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VIRTUAL WOLVERHAMPTON: RECREATING THE HISTORIC CITY IN VIRTUAL REALITY

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Keywords

Wolverhampton; urban historic reconstruction; virtual reality; oculus rift; unity game engine; 360° video; 3D models; historic environment record

Abstract

While many towns and cities have historic origins, the modern urban landscape is often unrecognisable from the past. Over the last two thousand years innumerable changes have occurred, from the Roman period to the Industrial Revolution, culminating in wide scale development and redevelopment of towns and cities during the 19th and 20th centuries. Fragments of the past survive as extant buildings, monuments, and areas, and are offered protection through mechanisms such as the National Heritage List for England. However, these buildings are part of a dynamic and changing environment, and their place within their original landscape not always visible. Meanwhile, the advent of mainstream and accessible immersive virtual reality offers opportunities to recreate and explore the past, and to disseminate a deeper understanding of the history and historic context of our heritage assets to a broader audience via new technologies. This paper discusses a project based on Wolverhampton that aims to create immersive and 360° experiences of the historic city that allows the user or viewer to explore how the city might have been in the past from a 'first person' perspective. It uses multiple approaches to gather, verify and validate archival data, records, maps and building style information. The project itself is a work-in-progress, with various approaches being explored. It looks at sources of information used to inform the virtual world; software and methodologies used to create the model; different forms of VR output; potential forms of funding for wider dissemination; and problems encountered so far.

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INTRODUCTION

History of Wolverhampton

The history of Wolverhampton can be traced back over 1000 years. In AD 985 King Aethelred made a grant of land at Heantune to the town's benefactress Lady Wulfrun, with Lady Wulfrun herself endowing a minster church nine years later (Farley, 1985). The name, 'Wolverhampton', known historically as Hampton or Heantun, may mean 'Wulfrun's settlement on a hill' (ibid.) or 'Wulfrun's chief manor' (Horovitz, 2005). It is said that King Wulfhere of Mercia founded an abbey in the site as early as AD 659, and it is possible that there was an earlier Iron Age hillfort there, although no evidence of either has been found (Upton, 1998). Outside St Peter's church today stands the base of a Saxon cross, a scheduled monument, erected to celebrate the founding of the town. The cross is possibly a re-used Roman column from Wroxeter or Wall (Baker, 1980).

The extent of the Saxon settlement has been postulated by Slater (1986), based on analysis of 18th century mapping. Centred on the higher ground with commanding views over the hinterland, it would have been surrounded by a fence or a ditch, that in part followed the alignment of North Street to the west, and Princess Street/Princes Square to the east (Figure 1). Wolverhampton is named as Heantun or Hantone in the Domesday book (1086), and is recorded as having fourteen slaves, six villagers and thirty smallholders with a total of nineteen ploughs, suggesting a settlement of over two hundred people (Farley, 1985).

From these humble origins, Wolverhampton developed as a centre of trade, having a market here in some form from at least 1179, and being granted a charter for a market and a fair in 1258. The wool trade was particularly important to the town in the 14th and 15th centuries, and the wealth of the town at this time resulted in a major reconstruction of St Peter's church at the end of the 15th century (ibid). The extent of the medieval town has also been suggested based on analysis of the mapping (Shaw, 2000), with the town in this period extending to include Red Lion Street and Victoria Street in the west, Market Street and Thornley Street to the east, Dudley Street, Bell Street and Salop Street to the south, and Paternoster Street and Mitre Fold to the north (Figure 1). The Lych Gate Tavern on Exchange Street has a mid-late 16th century timber-framed rear wing with a brick ground floor. A great fire in 1590 resulted in the destruction of 104 houses and 30 barns. It lasted for 5 days and would have had a major impact on the built environment at the time. 19 Victoria Street, known locally as 'Lindy Lou building', dates from the late 16th or early 17th century and may have been built following this event.

The town continued to grow, and Isaac Taylor's map drawn in 1750 shows the extent of the town during the mid-18th century, with a population at this time (according to Taylor) of 7454 inhabitants (Figure 1). Buildings shown on this map include Giffard House, built between 1727 and 1733, and Molineux House, built on land purchased in 1744 (Farley, 1985). Between 1751 and 1753 much of King Street was built. The construction of the canals in the late 18th century followed by the coming of the railways during the 19th century transformed the town further, with both massive expansion outwards and changes to the centre. The industrial revolution saw Wolverhampton flourish, with industries like ironworking, japanning, and lock-working becoming dominant and ubiquitous. During this time Queen Street and Darlington Street were constructed, and Lichfield Street widened, with grand, ornate buildings representing wealth and civic pride replacing much of the older building stock. The

20th century saw continued change, including major slum clearance and the construction of the ring road.

