Virtual tourism – Digital scanning, Augmented Reality and Virtual Reality as a Holistic Approach to Chinese Historic Building Preservation

by

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Digital scanning, Augmented Reality and Virtual Reality Combination as a Holistic Application for Chinese Historical Buildings Preservation
Yikai Zhang, Masters of Design in Digital Futures Program, OCAD University, 2016

Abstract

There are many historical buildings spread around the rural areas of China and very few of them have been documented through digital media. In the face of massive Chinese urbanization, many of these cultural relics are facing the risk of damage, collapse, and even disappearance. The undocumented disappearance of these monuments would be a great loss for Chinese traditional culture and therefore this thesis proposes to solve this preservation problem using a combination of digital media platforms including 3D digital reconstruction, virtual reality, and augmented reality to digitally document and present these monuments. This thesis introduces these three technologies individually by presenting case studies for each to illustrate in greater depth the value each technology brings into the realm of heritage preservation. In the final section of this thesis, a mixed reality educational mobile application is presented as a test of this integrated technology solution to explore the potential of implementing this solution on a massive scale.

Keywords: Chinese unprotected monuments, heritage digital preservation, 3D reconstruction, photogrammetry, virtual reality, augmented reality, panoramic image, educational mobile app, storytelling, Google Cardboard

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All figures and photographs are by the author unless indicated otherwise.

Chapter 1 – Introduction

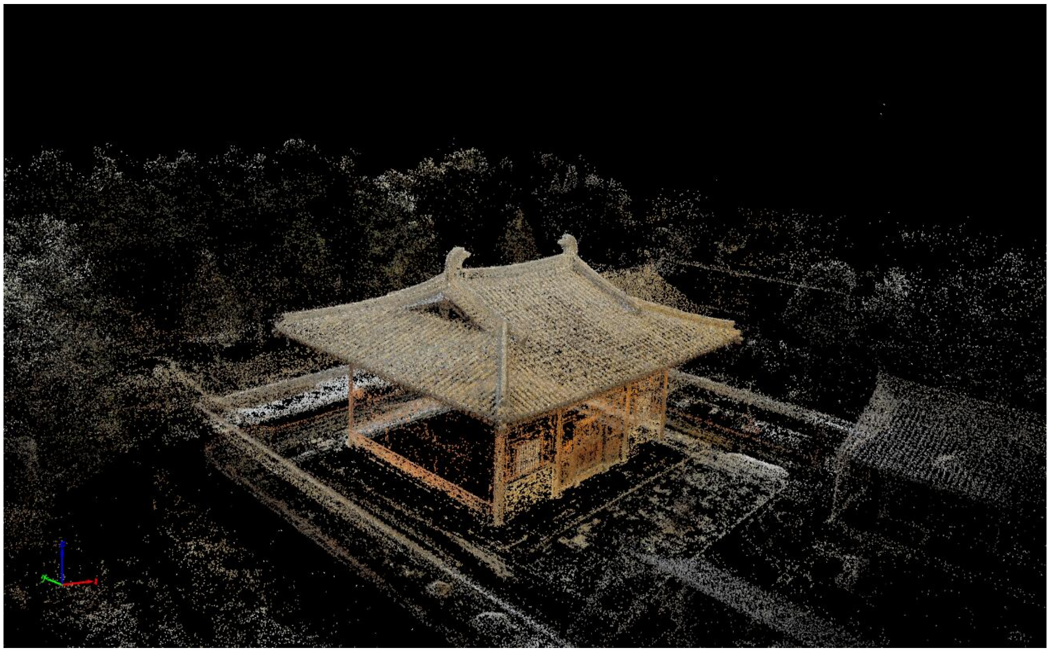

Figure 1 Point cloud of Nanchan temple

China has a remarkable array of historic towns and cities and historic sections of urban areas reflecting the country's rich cultural heritage. These historic sites reflect both physical tangible heritage values and intangible values related to regional building styles and traditions, ways of living, sense of place and a multitude of cultural assets.

In recent decades, economic development in China has been dazzlingly rapid. Urban areas have expanded exponentially. This has generally meant the destruction of traditional neighborhoods that are replaced with modern buildings and community spaces that are usually architecturally dull and unpleasant to inhabit. A great number of Chinese cities have lost their specific city spirit and symbol during this rapid urbanization. Nowadays, if you walked on the road in Beijing, Shanghai or Lanzhou, you would notice that the urban landscape are highly identical and it is almost impossible to distinguish where you are. Although these three cities locate at northern, southern and western part of China and each city has its own dialect, custom even dietary habits, these three cities look like one city. Locally unique architectural form has been totally wiped out in this unstoppable urbanization process.

Chinese government spends 36 years raising Chinese urbanization rate from 18.96%(1979) to 56.1%(2015) since Chinese economic reform (Urban population rate). On the one hand, this has created an economic miracle. On another hand, a huge amount of historic buildings has been demolished just for achieving the urbanization goal. At present, it's almost impossible to have a chance to see the local historic sites from Chinese first-tier cities all the way to third-tier cities. But ironically, when a city has been urbanized, in order to boom the local tourism, local government would spend great amount of money and effort on rebuilding those historic sites which had been torn down by themselves. However, due to the lack of data and artisans, these newly-built “fake historic sites” often unable to reflect the same verve which original historic sites had. Those historic places that remain are detached from their local, spatial, and temporal continuity, whilst still representing them as preserved authentic artefacts for cultural consumption.

During this research, I found the most severe problem in China is our indifference of the consciousness of heritage conservation, no matter in officials or the public. This is a sad consequence that the cultural revolution results in a generation of people who are lack of basic education. Skyscrapers can be fast built through the money accumulation; however, there is no shortcut to build up people's respect to the history and culture. This needs to be fixed bit by bit through the long period education. Nowadays, urbanization has infiltrated Chinese rural area. Some provinces which are underdeveloped economic but keep rich cultural heritages like Shanxi and Gansu will also soon be facing such problems and challenges. The whole society needs more realization that preserving urban districts architecturally does not prevent change, it accelerates it in effect. Local community voices need to be heard and allowed to participate in change that does not disenfranchise them. This is the original idea of this project: to rebuild Chinese society's awareness of heritage conservation by disseminating the value and importance of historic sites with the help of a series of new technologies and mobile platforms.

