappeared from the record, and Tutankhaten ascended the throne transferring the capital back to Thebes, reinstating the worship of the old gods in the process, and changing his name to Tutankhamun. Within nine years he too would be dead whether through illness or foul means and his successor Ay took the throne. This again was to be a short reign as four years later General Horemheb succeeded in becoming the last pharaoh of the 18th Dynasty.

Horemheb ensured that the 'heretic' Pharaoh Akhenaten and his successors Neferneferuaten, Smenkhkare, Tutankhamun, and Ay were removed from the historical record. As part of this, Horemheb had all representation of these Pharaohs erased from public record and began the systematic dismantling of the city at Amarna. The inscribed King's Lists at Abydos (inscribed 1290-1279 BCE) and Saqqara (inscribed 1279-1213 BCE) both show Horemheb immediately following Amenhotep III, Akhenaten's father, as Pharaoh (Figure 14). As time passed it may have been that the memory of the Amarna period faded. However, by the third century BCE the Egyptian priest Manetho wrote a history of Egypt in Greek, the *Aegyptiaca,* an important source of information regarding the chronology of the pharaohs of ancient Egypt (Waddell 1940). Manetho constructed the king list in the form of dynasties where the kings were grouped by location or extended genealogy, establishing a framework still in use today. The 18th dynasty Amarna period pharaohs are difficult to determine accurately, with Akhenaten potentially identified as Chenchres or Akencheres (St. J. Thackeray 1926, 200). It is during the reign of 'Achencheres' that Manetho states Moses became the leader of the Hebrews in their exodus from Egypt and thereby fuelling the minds of many modern authors as to a connection between Akhenaten and Moses (Waddell 1940, 119; Osman 2011; Montserrat 2000).

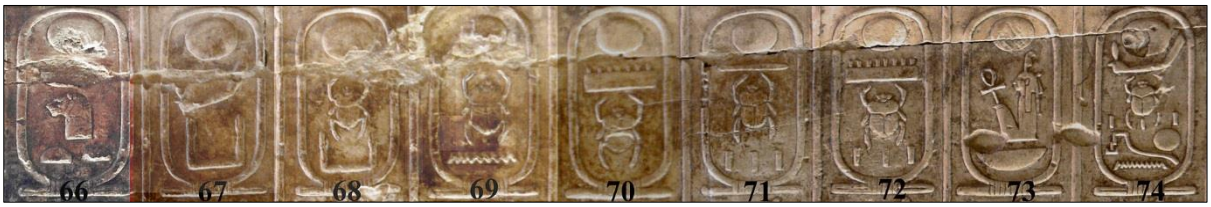


Figure 14, Royal Cartouches of the 18th Dynasty Pharaohs at Abydos. No 73 is Amenhotep III and No 74 is Horemheb. (image Wikimedia Commons)

The Amarna Period, although short lived, is a fascinating narrative but one which plays out at the topmost levels of society. The city of Akhetaten at Amarna however allows for the stories belonging to its inhabitants to be explored as a snapshot of Egyptian life during this period. Expeditions and surveys conducted since the 1700s have brought about a wealth of archaeological material much of which can be used to construct the environment as it may have been in antiquity along with the daily activities of those who lived there at the time.

2.2 Archaeological Resources

With a defined backstory the Storyworld can begin to take shape. However, the individual stories and the environment used to support them needs to be constructed from the archaeological remains. The requirement is to identify what is known about the site in terms of city layout, archaeological structures, what level of preservation there is, what finds have been discovered, and how the environment functioned in terms of bioarchaeological evidence. The material gathered here will help to inform both the visualisation of the site, including portable items and personal belongings, and any potential story plots. It should be noted that the Amarna Period is a distinct period in Egyptian History and one which deviated from the modern idea of ancient Egypt therefore the resources outlined in this section are essential to maintain accuracy.

2.2.1 Plans

The primary resource for reconstructing the city in 3D must come from the various surveys which have taken place over the years and their resulting maps and plans. Between 1798 and 1799 Edmé Francois Jomard, as part of the Napoleonic expedition to Egypt, surveyed a small region of the site around what is now known as the Central City and subsequently published it in the *Description de l'Égypte* in 1817 (*Planches* IV plate 63.6-9) shown in Figure 15. He describes the ruins of the Small Aten temple and the impressive size of the mudbrick pylons at the entrance which, although ruined at that time, still stood 7.33m in height. In terms of 3D reconstruction, the extant structure of the pylons informed the potential height when first built.

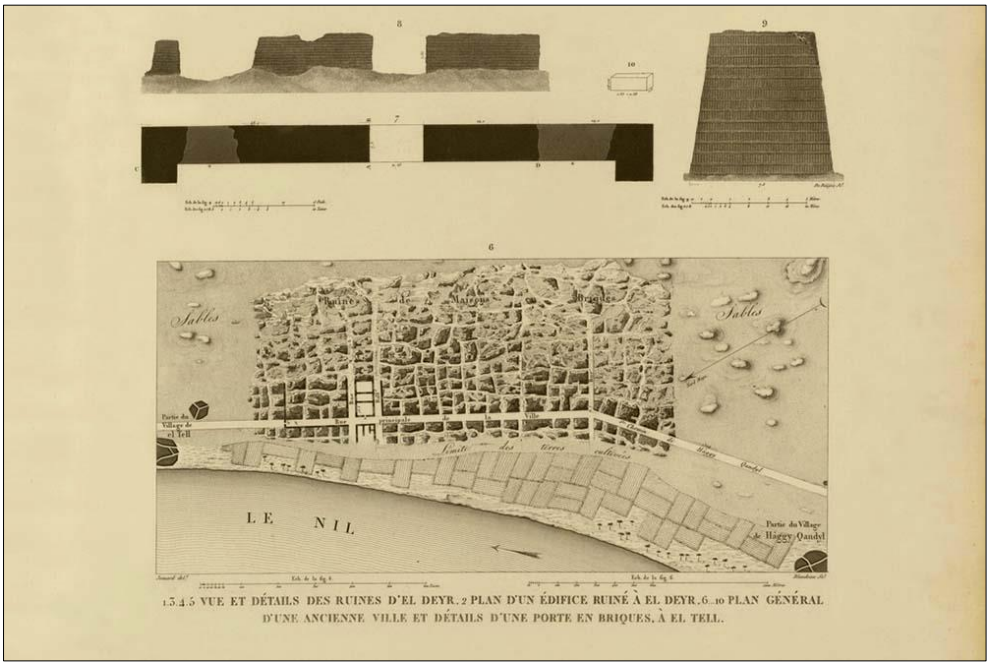


Figure 15, Edmé Jomard's Plan of Amarna and the Small Aten Temple Pylon

(Commission des sciences et arts d'Egypte 1822, Pl 63)

In 1824 the English antiquarian John Gardner Wilkinson visited the site and [re]discovered the rock tombs in the cliffs on the east side of the city. Wilkinson surveyed the Central City and made many casts and drawings of the inscriptions he found, later publishing a selection in his 'Manners and Customs of the Ancient Egyptians' (Wilkinson 1847, 350, Pl. VII) using a plan of the Central City as an example of ancient Egyptian town planning (Figure 16).

An acquaintance of Wilkinson, Robert Hay, who was also a well-known antiquarian and travelled regularly with Wilkinson throughout Egypt, visited the site in 1827. Hay made a detailed drawing of the boundary stela 'A' (Figure 17) where the statuary arrangement gives a clue as to how they may also have been represented at different sites across the city (de G. Davies 1908a, Pl. XLIII). During the summer of 1830 Hay also examined and recorded tombs 2 and 13 (Montserrat 2000, 63).

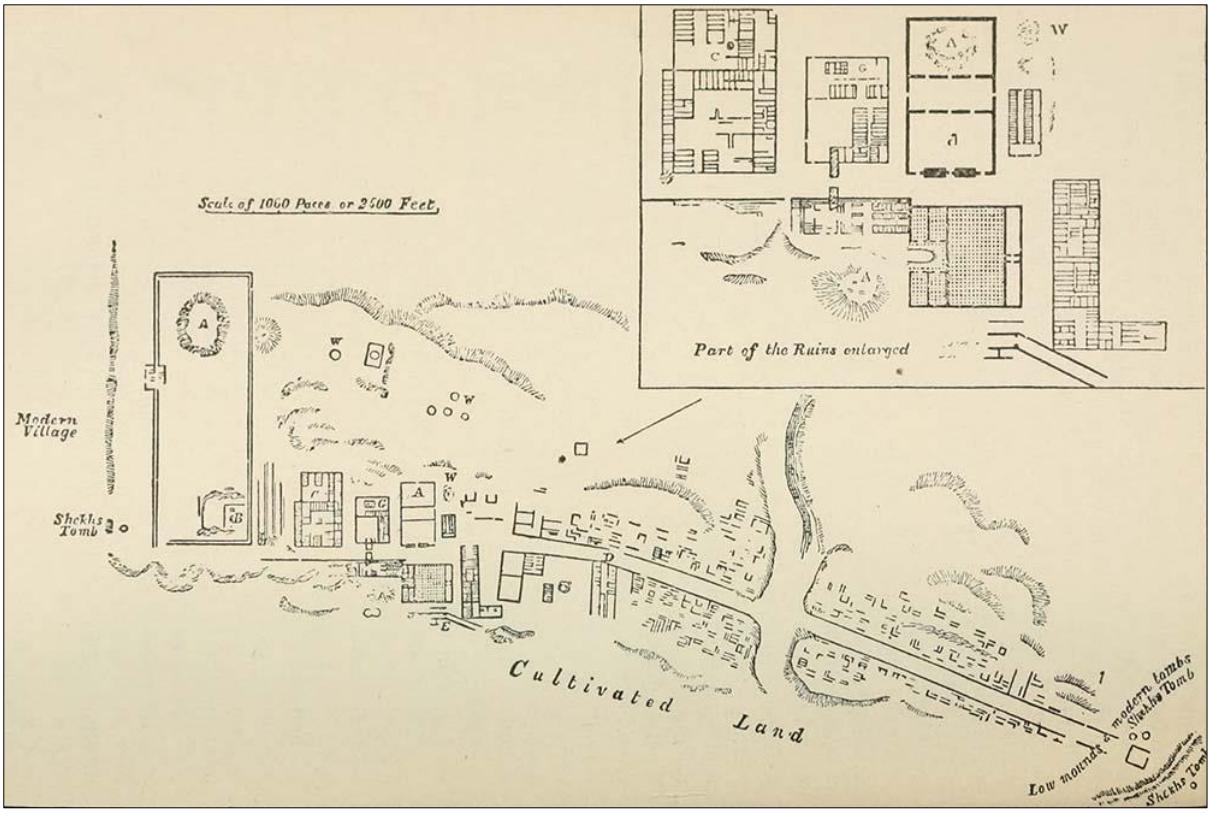


Figure 16, Wilkinson's Plan of Amarna c.1826 (Wilkinson 1847, 350, Pl. VII)

With each stage of excavation there is inevitably some irreversible damage done to the remains therefore it is important to track any changes through the subsequent excavation plans and collate this information prior to 3D model construction and layout of assets.

Figure 17, Robert Hay's sketch of Boundary Stela 'A' in 1827 (de G. Davies 1908a, Pl XLIII)

It was Karl Richard Lepsius who was to make a breakthrough in our understanding of what was known about the reign of Akhenaten. Lepsius visited Amana between 1843 - 1845 as the head of the Prussian archaeological mission to Egypt where he drew an updated ground plan of the ruins (Figure 18) and recorded the northern tombs (de G. Davies 1903, 4).

In 1881 Gaston Maspero and Urbain Bouriant working as part of the Missions Archéologiques Françaises au Caire began excavating the tombs at Amarna over a period of 3 years. During the 1883-1884 season Bouriant discovered the "Great Hymn to the Aten" in the tomb of Ay (Bouriant 1889).

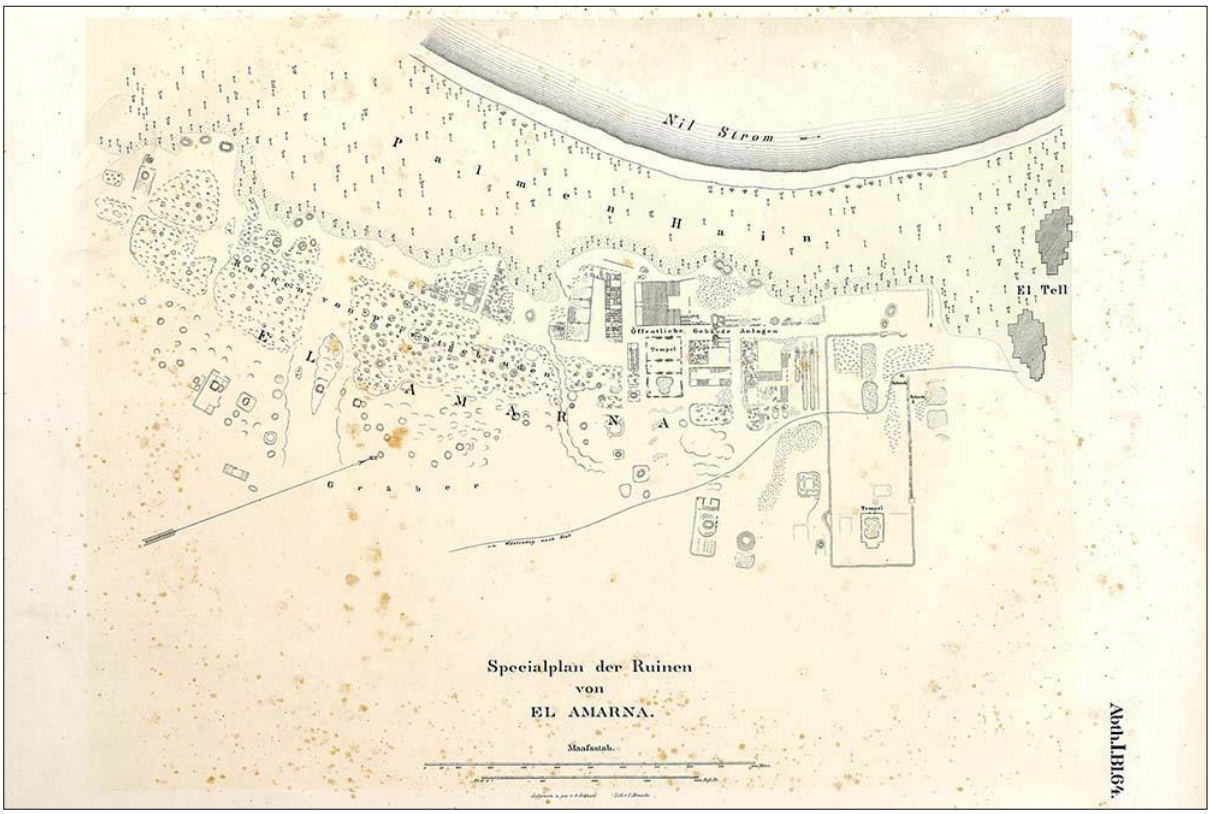


Figure 18, Plan of El-Amarna (Lepsius 1856, Abth.I.Bl.64)

The Egypt Exploration Fund of London (which would later become the Egypt Exploration Society – EES) sent an excavation team to Amarna between 1891 and 1892 under the guidance of William M. F. Petrie and his assistant Howard Carter. Petrie was the first to analyse the building layouts and sizes in terms of function and social standing, developing a basic typology as seen in Figure 19. This would go towards informing the 3D artist of materials and how each building should be dressed for function.

Interest continued to grow regarding Amarna and between the years 1901 and 1907 Norman de Garis Davies conducted a full survey of the rock tombs at Amarna, later publishing his research in 6 volumes (de G. Davies 1908a, 1905a, 1903, 1905b, 1908b, 1906). During this period, in 1903 Bouriant, Legrain, and Jéquier published the first scientific monograph of the Royal Tomb of Amarna (Bouriant,Legrain

and Jéquier 1903). The inscriptions give insights into the architecture of Amarna and when combined with survey plans create an invaluable resource for the 3D modelling of Amarna. The daily life and ceremonial depictions also feed into potential storylines.

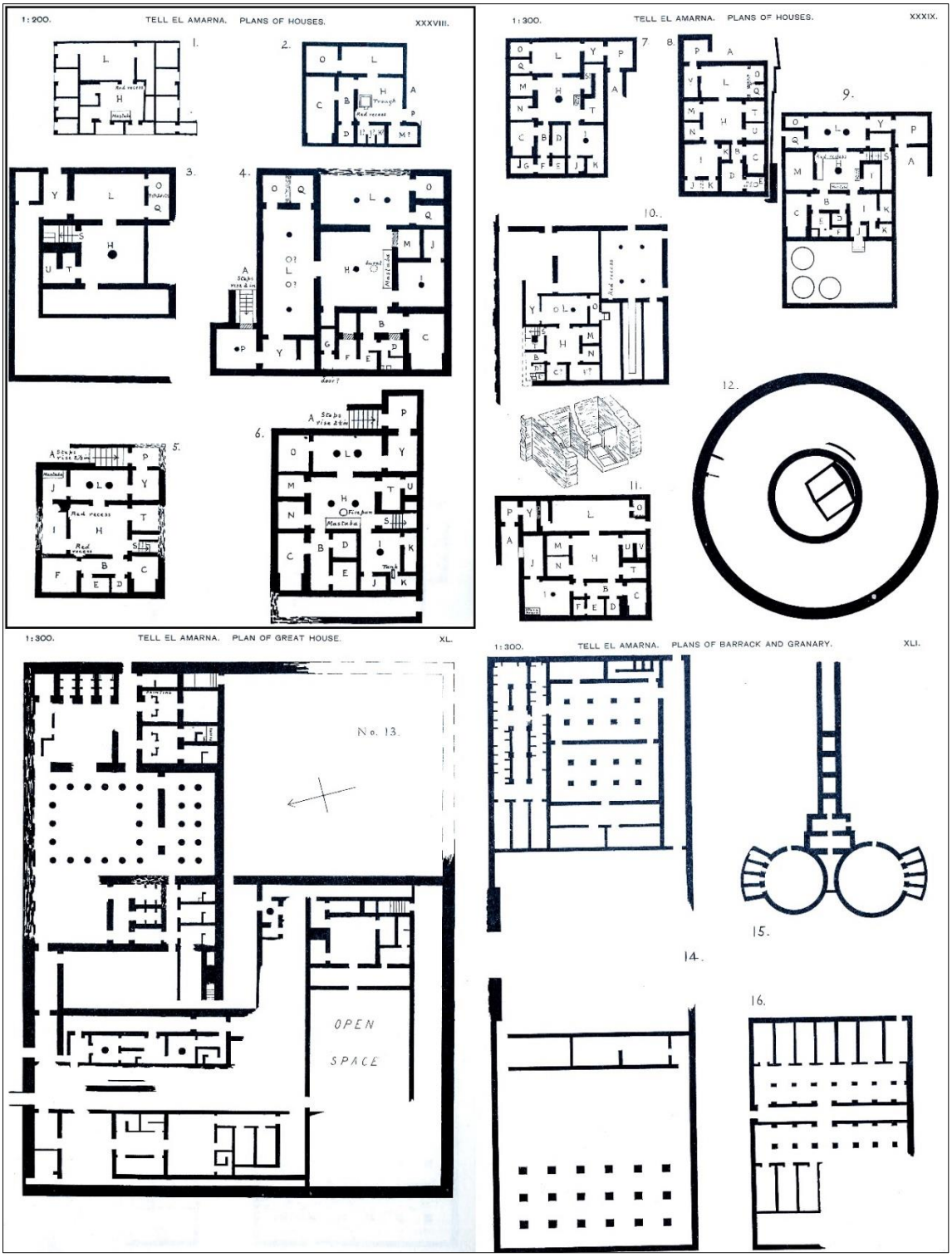


Figure 19, Petrie's housing plans (Petrie 1894)

In 1907 the Deutsche Orient-Gesellschaft (DOG – German Oriental Society) secured the concession to excavate at Amarna and Ludwig Borchardt began his first excavations of the site ruins; the most extensive up to that point (Borchardt and Ricke 1980). Borchardt continued his excavations in the southern city ruins up until the start of the First World War when all work at Amarna was halted. The DOG published the results of the excavations in Amarna between 1911 and 1914 under the title "Die Wohnhäuser in Tell el-Amarna" (The houses in Tell el-Amarna) which included 112 detailed house plans and a series of overview maps, see Figure 20 (Borchardt and Ricke 1980). Borchardt's plans are extremely well detailed and provide excellent blueprints for 3D modelling of the urban environment.

Figure 20, one of Borchardt's plans showing larger housing supported by smaller buildings. Plan 9 - Gehöft Q46.12,Häuser Q46.14-17 und 25 (Borchardt and Ricke 1980)

Work at Amarna recommenced in 1921 when the EES began extensive excavations in the urban area through to 1936 under the direction of Thomas Eric Peet, Leonard Woolley, Francis Newton, Henri Frankfort and John D. S. Pendlebury. The excavation reports were later released as 'The City of Akhenaten' in three parts (Frankfort and Pendlebury 1933; Peet and Woolley 1923; Pendlebury 1951). During this extensive excavation period the north suburb, eastern village, central city, and Maru-Aten were recorded (Frankfort 1929, 1927; Griffith 1924; Newton 1924; Peet 1921; Pendlebury 1931, 1932, 1935, 1936, 1933; Whittemore 1926; Woolley 1922). It was during the 1930 season that Mary Chubb accompanied the expedition and later published an account of their daily activities in her book 'Nefertiti Lived Here' (Chubb 1954) giving an interesting insight into workings of the expedition.

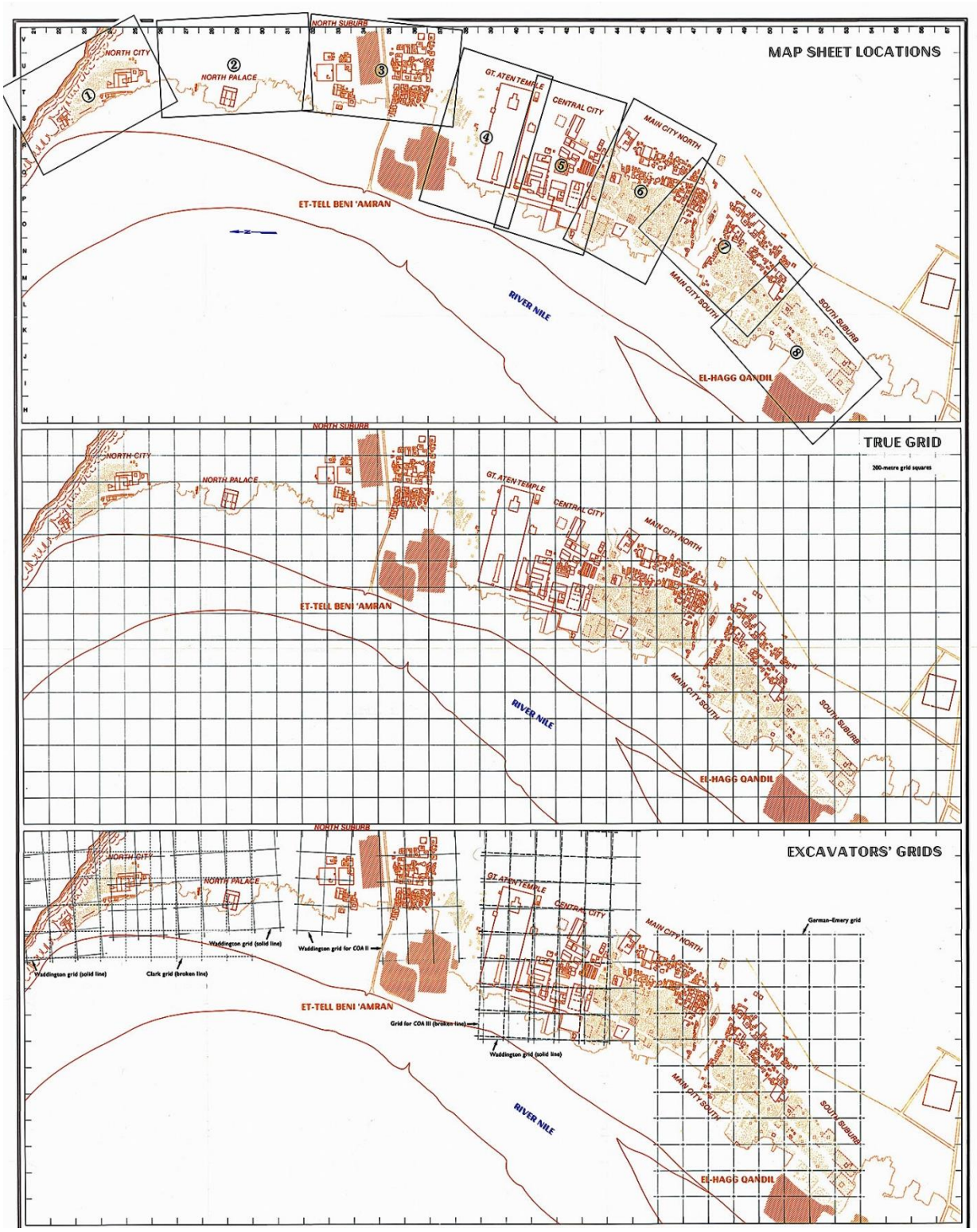


Figure 21, The 1977-1989 City Survey Sheets (Kemp and Garfi 1993)

During the 1960s the Egyptian Antiquities Organization (now the Ministry of Antiquities) excavated in the Kom el-Nana and el-Hagg Qandil areas, but no material has yet been published. So, it was in 1977

that the Egypt Exploration Society resumed excavations at Amarna under the direction of Barry J. Kemp; a position he still holds. Kemp initially set out in early 1977 to consolidate the previous survey work and update it as needed (Kemp 1978). He was assisted by Salvatore Garfi in 1981 and together produced the first large scale survey maps of the site by 1989 for publication four years later (Kemp and Garfi 1993). Figure 21 shows the extent of the work carried out. Kemp's focus at Amarna was to study the urban life across the full social and environmental spectrum and the nature of the site gives a unique opportunity to do so. A series of Amarna Reports were published between 1984 and 1995 (Kemp 1987a, 1984, 1995, 1985, 1986, 1989a) with further preliminary reports published in the JEA at the end of each active season to the present. In 1979 work began excavating the 'Workman's Village', a walled village set aside from the main city for the housing of tomb builders (Kemp 1987b), with similarities to the village at Deir el-Medina. The village caused interest in that there was evidence showing the active worship of gods other than the Aten (Kemp 1979). At the start of 1980, Geoffrey Martin recorded the surviving reliefs and inscriptions in the Royal Tomb along with a study of the potsherd left behind from previous excavators and published as Part VII of the 'Rock Tombs' series (Martin 1989).

Between 2002 and 2006 excavations took place on the house of an official named *Ranefer* and a group of eight adjacent houses known as 'Grid 12'. The house of *Ranefer* had been built over a previous smaller house and may have indicated a change of ownership in the later years of the city's life. The results were published in two volumes in 2010 (Kemp and Stevens 2010). Here we see an example of a small community which may have been dependent on the larger house, something common throughout the city and important when developing storylines for Amarna.

The Amarna Project are developing the Amarna Digital Atlas which is a compilation all the survey plans into one large .pdf file at a scale of 1:50 with a standard view of 555 x 400 cms which is capable of being zoomed in for greater detail. The large-scale survey maps produced by Kemp & Garfi have to some extent been converted by Dr Anna Hodgkinson into a Geographic Information Systems (GIS) database as part of her PhD research into the technology and urbanism in Late Bronze Age Egypt (Figure 22). I have a copy of this data which I have expanded on by georeferencing digitized copies of the small-scale plans. I have also had access to the aerial photography taken by Gwil Owen between 1992-2012 covering a large part of Amarna. By applying photogrammetric techniques to the photographic material, I have been able to create orthographic images of several areas (Figure 23). There are some issues with the WGS84 coordinate system not able to resolve the mapping accurately over the whole Amarna site so the Egyptian local grid coordinate system (EPSG:22992) has been applied although the vector data still requires appropriate adjustment.

Figure 22, Amarna survey maps as GIS data (Kemp, Hodgkinson, Docherty)

Figure 23, a selection of orthographic photography and georeferenced plans at different transparencies to show layering.

2.2.2 Flora and Fauna

Gardens were of great importance to the inhabitants of Amarna, indeed the earliest illustrations of gardens in Egypt are represented in the tomb paintings, for example that of Meryre (de G. Davies 1903, pl. XXXII). Large gardens would be enclosed by an outer wall and would include fruit bearing trees grown within their own container or pit to aid in watering. Water was provided by large wells, but this would not have been enough to sustain the gardens and household. There must have been a network of water carriers established as there is no evidence of water channels from the river to the houses. Sometimes the wells would feed an ornamental pool. Vegetables would be grown in rectangular plots laid out in a grid (Figure 24). Among the foods grown were grapes, dates, melon, lettuce, almonds, grass-pea, lentils, onions, and garlic. Much of the bulk cereal growing probably took place on the western side of the Nile as there was a large bread making industry required for offerings to the Aten. Several large grain silos were present in the city, for example O51.1, and all the estates had several silos situated next to the main house. Flowers were important to the inhabitants and along with herbs were used as medicines, herbal teas, spices, and perfumes (Wilkinson 1998, 50–62). Botanical evidence of the various species of plants and trees grown around Amarna has been found at the Workmen's Village, the Maru-Aten, Kom el-Nana, and the North Palace (Stevens and Chapman 2016) a list of the species recovered can be found in appendix 7.2.

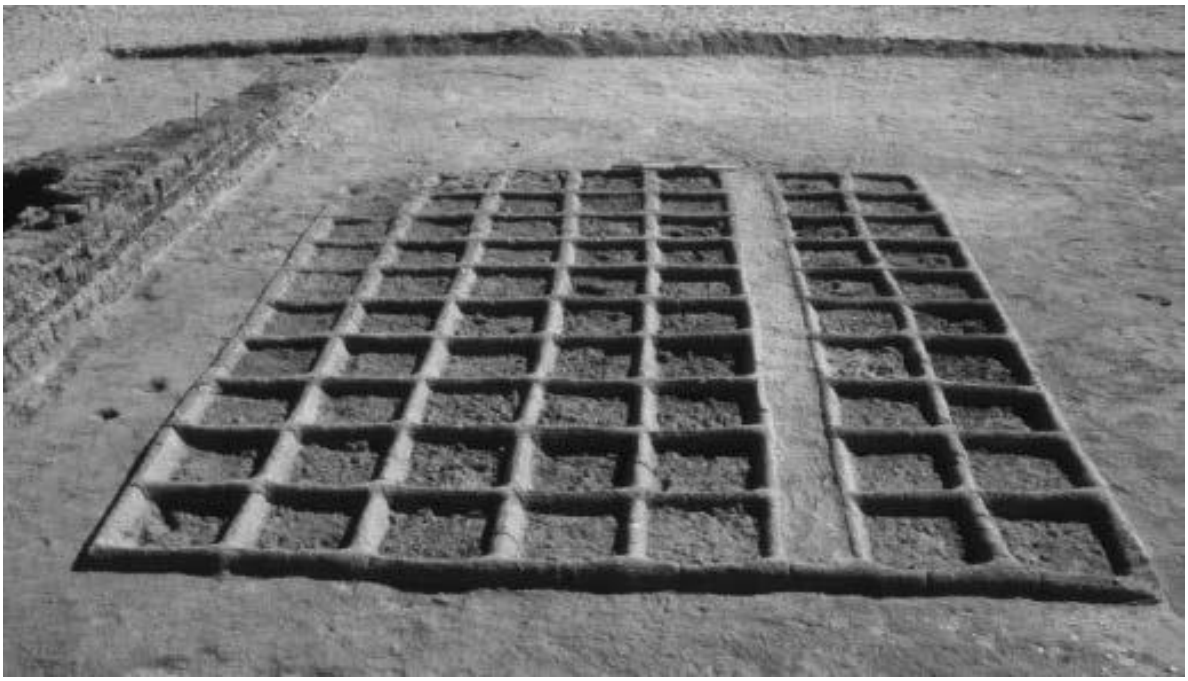


Figure 24, open garden plots at Kom el-Nana after excavation (Stevens and Chapman 2016)

Many gardens also housed small chapels to the Aten bringing a spiritual nature to some of the layouts. Whilst the smaller households had areas for some livestock namely cattle, goats, and pigs, the larger complexes such as Maru-Aten and the North Palace had a wider variety of animals suggesting a

menagerie mimicking the wider Egyptian landscape. Mudbrick manufacture made use of threshing waste from cereals and date palm leaves and fibre were used in roofing construction along with reeds (Stevens and Chapman 2016, 156). Larger mudbrick construction would also make use of timber to strengthen the walls and prevent wall collapse. Much of this timber has not survived to the present due to insect action. By understanding the bioarchaeology of the site, it is possible to accurately reconstruct the agricultural food sources, medicinal plants, and livestock as 3D assets.

2.2.3 Osteological Remains

During the 2003 and 2005 surveys of the southern tombs a series of disturbed burials were identified and subsequently excavated between 2006 and 2013 (Kemp 2007). A second cemetery was discovered at the north tombs 2 and 3 and excavated between 2015 and 2017, with a third cemetery, previously discovered by Helen Fenwick's 2001 GPS desert survey, beginning in 2018 (Stevens et al. 2019). The aim of this long-term study of non-elite cemeteries was to shed light on the lives of the people who lived at Amarna which could only be achieved in a limited capacity through the excavations within the city. There are many questions surrounding the people buried here, and work is still ongoing. One interesting discovery was evidence of a peculiar method of punishment which may have been enacted at Amarna. Normally reserved to constrain the movements of pigs, a hole drilled through the shoulder blade would be debilitating enough for an individual to prevent them from using their arm for work for a period until it healed (Kemp 2010, 8–9). Once healed the individual should regain the use of their limb. Preliminary data from the south tombs indicates that the average age of death for the local population who lived into adulthood was 34 for women and 30 for men based on 154 individuals (Kemp 2009, 4). The data also shows that older adults who had grew up elsewhere before coming to Amarna had an average height of 165cm for males and 156cm for females whilst those who had grew up in Amarna were 3cm shorter indicating the possibility that childhood nutrition at Amarna may have been poorer than elsewhere.

2.2.4 Amarna Art

The king's year 4 and 5 were also the start of a new style of art which moved away from the traditional formulaic constructs to a more realistic if not overly exaggerated expression of the royal household in everyday intimate scenes of relaxation and worship. This Amarna art style is very fluid and did not survive beyond the Amarna Period when a return to the more traditional formal depictions of the gods and royalty reaffirmed the move to wipe that period from history. An example of this style can be seen in Figure 25. For an accurate reconstruction of the city at Amarna it is essential that the uniqueness of the Amarna art style is understood and that it replaced the traditional Egyptian style of artwork.

Figure 25, an example of the Amarna art style portraying Akhenaten, Nefertiti, and three daughters (CC-0)

During the 1891/2 excavation, Petrie discovered wall-paintings in the King's House (Weatherhead 1995) and a beautiful painted floor in the North Harem (Weatherhead 1994). The floor was later broken up by a disgruntled farmer one morning in protest to travellers crossing his land to see the excavations. These remains are presently under a wood and glass enclosure in the Cairo Museum (Weatherhead 1992). The modern analysis of the painted walls and pavements by Weatherhead helps give an insight into the surface decoration of the royal and upper social class architecture (Figure 26). Many of the houses had evidence of painted walls and inscribed lintels Figure 27 shows a reconstruction of the west part of the south wall of Room 1 from the house of *Ranefer* N49.18 (Frankfort 1929; Kemp and Stevens 2010, 625).

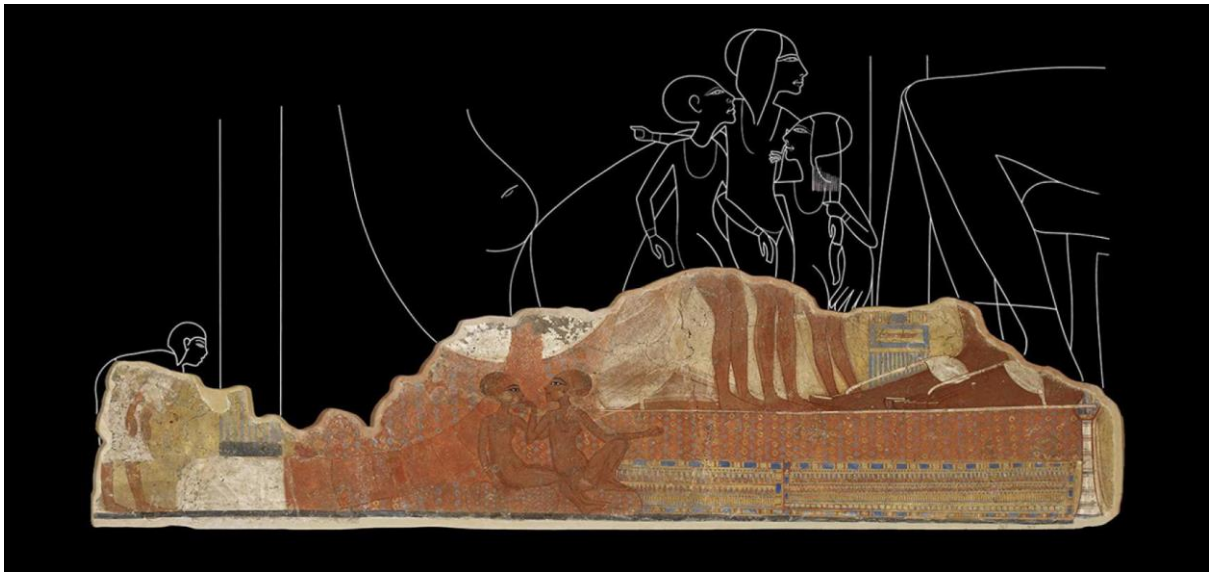


Figure 26, Princess Fresco, Tell el-Amarna, Egypt (image Ashmolean Museum, AN1893.1–41.267)

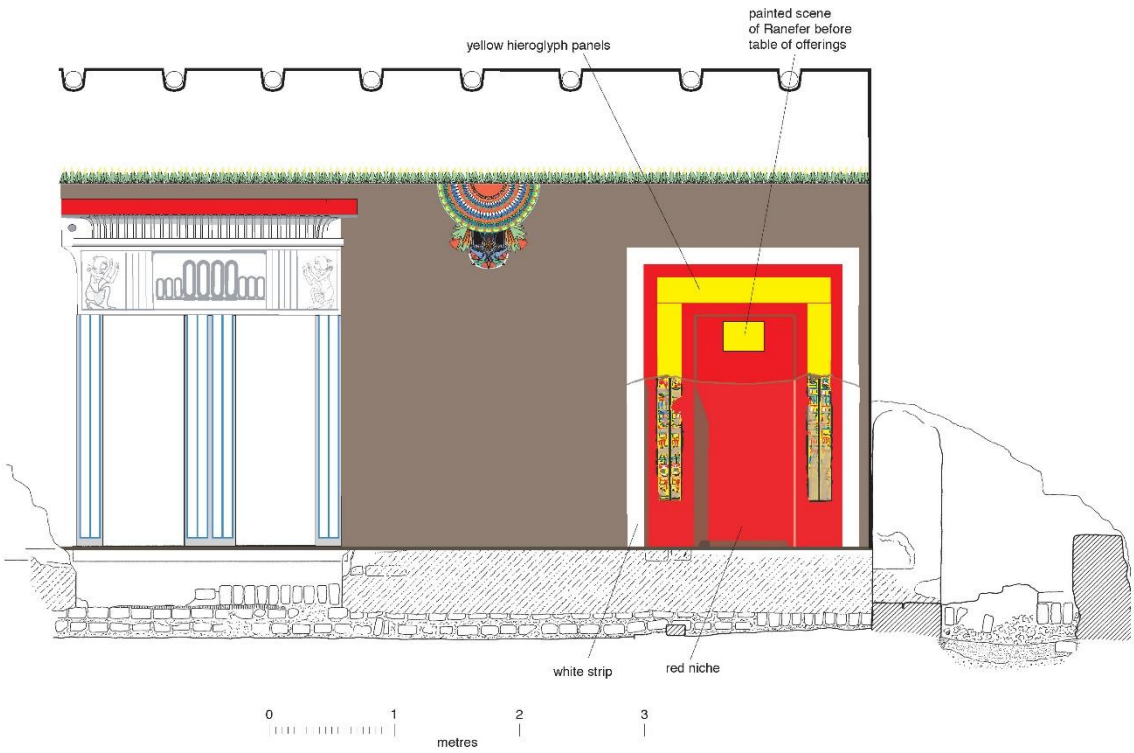


Figure 27, reconstruction of wall decoration from Ranefer's house N49.18 (Kemp and Stevens 2010)

During the 1912 excavations in the southern city ruins Borchardt whilst excavating the house of a sculptor, possibly named Thutmoses, found numerous model heads, amongst them the now famous bust of Queen Nefertiti (Borchardt 1916, 1923). The bust made its way to Germany under controversial circumstances and became one of the most iconic Egyptian works of art, Figure 28. The skill represented in its creation is remarkable given its realistic proportions which are in contrast with the colossal sculptures of Akhenaten.

Figure 28, bust of Nefertiti, Neues Museum, Berlin (CC-0)

In 1925 Maurice Pillet discovered two large colossi of Akhenaten whilst engaged in rescue work at the eastern gate of Karnak (Manniche 2010, 1–14), see Figure 29. This was followed up by a formal excavation conducted by Henri Chevrier in 1926 which recovered more fragments totalling 15 colossi. These would have been part of a peristyle courtyard dedicated to the Aten at Karnak; a similar albeit larger court was also located at Amarna. The colossi drew even more attention towards the physical appearance of Akhenaten.

The colossi are the best representation of Akhenaten to be discovered and allow for a full reconstruction in 3D (covered later in this work). This is fortunate as there are many locations around the city where his statue would have been present. The Great Palace has evidence of at least 100 colossal statues surrounding its main courtyard.

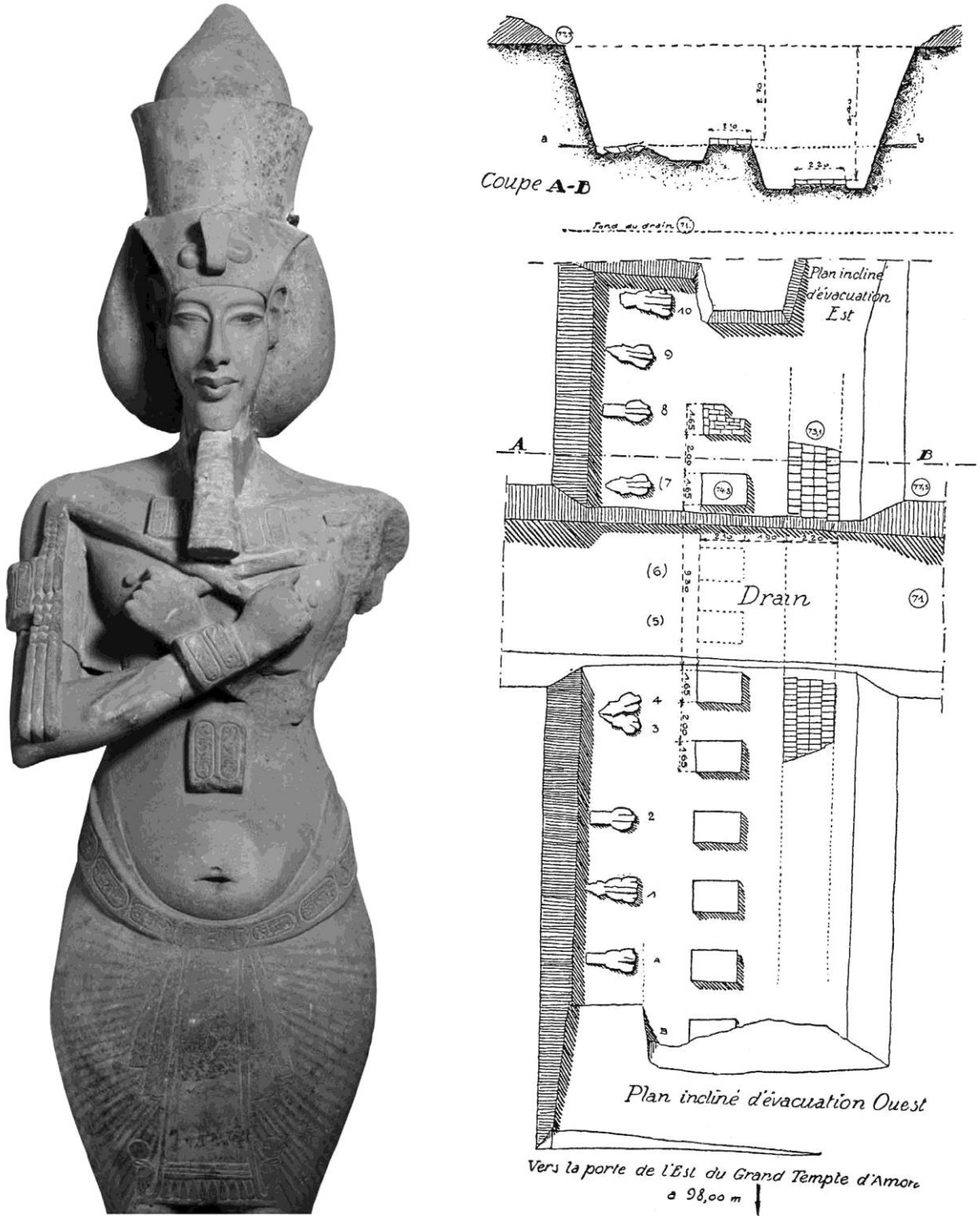


Figure 29, Left image: one of the first two colossi found (Manniche 2010, 2), right image: Chevrier's first plan of the excavation (ASAE 26, 1926, p. 192)

Since the 1890s decorated stone blocks of a uniform size had been discovered within the pylons of Karnak. These came to be known as the Karnak Talatat (Aldred 1988, 69–85; Hoffmeier 2015, 93). With their distinctive artistic style dating them to the time of Akhenaten and their number reaching to over 40,000 many have been able to be pieced back together providing important visual insights

into the art and history of the Amarna period (Figure 30). Originally done by hand it was later augmented through the use of IBM computers during the 1970s as the Akhenaten Temple Project under the direction of Donald B. Redford (Redford 1973). In 1939 west of Amarna, the German Hermopolis expedition under the direction of Günther Röder uncovered layers of talatat in the foundations of the ruined pylons constructed by Ramesses II (Montserrat 2000, 50). There was not enough time to photograph or store them safely, so they were buried in the hope of returning the following year. Unfortunately, the Second World War broke out and over the next few years the blocks were removed and sold on the open market. Many blocks were sawn into pieces and touched up with watercolours to appeal to buyers and after the war no blocks remained at the site (Aldred 1988, 86). It was clear though, from their subtle detailing, that these blocks were from the later Amarna period belonging to the temples and palaces at Amarna. Fortunately, many of these have since been recovered. By analysing the visual style presented in the talatat it may be possible to reproduce a similar art style throughout the 3D model of the city as material textures. However, this would require a large amount of time, planning, and guesswork on behalf of the artists, hence most visualisations of the city refrain from incorporating much in the way of wall art.

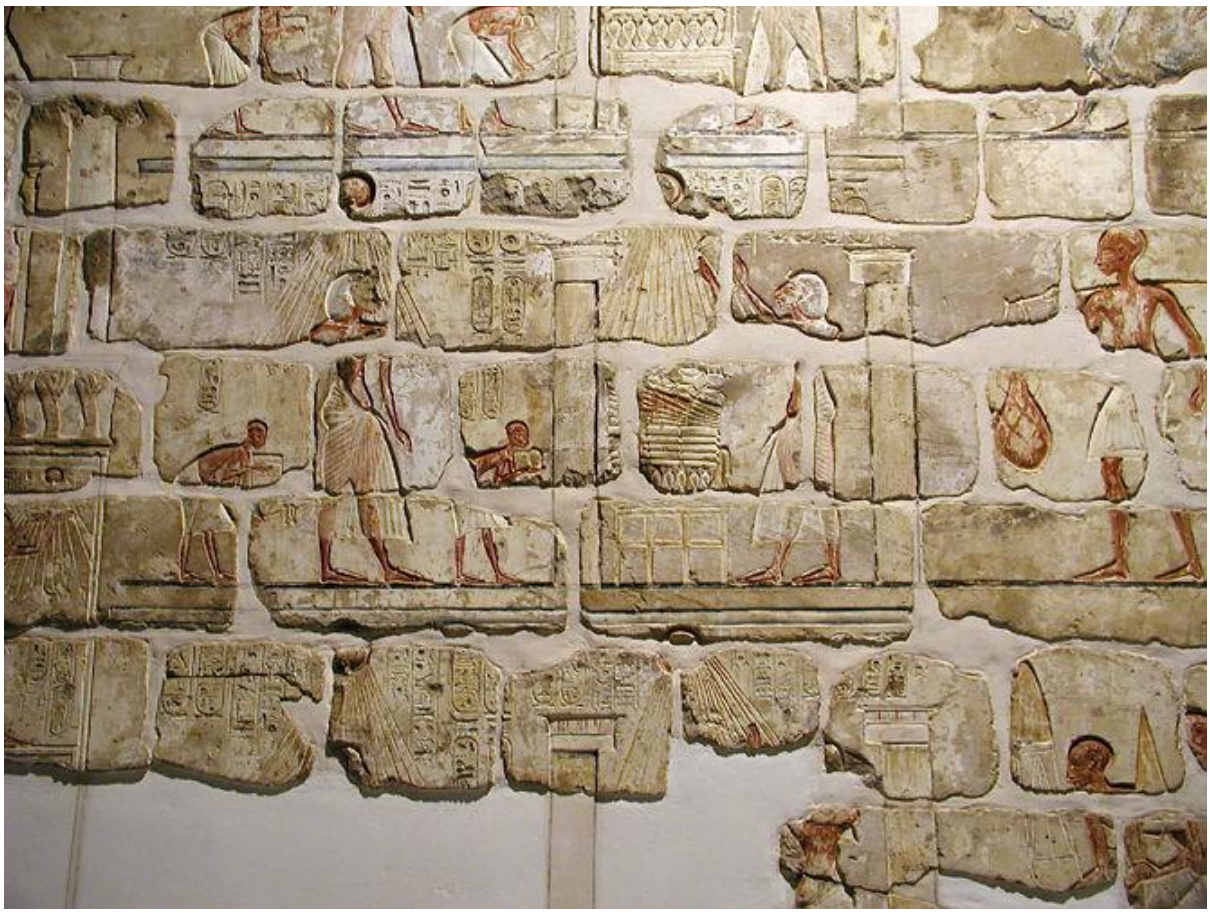


Figure 30, Talatat blocks assembled from Karnak (image Wikimedia Commons)

2.2.5 Epigraphic Material

It was in 1887 that an incredible discovery was made by a local woman whilst out looking for fuel, that of nearly 400 clay tablets inscribed in cuneiform script (Figure 31). Now referred to as the Amarna Letters they comprised the international diplomatic correspondence between Akhenaten's court and the lands under his control (Moran 1992, xiii). In a disastrous turn of events the woman travelled with the tablets unsecured in a sack to sell to Egyptologists who did not recognise their value at that time. Before their importance was realised many of them had been reduced to fragments. The remaining letters became part of the great debate at the time between archaeology and the historicity of the Bible (Montserrat 2000, 66). More clay tablets were fortunately discovered between 1891 and 1892 by Petrie at the site of the "State Archives" near the royal residence (Petrie 1894).

These tablets have been studied and commented on by several scholars (Mynářová 2007; Moran 1992; Rainey 2015) and give an indication of the domestic and foreign affairs which can be woven into stories of the time. An extended compilation of general texts including names and titularies from the Amarna Period was published as 'Texts from the Amarna Period' (Murnane 1995). The texts include tomb inscriptions, door jambs, and various fragments recovered from Amarna.

Analyses of the Amarna tablets give an insight into the administrative procedures and historical events helping to inform the construction of the Amarna storyworld.

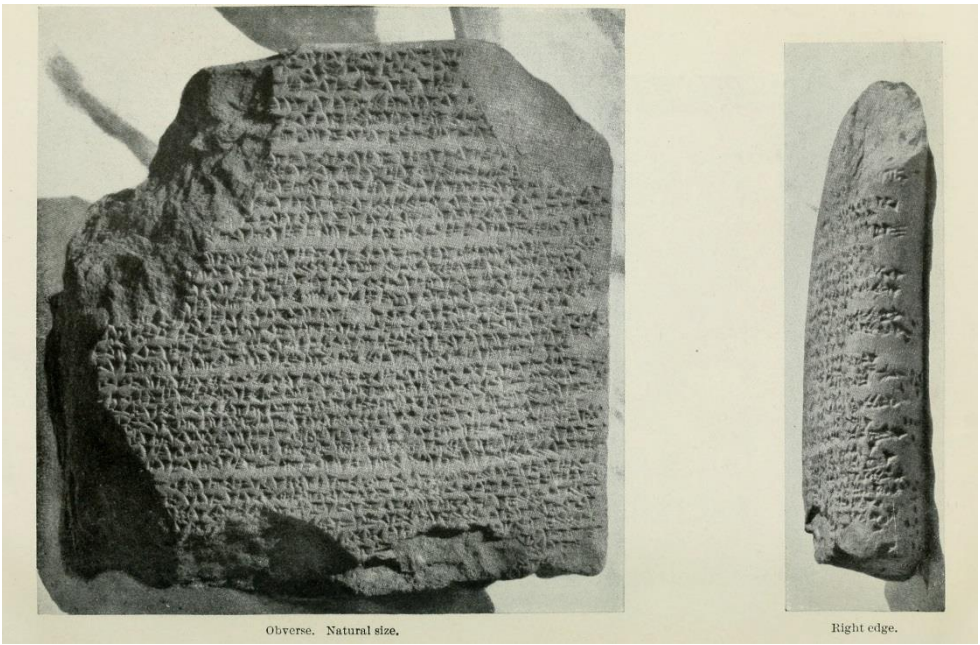


Figure 31, Clay Tablet found in House O47.2 (Borchardt 1916, Plate 11)

2.2.6 The Egypt Exploration Society Photographic Archive

The EES photographic archive for the period 1921-37 has been digitised and uploaded onto the online photo sharing platform Flickr, https://www.flickr.com/photos/egyptexplorationsociety/albums

Within the archive there are photographs of the excavations at different stages and a wealth of artefacts recovered. There is also a miscellany of interesting photographs, some showing workers posing as ancient Amarna citizens during the 1922 season at the Workmen's Village (Figure 32). Also present is the discovery of a 'crock of gold' in the floor of house T36.63 which caused a stir, recounted by Mary Chubb in her book 'Nefertiti Lived Here' (Chubb 1954, 131–140), Figure 33.

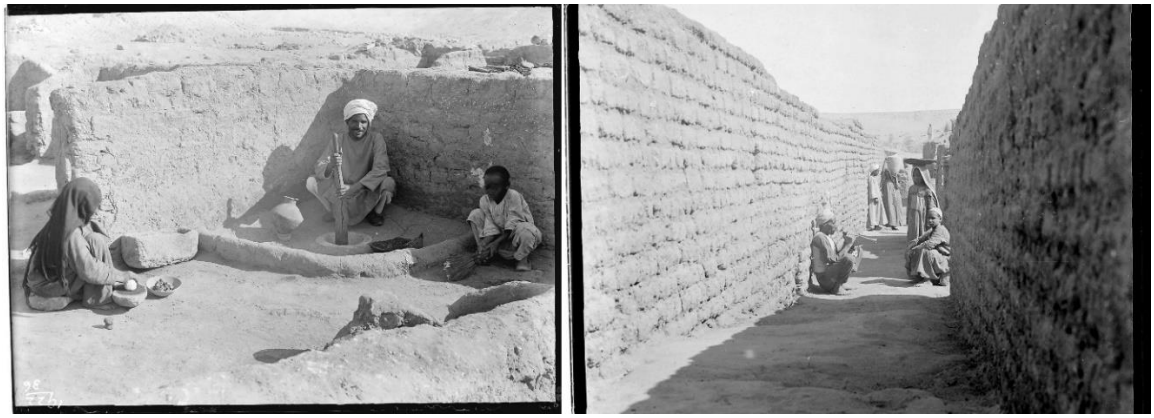


Figure 32, workers posing as ancient Amarna citizens during the 1922 season (EES)

Figure 33, the discovery of a 'crock of gold' photographed during the 1930-31 season (EES)

2.3 A Visual Tour of Amarna (Past and Present)

With the archaeology of the city established the following section focuses on how the city has been visualised over time by archaeologists, illustrators, and modellers beginning with the city as depicted by its inhabitants at the time it was constructed, through the tomb paintings. This is an essential exercise for anyone endeavouring to construct their own visualisation as it uses the previous work of others as a foundation from which to build on.

The site of Amarna lies approximately 270km south of the pyramids (as the crow flies) which is halfway between Cairo and Karnak with the coordinates of the entrance of the Small Aten Temple being 27.645501, 30.895374 (Lat, Lon). The city was constructed on clear ground on the eastern bank of the river Nile protected by a line of cliffs which curve inland in the form of a bow to the north and the south as shown in the satellite image in Figure 34. The full extent of Amarna in ancient times would also have included an area to the west of the Nile which was to be developed as agricultural land in support of the city making the total area over 200km^2 as marked by the Boundary Stelae.

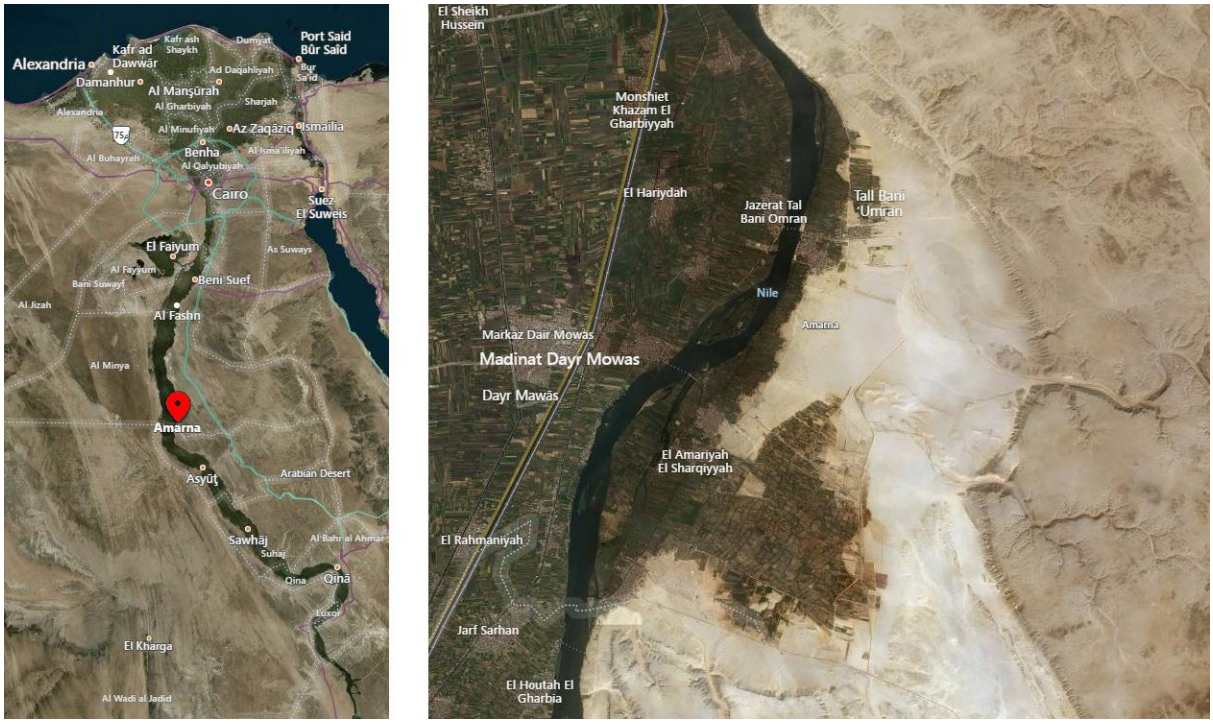


Figure 34, location of Amarna in Egypt (left), satellite image of the Amarna plain (right). Source Google Maps

The site had incorrectly been called 'Tel el-Amarneh' by early explorers and tourists during the nineteenth century. This was based on the tribe of the Beni Amran who settled in the area on both banks of the Nile in the 1800's and named the district el-'Amarneh (Peet and Woolley 1923). The main settlements were on the east bank and beginning in the north named et-Til, el-Hag Kandil, el-Amariyeh, and el-Hawateh. It is a common practice of naming a village with the district as a suffix so

et-Til became Til-el-Amarneh. Visitors misheard this and thinking the 'Til' was the word *tell*, meaning mound, and began to refer to the site as Tell el-Amarna. In modern times the name has been shortened to 'Amarna' and is commonly used to describe the whole site. When referring to it in antiquity we tend to use the name given by Akhenaten which is Akhetaten 'The Horizon of the Aten'.