Figure 1. Red outline shows the possible extent of the town in different periods. Height map generated from Lidar data (Source: © Environment Agency copyright and/or database right 2015. All rights reserved. Contains OS data © Crown copyright and database right 2017).

Evolution of virtual reality for heritage

Archaeologists have long appreciated the potential for computing and digital technologies to capture, analyse and visualise datasets to enhance our understanding of the past. As frontrunners in the social sciences and humanities in employing spatial approaches, archaeologists have used Geographic Information Systems (GIS) to model, analyse and visualise disparate datasets and generate new knowledge (Gupta and Devillers, 2016; Ramsey, 2013; Chapman, 2006). This technology originated as a digital 2D mapping technique, while adding height and temporal information creates 3D and 4D GIS. In particular, archaeological landscape analysis will often ask the question 'What did they see?' with GIS viewshed analysis being a common approach to finding the answers (Chapman, 2006; Wheatley and Gillings, 2000). However regardless of the quality of data input into any analysis, it is not without problems in the interpretation, not least because the visual aspect of perception is only part of the whole (Eve, 2017). GIS practitioners are aware of the limitations of abstract realities that simplify the complexity of the relationship between people and place (Richards-Rissetto, 2017).

As GIS developed in spatially mapping data, digital technologies have also been used to recreate and present the past in the form of 3D models. Often the aim is not only to capture, preserve and interpret information, but to make the interpretations accessible to the wider public, and using virtual reconstructions is an effective method of communication (Frankland and Earl, 2011). The first use of virtual heritage as a museum exhibit was in 1994 that provided a 'walk-through' of a reconstruction of Dudley Castle as it was in 1550 (Abdelmonem, 2017), with Game Engines such as Crytek's Cryengine, Unreal Engine, and Unity later providing widely accessible platforms for larger world creation (Ch'ng, 2007). Cryengine was used by Ch'ng to recreate the lost Mesolithic landscape of the North Sea (2007) and by students from De Montfort University who created a detailed reconstruction and animation around Pudding Lane in London before 1666, based on original maps of the area (Pudding Lane Productions, 2013).

The problem of authority and authenticity of archaeological visualisations has been acknowledged in the archaeological community (Frankland and Earl, 2011), where

reconstructions are often interpretations of data, but are potentially taken as fact by the audience. As Ch'ng notes (2007) 'the process that leads to the final delivery of the presentation layer of an archaeological visualisation is often a thorough and lengthy scientific process,' and argues that the credibility of the final product depends on the process that creates it. The veracity and comprehensiveness of the input data needs to be as complete as possible, and even then the end result will inevitably represent a certain amount of subjectivity on the part of the creator.

There are ever more sophisticated ways of capturing data from object to a landscape scale, such as high resolution laser scanning and photogrammetry, or remote sensing techniques like LIDAR and ground penetrating radar, and ever advancing methodologies to communicate and disseminate this captured digital data (Ch'ng et al, 2013; Feldmann et al, 2016).

With all these visualisations, however, there are still limitations on the experience. As Gillings (2012) says (quoted in Eve, 2017), 'if the interpretation of landscape [lies] not in its measurement, abstraction and representation, but instead through immersion, movement and perceptual engagement, then how [are] archaeologists to go about recognising, gathering and interrogating this data'. The same might be said of cultural objects, especially when viewed out of context in museum exhibits. Immersive VR has the potential to simulate immersion, movement and engagement, and by generating images, sounds and interactions mimic a user's physical presence in the environment (Kersten et al, 2017), as well as providing context for cultural objects and historic buildings. This may overcome problems associated with authenticity (Frankland and Earl, 2011) and can also provide a sensory experience and allow culture in context to be accessible to the general public (Guerra, 2015). Using virtual reality allows us to recognise the subtleties of embodied space, to be 'in' the world, and to interpret the spatial relationships between monuments (Ch'ng, 2009).

The year 2016 witnessed what might be considered the advent of accessible immersive virtual reality. While VR in a number of forms has been around for a while (Abdelmonem, 2017), 2016 saw the commercial launch of the Oculus Rift (launched initially as a crowd funded project in 2014), followed by the HTC Vive and Playstation VR headsets. This equipment is relatively expensive (£350 - £750 at the time of writing), and additionally requires high spec gaming computers or games consoles to run them, adding to the cost. Less expensive headsets that work with smartphones rather than PCs, such as the Samsung Gear VR and Google Cardboard have also been released, and standalone headsets that require neither PC nor smartphones are expected later in 2017. The price of the equipment might put off the average user, however the potential for this technology to be incorporated into museum displays or art exhibits is already being realised.