Digital technology has developed a great deal in the last two decades, including many important achievements in the field of heritage preservation. For instance, in the field of digital information acquisition and processing technology, researchers can use either image-based 3D reconstruction methods such as photogrammetry, or range-based 3D documentation methods (i.e., 3D scanning) to digitally document heritage objects to generate a point cloud and 3D mesh. This data can help researchers to comprehensively analyze the cultural object and develop further renovation plans. Moreover, the development of virtual representation technology such as augmented reality and virtual reality enable researchers to create a virtual experience that allows audiences to visit a particular cultural heritage site much easier. An advantage of a virtual presentation is that it allows for the protection of the cultural object by decreasing potential damage brought by tourists' excessive visits and unpredictable behaviour. In addition, virtual reality presentations can also increase the user experience of seeing a cultural heritage site by adding other interactions and additional information. Finally, more people may be attracted to learning about the cultural site through a digital medium than by actually travelling to visit the particular historical site. With the development of digital preservation technology, an emerging trend of preserving cultural heritage has begun. The ultimate ideal for this project is to use this advanced information technology for control, management, and decision-making, in order to record precious cultural heritage sites comprehensively for virtual representation and long term storage (Zhou, M., Geng, G., & Wu, Z. 2012).

This thesis is an attempt to integrate three emerging technologies: photogrammetry, augmented reality and virtual reality as a digital preservation solution to change the present state of Chinese historic buildings conservation.

To achieve this goal, I went to Shanxi province twice in November 2016 for field studies. In the first trip I learned more about the existing problems in Chinese historical building conservation. Meanwhile, I also discovered and documented unprotected historical buildings on the road. During the second trip I scanned two valuable historical sites using a consumer-level drone and took a series of panoramic images using an onboard camera. After the trip I created a mixed-reality mobile application which enables people to see and learn about these sites using a combination of 3D reconstruction software, augmented reality, and virtual reality for presentation via smartphone and Google Cardboard. The mobile app is constituted of both augmented reality (AR) and virtual reality (VR) components, where users can switch between AR and VR scenes during usage. In the AR scene, users can observe the 3D model of the historical building in 360-degrees, and also gather extra information about the building via panels of presented images, maps, and texts about the building. When the user switches to VR mode, they will experience a panoramic virtual tour both exterior and interior of the building. These two modes together provide users a coherent and comprehensive concept and experience about a historical building.

1.1 Research Approach

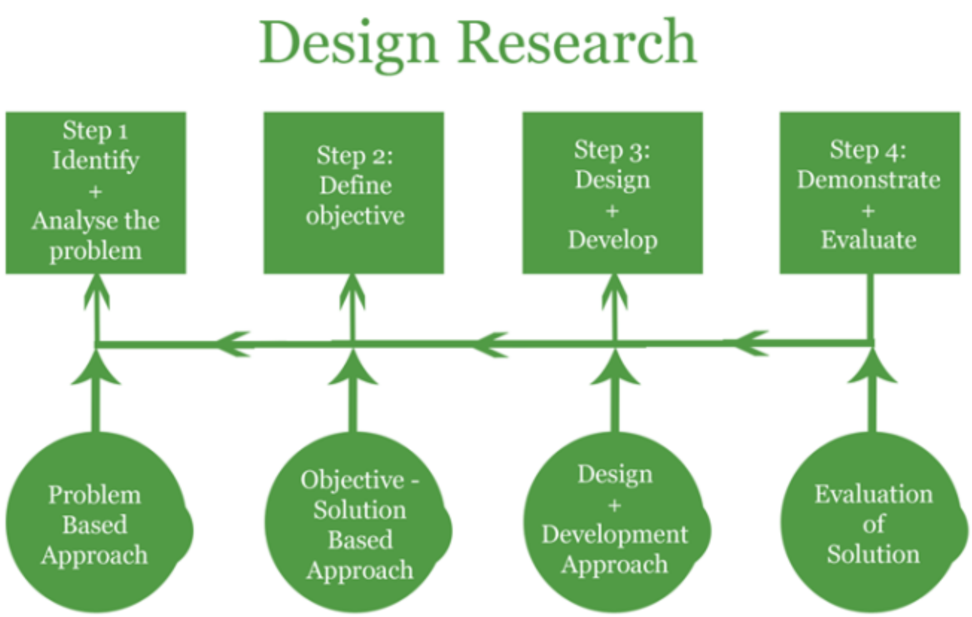

Figure 2 Design research, source: http://anm624katalina.wordpress.com/2011/05/23/design-research-framework/

This research is based on a specific social problem and is approached using the design research framework. This framework is based on an iterative approach that elaborates over the four stages of discovery, definition, design and implementation, and evaluation.

The stage of discovery here is composed of descriptive research. In chapter 2, I will present the status quo of historic site conservation in Shanxi, China. The mission of this section is to clearly present the problems existing in the Chinese historic sites conservation. In chapter 3, I will define the objective of this thesis based on the discovered problems. In chapter 4 I will present the process of design and development of my project. Finally, the project will keep improving and iterating based on the user's feedbacks and testing in the future.

Chapter 2 - The Conservation Status of Chinese Historic Buildings

The field study took place in Shanxi province in November 2015 because Shanxi has the greatest number of historic buildings in China. Shanxi has 28,027 historic sites, including temples, pagodas, and villages. There are 106 historic structures made of timber built before the Song Dynasty (before 1279), which include 4 built during the Tang Dynasty (618-907), 3 during the Five Dynasties and Ten

Kingdoms period (907- 979), and 99 built in the Song, Liao, and Jin Dynasties (960-1279). The existing historical sites built before the Song Dynasty account for approximately 70% of the total in China (Chai 1999). Due to the large number and high value of local historical buildings, Shanxi is an important province for heritage conservation research. During this trip we found that the state of historic buildings in Shanxi is generally quite concerning. Although there are no specific statistics on unprotected historical buildings in Shanxi, news about the destruction of historic buildings in Shanxi province is always cause for concern. During the trip in November 2015, I found that a large number of historic buildings in rural areas are in dilapidated or damaged condition. Chinese historical buildings are timber-structured architecture, which is prone to decay, rot, and damage due to the elements. No regulation or protection will prevent each buildings' eventual damage and collapse. Therefore, if such "conservation" continues at this pace, most of these centuries-old buildings will disappear within several decades. Considering the number of historic buildings in Shanxi, this has become a serious social problem that needs to be solved immediately.