2.3.1 Modelling Amarna

The city is an excellent example of urban settlement in ancient Egypt and has been used many times to showcase the daily life of the Egyptians. Over the years the city has been used to develop a range of models, usually depicting estates belonging to nobles. The largest and most detailed physical model of the city of Amarna was commissioned by the Boston Museum of Fine Arts (BMFA) and constructed during the summer of 1999. Hence, we refer to it throughout this work as the Boston model. It was designed by Michael Mallinson of Mallinson Architects under advisement from Barry Kemp and Dr Kate Spence. Construction was by Andrew Ingham & Associates Ltd at their Tetra workshop in Clapham, London. The model was built at a scale of 1:400 with a size of 3.6m x 4.9m and is based on archaeological survey and excavation with some reconstruction developed through interpolation in order to give a consistent level of detail throughout. In the autumn of 1999, the BMFA held an exhibition of the art of the Amarna Period after which the model was displayed at the Los Angeles County Museum of Art, the Art Institute of Chicago, and the Rijksmuseum van Oudheden, Leiden. The model covers the main religious and administrative area known as the Central City with the river Nile running down the western edge. It does not show the hills to the east where the tombs are located neither does it represent the Workmen's Village, Stone Village, or the Northern City. To reconstruct the entire Amarna landscape would have resulted in either an extremely large model or a smaller model with insufficient localised detail. The construction of a digital model would overcome this physical restriction whilst also allowing for a wider audience, albeit creating a different set of issues around museum patronship. If a museum was to pay for a digital model and showcase it online, then visitors would have less reason to attend the museum in person. However, a digital experience can be an attraction as seen in the exhibition 'Aton-Num, Akhenaten and Nefertiti in the digital age' developed by Archaeovision and hosted by the Learning Center Archaeology / Egyptology / SHS of the University of Lille in 2017 (www.aton-num.fr).

The Boston model is now on display in the Amarna Visitor Centre at Amarna and a photographic tour of the model is present on the Amarna Project website. The model was housed briefly at the Amarna Dig house prior to its installation in the Amarna Visitors centre. Figure 35 shows the model outside the dig house whilst Figure 36 shows a low-level close-up of the southern suburbs providing an almost eye level visualisation of the city as it may have looked in its prime. The Amarna Visitor Centre also includes a series of 1:200 scale models of the Great Aten Temple, the North Palace, Workmen's Village,

Maru-Aten, and the Royal Tomb. These models were commissioned by Eastwood Cook Ltd and constructed by Whetton & Grosch modelmakers; more of which later. Eastwood Cook Ltd also produced a 1:1 scale cutaway reconstruction of the house of *Ranefer* (N49.18) 'Master of the King's Horse', one of the larger houses at Amarna.

Figure 35, the Boston model outside the Amarna Dig House in 2010 prior to transport to the Amarna Visitor Centre (photo Barry Kemp)

Figure 36, close-up of the suburbs on the Boston model (photo Barry Kemp)

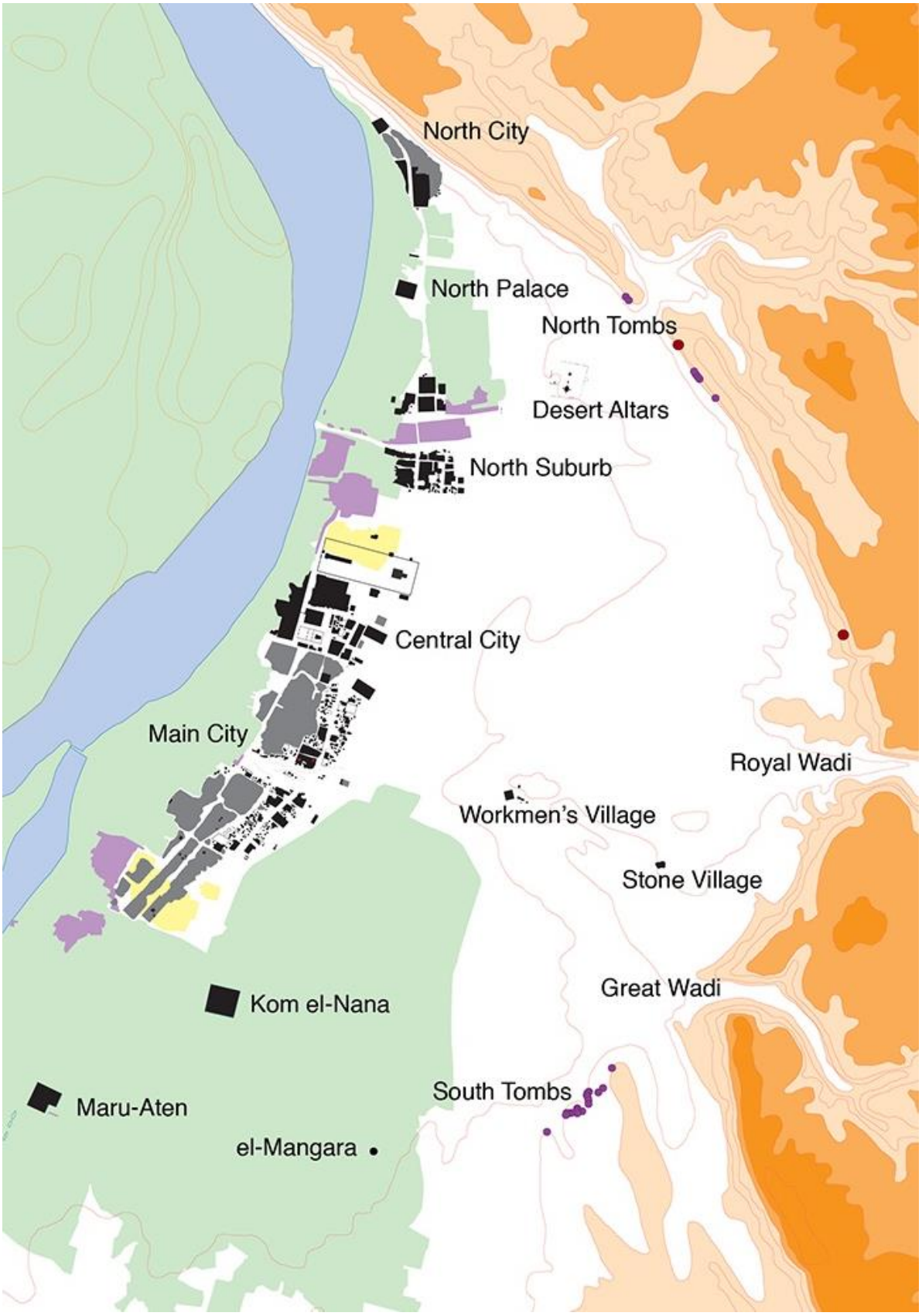


Figure 37, the layout of the city and its surrounds (image Barry Kemp)

2.3.2 The City in Parts

To gain a deeper understanding of the site we will take a tour of the city beginning in the northern most part of the city moving southwards before heading to a few eastern areas of note. This is a geographical look at the city to help with orientation and does not cover the chronology of the city development as that has already been covered in the earlier chapter on the Amarna Period. Amarna has distinct areas as shown in Figure 37, consisting of the North City, the North Palace, the North Suburbs, the Central City, the Main City, Kom-el-Nana, and the Maru-Aten in the south. Eastwards we have the Desert Altars, the Workmen's Village, and the Stone Village before we come to the rock tombs in the northern cliffs and the southern tombs. The following is an overview of each area, all of which should be explored further using the material resources described in the previous chapter prior to any 3D development.

2.3.3 The Tomb Paintings

As the first mudbricks were produced for the city houses work began on the tombs of the nobles and officials in the cliffs surrounding the Amarna plain. It is these tombs which give us vital clues as to how the city may have looked in its lifetime. The rock tombs have suffered over the years from both the natural elements and the hands of people who have visited them, only preserved by the epigraphic study and recording done during the start of the twentieth century which produced a detailed record of the wall paintings (de G. Davies 1903, 1905a, 1905b, 1906, 1908a, 1908b; Bouriant,Legrain and Jéquier 1903; Martin 1989).

The richly detailed paintings convey aspects of daily life albeit from the point of view of the tomb owner and the blessings of Akhenaten. The tomb painters were instructed to represent the Pharaoh and his entourage in their various royal and religious practices and in doing so captured much in the way of architectural features present at that time. If we combine the tomb imagery with the archaeological surveys, we can attempt to develop various visual reconstructions of the city which, if done digitally in 3D, can be further enhanced towards a more interactive environment for study and storytelling. Some structures are reasonably straightforward to identify within the city such as the Great Aten Temple and the King's House, whilst others are more difficult to locate and may be lost to modern development. The tombs all have a common theme in the representation of the Royal family worshiping the Aten and bestowing gifts to the tomb owner from the 'Window of Appearance' which may have been in the Great Palace. The tomb owner would also be presented in adoration to Akhenaten and there may be scenes depicting their profession albeit at a much smaller scale than the depictions of the royal family.

Figure 38, photogrammetric 3D reconstruction of the tomb of Meryra captured by Paul Docherty in 2020

Figure 38 shows a photogrammetric 3D section in tomb of Meryra. Behind the columns is a large section of the city illustrated in Figure 40 and reconstructed in Figure 41. The area depicted is as yet an unidentified location within the city whereas another section of the wall shows the King's house in the Central City which we know was located north of the Small Aten temple, Figure 39.

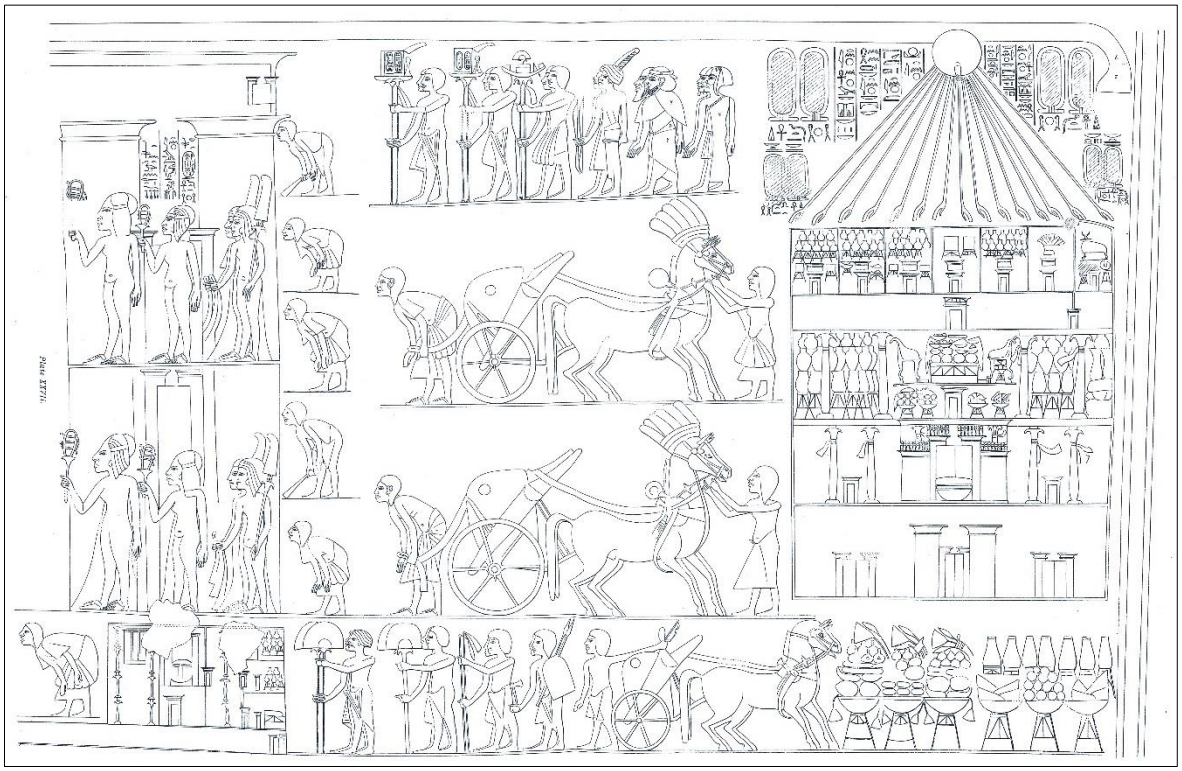


Figure 39, illustration of the King's house in the tomb of Meryra (de G. Davies 1903)

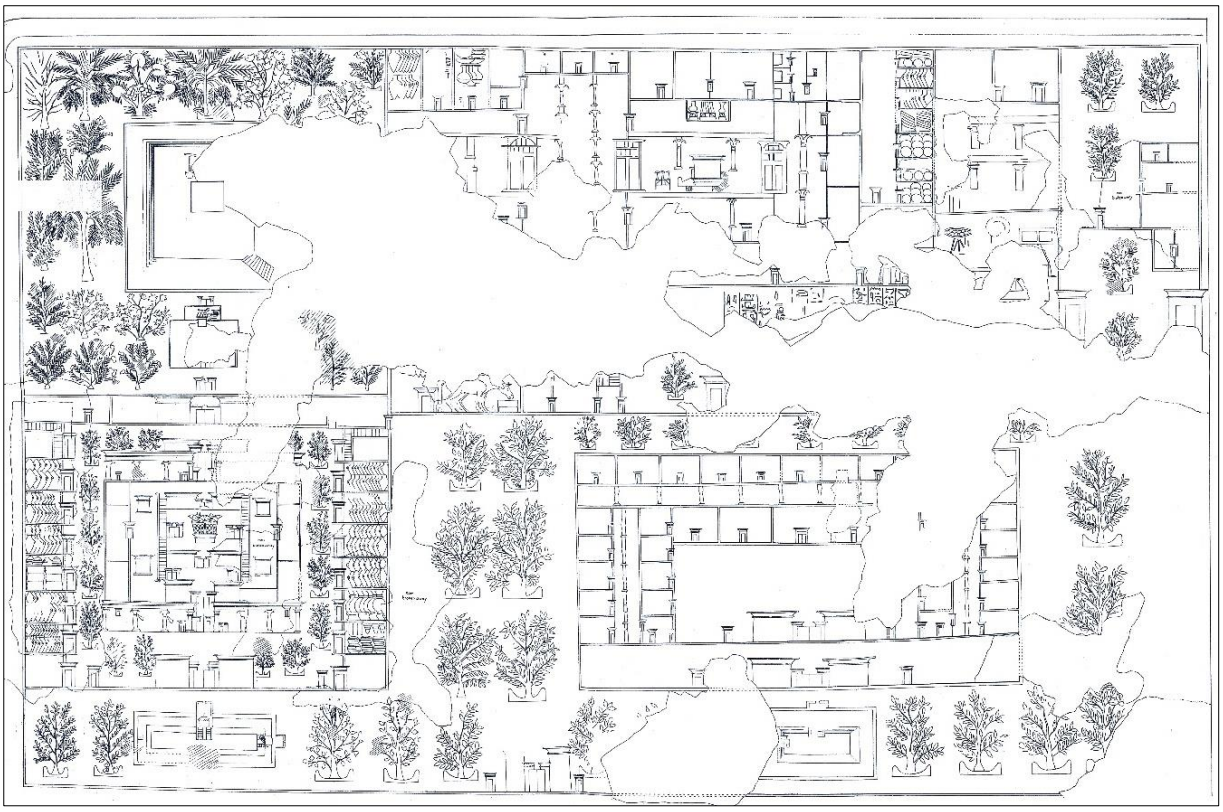


Figure 40, illustration of unknown buildings within the city, tomb of Meryra (D'Avennes 1878)

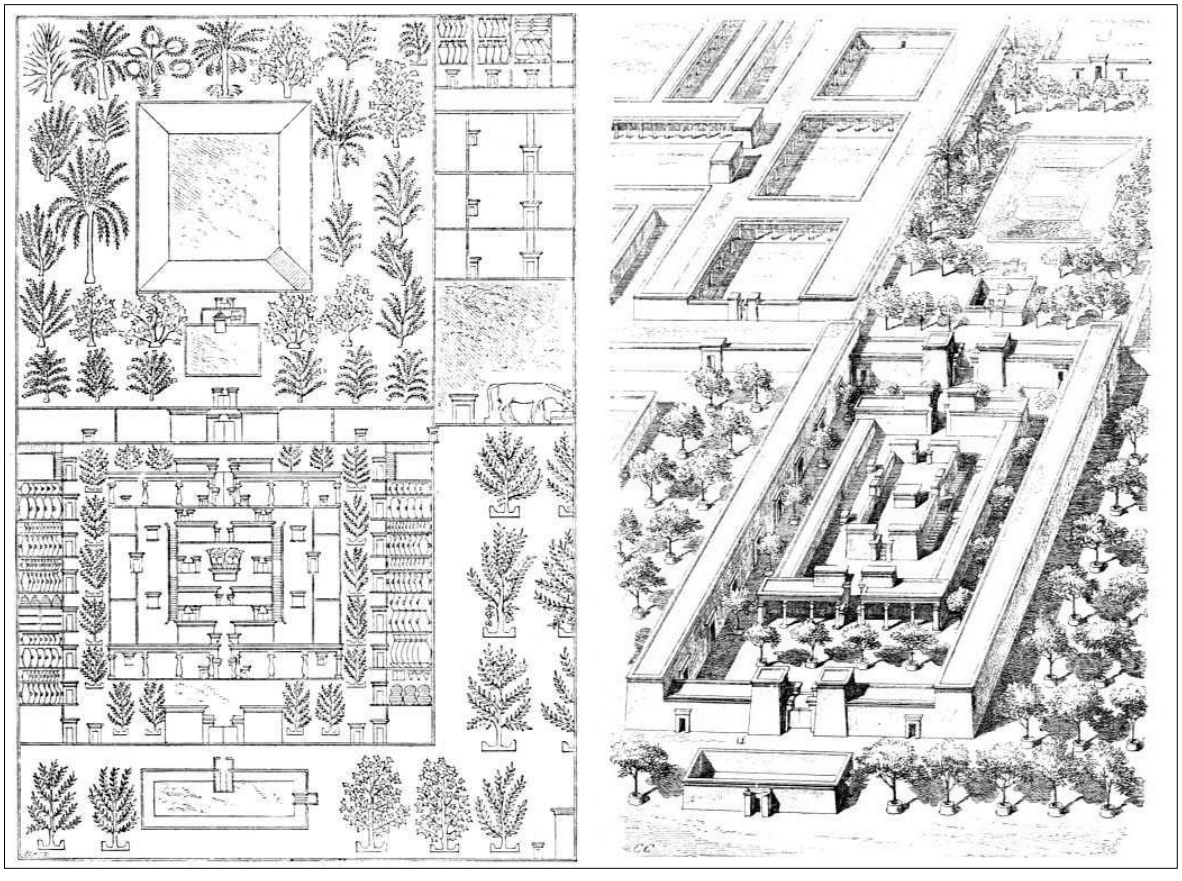


Figure 41, illustrated reconstruction of the buildings in Figure 40 (Perrot and Chipiez 1883)

2.3.4 The North City

A traveller sailing southward along the Nile would have their first glimpse of Amarna at the point where the cliffs almost meet the river, the view would have been almost identical to that in Figure 42.

Figure 42, the approach to Amarna from the north, view centre Nile towards south (Paul Docherty)

Once past this point the cliffs begin to run in a crescent shape eastward before returning towards the Nile some 10km further south. Figure 43 shows the riverside as it is at present. Moving round the northern tip we find the North City, an area which has not been as extensively excavated as other parts of Amarna, but it has certainly been dug over in the past by people seeking antiquities to sell. The map in Figure 44 shows the layout of what has been excavated to-date. The northern most structures include the North Administrative Building, the North Riverside Palace, a large house with storage magazines, and a range of ancillary housing which make up the North City. These fill a triangular region bounded on two sides by the cliffs and the Nile.

Figure 43, view of the north riverside from the Nile. Cliffs heading eastwards into the distance (Paul Docherty)

The main feature occupies grids T24 and T25 and consists of an immense brick-built wall which would likely have surrounded and fortified a large palace and the likely main residence of Akhenaten (Kemp 2012, 151). It would have run close to the riverside which in later centuries has destroyed all but slight traces of the corner structures and the Great Gateway which would have been the main entrance to the palace. whilst Figure 45 shows the North City and North Riverside Palace ruins reconstructed using photogrammetry from aerial photographs taken in 2002. The Great Gateway can be seen to the bottom of the image and the standing walls of the large house (U25.11) can be seen clearly. The large house was later reclaimed as the North Expedition House which was used by the EES during their early excavation work. The North Riverside Palace is tentatively the start of the Royal Road which runs almost parallel with the Nile in a straight-line south through Amarna. It is this road which is likely shown in several tomb paintings as the processional route regularly made by Akhenaten and his entourage to the Great Aten Temple, see Figure 46.

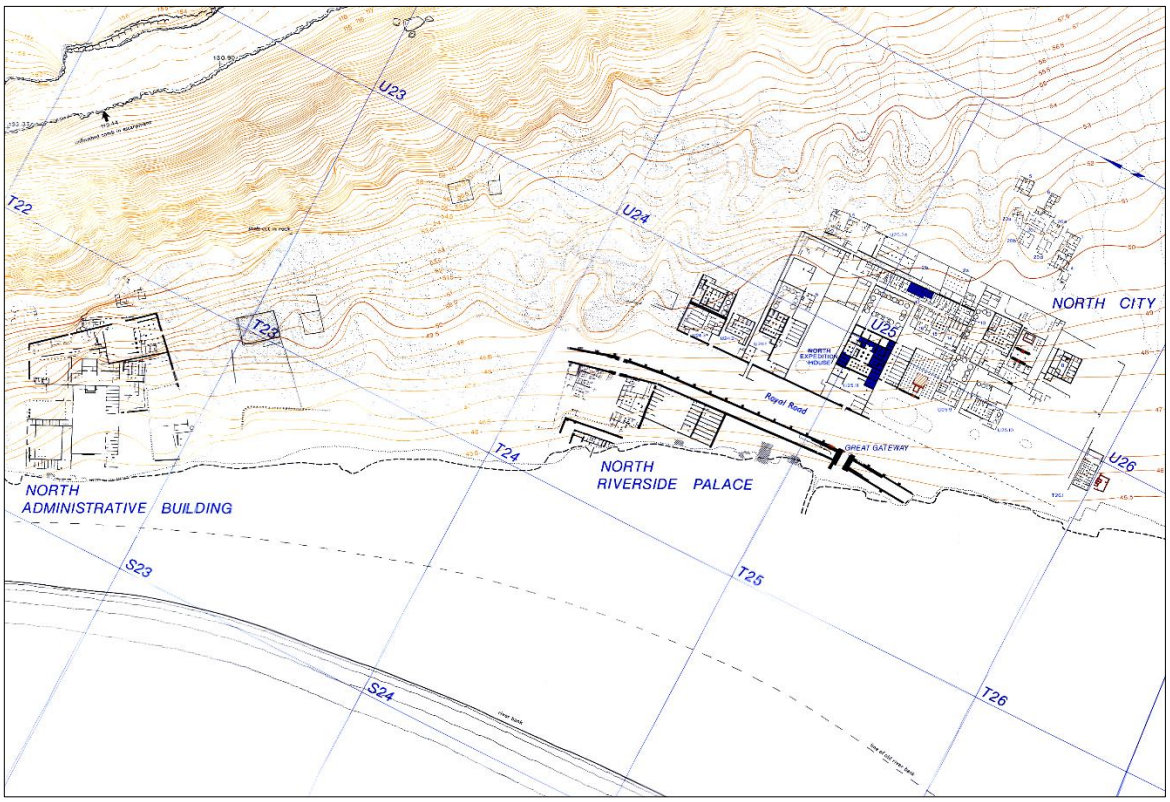


Figure 44, survey map of the North City, north is towards the top left (Kemp and Garfi 1993)

Figure 45, photogrammetric reconstruction of the North City ruins derived from balloon photography in 2002

(original photography by Gwil Owen, photogrammetry by Paul Docherty)

Figure 46, photogrammetric reconstruction of the north wall in the tomb of Meryra showing the royal procession

(captured by Paul Docherty 2020)

2.3.5 The North Palace

Continuing approximately 800m further south is the location of the North Palace which would have also been close to the riverside in ancient times but not enough to suffer any visible flood damage. Figure 47 shows the Nile bank at the point where the North Palace is located. The palace was situated on the east side of the Royal Road with its main entrance facing the Nile. It is impossible to tell if there was a quay or mooring point, but it cannot be discounted. It measures 148 x 115 meters and was excavated in 1923, 1924, and throughout the 1990's (Kemp 2012, 146). Figure 48 shows a photogrammetric reconstruction of the ruins of the North Palace during the 1999 excavation with the functional parts of the palace described on the plan in Figure 49.

Figure 47, photograph of the riverside adjacent to the North Palace location (Paul Docherty)

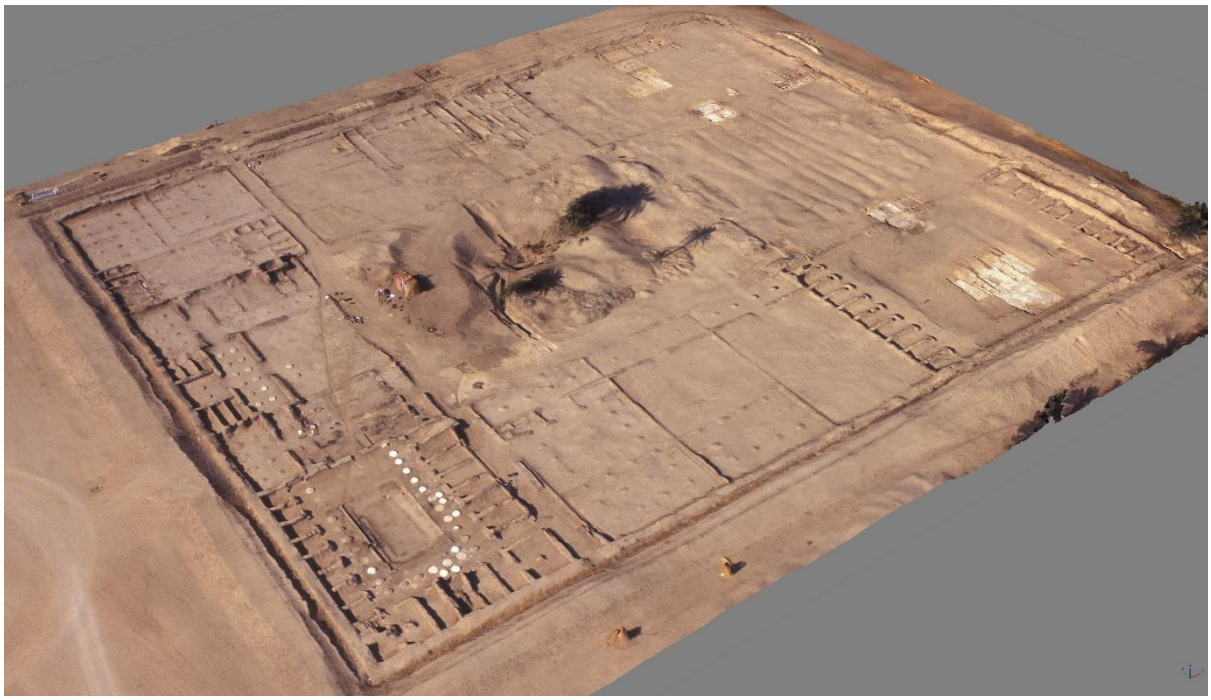


Figure 48, photogrammetric reconstruction of the North Palace remains using the 1999 season photography.

(original photography by Gwil Owen, photogrammetry by Paul Docherty)

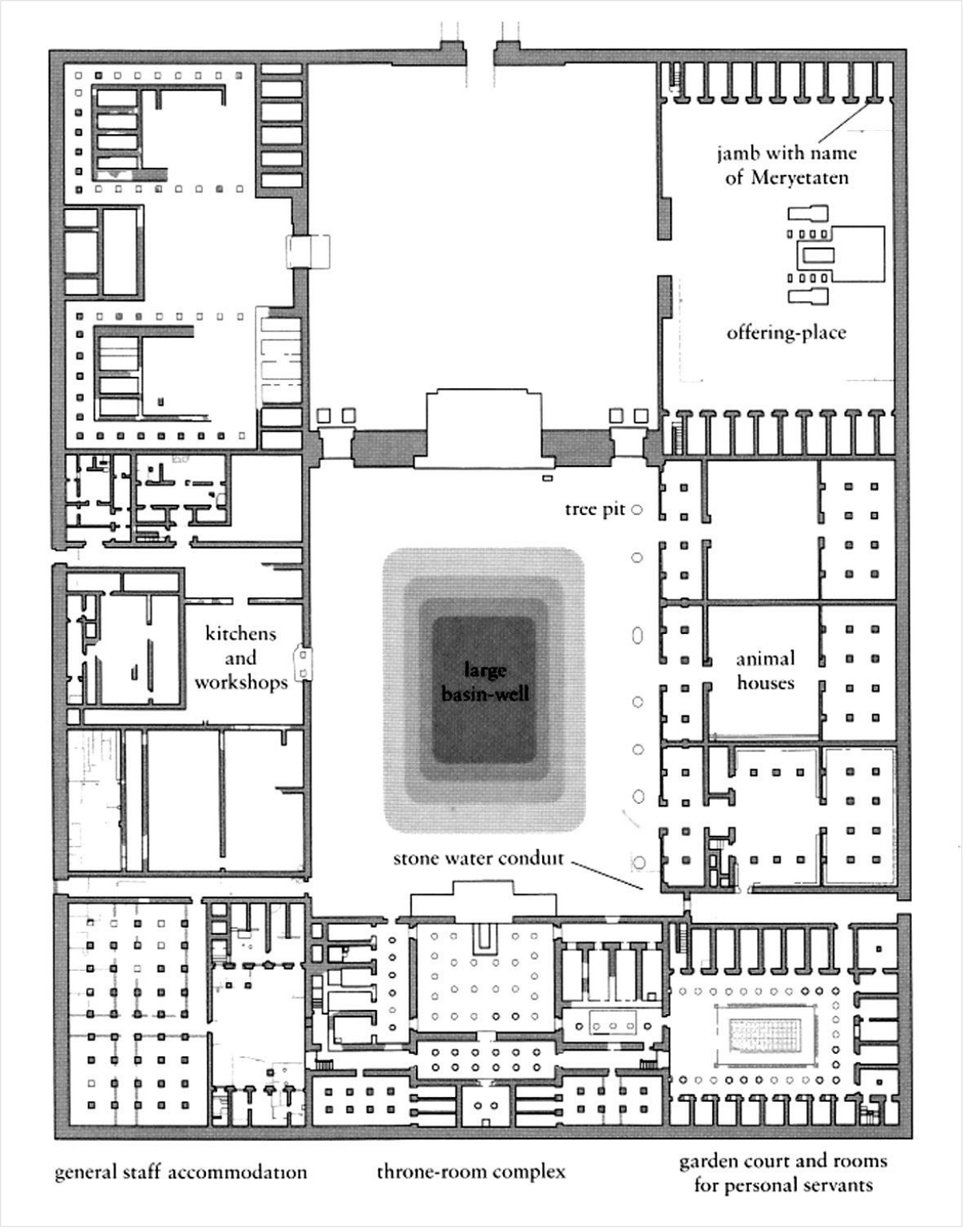


Figure 49, plan of the North Palace, north to the right (Kemp 2012)

Figure 50, model of the North Palace at 1:200 scale, image towards northwest (Whetton & Grosch)

The Whetton & Grosch model of the North Palace, presented in Figure 50 to Figure 52, shows several buildings surrounding a rectangular well which may have been a garden area as this was a popular feature of the larger house complexes throughout the city. The palace was decorated with fabulous paintings depicting marsh life with animals and birds, some of which was recovered during excavation prompting Pendlebury to think the structure was some form of zoological garden for the pleasure of Akhenaten. A common theory was that the palace was the residence of queen Nefertiti when she was supposed to have fallen from grace. We now know from inscriptions found in the palace that its original resident was a lesser royal wife named Kiya and later occupied by Akhenaten's daughter, Meritaten. In the eastern block of rooms there is evidence of several staircases indicating the likelyhood of upper floors in each wing. By looking at the potential usage of the rooms and taking into consideration the communal areas it has been speculated that the palace may have housed at least 50 people (Kemp 2012, 148). The palace was a 'working' residence in that it had kitchen's, animal houses, and workshops within its confines. The northwest corner was dedicated to ritual and worship of the Aten with a raised platform and steps flanked by two smaller platforms and a series of offering tables all facing north, which is at odds with a cult focused on the sun.

Figure 51, close-up of the central area on the 1:200 scale model of the North Palace (Whetton & Grosch)

Figure 52, close-up detail from the 1:200 scale model of the North Palace (Whetton & Grosch)

2.3.6 The Northern Suburbs

Continuing south down the Nile to a point some 3km from the north cliffs we reach the North Suburbs and it is here that a traveller may have left the Nile and ventured into the first of the main suburban areas. Throughout their journey they would have seen Shaduf water-lifts taking water from the Nile for crops and personal use, a task only differing today by the use of mechanical pumps. It may be that the first depiction of a water lifting device in antiquity is found in the tomb of Meryra in the northern cliffs (Kemp 2012, 50–51) see top left of Figure 40. Figure 53 shows the point on the Nile where the North Suburbs are located and the makeshift structure in the centre helps to helps to bring a little of the past to the present. The North Suburbs consist of smaller housing of a lower social status than that found elsewhere in the city and are split into two groups due to the route of a wadi as can be seen in the block plan in Figure 54. From the excavations at this site we have recovered evidence indicating that block V36.7,12 &13 was a tax collectors estate, T36.36 was the estate of a Mycenaean merchant, and T34.1 & 4 was the estate of Hatiay, Overseer of Works (Frankfort and Pendlebury 1933). This prompted the excavators to label this area the 'Merchant's Quarter'. Figure 55 and Figure 56 are excavators' illustrations of what the housing could have looked like based on the ruins; they correspond with the red zones marked in Figure 54.

Figure 53, photograph of the riverside adjacent to the Northern Suburbs. Note the use of pumping stations (white brick structures in the background) to provide water for agriculture (Paul Docherty)

Figure 54, block plan of the North Suburbs (Frankfort and Pendlebury 1933)

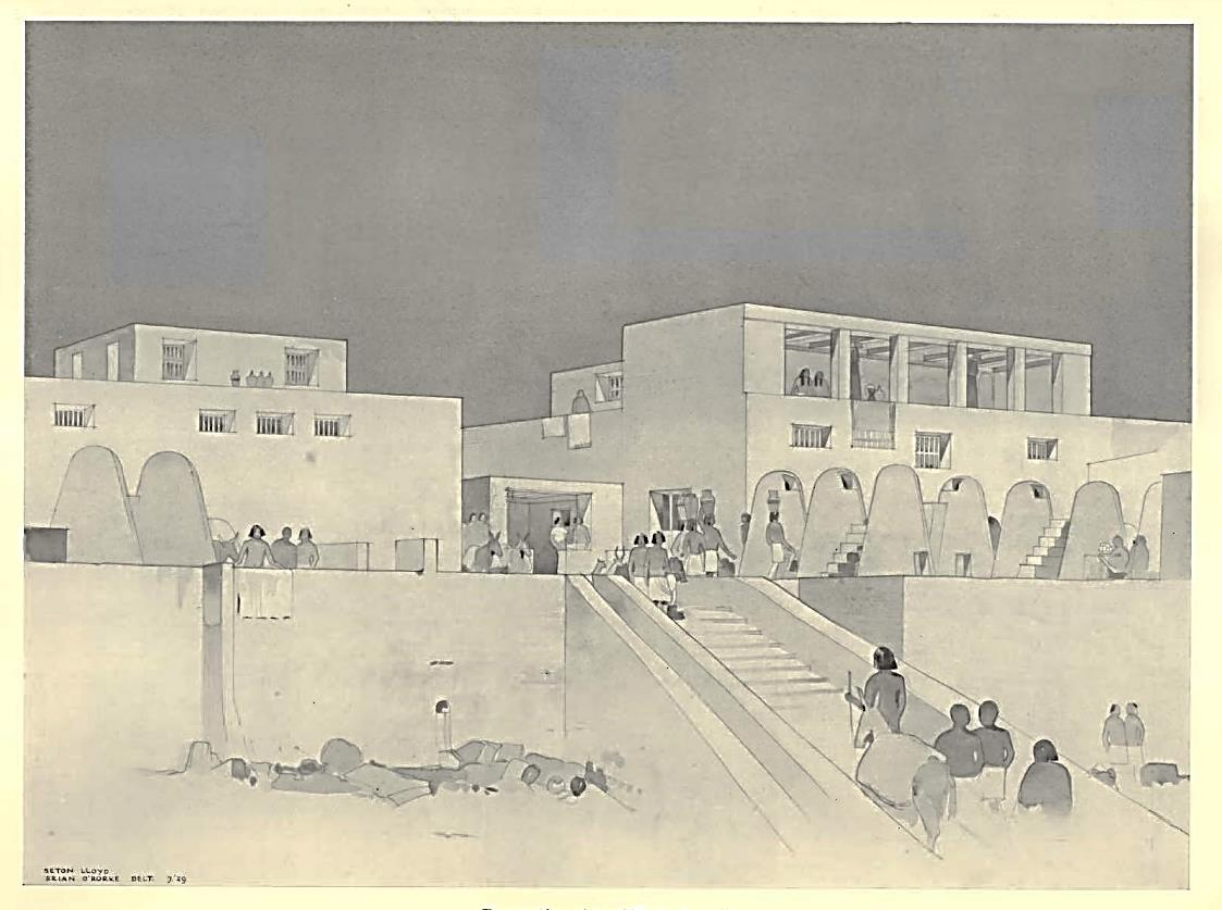


Figure 55, perspective view of T35.3 and T35.9. The 'Merchants Quarter' (Frankfort and Pendlebury 1933 Pl. XVII)

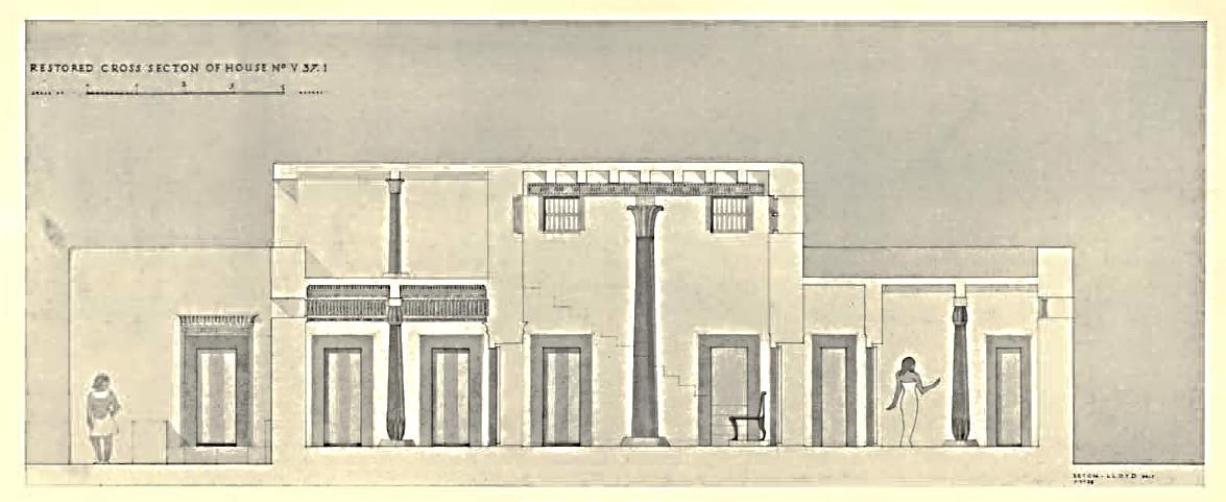


Figure 56, section through house V37.1 (Frankfort and Pendlebury 1933 Pl. XVI)

2.3.7 The Desert Altars

If we move eastwards, we come to the Desert Altars situated below the North Tombs. Consisting of four structures we have at the northern end a square platform, reached by four ramps, which may have supported a standing stone. The next structure is a group of three platforms or shrines. The southern structure is a large platform reached by four ramps and featured columned rooms. The fourth structure is a walled enclosure to the west which included a small stone chapel (Frankfort and Pendlebury 1933). It is possible that this is where the Year 12 foreign tribute took place.

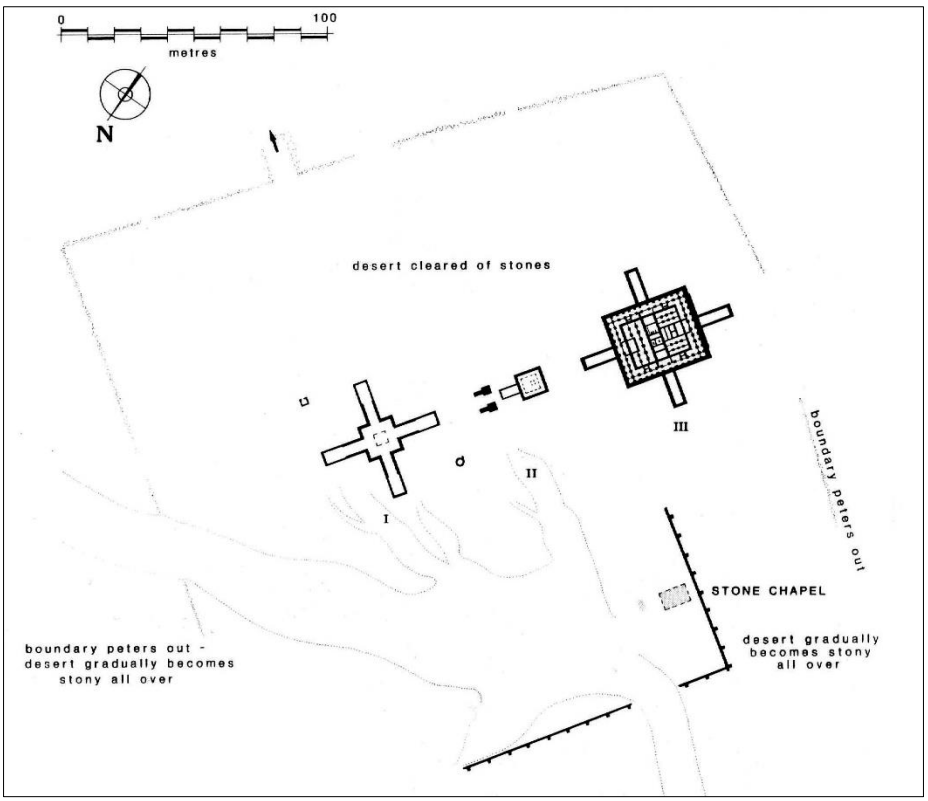


Figure 57, outline plan of the Desert Altars site (Kemp 1989b)

Figure 58, aerial photograph of the Desert Altars taken in 1993 (Gwil Owen)

2.3.8 The Central City

The Central City area has attracted the most attention with regards to visual reconstruction. Being the religious and administrative centre for the city it contains a variety of structures which are unique within Amarna. To date it remains the only ancient Egyptian example of a royal administrative estate. Figure 59 shows the block plan of the central city taken from the EES survey (Pendlebury 1951) and Figure 60 shows the same area on the Amarna3D model with the main structures identified. Within the Central City there are three distinct zones namely the Great Aten Temple Complex, The Great Palace, and the Royal Estate, which have been blocked out in red in Figure 60. Much of the royal activities depicted on the tomb walls were enacted within the Central City.

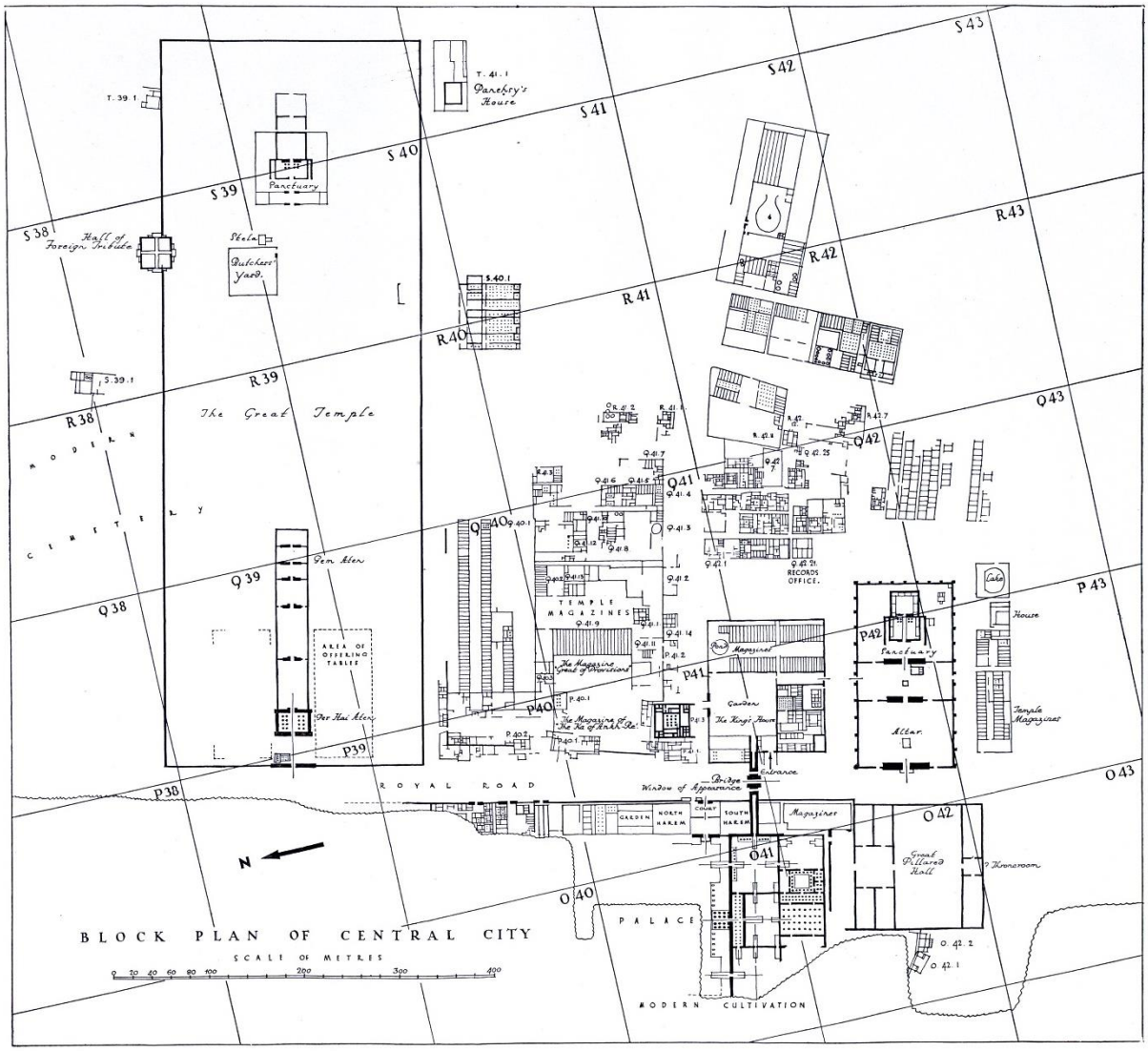


Figure 59, block plan of the Central City (Pendlebury 1951)

Figure 60, Amarna3D visualisation of the Central City based on the block plan

The largest structure constructed at Amarna is that of the 'House of the Aten' commonly referred to as the Great Aten Temple (Pendlebury 1951, 5–20). It was the most important building at Amarna constituting the centre of the cult of the Aten. The Great Aten Temple is a collection of buildings surrounded by a temenos wall measuring 800m x 300m constructed from mud bricks see Figure 60 parts 1 to 5. The entrance was on the western wall which was flanked by two mud brick pylons. The axis is west-east and almost in line with the opening in the cliffs further to the east known as the 'Royal Wadi' and the position where the sun rises. After entering the enclosure through the pylons there was a square building directly to the north referred to as the 'Altar' or 'Pavilion' by Pendlebury but now referred to as the 'Platform Building' and possibly further north still was an area for animal sacrifice. Directly east on the axis was the largest building sometimes referred to as the Gem-pa-Aten ("The finding of the Aten"), but now most commonly named the Long Temple (Pendlebury 1951, 191–197; Kemp 2012, 89). Running externally alongside the northern and southern walls of the Long Temple were large numbers of mud brick offering tables, although these may have gone out of use in the final phase of the temple. Continuing along the axis beyond the Long Temple there may have been some rectangular structures as depicted in the tomb pictures (de G. Davies 1903, 1905a) which could have been large offering tables, however this area is currently in use as a modern cemetery and as such excavation is highly unlikely to be undertaken in order to investigate this. Moving further east along the axis there was a walled area for animal sacrifice and beyond that a raised platform which likely

included a stela. Further north transecting the main temenos wall was a square structure known as the "House of Foreign Tribute". Finally, at the most eastern end of the axis was the temple Sanctuary. Situated to the south east of the main temenos wall, but external to it, is the official residence of Panehsy the High Priest to the Aten.

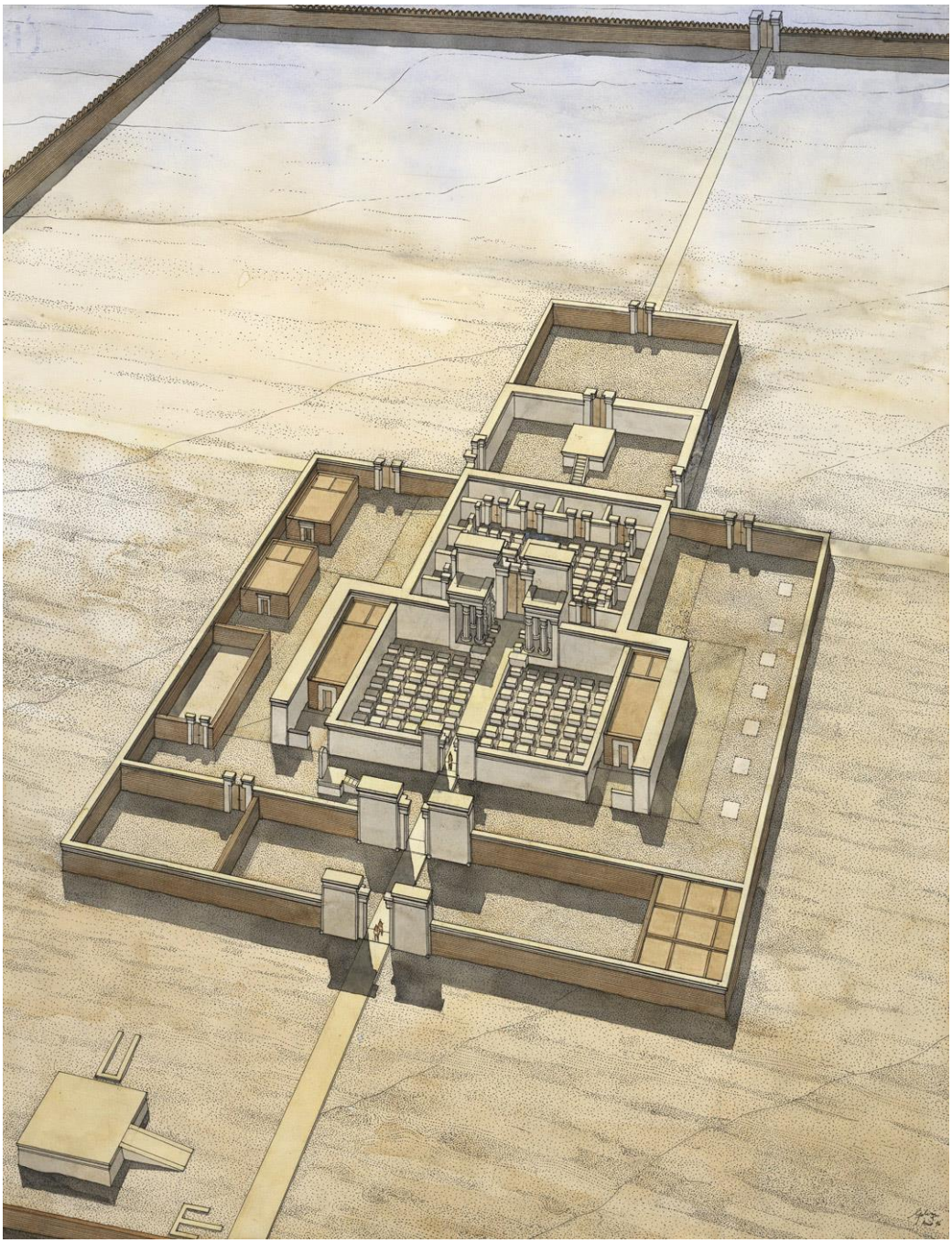


Figure 61, the Sanctuary of the Great Aten temple Figure 60(2) (Golvin 2018)

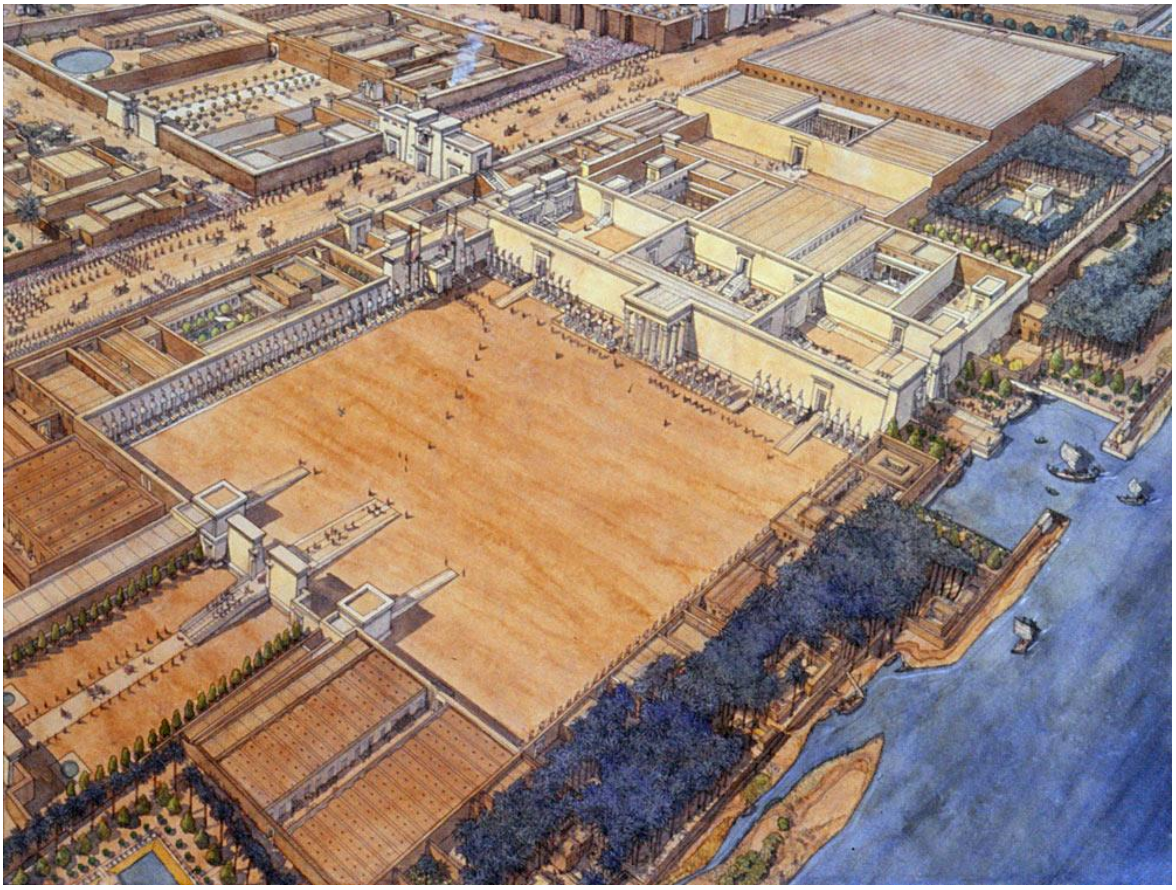


Figure 62, the Great Palace. The structure top right is a later addition known as the hall of Smenkhkara (Golvin 2018)

Figure 63, the Great Palace and Royal Estate on the Boston model (photo B. Kemp)

The Great Palace is the second largest structure at Amarna half of which had been lost to agriculture before any excavation could take place. The original structure stretched between the Kings Road and the Nile and included a colonnade along the riverside which had moorings for boats. We know this from scenes decorating tomb (no.14) belonging to May (de G. Davies 1908a, Pl. V) shown in Figure 64. The palace extended approximately 580m northwards where its entrance would have been.

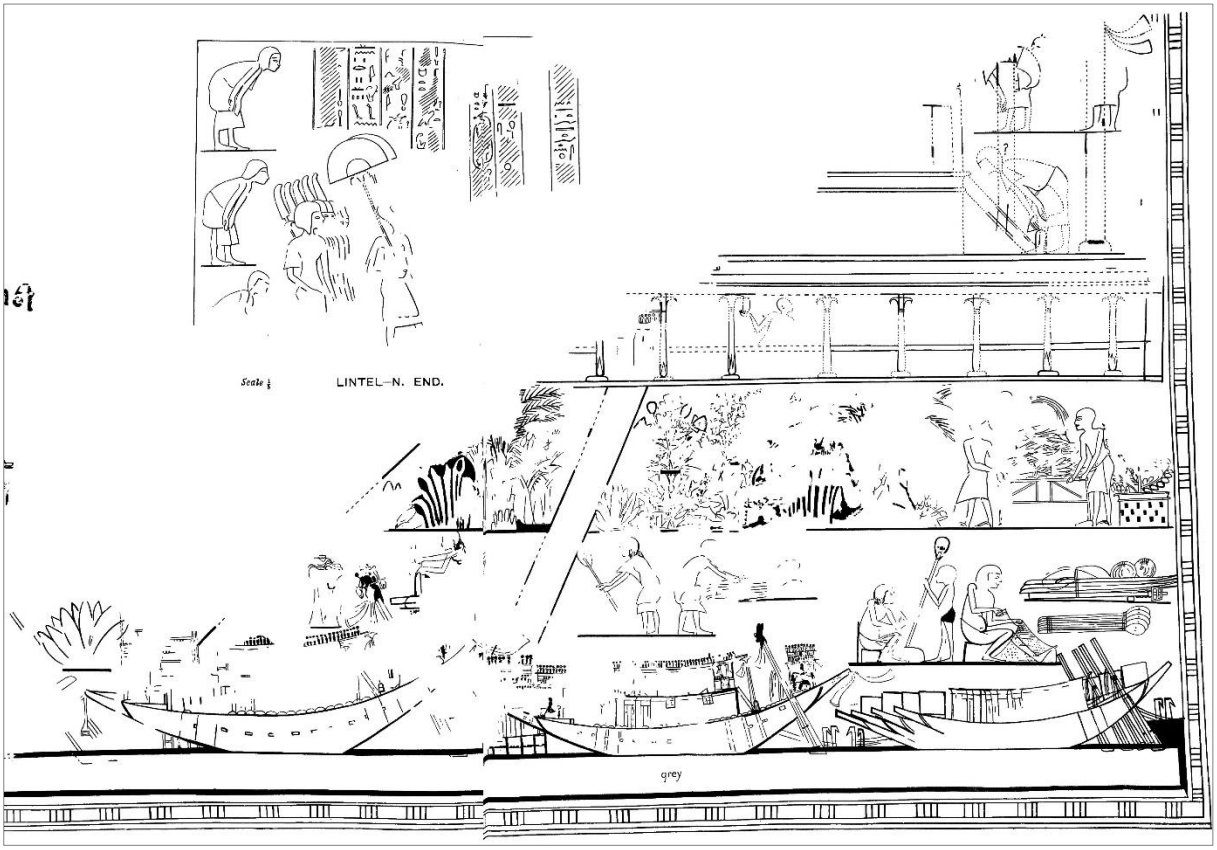


Figure 64, the Quay of Akhenaten, west wall, tomb of May (de G. Davies 1908a, Pl. V)

The Palace had a large courtyard measuring around 160m square and used for state occasions. It was surrounded on three sides by colossal statues of Akhenaten like those found at Karnak. The southern end of the courtyard had a sizeable terrace with a central portico which likely housed the 'Window of Appearance' used by Akhenaten to shower gifts on his nobles (Figure 65). Behind the portico was a ramp leading to a series of smaller courtyards. The central courtyard led to a large throne room and beyond that was the coronation hall of approximately 130m square constructed by Smenkhkare, the immediate successor to Akhenaten. On the east wing (and possibly west) are found a series of magazines and what has been described as the 'Harem Quarter' or 'Eastern Apartments' which consisted of a series of rooms and a central sunken garden with a pool. This is the location of the painted pavement excavated by Petrie in the early 1890s.

Figure 65, alternative view of the Boston model showing the Great Palace, north is to the bottom (photo B. Kemp)

Figure 66, the Boston model showing the Royal Estate, north is to the left (photo B. Kemp)

Towards the southern end of the eastern wing the King's Bridge connects the Great Palace to the King's House. Adjacent to the King's House is the Small Aten Temple and its dependencies known collectively as the Royal Estate (Figure 66). To the north of the King's House are found the Great Aten Temple Magazines and Bakeries. To the east of the King's House can be found the Records Office and surroundings including the Clerks Houses where the Amarna clay tablets were discovered. Further east are the Military and Police Barracks.

2.3.9 The Main City

The suburbs south of the Central City were of an earlier construction to their counterpart in the north and consist of mainly residential housing with some administrative buildings intermixed. Over the years the Main City has been referred to as three zones namely Main City (north), Main City (south), and the South Suburb, here we use the term Main City to refer to all three. The social status of the Main City can be said to be slightly higher than that found in the north with the estates tending to be bigger. The individual mansion houses tend to have larger floor space and include walled gardens with private chapels. An illustrated representation of how a small area of the Main City may have looked is shown in Figure 67.