There are an ever-growing number of examples of the use of VR technologies to create immersive and interactive experiences to enhance cultural exhibitions. The technology has been explored by Gonizzi Barsanti et al. (2015), who created a scenario regarding the 'path of the dead', to enhance the comprehension of significance of specific artefacts relating to this important ritual. Kersten et al. have used Unity Game Engine to create an immersive and interactive virtual reality experience of the Selimiye Mosque of Edirne in Turkey (Kersten et al., 2017). In August 2015 the British Museum invited visitors to experience a virtual reality Bronze Age roundhouse, and have more recently partnered on a major exhibition at the Yorkshire Museum brining back to life a Viking camp based on research at Torksey, Lincolnshire (Alberge, 2017).

THE RATIONALE BEHIND VIRTUAL WOLVERHAMPTON

The Virtual Wolverhampton project is creating two immersive virtual reality experiences of the historic city; one based on its founding as a Saxon settlement and one of the possible townscape in the mid-18th century. Both models were informed by a wide range of data and information. We know little about Saxon Wolverhampton beyond the date of its founding and the possible extent of the settlement, with the Saxon cross base being the only surviving monument of this period. As such, much of the model is hypothetical, using information from other examples of Saxon buildings, notably the Saxon reconstructions at Bede's World and West Stow, and surviving Saxon churches such as Escomb in County Durham. Archaeological evidence from excavations elsewhere provided examples of the possible size and shape of enclosures, as well as information on details such as animals that would have been kept, and artefacts that may have been present.

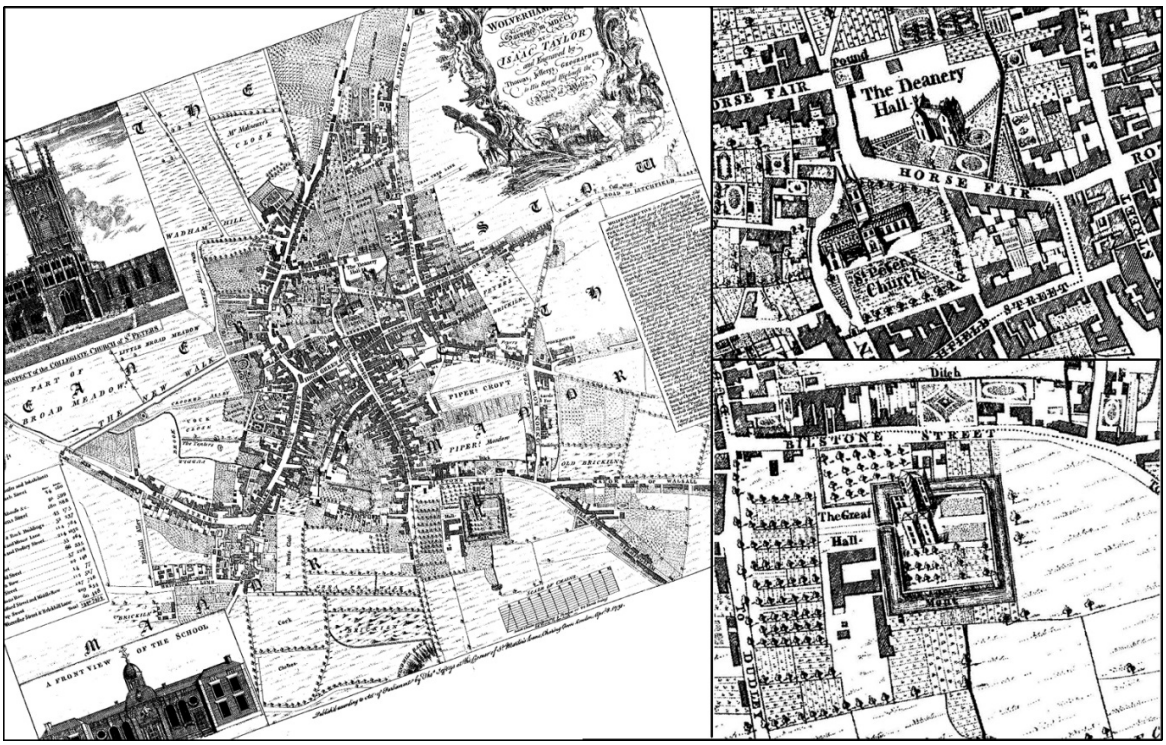

Figure 2. Isaac Taylor's map of Wolverhampton 1750 (Source: Author).