2.1 Three Root Causes Behind the Problem of Chinese Heritage Conservation

The large number of unprotected historical buildings demonstrates many of the problems that exist in Chinese heritage conservation. Through my research and communication with Chinese researchers, I was able to determine that there are three primary causes: the effects of the rating system, the lack of funding, and a lack of specialists.

2.1.1 Rating System

In Shanxi province a large number of historic buildings are not owned by the state. There are many non-registered historic buildings in Shanxi that are still considered residential buildings. Local officials state that in Shanxi registered historic buildings account for 80% of the total, and another 20% are non-registered buildings. Because these non-registered buildings are still considered dwellings, basically they don't have any protection or renovation (Yong, & Zhao 2014). However, registered buildings also suffer the problem of rating. Under the Regulation for the Implementation of the Cultural Relics Protection Law of the People's Republic of China, unmovable cultural relics are divided into protected units at the national level, provincial level, city level, county level, and undecided level. Most registered unmovable cultural relics belong to the last category – the undecided level. Take Quwo County as an example: There are 74 registered

historic buildings which are rated as having a protected level. Besides that, there are 418 registered historic buildings classified at the undecided level (2014).
In many cases, considering the local funding for heritage conservation in Shanxi, the scope of renovation for the local administration of cultural relics can only be limited to those rated units. Many undecided level buildings also cannot get the benefits of any sort of protection, just like those non-registered sites.

2.1.2 Funding

Shanxi is a vital province for culture relics. However, such an important province only has a 530 million RMB (around US $80 million) government budget for 28,027 buildings, with each historic building receiving less than a 20 thousand RMB (around US $3,000) budget per year. In addition, because of the large number of historic buildings in Shanxi, local government can only implement regular maintenance for national and provincial level sites. A large number of protected sites at the city, county, or undefined levels have neither funding support nor human resources. Some county bureaus of cultural relics only have 5 staff members in total. It is therefore impossible for them to regulate every historic building in their area (2014).

2.1.3 Specialists

In addition to the rating system and funding, there is another issue that is very difficult to fix in a short period of time – specialists. There are only 705 staff members who have a recognized renovation certificate in Shanxi. However, these seven hundred people are dealing with more than 20,000 historic buildings. Among all universities and colleges in China, only Peking University and Tongji University have a program in historic building renovation and protection. Other universities and colleges have only a few topic-related classes in their schools of architecture. This results in an imbalance between the researcher and the artisan. Because of the lack of experienced artisans, most renovation projects finished in recent years do not meet aesthetic and technical standards (2014).

2.2 Case Studies

These root problems result in a large number of unprotected historic buildings distributed around Shanxi province. Many historic buildings are in a condition of severe damage. This is reflected in three primary ways: a lack of supervision, bad management, and functional use.

2.2.1 No Supervision

2.2.1.1 Miaojue Temple

Miaojue temple was built in the Ming Dynasty, and it is a major historical and cultural site protected at the national level. Most existing halls are severely damaged. The eastern and western walls of the main hall are decorated with frescos. However, the roof above the western wall has collapsed. As a result, most parts of the fresco painted on western wall are soaked by mud. This temple has already been rated as a national level historic site, but it has basically no regulation or supervision (Tang 2015).

Figure 3 Front hall of Miaojue temple, source: http://blog.sina.com.cn/s/blog_4a877d4d0102ew9h.html

Miaojue temple is located at Xin village, 5 kilometers away from the town of Taigu in Shanxi province. Miaojue temple has a main hall, back hall, and eastern and western side halls. Most halls were built in the style of the Ming dynasty. The entire courtyard has been unattended for a long time, and it has various damages to its roofs and walls. The condition of the main hall is the worst. Tiles on the roof are loose and both the front and back eaves above the western wall have collapsed. Consequently, the western wall is exposed to the rain and wind. Due to long term rain erosion, the main part of the fresco on the western wall is covered by mud. The loss is irreversible (2015).

Figure 4 The collapse on the roof of the main hall of Miaojue temple, source: http://blog.sina.com.cn/s/blog_4a877d4d0102ew9h.html

Figure 5 The fresco in Miaojue temple covered by mud, source: http://blog.sina.com.cn/s/blog_4a877d4d0102ew9h.html

Although Shanxi province has the most historic buildings in China, it is rare to see frescos inside the buildings. In Shanxi, only 5% of historic buildings have old frescos. It is even rarer to see them in any other provinces. In many provinces, intact frescos have disappeared. This kind of loss is almost unimaginable (2015).

Figure 6 The fresco in Miaojue temple covered by mud, source: http://blog.sina.com.cn/s/blog_4a877d4d0102ew9h.html

Figure 7 The collapse on the roof in Miaojue temple, source: http://blog.sina.com.cn/s/blog_4a877d4d0102ew9h.html

2.2.1.2 Zhenwu Temple

Zhenwu temple in Qixian has a large courtyard. Although it is very dilapidated, most halls are still standing, including the main hall, the back hall, and most side halls. Because of leakage and the loss of walls, the frescos inside the main hall have been covered by mud. In the period of the people’s commune, the back hall was used as a warehouse and entire walls with fresco were painted over in white lime. Now some parts of the lime have started to come off and reveal the original frescos. Zhenwu temple still has many frescos, which are very valuable. But once the building collapses, we shall never see these frescos (Tang, 2014).

Figure 8 The back hall and side halls of Zhenwu temple. Buildings are dilapidated, and the entire courtyard is full of tiles and wooden component that have fallen down, source: http://blog.sina.com.cn/s/blog_4a877d4d0102ew9h.html

Figure 9 The fresco on the wall in the main hall of Zhenwu temple. Because of leakage, the fresco is covered by mud, source: http://blog.sina.com.cn/s/blog_4a877d4d0102ew9h.html

Figure 10 The fresco inside the main hall of Zhenwu temple, source: http://blog.sina.com.cn/s/blog_4a877d4d0102ew9h.html

2.2.2 Bad Management

Although some monuments are being managed, oversights always happen. Due to the limitation of human resource, many historical buildings only have the most basic of management. There is still a long way to go for a higher level of conservation.