Figure 67, illustration of a group of houses within the suburbs (Golvin 2018)

Additional evidence of the higher social status present within the Main City can be found on the stone door jambs and lintels excavated from the larger houses. Some of these have inscriptions identifying the owner of the house by name, title, and occupation. Some of these include General *Ramose*, High Priest *Pawah*, the Vizier *Nakht*, Chief Builder *Maanakhtuef*, and Chariot Officer *Ranefer*. One of the

sculptors to have resided here is the well-known Thutmose who produced many royal sculptures including the famous bust of Nefertiti.

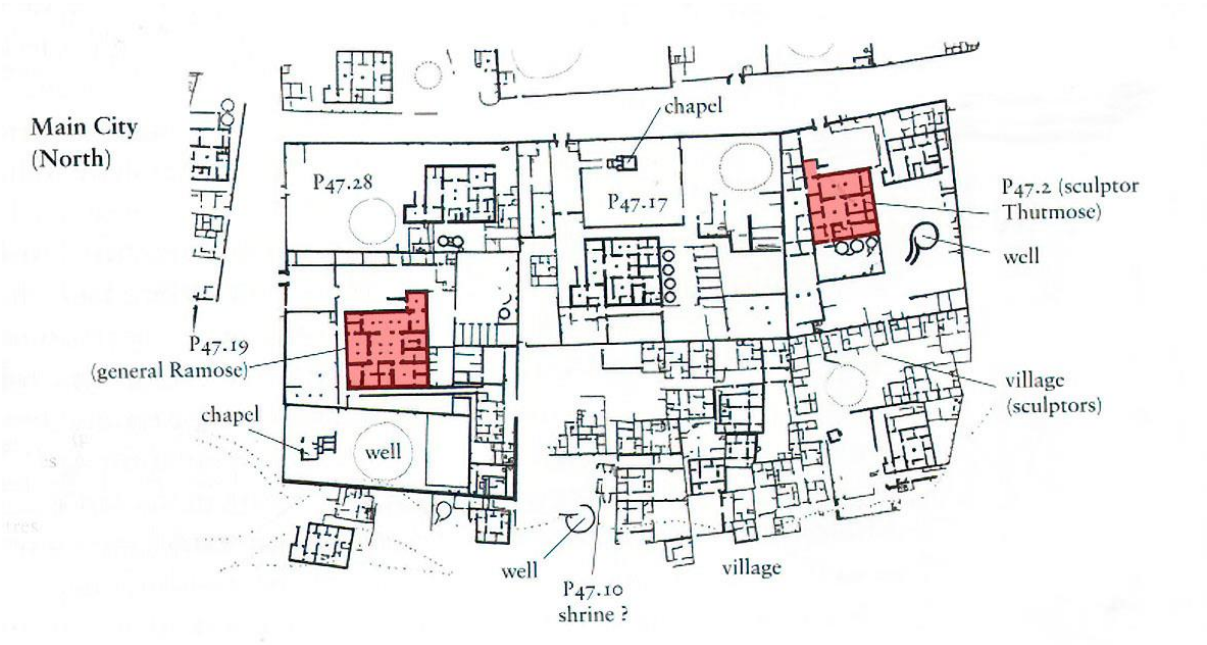


Figure 68, grid P47 showing the location of the houses belonging to General Ramose and the sculptor Thutmose (after Kemp 2012, 165)

Figure 69, grid P47 on the Boston model (photo B. Kemp)

2.3.10 Kom el-Nana

Further south beyond the Main City we have the Sun Temple for Nefertiti known as Kom el-Nana. It has been theorised that its orientation was aligned with the main royal, religious, and administrative structures forming the processional route envisioned by Akhenaten during the initial construction of the city. However, the southern suburbs soon prevented any direct route between Kom el-Nana and the North City. Parts of the site were built over by a monastery dating from the 5th and 6th century but enough has remained to determine it was likely a ceremonial site for the royal family.

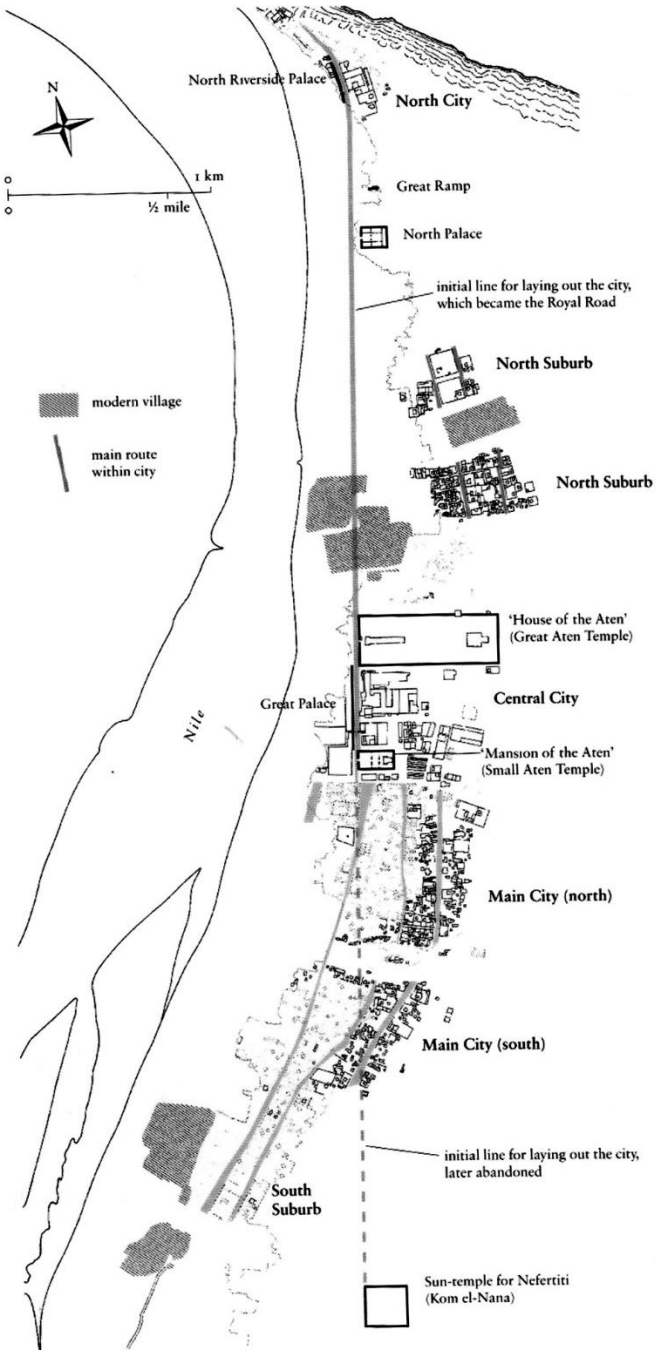


Figure 70, general layout of the city ruins along its potential processional route (Kemp 2012)

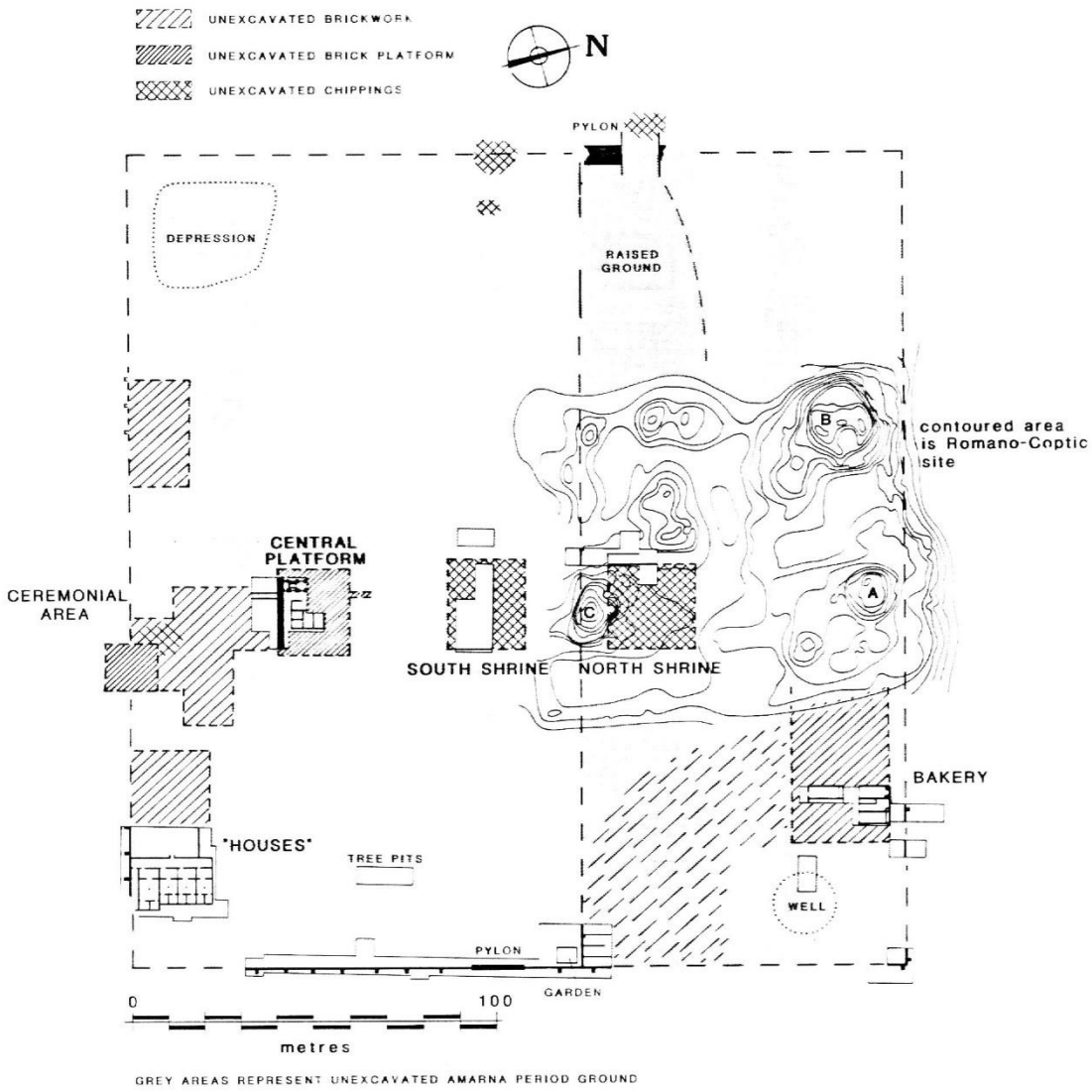


Figure 71, outline interpretation of Kon el-Nana (Kemp 1989b)

The structure measures 228m x 213m with an outer buttressed brick enclosure and pylon gateways on all four sides, see Figure 71. Internally it was split unequally by a wall running east-west with the larger ceremonial area being within the southern enclosure. The northern enclosure was mainly focused on food production but also contained the North Shrine. The structures within the southern enclosure include a Central Platform, South Shrine, and South Pavilion. The layout of the Central Platform suggests there may have been a 'Window of Appearance', facing towards the west, where rewards would be given to those deemed deserving (Figure 72). The eastern side of the southern enclosure included a group of houses and a series of cubit-sized garden plots (Kemp 1989b, 1990, 1993). This site has limited reconstructions as the data from the excavations conducted in the area is still being analysed.

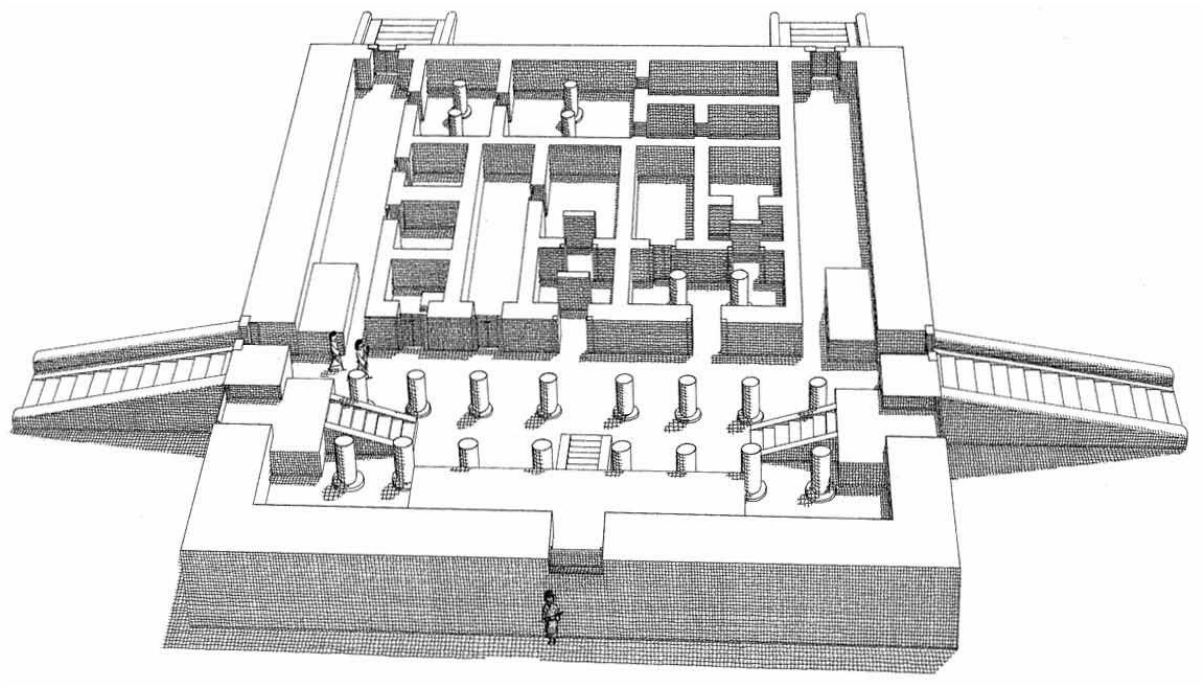


Figure 72, reconstruction of the Central Platform at Kom el-Nana (Kemp 2012, 140)

2.3.11 Maru-Aten

The southernmost structure, except for the South Tombs and southern stelae, is the Maru-Aten complex. Like Kom el-Nana this was also a sun temple, originally constructed for an earlier queen of Akhenaten named Kiya but later dedicated to Akhenaten's eldest daughter Meritaten. The site comprised of two enclosures the larger approximately 220m x 110m and the smaller 150m x 85m. Several feature structures were present as shown on the plan in Figure 73, referred to by the letter 'M' plus a roman numeral. The site had extensive gardens spread throughout all dominated by a large, albeit shallow, lake measuring around 120m x 60m complete with its own causeway and quay marked as 'M V' on the plan. Area 'M I' was a series of interlocked 'T' shaped basins with painted paving surrounding them, 'M II' was an artificial island with a stone shrine connected by a small bridge to another stone structure. At the eastern end of the larger enclosure 'M VI' was a walled area with living quarters perhaps for servants. Figure 74 to Figure 76 show the model of the Maru-Aten complex now housed in the Amarna Visitor Centre. Unfortunately, during the 1970's the whole site was destroyed when a huge irrigation channel was constructed to supply the surrounding area with water for agriculture. Figure 77 shows the last aerial view of the site taken in 1964.

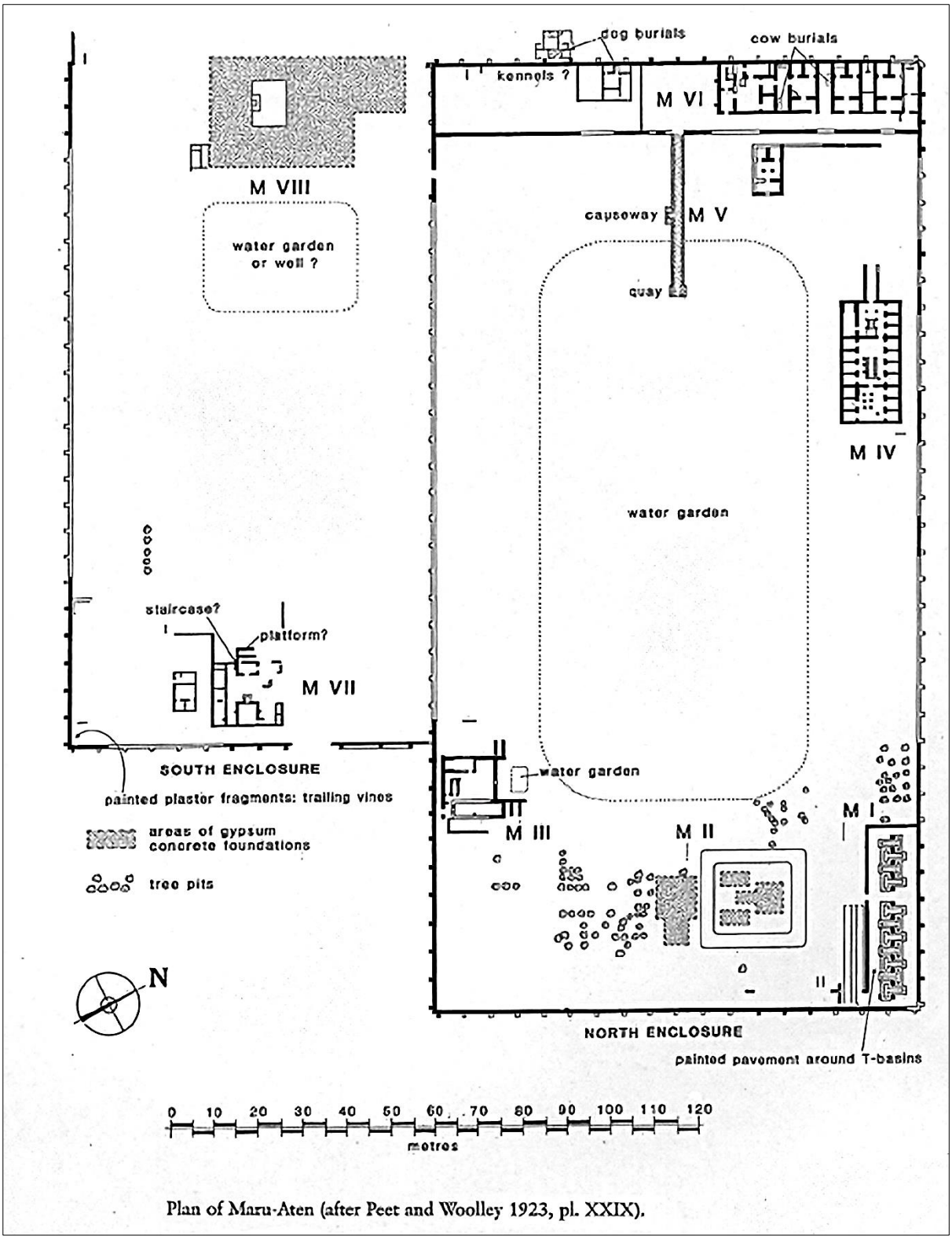


Figure 73, plan of Maru-Aten (Peet and Woolley 1923 pl. XXIX)

Figure 74, model of the Maru-Aten (Whetton & Grosch)

Figure 75, close-up of the Maru-Aten model (Whetton & Grosch)

Figure 76, close-up of the arteficial lake on the Maru-Aten model (Whetton & Grosch)

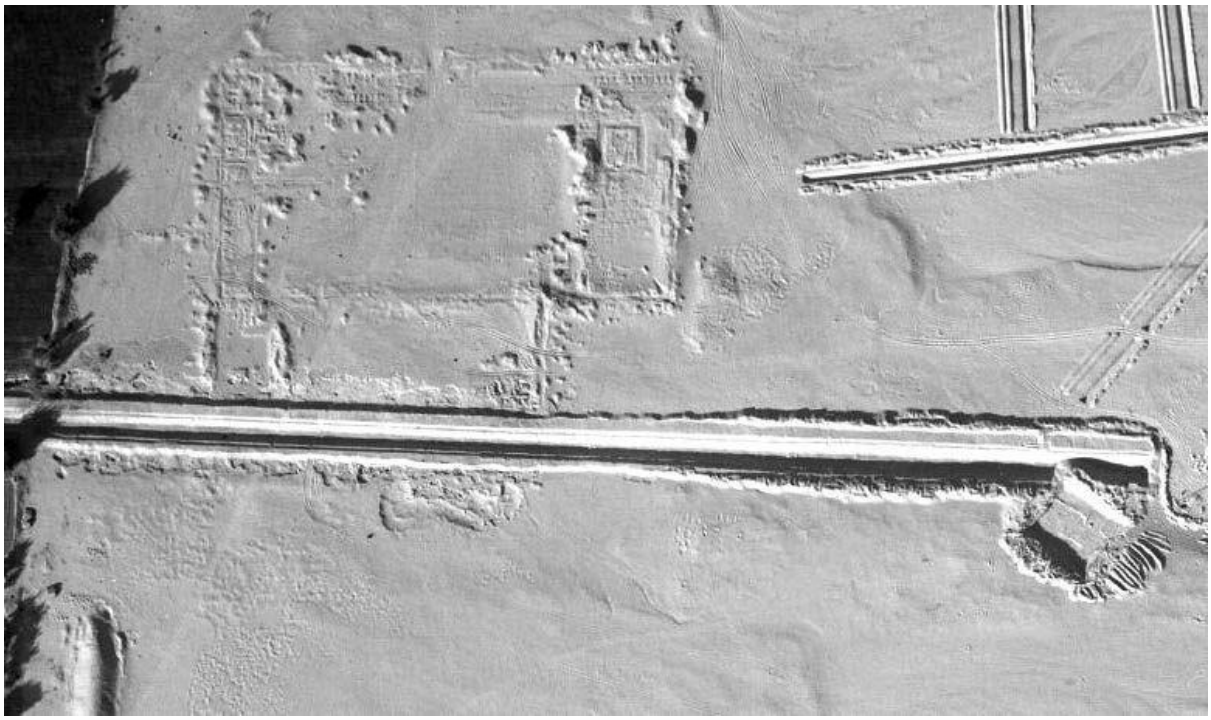


Figure 77, the last aerial photograph of the Maru-Aten site before it was lost to agriculture taken in 1964 by the French Geographical Institute (Kemp 2017b).

2.3.12 The Workmen's Village

To the east of the Main City is a small self-contained community which has been called the Workmen's Village (some reference it as the Eastern Village (Peet and Woolley 1923)) due to evidence of craft materials and its parallels with the village at Deir el-Medina. It is positioned on the south side of a low desert plateau. A walled enclosure of around 70m square contained 72 houses laid out in a series of parallel streets with a larger house, potentially that of an overseer, situated in the south-eastern corner. The houses were all built in a similar style and included an upper floor. Evidence of painted walls have been found in some of the houses. Outside the walled enclosure were a few small chapels and animal pens. Figure 78 to Figure 80 show the site as it may have looked in antiquity. A small cemetery was also present which had been robbed in ancient times. The whole village was encircled by a road/path giving the impression that this entire site was patrolled, possibly with the intention of keeping it isolated from the main city suburbs. The village would have been dependant on the main city for supplies and water as it had little means of providing everything it needed to maintain its inhabitants.

Figure 78, illustration of the Workmen's Village (Golvin 2018)

Figure 79, model of the Workmen's Vilage (Whetton & Grosch)

Figure 80, alternative view of the model of the Workmen's Vilage (Whetton & Grosch)

2.3.13 The Stone Village

A short walk further eastwards brings us to the Stone Village so named because of the remains of stone craft and tools linked to quarrying. The village may have been created before the Workman's Village as it is smaller and less organised in its layout and construction. Its function was likely to house those working on the tombs including the Royal Tomb further east. Like the Workmen's Village it too had to rely on provisions sent from the main city and was enclosed by a circular road.

2.4 Experiencing the Place

This section will take a brief look at my time at Amarna as part of the Amarna Project team and how this experience can help to inform the construction of a new 3D model of the city and the stories it can support. Many 3D reconstructions are performed by specialists who do not directly experience archaeological excavation; in this section I will demonstrate the importance of experiential data and archaeological practice in digital reconstruction.

In February 2020 I joined Barry Kemp's team working at Amarna as a digital archaeologist recording the site and surveying areas for future work, in particular the sanctuary at the eastern end of the Great Aten Temple temenos. After 20 years of researching and constructing the city of Amarna in 3D, I was there in person (Figure 81). Although my time was cut short by the COVID-19 pandemic, I did manage to capture a substantial area as outlined in the Great Aten Temple Report on Recent Work (February–May 2020). Photogrammetry enables real-world data to be used in the construction of assets and materials for the Amarna3D model. Visiting and working at Amarna gave me an invaluable insight into the environment and the opportunity to discuss the site in a wider context with the archaeological team who had worked there for many years. In addition, I was able to study the materials present in the construction of the city, the flora, fauna, and weather, all of which can be used to develop the next evolution of the Amarna3D model.

2.4.1 Arriving at Amarna

The Amarna Dig House is located on the southern edge of the southern suburbs approximately 1km from the village of El-Hagg Qandil. Flinders Petrie was the first to build a house at the site in 1891 with Borchardt erecting a larger house over the excavated remains of an original Amarna house in 1908. It was used for his excavations between 1911-1914 and housed the famous Nefertiti bust until it was transferred to Berlin. This house had been identified by a door lintel as belonging to 'Nekhu-em-pa-Aten, chief of bowmen in Akhetaten' (Murnane 1995, 168). It was used by the EES during the 1920's and for a short season in 1932 before being abandoned until 1977 when Barry Kemp arrived and started the process of restoration and expansion into the present house and magazine complex. The complex is self-contained (Figure 82) with individual rooms for team members (Figure 84), a shower block, kitchen, dining room, and workspaces (Figure 83).

By living in one of the original Amarna houses, albeit reconstructed and extended, it was possible to appreciate the materials, colour, close proximity to other members living in the adjacent rooms, and the changes in elevation when moving throughout the complex. This was embellished with some of the rooftop social areas and the range of storage methods using rooftop space (see Figure 81).

Figure 81, sunrise over Amarna, February 2020

Figure 82, panoramic view of the Amarna Dig House central courtyard

Figure 83, panoramic view of the Amarna Dig House central work area

Figure 84, accommodation at the Amarna Dig House (left) and social space in the evening (right)

2.4.2 Data Capture

My primary remit was to attempt a photogrammetric survey of the structures within the Great Aten Temple enclosure which measures approximately 800 x 300m. For this season I would be working on the eastern end. We are not permitted to use drones to photograph the site so surface based methods would need to be used.

In addition to this task, I wanted to capture small areas for use within a 3D reconstruction of the city either as material textures or 3D assets. I was also keen to get a feeling of the environment in terms of topography, sounds, smells, temperature, etc. A mixture of photography, video, photogrammetry, and casual interviews with the team were used to gain a deeper understanding of the site which cannot be gained remotely. I had several opportunities to walk through the city with other team members (and local police) where I was able to see structures I had only seen in plan or old photographs. It was invaluable to me as a 3D artist / archaeologist to gain a sense of scale for the city layout.

Figure 85, photogrammetry markers being prepared (left) and in use (right)

2.4.3 Equipment and method

Photogrammetry uses a series of photographs taken from many viewpoints to cover all visible surfaces of the subject so that it can be reconstructed as a 3D model later using suitable 3D photogrammetry software. The process is widely described online and in numerous papers (for example Mallison and Wings 2014) and I wrote a quick overview of the process for the Amarna Project website (Docherty 2019). For the spring 2020 season I used three methods to capture data, using a Canon EOS M series digital SLR, a miniature camera and gimbal (DJI Osmo Pocket), and a specially constructed gravity gimbal I designed in CAD and 3D printed myself, see Figure 86. The gravity gimbal allowed 3 action cameras to be mounted horizontally giving a 360-degree coverage as both still frame and video footage. This allowed for a light compact and portable system to be taken to Amarna and the opportunity to experiment with different methods of capture which I outlined in the subsequent

Amarna Excavation Report (Barry Kemp et al. 2020). Both the Osmo and the 360-rig were mounted on an extendable boom pole to give added height. The 360-degree rig was scheduled to be used to take 360-degree video for testing as a VR experience. I had organised for this capture to take place towards the end of the excavation period prior to site closedown. Unfortunately, due to the COVID-19 pandemic the trip was cut short and the capture did not take place. It has been rescheduled for the next time I am able to travel to Amarna.

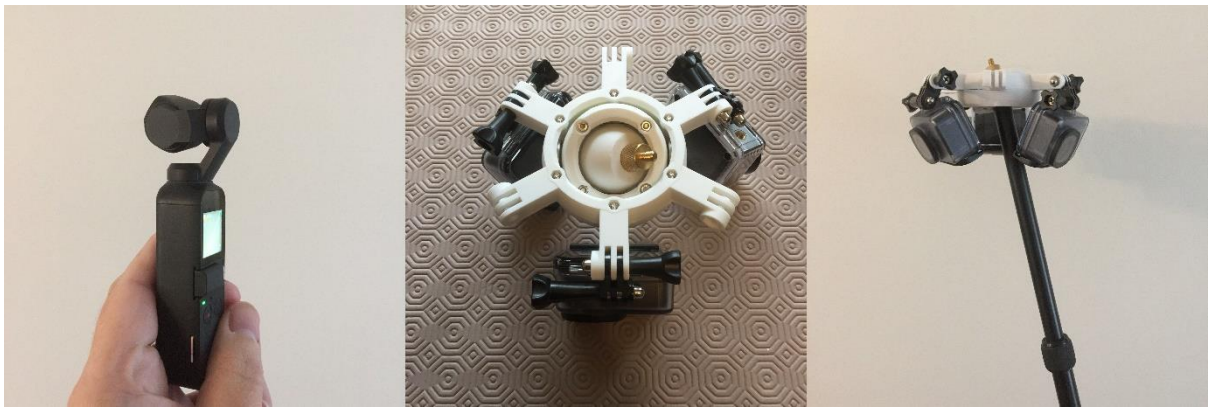


Figure 86, photogrammetry equipment. DJI Osmo Pocket (left), custom action camera rig (middle & right)

To maintain accuracy in the physical measurement of the site, ground control targets (GTC) were laid down and surveyed by Anna Hodgkinson and Miriam Bertram. The data from these GTC's was then used to scale and orient the reconstructed models later in software. Captures took place at just after midday to prevent long shadows as the site was too large to shade by sheets, tents, etc. Capture processing on the laptop was done overnight and into the morning prior to the next capture slot in the afternoon. The electricity supply at the dig house could go off periodically through the evening and night so I setup batch scripts which allowed for the processing to be saved and resumed if required; fortunately, the laptop battery held out during those episodes.

2.4.4 Summary of captured features and areas

Initial capture was directed towards the eastern end of the temple enclosure wall encompassing the Sanctuary, the house of Panehsy, the building in the north-eastern wall, the House of Foreign Tribute, and the Butchers Yard. Unfortunately, there was not enough time to capture all these areas, and there were some failed captures. However good progress was made, and Figure 87 shows the areas which were successfully captured and the areas which are yet to be processed are shown as red grids. The background grid squares are at a size of 200 x 200 m. The following pages give a brief overview of the features captured during my time at Amarna.

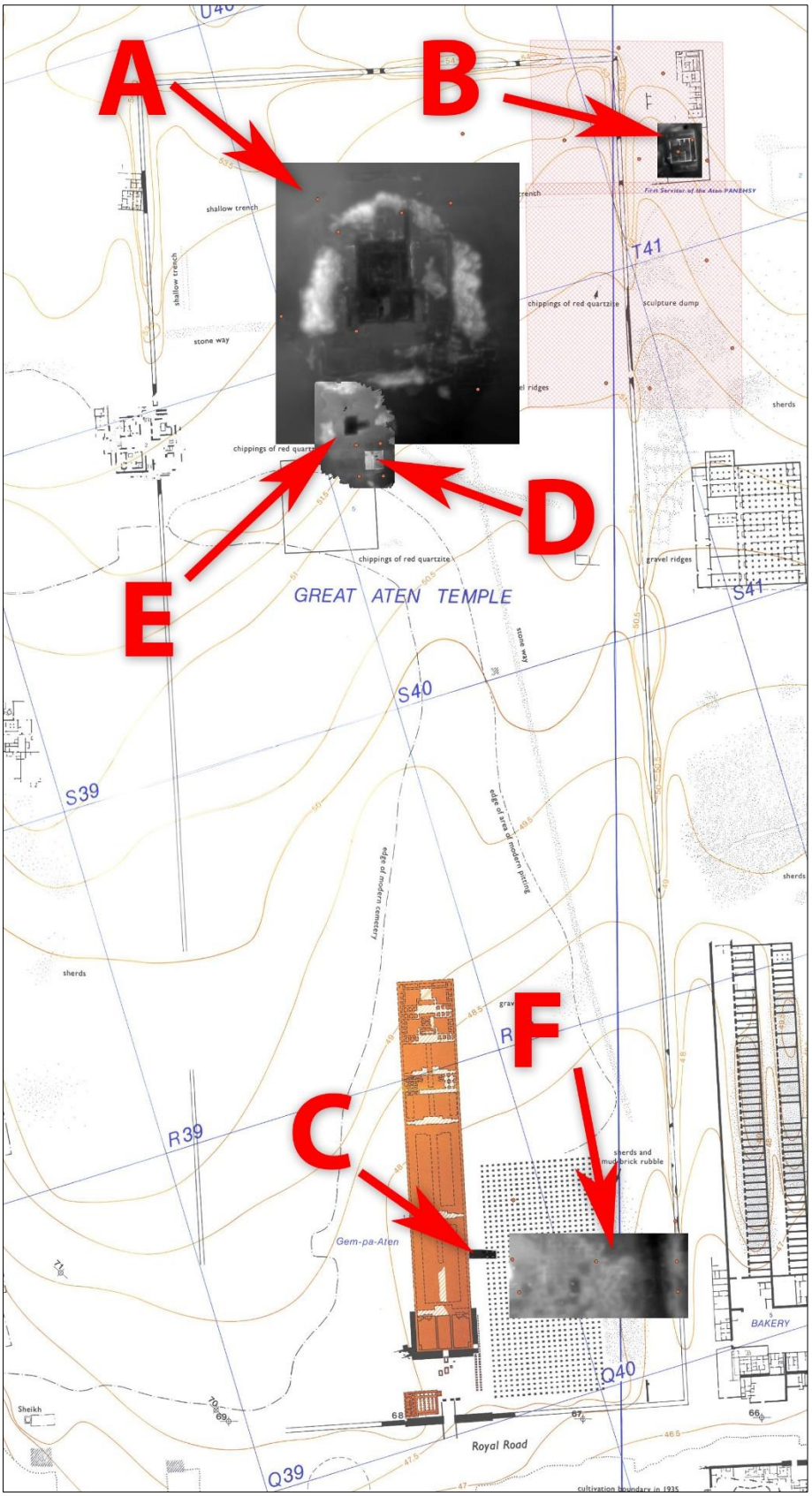


Figure 87, areas around the Great Aten Temple captured through photogrammetry; (A) the Sanctuary, (B) Panehsy's House, (C) offering tables, (D) the Butchers Yard, (E) site of the Stelae, (F) site of possible temple dump

2.4.4.1 The Sanctuary (A)

Figure 88 shows the Sanctuary model from above facing north-east, whilst Figure 90 shows the derived surface height, from the model, as a colour gradient. For an illustration of what the Sanctuary may have looked like please refer to Figure 61 in 2.3.8.

Figure 88, the Sanctuary model from above facing north-east

Figure 89, the Sanctuary model view to the west

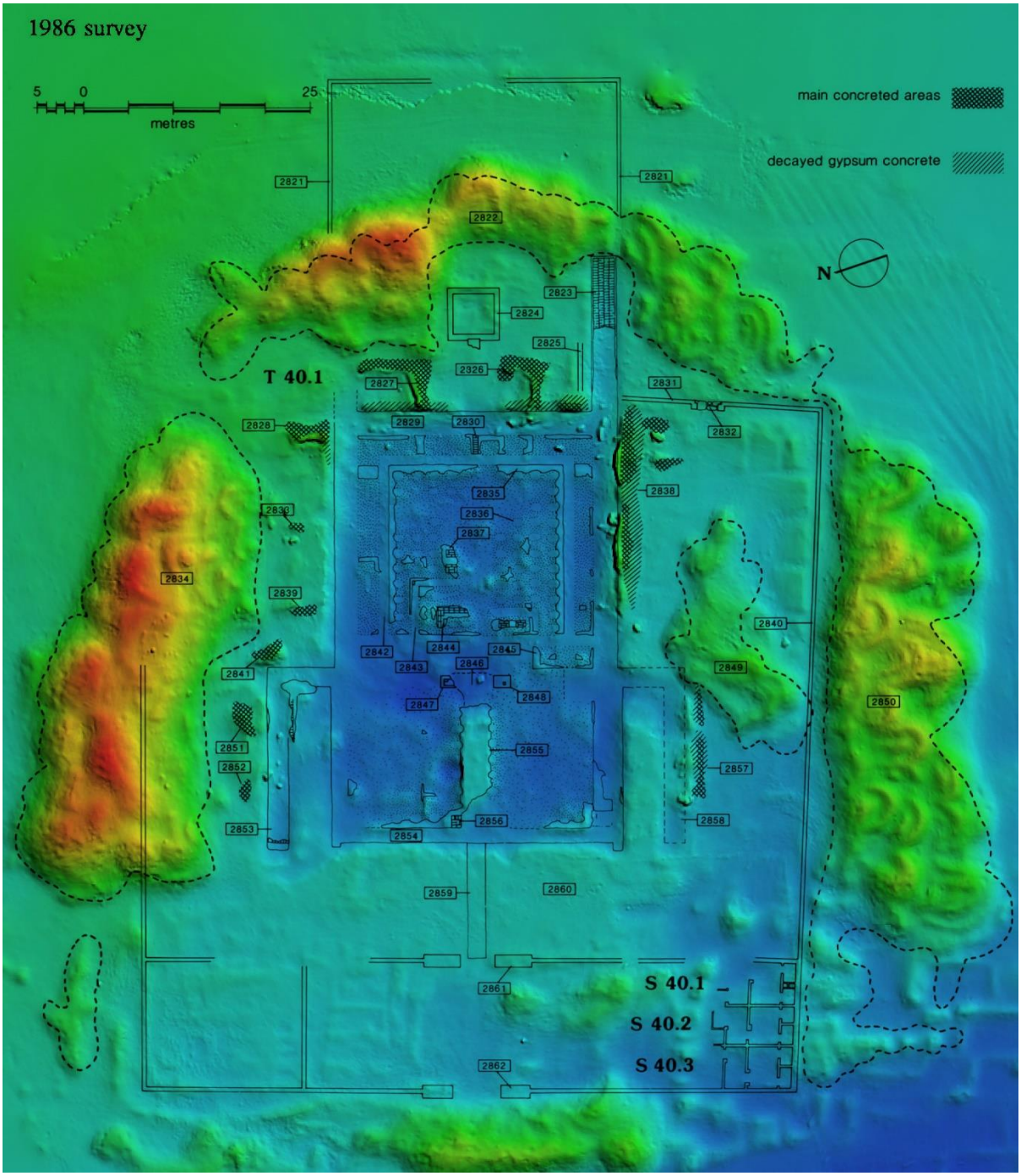


Figure 90, the Sanctuary surface height represented by colour gradient with 1986 survey overlaid

2.4.4.2 Panehsy's House (B)

Figure 93 shows the house of Panehsy looking towards the north-west whilst Figure 92 shows a side elevation looking towards the south and Figure 94 shows an orthographic top view.

Figure 91, the house of Panehsy model view towards the south

Figure 92, the house of Panehsy model side elevation view towards the south

Figure 93, the house of Panehsy model view towards the north-west

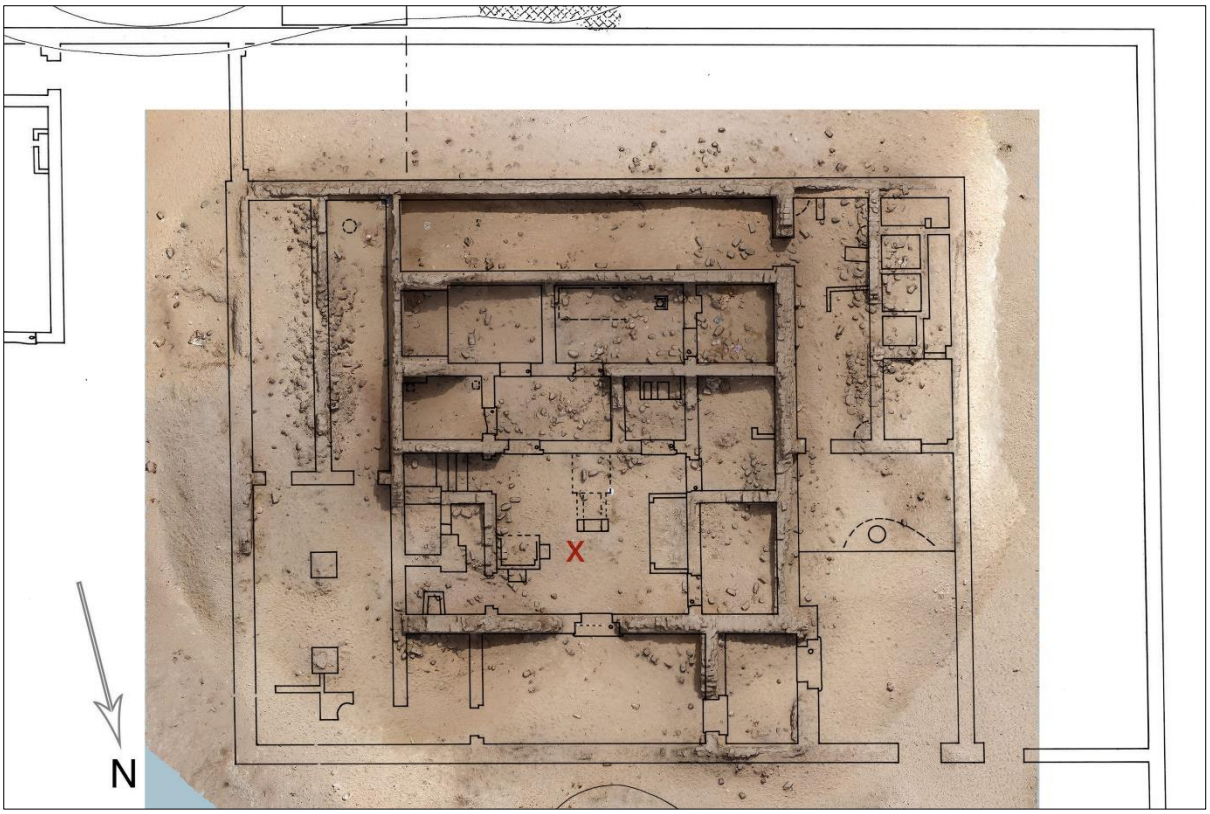


Figure 94, the house of Panehsy orthographic top view of model with 2006 plan overlaid

This capture was useful in enabling me to see the brick construction of the houses. The resulting photogrammetric model can be used for 3D assets and 3D textures, see Figure 95. This is achieved by identifying useful features and cropping the model to isolate them for later use.

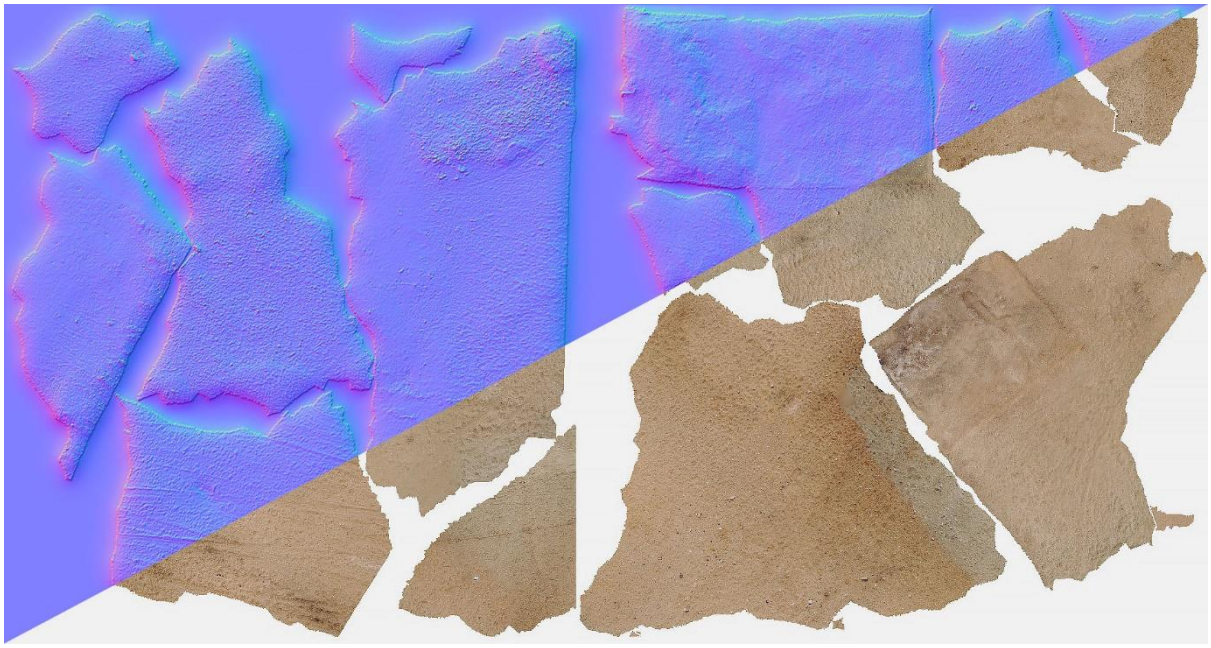


Figure 95, texture swatches derived from photogrammetry. Normal map (top) diffuse map (bottom)

2.4.4.3 Great Aten Temple Offering Tables (C)

Photogrammetry was also used to record the trench on the south of the temple wall where 4 offering tables were excavated as shown in Figure 96. A top view orthophoto was derived from the 3D model along with profiles of the trench walls. These can aid in the interpretation and subsequent illustration of the trench particularly where it is possible to remove elements of the structure for clarity. This can be seen in the profile sections in Figure 97 and Figure 98 where the offering tables have been removed digitally showing the wall strata in more detail.

Figure 96, trench with offering tables

Figure 97, section of trench looking towards the west

Figure 98, section of trench looking towards the east

2.4.4.4 The Butchers Yard (D)

After excavation was completed at the Butchers Yard, the site was also captured and the results are shown in Figure 99. Additionally, a small collection of broken pottery was captured in detail using the dSLR with the resulting model shown in Figure 100. By having a 3D model, it is possible to revisit the pottery assemblage as it was prior to excavation and so aid in later interpretation.

Figure 99, the Butchers Yard perspective view towards the north-east

Figure 100, pottery assemblage from the Butchers Yard

2.4.4.5 Juvenile Skeleton

During excavation of the northern wall of the first court of the temple the remains of a juvenile were found. This was also captured for 3D reconstruction with the dSLR being used in this instance to record the remains in more detail. Figure 101 and Figure 102 show a perspective and side view of the skeleton prior to removal.

Figure 101, juvenile skeleton perspective view

Figure 102, juvenile skeleton orthographic side view

2.4.4.6 The North Tombs

A visit to the Northern Tombs offered an opportunity to capture the inside of the tombs belonging to Panehsy and Meryra. Internal photogrammetry relies heavily on good lighting and without an appropriate lighting rig the images will normally have additional noise and colour casts that will impact the quality of the 3D reconstructions. The Osmo Pocket was used to capture the outer chambers of both tombs and coped extremely well with the reduced lighting. The pole mount was utilised where appropriate to maintain a regular distance from the wall surfaces and achieve the necessary height.

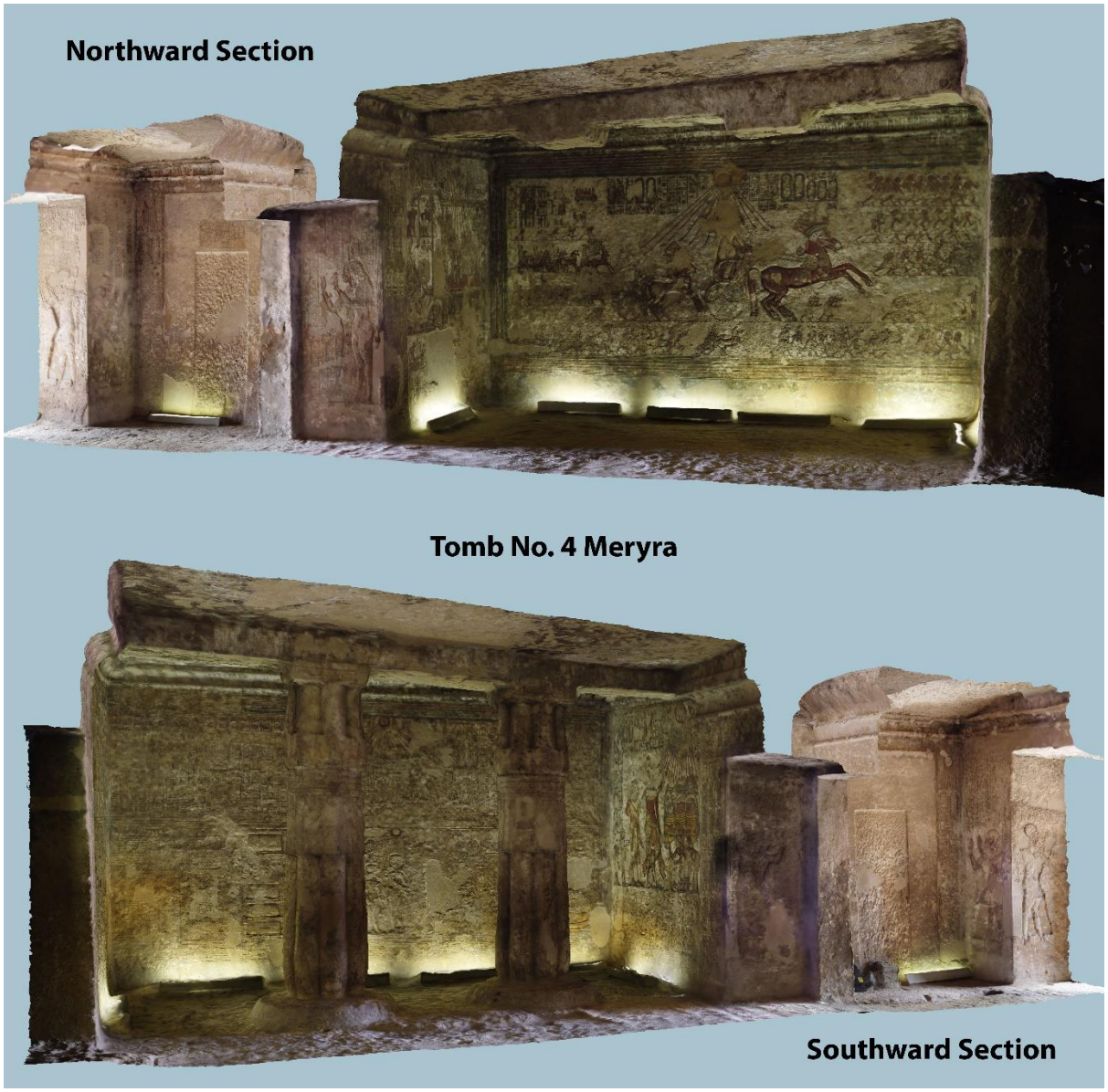


Figure 103, photogrammetric reconstruction of tomb no.4 belonging to Meryra

Figure 103 shows a half section of the tomb in 3D. Figure 104 shows a cropped corner of the tomb with the western wall highlighted and presenting the wall surface relief in 3D detail. Figure 105 shows

the western wall painting with the nearby column removed for clarity and simple colour enhancement to indicate what may be possible given better lighting conditions.

Figure 104, cropped corner of the tomb with the western wall highlighted and presenting the wall surface relief in 3D detail

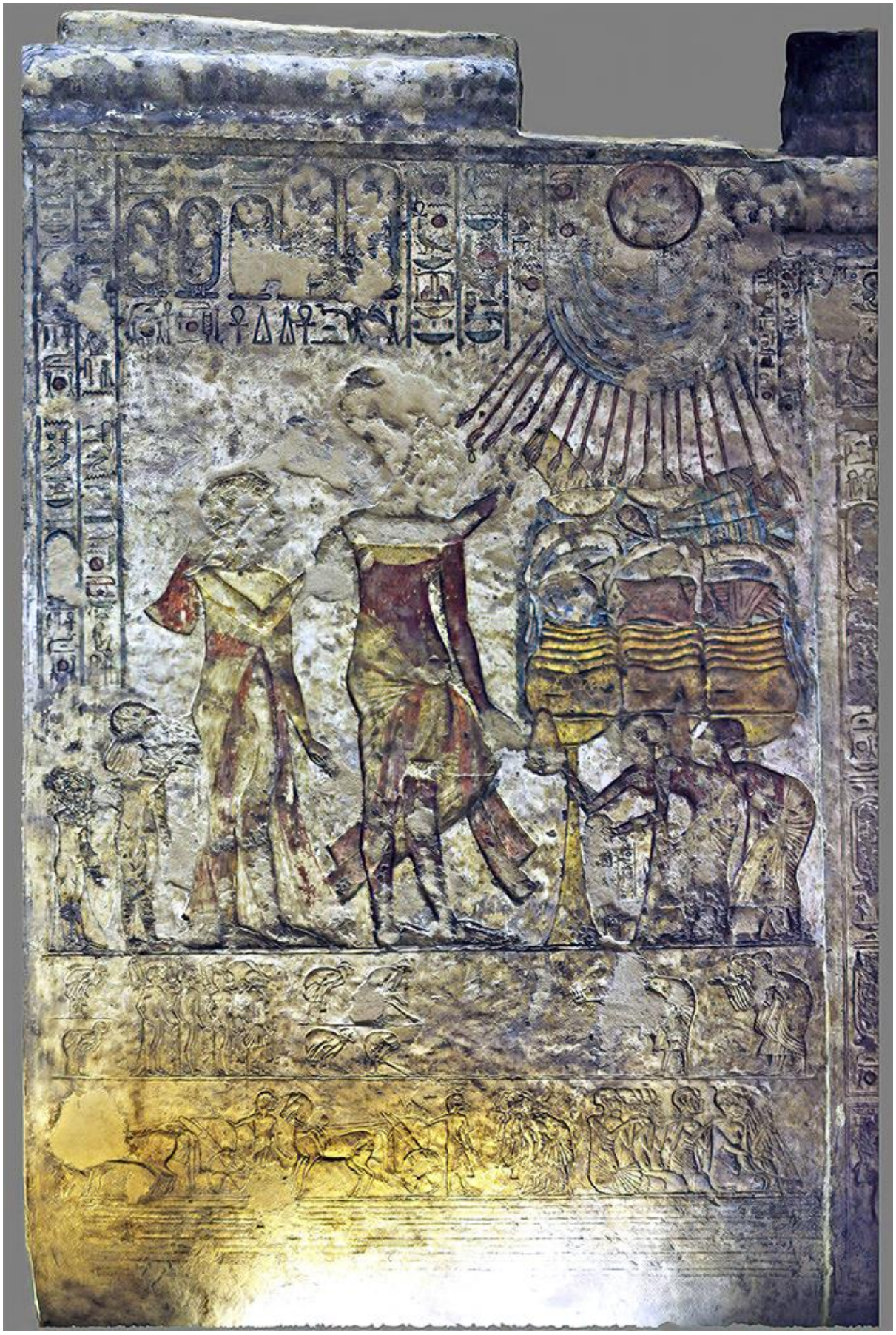


Figure 105, orthographic model view of the western wall painting with column removed to aid clarity

Figure 106, photogrammetric reconstruction of tomb no.6 belonging to Panehsy

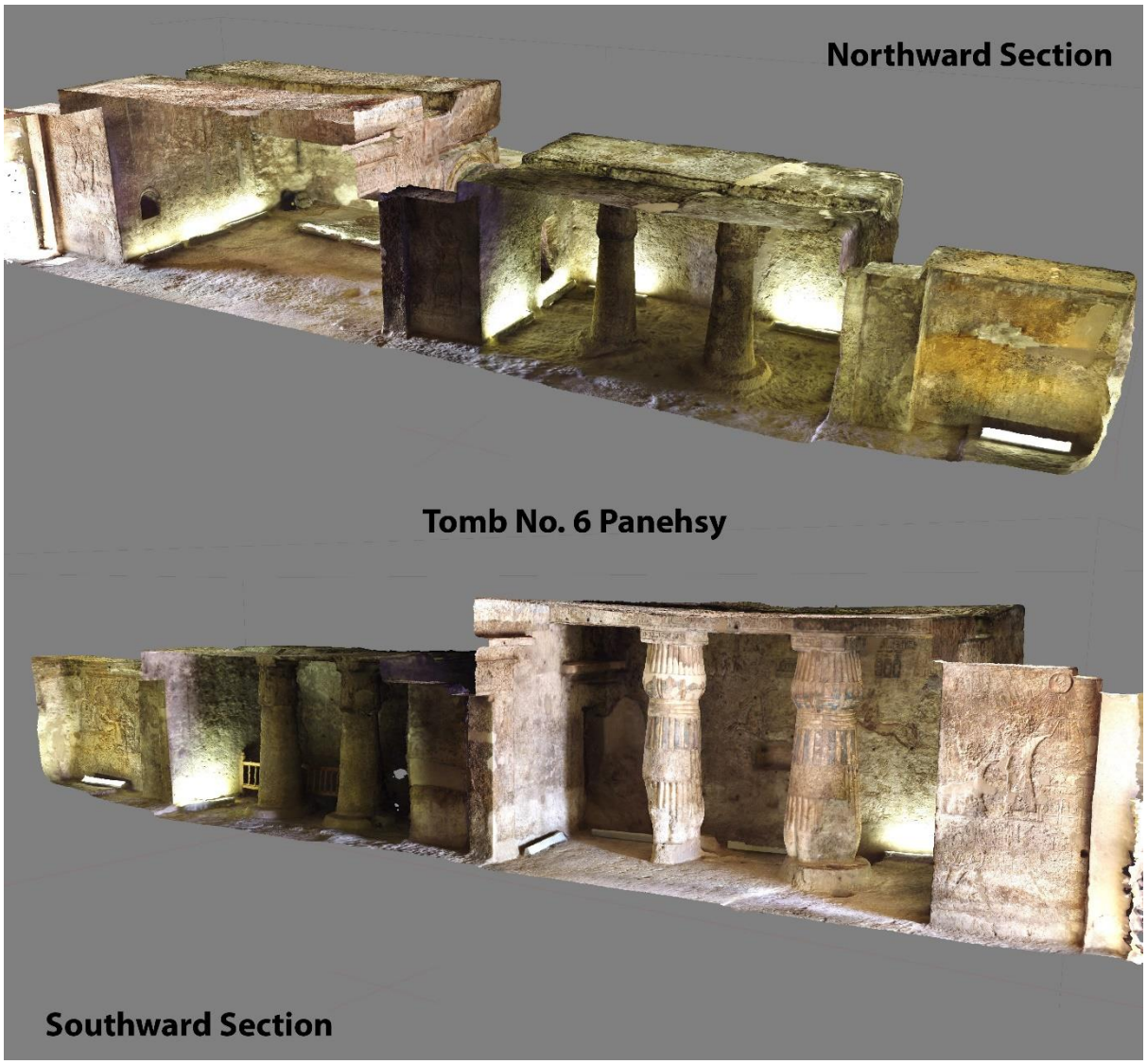


Figure 107, photogrammetric reconstruction of tomb no.6 belonging to Panehsy

2.4.4.7 The Amarna House

The house identified for tourists as 'the Amarna House' (Q44.1) is located near to the south side of the Small Aten Temple. It has been preserved as a show house and includes a raised observation platform from which visitors can look down into the structure. I made a quick capture of the house and was planning a more detailed capture to be used later for material creation towards the end of my planned time at Amarna. Unfortunately, circumstances prevented this from happening, although the initial 3D model results can be seen in Figure 108.

Figure 108, photogrammetric reconstruction of the Amarna Observation House

Photogrammetry is an extremely useful and cost-effective tool for capturing and archiving not only artefacts but sites and features. Its use extends to the capture of assets which can be implemented later within a larger 3D reconstruction.

2.4.5 Environment

As can be expected in a desert setting the sand builds up if not checked. The dig house was swept and wiped down daily, a chore which would have changed little since antiquity. The air is mostly dry, and smells were very minimal. Nights were very cold; days were hot but tolerable. The season was moving into spring so not typical of the rest of the year. Appendix 7.3 shows the average temperatures and rainfall at Amarna. There is a prevailing north wind which many of the larger estates took into consideration when orienting their houses. Evidence can be seen in the positioning of the outer reception room (sometimes referred to as loggia by the excavators) and the bedroom of the head of house, where the vent in the ceiling would be constructed to shelter from the wind where possible.

2.4.6 Campfire Stories

On the evenings after the meal members of the team would either sit in the courtyard area around a small firepit or go up to the roof to a seating area which looked out over the cityscape. This was an ideal setting for them to chat about previous experiences at Amarna and tell stories about what it must have been like to live at Amarna during the time of Akhenaten. I made note of some of these to see if they could be combined to form larger narratives.