The basis for the 18th century model is Isaac Taylor's map of Wolverhampton from 1750 (Figure 2). This map is incredibly detailed, and shows not only main buildings, but smaller buildings, workshops, paths, gardens, walls, property boundaries, and even trees. While the town at this period was larger than the medieval core (Figure 1), it was likely to have the same main street pattern and layout. This map is being used as a guide to determine the placing of individual buildings, to recreate the town down to the finest possible detail of the time. Extensive use of the Wolverhampton Historic Environment Record (WHER), along with additional research of documentary sources, historic maps, photographs and pictures is being used to identify buildings that would have been standing at this time, and to inform educated guesswork where no information is available. It is hoped to bring this map to life, to reconstruct the streets, gardens, walls exactly as they are shown.

The software used to create the content for the models was mostly open source and/or freely available. Blender (open source 3D modelling software) was used to generate 3D models and GIMP (open source graphics software) was used to generate the textures for the models. The virtual worlds themselves were constructed in the Unity 5 game engine, and tested using the Oculus Rift DK2.

METHODOLOGY

Data collection

Wolverhampton is situated on higher ground at the northernmost point of a north-south ridge of land, with commanding views over the hinterland (Figure 1). The topography of the city, therefore, very much influenced its initial position and evolution, and it was important to generate an accurate topographic base on top of which the virtual worlds could be created. The Environment Agency has made available for download LIDAR data for much of the country, at resolutions varying from 0.5m to 2m. LIDAR is a remote sensing technique that uses a laser to scan and map the landscape, to create terrain models at very high resolution. The data comes in two formats – DSM and DTM – both of which are useful in different ways. The DSM (digital surface model) includes the heights of buildings and trees within the landscape and was useful in calculating height dimensions to model the extant buildings, while the DTM (digital terrain model) strips these objects out and is representative of the underlying terrain. This data was imported into a GIS project, along with modern mapping and rectified historic mapping (Figure 3).

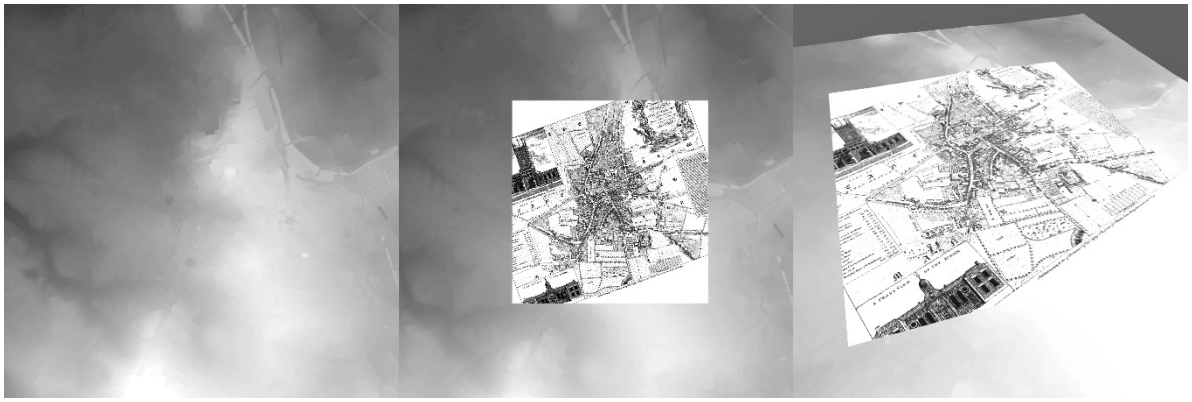

Figure 3. Height map of the city centre using LIDAR DTM 1m resolution © Environment Agency copyright and/or database right 2015. All rights reserved. Middle – With Taylor's map overlain. Right: As a painted terrain base in Unity 5 (Source: Author).

Taylor's map, which provides the base information for the 18th century model, is highly detailed but stylistic, and the rectification of this map could not be done on a building-to-building level. Instead points at surviving road intersections were taken to position the map in its approximately correct place, without warping the image too much. The changes in road layout between 1750 and today are extensive, however, historic map sequences such as the Ordnance Survey 1st Edition 1884 provided a suitable map to rectify to, as this predated the modern urban changes. Other historic maps, such as Godson's map of 1788, and the Wolverhampton Tithe map of 1842 were also consulted. Elements of Taylor's map were also used to inform the Saxon model, such as the location of the Puddle Brook (likely to be an important water source), and the basic road layout.