2.2.2.1 Yuanzhi Temple

Yuanzhi temple is a major historical and cultural site protected at the national level. It is located at Taigu village, in Jinzhong city, Shanxi province. Nowadays, it is very rare to see a Ming dynasty building with the style of three halls and two internal courtyards and more than one hundred square meters of fresco. Inside the temple, Qianfo hall was built in 1501. The building is 3 bays wide with a hip-and-gable roof and no wooden beams. Because there are one thousand Buddhas painted on four walls of the hall, it is called the "one thousand Buddha temple." There are two Heavenly Kings painted on each side of the door on the southern wall (Tang, 2014).

Figure 11 Original one thousand Buddha fresco in Yuanzhi temple, source: http://blog.sina.com.cn/s/blog_4a877d4d0102uxin.html

However, a fire broke out at Yuanzhi temple on March 31, 2014. No one knows the cause of the fire. During this fire, Qianfo Hall was completely gutted, and only four walls are left. The original colorful frescos were totally blackened by smoke. Most walls had begun to peel, and the two paintings of Heavenly Kings on the wall were also completely ruined. The entire site is a mess. After the fire, the ruin was covered by a steel shed (2014).

Figure 12 Yuanzhi Temple after fire, source: http://blog.sina.com.cn/s/blog_4a877d4d0102uxin.html

Figure 13 The fresco inside Yuanzhi temple was completely ruined, source: http://blog.sina.com.cn/s/blog_4a877d4d0102uxin.html

Timber structured buildings are very fragile. Fire is their biggest enemy. Yuanzhi temple was already a national level monument and still was not able to escape the fate of fire. Yuanzhi temple had been a provincial level protected site before becoming a national level one, and it had been operated and renovated by local residents over the long term (2014). Shanxi province has very limited fiscal capacity to support all 28,000 historic sites. Only a few important site can be protected.

2.2.3 Functional Use

Most historic buildings have been out of repair since the 1980s and ’90s. Before that period, rural areas in China were underdeveloped. This resulted in most historic buildings continuing to be utilized for functional uses. Buddhist temples and ancestral temples started to become schools, grain depots, and offices. During the period of Chinese economic reform, companies began to have their own workplaces. Historic sites immediately returned to be unused and unmaintained, so that in a few years these buildings had been become dilapidated. Actually, the first wave of damage to these buildings started from functional use. People who used one building as a grain depot made a hole in the wall for ventilation, for example. Those who used buildings as classroom painted over frescos for a blackboard.

2.2.3.1 Tangwang temple

Tangwang temple is located at Jin city in Shanxi province, and it is a historical and cultural site protected at the city level. The main hall is a double-eaved building with in the style of the Yuan dynasty, 9 bays wide and 3 bays deep. Its grand scale makes this building very valuable. In the past, this building was used as a grain depot, but now it is neglected. Other buildings had been demolished in the period of grain depot. The main hall is still in fairly good condition, but the entire building is still wrapped in a layer of white lime (Tang, 2013).

Figure 14 Main hall of the Tangwang temple. Cap and block are wrapped in a layer of white lime, source: http://blog.sina.com.cn/s/blog_4a877d4d0102erzw.html

Figure 15 The interior of the main hall in Tangwang temple is also wrapped in white lime, source: http://blog.sina.com.cn/s/blog_4a877d4d0102erzw.html

Figure 16 The main hall's eaves of Tangwang temple are revealed though a hole in the wrapping, source: http://blog.sina.com.cn/s/blog_4a877d4d0102erzw.html

2.2.3.2 Baohe Temple

Baohe temple is located in Jin city, and it is a historical and cultural site protected at the city level. Today, the entire building is wrapped in white lime. The main hall is 5 bays wide but the details cannot be seen. It seems to have been built in Yuan dynasty, to judge from the exposed structure. The stage was built in Qing dynasty. Although it is a monument at the city level, it is still used as a grain depot (2013).

Figure 17 The stage of Baohe temple, source: http://blog.sina.com.cn/s/blog_4a877d4d0102erzw.html

Figure 18 Guanzheng Hall inside Baohe Temple, source: http://blog.sina.com.cn/s/blog_4a877d4d0102erzw.html

Figure 19 The main hall of Baohe temple is still wrapped in the white lime, source: http://blog.sina.com.cn/s/blog_4a877d4d0102erzw.html

Chapter 3 - Digital Protection for Cultural Heritage

Cultural heritage around the globe suffers from wars and human negligence. The importance of cultural heritage documentation is well recognized and there is an increasing pressure to document our heritage both nationally and internationally (Li, Z., Chen, J., & Baltsavias, E. P. ,2008). Therefore, how to protect these precious heritages using the contemporary science and technologies has become a challenging problem faced by the entire human race.

3.1 Digitalization of Cultural Heritage

The digitization of cultural heritage is the process of digitizing the movable or unmovable cultural heritage using contemporary remote-sensing and virtual technologies to achieve 2D or 3D digital archiving. The result can be used for many purposes, such as historical documentation, digital protection, cross-comparisons, monitoring of shape and colors, simulation of aging and deterioration, virtual reality/computer graphics applications, 3D repositories and catalogues, web-based geographic systems, computer-aided restoration, multimedia museum exhibitions, visualization and so on (Remondino, F., 2011).

3.2 Meaning and Value of Cultural Heritage Digital Protection

Information technology not only provides benefits like huge data volumes, high speed computation, multimedia presentation, and on-line access, but also gives an essential and effective approach to protect cultural heritage. As technology develops, there are more and more approaches to restore these destroyed relics by using computer graphics, image processing and other new technologies, combined with traditional protection and display methods. In the perspective of displaying these cultural heritage, museums and other protection organizations could utilize digital technologies and devices, such as multimedia and virtual reality, to rebuild the "Museum Experience", where the audiences could navigate to view the virtual cultural heritages and understand the meaning of cultural heritage as a whole. A comprehensive and complete space of meaning could be rehabilitated and reproduced thus the educational role of digital cultural heritage could be fully exploited.