The Amarna Period features stories of the birth of monotheism and attempts to link Akhenaton with Moses. The many ideas surrounding the death of Tutankhamun and who the mysterious Smenkhkare was. There is the curious story of the Egyptian Queen who wrote to the Hittite King asking to marry one of his sons; was it Ankhesenamon the widow of Tutankhamun or Nefertiti the mother of Tutankhamun? The offer was accepted only to find the Hittite Prince ambushed and murdered on route to Egypt. Whilst these stories were fascinating and full of drama, they are too high level to be developed into interactive stories. I was looking for a more personal level revolving around daily life and how the archaeology had helped to realize them.

During the previous 200 years of excavation there have been many individuals identified as living in Amarna in antiquity, see appendix 7.4. Some of these have been located to specific houses within the city by the inscriptions on door jambs and lintels. These also indicate the occupations of the individuals such as the vizier Nakht, chief builder Maanakhtuef, chariotry officer *Ranefer*, chief of seers of the Aten Pawah, sculptor Thutmose, army general Ramose, first servitor of the Aten Panehsy and chief of works Hatiay (Kemp 2012, 268). Stories could be developed for each of these individuals through the finds excavated from their estates and what is known historically about their occupations. However, the evening conversations were relaxed and did not involve digging through a database of finds for stories. Sitting on the rooftop meant we could look out over the city and point out locations and chat about interesting events that may have taken place there. Some conversations revolved around the city layout and several boundary issues which question whether laws or rules were in place regarding plot ownership during the growth of the city.

In the North Suburb a few large houses picked plots on two sides of a rectangle (T36.10, T36.5, and T36.21). They may have had family or financial connections with each other as their houses were constructed at the same time. But a delay in construction meant that the land they had claimed was built on by smaller village housing (Kemp 2012, 168). There may have been a scramble for large plots as some of the larger houses are packed together. With the North Suburbs identified as a merchant's quarter the nearby location of a large wadi could indicate a transportation link suggesting this may have been a desirable area for merchants and associated workers.

A similar boundary issue occurred in the north of the Main City. The owner of Q47.1, a large house was intending to create a long-walled estate with an additional walled garden and pylons facing out onto the street. He was constructing a chapel on the side of a large well or sunken garden but at some point, a delay gave rise to an opportunity for others to cut into his planned residential grounds and construct several small houses. These boundary issues raise some interesting questions which in turn could be used in forming a story narrative. Were there periodic shortages of construction supplies? Was it financial? Was there a death halting construction? Was the owner too greedy? Was there a change in ownership? Was there any real plan for city development? The discovery of marker stones at the house of *Ranefer* (N49.18) indicates that there was some form of planning in place and that some individual was responsible for it, with mixed success based on all the plot incursions! (Kemp and Stevens 2010)

Ranefer, a chariot officer, built his house over an existing one (N49.58). We know when it was constructed as the door jamb includes the name of Ankhkeperure Nefernefruaten (Smenkhkare) the pharaoh after Akhenaten. It is difficult to determine if *Ranefer* owned both houses and was in the process of upgrading the original. He may have inherited the earlier one or simply purchased it from the previous owner. The interesting fact about this is that the city was still evolving, showing no sign at that moment of a decline.

Further conversations lead to Barry Kemp sharing a short story he had developed based on archaeological evidence and generations of research built up not only from Amarna but Egypt during this period. The story is based around the family and dependants of *Ranefer* and was originally created to accompany displays within the Amarna Visitors Centre at Amarna. Within this story there is mention of glass bead manufacture and fortunately one of the team members, Dr Anna Hodgkinson, was conducting some experiments in this which I was able to experience first-hand (Figure 109). This experience would be useful should an animated sequence of glass bead manufacture be required during the development of AmaranXR.

Figure 109, glass bead manufacture by Dr Anna Hodgkinson at Amarna March 2020

This chapter has explored a range of resources which can be used to develop an interactive model of Amarna for storytelling purposes i.e., AmarnaXR. However there have been other digital models of Amarna namely the authors own reconstruction entitled Amarna3D (Docherty 2020).

The Amarna3D digital model has been in existence since 2000. The initial build took place over a period of 3 months totalling around 600 hours of actual construction time resulting in a 3D model constructed from 4.5 million polygons: a significant size at that time. Since then, it has grown in both size and complexity, with the model having been repurposed several times. The model has undergone many modifications throughout its lifetime but has reached a point where it would need a complete rebuild to be used as a modern interactive platform for storytelling.

The following chapter is a review of the working life of the Amarna3D model from its initial conception, initially unrelated to the heritage sector, through to its present state, highlighting the various roles it has played during this time. The development of the Amarna3D model has, however, presented a series of experiential challenges which will be used to inform the development of a new series of 3D model assets for inclusion within AmarnaXR.

3 Amarna3D

The Amarna3D Project (Docherty 2020) is a long term 3D reconstruction project which began in 1999 and has grown and changed significantly since the first model was built. In much the same way a real-world city can never be regarded as finished the Amarna3D model, as conceived, has never fully been completed, existing as a digital landscape under regular development. The Central City area, as presented within this thesis, is the only large-scale region of the model developed to a point where it has been used for historical visualisation (Bernstein 2005; Cassel 2006; Chu 2016; Docherty 2003, 2004; Hurley and Murray 2018; Rotger and Gonzalvez 2010; Stubberfield 2014; UDIMA 2016). Smaller, isolated areas have been constructed but remain unpublished. Early versions of the city included models of the inhabitants albeit at a reduced detail, later visualisations do not include any life resulting in an abandoned feel to the city. The digital file structure used in its creation includes "updates, patches, bug fixes, mods, and expansions" which according to Reinhard present evidence of past human activity making it an archaeological site in its own right (Reinhard 2018, 91). One update to the Amarna3D model has also been used to visualise the real-world construction of the Great Aten Temple entrance (Kemp 2018, 2019a; Barry Kemp et al. 2020). The visualisation worked through the layout of the brickwork which informed the physical construction see Figure 110.

Figure 110, the Great Aten Temple entrance construction; physical (left) virtual (right)

The visual style for the Amarna3D Project has changed over the years beginning with an idealised soft-focus look - a style which is too clean (Kemp 2012, 72) - through to a more physical material-based look. The model had a brief representation in 2003 using a glowing wireframe reminiscent of the visuals found in the 1982 TRON and 1999 Matrix movies as part of an unpublished experiment in augmented reality, see Figure 111. A version of the Matrix 'rain' was implemented using hieroglyphs which formed parts of the 'Hymn to the Aten' as inscribed on the tomb walls at Amarna. This type of unpublished work can be thought of as developer art in that its creation is only possible by the developer using the raw code and may never be seen outside the studio, being a playful by-product

of research and development. In an archaeogaming context this is analogous to material culture which may have been lost to the archaeological record.

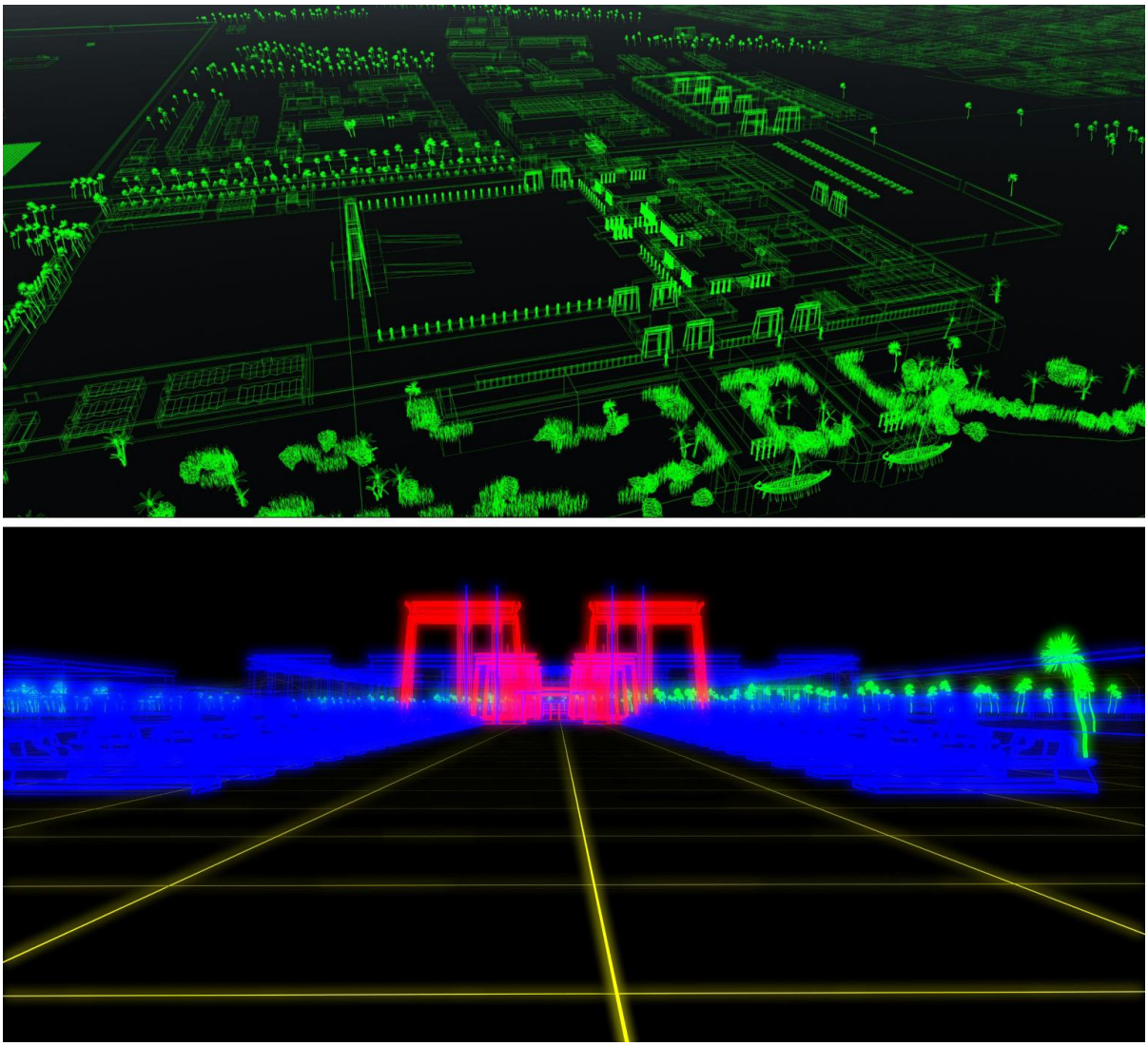


Figure 111, the Amarna3D Matrix (top) and TRON (bottom) visual style experiments

3.1 Origins

Within the computer games sector decisions surrounding the type and style of games which are green lit for production by a company are determined by several factors. Some companies will pursue a license to develop content based on a pre-existing media franchise or, if they have a successful in-house series, they may decide to continue with that until it is no longer profitable. It is common practice that games development companies encourage emerging talent within the studio with the opportunity for staff to put forward potential game ideas for consideration. It was in the spirit of this that the Amarna3D project took root.

Between 1998 and 1999 I developed an adventure game concept based around the exploits of an archaeologist / explorer in Egypt. It was deliberately designed to capitalise on the success of the Indiana Jones (first released in 1989) and Lara Croft (first released in 1996) franchises. Whilst the gameplay had to be a driving factor in the design concept, it was important to develop characters that viewers would engage with. A compelling storyline was also an essential requirement which could, if successful, lead to further serialisation. The complexities of the game concept are beyond the scope of this dissertation, but one of the main game environments centred on Amarna and this directed the initial development of the Amarna3D model as a set prototype.

Although the game concept was accepted in principle as viable, I left the game industry in January 2000 to pursue a career in academia before it could be realised. The development of the Amarna city model then became a personal art project and work began on the construction of a 3D visualisation based around the Central City area. My focus on the Central City was mainly due to the accessibility of research material at that time. The internet and search engines were still growing their datasets and had limited visual material relating to the city at Amarna. Many of the standard archival sources relevant to this project were either unknown or unavailable to me at this time; although this would change as the model progressed. The most widely available plan of the city was a modified overview (original source unknown) extracted from the Pendlebury report with an accompanying isometric sketch of the area looking across the King's bridge towards the Small Aten Temple, see Figure 112 and Figure 113.

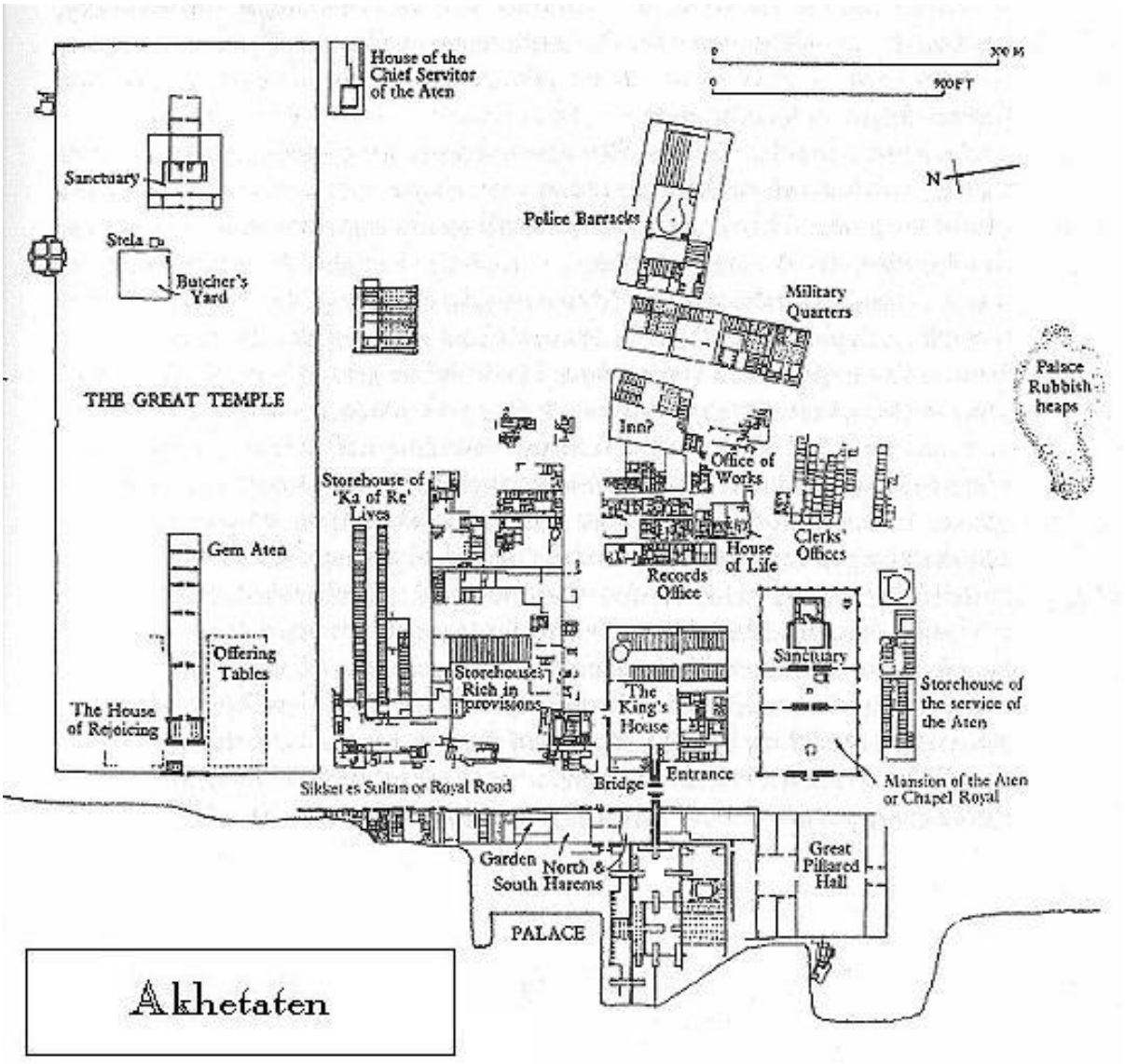


Figure 112, the original poor resolution image of the Central City plan used for the project (after Pendlebury 1951 Pl. I)

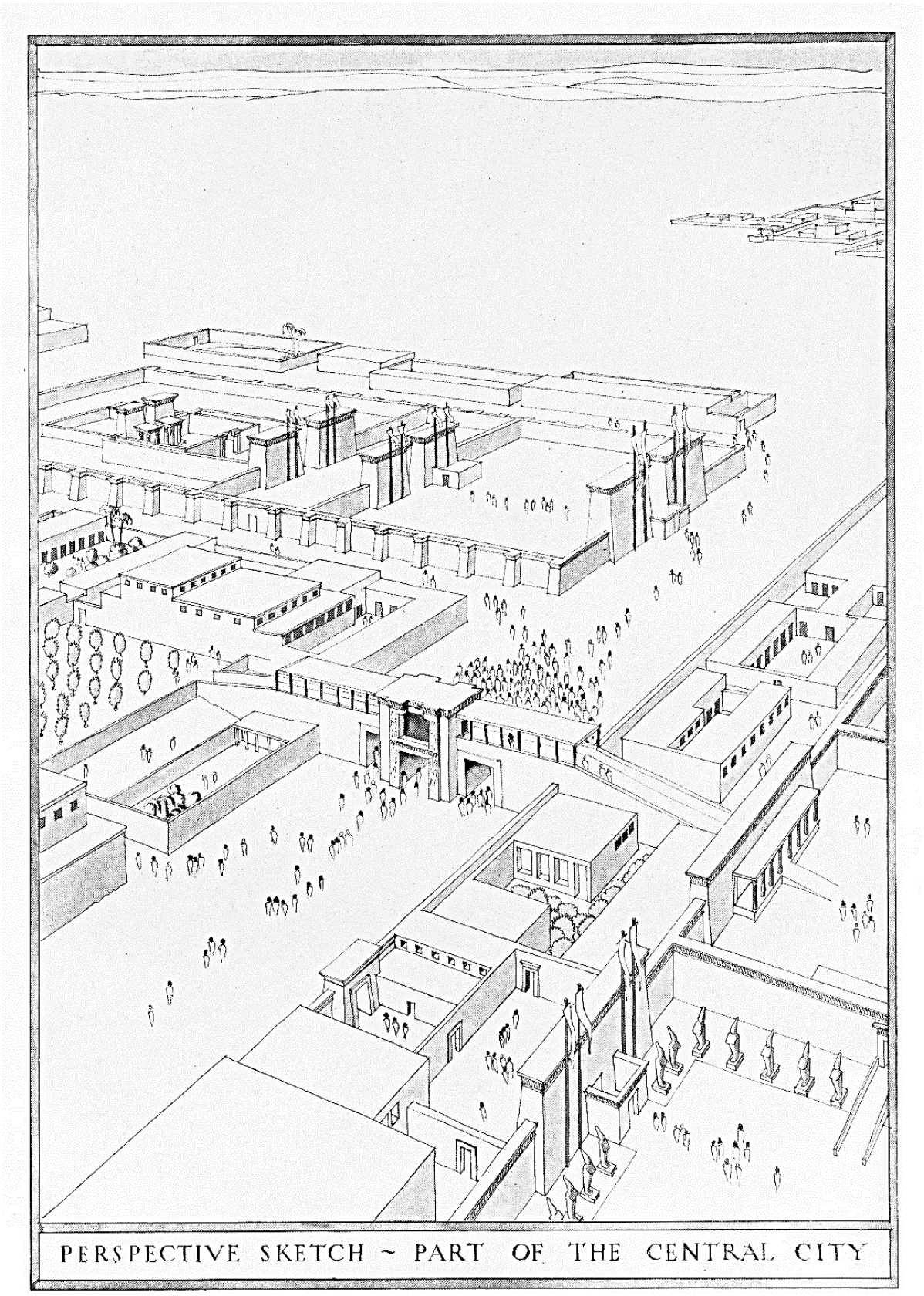


Figure 113, perspective sketch of part of the Central City (Pendlebury 1951 Pl. II)

The initial construction was time constrained to the summer period before the start of the 2000/1 academic year as I believed my teaching commitments would be too heavy to allow me to continue. However, it soon became clear that the model construction could be integrated into the delivery of the new 3D modelling modules I had developed for games, animation, and visualisation degree programmes at Teesside University. This had the advantage of extending the build time, encouraging meaningful debate around design choices with students, and the demonstration of relevant modelling techniques as the construction developed. At this point the geometric size of the model was moving away from what was then possible for implementation within a game engine and eventually pushed the focus of the model construction towards a virtual set which could be used for documentary visualisations. Where appropriate I compared real-time issues with those of pre-rendered animation sequences and demonstrated how to build for either pipeline.

Construction methods, toolsets, and supporting technologies have changed a great deal in the two decades since the initial Amarna3D model was built so before we look at a modern approach it may be helpful to review the original build process and why particular construction decisions and revisions were made over this period.

3.2 Phase 1 - Initial model construction

The Amarna3D model was constructed using Autodesk 3ds Max (3dsmax) for the 3D assets and Adobe Photoshop for the 2d textures. The hardware used was a Dell Inspiron 8000 laptop which had an Intel Pentium III processor, 256 MB RAM memory, and a Nvidia GeForce2 Go graphics card with 32 MB of video memory. It was this specification which initially set the limitations on the scale of the project.

To construct the model the image of the Central City plan derived from the EES excavations was used as a reference guide within 3dsmax allowing for the geometry to be constructed to scale. The plan was a very poor copy found on the internet at that time and as a reference image within 3dsmax it was difficult to work with. This was due to a combination of low image resolution, hardware limitations, and software issues. As an attempt to work around these problems the map was reconstructed as vector artwork and imported into 3dsmax as a spline shape for use as construction lines as shown in Figure 114. Whilst there can be a use for this technique in some modern applications, the use of image reference planes is the preferred method today.

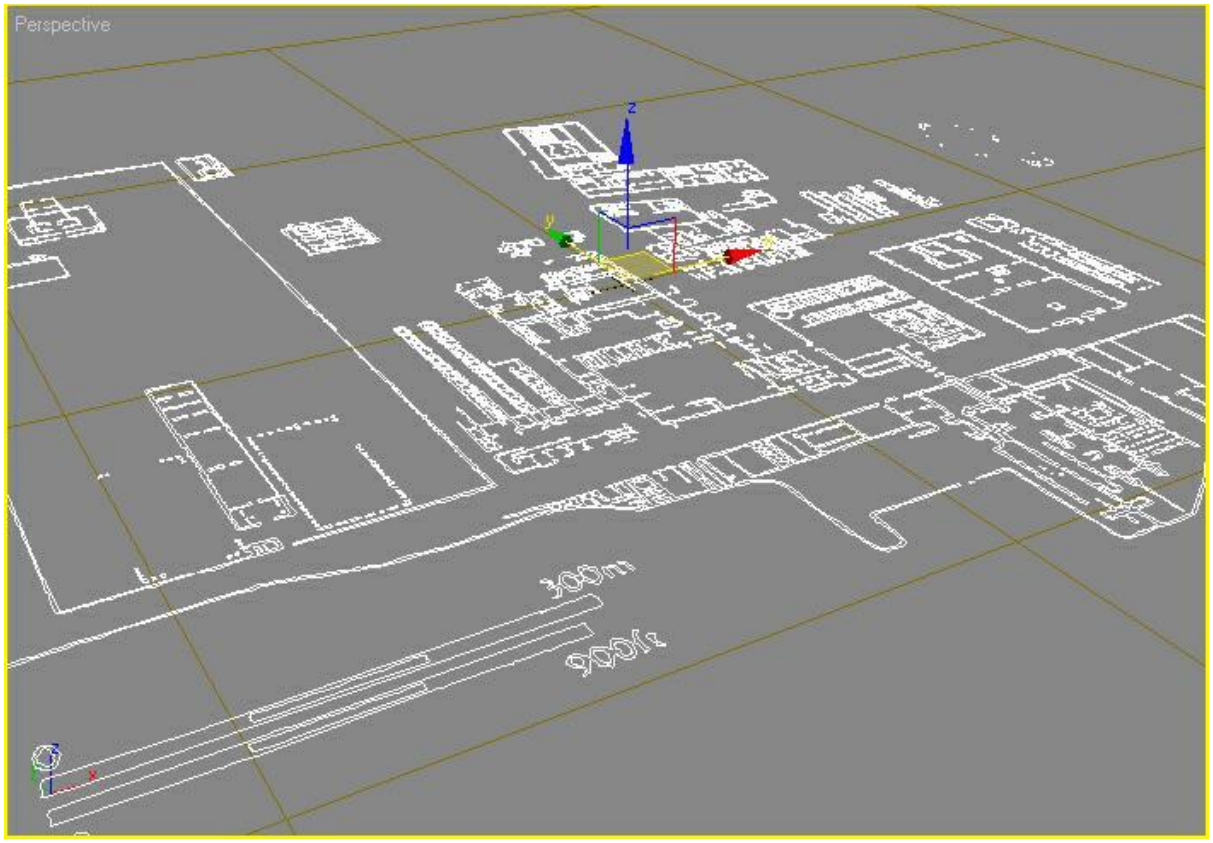


Figure 114, Central City plans imported into 3dsmax as construction guide

With the building layout scaled correctly to meters within 3dsmax the next stage was to gain an understanding of the various building heights. As a quick visual reference boxes with a height of 1.7m, representing an average human height, were placed around the environment. The use of a humanoid model is now very much a standard practice when doing an initial 'block out' of an area. To assist in understanding the building heights and volumes direct reference was made to the excavator's perspective sketch of the Central City. In September 2000, the official Amarna Project website, dealing with the history and archaeology of the site, went live and utilised photographs of the Boston model to assist in describing the city's architecture and layout (Kemp 2000). The photographs of the Boston model greatly influenced the development of the digital model, particularly when gaining clarity on building layouts and heights.

The first building created was the King's Bridge (see Figure 115) and the plan was to build outwards from this point. A box-modelling technique was utilised at first for the construction of the bridge. Appendix 7.1 gives an example of box-modelling used to construct an Amarna house. This method begins with a primitive box which is converted into an editable object and the faces are cut and extruded to form the required shape. The roof supports for the bridge were simple cylinder primitive objects arranged and attached to the main bridge construction.

Figure 115, the 'King's Bridge', the first building to be constructed

At this stage all model construction was deliberately kept to a low polygon count for several reasons. Initially, I wanted to block out the city quickly as project time was limited. By blocking out an environment it would also be possible to render perspective images of the layout to be used as backgrounds for over-sketching in Adobe Photoshop; should the project be relegated to 2D visualisation artwork. The use of blocking out minimises processing overheads during the initial construction and allows for rapid corrections to be made in layout and general structural volume, see Figure 116. Low polygon structures can later be swapped out for more detailed versions as the project evolves; a process which has continued with the Amarna3D model to the present.

Much of the initial modelling was done by modifying primitive objects, however the more complicated structures such as enclosure walls were constructed by spline extrusion. For this method, the floor layout is drawn out as a closed spline shape and extruded upwards with the software automatically capping the top and bottom resulting in a solid model. Once the full layout had been blocked out each area was refined with additional detail. This included for example, chamfering edges, adding torus moulding, coving, lintels, doors, and columns.

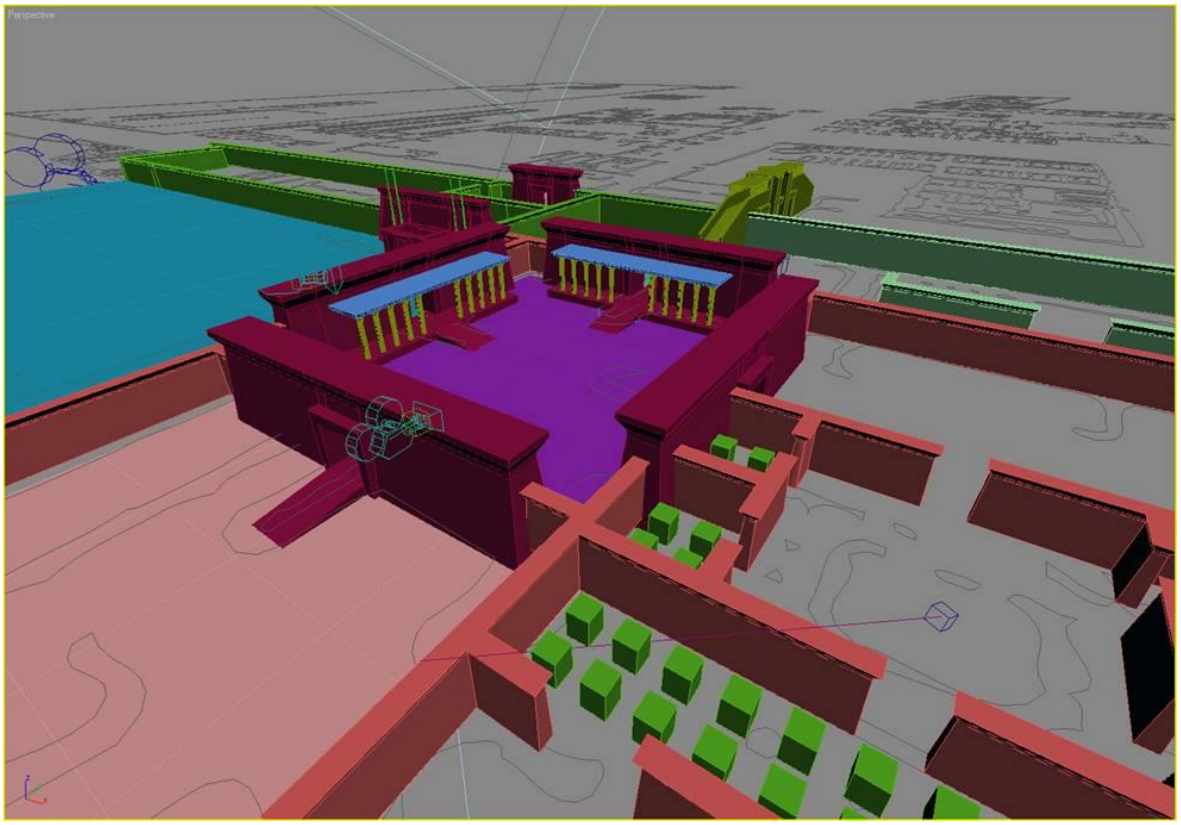


Figure 116, initial blocking out of the Central City area with low polygon models

Once the overall layout of the city was complete it was time to work on the landscape by implementing a ground layer with scattered vegetation in the form of trees, reeds, and grass. The landscape was initially constructed using spline shapes and a combination of cross section and contour modifiers to generate a solid riverbank which dipped under a large plane representing the River Nile. In referencing the Boston model there were two quays which stretched towards the river. These were built and supplemented with a scattering of rocks and clumps of reeds. The rocks were constructed by applying a noise modifier to a sphere and then distributing them randomly along the waterfront using the scatter tool with variations in scale and rotation. The same scatter routine was implemented with the trees with the excess being manually edited afterwards. Grass was initially applied as a hair modifier but due to the primitive nature of its implementation at that time, and with the result only viewable as a post render effect, it was removed from the model. The inclusion of post render effects meant that there would never be an option to make the model real-time viewable and increased the render time per frame dramatically. Testing the hair effect as grass can be seen in Figure 117 before it was removed.

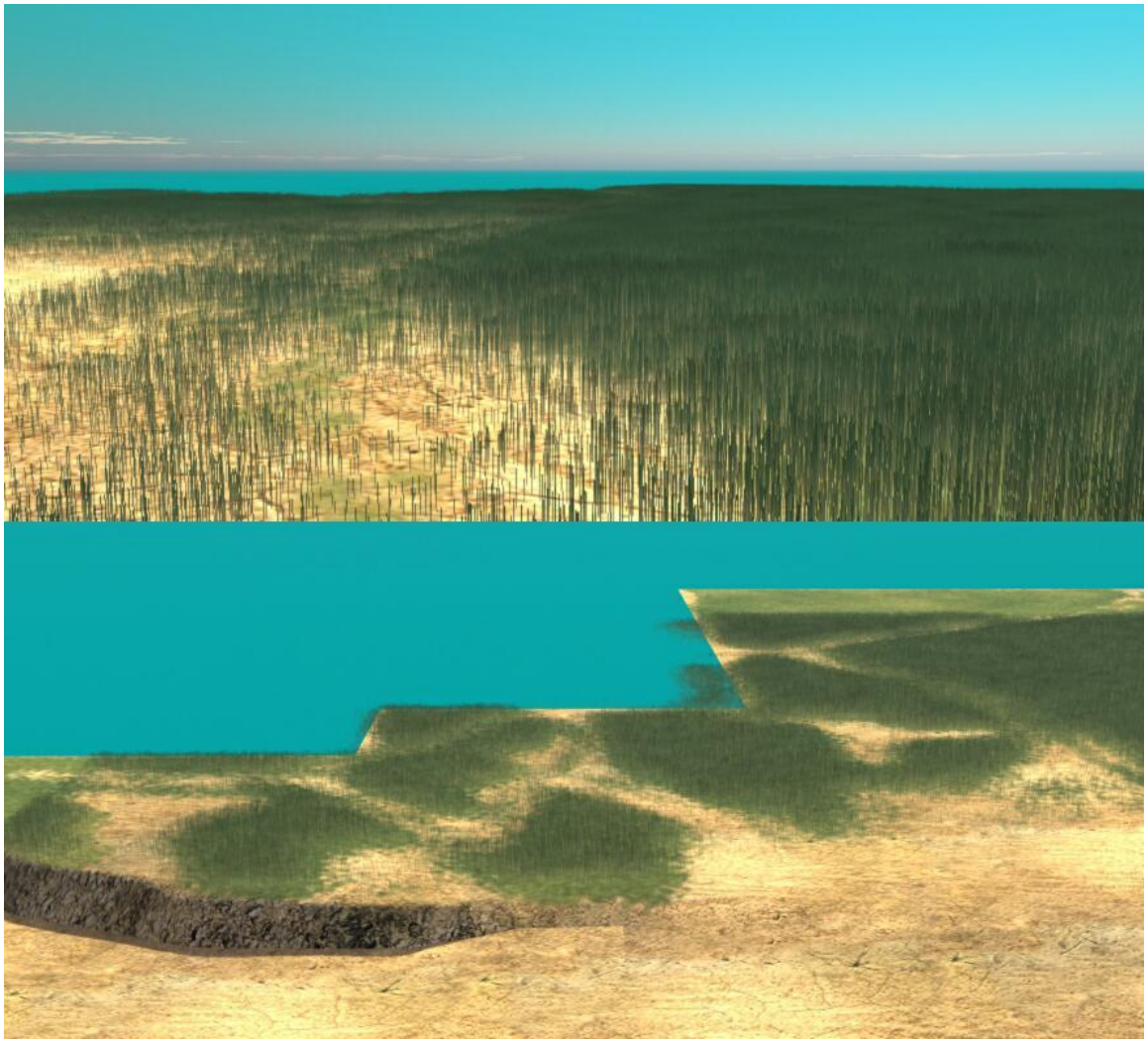


Figure 117, implementing grass through the hair post render process

One of the last construction stages regarding the initial Amarna3D model iteration was to develop a suburban area surrounding the Central City giving the illusion of daily life outside the religious and administrative structures. The housing was created using a plane with an edge grid layout that resembled street patterns, with each edge bevelled upwards to create a range of walls. The polygon areas within the wall boundaries were selected for the target distribution of cubes using the scatter tool once more. By adding variations in scale, I was able to generate the approximation of housing with a directional alignment (Figure 118) and basic texture maps applied to represent detail (Figure 119). Without additional survey maps for reference the results were an effective representation from a distance but would not hold up to close-up scrutiny; the nature of their layout and construction approximating the actual site.

The suburban block was then duplicated and positioned around the Central City for effect with some distortion and mirroring applied to prevent repeating areas as best as possible (Figure 120).

Figure 118, scattered cubes representing suburban housing

Figure 119, scattered cubes with basic texture maps applied

Figure 120, duplicated suburban areas arranged around the Central City

To complete the construction at this stage a few complex models were needed. The first was a statue of the pharaoh which could be distributed around the city. With Akhenaten having such a unique representation there was a requirement to construct a unique model however due to time constraints a compromise had to be made. Fortunately, I had worked on an Egyptian game level some years prior and decided to reuse one of my old models until such a time as it could be swapped out with a more accurate version (see Figure 121).

Figure 121, Pharaonic statues [mis]representing Akhenaten

With the Royal Quayside and the River Nile both prominent features of the model it was also essential that I had some form of shipping present. By using reference photographs taken of boat models discovered in the tomb of Tutankhamun I was able to construct a simple model (Figure 122) which could be varied in shape and size for use within the project. The construction method used a spline cage, where a series of splines are created representing cross sections of the hull and additional splines are used to connect these cross sections together. Once this has been achieved a surface modifier is applied to the spline cage resulting in a solid surface which can be further refined using standard polygon editing tools. The mast was a primitive cylinder, and the oars were cylinders converted to editable polygon meshes with the ends flattened and scaled to create paddles. Two sails were created from edited planes with one being unfurled and the other rolled for variation. The finishing touch was to add rope rigging by drawing with splines and converting them to renderable objects. The results of the final city model prior to texturing is shown in wireframe within the 3dsmax interface in Figure 123.

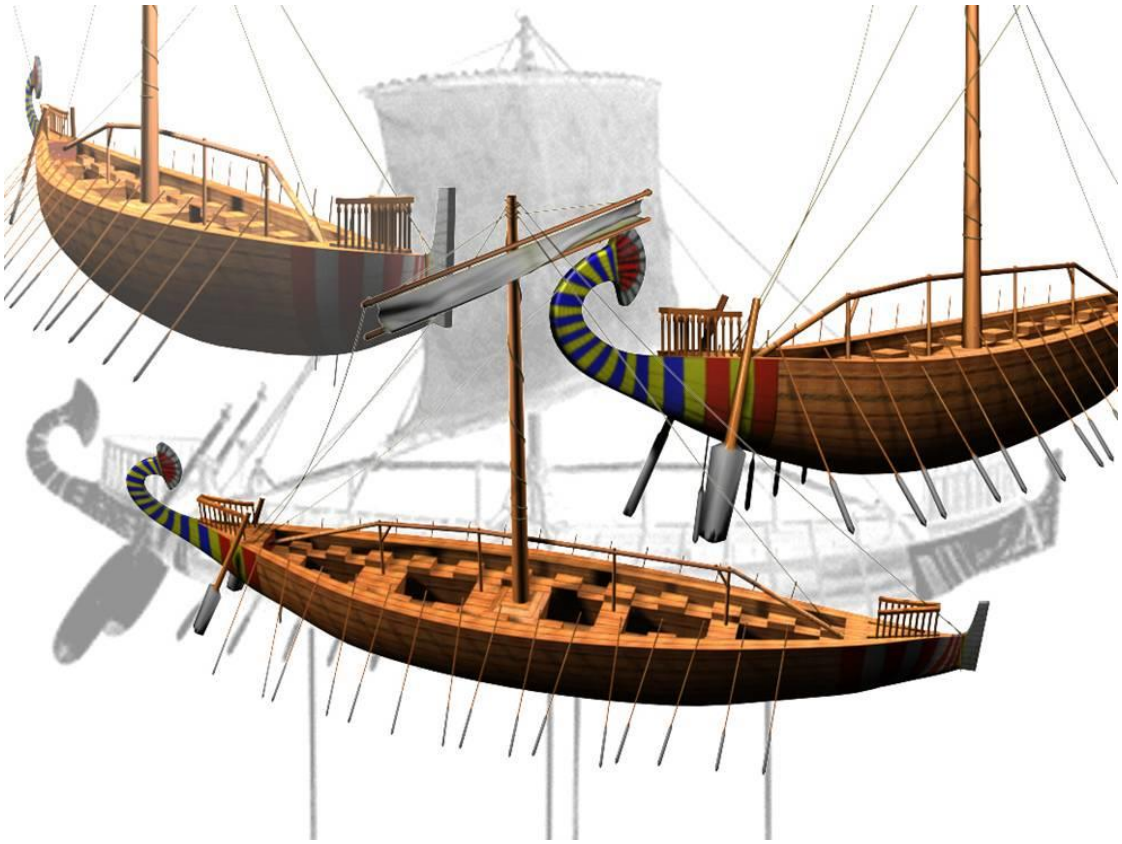


Figure 122, spline cage boat model based on the one discovered in the tomb of Tutankhamun (pictured in the background)

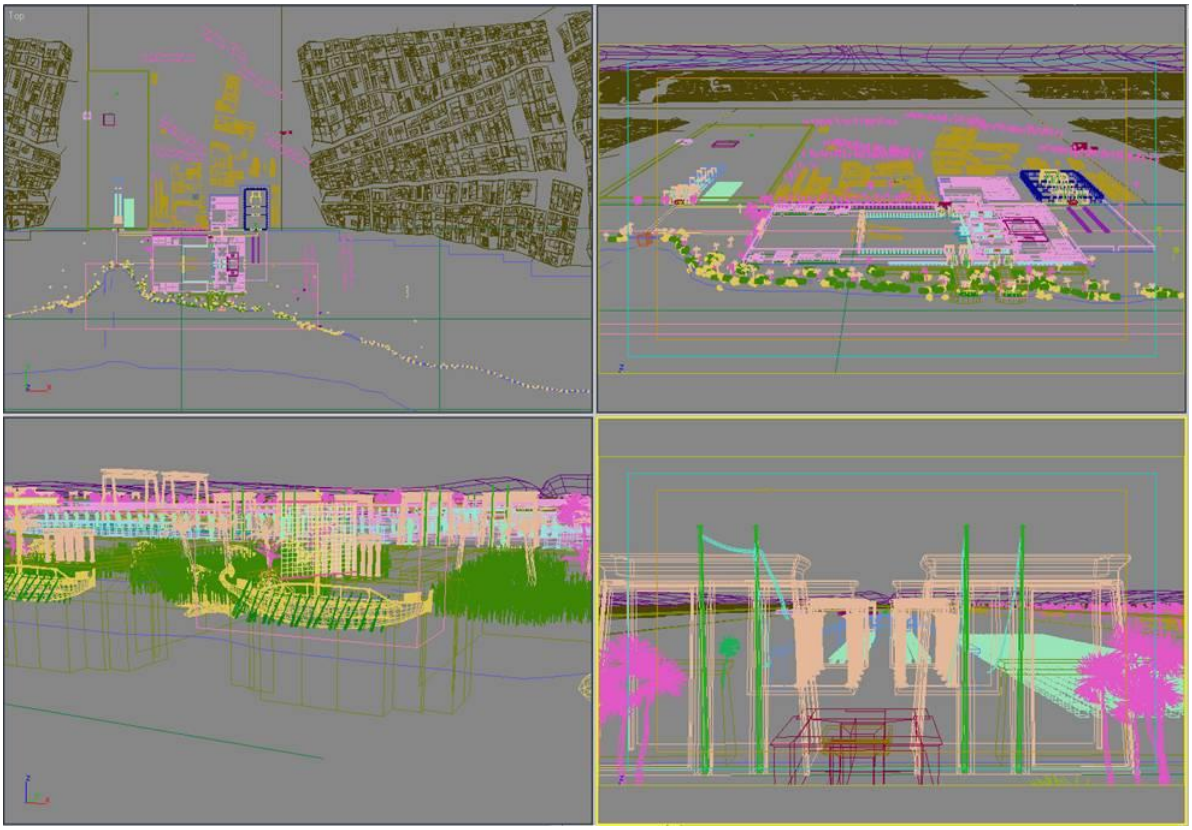


Figure 123, the complete initial build of the Amarna3D model within 3dsmax

3.2.1 Materials

Creating materials for 3D models is a time-consuming process and as a rough guide will certainly equal the time taken to build the associated 3D model, if not longer. In its most basic form, material construction is the process of wrapping the surface of a model with an image (texture map) representing both the physical material and any finer details not already present in the model geometry. The physical material properties include colour and glossiness, and the finer detail could be anything from wood grain to rivets; with some textures representing major features like windows.

Material construction has changed significantly over the last two decades, but the texture maps used still fall into two types: bitmap and procedural. A bitmap is a single image which has either been painted by hand or edited from photographic resource. Bitmaps are fixed at a specific resolution and allow the associated model to be translated from one 3D platform to another whilst maintaining visual integrity. Procedural textures are based on algorithms and are resolution independent offering the opportunity to construct more complex materials. The main drawback to procedural textures is the dependence on the parent development software, 3dsmax in this case, to provide the rendered output, which rarely maintains visual integrity when viewed across multiple 3D platforms.

By moving away from the development of a real-time model I opted to work with a combination of bitmap and procedural textures to speed up the completion of the project. The difficulty with texturing Amarna was that there was little of the physical city remaining to provide adequate reference. In addition, the artistic style of the Amarna period had deviated from the traditional ancient Egyptian style and I was aware that any representation of hieroglyphs would need to be based around the worship of the Aten and not the wider Egyptian gods. Because of this I kept the representations very simplistic and for the most part utilised hieroglyphic text taken from the 'Hymn to the Aten' with some taken from the Description de l'Egypte (Figure 124). A few years later I decided to remove much of the textures and move towards a physical based material approach focusing on representing the construction materials as real-world surfaces without hieroglyphs.

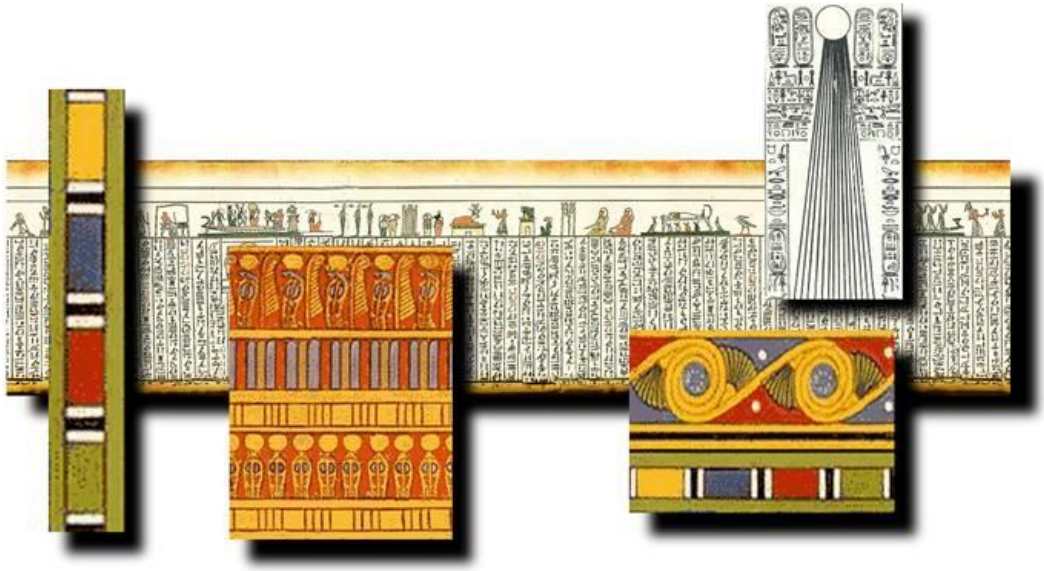


Figure 124, a selection of images used as texture maps within the initial city build

The landscape material needed care in its construction as it had to stand up to relatively close inspection, so could not be pixelated from a ground perspective, and be viewed from above without noticeable tiling artefacts appearing. In addition, I wanted to represent the general dirt-based nature of a city and the movement of people in the form of tracks. To achieve this, I developed a layered material which combined a tiled ground detail with a large-scale procedural noise to hide any noticeable repeats. This was further combined with a dirt map and a sandy material for tracks, both of which would be blended with the initial material using a mask (Figure 125). The original masking method utilised vertex painting where each vertex within a mesh can hold a grey or colour value painted through the viewport using simple brush tools. This method requires a mesh to have enough vertices distributed evenly throughout to provide the required detail for a mask which in the case of

the Amarna model was not an option. The results of the initial test can be seen in Figure 126. The alternative method was to use a large grayscale bitmap and paint the dirt areas and track positions as shown in Figure 127.

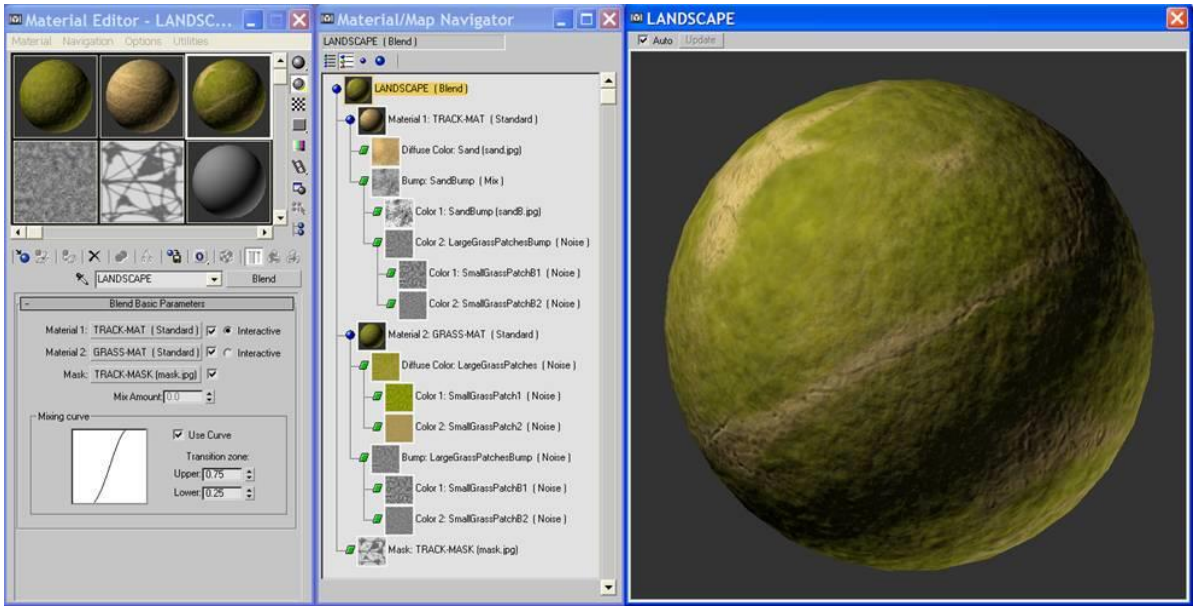


Figure 125, the landscape material

Figure 126, masking through vertex painting

Figure 127, masking through raster bitmap

3.2.2 Lighting

To complete the initial scene the environment was lit using a sky dome process to give the illusion of bounced light as global illumination and final gathering methods were not well implemented at that time. This involved the creation of an inverted hemisphere which had a high-resolution image of a sky mapped onto its surface and given a self-illumination value to ensure it was not in shadow. A maxscript was written to place omni lights on each vertex of the hemisphere and sample the colour of the sky material at that point. Figure 128 shows a test scene for the sky dome rig and Figure 129 shows three skies created in Bryce (Daz 3D 2005) representing different times of day used within the project. The script could be run for different sky textures to update the scene lighting in a similar fashion to modern image-based lighting. A directional light was also setup to represent the sun position and colour in the sky texture to produce scene shadows.

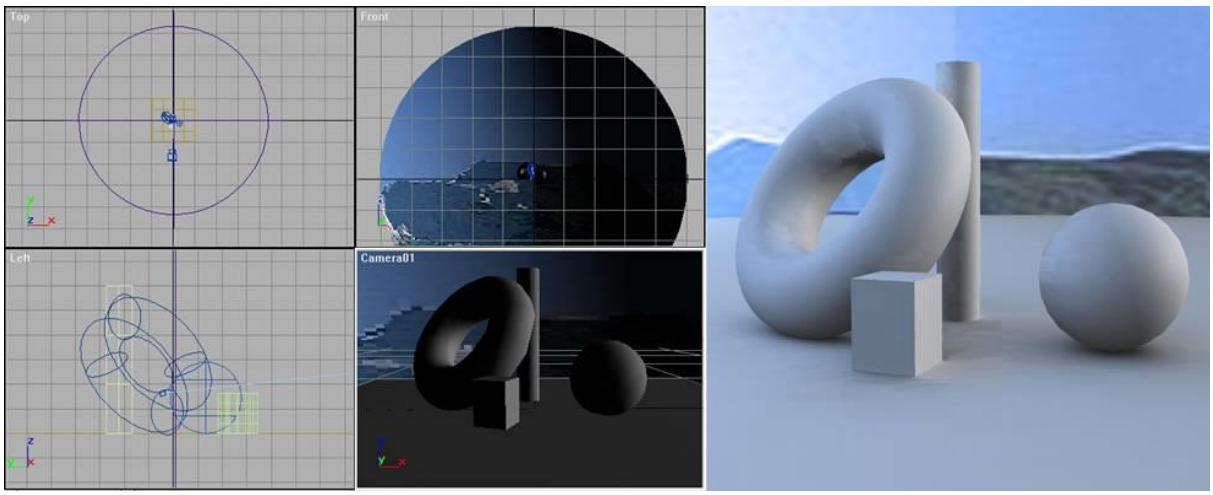


Figure 128, the sky dome rig using omni lights to mimic modern image-based lighting

Figure 129, skies rendered from Bryce representing different times of day

3.2.3 Crowd Control

With the initial model completed I investigated using procedural crowd animation to populate the city. 3dsmax has a simple but effective crowd simulation system which uses collision detection and behavioural patterns to simulate crowd behaviour and drive the movement of actor nodes. Each actor can be linked to an instanced character which in turn can have a set of range of skeletal animations such as walking, running, idle, turn, etc. configured using a motion flow. The motion flow is a matrix of transitions, between each animation cycle, allowing automatic changes from one animation to another; for example, walk > turn 45' left > walk > turn 180' (Figure 130). The resulting crowd simulation was successful in that it proved the system worked but highlighted the need for additional animation cycles for a more natural character motion. Figure 131 shows the Amarna3D model with the crowd system implemented.

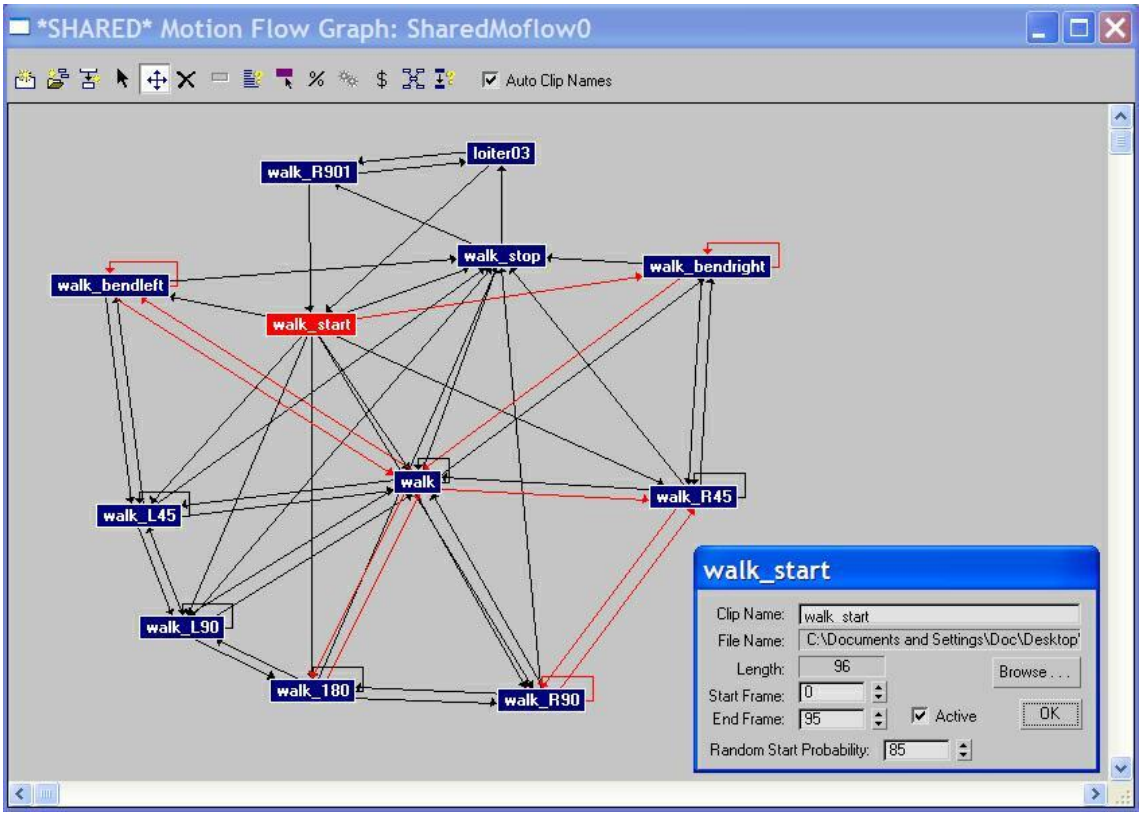


Figure 130, individual character motion flow for use within the crowd simulation

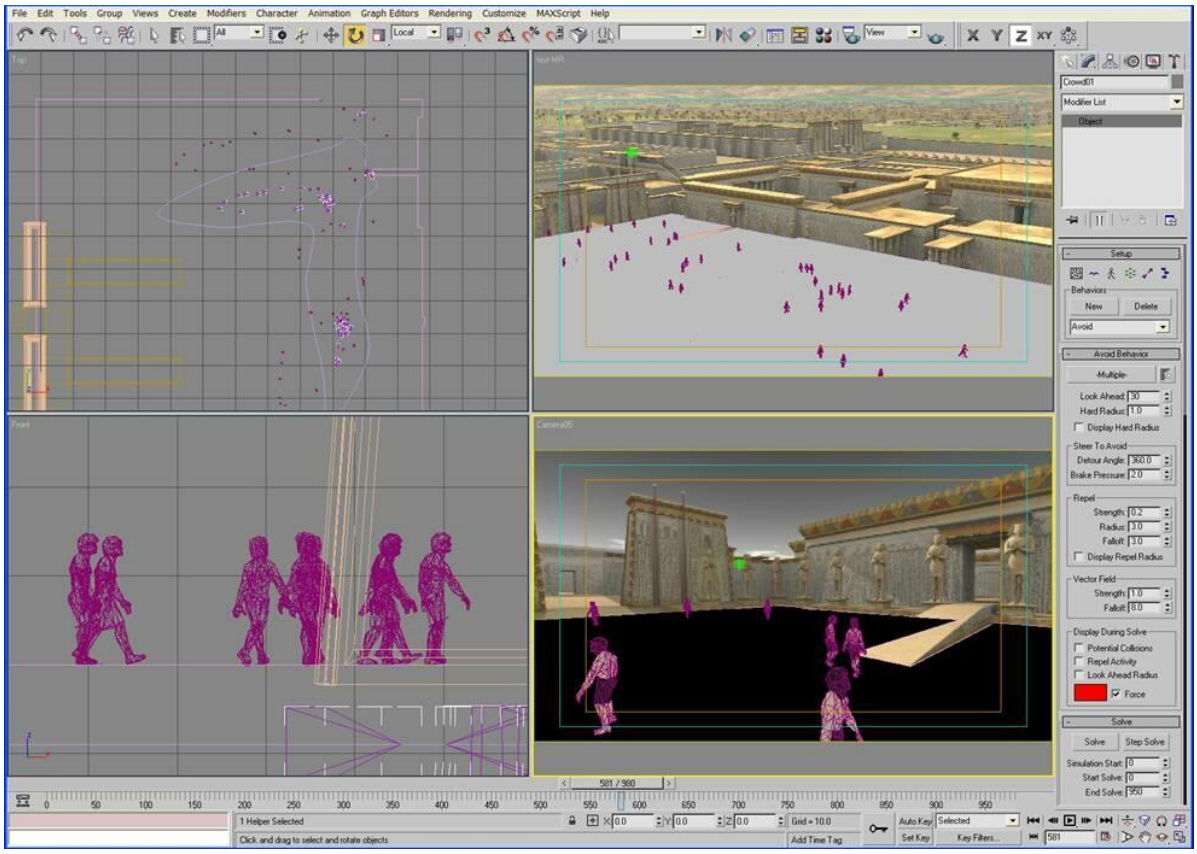


Figure 131, the crowd simulation controlling instanced character meshes

3.3 Phase 2 - A Career Model

Once the initial model was completed, I created a spoof film trailer to present to the undergraduates studying visualisation at Teesside. A series of animated sequences including flyovers, the crowd simulation, character animation, and VFX were assembled with a soundtrack. The result was not very polished but did give a sense of what could be accomplished with the model. A selection of clips from the trailer can be seen in Figure 132. I expected the Amarna3D model to be used for teaching on the modelling modules at Teesside for a couple of years before being retired and archived for good, however this was just the beginning of the model's 'career'.