The Wolverhampton Historic Environment Record (WHER) formed the basis for the research, and was consulted to identify the dates of known buildings that would have been built prior to 1750. Where these buildings are extant, they were then photographed (Figure 4). Research at the City Archives additionally identified a number of other buildings and streets for which there were paintings, sketches and photographs that could inform models. The locations of these buildings were then identified on Taylor's map (Figure 5). Research is continuing, with more information and sources coming to light as the project goes on.

Figure 4. Extant buildings dating to before 1750, plotted onto Taylor's map. Left – City Archives (Molineux House), Giffard House, 19 Victoria Street. Right: Rear of 44 Exchange Street, front of 44 Exchange Street, Quicksilver Amusements (Source: Author).

As well as images of specific buildings and streets, written descriptions of the town by antiquarians were sourced to provide detail. For instance in Robert Plot's Natural History of Staffordshire in the 17th century describes the town wells, located at Townwell Fold:

'where they have but four weak springs to supply that large town, which too rise all together behind the Cock-Inn, having different names appropriated to their respective uses, as the Pudding-well, the Horse-well, the Washing-well and the Meat-well' (Plot, 1686).

Account books of Wolverhampton constables from 1688 to 1750 contain many references to wells and pumps within the town (McMillan, 1947), the locations of which have been provisionally mapped on the Historic Environment Record. Documentary evidence of the Saxon period is not as descriptive, however, a number of routeways are mentioned in the

Anglo-Saxon Charters and these have been provisionally plotted in the Historic Environment Record. These fragments of information from the Charters were used to give a best guess at the layout of the settlement and the roads leading to it.

Figure 5. Locations of buildings prior to 1750 identified from paintings and historic photos. Left – The Deanery, High Green, High Hall. Right – Lichfield Street, High Green, the Great Hall. Historic images reproduced with kind permission from Wolverhampton City Archives (Source: Author).

Other forms of evidence available to inform the model, and directly relating to Wolverhampton's history, include a number of archaeological excavations undertaken in the city centre. A series of excavations were undertaken at the Great Hall, where the foundations of the original hall were uncovered and sections through the moat demonstrated not only the width and depth of the moat itself, but contained artefactual evidence relating to the hall's inhabitants, and environmental evidence that can potentially help reconstruct the past vegetation in the vicinity (Hewitson et al., 2010, Figure 6). Archaeological excavations have also been undertaken to the rear of 19 Victoria Street identifying a stone wall foundation set in a shallow trench, presumably for a timber-framed building and indicating that there was likely ancillary building in this area (Malam, 1982-3).

Figure 6. Archaeological excavations at Old Hall Street. Left – a section through the moat, right – the remains of wall foundations of the Great Hall (Source: Author).

Where evidence directly relating to Wolverhampton was not available, alternative sources of information were searched for. For the Saxon virtual world, for instance, images and information on possible building types of the period was collected, such as reconstructed examples at West Stow Anglo-Saxon village and Bede's World (Figure 7). For the 18th century model, information was also gained regarding specific industrial processes and structures, such as those relating to brick kilns during this period. This allowed for the interpretation of individual buildings in these areas, and allowed for reconstruction of these elements of the map.

Figure 7. Reconstructed Anglo-Saxon houses at Bede's World and West Stow. Images by rob bishop, dun_deagh, Midnightblueowl: via Wikimedia Commons (Source: Author).

VIRTUALISING HISTORIC CONTEXT: BUILDING THE MODEL

Once the DTM, the modern mapping and the historic mapping were in the GIS project, an appropriate extent for the virtual world was identified and each of the layers exported as an image. The DTM black and white image was converted into a RAW file, then imported into Unity 5 as a height map to inform the terrain. The terrain was scaled to ensure that one metre experienced in the virtual environment in the model was as close as possible to one metre in reality. The lowest and highest heights within the extracted extent within the GIS project were calculated, and the difference between them used to generate the highs and lows of the terrain height. Where hard edges were present in the DTM due to modern landscaping or artefacts in the data, these were smoothed out. The terrain was altered manually to recreate the course of the Puddle Brook, the moat surrounding the Old Hall, and the ditch that possibly surrounded the Saxon settlement.

Once the terrain was created, the modern map and Taylor's map were imported into the project as textures. These textures 'painted' the terrain, and acted as guides to determine the placing of buildings, roads, and other elements, both for the Saxon world and 18th century

world. For the Saxon world, the reconstructions at West Stow and Bede's World (Figure 7) were used as examples to model the possible buildings within the Saxon settlement. The buildings were modelled in Sketchup and Blender, the faces were UV mapped and textured with tiles of appropriate materials which were amended in GIMP graphics software prior to use. The church was based on Escomb church, County Durham, and images sourced via Google provided the base information for this model. The cross was modelled using a combination of real life data for the base, with the top reconstructed from other examples of Saxon crosses. The carved detail on the cross base was create using a bump map image generated from a picture of the cross base detail in Rix, 1960 (Figure 8).