The "Quebec Declaration" passed in the 17th ICOMOS General Assembly states that "Considering that modern digital technologies (digital data bases, web sites) can be used efficiently and effectively at a low cost to develop multimedia inventories that integrate tangible and intangible elements of heritage, we strongly recommend their widespread use in order to better preserve, disseminate and promote heritage places and their spirit. These technologies facilitate the diversity and constant renewal of the documentation on the spirit of place, understanding technology, research and training is necessary." (Québec Declaration on the Preservation of the Spirit of Place: Adopted at Québec, Canada, October 4th 2008., 2008)

3.3 The Trend of Digital Preservation for Cultural Heritage

Digitization technologies have recently generated a large number of projects, which have realized high quality results in heritage preservation. Ultrasound systems, or X-ray, in the historical or archaeological analysis of ancient buildings or biological finds has helped the researchers to evaluate the data from another point of view. The computer can elaborate the data, showing images and performing 3D reconstructions, or it can help to find new relationship from a large amount of data (Brogni, B., Avizzano, C., Evangelista, C., & Bergamasco, M. 1999). Remote sensing technologies and methodologies for Cultural Heritage 3D documentation and modeling allow the generation of very realistic 3D results that can be used for many purposes, such as historical documentation, cross-comparisons, monitoring of shape and colors, simulation of aging and deterioration, virtual reality/computer graphics applications, 3D repositories and catalogues, web-based geographic systems, computer-aided restoration, multimedia museum exhibitions, visualization and so on (Remondino, F., 2011). The availability and use of 3D data opens a wide spectrum of further applications and allows new analyses, studies, interpretations, conservation policies or digital restoration. Thus 3D virtual heritages should be more frequently used due to the great advantages that remote sensing technologies and the third dimension offer to the heritage world and to recognize the digital documentation and preservation needs stated in numerous international charters and resolutions.

3.4 Status of Digitized Heritage Conservation in China

In China, many research institutes and universities have started to harness digital technology to protect cultural heritage. For instance, the CAD & CG lab of Zhengjiang University has started a digital project to protect the cultural heritage in Dunhuang since 1997. The project integrated fresco copying techniques and fresco colorific evolvement techniques to create a virtual travel system of Mogao Cave(Agnew, N., 2010). Peking University also launched a digital preservation project for Longmen Grottoes. The project used different types of 3D scanners to build models of Buddha sculpture in Longmen Grottoes. Beijing Normal University started a research by using computer aided technology to repair Terracotta Warriors and Horses of Qin Shi Huang. With fractures' information acquired by digital systems, they first performed auto-splicing by shape matching techniques, followed with a manual adjustment step to accomplish heritage's virtual repairing (Zhou, M., Geng, G., & Wu, Z., 2012).

Chapter 4 – Technologies in Digital Preservation

Due to the variety types of digital preservation technologies, it's impossible to list each of them in this paper. In the next section, I will introduce three important parts that constitute my thesis project: Digital Data Acquisition, Digital Reconstruction and Digital Presentation for Cultural heritage. These three parts includes three emerging technologies: 3D reconstruction, Virtual Reality and Augmented Reality. The implementation of these three technologies constitute a complete solution of digital documenting, disseminating and preserving historical sites.

4.1 Digital Acquisition in Cultural Heritage

3D reconstruction technologies evolved dramatically in generating the 3D representation of real objects, buildings and environments. In heritage preservation, this technology has been used to build the digital database for the cultural heritage. Virtual reality and augmented reality technologies are becoming a very important medium to display and transmit the digitized cultural heritage. Meanwhile, the development of the internet ensures that the high-fidelity digital replica of those cultural heritage can be seen anytime at anywhere. Centered on digital techniques, new protection theories have been established, and work specialization have been formed, thus gives solid guarantee for cultural heritage protection, and provides new solutions in this area.

4.1.1 Non-real 3D modeling and Reality-based 3D modeling

3D data has always been a critical component to permanently record the form of important objects and sites. As a digital form of these historical sites, they could be passed down to future generations.

In the past, most 3D modeling of historical buildings was done by using non-real 3D modeling approaches or procedural modeling approaches. Since non-real 3D modeling approaches are purely based on computer graphics software (Maya, Blender, 3D Studio Max, etc.) without any particular knowledge or survey of a site. The final result generally loses its metrical results and high-definition textures. However, the heritage conservation has received a lot of attention and benefits from the recent advances of range sensors and imaging devices. These technological advances trigger the appearance of reality-based 3D modeling approach.

Reality based 3D surveying is a process of capturing the shape and appearance of any real objects (3D reconstruction). This process can be accomplished either by passive or active methods. Each method under the reality-based surveying has its own advantages and disadvantages. The choice or integration depends on required accuracy, object dimensions, location constraints, system's portability and usability, surface characteristics, working team experience, project's budget, final goal and so on (Remondino, F., & Rizzi, A. 2010).

4.1.2 Techniques for Reality-based Modeling

Generally, reality-based 3D reconstruction includes two sub-categories: range-based method and image-based method.

4.1.2.1 Range-based modeling

3D geometric information of an object can directly capture through this technique. It is based on costly active sensor that often lack in texture information, but can give a very detailed and precise illustration of most shapes. However, the information of texture or color can be attached from the scanner through color channel or from separate digital camera (Remondino, F., & El-Hakim, S. 2006). Because this method needs to capture data by using active sensors, range-based methods actively interfere with the reconstructed object, either mechanically or radiometrically using rangefinders, in order to acquire the depth map, e.g. structured light, laser range finder and other active sensing techniques. To wrap every aspect of the object, it is generally required to make multiple scans from different locations, which appropriate to object size, shape and occlusions.

Figure 20 3D scan using 3D scanner, source: http://lanmarservices.com/2014/05/15/3d-imaging-lidar/

4.1.2.2 Image-based modeling

Image-based modeling and rendering (IBMR) methods rely on a set of two-dimensional images of a scene to generate a three-dimensional model and then render some novel views of this scene (Image-based modeling and rendering.) It is the reverse process of obtaining 2D images from 3D scenes. This method also can be called as a passive method, which implies that this modeling method needs to use passive sensors (mainly image sensors) to finish data acquisition. Passive methods of 3D reconstruction do not interfere with the reconstructed object; they only use a sensor to measure the radiance reflected or emitted by the object's surface to infer its 3D structure through image understanding (Buelthoff, H. H., & Yuille, A. L., 1991). This method uses a mathematical model to pick up 3D object information from 2D image dimensions or they get 3D data using methods such as shape from shading, texture, specularity, contour and from 2D edge gradients.