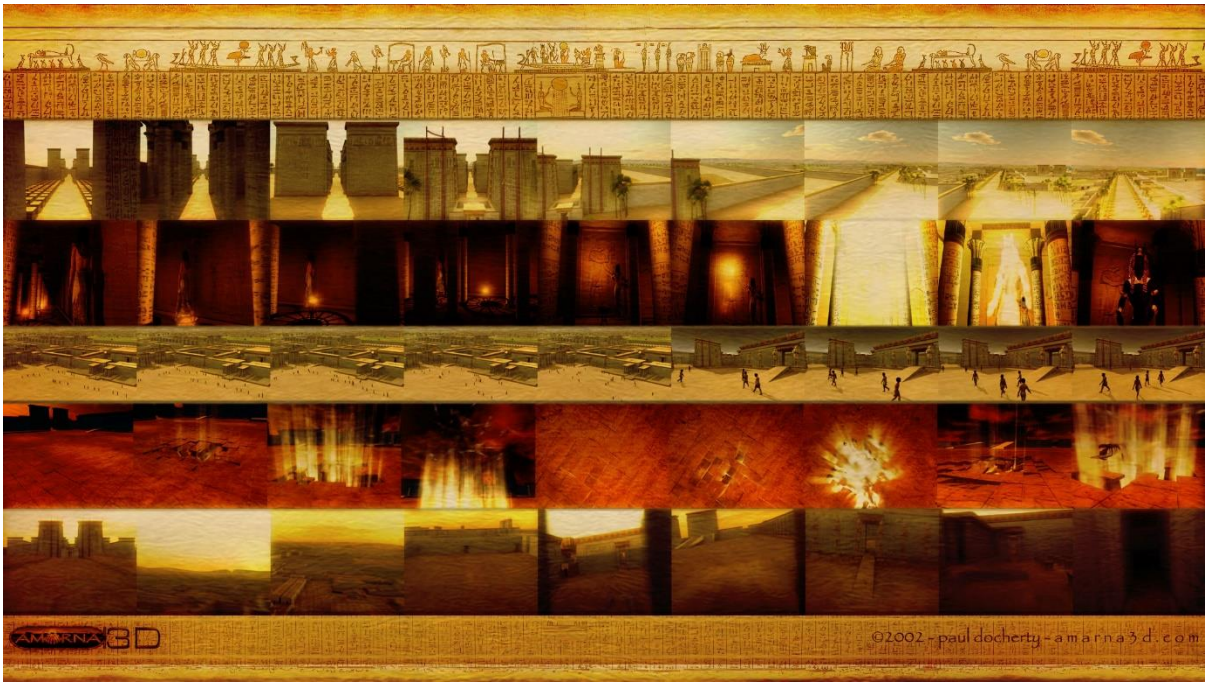


Figure 132, a selection of clips used to create the 'spoof' trailer. Top, pullback and pan from inside the Great Aten Temple - 2nd from top, priestess summoning Anubis from a secret temple location – Middle, the crowd simulation - 2nd from bottom, the gods rise against Akhenaten - Bottom, the deserted city fly around.

Early in 2003 I was encouraged to submit renders of the city to 3D World magazine, the leading publication for 3D modelling and visual effects. In August that year the Royal Quay image (Figure 133) was showcased in the gallery section of that publication (Docherty 2003). This effectively launched the model's career, and I was soon contacted by Ballistic Publishing regarding the inclusion of images in one of their forthcoming titles. Three pieces were selected for inclusion into the book 'Elemental: the world's best Discreet [Autodesk] Art' which placed me within the top 150 3D Studio Max artists at that time (Docherty 2004). One of these images (Figure 134) presented a view of the Royal Quay at sunrise demonstrating how the lighting rig could adapt to the sky texture. With the model showcased on my personal website I started to see copies appearing on sites related to ancient Egypt, particularly

those referencing Akhenaten and the Amarna period. At the start of 2005 I was contacted by the BBC Research and Development department to discuss the use of the model in research they were conducting into augmented reality. They were developing technology to allow live presenters to step into virtual sets and they wanted to push their engine performance with the Amarna3D model. There were some technical difficulties in doing this, mainly surrounding the procedural materials I had used and the high polygon count, so it never made it to screen at that time. The model was however helpful in their AR research providing a steppingstone to what we see in use today.

Figure 133, first published image of the Amarna3D model (Docherty 2003)

Figure 134, Sunrise over the Royal Quay (Docherty 2004)

During 2005 the model made its debut as an animated sequence for television. Appearing on the History Channel in the episode 'Nefertiti: The Mummy Returns', part of the series 'Digging for the Truth', as an animated flyover of the Central City. This was particularly problematic as the model took approximately 24 minutes to render each frame at the required resolution on the equipment available. Generating a sequence of 10 seconds took around 96 hours of render time. Unfortunately, the sequence had some shadow errors, which were only obvious once the sequence had been fully rendered, resulting in an additional render period. Modifications were made to the model to prevent similar issues occurring and to pre-empt any future requests I created several variations on the sequence should other productions require similar footage. In 2006 the History Channel used one of these for another documentary (Engineering an Empire: Egypt 2006) with the series receiving critical acclaim. Work halted on the Amarna3D model due to other projects and teaching until the start of 2008 when, having gained access to additional source material through the EES and the Amarna Project, I decided to update the model. With new computing power and updated software I was able to use the survey plans (Kemp and Garfi 1993) as reference planes within 3dsmax and began an update of the Small Aten Temple. A comparison between the initial temple model and the work-in-process for the new model over the next few years can be seen in Figure 135, Figure 136, and Figure 137.

Figure 135, initial model of the Small Aten Temple 2002

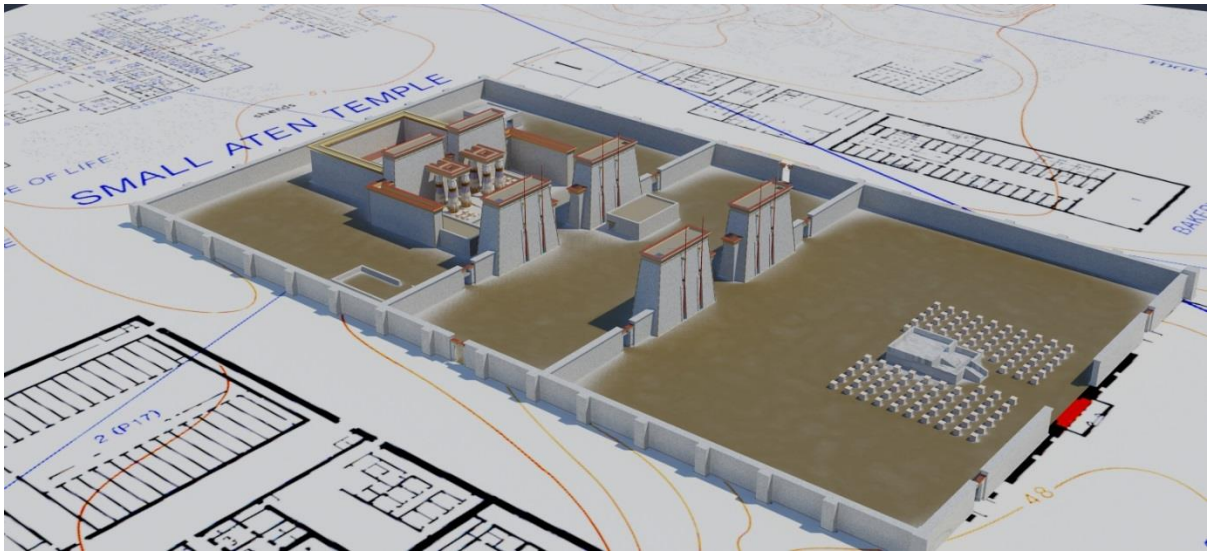


Figure 136, updated model of the Small Aten Temple 2009

Figure 137, material updates on the model of the Small Aten Temple 2014

The move to update the city meant the introduction of new techniques, mainly in material construction. The scale of the project meant that I had to continue to rely on the initial model for published material due to its overall level of completeness. Updating the Central City was an enormous task and work progressed slowly during the summer periods over the next few years with only one publication in 2010 where *Sapiens*, a Spanish history magazine, asked to use six views of the city for a special article on Akhenaten (Docherty, 2010).

2014 saw the next surge in interest for the model and I was contacted by National Geographic for use of an aerial image of the Central City for a double page spread in *Historia* one of their Spanish magazines (Docherty, 2014). I was also contacted by the BBC regarding a documentary (Tutankhamun: The Truth Uncovered 2014) regarding an analysis of the death of the young pharaoh. They were

interested in using the model and associated template files as a base for further 3D model reconstruction and texturing within the animated sequences. As I was working on an updated model it was agreed that they could use the older version, limited to this production. In January 2015 National Geographic published another aerial view in their Italian magazine *Storica* as a double page spread (Docherty, 2015). That summer also saw the model move into the world of music performance and the model needed further refining through additional modelling and texturing. Luca Scarzella a video director from Studio Vertov in Italy approached me about using sequences in an orchestral production of the opera 'Akhnaten' by composer Philip Glass to be performed at the MiTo Music Festival later that year. The performance had two projection screens above the stage, as can be seen in Figure 138, and took place in Turin and Milan on the 13th and 15th September (Glass, 2015).

Figure 138, sequences of the Amarna3D model shown during the MiTo Music Festival September 2015, Turin and Milan

Following on from this performance I created an updated animated aerial sequence for the Channel 5 documentary (King Tut's Tomb: The Hidden Chamber 2016). The update was also used for display as background graphics to a selection of Amarna artefacts on display within an exhibition at the Israel Museum in Jerusalem titled 'Pharaoh in Canaan: The Untold Story' (IMJ 2016). A new aerial view of the model was also created for a double page spread in the Italian magazine *Focus Storia* in August (Docherty, 2016).

3.4 Phase 3 – Rebuilding for Academic Use

In December 2015, I left the University of Teesside to pursue a degree in archaeology. I wanted to gain a greater understanding of the development of 3D reconstructions. I had decided to work on a new

update of the Great Aten Temple (Figure 139 through to Figure 144) based on Kemp's reconstructed version of the Lavers plans from the 1930s EES expeditions (Kemp 2012, 90). Images of the model began to attract the attention of academic and teaching publications. The first to contact me was Dr. Jesús Esteban, professor of Egyptology at the Universidad a Distancia de Madrid (Udima) who wanted to use the Great Aten Temple within an online lecture/documentary they were producing about the Amarna period (UDIMA 2016). Other academic publishers included Oxford Press for their Antiquity 2 series (Hurley and Murray 2018).

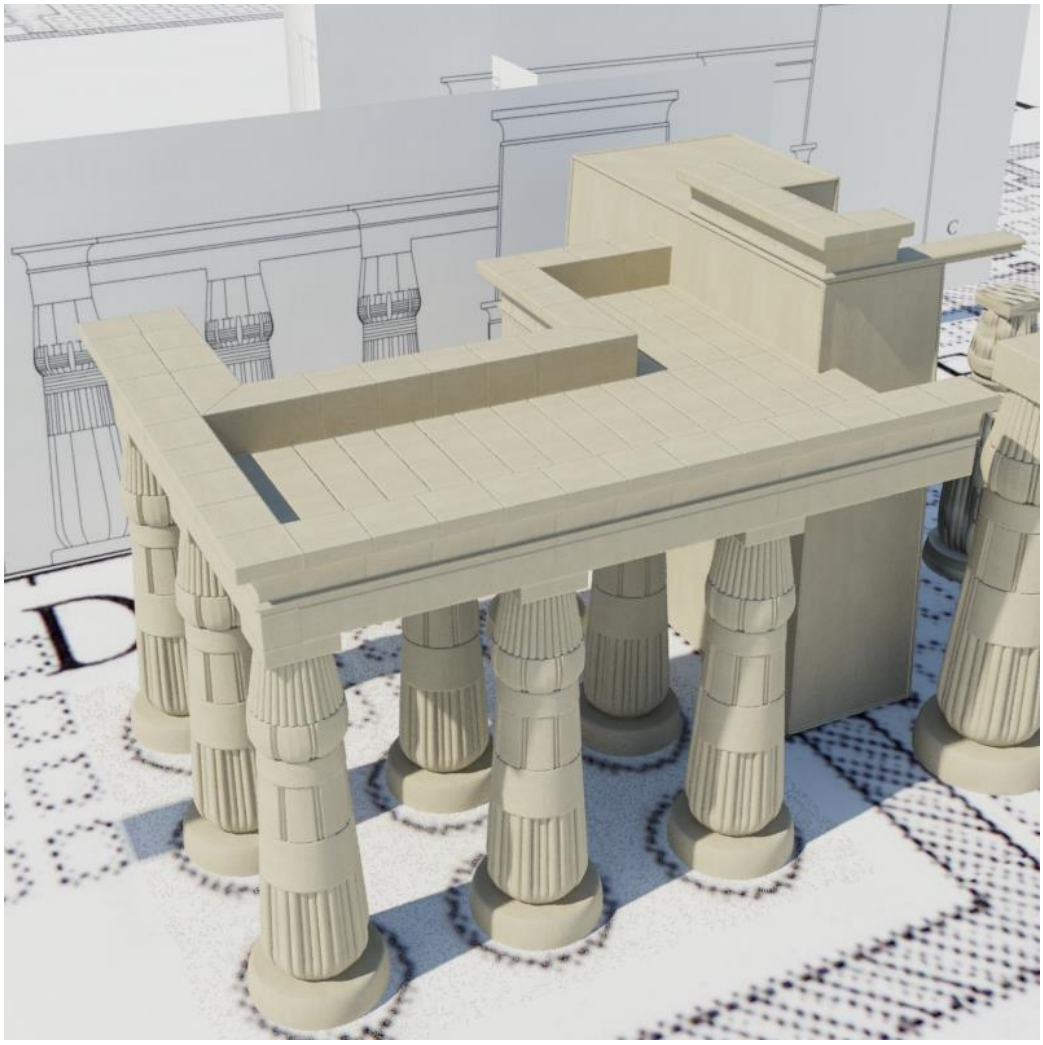


Figure 139, reference planes and resulting meshes created during the beginning of the early 2016 Great Aten Temple remodel

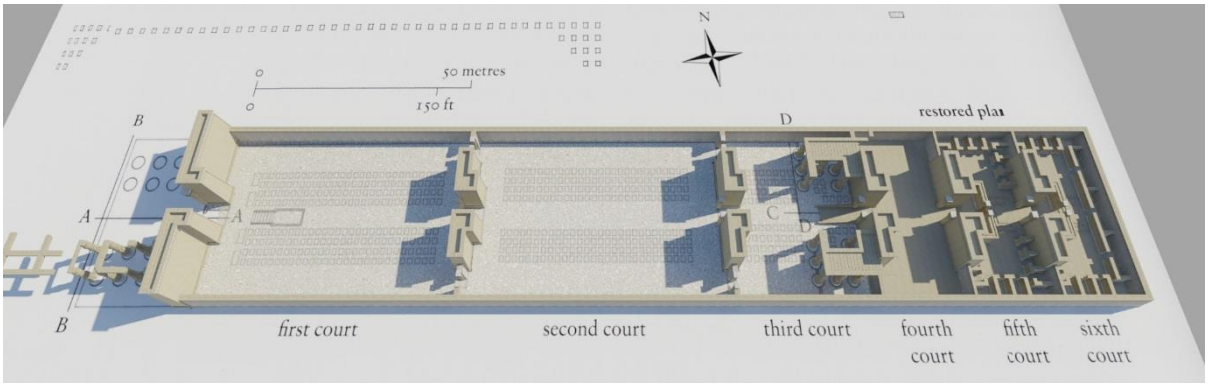


Figure 140, remodelling the Great Aten Temple, early 2016

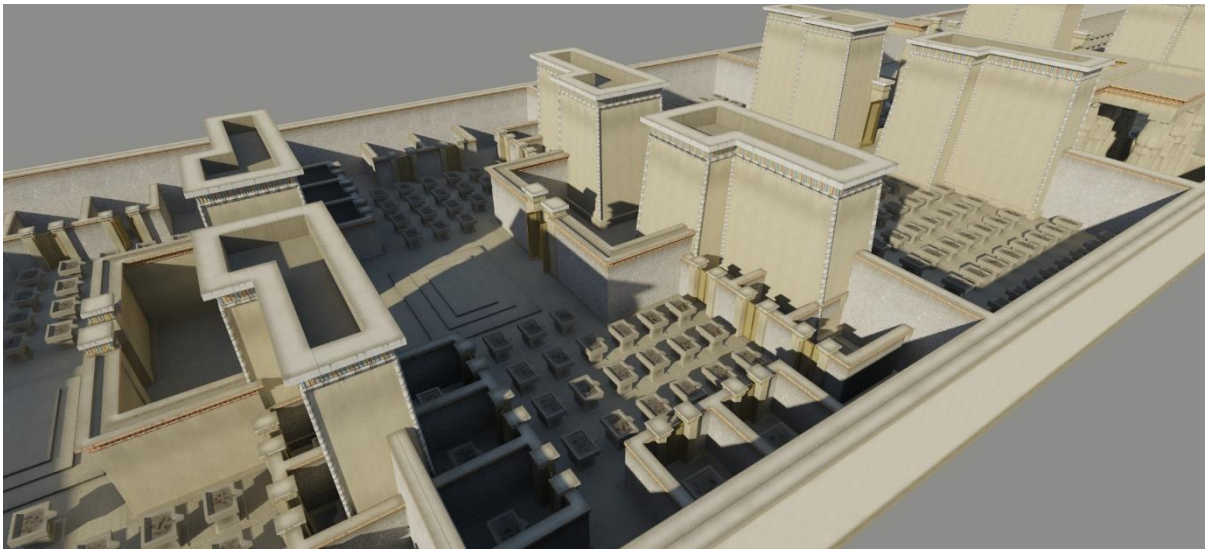


Figure 141, early 2016 Great Aten Temple closeup centred on the fifth court

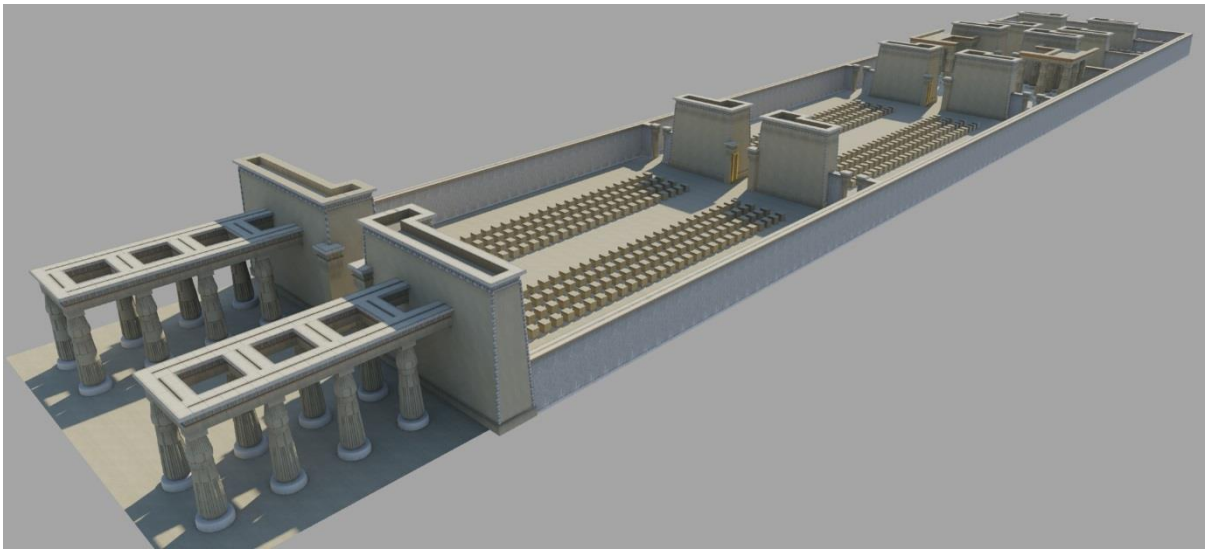


Figure 142, the completed remodelling of the Great Aten Temple, early 2016

Figure 143, view from the third court of the early 2016 Great Aten Temple build

Figure 144, view from entrance colonnade of the early 2016 Great Aten Temple build

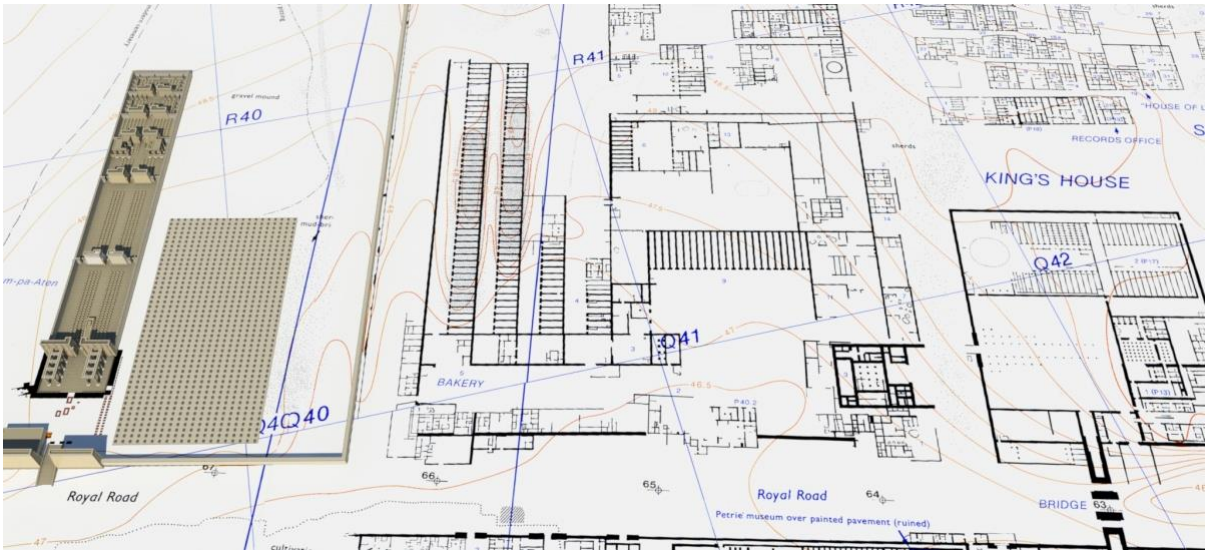


Figure 145, the Great Aten Temple sited on the Kemp and Garfi survey map

Although I was happy with the outcome of the Great Aten Temple rebuild (see Figure 145 for its position on the Kemp and Garfi survey map) the recent excavations at the Great Aten Temple had begun to shed new light on its construction and appearance. I realized the offering tables were incorrect and too elaborate; the originals being more of a simple brick construction. The pylons, although represented in this form within other academic publications, were incorrectly shaped and would have been simpler in construction. I was also now aware that my idealistic visualisation of the temple and the extended city model did not accurately represent the environmental conditions during the Amarna Period requiring a more worn and rugged approach. Given the interest in an accurate model of the temple I decided to investigate an even more detailed version of the model this time constructing it brick by brick as a venture into digital experimental archaeology shown in Figure 146.

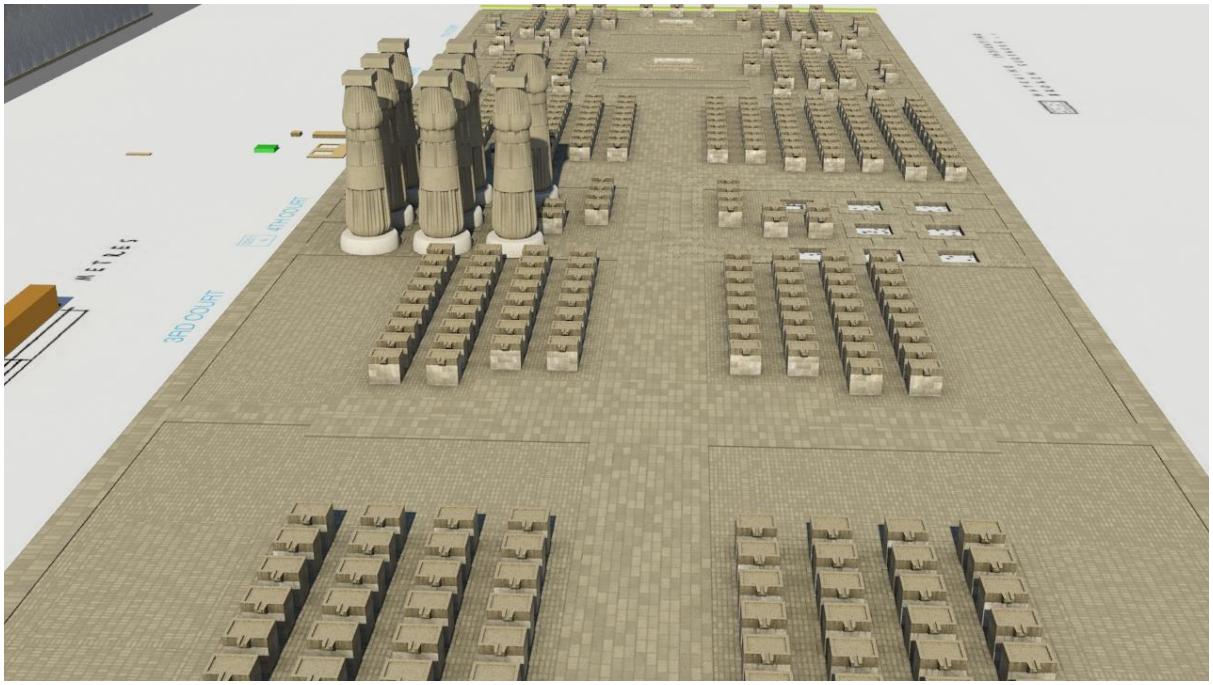


Figure 146, late 2016 Great Aten Temple rebuild using a brick-by-brick construction

At this point I was looking at ways of creating a more accurate material system which would show weathering and dirt. One of the biggest problems with repetitive textures is the issue of noticeable tiling which can occur on large areas. By building the temple with individual bricks I could randomise the colour and use world space coordinates to trigger colour changes variations across the model reducing any repetitive patterns. In addition, I used ambient occlusion maps as a mask to allow clean and dirty versions of the texture to appear based on the topography of the mesh geometry. Although ambient occlusion is a render process effect it is now more commonly used in game engines through pre-baked textures. Once happy with the brick built layout, I created a simplified mesh, which was in effect a skin of the model, and baked (projected) the textures from the detailed geometry to the simplified mesh (Figure 147 and Figure 148).

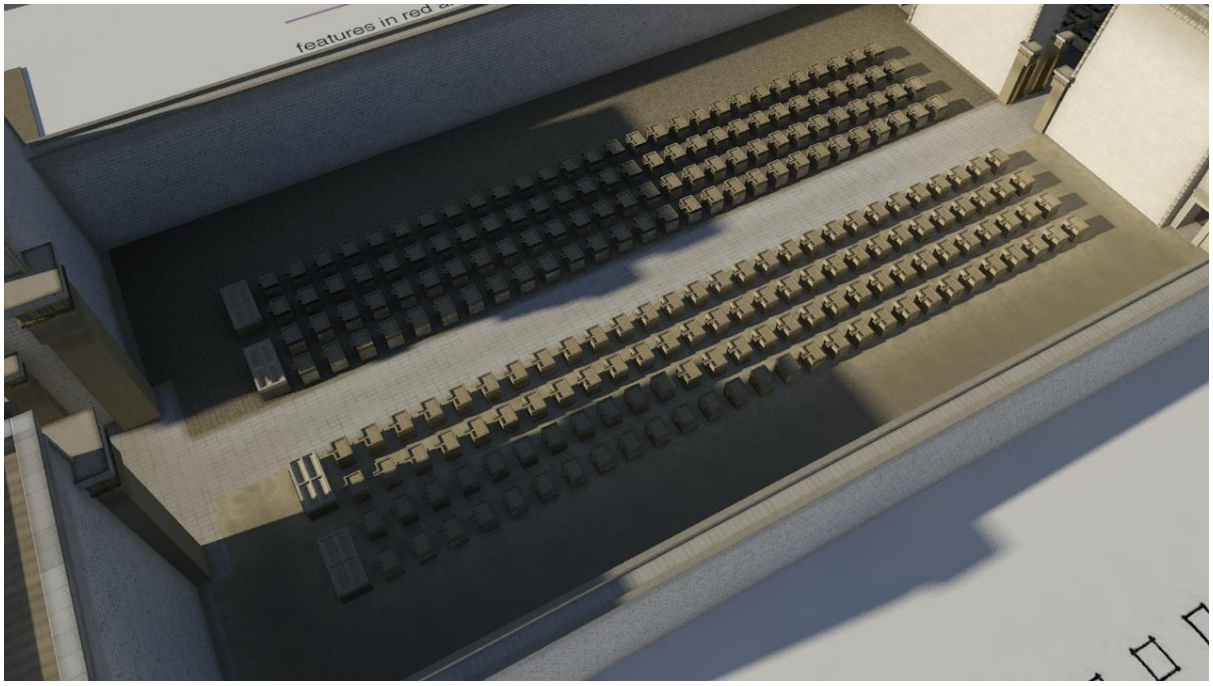


Figure 147, transition from individual brick construction (north of the axis) to solid model (south of the axis)

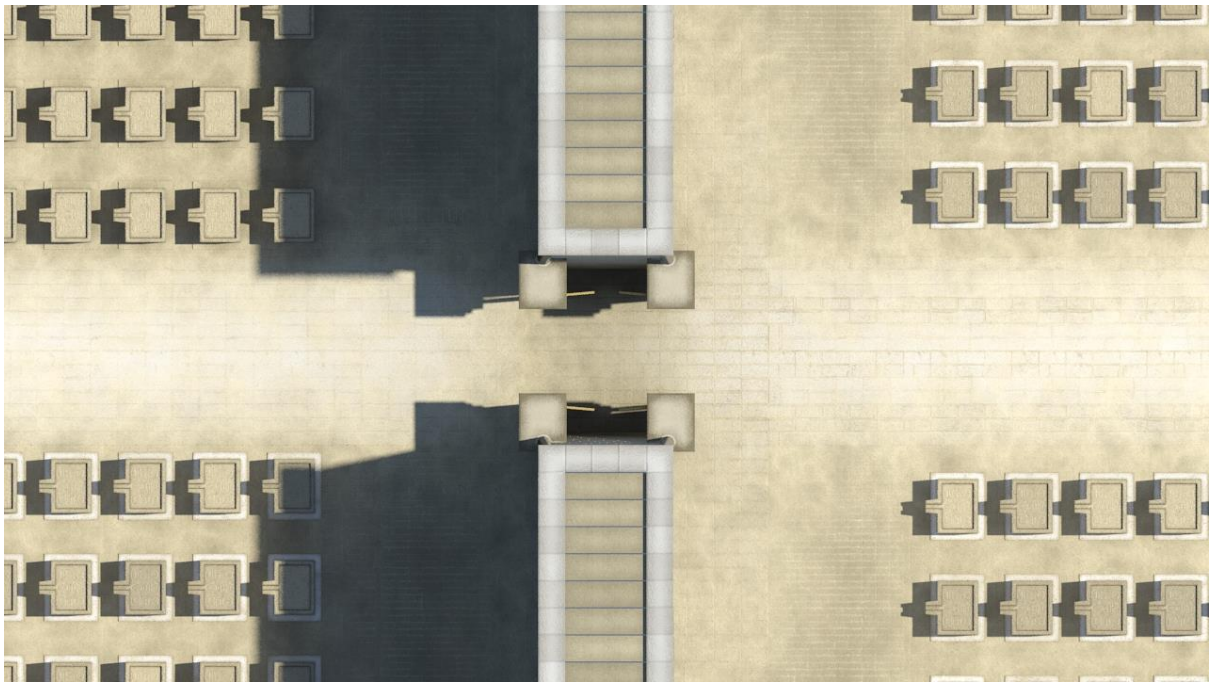


Figure 148, combined bitmap and procedural texture of the floor showing ambient occlusion used as a mask between dusty and 'walked' areas.

In May 2017 I was invited by Dr Matthew Nicholls to present my work on the city at the Digital Visualisation in Education and Heritage one day colloquium at Reading University. Nicholls had built a detailed 3D version of Rome (www.virtualrome.org) for use in teaching and research. The day brought academic and heritage sector practitioners together to discuss how digital visualisation can be used to present historical architecture and landscapes to the public. The event prompted me to look further into the uses of the city model and continue to investigate ancient Egyptian building and construction methods alongside alternative representations, focusing on a series of contradictions between the archaeological surveys of the Great Aten Temple and the various depictions of it within the rock tombs. I was also very much aware that the rest of the city needed attention and began intermittent work on the North Palace and the Maru-Aten structures to the south based on the survey material and physical models constructed by Whetton & Grosch as shown in Figure 149 through to Figure 152.

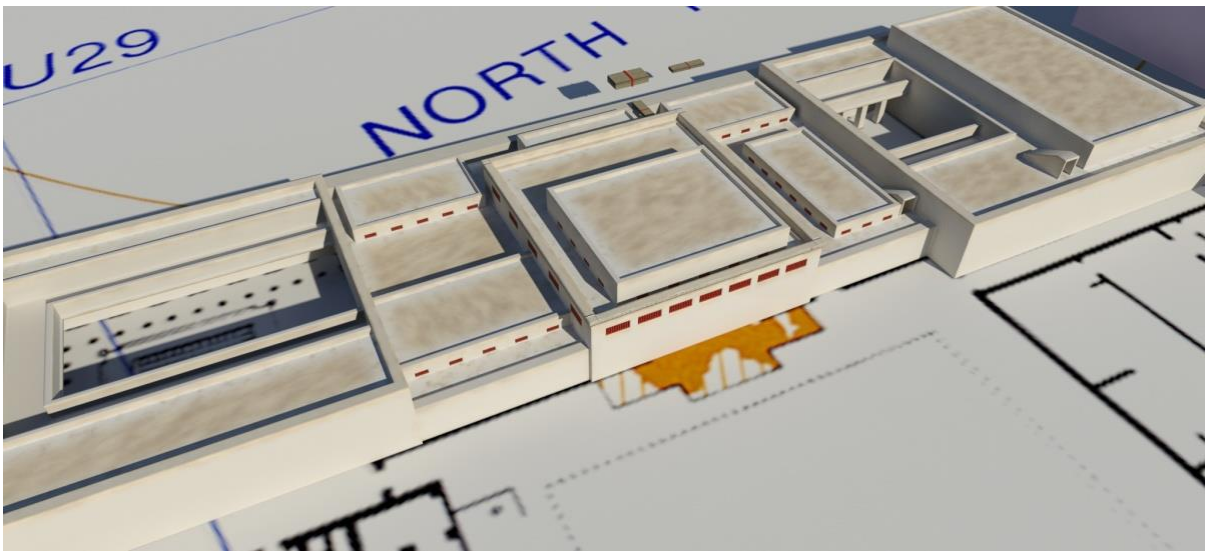


Figure 149, initial construction of the North Palace

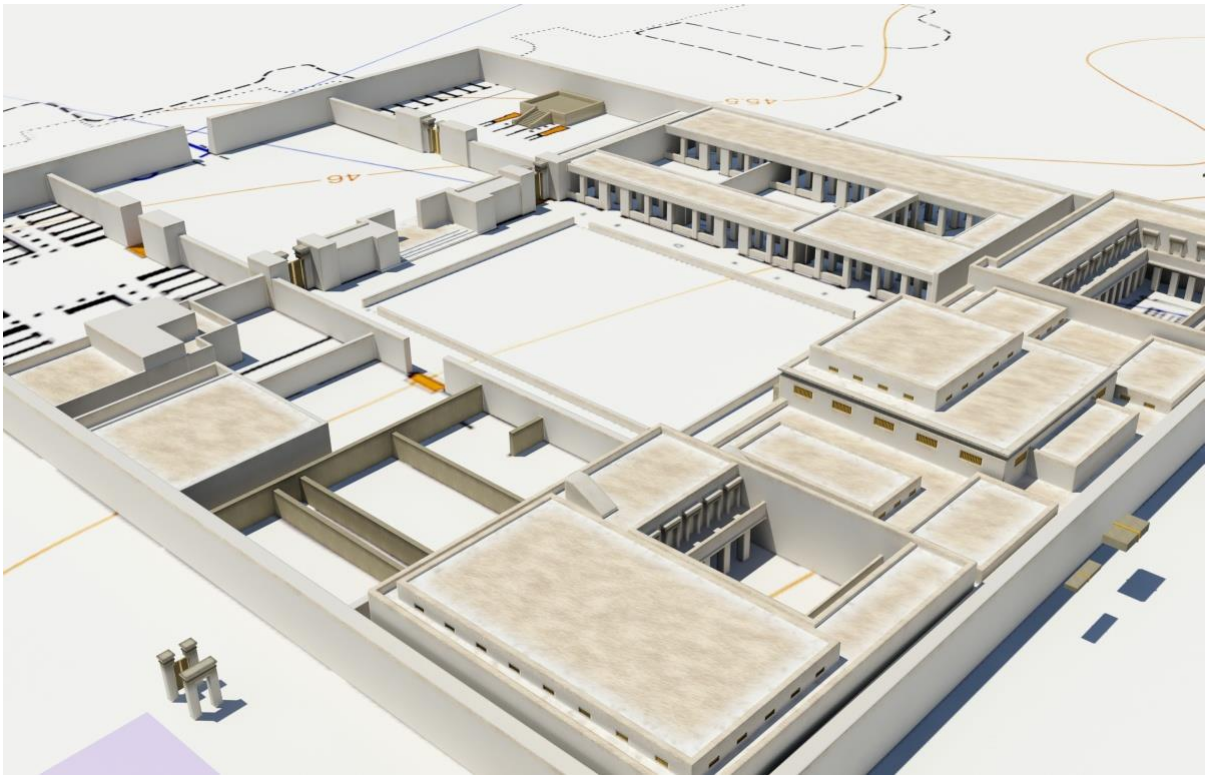


Figure 150, later construction stage of the North Palace

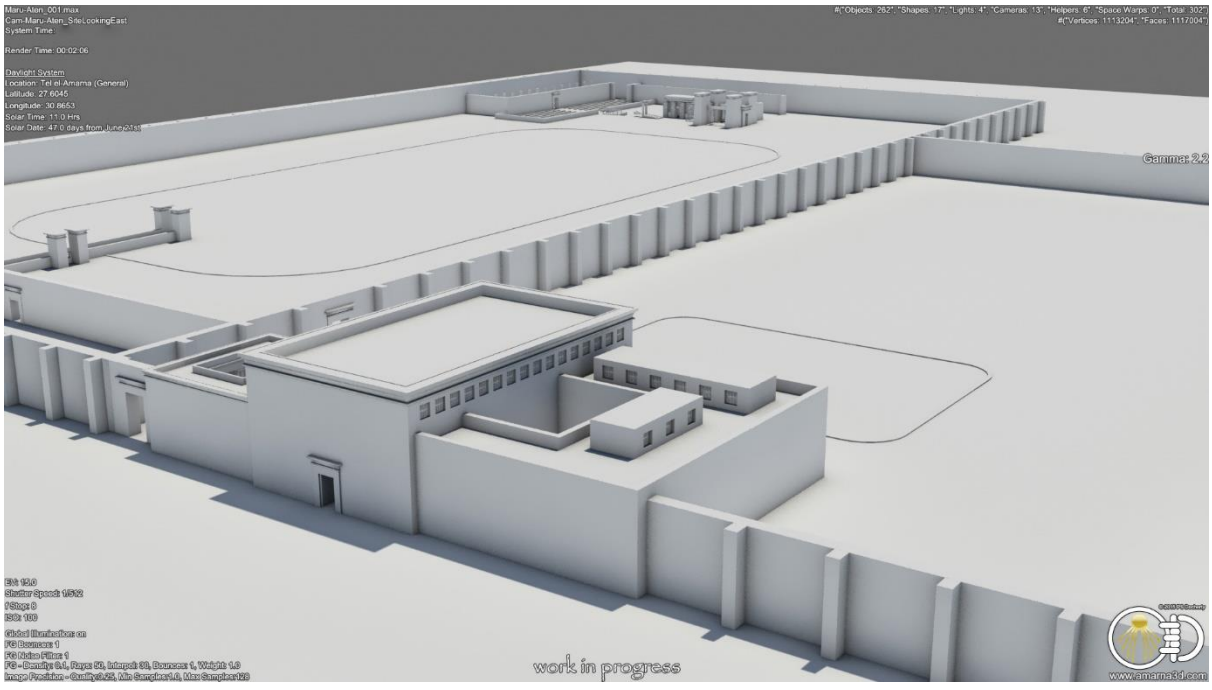


Figure 151, construction of the Maru-Aten site

Figure 152, detail from the Maru-Aten site. The water feature (left) and the island feature (right) both located top centre of Figure 151

My plan was to focus on specific detailing of the main city structures in isolation with a view to consolidating them later into one definitive model. This extended into other administrative buildings and suburban housing. For the later it was important to understand how the suburban houses were constructed regarding layout and whether there was more than one floor. The work of Tietze (2008) following on from Petrie (1894) was relevant to layout but it was the three-dimensional analysis of housing by Spence (2004, 2015) which was of great value in confirming the look of the buildings and indicating how the upper and lower floors may have been constructed as shown in the development of house M47.4 (Figure 153) and the house of General Ramose P47.19 (Figure 154).

Figure 153, the house M47.4 constructed from details developed by Kate Spence (Spence 2004)

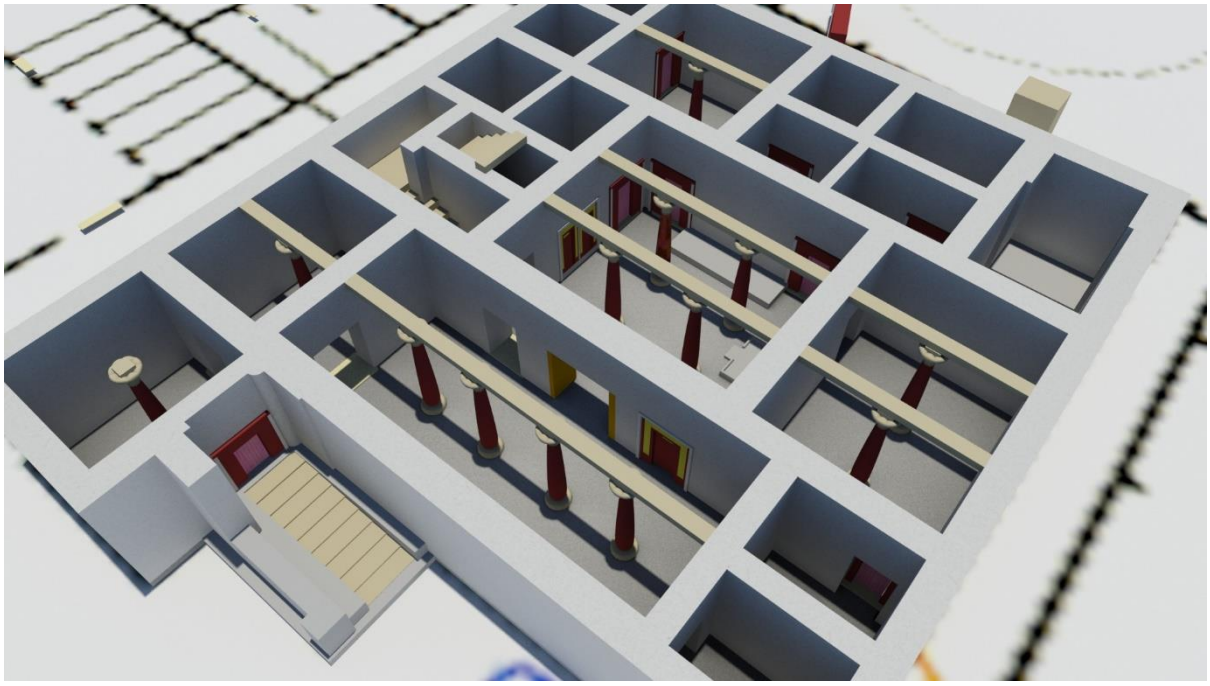


Figure 154, the ground floor of the house P47.19 showing columns which could have supported an upper floor

3.4.1 Amarna3D 360-degree Streetview Experiment

In 2015 I developed the Great Aten Temple and North Palace into a 360-degree VR experience linked to positional and rotational information in Google Maps as shown in Figure 155. It was created using several 360-degree renders at specific points and was meant to mimic the functionality of Google StreetView. The test can be found online at http://www.amarna3d.com/streetview/

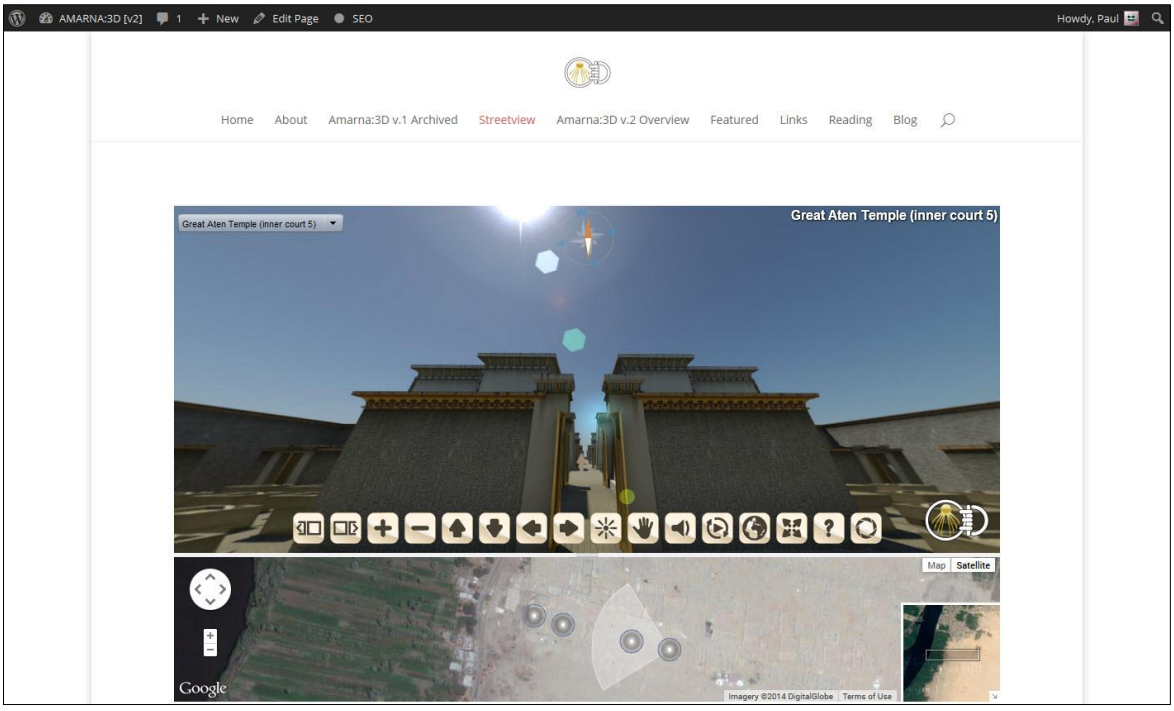


Figure 155, Amarna3D 360-degree Streetview test

3.4.2 Becoming part of the Amarna Project

In 2018, I was contacted by Prof Barry Kemp Director of the Amarna Project to create a 3D visualisation of the foundations of the entrance to the Great Aten Temple and the newly discovered main altar staircase. The model was developed to help the local builders and project patrons visualise the overall look of the modern temple front and the layout of the talatat blocks used in its construction. It was developed from the earlier brick-by-brick construction experiment I had recently completed, and the resulting stonework can be seen in Figure 156 and Figure 157. The progress was published in the Great Aten Temple Reports on Recent Work (Kemp 2018, 2019a; Barry Kemp et al. 2020).

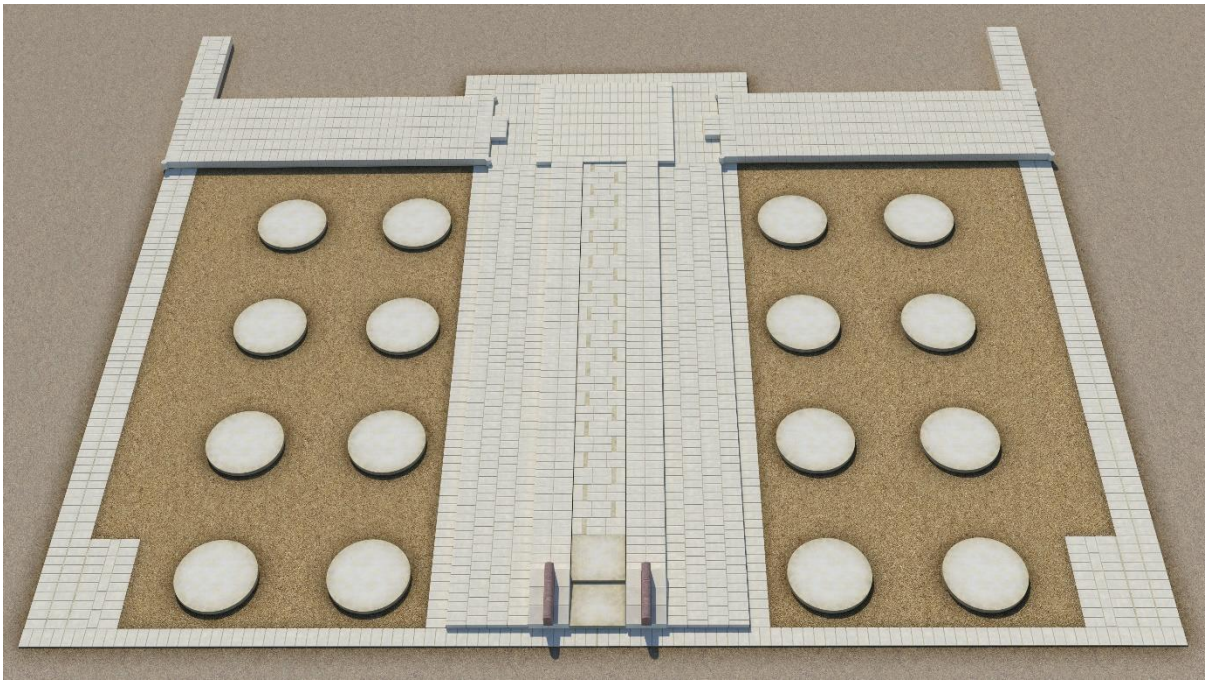


Figure 156, the 3D visualisation of the foundations of the entrance to the Great Aten Temple

Figure 157, photograph of the Great Aten Temple stonework taken in March 2020, view to the east

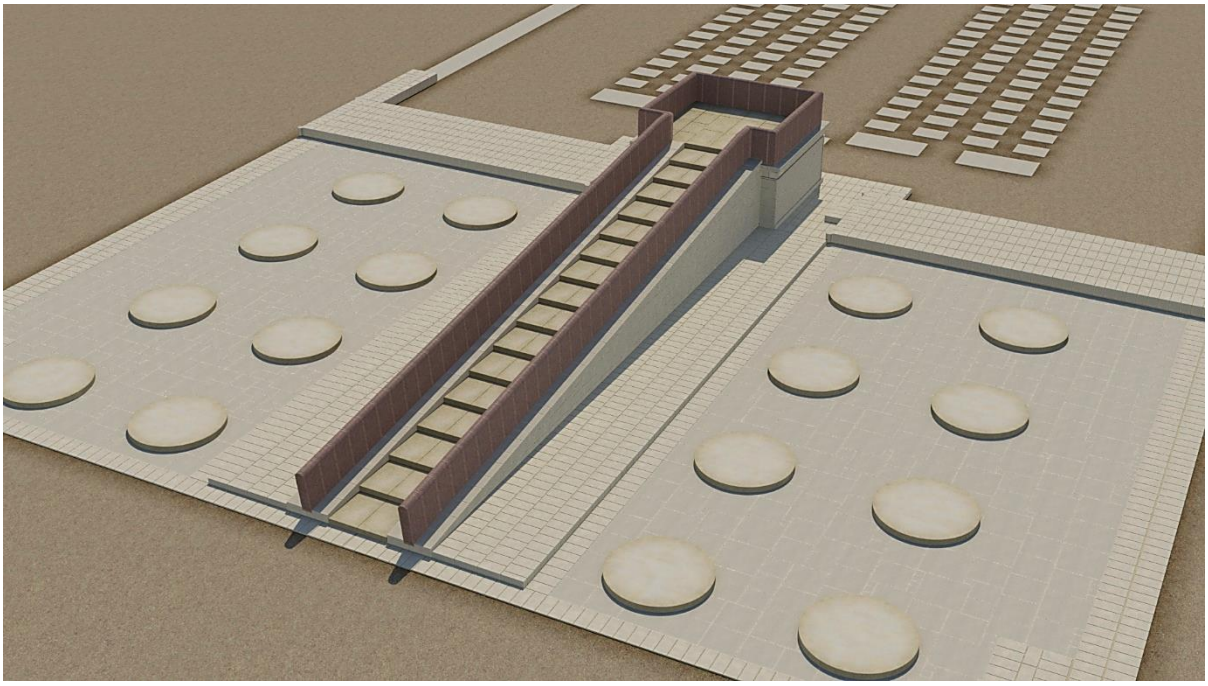


Figure 158, a visualisation of the stairway to the main temple altar as it may have been in antiquity

Once the modern visualisation was complete, I decided to investigate the alignment of the temple with the path of the sun to determine if it would rise between the pylons. To manage this successfully the architectural sunlight system within 3dsmax would need to be setup as accurately as possible. The sunlight system requires geographical map coordinates and a north heading. It then positions the sun's azimuth and inclination according to the time and date dialled into the system (Figure 159). The map coordinates for the temple were taken from Google Maps but due to the date and time limitation of the Gregorian calendar used within the system I could not reconstruct the sun path from the Amarna period. To do so would involve looking into astrophysics for the azimuth and inclination so I decided to stick to the current year (2018) as proof of concept. To check the accuracy, I asked if a series of photos could be taken of a view of the temple entrance located on the SW corner of the southern pylon base. I then created a camera within 3dsmax along the same view as that in the photograph. Using the metadata within the photo I determined the time and dialled that into the sunlight system. With a slight adjustment to the north heading of the sunlight system I found that the shadows cast digitally matched those of the actual location perfectly (Figure 160). This allowed me to run the sunlight simulation and produce the path the sun took over the temple during the year as shown in Figure 161 and rendered in Figure 162. Aerial views of the entrance can be seen rendered in Figure 163 and Figure 164. This was later published as a joint paper (Kemp and Docherty 2019).

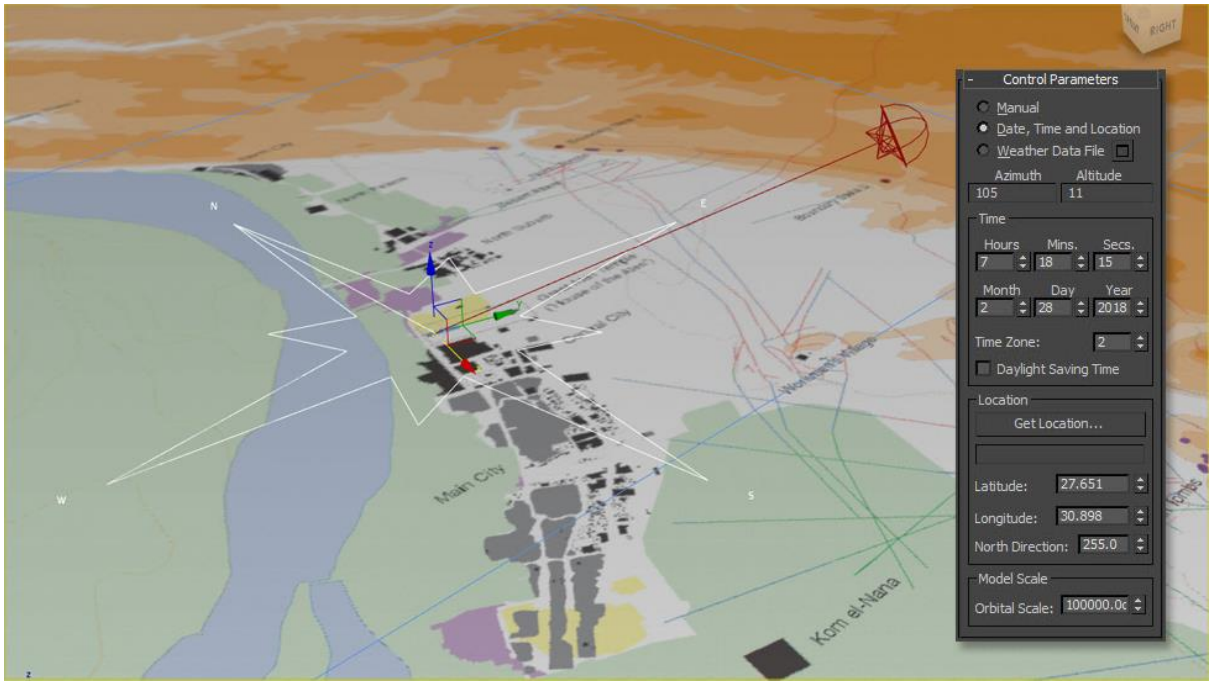


Figure 159, view of the sunlight system in 3dsmax using a proxy map for initial setup

Figure 160, checking the accuracy of the sunlight system using photographic reference

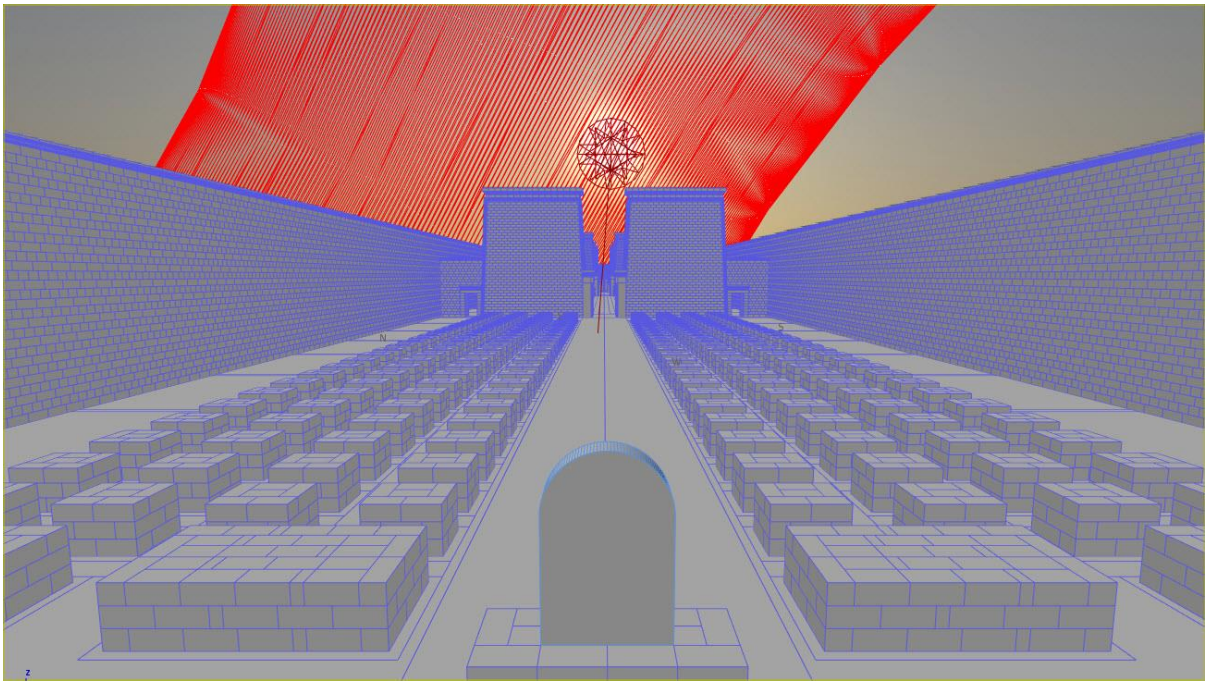


Figure 161, a visual representation of the suns path over the Great Aten Temple for the year 2019

Figure 162, a rendered view from the main altar at the Great Aten Temple entrance at 6:40am 12-10-2018. View to the east

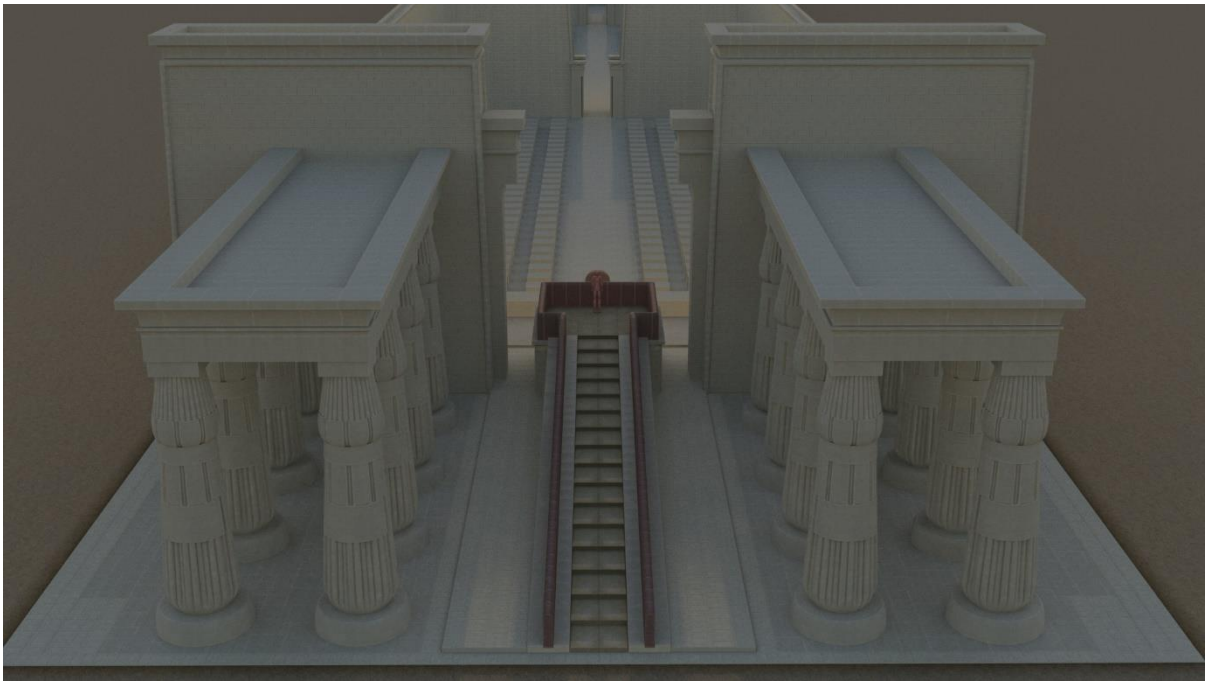


Figure 163, a rendered view of the entrance to the Great Aten Temple at 6:40am 12-10-2018. View to the east

Figure 164, a rendered view of the entrance to the Great Aten Temple at 6:40am 12-10-2018. View to the west

Figure 165, a visualisation of the entrance to the Great Aten Temple as it may have appeared in antiquity

Figure 166, an alternative visualisation of the entrance to the Great Aten Temple as it may have appeared in antiquity

Once the sunlight study had been completed there was a discussion within the Amarna Project team regarding the construction of the entrance to the Great Aten Temple in the area surrounding the colonnade. This prompted the construction of a series of variations to the front area, two of which are presented in Figure 165 and Figure 166. The models I developed for the Great Aten Temple were

presented at the British Museum in September 2019 as part of The Raymond and Beverly Sackler Distinguished Lecture in Egyptology with Barry Kemp, entitled ‘The 'House of the Aten' at Amarna: whose needs did it serve and how?’. The results of the stonework reconstruction, sunlight study, and alternative entrance visualisations were then merged into the main Amarna3D model and used to redevelop that area of the Great Aten Temple.