Figure 8. Reconstructed Saxon cross, church and buildings (Source: Author).

Figure 9. Molineux House (Source: Author).

For the 18th century virtual world, there is significantly more data that could be used to inform and model specific buildings, and more information is likely to exist within the archives and personal collections as the project progresses. For buildings such as Molineux House and Giffard House, their approximate size and height were taken from the GIS project, and modern photographs were used not only to inform the base model but to provide in places photorealistic textures (Figure 9). For buildings such as High Hall and the Great Hall, which no longer exist, similar texturing techniques (using appropriate material tiles) as that used on the Saxon world was implemented (Figure 10).

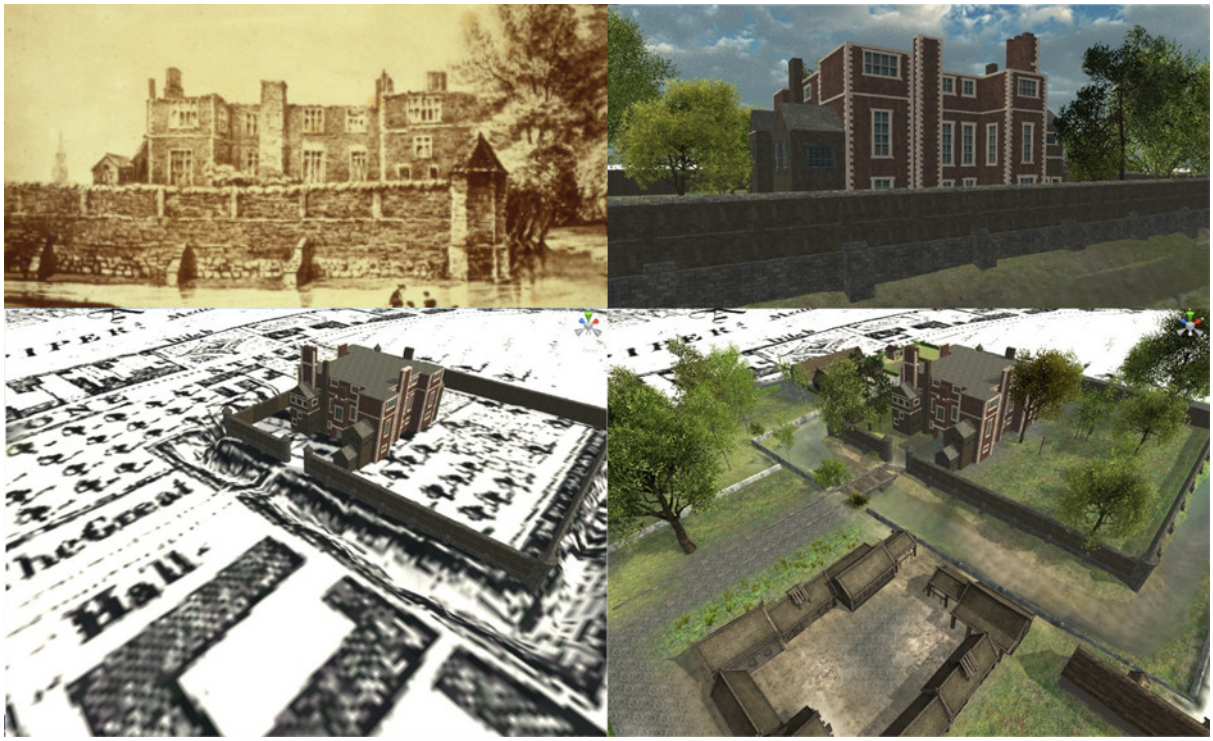

Figure 10. The Great Hall (Source: Author).

However, even though there is a lot of information available, there are significant gaps in our knowledge of the built environment at this period. By the 19th century, many of the older buildings that would have been standing in 1750 had already been demolished. In addition, there is not a full photographic record of the city centre. For streets or buildings for which there is no evidence, we can still apply knowledge to the types of buildings that may have been present. For instance, we know that there were timber framed buildings in the heart of the city, 3 stories high, and with a brick first floor, as we can see this in the surviving elements at the rear of 44 Exchange Street. Likewise, further along the arterial routes towards the outskirts of the town at the time the buildings and plots shown on Taylor's map of 1750 are smaller and are interpreted as less ostentatious dwellings, cottages, or buildings of a similar form perhaps to 19 Victoria Street. We can use surviving examples from other towns to inform the models, identifying the local vernacular as best we can.