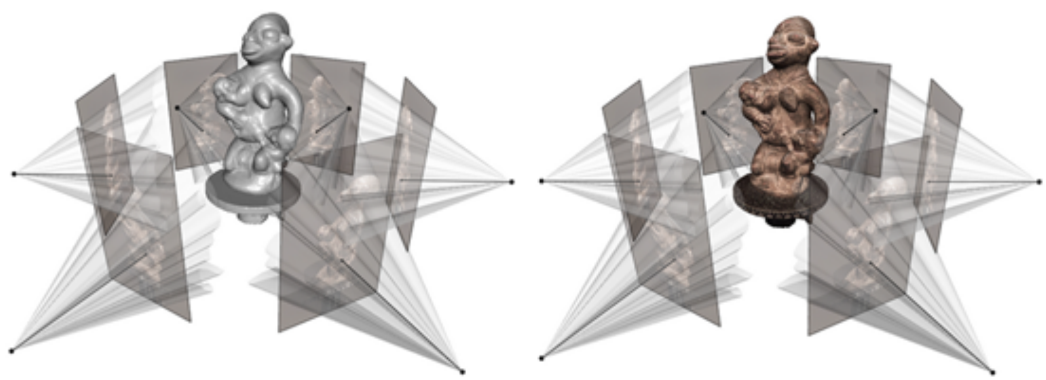

Figure 21 3D object modelling: 3D reconstruction and texture mapping, source: http://3dvisa.cch.kcl.ac.uk/project86.html

Apart from creating professional 3D mesh, the biggest advantage of this technique is the capacity of generating highly detailed model texture. This is known as image-based rendering. Image-based rendering uses images as modeling and rendering primitives. The goal of this technique is to get more realistic and faster renderings and to simplify the modeling task. The technique relies on accurate camera positions or performing automatic stereo matching, where the absence of geometry data, need a large number of closely spaced images to succeed. Most of image-based rendering match to image-geometry hybrids, by means of the equivalent amount of geometry ranging from per-pixel depth to hundreds of polygons. This technique commonly used for architecture, entertainment, engineering, manufacturing, quality control, police investigation, and geology.

Figure 22 Utilize DSLR cameras and image-based modeling to generate super high resolution assets, source: http://www.quantumcapture.com/

Figure 23 Image-based rendering, source: http://www.quantumcapture.com/

4.1.2.3 Photogrammetry

Photogrammetry is a very important image-based technique. The technique employs high-speed imaging and remote sensing in order to detect, measure and record complex 2D and 3D objects. Photogrammetry is considered the best technique for the processing of image data, being able to deliver at any scale of application accurate, metric and detailed 3D information with estimates of precision and reliability of the unknown parameters from the measured image correspondences (tie points) (Remondino, F., 2011). The image data can be acquired from ground level or at different altitude and with different sensors. The main benefit of photogrammetric technique is the possibility to simultaneously provide both geometry and surface texture for depicted objects.

Recent technological advances in digital cameras, computer processors, and computational techniques, such as sub-pixel image matching, make photogrammetry a portable and powerful technique. It yields extremely dense and precise 3D surface data with a limited number of photos, captured with standard digital photography equipment, in a relatively short period of time. In the last five years, the variety and power of photogrammetry and related processes have increased dramatically.

Figure 24 3D reconstruction by photogrammetry software of 52 McCaul St. Toronto

4.1.3 Recording Optical Sensors

3D recording and modeling with photogrammetry and 3D scanning involves a wide range of tools. Generally, there are two categories of the most accepted and practically tested optical sensors: passive sensors and active sensors.

Passive sensors (e.g., digital cameras) deliver image data which are then processed with some mathematical formulations to infer 3D information from the 2D image measurements. On the other hand, active sensors (e.g., laser scanner) can provide data directly for 3D information or ranges. Terrestrial active and passive sensors employed to derive 3D shapes are often referred to 3D imaging techniques (Sansoni, G., Trebeschi, M., & Docchio, F. 2009).

4.1.3.1 Active Optical Sensors

Optical range sensors like laser scanners have received much attention in recent years, also from non-experts, for 3D surveying and modeling purposes. Range sensors directly record the 3D geometry of surfaces, producing quantitative 3D digital representations (point clouds or range maps) in a given field of view with a defined measurement uncertainty. The point cloud data can then be used to extrapolate the shape of the subject (a process called reconstruction). Range sensors are getting quite common in the mapping community and heritage field, despite their high costs, weight and the usual lack of good texture.

Airborne and terrestrial range sensors are two main categories of active sensors. Airborne laser sensors are always deployed on a moving platform such as helicopter and terrestrial laser sensors normally used in a fixed position. Laser scanners used on airborne platforms are generally called LIDAR (Light Detection and Ranging) but preferably Airborne Laser Scanning (ALS). ALS is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth. An ALS instrument principally consists of a laser, a scanner, and a specialized GPS receiver. Airplanes and helicopters are the most commonly used platforms for acquiring ALS data over broad areas. (What is LIDAR?) It is coupled with GNSS/INS sensors to accurately measure the position and orientation of the system for Digital Surface Models (DSM) generation, city modeling, forestry applications, corridor mapping, structural monitoring and change detection (Remondino, F., 2011).

Figure 25 WR&D's Bess 206L Long Ranger equipped with a Leica ALS60 Corridor Mapper and Leica RCD105 digital camera, source: http://www.wrd-ltd.com/aerialphoto.html

Terrestrial laser scanners create a 3D image through projecting a laser dot or onto an object and a sensor inside the scanners (typically a charge-coupled device or position sensitive device) measures the distance to the surface. Due to optical technologies still encounter many difficulties with shiny, mirroring or transparent objects. Terrestrial range sensors can work from very short ranges (few centimeters up to a few kilometers) in accordance with surface proprieties and environment characteristics, delivering 3D data with accuracy from some microns up to some millimeters. Terrestrial range sensors generally use a predefined wavelength although multispectral laser scanning systems would allow the identification of surface's material, humidity, moisture, etc.

After scanning, data is collected by a computer and recorded as data points within Three-dimensional space, with processing this can be converted into a triangulated mesh and then a Computer-aided design (CAD) model, often as Non-uniform rational B-spline surfaces. Hand-held laser scanners can combine this data with passive, visible-light sensors which capture surface textures and colors to build a full 3D model.

Figure 26 Faro Focus 3D laser scanner, http://www.core77.com/posts/21765/iF-Design-2012-Gold-Award-Winners-Product-Design-Picks

4.1.3.2 Passive Optical Sensors

Image-based modeling generates 3D models by transforming 2D image measurements into 3D information base on a mathematical formulation. Image data can be acquired either by terrestrial digital cameras or aerial cameras. The choice or integration depends on the object dimensions, location constrains, final goal of the survey and so on.