In addition to the 3D modelling work I was doing on the city I suggested that it may be possible to do photogrammetric reconstruction remotely by directing someone at the site to take a series of photographs suitable for processing within photogrammetric software. One of the lead archaeologists in the Amarna Project, Miriam Bertram, agreed to take the photographs and send them to me in the UK and I subsequently managed to reconstruct the area around the main temple entrance as seen in Figure 167.

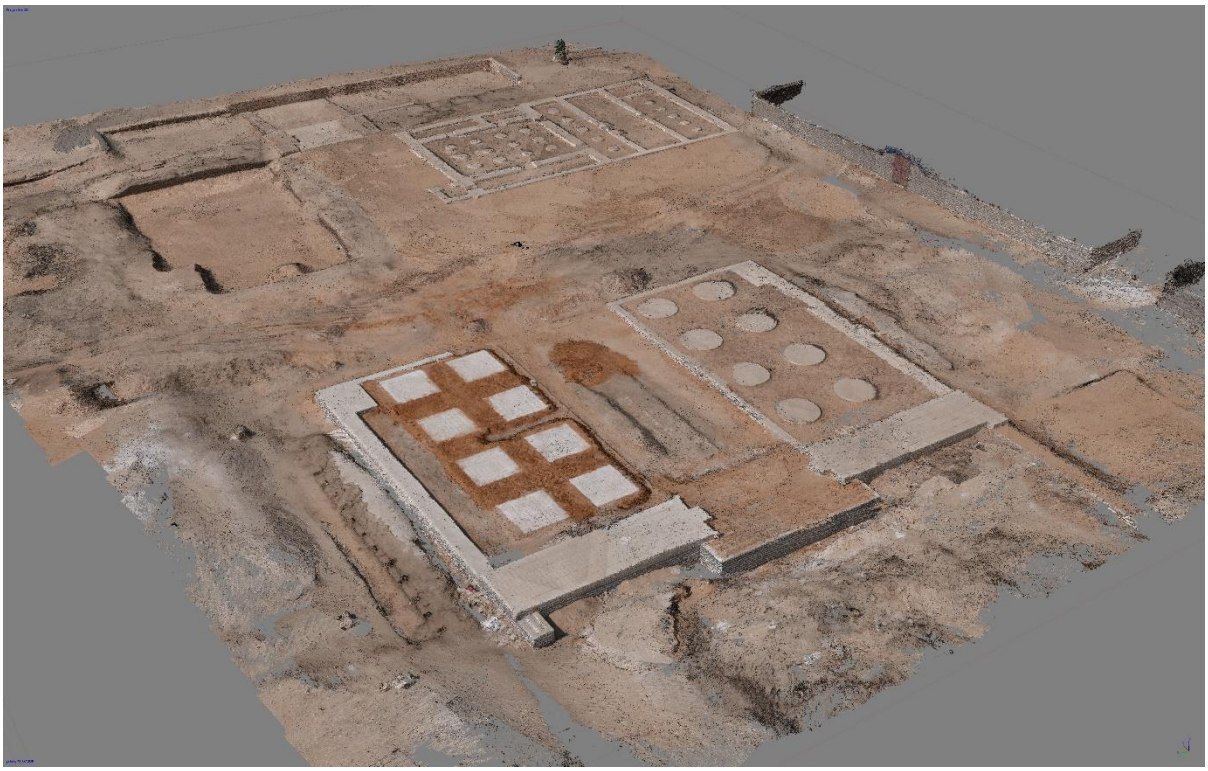


Figure 167, 3D point cloud of the Great Aten Temple entrance (autumn 2018) created through photogrammetry, view to the NW

3.5 Other 3D visualisations of Amarna

Since the first Amarna3D model was built at least two other digital models have been constructed for exhibition or documentary publication. The Terra X documentary series 'Ägypten' (ZDF 2011) included an aerial sequence over Amarna focusing on the Central City. It was successful in conveying a busy cityscape by including a level of weathering across the landscape (Figure 168 and Figure 169).

The exhibition 'Aton-Num, Akhenaten and Nefertiti in the digital age' (Archaeovision 2017) included a digital sequence focused on the Central City and some ground based footage displaying some of the known vegetation present around the city (Figure 170 and Figure 171). In contrast to the Terra X model the Aton-Num model maintained an idealised clean look which is not fully representative of how the city would have been in antiquity (Kemp 2012, 72). Both sequences were pre-rendered animations and not real-time environments allowing greater visual scope at the cost of interactivity.

Figure 168, still frame from Ägypten (3/4): Im Zeichen des Sonnengottes (ZDF 2011)*, view to south*

Figure 169, still frame from Ägypten (3/4): Im Zeichen des Sonnengottes (ZDF 2011)*, view to east*

Figure 170, still frame from 'Aton-Num', view east towards the Small Aten temple (Archaeovision 2017)

Figure 171, still frame from 'Aton-Num', garden vegetation (Archaeovision 2017)

The Amarna3D model has existed for 20 years to date, a period longer than the habitation of the actual city. It has played many roles from a game concept, teaching demonstration model, animated visualisation for documentaries, general interest publication, academic reference, operatic backdrop, blueprint for real-world construction, and experimental archaeology. It is clear though, that as we embrace new visualisation technologies and methods of storytelling the model is no longer suitable. To allow for a ground-based walkthrough of the city at a visual level appropriate for storytelling the original Amarna3D model would require a great deal more detail to be implemented. The amount of work involved in modifying the existing model cannot be justified and a more efficient use of time would be better placed in constructing a new model, taking on board the archaeological data available in a similar fashion to the later 3D reconstruction of the Great Aten Temple.

The AmarnaXR build has many issues to be worked through in terms of scale, quality, and build time; all of which will be explored in the following chapters. In order to plan effectively it is important to identify what areas of the city require the most attention; these being directly related to the active story and the locations essential for its delivery. The next chapter introduces the story of Ranefer by Barry Kemp and how it could potentially translate into an interactive storytelling experience. This begins to showcase the scale of the workload which would be required to develop the story as part of AmarnaXR.

4 The Story of *Ranefer*

A short time after the construction of the Amarna Visitor's Centre at Amarna, Barry Kemp was asked to write a series of short stories about life at Amarna. One of these was centred on the chariot-officer *Ranefer*, whose house (N49.18) was first excavated in 1921 and later in more detail between 2002 and 2006 (Kemp and Stevens 2010; Peet and Woolley 1923). The house has been partially reconstructed in the Visitor Centre as a full-scale exhibit. Adjacent to *Ranefer*'s house within the city is a group of smaller houses designated as Grid 12 and, whilst they may not have been actual dependents of *Ranefer*, they would have operated in a similar way towards their 'master household' and as such are a useful reference.

The short stories remain unpublished however permission was given by Barry Kemp (to which the author is indebted) to use the story of *Ranefer* for this project. The full text is included in appendix 7.5. The story is laid out in nine parts with the first being an introduction identifying the story as a work of fiction albeit one which is constructed from archaeological evidence and research gathered from the same resources outlined in chapter 2.2 and other ancient Egyptian sites.

4.1 Imagining *Ranefer* (summary and sources)

The story begins in part 2 by introducing *Ranefer* 'the first charioteer of his majesty, the master of horses of all the stables' and his family who have just moved to Amarna after the death of Akhenaten. As mentioned in the previous chapter (2.4.6) a house was built by *Ranefer* (N49.18) over an existing house (N49.58). It is difficult to determine if *Ranefer* owned both houses and was in the process of upgrading the original. He may have inherited the earlier one or simply purchased it from the previous owner. To enable the story to be told effectively a fictitious family have been created which include his wife *Satia*, two sons *Any* (12) and *Ramose* (10), his daughter *Neferu* (9), his mother *Qede*, and his unmarried sister *Baket*. Their existence was constructed from the remains of the house including its layout, room function, and artefacts found (Kemp and Stevens 2010). The extended household numbers around 80 people comprising a steward named *Huy* assisted by his son *Yuny*, 25 men (and families) who hold a range of general jobs (bodyguards, sailors, charioteer, brewer, craftsmen, etc.) and live in the 17 small adjacent houses. *Ranefer* also has 12 slaves (5 men, 7 women) who tend to the domestic chores such as water carrying, cooking, laundry, and weaving. It is noted that four of the slaves are from Canaan and speak mostly Akkadian which *Satia* cannot and as such is unnerving to her. The slave nationalities are based on events happening at the time the city was active. The slaves do not have their own houses and sleep in areas around the main house.

Part 3 looks at the duties and responsibilities *Ranefer* has to his dependants and to the Pharaoh. He tries to live his life by being fair but firm seeking the respect of those around him. He is well read and

has followed the teachings of Akhenaten and notes the words of wisdom carried over from past wise men. However, he is uncomfortable with the bitterness Akhenaten clearly had for the religious cults he believed had been disloyal towards his forebears. This is a reference to the boundary stelae texts where Akhenaten shows his disdain for the Amun cult. The story continues with *Ranefer* initiating his tomb construction to ensure his life eternal and how his status in the household is maintained through a shrine along with pictures of himself painted on the walls. *Ranefer* is the head of the extended household and as such acts as the judge for all disputes between his dependents. He also has a duty to prevent any dissention towards the pharaoh and would need to hand anyone guilty of this over to the higher authorities. Being an official, *Ranefer* has a duty to present gifts to the king annually and has contracted a sculptor to create a statue of the king for this year's tribute. Last year he had given a battle-chariot and associated leather harnesses, a gift which was certainly appropriate to his occupation and rank.

In part 4 we are given an insight into the military and diplomatic side of *Ranefer* and his time away from home on various missions for the king. We learn that he has fought in Syria and on one occasion incurred an injury which has left him with a limp. At home, one of his duties is to periodically serve in the king's bodyguard stationed in the barracks in the northern part of the city. As a loyal and trusted servant to the king he has been appointed as an official messenger which takes him on long tours to Babylon, Canaan, and Syria. Whilst away he writes regularly to his family and has become conversant in Akkadian, no doubt a relief to his wife *Satia*. During his time away *Satia* continues to run the house with her steward *Huy*. She is concerned about the safety of her husband and prays to two of the old gods, Hathor and Ptah, for his protection. On his return, *Ranefer* presents gifts to Pharaoh including several female slaves and is in turn rewarded by Pharaoh with a collar of gold discs and an increased share of food offerings from the House of the Aten.

Part 5 examines *Ranefer*'s possessions and wealth beginning with a house in Memphis and a country estate in addition to plots of land used to grow crops. The estates are managed by a steward named Nebmehy who is in regular contact with *Ranefer* and periodically sends grain and one or more cows to the Amarna estate. *Ranefer*'s share of food offerings received from the House of the Aten include bread, beer, meat, and fowl, which are collected by *Ranefer*'s men under the control of *Huy*. All of this takes place with the usual administrative paperwork. *Ranefer*'s wealth is mainly centred on his land, produce, and people. The only possessions of value are those received from Pharaoh or the palace and those belonging to his station i.e., chariots, horses, and equipment. He has built up a store of material supplies which can be used by craftsmen to produce domestic objects or in the case of some gold sheet for the decoration of his and *Satia's* coffins which will be stored within the house.

Part 6 focuses on some of *Ranefer*'s dependants, the family of *Efankh* a widower and maker of jewellery, his daughter *Heket* (7) and son *Khay* (8). *Efankh* has a back injury from previous labour in the quarries and *Heket* was born with a hip dislocation making it difficult to walk. The family work in the manufacture of linen (*Heket*), glass beads, and quern-stones (*Efankh* and *Khay*) and are provided with a share of food offerings passed to them from *Ranefer*'s quota. There work is hard and even with the food supplied to them they are pale and thin.

Part 7 takes us back to the main house and the birth of *Satia's* latest baby, a boy who will be named *Nedjem-Aten* after a period of forty days has passed. The birth is described in terms of the rituals enacted to protect the baby from harmful spirits and again we see the inclusion of one of the old gods, Bes, as part of the rites. A celebration is prepared, and two cows are offered to the House of the Aten with the expectation that enough will return for their guests at the banquet. The guests are received in the front reception room and gifts are presented to the child, the party then moves to the central reception room where musicians are playing, and food and wine is served. Outside the lesser household members have surplus food brought out to them so they too can celebrate the new baby.

Part 8 brings the sickness into the story in the form of a plague which may have been ravaging Egypt during this time, evidence of which may have been found at Amarna (Panagiotakopulu 2004). The story talks of women mourning, and incense being burnt along with magic incantations to ward of the disease. We hear of the trauma people are going through to bury their dead and the tragic death of *Heket* and *Kay* through the night. At the age of two *Ranefer* and *Satia's* son *Nedjem-Aten* succumbs to the disease and the family are distraught.

Part 9 takes us through the last days of Amarna two years after the new king Tutankhaten was crowned. The people wear faience rings with his name on to honour him, 28 of which were found at Amarna between 1921-31 (according to the Amarna Finds Database). As the king is seated at Memphis the city is being wound down in its official capacity and the administrative elements are relocated to Memphis. *Ranefer* is away fighting in Syria and there are rumours of defeat. *Satia* is organising the move to their estate in Memphis and the shutting down of the property at Amarna. Looters have already robbed the graves, and no one buried there is spared. The story ends with the family leaving by boat never to return.

4.2 Transferring the story to a VR Experience

The story of *Ranefer*'s family covers the later years of the Amarna period but one which would have common elements to families throughout the city and its lifetime. As a story it is linear and could be told using traditional methods such as an illustrated book or comic, a film, a tv series, or an animation.

The translation of this story into a VR experience can be done in a few different ways. It must be noted that a detailed breakdown for every scene would be beyond the scope of this thesis and as such is represented here as an outline design. The most basic form would be as a 360-degree film viewed through goggles allowing the viewer a choice of direction whilst the film was playing. If the film were recorded as a 360-degree stereoscopic 3D film, there would be an extra level of immersion experienced. However, to transfer the story into fully immersive and interactive virtual reality experience would require the construction of a series of linked 3D environments, one for each location mentioned in the story, see Table 2 and Figure 172. The narrative elements could be delivered as either a voice over or through interaction with non-player characters (NPC's) adding to the complexity of the construction and would require several elements to be developed:

- Individual locations present in the story, based on the events.
- Primary interactive assets for each location (always present)
- Secondary interactive assets for reoccurring locations (scene dependant).
- All individuals (characters) and any costume changes.
- Dialog for all characters.
- Animation for each character.
- Assembly of environment, models, characters, animation, and dialogue.

The player point of view can be that of an observer or participant. The observer point of view needs no explanation within the story as the player could effectively be a disembodied entity within the scene. However, if the player is to be a participant then they need to take on the role of a character within the scene. In the story of *Ranefer* the player could take on the role of his eldest son, *Any*, with the pretext of learning to be the master of the estate after his father. This would allow him access to each of the events in the story and for the parts where *Ranefer* is away on foreign affairs he could be reading the correspondence from his father with his mother. Learning to be master of the estate would also enable the player to interact with the craft-based events.

Chapter	ID	Event	Location
C2 Ranefer's household	1	A New Home	Ranefer's house
	2	The Extended Household	Ranefer's Village
C3 Respecting Ranefer	3	Words of wisdom	Ranefer's house
	4	Ranefer's Tomb	The Rock Tombs
	5	The Shrine	Ranefer's house
	6	The Judge	Ranefer's house
	7	Paying Annual Tribute	Thutmose's house
C4 Away from home	8	The Barracks	The Barracks
	9	Pharaoh's Envoy	Ranefer's house
	10	The Old Ways	Ranefer's house
	11	Ranefer's Return	Ranefer's house
	12	Ranefer's Reward	The Palace
C5 Ranefer's rewards and wealth	13	The Delivery	Ranefer's house
	14	Food Offerings	The Temple
	15	Personal Possessions	Ranefer's house
	16	The Coffins	Ranefer's house
C6 Heket and Khay	17	The Dependants	Ranefer's Village
	18	Regular Tribute	Ranefer's Village
	19	Home Industry: Linen	Ranefer's Village
	20	Home Industry: Glasswork	Ranefer's Village
	21	Home Industry: Quern-stones	Ranefer's Village
C7 Satia's Baby	22	Preparing for the Birth	Ranefer's house
	23	The Birth	Ranefer's house
	24	The Naming	Ranefer's house
	25	A Celebration: The Guests	Ranefer's house
	26	A Celebration: The Household	Ranefer's house
C8 The Sickness	27	Death in the Neighbourhood	Neighbourhood
	28	No one is spared	Central City
	29	Ranefer and Satia's Loss	Ranefer's house
	30	The Watchman	Neighbourhood
	31	Efankh's Loss	Ranefer's Village
C9 The Last Days	32	The Royal Decree	Central City
	33	Another Tour of Duty	Ranefer's house
	34	Packing up the House	Ranefer's house
	35	The Boats	Riverside Moorings
	36	Transfer the Dead	The Rock Tombs
	37	The Grave Robbers	Cemetery
	38	A Last Goodbye	Nile Boat

Table 2, list of events identified in the story of Ranefer

Figure 172, locations identified in Ranefer's story and mapped using QGIS

The initial introduction could be a cut sequence to orient the player within the environment and to introduce the characters. The player would explore and interact with the environment using a VR controller or mouse, looking at an object could bring up a description if required. This should be designed to increase the players knowledge of the environment and events. All of this would be assembled within the game engine level editor by the level designer but in order to do so the visual assets need to be created. With such a large environment to build it is essential that modelling is done in an efficient manner.

It can be seen through the location map (Figure 172) that the story takes place in locations across the city and that large sectors would need to be constructed at a comparatively high level of detail to allow

for a seamless visual experience whilst moving from one site to another. This puts increased stress on the engine and the workload of the development team. With one story plotted throughout the city it is possible for a series of routes to be established and contained using visual ringfencing thereby reducing the development workload. This would involve the positioning of 3D models to visually obscure areas of the city which are not required for the story and can either be left barren or utilise lower quality models representing the unused sectors of the city. However, if further stories were to be implemented or a decision was made to develop the environment as an open world where the player can roam freely throughout then the associated locations would also require construction at the appropriate level of detail increasing the complexity of the environment. The next chapter looks at these issues in more detail showing how design implementations used to aid game engine efficiency can increase asset development workload.

5 AmarnaXR Development Observations

The previous chapter analysed how a suitable story can be broken down into elements for construction within a game engine. Modern game engines such as Unreal Engine 4 (Epic Games 2020a) and Unity3D (Unity Technologies 2020) can now display complex 3D environments in real-time as long as they are constructed in an efficient manner. There are several development optimisations which must be implemented during the construction of all 3D assets which make up the environment. This chapter looks at how this could be achieved and what problems must be overcome with regards to the 3D construction. The fundamental issue here is not just the size of the site but how to develop a model which can transition between a large range of visual scale levels. Due to the scope of this project the modelling is focused on environment construction and not character modelling.

5.1 Level of Detail (LoD)

Every geometric model in the level must be optimised in terms of polygon density and texture map resolution to enable smooth movement throughout the environment. Real-time scene detail is limited by the hardware. Modern graphics cards consist of a graphics processor unit (GPU) incorporating multiple processor cores working in parallel and supported by large memory banks designed to hold scene data such as geometry and texture maps. Increasing the number of GPU cores and memory size allows for more data to be processed which in turn enables higher detail to be presented to the player.

The LoD for any scene object is determined by its size on screen and as such is linked to the distance from the player's position. Implementing LoD in a scene requires the creation of multiple resolution models for the same object with the highest detail level ascribed to LoD0 and lower detailed versions LoD1, LoD2, etc., see Figure 173. When placed within a scene the LoD0 will be the version presented near the player. As the player moves away the LoD0 will be swapped out for the lower LoD's each based on distance, see Figure 174.

Object textures also have a LoD implemented through a process known as mipmapping where each high-resolution texture map has a series of smaller copies each being half the dimension of the previous. Game engines all include the option to generate mipmaps automatically when importing objects from external 3D modelling software. Figure 175 shows two variations on mipmapping. Controlling the LoD within a scene is fundamental to ensuring smooth movement with no visual artefacts, without it large scenes could not be developed.

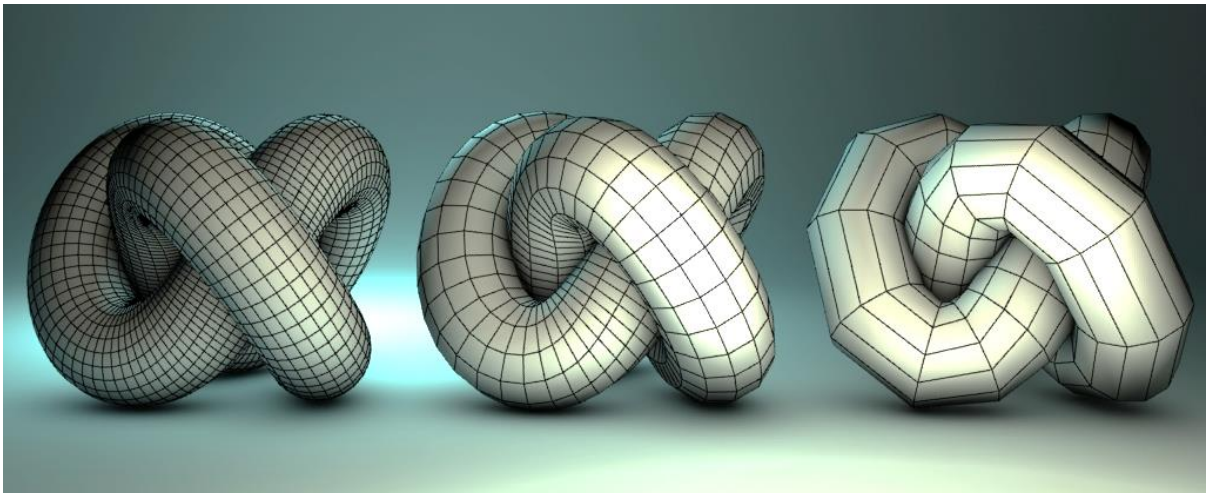


Figure 173, level of detail example – LoD0 11,136 polygons (left) LoD1 2880 polygons (middle) LoD2 840 polygons (right)

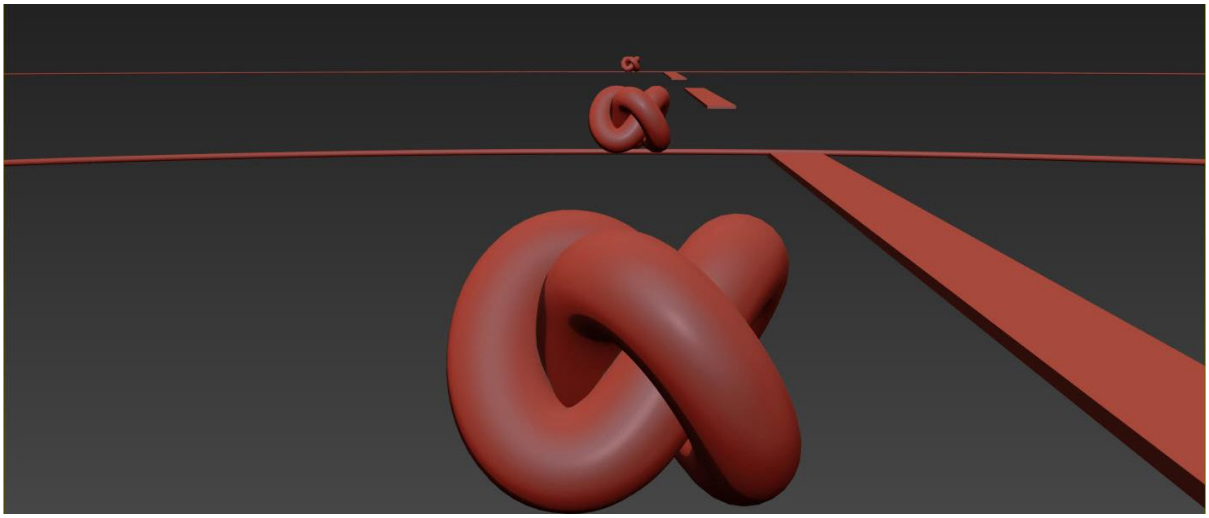


Figure 174, level of detail with distance – LoD0 (bottom) 1-unit distance LoD1 (middle) 5-unit distance LoD2 (top)

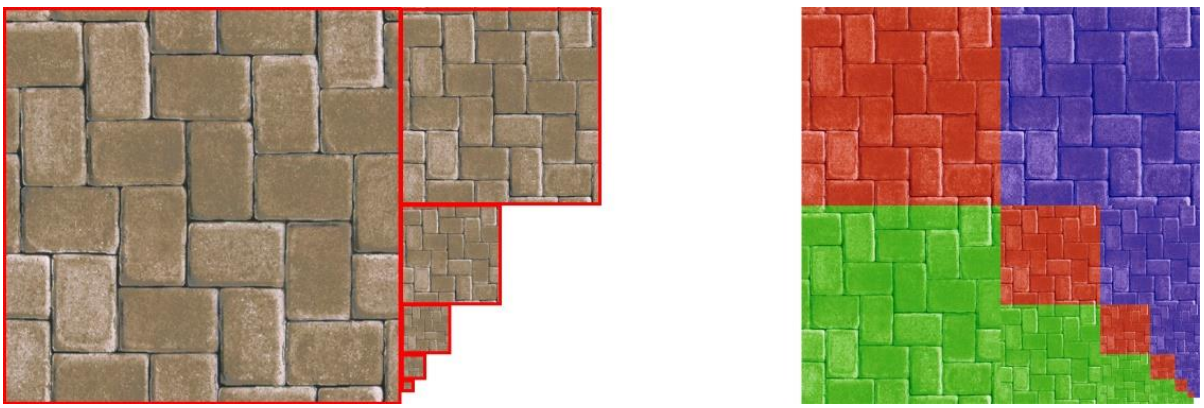


Figure 175, mipmap downsizing (left) and colour channel (in pseudo colour) mipmap downsizing (right)

5.2 Instanced Objects

Another essential scene optimisation method is the use of instanced objects. This involves scene shape analysis by the 3D artist to find any repetitive geometry. An example of repetitive geometry would be a column which may be used hundreds of times within a scene. To save on memory space and processing one column would be created with the appropriate LoD's and then placed as an instanced object within the scene. The game engine then only needs to reference one object dataset when drawing many hundreds in the scene. By creating architectural parts, it is possible to construct many variations of buildings whilst keeping hardware overheads low.

5.3 Collision detection

To prevent player movement through objects everything must have a collision cage applied. This is a low-resolution model cage which is invisible to the player and surrounds the art asset providing a solid barrier to the player and all other objects within the scene. The cage allows for basic physics to be applied to an object in the form of gravity and rigidity. Examples include objects falling or bouncing and clothes on a washing line to blow in the wind. The cage can be created by the engine on object import or as an edited mesh.

5.4 Scene Scale

For a project as large as Amarna where the area to be constructed is measured in kilometres there is going to be an issue with geometry overload. Managing the detail at different visual scale levels is paramount importance and an understanding of each scale level is essential.

5.4.1 Global Scale

Whist not strictly encompassing the planet this is the topmost level within which everything resides, it is the whole ecosystem relating to the Story World. It includes as a base the environmental topography and the cityscape. Terrain can be constructed using a grayscale height image where white corresponds to the highest point and black the lowest. For large areas data from aerial surveys can be used in the form of Digital Elevation Models (DEM) which are 16-bit grayscale images giving 16,536 levels of height derived from the tonal range. If an 8-bit grayscale image is used, then it is limited to 256 height levels which will create visible steps in the resulting model. For this thesis, the terrain height data was exported from QGIS as a series of tiled grayscale images with a 1m per pixel scale for direct import into the Unreal Editor (UE4). Within a game engine the DEM data is applied to a polygon mesh grid and used to upwardly displace the vertices of the mesh creating a terrain. Figure 176 shows the northern section of the Amarna site as 3D terrain textured using satellite imagery from Bing Maps. Figure 177 through to Figure 180 show satellite imagery and DEM data converted into 3D model geometry for import into Unreal Engine 4 (UE4).

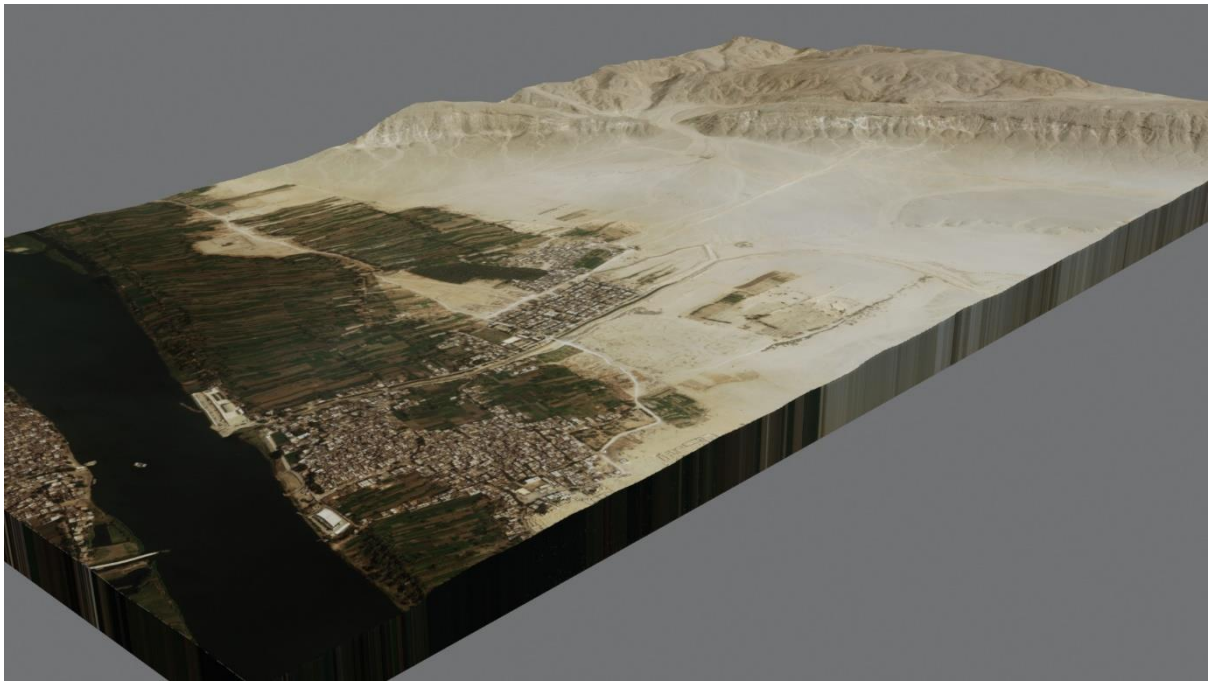


Figure 176, Amarna terrain constructed from height data combined with satellite imagery from Bing maps

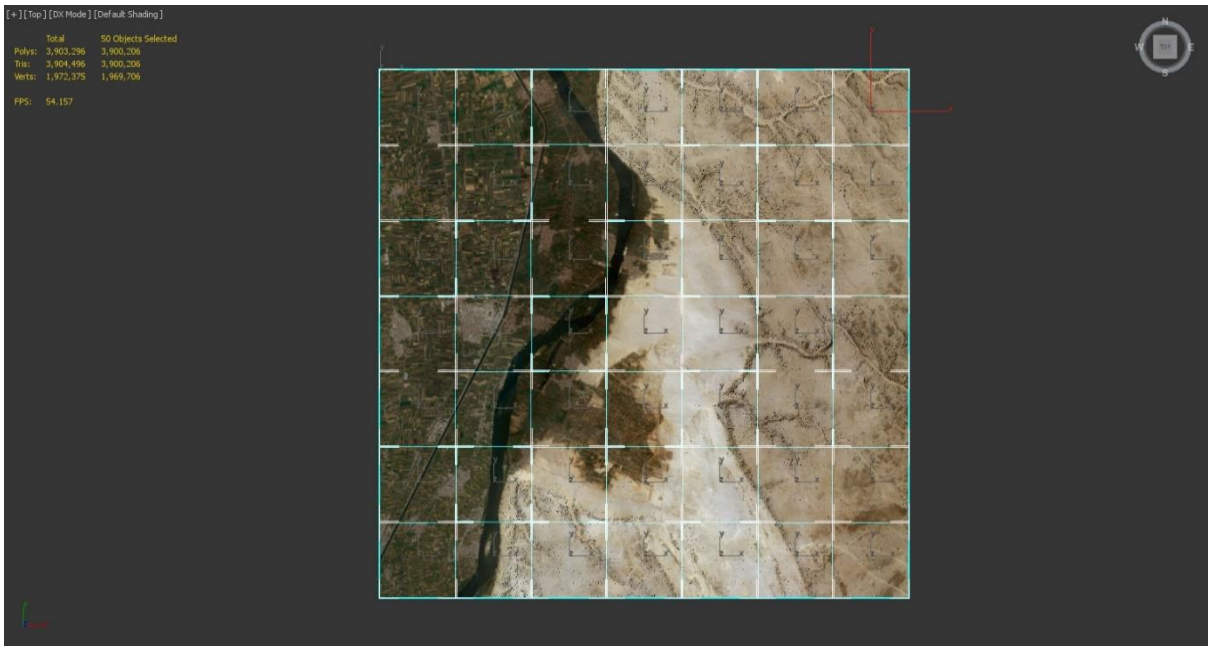


Figure 177, satellite imagery and height data exported from QGIS to 3dsmax as tiles (top view)

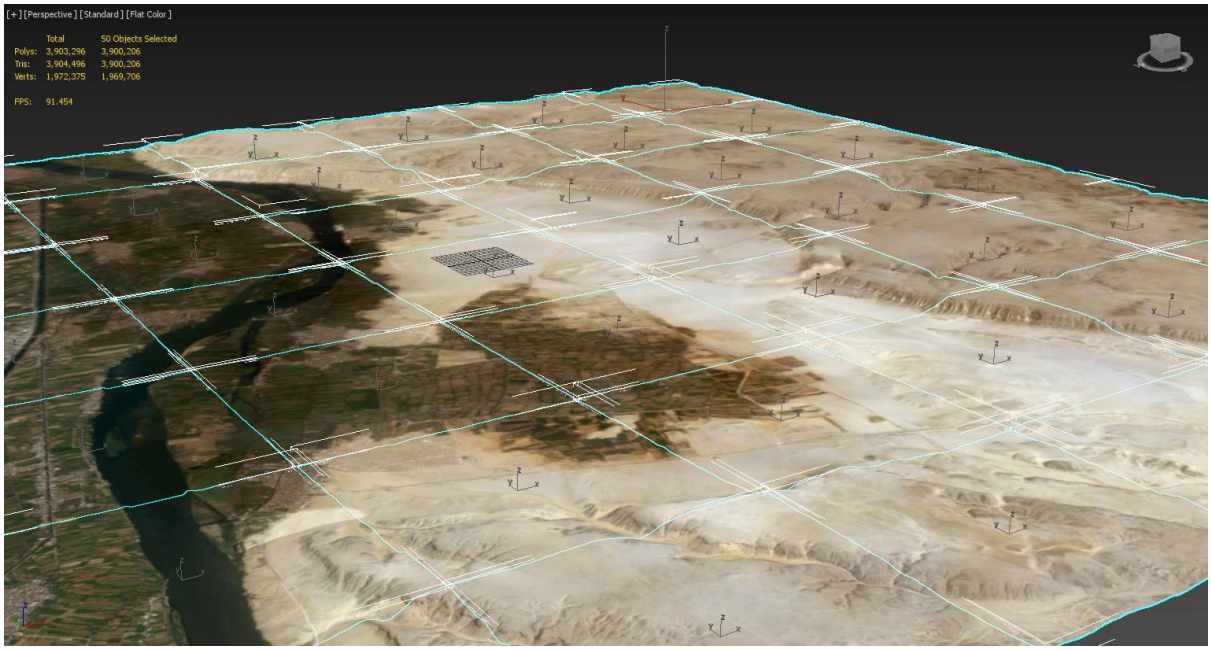


Figure 178, satellite imagery and height data exported from QGIS to 3dsmax as tiles (perspective view)

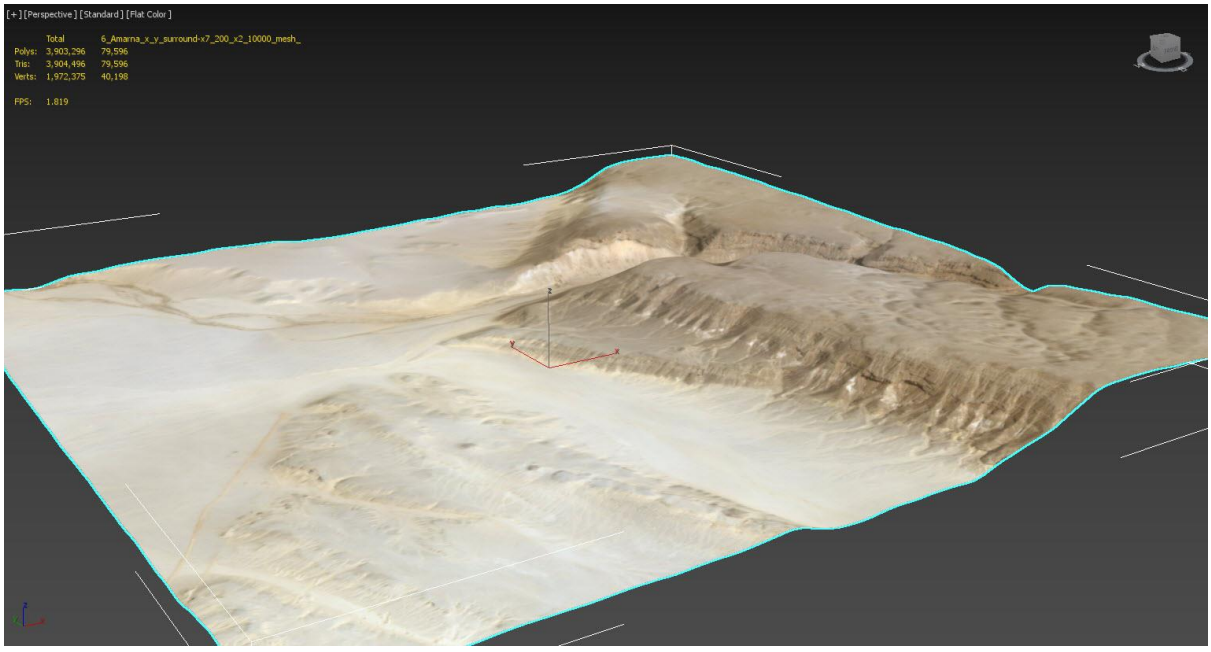


Figure 179, satellite imagery and height data exported from QGIS to 3dsmax as tiles (single tile)

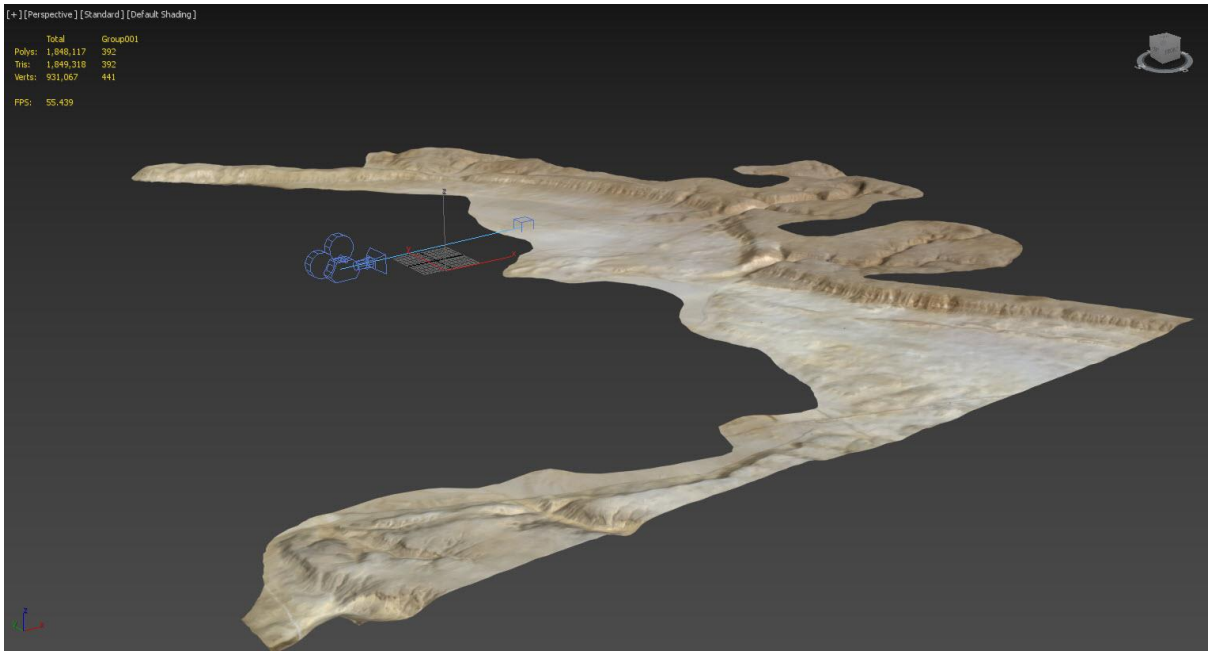


Figure 180, edited cliff geometry reducing the polygon count down from 4 million to 1.8 million polygons in partial optimisation

At this visual scale major structures would be present, each at their lowest LoD due to their distance from the player. Small scale objects would not be viewable at this scale and would be excluded by the engine to maintain efficiency. The Level Designer would normally use this scale to determine the placement of procedural flora and fauna along with environmental conditions such as dust, rocks, fog and sunlight. Major dynamic features such as the river Nile would also need to be implemented.

5.4.2 Neighbourhood Level

The next scale level is the street or local community zone. In the case of Amarna this is the collection of close-knit houses often referred to by the site archaeologists as the estate or estate village. Figure 182 through to Figure 186 shows experimental housing placement in UE4 using the survey maps as placement guides. The neighbourhood level allows much of the distance structures to be occluded by the local housing including walled areas and vegetation. The neighbourhood level creates a form of enclosed and manageable space for the player to move through. Everything outside this range will be at a lower LoD. House interiors will not be present, this is predominantly an exterior space. With a large-scale environment like Amarna problems arise when moving from a global view to a ground view as the surface texture detail is not at enough resolution for closer inspection (Figure 181). This is where the large-scale terrain materials need to adapt to the change in scale switching to local tiled textures which can perform efficiently and maintain visual fidelity.

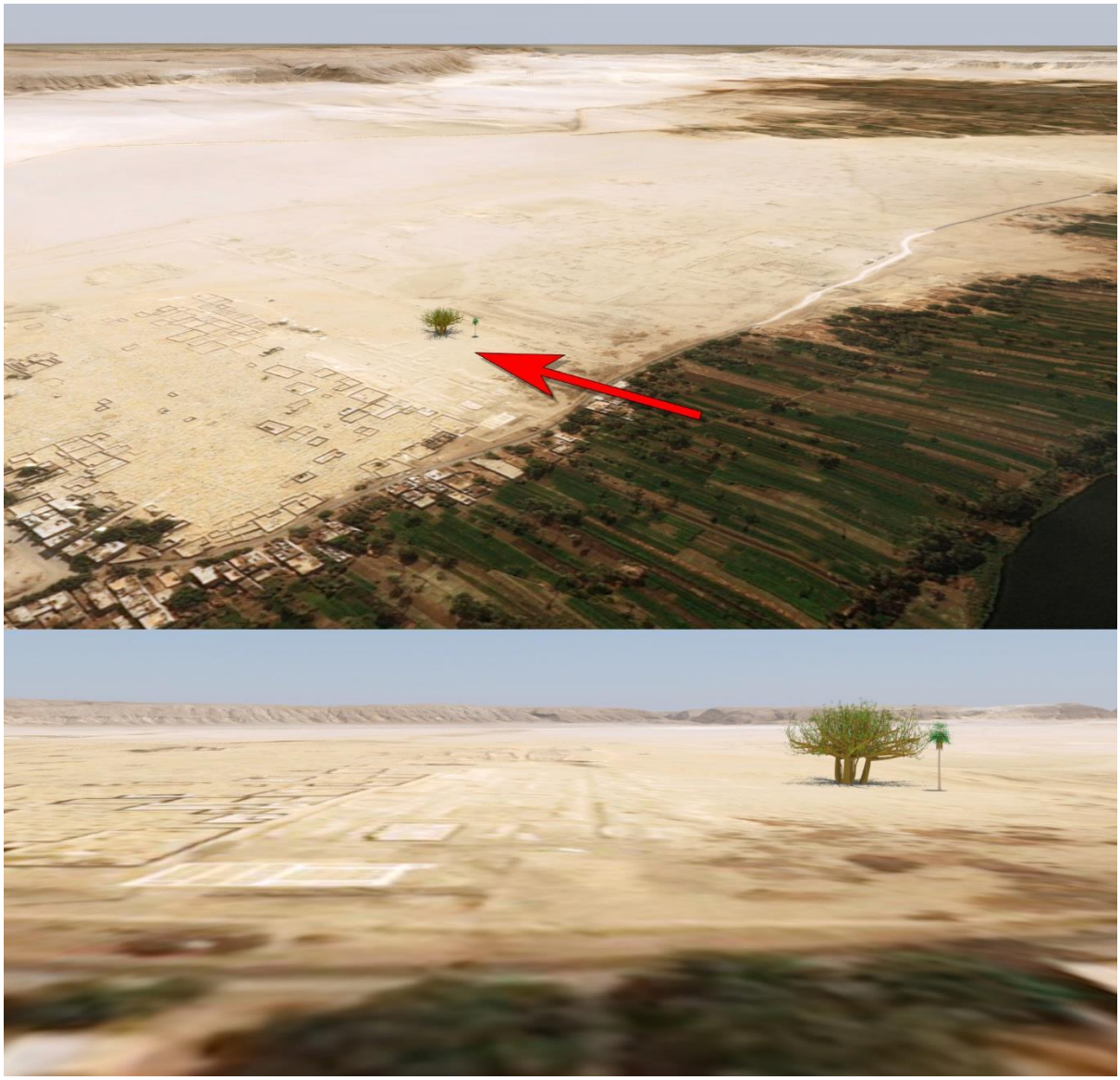


Figure 181, problems in terrain texture resolution when transitioning between visual scales

The use of instanced objects is important at this level as there can be a large amount of geometry present and the scene must be optimised and tested regularly to maintain efficiency. Figure 187 through to Figure 194 show instanced assets being used in the construction of the new Amarna Great Palace.

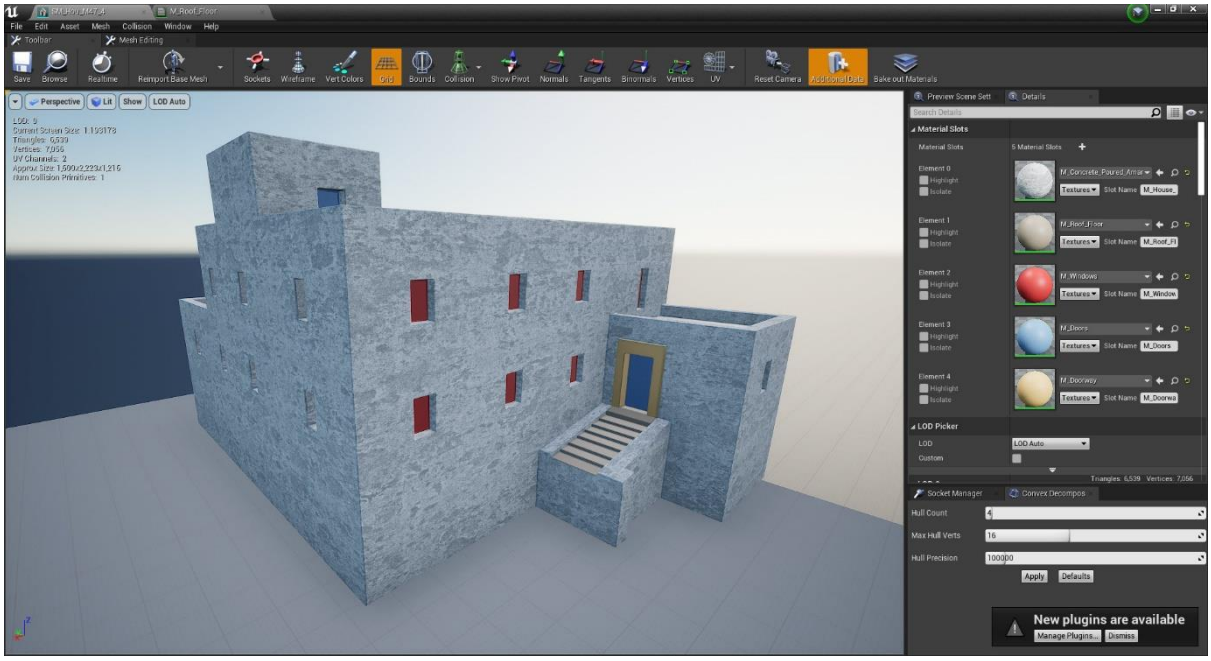


Figure 182, low resolution box-modelled house imported into UE4

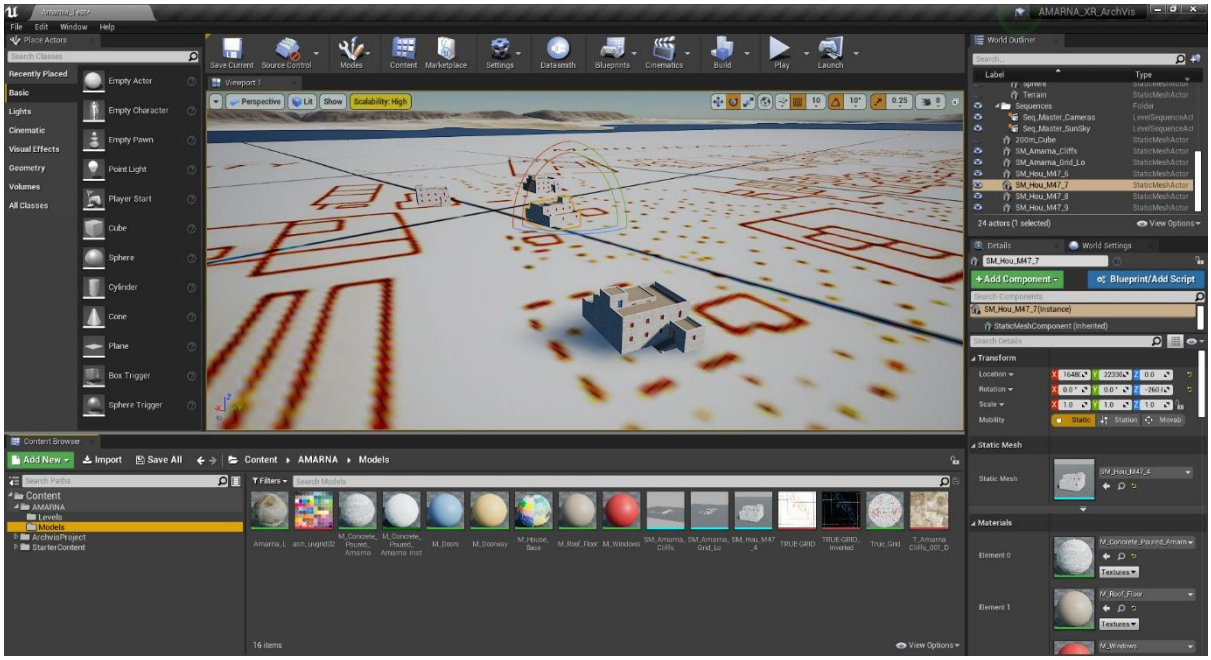


Figure 183, Amarna cliffs and temporary house placement test in UE4

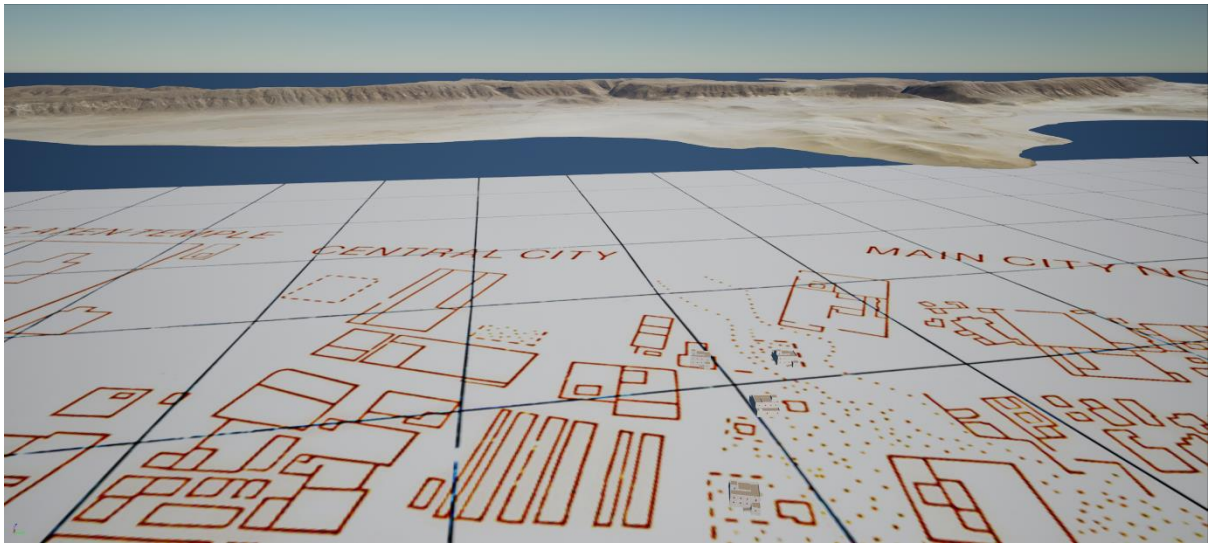


Figure 184, temporary house placement test in UE4 showing Kemp & Garfi survey map implemented as a guide

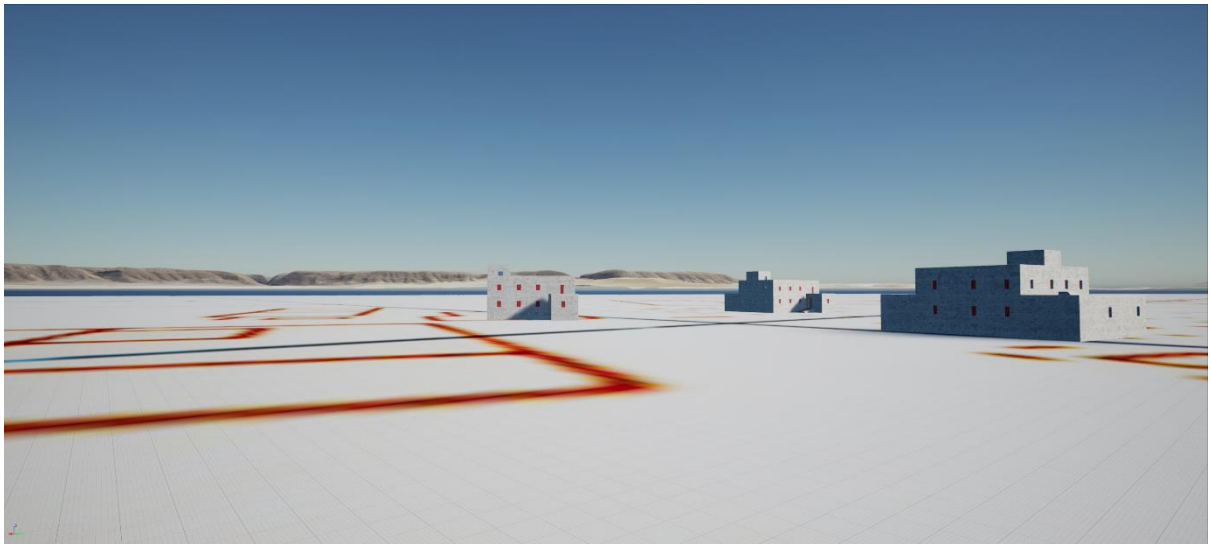


Figure 185, temporary house placement test in UE4

Figure 186, third person player view of the Amarna cliffs at a distance of 2.5km in UE4

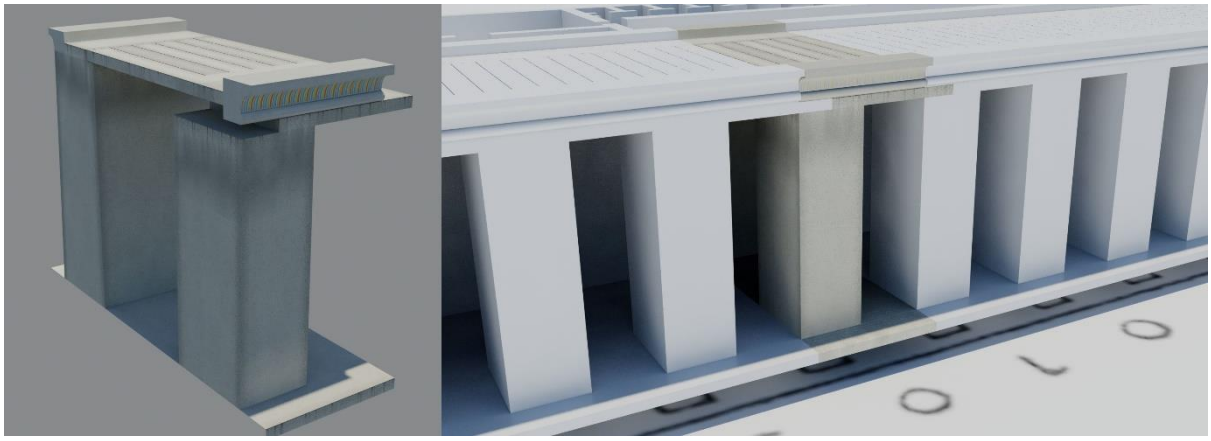


Figure 187, an assembly of instanced objects (left) used to construct a larger colonnade (right)

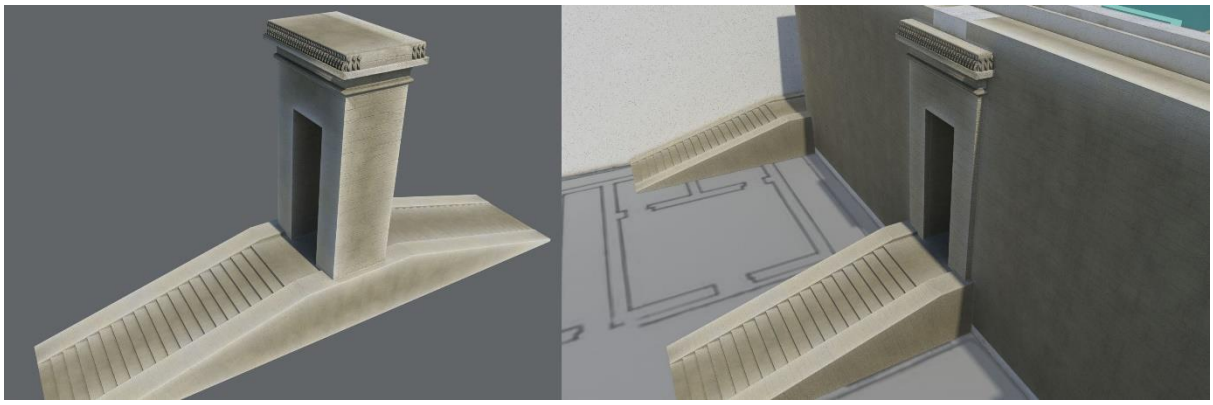


Figure 188, an assembly of assets forming a stairway and doorway (left) in situ (right)