Pre-made model packs available to purchase online in places like the Unity Store, are currently being used to fill in these gaps in the model where no information was available. A wide range of model packs are available, in a variety of styles, under the 'historic' or 'medieval' umbrella, and not all of these were deemed suitable for the project. Packs with a highly ornate or cartoonish style of building were disregarded, as were medieval sets based around stone castles. However several of the packs contained buildings that may be similar to ones that existed within the town, of a similar style and materials as found at 19 Victoria Street and 44 Exchange Street. Packs containing utilitarian buildings such as sheds, stables, workshops, constructed from wood were also purchased to help infill the yards and folds at the rear of the properties fronting the streets.

Additionally these packs contained extra props including market stalls, and elements such as wells, barrels, hay bales, grain sacks, carts, and fences which were also be used to populate both the Saxon model and the 18th century model without having to model all these

elements from scratch. Where specific props were required and not available as pre-made models, such as the brick moulds for the kiln, these were modelled using the same software and techniques as the buildings (Figure 11).

Once the terrain and the buildings were ready, the worlds were constructed by dragging and dropping (with scale and rotate) the various elements into their correct location. Buildings and structures for which we have information for were placed on their correct location on the map - these include the Saxon cross base, the church, and the 18th century buildings. After this the gaps were filled in with pre-made buildings and props that were deemed most suitable for that location, the terrain itself was re-textured to provide roads and fields, and vegetation such as trees, bushes and grass (Figure 12).

360° photographs, similar to Google Streetview spheres, were incorporated into the virtual worlds to allow the participants to experience the 'historic' Wolverhampton in relation to the modern city. As both of the models were related to the real world in terms of scale and road layout etc., locations were selected that could be identified in both – for instance the junction of Queen Street and Dudley Street is hypothesised to be near the southern extent of the Saxon settlement, Queens Square (once High Green) as the location of the medieval market, and opposite 19 Victoria Street is close to the course of the Puddle Brook. The 360° photos were taken using a Ricoh Theta camera. These images were then used to texture the inside of spheres that were placed within the model, with the idea that when the participant moved within the sphere inside the virtual world, they would see a 360° view of the real world that could be turned on and off (Figure 13). One of the elements still missing in the virtual worlds is people. Buildings, structures, artefacts and environments are relatively easy to produce in comparison to people which, due to their complexity, are far harder to model. Flat 2D images of people, used in Unity as sprites, are one way of populating the model, and this may be explored in the future.

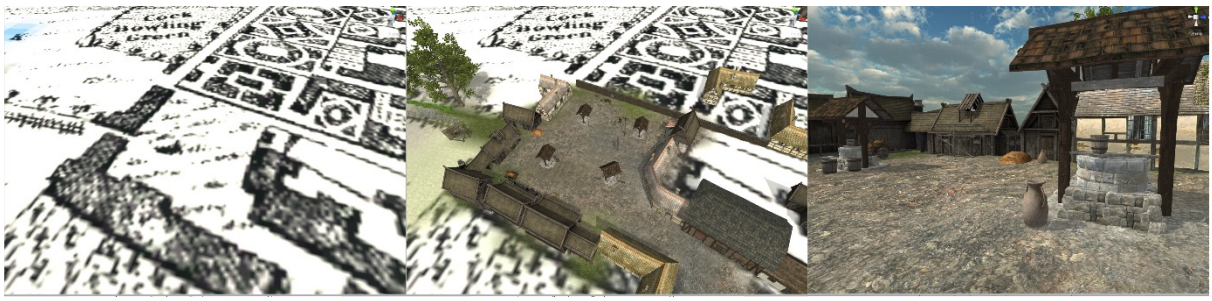

Figure 11. Townwell Fold (Source: Author).

Figure 12. The full reconstruction of Saxon Wolverhampton (Source: Author).

Figure 13. Photospheres within the virtual worlds depicting the modern view at selected locations (Source: Author).

IMMERSIVE EXPERIENCE IN THE PAST: OUTPUT AND DISSEMINATION

A full immersive experience requires a proper VR head mounted display (HMD) and (at present) a computer or games console to run it, so sharing the virtual reality experience in its full form is likely to prove difficult. However this is less of a problem when creating experiences that can be shown in public places such as museums and art galleries, that have (albeit limited) resources to put on exhibitions including both content and infrastructure. With this in mind, initial thought has been given as to how to fund such an experience, with particular consideration given to crowd-funding. Crowd-funding, on platforms such as Kickstarter or Go Fund Me, has been utilised effectively in generating resources within the heritage sector for art endeavours, exhibitions and museum displays. While there are a number of different crowd-funding sites, a lot of the elements are the same including some kind of reward for donation, from small rewards to larger ones dependent on the size of the donation itself.