Terrestrial digital cameras come in many different forms and format: single CCD/CMOS sensor, frame, linear, multiple heads, SLR-type, industrial, off-the-shelf, high-speed, panoramic head, still-video, etc. Common terrestrial cameras have at least 10–12 Megapixels at very low price while high-end digital back cameras feature more than 40 Megapixel sensors. Mobile phone cameras and action cameras have up to 12 Megapixels and they could be even used for photogrammetric purposes (Remondino, F. 2011).

Figure 27 Canon EOS 6D DSLR Camera with 24-105mm f/4L Lens, source: http://www.kentdiscos.me.uk/photography/

Almost ten years after the introduction into the market of the first digital large format aerial camera, we now have a variety of aerial digital sensors which are generally classified as small, medium and large format cameras. Between the available aerial acquisition platforms, particular interest has been devoted to the UAVs, (Unmanned Aerial Vehicles) like low-altitude model helicopters which can fly in an autonomous mode, using integrated GNSS/INS, stabilizer platform and digital cameras (or even a small laser scanner) and which can be used to get data from otherwise hardly accessible areas. In particular, High Altitude Long Endurance (HALE) UAV platforms are covering the gap between space and airborne systems and could be a useful geometrics platform (2011).

Figure 28 DJI Phantom 3 Professional Quadcopter with 4K Camera and 3-Axis Gimbal, source: http://www.slashgear.com/dji-phantom-3-drone-revealed-with-newly-chopped-price-points-08377962/

For example, photogrammetry software company Pix4D created a highly accurate and very dense 3D model of Chillon Castle by integrating both aerial and terrestrial images acquired with aerial camera DJI phantom 2 Vision, terrestrial digital camera Canon 6D, Sony alpha 7r cameras with Fisheye lenses and action camera GoPro Hero 3+. The final 3D point cloud integrates the indoor and outdoor structures of this highly complex architecture with a resolution of up to 5mm. The entire project took 6227 images and generated 95 million points. The integrated camera solution helps to enable this huge data acquisition process to be finished within 6 hours (Pix4D).

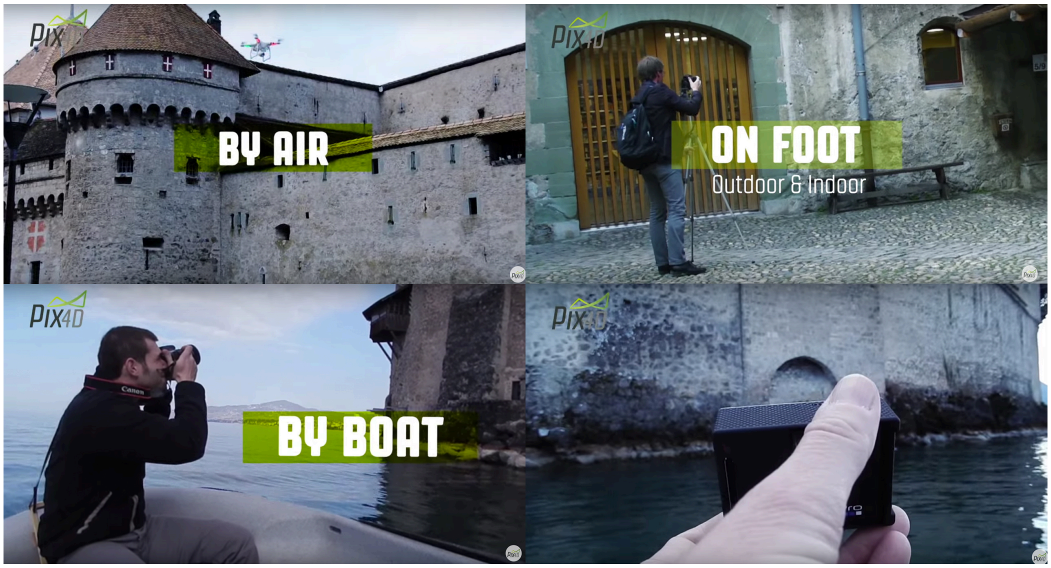

Figure 29 Using different cameras to record Chillon Castle, source: https://www.pix4d.com/chillon/

4.2 Digital Representation in Cultural Heritage

Although 3D models are useful to preserve the information about historical artefacts, the potential of these digital contents are not fully accomplished until they are used to interactively communicate their significance to non-specialists. From this point of view, a new form of content presentation to provide visitors with more information and interaction should be implemented into the virtual heritage. In recent years, with the increase of computational speed and advancement of computer technology, virtual reality or augmented reality have started to become feasible in multidisciplinary areas such as in simulation, education, entertainment, medical and game. Researches in Virtual Reality (VR) and Augmented Reality (AR) have shown considerable growth with the development of interactive computer technology and sophisticated 3D modeling packages (Noh, Z., Sunar, M. S., & Pan, Z., 2009).

In terms of heritage preservation, VR and AR technologies helped in this last years to show 3D models of ancient place or objects to explore a lost world from an atypical perspective.

4.2.1 Virtual Reality

Virtual Reality (VR) can reproduce an environment or an object through software and display technologies as an immersive experience of that space. It is possible evolve in this environment, observe and examine it and also work with it inside it, as though it were a real and natural world. VR allows an intuitive, unconscious, almost childish approach to a phenomenon: this is the first and the most natural knowledge form.

4.2.2 Virtual Reality in Museums and Cultural Heritage

One possible application of Virtual Reality and 3D reconstruction is in cultural heritage. It can be used to provide a sensory experience and allow culture to be accessible to the general public, the preservation of the sites and environment, replace the actual visit of the site threatened or inaccessible by the virtual visit of tourists, explorers and researchers, with the potential for multiple virtual experiences, in terms of interaction and immersion. Another possibility is that virtual exhibitions can be easily transferred from one place around the world to another and can take place in several locations at the same time and could be arranged in small towns or even villages, therefore being accessible by more people.

4.2.3 Augmented Reality

One of the most powerful areas in the Virtual Reality (VR) field is related to the systems designed to augment the user's view of the real world by embedding additional visual information, graphics and text: this area of research is called Augmented Reality (AR).