Figure 189, a series of assets based on fragments found at Amarna

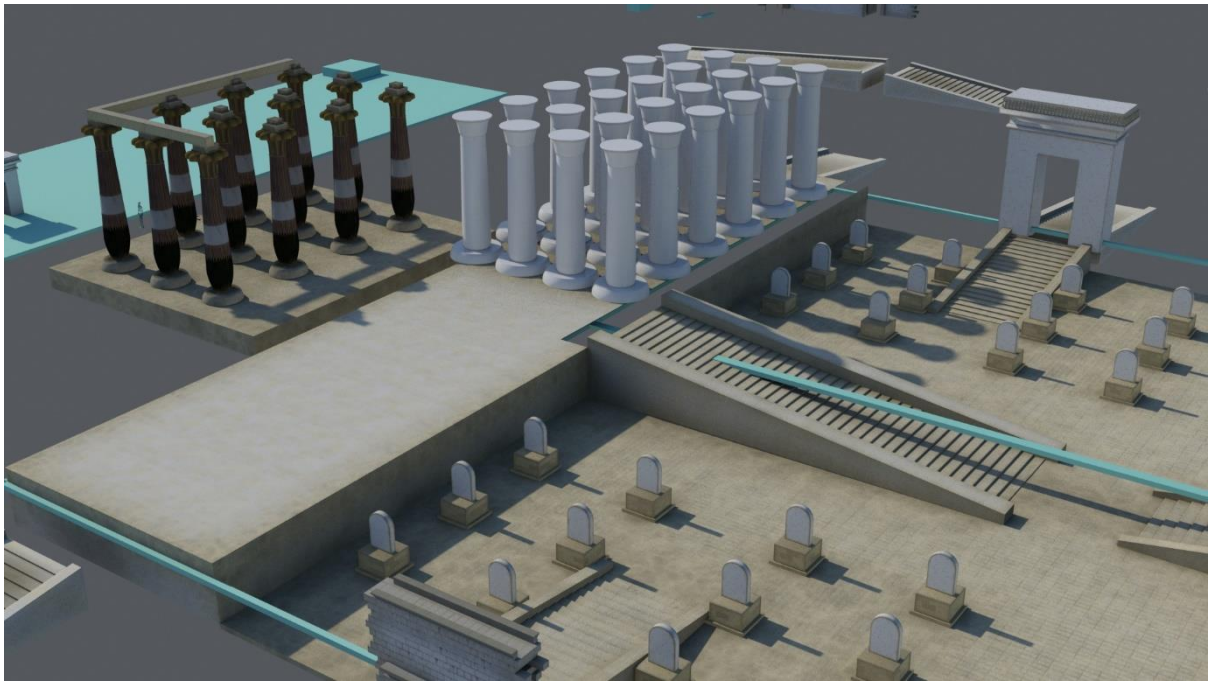


Figure 190, instanced assets (columns, stelae, ramps, doorways, etc.) placed within the scene

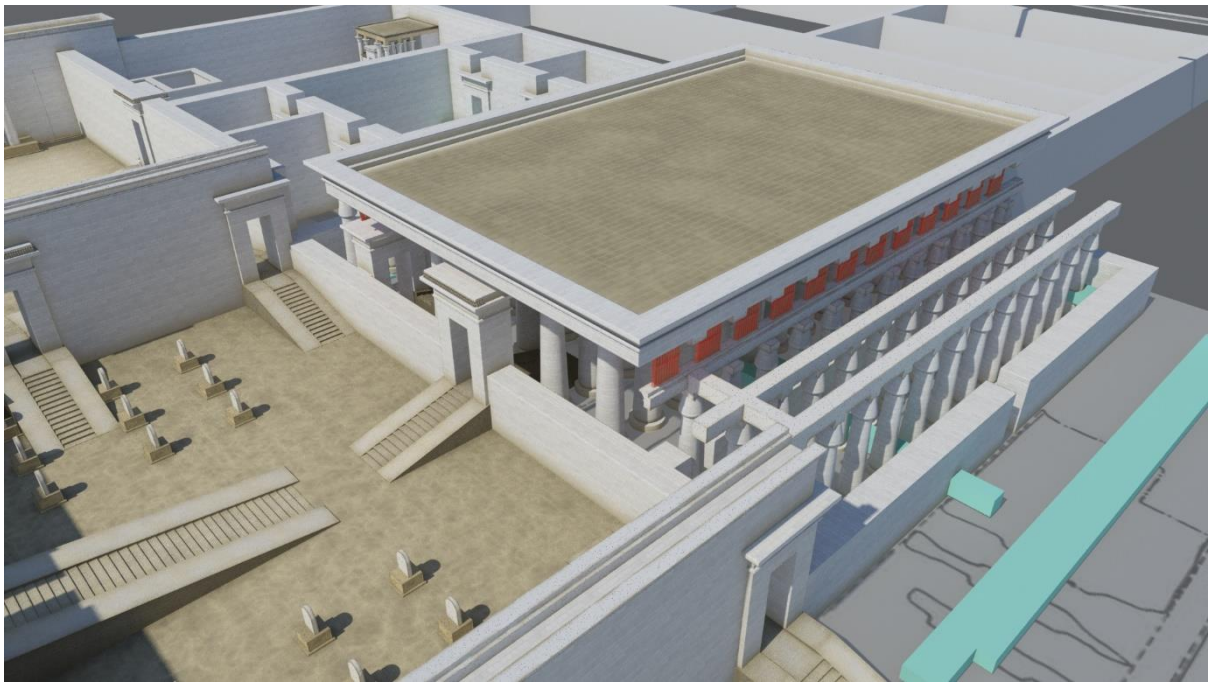


Figure 191, instanced assets placed within the scene forming part of an interior space

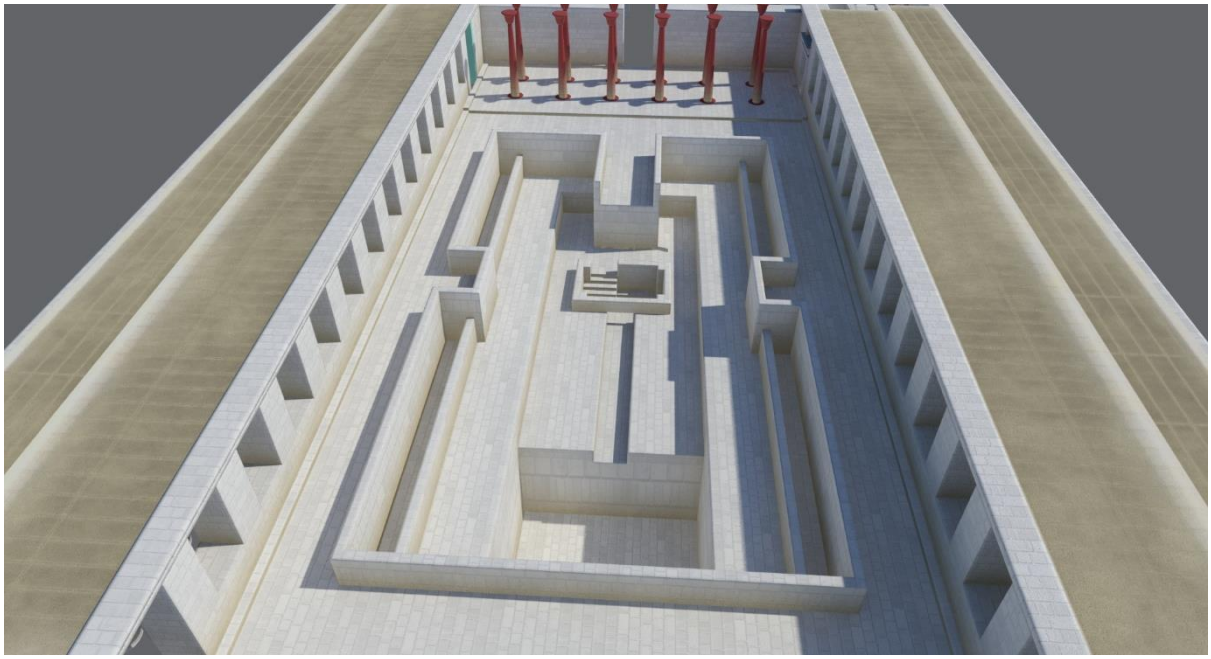


Figure 192, the North Harem pool and sunken garden area constructed from instanced objects

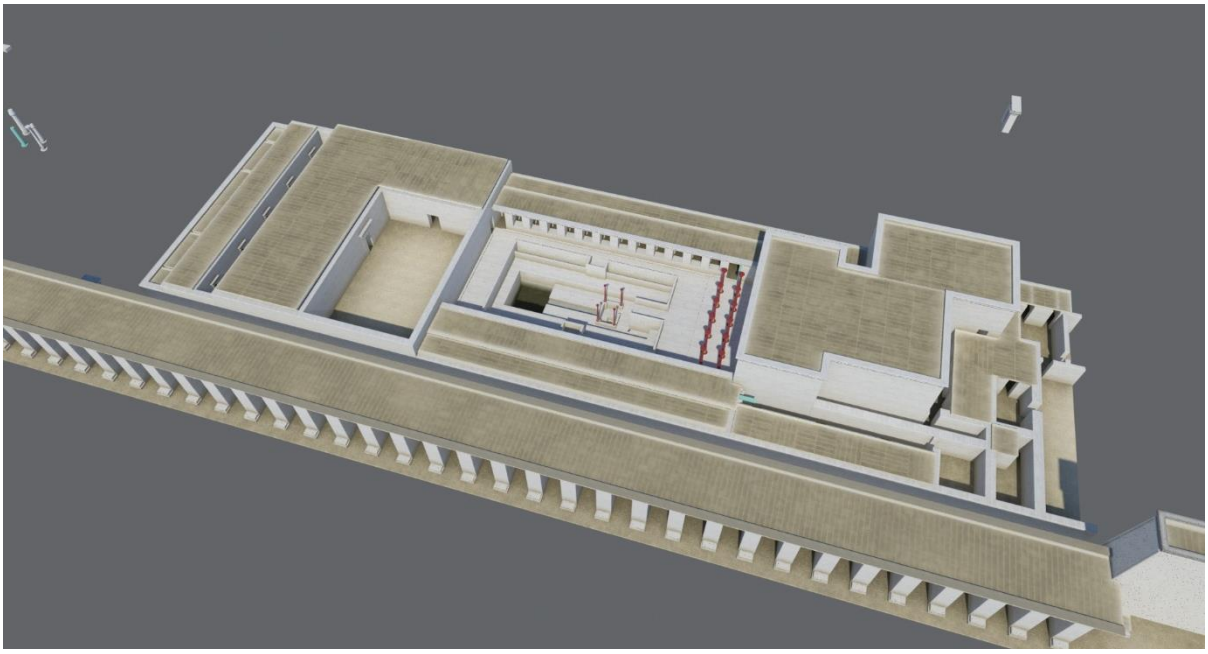


Figure 193, the North Harem in situ. Note miscellaneous instanced assets (top left / right) ready for placement

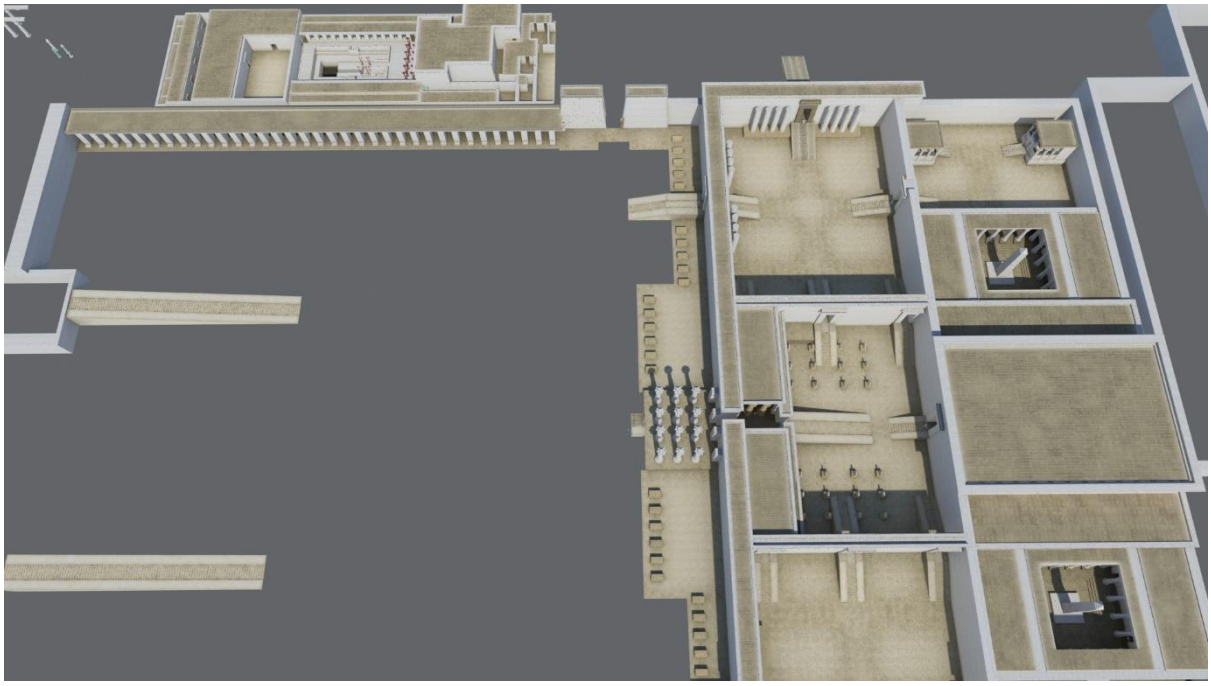


Figure 194, the Great Palace3D model work-in-progress as of January 2020

5.4.3 House Level

The house level may incorporate the immediate grounds but is mainly the interior. There are several issues to note when transitioning between the street level and house interior. The lighting will require attention as all external scenes will be lit by the sunlight system whilst the interiors will be lit by either dynamic lighting from candles or fires. Interior lighting may need to be supplemented by additional lights placed externally at the windows. Interior spaces are already in shade so additional shadows may need to be baked into the interior textures. Figure 195 shows how baked shadows can increase the visual aesthetics of an interior making it less flat in appearance and more 3D. At this stage it is important to begin some form of personalisation by including imperfections in the modelling, wear & tear, and dirt, so it looks lived in.

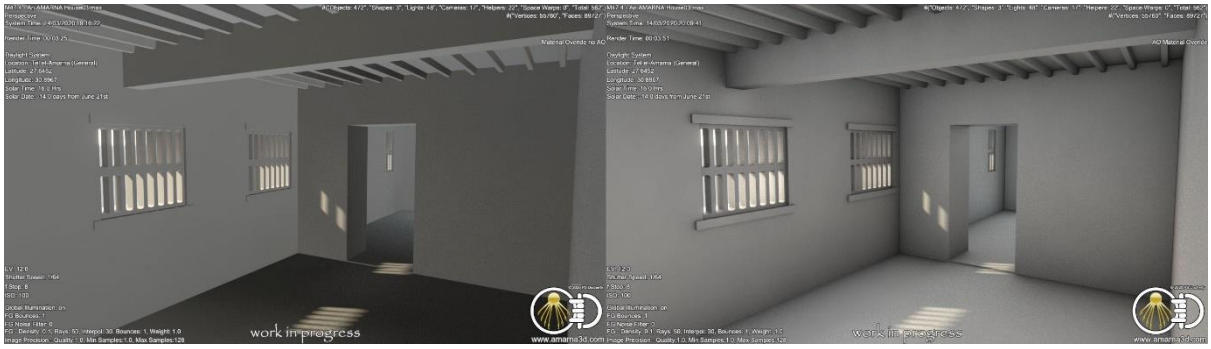


Figure 195, interior of Amarna house M47.4 (left) with baked internal shadows applied (right)

5.4.4 Dynamic Object Level

This can be considered the artefact level created in most cases from the drawings and photographs present in the finds catalogue. Dynamic objects will normally include real-world physical attributes in the form of rigid-body or soft-body dynamics. Both rigid-body and soft-body react to any collision and are affected by forces such as gravity and wind. Soft-body objects can also deform like cloth or flex like rubber. All household items, personal belongings, tools, etc. belong to this scale level.

5.5 Procedural Objects

Some scene objects can be implemented through procedural algorithms which can be then generated automatically by the engine. In addition, these objects can also be given procedural animation reducing the animator's workload. The main use for procedural objects is in plant and animal generation. It is possible to define areas of plant growth within the scene which the engine then dynamically assigns a LoD to as the player moves through. Animals can be distributed in a similar way and the individual animation will adapt to the environment. For example, birds can be programmed to fly in formation, fish swim within boundaries, and deer feed and run whilst constrained to the terrain topography as shown effectively in the Open World Kite Real-Time Demo in UE4 (Epic Games 2015).

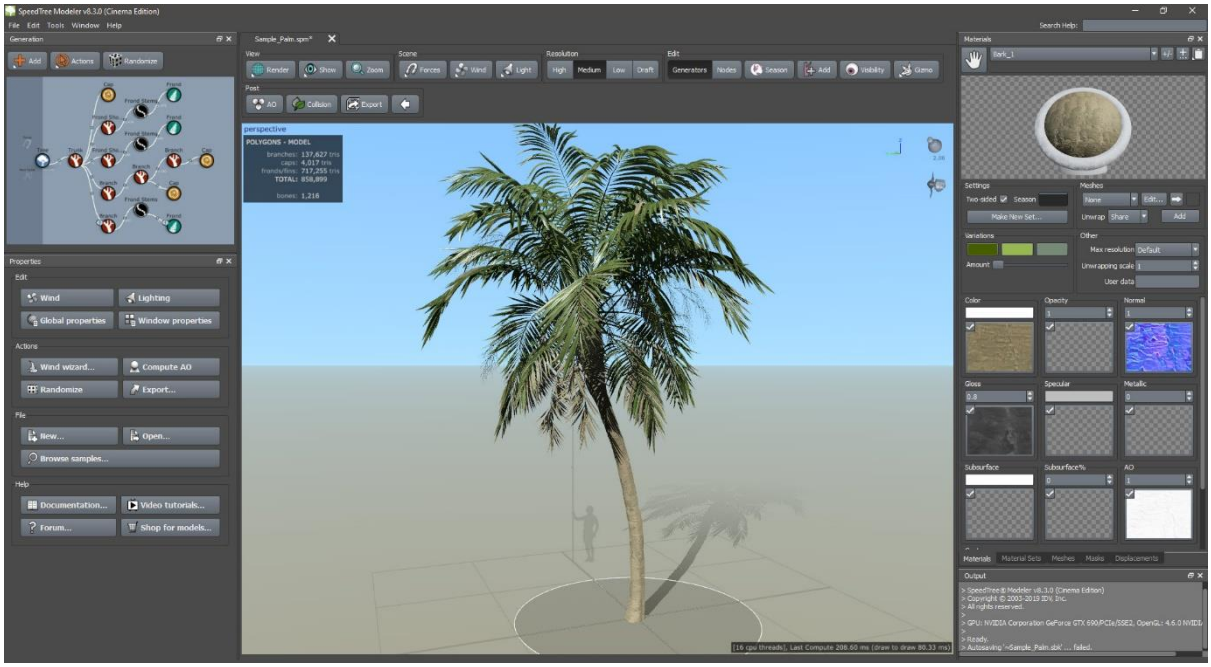


Figure 196, the SpeedTree interface for creating 3D plant geometry (Interactive Data Visualization Inc. 2020)

5.5.1 Botanical Modelling

Plants can be modelled using specialist software such as SpeedTree (Interactive Data Visualization Inc. 2020). SpeedTree enables a semi-procedural modelling approach allowing for parameters to be setup for plat growth whilst also allowing for manual editing of features (Figure 196). The resulting plants can be exported as animated meshes for use in other modelling software or imported into a game engine through a native SpeedTree format which allows the engine to take control of wind deformation and growth parameters.

5.6 Photogrammetry

Photogrammetry is an extremely useful tool not only for creating a digital archive of artefacts, excavations, and standing buildings, but also for 3D reconstructions. However, if is used for artefacts, then the capture will record the artefact in its worn or fragmented condition. For a reconstruction the artefact will be required to look as it was when first manufactured or after a short period of use. In many cases it is more efficient to construct a new model by hand based on the data. When photogrammetric models are used, they will need to be edited to optimise the surface topology making a clean and efficient version for use in the game engine. In the case of statues this is often the best method as it allows for an accurate representation of the original work. Figure 197 shows a photogrammetric reconstruction of the Nefertiti bust in 2014 (Docherty 2015) and one of the Colossi of Akhenaten; both undergoing surface topology editing to create cleaner models and reduce the polygon count from millions to a few thousand.

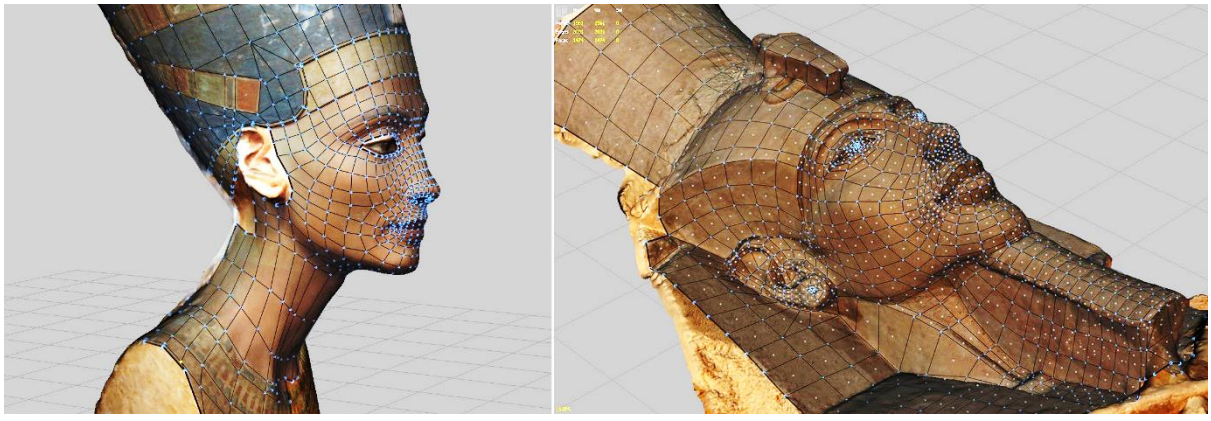


Figure 197, edited 3D surface topology from dense photogrammetric mesh. Nefertiti bust (left), Colossi of Akhenaten (right)

In the games industry photogrammetry is rapidly becoming the recommended method for texture creation alongside procedural materials. Previous methods relied on general photography or hand drawn textures. Photogrammetry enables the real-world environment to be merged into the virtual one. The advantage of photogrammetry over photography is the ability to extract 3D surface detail and physical based colour information which can be used for physical based rendering (PBR) within a

game engine (McDermott 2018). The base colour (albedo), surface roughness (micro-surface detail), and dielectric properties (shininess) can be extracted as 2D images and by recombining them with a bump or displacement map will result in a realistic depiction of the original material, Figure 198 and Figure 199.

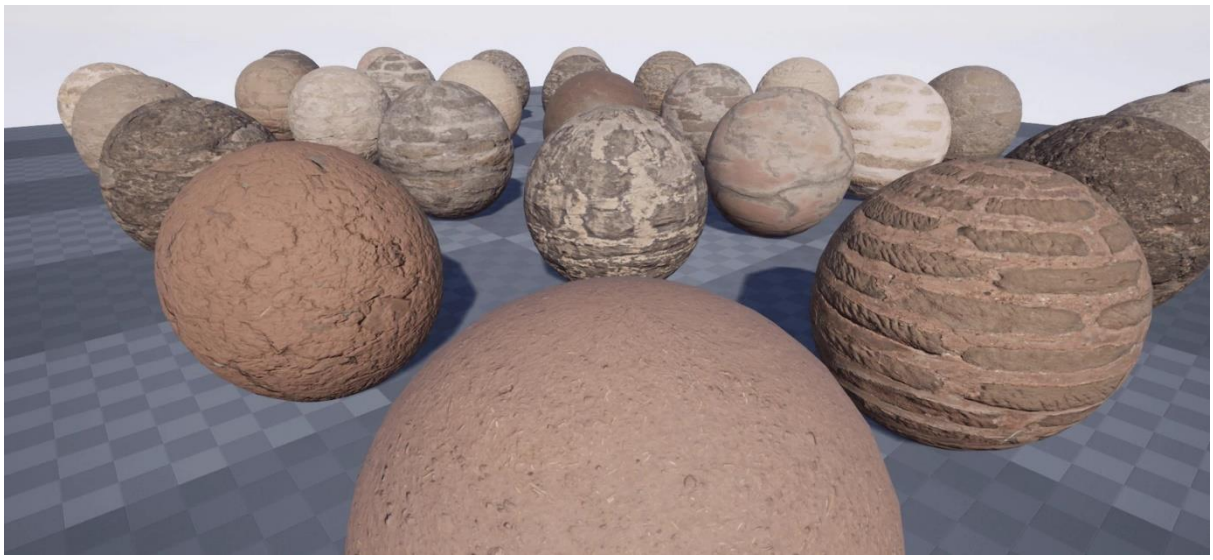


Figure 198, examples of photogrammetric textures from the Quixel Megascans collection (Epic Games 2020b)

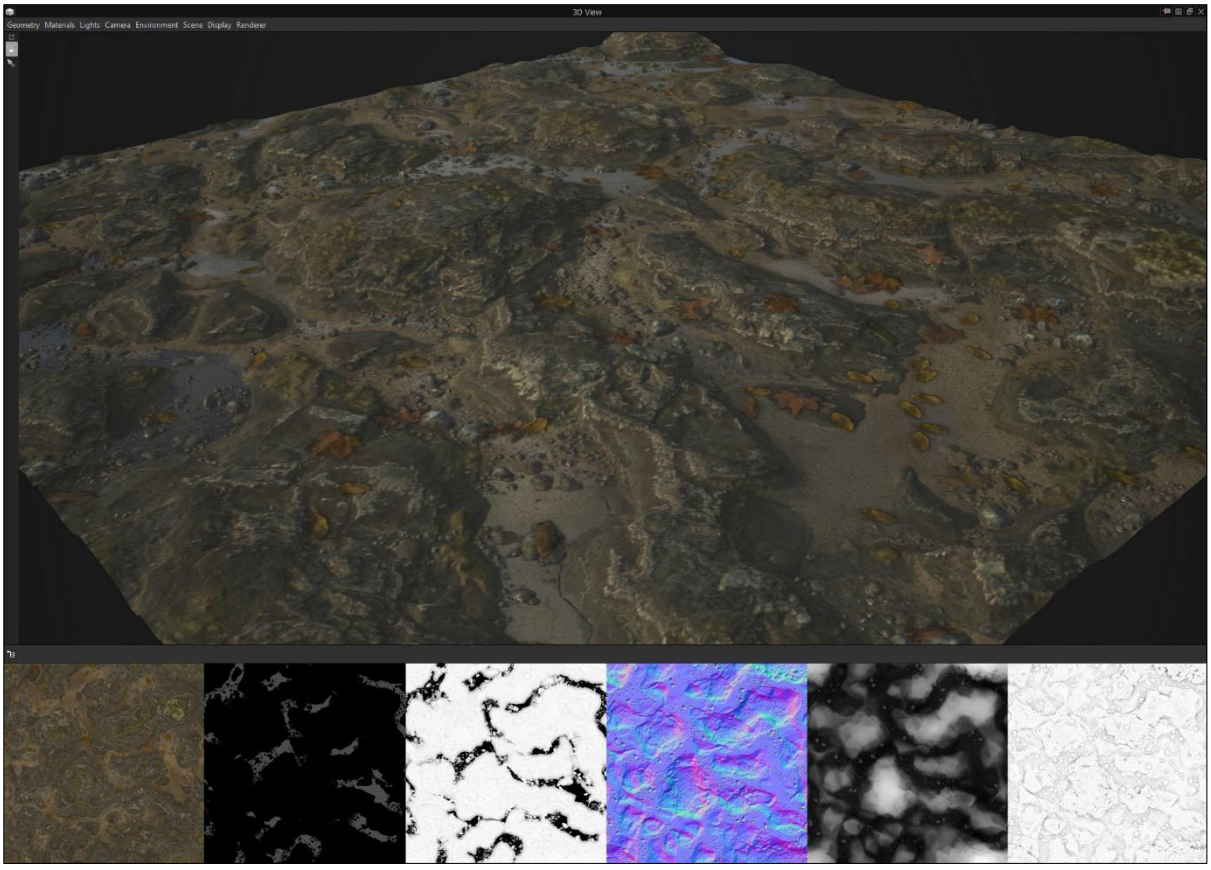


Figure 199, PBR maps (bottom left to right) used to create a physically based material (top)

5.6.1 Digital from physical models

It may also be possible to utilise existing exhibition models and convert them into digital 3D models which could be further edited for use within a game engine. An experiment was conducted using the photogrammetry software MetaShape (Agisoft 2020) with a set of photographs taken by Barry Kemp of the Boston model, the results of which can be seen in Figure 200. The model does not have clean geometry and would not hold up to first person perspective viewing however it could be used for convincing aerial viewing. By exporting the model into an external 3D modelling editor and reconstructing the model with clean and optimised geometry it could be imported back into the photogrammetry software and the textures re-projected back on to the model as a composite material.

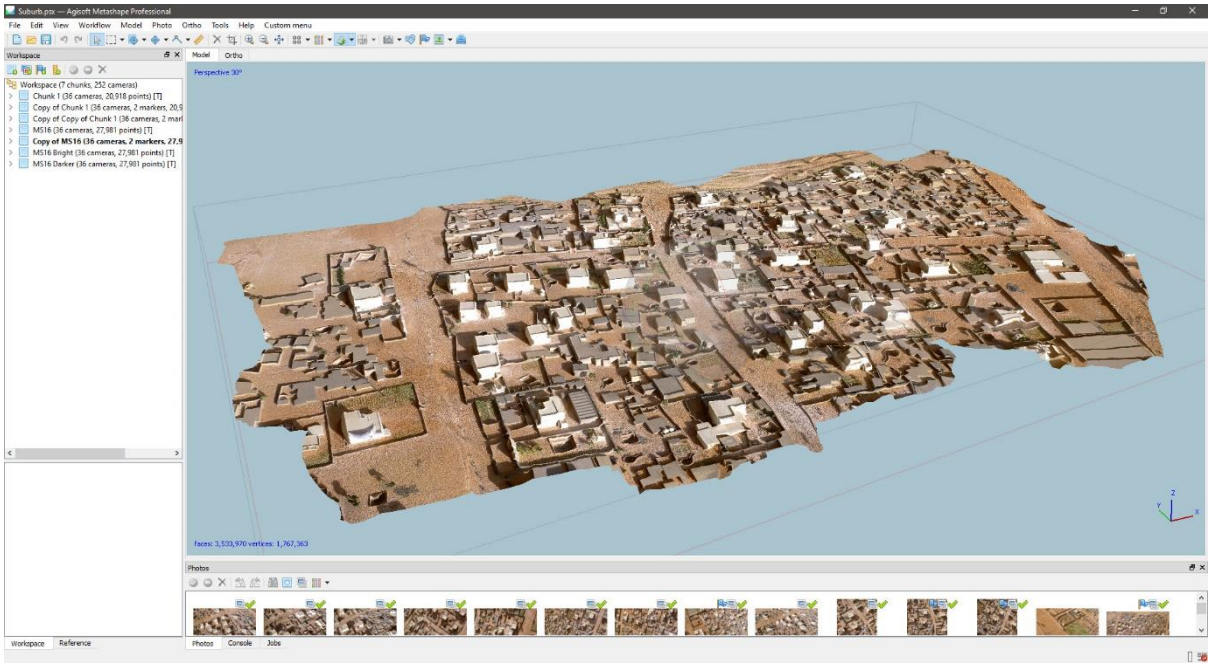


Figure 200, photogrammetric 3D model of part of the Boston model

The development of a citywide model as a platform for interactive storytelling is certainly a big task with an extremely large workload. It is possible for some tasks to be streamlined by utilising procedural construction methods and repurposing some existing digital models such as the Amarna3D set or photogrammetric models derived from physical displays. When setting out to develop an archaeological site careful consideration should be given to whether it is to be developed solely as a visual display or whether the additional workload should be implemented from the beginning to develop the assets for use as a visually immersive interactive storytelling experience.

6 Discussion and Conclusion

This thesis has focused on the visual storytelling of one site, highlighting the individuality of the research and development required. This body of work does not set out to develop a general 3D development framework for all archaeological sites but attempts to highlight the planning and range of materials required to realise one site. The research conducted for this thesis has covered the mechanisms of interactive and visual storytelling, the archaeological material available for use in the design of an interactive experience based on the ancient Egyptian city of Akhetaten at Amarna, and a review of the visual material and the 3D modelling constructed through the Amarna3D project. The research also explored the types of stories appropriate for this site and the importance of knowing the site on a first-hand basis. It is important that the archaeologists who have a long-term association with the site have their input and this has been implemented throughout this work. The story of Ranefer afforded an opportunity to explore how a solid story based on the historical and archaeological evidence can be developed for VR and the scale at which the digital site would need to be constructed to accommodate it. Much of what has been covered in this thesis can be applied to other sites but with the caveat that each site is inherently unique and every element within has its own story to tell. It could be argued that the development of the Amarna3D model is a form of visual storytelling which helps to familiarise the reader with the site and its history.

6.1 How can storytelling be introduced to VR reconstructions of archaeological sites?

Amarna has a wealth of material which has been analysed over a long period of time. Satellite data presents an overview of the site as it currently exists and by excavating the structural remains the extent of the occupation can be determined along with identifiable areas relating to religious practices, farming, manufacture, and trade. The layout of the housing shows social status through the identification of elite estates and dependent communities. Excavation can indicate the order in which buildings were constructed determining how the city grew during its lifetime. Building methods can be established through the materials and decorative remains of the houses and, although the city was systematically abandoned after 17 years, the finds that were left behind offer a tantalising glimpse into the lives of those who dwelled there. The wall paintings in the tombs are visual snapshots allowing a glimpse of selected moments which took place over three thousand years ago.

This material, when gathered, can be used to develop multiple narratives. High level stories will give an overview of the period and the major events which took place. Lower-level stories bring to life the daily events of the people. These begin with very similar themes centred around their occupation and social status, but when placed in a location within the city their point of view generates a unique

narrative. By using identified individuals who lived in the city it is possible to establish an emotional connection between player and virtual character.

The story of Ranefer used within this thesis portrays the life of a small community within the city over a short period of time. It uses a plausible narrative based on the archaeological evidence from the site and a wider knowledge of the region and period derived from generations of research. To explore these narratives as immersive experiences there are several questions which need to be asked.

6.1.1 What is the mode of delivery?

The simplest form of VR experience is the 2D 360-degree panorama allowing the player to rotate their viewpoint around a point to see their full surrounds. This is the modern version of the panorama tourist experience which can be enhanced through stereoscopic vision giving a perception of depth to the scene (see 1.1). It can be implemented in the form of a still image or video sequence. With a still image the player is restricted to views from set points and the only animation would be through additional overlaid visuals. This was experimented on with the Great Aten Temple as a Google StreetView style experience (see 3.4.1). The result worked as intended but as a storytelling experience the delay between point-to-point travel would reduce the narrative flow, disengaging the players interest. With a video sequence movement would only be possible along a set path as implemented by the designer. A full 3D environment, however, allows for free movement under player control (agency). The player is only limited by the extents of the environment and the obstacles placed within.

6.1.2 What type of narrative?

Determining the type of narrative is fundamental to the development of the experience and based on traditional storytelling and gameplay mechanics it is possible to identify three types of narrative namely observer, explorer, and participant.

The observer narrative is the simplest implementation as used in traditional film or documentary production (Bernstein 2005; Cassel 2006; Chu 2016). As a fly-through the player would be carried throughout the city as a disembodied spirit listening to a voice-over narrative explaining the events taking place around the city. The observer narrative can also be used to allow the players POV to be centred on the actions of a character being pulled through the story experiencing, but not interacting with, the events of the plotline. With an observer narrative the player can look all around them, so it is essential to ensure the player is looking in the right direction at the time a narrative event occurs. If the moment is missed, the plot may not make sense to the player. This could be avoided by signposting within the scene as either a visual or audio cue to redirect the players attention.

The explorer narrative is based on the informal play described by Parlett (1999, 3) which allows the player to have full control over the movement and interaction with the environment. By exploring the environment, the player can create their own narrative based on visual cues and information embedded in the environment, decoding it in a similar way to a crime scene. The clues placed within the environment should enable the player to identify the function and purpose of the place, who lives there and what their living conditions are. The environment should be dressed in such a way as to signpost any events which may have taken place in that location up to that point and indicate what may happen next. This should be derived from the archaeological material recovered from the site and worked into mini narratives which can be implemented visually. By incorporating this material into the virtual world the player is able to make their own interpretation of the events (Morgan 2009, 482). Explorer narratives are not time restricted in the sense of gameplay and places no pressure on the player to compete in quests unless that is part of the design. It is possible that time runs at a different rate in the explorer narrative. One possibility is that the exploration only takes place at night when all are asleep with the player taking the role of an individual from the afterlife revisiting the city as represented in Akhenaten's new religion (2.1).

The participant narrative requires the player to become an active participant in a story and is closer aligned to Parlett's formal gameplay. Once the player engages with the VR environment the story begins and progresses towards the end, the player cannot affect the direction of the plot but can contribute through actions to it (Adams 2010, 159–160). With the story of Ranefer the player could become any character, but to gain the most from the story needs to be a character who is plausibly present for each plot event within the story. In this case the choice of the eldest son, *Any*, allowed the character to be present at all events outlined in chapter 4.2 Table 2, with the events in 'C8 The Sickness' being the most tentative. However, for the funeral it could be that the player, as *Any*, watches *Efankh* the father of *Heket* and *Khay* leave for the cemetery and choose whether to go with him out of respect or stay and see him return alone. If he goes with *Efankh* does he then cause the death of his brother *Nedjem-Aten* or was it fate that the child was to die anyway without his presence, as the plot was fixed aleady by the designer? The story allows for player / character interaction through dialog and assisting in tasks; for example, the player may decide to help *Heket* and *Khay* in the manufacture of glass beads and quern-stones. Higher level storylines can be engaged with through the reading of *Ranefer's* letters which the player may or may not choose to do. The player could be party to the offering of cows at the temple by taking charge of one or both cows in driving them to the butcher's yard. The player could experience the music of the period and may, as part of the evenings event, be given instruction into how to play an instrument. Time will always progress in the participant narrative and the spaces between structured events will allow for exploration of the

environment. Duties of the day will give way to duties of the night with the environment changing dynamically to follow suit. Temperature variations into the night will require costume changes and fires to be tended. Cooking through the day might rely on dungballs for fuelling the ovens, which will need to be made and dried in the sun. All these tasks will give a sense of immersion and agency to the player without having any impact on the overall plotline.

6.1.3 Who is it for?

Understanding the audience will ensure that the storyworld is properly represented at the correct academic level and that the appropriate detail is included within the environment. Depending on the knowledge and experience of the player the scene complexity will need to be adjusted. For general public engagement a simplified backstory will be required to get over the main events of the period, in this case the religious upheaval and relocation of the capital to Amarna. If the backstory is too convoluted, then the player may lose interest and disengage with the experience. As an educational tool knowledge transfer will be commensurate with the target academic level and the interactivity may need to be more involved. If the target audience are researchers then it may be that the interactive features allow for greater manipulation or user modification of both the environment and the objects within (Morgan 2009, 478) as evidenced in the sunlight study (Kemp and Docherty 2019) and temple entrance (Kemp 2019b). The target audience will also determine funding for the project which will have an impact on the scale, level of detail, accuracy, quality, and build time.

6.1.4 How is it constructed?

For this thesis, the logic for the story of *Ranefer* was mapped out using a geographic information system, QGIS (4.2). Archaeologists use GIS software to record site plans for large scale sites and perform various statistical and spatial calculations during their research. These are tools that the archaeologist is already familiar with and would speed up the development process by integrating them into the construction pipeline (Andrews and ESRI 2020; Cozzi and Cesium 2020; Marre and Aerometrex 2020; Reinhard 2017). By using the same system and available data to plan narrative events the developer's workload is made more efficient. Once the locations associated with the plot events are identified then movement patterns can be established and the scope of 3D modelling can be determined. By keeping the data in a non-proprietary format such as that used in GIS means that it maintains an archival status. With everything mapped to a meter grid it is possible to have direct spatial connections between the GIS software and the game level editor through simple Python scripts or CSV text data, see chapter 5.4.1. The use of a local coordinate system instead of longitude / latitude coordinates is essential here to match the units in the game editor.

Using GIS data allows for the identification of potential narrative events based directly from the archaeological data such as landscape topography, travel distance times, artefact locations, thought-provoking artefacts, identification of functional zones i.e., markets, craft, stores, etc. By tracing out narrative events as spatiotemporal routes in GIS for multiple individual characters it may be possible for additional crossover narratives to be constructed depending on individuals being present in the same location at the same time. Depending on the nature of the event it may be possible to develop shared experiences with other players for part of their narrative for example temple worship, markets, or construction.

6.2 Can reconstructions of archaeological sites be re-purposed for storytelling?

6.2.1 Is Detail a Factor?

When playing a visually rich game such as Assassin's Creed Origins it is easy to become immersed in the detail of the environment but is the level of detail essential to the narrative? Assassins Creed is certainly popular and at more than 100 million unique users (Ubisoft 2020) it is not selling on plot alone. Microsoft's sandbox adventure game Minecraft however, has over 126 million users playing each month (Total Gaming Network 2020) with graphics which are arguably blocky. The use of sandbox environments like Minecraft and Second Life are certainly useful tools for the archaeologist (Morgan 2009, 473) but the lack of export options means having to rely on the continued development of the platform and subscription to it.

6.2.2 What constitutes re-purposing?

The purpose of developing any archaeological reconstruction is to disseminate information and understanding of a site and its contents; in doing so they already illustrate a story of some aspect of the site. So, what about the mode of delivery? Can one format be repurposed to tell a story in a different format? Developing a VR experience using a 3D model is certainly an effective method of delivering a story to a wider audience however with Amarna3D as the starting point are there any alternative ways the site reconstruction could be re-purposed for storytelling.

6.2.3 2D to 3D

One established method of constructing 3D models is with 2D CAD drawings where the structure outlines are used to form the 3D surfaces through extrusion as shown in chapter 3.2. This form of exploration requires some interpretation which in turn allows for building methods to be explored. Whilst not strictly storytelling it does create a form of narrative about the phases of construction of the site. The act of building a 3D model from a series of plans is extremely valuable to the archaeologist as it can present new observations on how the site was developed (Morgan 2009, 475).

Sections of the model or individual buildings could be unfolded through their UV mapping coordinates into papercraft models which can be printed and assembled as a physical 3D paper model (Papercraft3d 2020; Tama Software Ltd 2020). These models could be generated to construct parts of the city by schools which could develop their own narratives through exploration.

By mapping the EES photographic archive onto individual geometric planes and registering them in 3D space overlaid on to the model reconstruction of the city it would be possible to generate a narrative of the excavations which have taken place. This 2D in 3D space would highlight some of the discoveries from the site and by utilising voice-over narratives taken from the expedition notebooks and Mary Chubb's account of her time there it could present an insight into how the site has been interpreted by archaeologists over time.

6.2.4 3D to 2D

Renders from specific angles throughout the model could be edited in such a way as to produce a 2D graphic novel. Depending on the visual style of the novel it would also be possible to alter the materials to provide a cell shaded (cartoon) visualisation if that was felt necessary. The renders can be extended into animated flythrough sequences as already seen in documentary storytelling.

An alternative 3D flythrough could also be achieved using a physical 3D model such as the Boston model and those produced by Whetton & Grosch as shown in chapter 2.3. By using a small camera such as the DJI Osmo Pocket (chapter 2.4.3) dynamic close-up shots of the physical models combined with aerial shots could be edited into an explorer or observer narrative. The Osmo Pocket is particularly suited to this as its small formfactor enables close-up shots between model structures and the motorised gimble can be controlled remotely by smartphone.

6.2.5 3D to 3D

Turning back to the physical world, photogrammetry could be used to not only develop models of the real-world site but create 3D digital models of the physical display models (chapter 5.6.1). These could be further edited and enhanced to extend the narrative of all the models either as standalone or merged entities. Likewise, the digital models could be 3D printed for display and include animated visuals from the digital models projected onto the 3D printed surface through LCD projectors to present yet another mode of storytelling.

6.2.6 Transmedia

The story of any site or period could be split into different narratives and retold across different platforms as transmedia, discussed by Henry Jenkins (2007). Many of the aforementioned transmutations of the Amarna models could be used to tell a part of the story and together would

represent the whole narrative. This has been done successfully in the entertainment industry where graphic novels have introduced a storyworld which has been continued in a film or TV series with tie-ins via video games each telling their own part of the story. The access to physical models on display can be restrictive however by developing a storyline across VR, graphic novels, and paperplay models would reach a wider audience. The paperplay as a craft-based option would help to generate discussion about communities, construction, etc.

6.2.7 Initial Model State

The creation of any 3D model involves reference data to be used for scale, morphology, function, material, and local detail. The initial model will reflect the quality of this data and in turn this will decide its suitability for different narratives. With the initial Amarna3D model both the reference data and the development hardware were limited resulting in a model which was best suited for aerial visualisation. However, as the more data became available and the hardware and software became more powerful the original Amarna3D model grew in complexity. This coupled with a more informed understanding of the site meant that narratives based on experimental simulation such as the sunlight study (Kemp and Docherty 2019) and brick-by-brick construction methods could be explored. Fortunately, digital models are extremely adaptable by nature and depending on their initial state can either be downgraded or upgraded in their complexity to suit the required narrative with relative ease. However, where a model is of poor geometric or topographical quality it may be more suited for a total rebuild.

6.3 Can future reconstructions of archaeological sites incorporate elements that make them more suited for re-purposing by the creative digital industry?

The creative digital industry is constantly changing and improving its technology. Projects which are cutting edge state of the art one day will be out of date shortly after. Digital file formats are often proprietary and under the control of the software developers who created them. Open-source file formats require a dedicated team of developers to maintain currency and compatibility with the 3D tools which use them for data storage. Software which relies on plugins for model construction and rendering can lose functionality if the plugin developers change their design or go out of business. During the lifetime of the Amarna3D Project there have been changes in the core functionality of the 3D software (3dsmax) which has made older files difficult to open without some form of conversion. Maintenance costs can also affect the decisions to continue with a software pipeline. This is very problematic for large scale environments like the Amarna3D model where preserving the model for future development is important. The subject of archiving 3D model data is an extremely large one and beyond the scope of this thesis but in preparing for the next development phase for the Amarna3D

model meant looking at some of the issues faced when creating large scale reconstructions of archaeological sites.

6.3.1 Asset Management

When creating a city for real-time use there will inevitably be geometry overload, so it is essential that this is managed efficiently. Amarna has around 1150 catalogued structures which have been excavated to date. Using six 200-meter grids an average of 50.7 houses per grid were found (Kemp 2012, 272). With 60 grid squares potentially used for housing this equates to the construction of approximately 3040 houses at Amarna. If one person was to construct one house in a day, then it would take close to nine years to build all the houses for the city. Clearly this is extreme so some shortcuts would need to be taken. There are some estates which are of more interest than others due to their layout or owner identification and these would be required to be constructed in full detail. Other areas of lesser interest could be constructed from an asset pack consisting of generic building parts which, when combined, would give the impression of a small community. In this way the city would be blocked out with enough detail initially and as research continued new areas of interest could be swapped out with more accurate models. This would allow for a collaborative approach to the city construction and additionally allow for alternative interpretations of housing to be developed in various areas of the city (Spence 2004).

6.3.2 Physically Based Materials

3D model geometry provides a solid form which, as an in-game asset, provides a basis for collision, visual occlusion within the scene, reference for shadow casting, and a frame to display finer surface detail through material textures. Physical based materials are extremely accurate representations of actual surfaces constructed from real-world sources. They are created by the 3D artist usually through photogrammetry and include not only the colour and reflective properties of the surface but its topographical features as heightfields. These height maps can also be used to deform geometry, reinstating geometric detail if required. When recording an archaeological site, it would therefore be appropriate to record texture information of relevant surfaces for later implementation on 3D models of the site. In addition, 360-degree high dynamic range (HDR) panoramic images of several locations around the site can be used later to understand the wider environment and provide image-based lighting.

6.3.3 Archaeologist as Professional 3D Modeller

It has long been the case where visual reconstructions of archaeological sites have been created by archaeologists as they have the expertise required to interpret the site. Recording methods such as site planning, illustration, and photography have been the main methods used with 3D modelling,

photogrammetric capture, and 3D laser scanning being more recent additions. However, once these processes have been completed for a site what happens next? To tell the story of an archaeological site as a VR experience usually requires the knowledge and skillset of a software developer. Within the developer studio the essential roles required for this are Designer, Programmer, and 3D Artist (chapter 1). Whilst it is entirely possible for an archaeologist to retrain in all these areas this would undoubtedly move them away from their primary work. It is my belief that there is a need for archaeologists to specialise in 3D modelling at the same level as other archaeological subdisciplines. To become proficient in 3D modelling requires considerable investment of time commensurate with other subfields of archaeology. Whether the role is titled 3D archaeo-modeller (not to be confused with statistical modelling), archaeo-developer, virtual archaeologist, or something similar is up for debate but the role itself is valuable in creating a solid connection between archaeologist and developer. By taking ownership of the 3D model development the archaeologist would be secure in the knowledge that the asset would be fit for purpose within a VR experience and not based on artistic license (Morgan 2009, 475). If the archaeologist understands the requirements and features of the game engine and the toolkit used to create the content, then there are several benefits. The archaeologist has an opportunity to understand the original construction methods through the digital construction of the model and test out their interpretation of the site (see chapter 3.4). The interpretation would be based on sound archaeological knowledge and could be tested, or peer reviewed by other archaeologists before becoming a published version. Models would be constructed in an efficient and optimised manner as game-ready assets. Currently most of the models generated from the heritage sector are extremely poor quality in terms of surface topology and geometric density. This is usually the by-product of a “hit and run” attitude to 3D scans, photogrammetric captures, and 3d reconstructions where the priority is to capture the site in 3D and produce a model. However, the resulting geometry may be so dense that it could only function as an isolated visualisation. The issue can be demonstrated through the online 3D model hosting platform, SketchFab.com. A quick search for heritage models will result in thousands of models ranging from site captures to artefact photogrammetry. By examining the model wireframe structure through the model inspector, it is possible to see how clean the geometry is. The two examples shown here are recent additions to the SketchFab Cultural Heritage and History database selected at random to show the difference between a clean model Figure 201 and an inefficient model Figure 202. An inefficient model will cause problems with the game engine performance particularly when the polygon count is excessive, and several such models are assembled in the scene. A 3D archaeo-modeller would be capable of cleaning 3D scans without removing features and would be skilled at interpreting a site as a 3D reconstruction for use within VR experiences. In the video games industry, the modern 3D artist

pipeline requires a high-resolution 3D model to be created and then reduced to a lower polygon count suitable for real-time implementation. This process sees multiple resolutions of the original model each with an optimised and efficient surface topology. The results of this can be seen in chapter 5.6 where the bust of Nefertiti and the colossi of Akhenaten were re-topologised from the original high density photogrammetric meshes (Docherty 2015).

Archaeologists and other heritage sector specialists would benefit from published 3D models in the same context as research papers. Published models developed under peer review could be used in other projects, safe in the knowledge that they had been subject to due diligence and were recognised as an authoritative reconstruction. The models could be published as different phases from a site and would be constructed to the correct scale. By incorporating models at several levels of detail, the models could be used for a range of purposes such as visual storytelling, sunlight analysis, acoustic analysis, physics simulation, etc. Academic institutions could initially promote this through the development of appropriate courses encouraging implementation within the research community and the creative digital industry. However, these courses would require a commitment to the tools and techniques used in asset creation to produce modellers of the correct standard capable of working in such a capacity.

Figure 201, Gislinge Viking Boat (Opus Poly 2020)

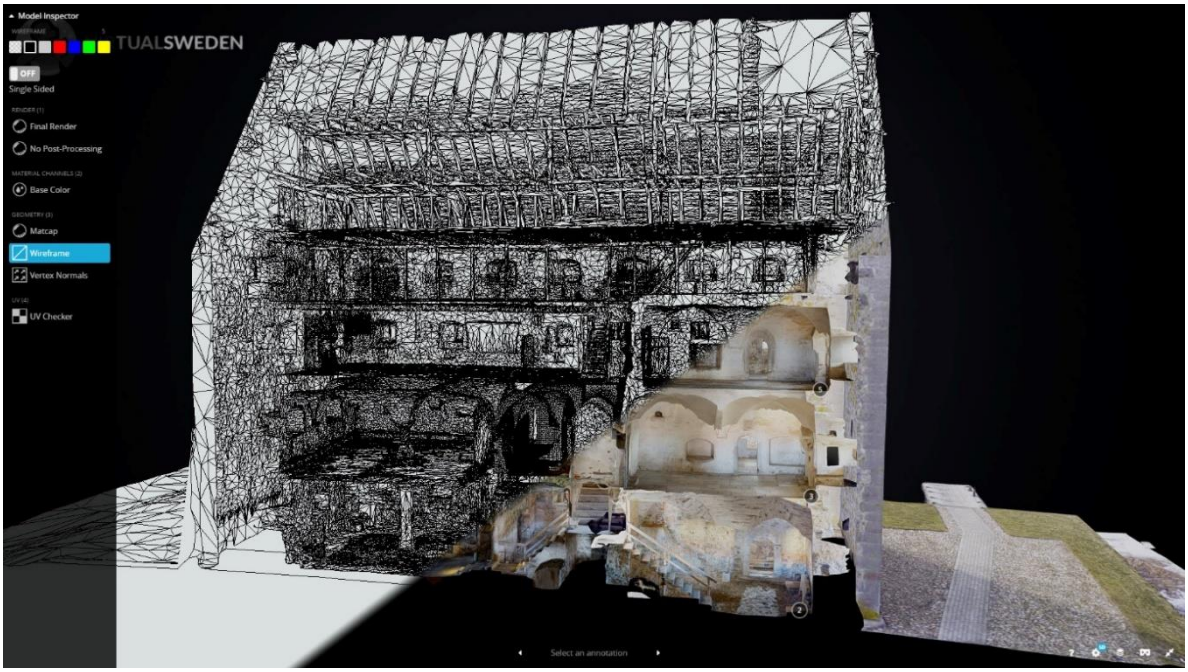


Figure 202, Glimmingehus medieval castle (Virtual Sweden 2020)

6.4 Concluding remarks

During the early stages of research for this thesis it was clear that there was a large area to cover in terms of virtual reality technology, visual storytelling, and the 3D modelling of a large-scale archaeological site at a detail which could be viewed and interacted with at ground level. This thesis focused on the design stage that would enable archaeologists and software developers to create an interactive virtual reality experience based on the lives of the inhabitants of the city of Akhetaten at Amarna during its active lifetime. As 3D content creation software undergoes a rapid rate of continual improvement, this thesis has focused on highlighting the resources required, and some of the development issues which must be addressed, to drive forward the development of a new series of 3D models of Amarna. In doing so more research into potential narratives like the story of Ranefer is required.

Using the layout of the city to map these additional narratives gives an opportunity to study how crossover narratives could be developed based on local timelines and geographical location within the city. This thesis did not cover character modelling or avatars which are an extremely important part of storytelling. Research has already been done in procedural dialog and artificial intelligence personalities and this would be the next stage for the AmarnaXR project once the city modelling is complete. Without characters it is still possible to generate experiences which tell stories and research into environmental storytelling is a large area which has not been fully exploited at present. By using visual signposting in the environment, the player can interpret clues around them as a whole thereby

furthering the narrative of the experience and enabling the player to author their own environmental storytelling moments (Smith and Worch 2010).

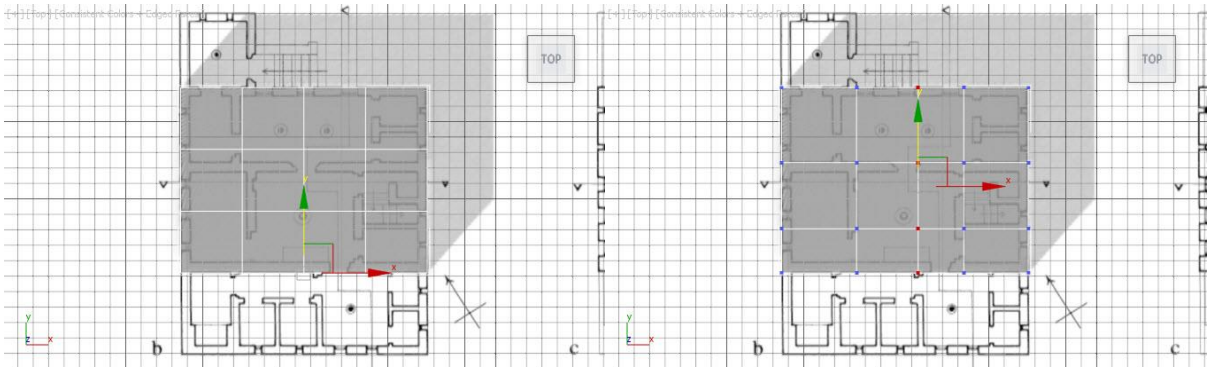
To push the development of AmarnaXR requires a larger workforce than it presently has (the author) so there is a pressing need to develop an outsourcing pipeline which enables collaboration between 3D [archaeo]modellers. The games industry has used outsource methods for many years but in a different context and one which revolves around a fixed commercial deadline. The development of the AmarnaXR model would be more fluid to allow for new interpretations to be implemented as and when they are formulated. The software used to develop and present the city model will need to be carefully thought out. This brings about the question of whether a game engine can be used as an archival system and how that would be designed for longevity.

Finally, the Amarna3D Project has been in existence from 2000 to 2020, a period longer than the habitation of the actual city. It has played many roles from a game concept, teaching demonstration model, animated visualisation for documentaries, general interest publication, academic reference, operatic backdrop, blueprint for real-world construction, and experimental archaeology. At the start of the Amarna3D Project I was a developer with little archaeological knowledge and limited understanding of the resources available to develop a project of this type. As the Amarna3D Project matured so did my understanding of the archaeological material and how to interpret it to improve the reconstruction to a point where it has been used for academic publication. This reinforces my belief that there is a need for someone who can bridge the gap between archaeologist and developer. The role of an [Archaeo]modeller would present a skilled craftsperson who would have the background in archaeology that regular 3D artists do not have. As archaeologists embrace, and take ownership, of the skills required and employed in new visualisation technologies and methods of storytelling, I expect to see more projects of this scale completed to an incrementally higher standard in a fraction of the time.

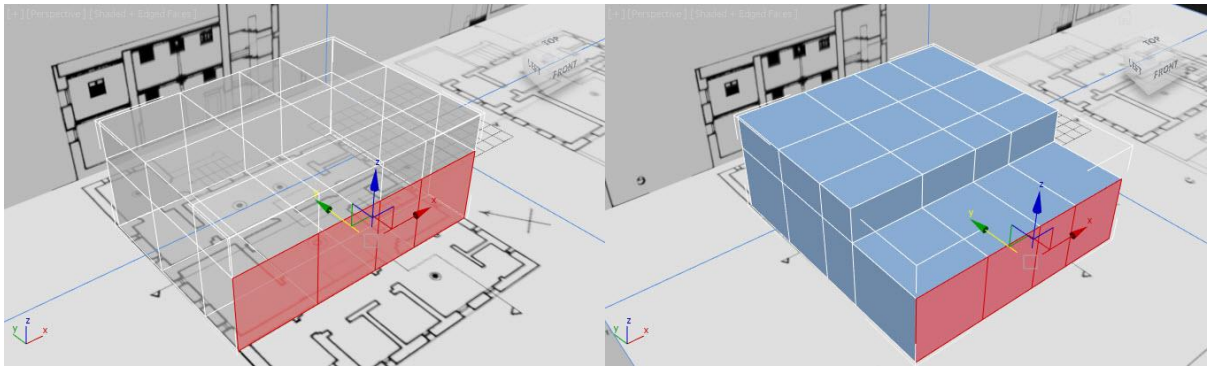
7 Appendices

7.1 Appendix – Amarna House - Basic Box Modelling

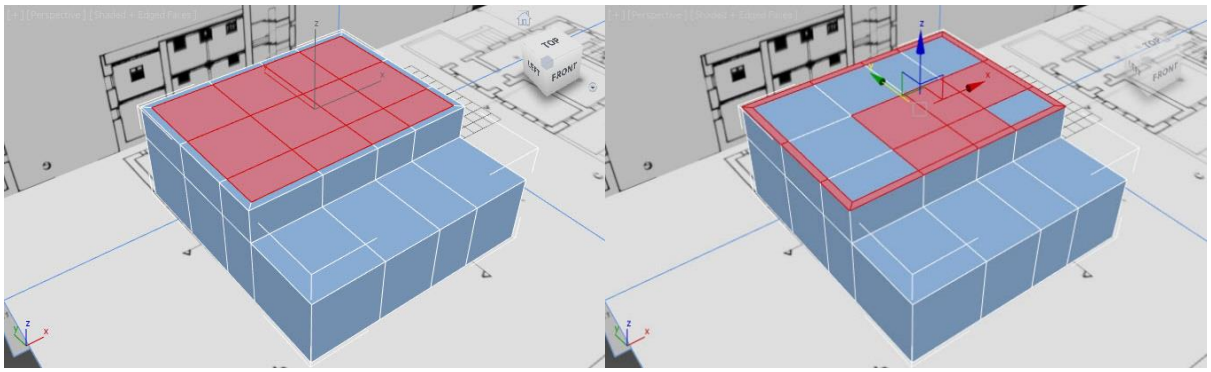
Box-modelling is a technique where a primitive object such as a cube is used as the initial building block and its faces are cut and extruded to form a more complex model. The following is a basic outline of the steps taken to model a typical Amarna house using this method. The first step is always to create reference planes with the house plans scaled in real-world units.