Another form of output and dissemination is to use the models to record 360° animated fly-throughs that can be viewed via video hosting sites with 360° capability such as YouTube. These videos can be watched on the more expensive VR headsets, but they also be viewed on smartphones using a Google Cardboard viewer, or Samsung Gear VR headset. Google

Cardboard viewers cost only a fraction of the price of Oculus Rift and HTC Vive VR headsets, and while this kind of experience is less interactive, the videos would be available to a much wider audience.

The project is a work-in-progress, however a number of problems have already been encountered, not least because the larger the model the more processing power needed to render the virtual worlds. This was not a problem for the Saxon world - this covers a smaller area and has fewer buildings, all of which were modelled bespoke to ensure a low polygon count as well as historical accuracy. The use of pre-made buildings in the 18th century model, however, while saving time on creating content, is adding a large amount of unnecessary detail. This is slowing down the rendering, which in turn is making the virtual reality experience increasingly uncomfortable. The answer to this problem is, in part at least, to create more of the buildings from scratch. On-going research as the project progresses means more building specific information is identified, so pre-made buildings can be swapped for informed bespoke buildings as and when they get created. This will increase the authenticity, local accuracy, and hopefully usability of the model, and while this means the 18th century model will take longer to create, the end result will be significantly better.

CONCLUSION

The advent of mainstream virtual reality has created a number of opportunities for the heritage sector to generate new and immersive ways of exploring and understanding the past. A virtual experience, however accurate or detailed, is not the same as a real experience and should perhaps be seen as an experience in itself rather than aiming for absolute realism. Creating (or recreating) elements of the historic environment in virtual reality will never be an alternative to the conservation and preservation of extant buildings, structures and monuments. However, where heritage no longer exists, or only exists out of context, such as urban centres or altered man-made landscapes, or is impossible to get to such as the inside of pyramids or landscapes that are now submerged under water, creating virtual reality worlds may be seen as a valid exercise. As new ways of capturing, modelling and analysing the past develop, new sources of information will be produced that can inform these virtual reality models alongside more traditional approaches such as archaeological excavation and archival research. The wider the range of sources consulted, the more authentic the virtual experience.

It is acknowledged that neither model of this project should be considered a true depiction of historic Wolverhampton, mostly due to a lack of information, a problem noted by Frankland and Earl (2013) when discussing authority and authenticity. The buildings shown on Taylor's map for instance, are likely to have been from a range of original dates, however we have no way of knowing precisely what date they were constructed and in what form. Additional archival research may enlighten us to a certain extent, however there would also be partial iterations of buildings (including those for which we do have information), with changes such as altering the roof, building extensions, or changing the doors or windows adding additional complexity that are unlikely to have been documented. However the virtual reality worlds have the potential to communicate and explore the broader historic environment as an 'experience' rather than a representation of accurate details, from the views of the open, rural nature of the Saxon settlement, to the narrow streets of Lichfield Street and bustling markets of Queens Square in the 18th century,.

The technology is still developing (albeit rapidly) and is not without problems. There is still the dominance of the visual aspect of the immersive experience, with an obvious need to address other senses and incorporate elements such as 3D sounds into the worlds. The use of 'serious gaming' – videogames designed for educational purposes – has clear potential in the cultural heritage sector (Mortara, 2014), which may have the benefit of attracting younger audiences, however, while a study by Fabola and Miller (2016) demonstrated the efficacy of virtual reality as a tool for learning history, it also showed that higher levels of immersion (where the interactivity was confined to specific view points) did not stimulate young pupils' interest more than screen based experiences that allowed for a free-form type of interactivity.

However research has also shown that using VR (and augmented reality) in museums enhances visitor experiences in terms of appreciation of the exhibit and the intent to revisit (Jung, 2016), which has significant implications at time when museums and other cultural heritage institutions are struggling for funding.

It is hoped to present the Saxon World as an immersive, interactive experience using Oculus Rift within a future Saxon exhibit at Wolverhampton Museum and Art Gallery, supplemented by 360° video fly-throughs of the world hosted on YouTube. By generating new and immersive ways of experiencing and exploring the city's past, a new understanding can be found of its history by both academics and the general public and by using exciting new technologies, new audiences within Wolverhampton and the wider community can be engaged.

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