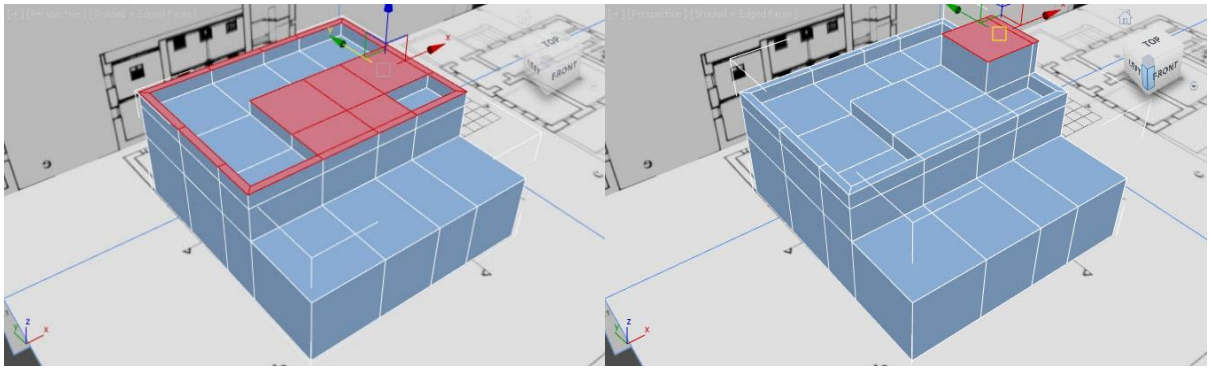
Create and position a cube with enough segments to enable extrusions based on the wall topography. Adjust the segments to follow the underlying plan by selecting loops of vertices or edges and translating them to suit. It helps at this stage to make the model transparent.



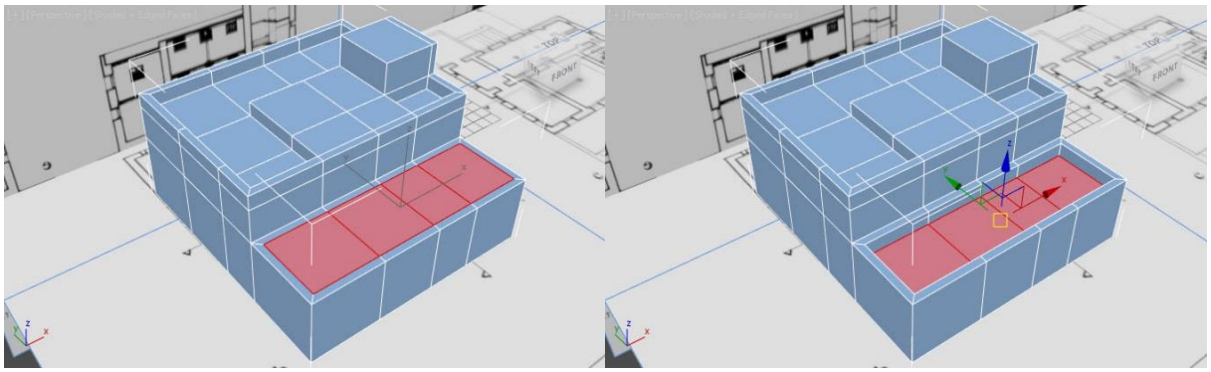
In this example the lower segments/polygons represent the ground floor which are selected and extruded to match the plans.



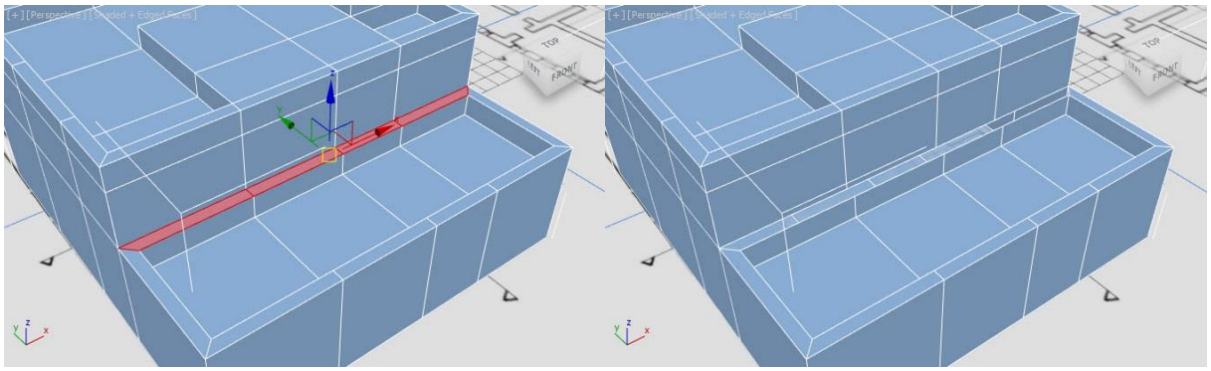
The roof segments/polygons are selected and inset to provide an outer frame from which the upper boundary wall will be extruded later. This frame is selected along with the polygons relating to the central room.



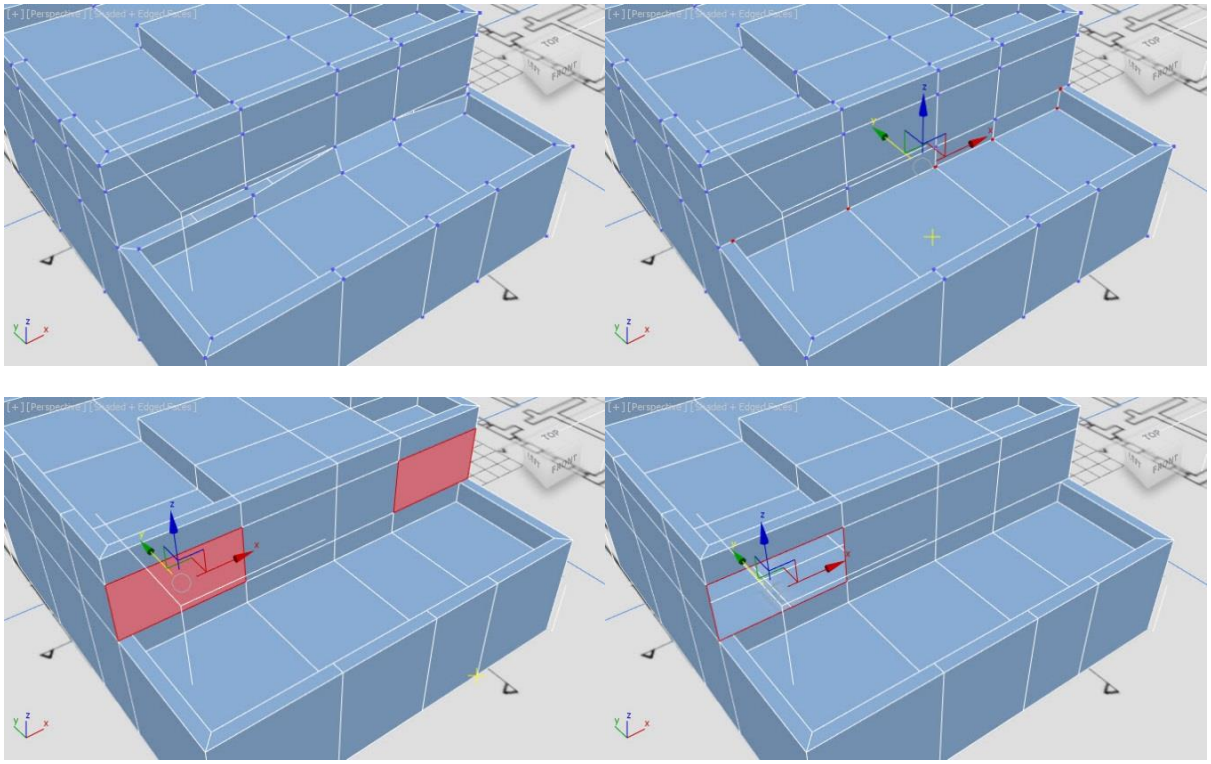
The selected polygons are extruded to a height representing the upper walls and, in this instance, polygons representing the stairwell are selected and extruded to the appropriate height.



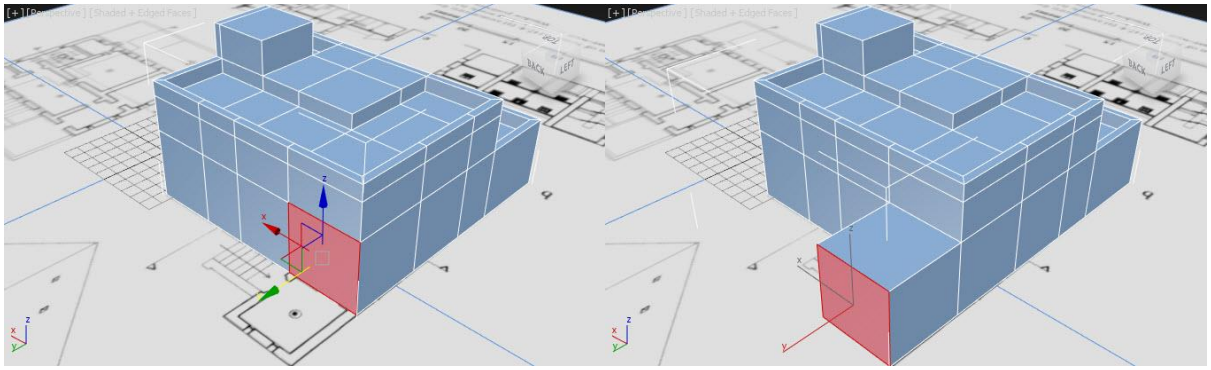
Returning to the ground floor, the roof polygons are selected and inset and extruded downwards to lower the roof and produce a short rooftop wall.



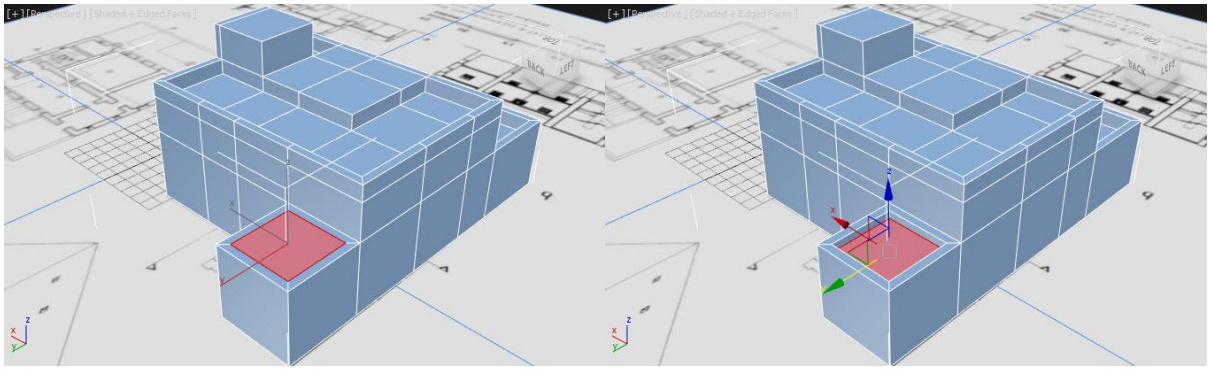
If necessary, the adjacent wall can be removed and made flush with the upper floor walls. To achieve this, select the strip of polygons and delete. In the following images the open area is closed by welding adjacent vertices using target weld. The lower rooftop vertices can then be translated to snap under the previously welded vertices creating a flush wall space.



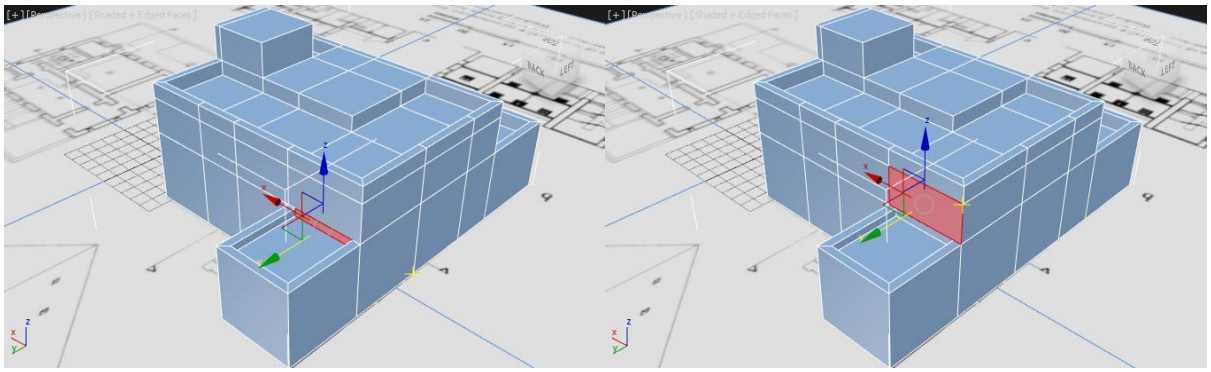
The previous action will have created open edges where the lower roof wall rim meets the upper floor. This can cause problems later when texturing and rendering the model so to fix this select the upper polygon and delete it. Then select the open edges and use the cap tool to rebuild the polygon without any open edges.



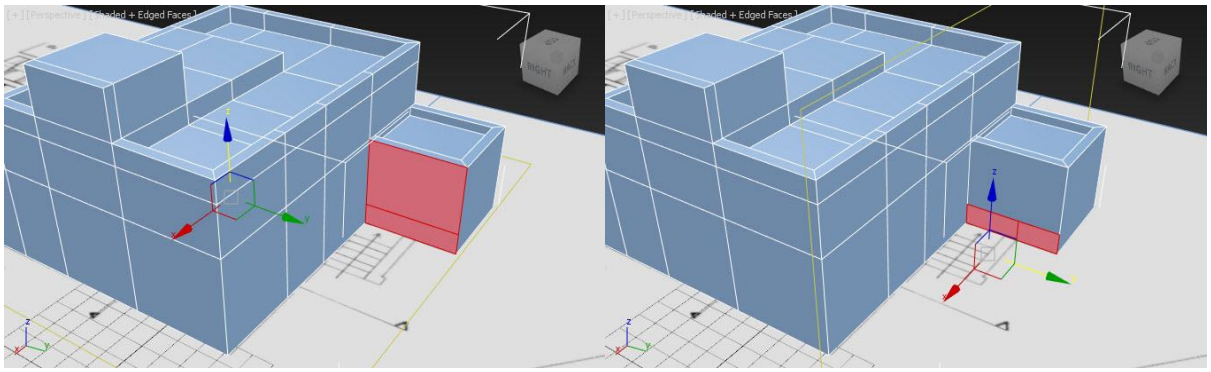
Moving around to the entrance porch of the house, select the relevant polygons and extrude as before using the plans as a guide. The stairs will be handled shortly so ignore those polygons for the moment.



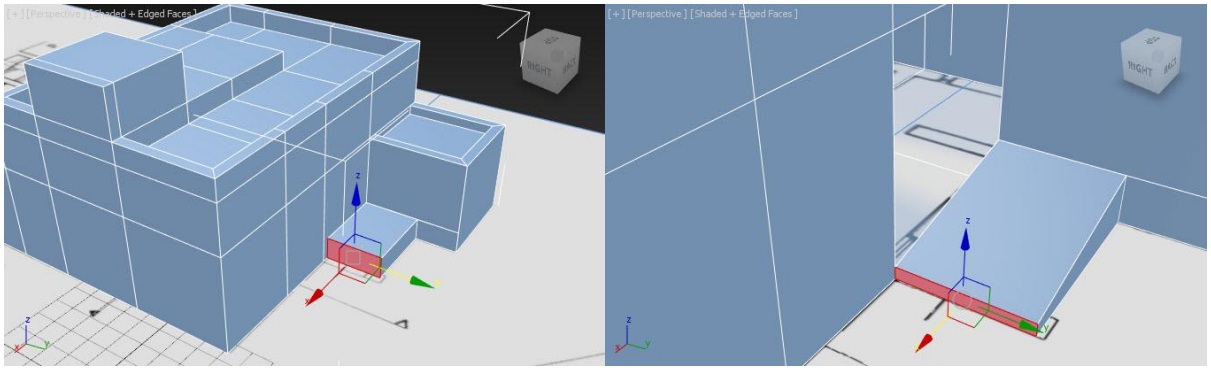
Create a short wall around the top of the porch by selecting the roof polygon, inset, and extrude downwards.



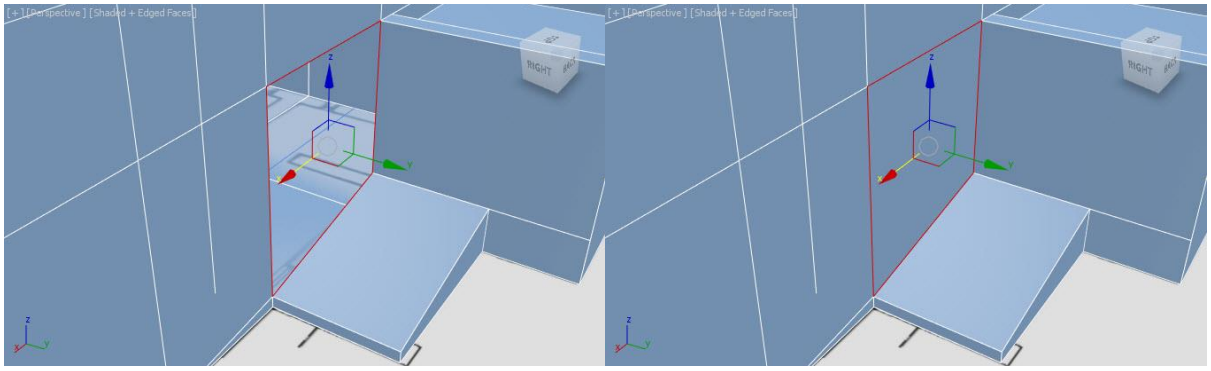
The adjacent wall can be made flush in the same manner as earlier by removing the upper polygons, adjusting the vertices, selecting the open edges, and using cap to rebuild the wall polygon.



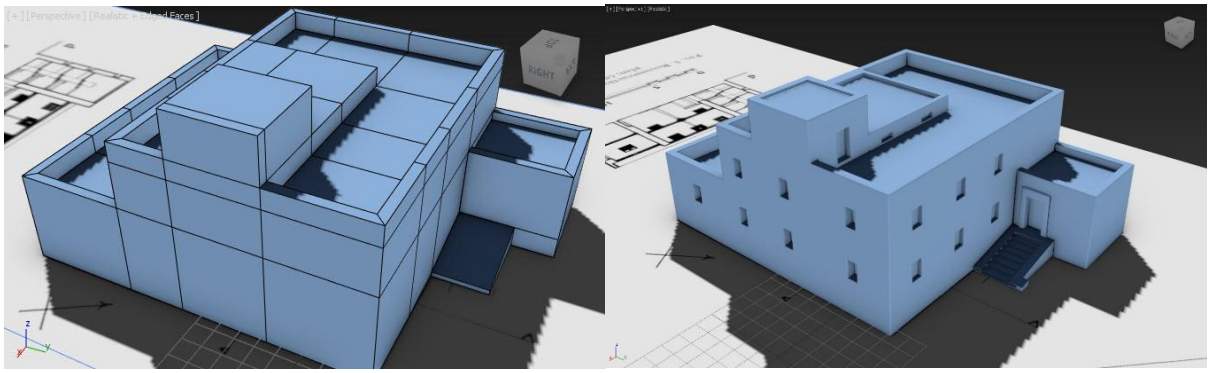
To create the entrance stairs first select the wall polygon and used the slice tool in a horizontal mode to cut the wall at an appropriate height.



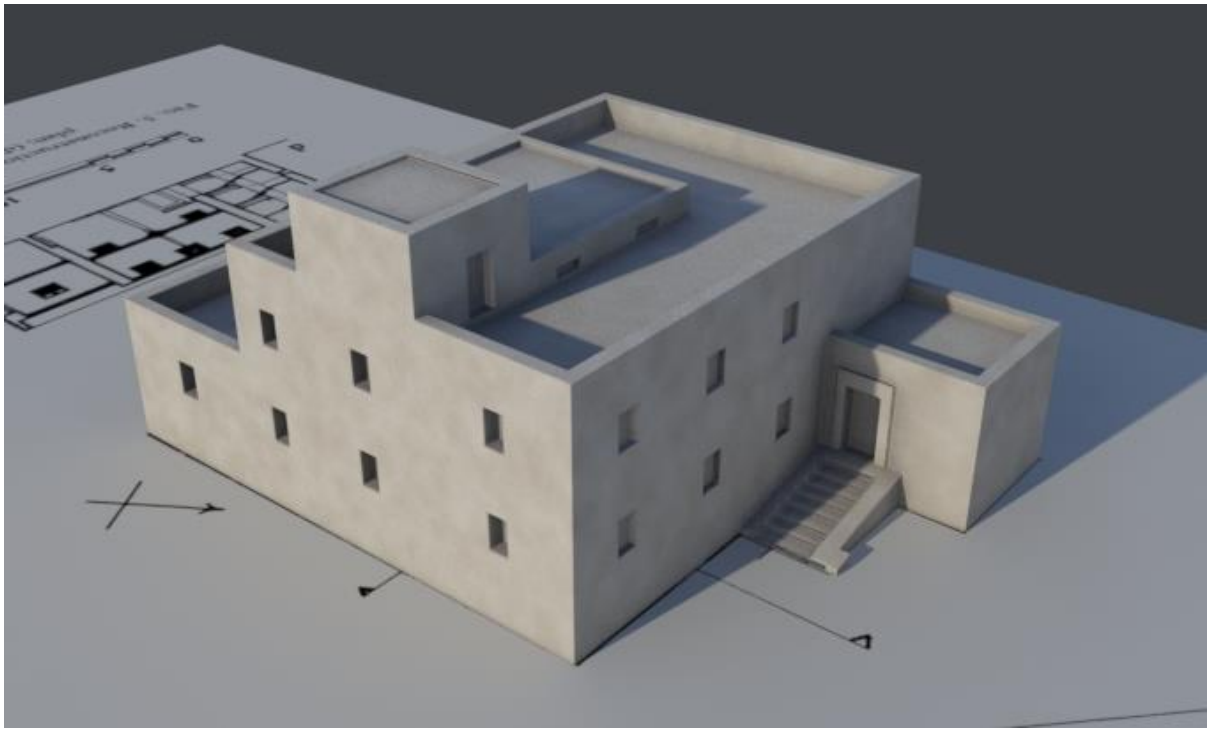
Extrude the lower polygon representing the stair and extrude out for the length of the stair using the plan as a guide. Scale the polygon down to the height of the first step by either selecting the top edge or top vertices and translating downwards.



At this point the adjacent wall will overlap the stair so needs to be removed along with the inner side of the stair ramp. Before closing the open edges, it is necessary for the main wall polygon to be cut freehand along the base to match the top of the first step. The vertices at this point where the first step and the main wall intersect should be welded together allowing for the open edges to be closed using the cap tool as before.



You will now have a solid model in the shape of the Amarna house which can be further modified using combinations of inset and extrusion (for doors and windows) along with slice and chamfer (in the case of the stairs) resulting in the model shown above right.



The resulting model after further work and basic textures applied. UV mapping coordinates were created using the ‘UnwrapUV’ modifier, selecting all the polygons, and applying box mapping followed by pack UV’s using normal space to maintain a uniform size.

This model can be created very quickly but relies on a clear understanding of the plans used as reference. It is also a low polygon model representing the overall shape of the house. Further work would include rounding off edges, breaking up the straight lines of walls, adding window grills, doors, mats, and an assortment of object relevant to daily life. Textures would need to include worn and damaged areas, weathering from rain and sand, and repairs.

7.2 Appendix - Species Recovered from the Botanical Samples at el-Amarna

Source:

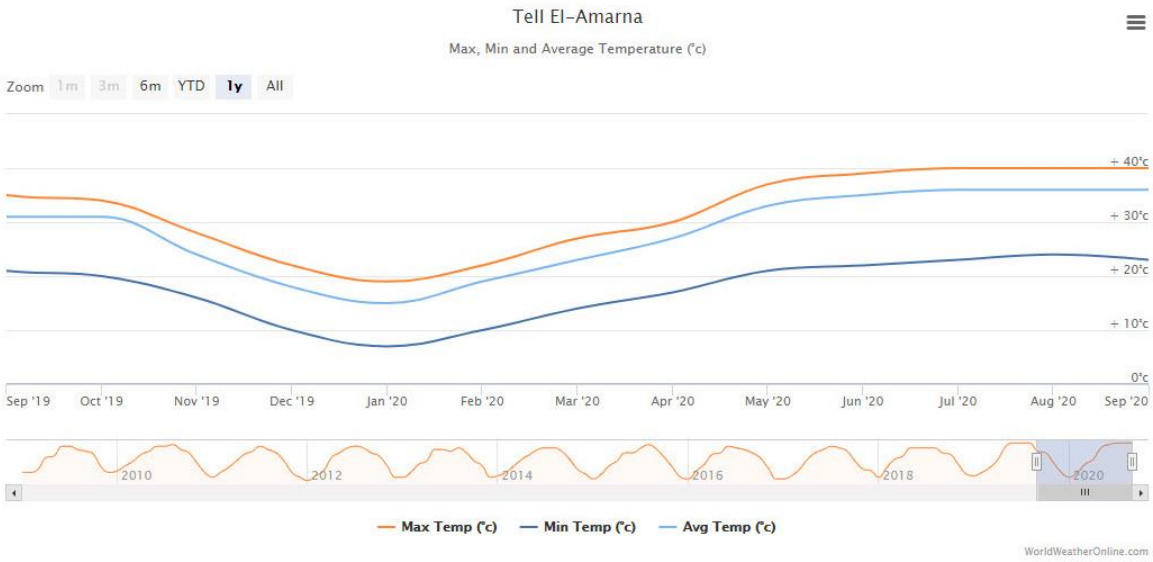
Stevens, C. J. and Chapman, A. J. (2016). Botanical Insights into the Life of an Ancient Egyptian Village: Excavation Results from Amarna. In: Stevens, C. J. et al. (Eds). *Archaeology of African Plant Use*. London : Routledge. p.157.

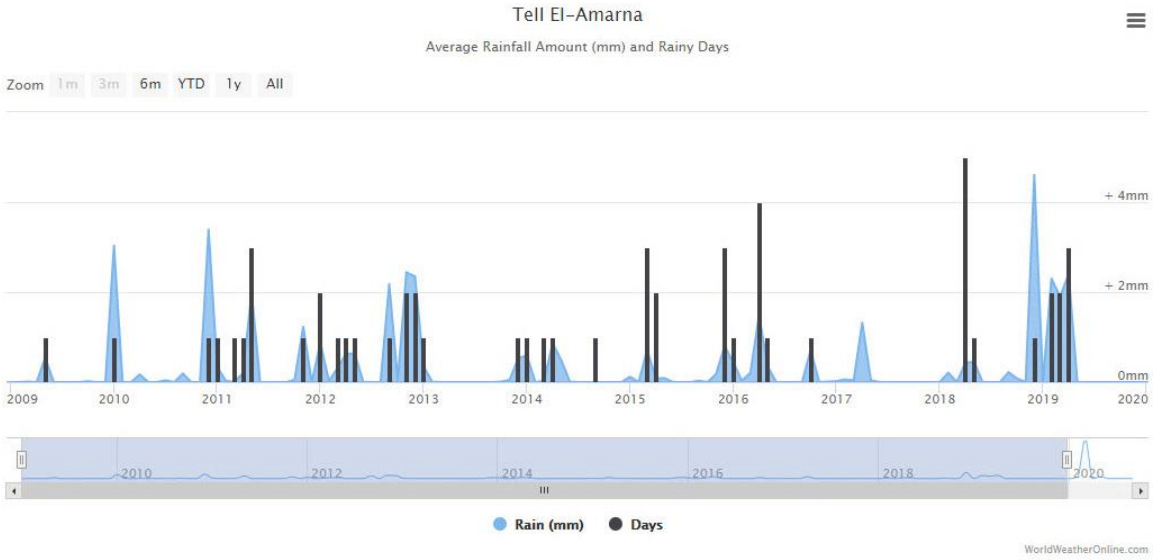
Species	Parts	Family	Species	Parts	Family
Acacia cf. *nilotica* (L.) Delile	S, T, St,	Leguminosae	*Fimbristylis bisumbellata*	S	Cyperaceae
Allium cepa L.	Tu	Liliaceae	*Francoeuria* sp. and/or *Pulicaria* sp.	Fl	Asteraceae
Allium sativum L.	Tu	Liliaceae	*Heliotropium bacciferum* Forssk.	S	Boraginaceae
Ambrosia maritima L.	S	Asteraceae	*Hordeum vulgare* subsp. *vulgare* L.	S, C	Poaceae
Amygdalus communis L.	S	Rosaceae	*Hyphaene thebaica* (L.) Mart.	S/F	Palmae
Asphodelus sp. L.	S	Asphodelaceae	*J. oxycedrus* L./*J. excelsa* M. Bieb. Possible *J. phoenicea* L.	S, cf. L	Cupressaceae
cf. *Anthemis pseudocotula*	Fl	Asteraceae	*Lathyrus sativus* L.	S	Leguminosae
Apium graveolens L.	S	Apiaceae	*Lens culinaris* Medik.	S	Leguminosae
Artemisia judaica L.	L	Asteraceae	*Linum usitatissimum* L.	S, F, St	Lineaceae
Arundo sp. L./*Phragmites* sp. Adanson	Im	Poaceae	*Lolium* cf. *temulentum* L.	S, C	Poaceae
Balanites aegyptiaca (L.) Delile	S	Zygophyllaceae	*Lupinus albus* L.	cf. S	Leguminosae
Ocimum cf. *basilicum* L.	S	Lamiaceae	*Mimusops laurifolia* (Forssk.) Frilis *M. schimperi* Hochst.	S	Sapotaceae
Bassia muricata (L.) Asch	S	Chenopodiaceae	*Nigella sativa* L.	S	Ranunculaceae
Beta vulgaris L.	S	Chenopodiaceae	*Olea europaea L.*	S, L	Oleaceae
Carthamus tinctorius L.	S	Asteraceae	*Phalaris* cf. *minor L.*	S	Poaceae
Citrullus colocynthis (L.) Schrad.	S	Cucurbitaceae	*Phalaris paradoxa* L	S	Poaceae
Citrullus lanatus (Thunb.) Mats. & Nakai	S	Cucurbitaceae	*Phoenix dactylifera* L.	S, L, ?Fl	Palmae
Coriandrum sativum L.	S	Apiaceae	*Picris* sp. L.	S	Asteraceae
Cornulaca cf. monacantha	S	Chenopodiaceae	*Ricinus communis* L.	S	Euphorbiaceae
Cucumis cf. *melo* L.	S	Cucurbitaceae	*Rumex dentatus* L.	S, F	Polygonaceae
Cyperus esculentus L.	Tu, cf. S	Cyperaceae	*Schouwia purpurea* (Fofssk.) Schweinf	S, F	Cruciferae
Crypsis sp.	S	Poaceae	cf. *Sinapis alba* L. *Raphanus* sp. L.	F	Cruciferae
Daucus cf. *carota* L.	S	Apiaceae	*Tamarix aphylla* (L.) H. Karst	L	Tamaricaceae
Desmostachya bipinnata (L.) Stapf/*Imperata cylindrica* (L.) Beauv	St	Poaceae	*Trigonella foenum-graecum* L.	S	Leguminosae
Echinops spinosisimus Turra	F/Fl	Asteraceae	*Triticum turgidum* L. ssp. *dicoccum* (Shrank) Thell.	S, C	Poaceae
Echium cf. *rubrum* Forssk. *E. angustifolium* (Mill.)	S	Boraginaceae	*Vitis vinifera* L.	S	Vitaceae
Echium rauwolfii Delile	S	Boraginaceae	*Withania somnifera* (L.) Dunal.	S, F	Solonaceae
Emex spinosa (L.) Campd.	S	Polygonaceae	*Zilla spinosa* (L.) Prantl.	S, cf. St	Cruciferae
Fagonia sp. L.	S, F	Zygophyllaceae	*Ziziphus spina-christi* (L.) Desf.	S, L, St, T	Rhamnaceae
Ficus sycomorus L.	S, F, cf.	Moraceae	*Zygophyllum* spp. L.	S	Zygophyllaceae

Key: S = seed and/or stone; F = fruits; L = leaves; St = stems; T = thorns; Tu = tuber; C = chaff; Fl = flower-head; Im = impressions.

7.3 Appendix – Temperature and Rainfall at Amarna

Source: WorldWeatherOnline.com





7.4 Appendix - List of Individuals Identified from Amarna

Compiled from various sources including (Malek,Magee and Miles 2008) and (Murnane 1995)

Position	Name	Title(s)	Notes
Court Official	Ahmose	King's true scribe', 'Fan-bearer at the right of the King', 'Overseer of the Front Hall', 'Steward of the house of Neferkkheperure-Waenre	Inscriptions found in Ahmose's tomb (no.3) at Amarna
	Apy (Ipy?)	King's scribe', 'The overseer of the large inner palace of the pharaoh', 'The steward'	Inscriptions from a doorjamb located in his house and in Apy's tomb (No.10)
	Aye	The true king's scribe', 'Fan-bearer at the right hand of the King', 'The king's confidant throughout the entire land', 'Commander of all the Horses of the king', 'God's Father (it netjer)', 'Chief of Archers'	His wife Tiyi [Tey] was the great nurse [wet nurse] and later tutor of Nefertiti. Tiyi had two attendants named Hemetnisweterneheh and Mutef-Pre who are depicted as dwarves. Aye would later become Pharaoh.
	Huy(a)	Overseer of the Royal Quarters, the treasurer, Steward of the King's Chief Wife Tiyi', 'Overseer of the Royal Harem', 'Overseer of the White House (treasury) of Queen Tiye', 'Steward in the House of the	Inscriptions from the tomb (no.1) of Huya. There is also mention of 'the scribe of the House of Charm!' named Nakhtiu, and a sculptor named Iuti-Iuti is panting a statue of the princess Baketaten.
	Pentu	Royal scribe', 'King's chief', 'First servant of the Aten in the mansion of the Aten in Akhetaten', 'Chief physician', 'The two legs of the Lord of the Two Lands', 'Chamberlain', 'One who approaches the person of the king', 'Chief of Chiefs', 'Noble of the first rank among the sole	Inscriptions at tomb (no. 7) of Pentu at Amarna.
	Py	True favourite of Waenre'	Lady of the Court
	Tutu	His many titles include 'Chamberlain', 'Chief Servant of Neferkheperure-Waenre (Akhenaten) in the House of the Aten', 'Chief Servant of Neferkheperure-Waenre in the Wia-Barque', 'Overseer of all Craftsmen of the Lord of the Two Lands', 'Overseer of all the Works of His Majesty', 'Overseer of Silver and Gold of the Lord of the Two Lands', 'Overseer of the Treasury of the Aten', 'Chief	Inscriptions at tomb (no. 8) of Tutu at Amarna.
Government Official	Aperel	Vizier of Lower Egypt'	Aperel, also called Aperia was buried with his wife Tauret and son Huy, a General in Saqqara. Also mentioned in the tomb are Aperel's sons Seny and Hatiay. Aperel was a child of the kap (royal nursery) and became vizier under Amenhotep III
	Mahu	Chief of Medjay [Police] of Akhetaten'	Inscriptions from tomb (no. 9) of Mahu at Amarna.
	Meryre II	Overseer of the Royal Quarters', Overseer in of the double treasury', 'Royal Scribe', 'Steward', 'Overseer of the royal harem of the Great Royal Wife [Nefertiti]', 'Chief of the menesh-boat'	Inscriptions found in the tomb (no. 2) of Meryre II at Amarna.
	Nacht-pa-Aten	Herediary prince, count, sealbearer and vizier', 'Chancellor and Vizier'	Originally from the doorjamb of the tomb (no. 12) of Nacht-pa-Aten at Amarna. The doorjamb no longer exists.
	Neferkhepre-her-sekheper	Mayor in Akhetaten'	From rough painted inscriptions in the unfinished tomb (no. 13) of Neferkhepre-her-sekheper at Amarna.
	Parennefer	Pure handed cupbearer of the king's Person', 'Royal craftsman pure of hands', 'Overseer of all the craftsmen of the king', 'Overseer of all the works of the king in the house of the Aten', 'Foremost of commoners', 'One who accompanies the Lord of the Two Lands in every place', 'Overseer of the prophets of all the gods'	Inscriptions found in the tomb (no. 7) of Parennefer at Amarna and Theban tomb (no.188). His wife (who's name is lost) was recorded as 'A favorite of the King's Chief Wife Neferneferuaten Nefertiti'.
	Ptahmay	Guardian of the treasury'	Ptahmay probably lived in Memphis. A stela is known showing Ptahmay, his wife Takhert, his son Paatenemheb and his daughter Meryt. Also shown are Huy and his wife Wabt with son Hat and daughter Wadj. Another pair on the stela is Ramessu and Iwy, who are identified as 'his son' and 'his daughter' (maybe referring to Ptahmay?).
	Ramose	Vizier', 'Wearer of the royal Seal', 'Chief of the Prophets of the North and the South'	He was buried in Sheikh abd-el-Kurna (Thebes) in tomb 108. His tomb and its inscriptions provide proof that Akhenaten was previously known as Amenhotep IV.
	Sutau	Overseer of the double treasury of the Lord of the Two Lands'	Inscriptions from the tomb (no.19) of Sutau at Amarna.
Army Official	Aye	Fan-bearer on the right of the King', 'Master of All the Horses of his Majesty', 'God's Father (it netjer)', 'Chief of Archers'	His wife Tey was the great nurse and later tutor of Nefertiti. Aye will later become Pharaoh.
	May	Wearer of the Royal Seal', 'Commander of the Army of the Lord of the Two Lands', 'Overseer of the 'House of Sending Aten to Rest'', 'King's Attendant in his august barge', 'Chief of all the works of the King [Breasted]', 'True king's scribe', 'Fanbearer at the right hand of the king'.	Inscriptions from the tomb (no.14) of May at Amarna.
	Nekhu-em-pa-Aten	Chief bowman', 'Master of the horse', 'Royal cupbearer'	From a lintel of his house in Amarna.
	Pa-Aten-emheb	Royal scribe', 'General of the Lord of the Two Lands', 'Overseer of the works in Akhetaten'	From inscriptions in the tomb (no. 24) of Pa-Aten-emheb at Amarna.
	Ramose	Scribe of Recruits', 'General of the Lord of the Two Lands', 'The king's scribe', 'Steward of the house of Nebmaatre (Amenhotep III)'	Inscriptions from the house of Ramose in Amarna and the tomb (no. 11) of Ramose in Amarna.
	Ramose	Military Standard-Bearer of the company called 'Aten is caused to be satisfied''	Inscription from a bronze vase found at Amarna. This individual may be the same person as General Ramose.
	Ranefer	The first charioteer of his Person', 'The master of the horse of the entire stable', 'The great favorite'	Inscriptions from fragments found in the house of Ranefer in Amarna.
	Suty	Standard-bearer of the bodyguard of Neferkheprure- Waenre (Akhenaten)'	Inscriptions found in tomb (no. 15) of Suty at Amarna

Position	Name	Title(s)	Notes
Priesthood	Any	True king's scribe', 'Scribe of the offering table of the Lord of the Two Lands', 'Scribe of the Aten's offering table on behalf of the Aten in the house of Aten in Akhet-Aten', 'Steward of the House of Aakheprure [Amenhotep II]'	Inscriptions found in Any's tomb (no.23) at Amarna
	Hatiay	Scribe', 'Overseer of the granary in the house of Aten'	His tomb was found in Thebes
	Meryre I	High Priest or Greatest of Seers of the Aten', 'Fanbearer at the king's right hand'	Inscriptions found in the tomb (no. 4) of Meryre at Amarna. His wife Tenro is named Great Favorite of the Mistress of the Two Lands (Nefertiti).
	Meryre	The cupbearer of the house of Aten in Akhet-Aten', 'The cupbearer of Neferkheperure (Akhenaten)'	Meryre was married to Nubnefer (Nubnefret). They had two sons, Huy and Yuny, and two daughters, Hetepy and Itiat. The text indicates that the son Huy was a (ritual) dancer (?) of Neferkheperure (Akhenaten)
	Meryneith (Meryre)	Greatest of seers of the Aten', 'Steward of the temple of Aten', 'Scribe of the temple of Aten in Akhet-aten (and) in Memphis', 'First prophet of the temple of Neith'	His tomb was found in 2001. His wife was named Anuia (or Iniuia)
	Panehsy	First servant of the Aten in the house of the Aten in Akhetaten', 'Second prophet of the Lord of the Two Lands Neferkheprure-waenre (Akhenaten)', 'Overseer of the double granary of the Aten in Akhetaten', 'Overseer of cattle of the Aten'	Inscriptions from his houses at Amarna and the tomb (no. 6) of Panehsy at Amarna.
	Pawah	Greatest of Seers of the Aten in the house of Re'	From a doorpost of his house in Amarna.
	User	The overseer of the front hall', 'Overseer of the courtyard(?) of Aten in the House of Rejoicing of the Aten'	From an inscribed limestone weight found at the entrance of the Great Aten Temple
Other	Apy	The Chief Workman'	Inscription taken from a scarab
	Bak	Architect and Master-Sculptor'	Bak was the son of the Chief of Sculptors, Men and the lady Royenet. Inscription found in the Granite Quarry at Aswan. He may have had a sister who was the 'house-wife' Tahere.
	Hatiay	The overseer of the works projects', 'Confidant of the Lord of the Two Lands'	Inscription found on a lintel from the House of Hatiay at Amarna.
	Maanakhtef	The overseer of successful building projects in Akhet-Aten'	Inscriptions from doorframe to his house in Amarna.
	Men	Chief Sculptor in the big and important monuments of the king'	Son of Baimyu. Inscription found in the Granite Quarry at Aswan and a fragment at Luxor.
	Khay	Scribe of the altar of the Lord of the Two Lands', 'Beloved of his god lord of Heliopolis'	Son of Panehsy , 'Overseer of the cattle of the temple of Re, wab priest', and wife Tuy. Remains of scene with [Panehsy and wife] before hawk-headed Re-Harakhti, Musée National du Louvre, C 321. (dated to the time of Akhenaten)

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7.5 Appendix – Imagining *Ranefer*

The following story was conceived and written by Professor Barry Kemp, Codirector of the Amarna Project and one of the world's foremost authorities on the Amarna Period and the city at Amarna. The story is an outline designed for use within the Amarna Visitor Centre at Amarna but remains unpublished at present. Permission was given for its use within this current project by Barry Kemp during the summer of 2020.

C1. Imagining Ranefer

All we really know about Ranefer is contained within the short list of his titles (preserved on panels that surrounded some of the doors of his house), and the fact revealed by the excavation of his house, that he built (or rebuilt) it in the years immediately following Akhenaten's death. No tomb for him has been identified at Amarna.

We do have extensive information, however, on how society worked and how people lived in the general period in which Akhenaten's reign is set. The account of Ranefer and his family that follows is a work of the imagination but reflects the knowledge about ancient Egypt and Amarna that generations of research have built up. Some things, however, must remain inventions.

C2. Ranefer's household

Ranefer is 32 years old and has recently moved to Amarna from Memphis, following a promotion. He is now 'the first charioteer of his majesty, the master of horses of all the stables'. He moved in the year of Akhenaten's death, and was on duty at the coronation of the new young king.

Ranefer's wife, who is five years younger, is the 'lady of the house' Satia. She has given birth to seven children but only three have survived. There are two boys — Any (12) and Ramose (10) — and one girl, Neferu (9). Ramose is agile and intense. Ranefer wants him to join the chariot-corps of Pharaoh and has petitioned to have him accepted for training at the royal stables in Memphis.

They share the house with Ranefer's mother (the 'lady of the house' Qede) and an unmarried sister of his, Baket.

They have little privacy though this is natural for them.

Ranefer heads an extended household of around 80 persons who live in close proximity. They comprise:

- 1 steward, his name Huy
- 1 steward's assistant (his son, Yuny, a scribe, who has an added interest in healing, using potions and protective spells, and interpreting dreams)
- 25 men and their families who collectively do various jobs, act as bodyguards when Ranefer attends court gatherings (3 of them are also sailors for his river boat, 1 is his personal charioteer), scavenge for firewood, and manufacture goods for general household consumption and for a levy that goes to the palace. One of them (Aper) is a skilled brewer. Another (Tia) is a woman whose advice is often sought and who is skilled at assisting childbirth. They are not slaves, but they accept their place, receiving, in exchange for their service, food and protection from Ranefer. They live in 17 small adjacent houses which also act as workshops.

- 12 slaves, 5 of them men, and 7 of them women. They fetch water, cook, launder the clothes, dress Satia's hair; some of the women also spin and weave. They mostly answer to Satia. They have no houses of their own but sleep in and around the house and do not go far outside, apart from when 4 of the men act as rowers on Ranefer's river boat. 3 of the women and 1 of the men are from Canaan (Palestine) and mostly talk in their own dialect of the Akkadian language. Satia, unable to understand them, finds this disturbing.

C3. Respecting Ranefer

Although still a long way from the ideal Egyptian lifespan of 110 years, Ranefer is firmly in charge of his household. When he is at home his household feels that all is well and secure.

As a boy his father instructed him in the teachings of one of the wise men from the past, written on a roll of papyrus. To be respected is to be reticent and grave, quiet in speech, modest in one's own needs but generous and fair to those beneath you. Ranefer tries to follow this path.

Ranefer also owns a copy of the teachings of Akhenaten. Their main subject is the avoidance of falsehood. Some parts, which borrow from the teachings of the past, are easy to understand and Ranefer has memorized them. Other parts, in which Akhenaten tells of mounting disloyalty and treachery against the kings who ruled before him, and which are written in an emotional style, Ranefer finds difficult.

Ranefer has a letter of permission from Pharaoh to excavate a tomb and its chapel in the sacred eastern mountain. He chose the place not long ago and paid the head quarryman for one month's work of stone cutting. The tomb now has a doorway, and behind this the beginnings of a chamber with the shape of one column emerging from the stone. Although he will continue to pay for this work one month at a time, he has also made a contract with a draftsman and with a stone-carver to start the decoration of the doorway. It is important for him that his name is remembered.

In a room beside the central living-room of his house, on a shelf, is a painted wooden statue of himself seated beside Satia. A little wooden table of light construction stands in front of it on which is always kept a pot of water, regularly replenished by one of the slaves. The statue, and pictures of Ranefer seated in the same way but painted on the wall of the front reception room, are constant reminders of how Ranefer's presence pervades the house.

As head of his extended household Ranefer has responsibilities and obligations. His people — his 'village' — live close to one another and are, to some extent, dependent upon one another, exchanging goods and services, and sometimes intermarrying. Disputes amongst them often break out. They come to him to complain, first telling the steward Huy. One man seems to be the cause of more trouble than most and is often named. From time to time Ranefer and Huy sit on mats outside in the shade of the house and listen to both sides of disputes. Ranefer gives judgement. Mostly his judgments are orders for one person to recompense another. It is only rarely that he orders a beating or mutilation. Everything he decides Huy writes down and files away for future reference.

He is alert to rumors of words that have been said or actions planned that will harm the king and his possessions. In such a case he must hand over the suspect to the court of the vizier. He has not yet had to do this.

As a loyal official of the king it is also his duty, at the festival of the New Year, to present the king with a gift. This year he has chosen to give a fine statue of the king made in hard stone. Once received it will be placed in one of the king's buildings. To do this he has to make a contract with one of the city's statue-sculptors and agree upon a price, which will be high, paid in cattle and gold. His

gift to the king last year was a battle-chariot with a full set of decorated leather harnesses for the horses.

C4. Away from home

Ranefer holds the rank of chief charioteer, and so is one of the king's trusted officials as well as being a serving soldier.

Periodically, for a month at a time, he is part of the king's bodyguard and lives in a barracks attached to the palace at the northern end of the city.

He has fought in two battles in Syria, against a coalition of cities who prefer to be allies of the Hittite kingdom to the north. In the second of these battles, an arrow fired at his horses missed its target and instead penetrated through his bronze scale armour, piercing his right hip. He now walks with a limp.

Shortly after Ranefer moved to Amarna the king appointed him to be the messenger and envoy to the king of Babylon, who is named Burnaburiash. The journey there and back, and the stay at the court of Babylon, took the whole year. In a leather satchel slung across his shoulder he carried clay tablet-letters to the king of Babylon, and also to several of Egypt's vassal princes in Canaan, and to the prince of Aleppo in Syria.

He traveled with his personal charioteer-servant, with five soldiers and a scribe provided by the king, and with five of his own men traveling in an ox-wagon that carried supplies and also gifts from the king to the distant princes he would visit.

Whilst in Aleppo he wrote several letters on papyrus, to Satia and other members of his family, sending them back with a fellow Egyptian officer returning from another mission. He begins his letters by asking the Aten to protect each of them. By now Ranefer can speak some Akkadian, the language of many of the people he meets. He can also use it with his Canaanite slaves when back at home.

During his absences, both short and long, Satia runs the household, assisted by the steward Huy. Each day she kneels at the tiny altar built on the floor in one of the rooms of the house. She unwraps from its cloth a small wooden panel bearing images of the god Ptah. She burns incense in a pottery bowl. She spreads out on the altar a painted pottery figurine of Hathor and a shiny, bright blue faience amulet that she knows will attract the goddess's attention. She pours a little water over them. She speaks softly a plea that Hathor and Ptah will protect Ranefer against all dangers.

On his return he brought back tablet-letters of reply to Pharaoh, some gifts for him (including six female slaves skilled in weaving from the prince of Aleppo who travel in their own wagon and with their own bodyguard), and a bale of fine cloth for Satia and a dagger with an iron blade for himself. To show his thanks, Pharaoh invited Ranefer to one of the public reward ceremonies at the palace, gave him a collar of gold discs and increased his share of the food from the offerings in the House of the Aten.

C5. Ranefer's rewards and wealth

Ranefer owns a house in Memphis and a country estate in the eastern Delta, both inherited from his father.

He owns cattle and pigs and owns or rents many separate plots of land where wheat and barley are grown, as well as fodder for the cattle. The estates are managed by another steward, Nebmehy, who

regularly writes letters to Ranefer reporting on the affairs of the estate. Once a year a boat loaded with grain from Ranefer's harvest arrives at Amarna. Ranefer's men carry the sacks of grain through the city to his house and pour their contents into Ranefer's three circular grain silos. They also bring more cloth and a consignment of blank rolls of papyrus, both made on the estate in the Delta where papyrus grows abundantly. At other times in the year, in response to a letter from Ranefer, Nebmehy sends one or more cows for final fattening at Ranefer's Amarna house.

As one of Pharaoh's officials, Ranefer's name is on the long list of people who receive a share of the food-offerings periodically laid out in the House of the Aten. Every ten days, his steward Huy takes some of Ranefer's men and several donkeys and they walk to the office of food distribution, located in a collection of mud-brick buildings beside the great temple. There, in a large noisy crowd, they wait their turn for Ranefer's ration of bread and beer and, on some days, a portion of uncooked meat or a goose. Sometimes firewood and fish are also added to the rations. Huy takes with him Pharaoh's letter of authorization, which is examined carefully by the scribe in charge before the rations are released. Huy then signs a receipt.

Ranefer's wealth consists mainly of his land and its produce, and his people. Objects of value are not many. Most valuable are his two chariots — one for battle and one for local journeys — and their horses and equipment. Of gold he has a necklace (a gift of Pharaoh), three drinking-vessels and a heavy finger-ring; Satia owns gold earrings and a shawl of the finest linen on which are sewn many small gold flowers (also a gift from the palace). Between them they have ten boxes filled with linen, and an assortment of bronze vessels and tools and implements. In a bag kept in Ranefer's private room is a box containing many sheets of gold foil wrapped in cloth. This he gives out from time to time to craftsmen, either his own or others who do commissions for him. He intends to use some of it soon in the making of his own and Satia's coffins, which will also be stored in the house, shrouded in linen.

C6. Heket and Khay

Heket and her brother Khay are children of one of Ranefer's dependants, Efankh, a maker of jewellery. He injured his back many years before when he was called upon to labour in the quarries in the first year of the city's creation. He can walk only with the aid of a stick and is often in pain. He is also a widower. This little family live largely on bread and beer, and occasional pieces of meat, supplied regularly from Ranefer's house.

Heket and Khay are thin and pale. Heket walks with difficulty, having been born with a hip dislocation caused by a difficult birth. They are aged 7 and 8, and spend their days working.

Ranefer is under instruction from the king's treasurer to make regular deliveries to the court of linen, of glass beads and of quern-stones. He is able to do this through the skill and labour of his dependants. Heket's tiny fingers are able to make the finest of linen threads that she passes to one of the neighbouring houses that has a loom. She spends most of the day at work, making the thread, squatting against the wall of her living-room sometimes helped by the youngest of the Canaanite slaves from Ranefer's house.

Khay mostly works in the little courtyard beside the house. He crushes quartz pebbles to fine powder that he uses to cut and polish beads made from small flat strips of glass that are coloured red, or blue or green. These his father produces by remelting broken fragments from glass ingots that the steward brings in from time to time. The kiln is in the same courtyard and Khay often helps his father. Khay's fingers, coated in fine quartz dust, are constantly rubbing tiny pieces of stone together, polishing the surfaces. It takes perhaps half a day to finish one small bead.

With his thin arms he can also wield a rounded stone hammer against a piece of quartzite, chipping it to the shape of a quern-stone and then finally smoothing the upper surface by rubbing it with a smooth stone and fine quartz powder.

C7. Satia's baby

Satia is awaiting the birth of her latest baby.

In Ranefer's house there is one specially built bedroom, with a raised alcove at the back covered with a wooden hood that funnels cool wind into the room. Ranefer's mother and the slaves have cleaned the room and spread new linen on the bed. On the floor they have set up two bricks on their edge and gathered a pile of small pieces of cloth and a row of filled water jars. Huy has sent some of the men to the house of a neighbour that has a large garden beside it, to ask for lengths of the convolvulus plant. They string it between wooden pegs fixed at the top of the sides of the bed alcove. Against each of the bed's legs, and facing outwards, a pottery bowl has been placed that has the figure of a rearing cobra rising from the middle. The cobras will drive away harmful spirits especially at night, as will a polished black wooden statuette of the god Bes placed under the middle of the bed. Yuny, the steward's son, has brought in his collection of scrolls that contain spells to protect newly born children.

In the night Satia begins her labour. She struggles to sit herself on the bricks, leaning back so that her head and shoulders are held by one of the women. The woman Tia squats in front of her holding ready a pad of linen cloths. Satia gives birth easily to a baby boy. With a little sharp bronze chisel mounted in a wooden handle the umbilical cord is cut, washed, and carefully wrapped for safekeeping. Soon she is sitting on the bed, suckling her baby and receiving a stream of visiting women, from the household and from neighbours. In a corner Yuny has quietly taken his place, ready to smear on the baby's forehead a potion he has prepared and to read the words of a protective spell.

Forty days pass and Satia and the child live. He is given his name: Nedjem-Aten. The Ranefer household prepares a celebration. Ranefer himself donates two cows to the House of the Aten, arranging to receive in return enough meat for a banquet at his house.

As the sun sets, the house fills with guests, wearing their finest linen and bright jewellery. Some carry bouquets of lotus flowers that soon fill the house with their sweet and heavy perfume.

Ranefer and Satia greet their guests in the front reception room, the woman Tia holding the baby for all to see. Their other three children stand shyly alongside. Ranefer notes with concern who, amongst his friends, have been unable to attend. Satia's elder sister has come, though, despite the distance. She is a personal servant to the queen and lives, unmarried, at the palace. She brings with her, as a gift from the queen, a tiny ring made from gold engraved with the design of a horse set between palm trees. Maybe the child will follow his father and be a chariot-warrior.

At a signal from the steward everyone passes into the central reception room. Ranefer and Satia sit solemnly on carved wooden chairs on the low dais at the back. Everyone else squats easily down on the fresh mats laid over the floor, married couples together, the unmarried men and women in separate groups. Three girl musicians from the palace enter and start to sing and play flute and lyre. The slaves pour wine into cups from heavy pottery amphorae and bring in the food on pottery platters. Conversation rivals the music. Seven of the female guests play a game in which, one at a time, they pretend to be the goddess Hathor, predicting the baby's fate. Perhaps he will marry a king's daughter.

Outside the house, all of the lesser members of the household gather and sit in the courtyard, waiting for surplus food to be brought out to them, and drinking the reddish beer that Aper the brewer made a few days before.

Ranefer and Satia emerge through the house door and descend the steps, followed by Tia carrying baby Nedjem-Aten. The household people stand, they clap their hands rhythmically as one man starts to sing a song of welcome and thanks to the gods for perpetuating Ranefer's line further.

For a short time people forget their cares.

C8. The sickness

The mother of Heket and Khay died from a sickness that people said came from Asia. It has reappeared in the city. People say their limbs turn to stone. Their bodies grow hot, yet they shudder and writhe, and in their sleep they see the spirits of the dead around them. Young people who become sick in this way die quickly; older people more slowly, and some recover though they remain weak. The high shrieks of women mourning the dead are everywhere in the dense neighbourhoods. People pray and burn incense in their homes but feel that the gods have deserted the land. Yuny, the son of Ranefer's steward, spends much time in the houses of the neighbourhood, tending the sick and attempting, with a fierce voice that speaks the words of the god Horus, to compel the demons of disease to flee.

The sickness appears unpredictably. Six of the queen's young companions die in a single night, the king's physician has been called to the house of the high priest himself. A young man on his way out to the cemetery, on his own, leading a donkey laden with the bodies of his mother and wife who are wrapped in mats made from long sticks tightly tied round with rope, collapses on the track. A returning family cover him with a blanket and lead the donkey on, making a shallow grave for the dead pair. By the time they reach the young man again, he, too, has passed away and so they make a third trip back to the cemetery to bury him. Little Nedjem-Aten becomes a victim, towards the end of his second year. Despite the frequency of deaths in the city Ranefer and Satia are overwhelmed with grief.

The hyaenas who prowl the desert are growing bolder and are entering the city at night. A watchman who had fallen sick is found half-eaten in his hut at the end of the alley that leads to Ranefer's quarter.

In the middle of the day, as he helps his father stoke the kiln, Khay's arms and legs begin to ache and his head to throb. As he leans himself against the side of the kiln his father takes hold of him and drags him into the house. At sunset, as he shivers on the ground, Heket lies beside him to give him warmth and comfort. By morning Khay is dead; Heket by the following evening. Ranefer, when he hears, issues cloth and lengths of sturdy matting to wrap the bodies in. He instructs some of his men to accompany Efankh, their father, to the cemetery and to carry the bundled bodies to the grave they will dig. He orders an unmarried daughter of one of the householders to attend Efankh regularly and look after him.

C9. The last days

Two years ago, a new king, Nebkheperura Tutankhaten, was crowned, but not at Amarna, which he had visited only twice from his place of birth at Memphis. As has become the custom, everyone quickly made little faience rings to wear, that carry his name. Now the king has issued a decree. The army units and all officials of the king will return to Memphis within two months, except for officials of the treasury, who will stay longer to supervise the emptying of royal storehouses and the transfer

to Memphis of all treasures and other goods. Fresh sets of soldiers and police have arrived to guard the tombs, and the palaces and temples.

Ranefer is away again, with Pharaoh's army in Syria. Satia has no news though there is a rumour of defeat.

Satia sends the steward Huy to Memphis to prepare the family house there. Everyone in the household starts to pack their generally few possessions into linen sacks and baskets and the occasional box. As they pack, they start to dig up the soft floors of their houses and courtyards, looking for objects they have buried or dropped.

Many remove wooden doors and window shutters. They join lines of others carrying possessions down to the boats moored at the riverbank. Many boats have only recently arrived. As news has spread of the exodus, owners of boats throughout Egypt have converged on Amarna, asking high prices for transportation.

One of Ranefer's fellow-officers has decided to transfer the burial of his father from a sealed chamber in their unfinished rock tomb at Amarna to the previous family tomb at the city of Akhmim in the south. Ranefer's household have made no elaborate burials and so are spared this. They will leave their dead behind in the distant desert cemeteries. Already the looting of the graves has begun. Heket's and Khay's bodies have been pulled from their double grave by robbers and their detached skulls lie in the sun; a trader is on his way to Thebes with a sack of objects hoping to sell them. Amongst them is the gold ring taken from the grave of Nedjem-Aten.

On a cloudy day in early summer, with an unseasonably cold wind blowing from the north and slowing down the boat, Satia looks at Amarna for the last time.

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