Its basic concept is to coherently integrate a computer-generated virtual scene into the user’s perception (usually field of view), registered within the environment. Unlike VR, user have to wear a Head Mounted Display(HMD) which separates the user from the real world and user will be totally immersed in the virtual environment. In an Augmented Reality application, the virtual images are merged with the real view of the user, and the two sources of images have to be coordinated very well in order to give a coherent superposition effect.

4.2.4 Augmented Reality System

Augmented Reality (AR) has several different systems based on different terminal hardware. Normally, in all AR applications, the virtual wold is generated by the computer, but for the real content there are many techniques used. AR application needs to be used with a digital eyewear and there are two types of digital eyewear are being widely used today in AR industry. One is optical see-through devices and another is video see-through devices.

Video see-through devices such as smartphones and tablets have been widely used now. These devices can be use with AR/VR goggles such as Samsung Gear VR or Google cardboard to achieve a better AR experience which is similar to wearing an optical see-through device. In the system of video see-through devices, a camera records the real world from the perspective of the user. Video frames are analysed to know the object’s position and identify the real objects in the environment. Then the computer merges the images from the camera and the virtual environment. Finally, the display for example the cellphone, shows a mixed reality scene.

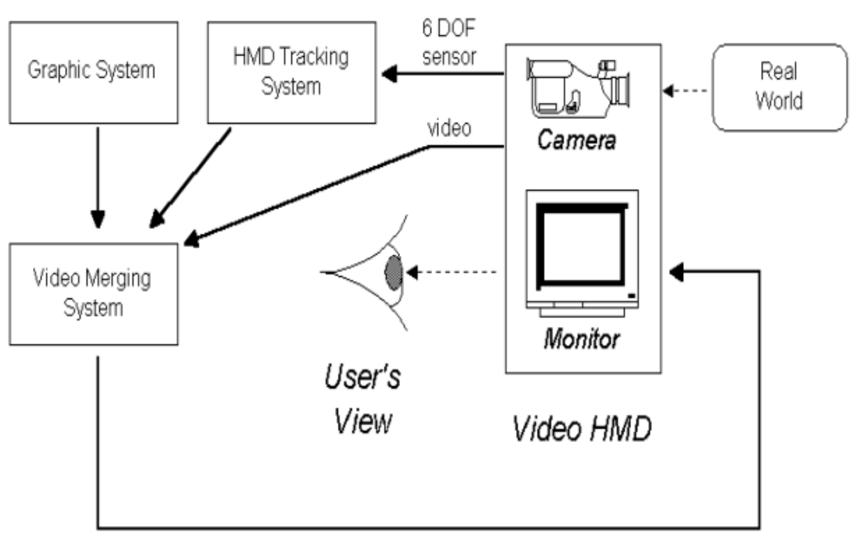

Figure 30 AR system using the video see-through HMD, source: http://www0.cs.ucl.ac.uk/staff/ucacaxb/public/download/1999_Brogni_TAF.pdf

Optical see-through devices such as Epson Moverio BT-200 or ODG R6 are a more professional platform for the user to experience AR content. Theses device are able to control the opacity of the glass and to allow the wearer to have a direct vision of the real environment by looking through it. The system offers a perfect view of the real environment and can also trace the virtual objects by tracking user's head movement.

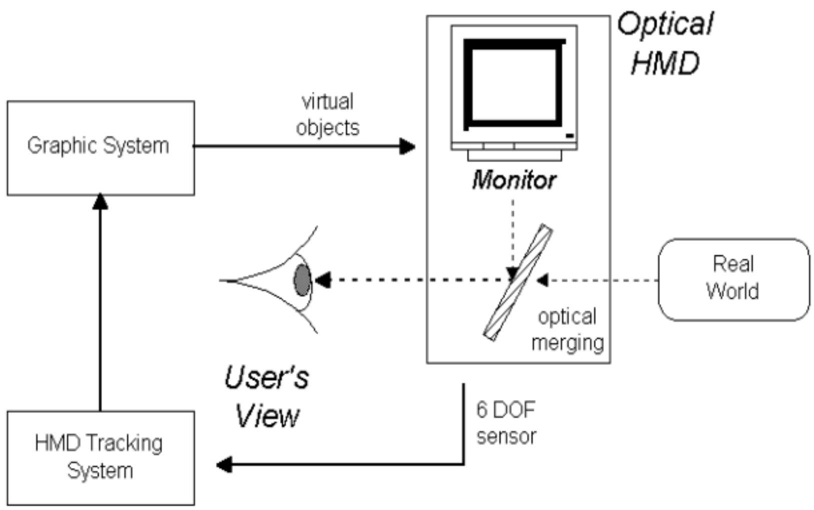

Figure 31 AR system using the optical see-through HMD, source: http://www0.cs.ucl.ac.uk/staff/ucacaxb/public/download/1999_Brogni_TAF.pdf

4.2.5 Augmented Reality in Cultural Heritage

Several characteristics of AR can produce benefits in the world of cultural heritage, mainly as regards acquisition, management and dissemination. First, it helps to reduce time and final costs related to acquisition, modelling and management due to the non-modelling of the present scenario. Second, it can improve the understanding of cultural heritage, as it has the power to generate hybrid environments (real and virtual), mixing together past (non-existing part, virtually modelled) and present (real part, not modelled) scenarios. Third, AR improves user immersion over VR systems, as the user can move around, see the objects in their present size and explore them in a more natural way, thus allowing applications in real time, on site (Portales, C., Lerma, J. L., & Perez, C., 2009). Recently, AR is widely being used in many applications such as education, entertainment, virtual heritage, simulation and games. In virtual heritage, AR is used to enhance the overall experience of the visitor of a cultural heritage site. Furthermore, with the interactive, realistic and complex AR system, it can enhance, motivate and stimulate students' understanding of certain events, especially for the traditional notion of instructional learning that has proven inappropriate or difficult (Noh, Z., Sunar, M. S., & Pan, Z., 2009).

4.3 Case Study: Preserving American History - Colonial Era Church Ruins

Figure 32 The point cloud of Colonial Era Church Ruins, source: http://blog.pix4d.com/post/137289919546/preserving-american-history-colonial-era-church

The Sheldon Church Ruins is an American colonial-era structure in South Carolina, which is in a structurally-precarious states. In order to help save these National Historic Landmarks, photography company Abovit Aerialography created 3D point clouds to digitally preserve the buildings and assist in the design of potential support structures.

The Sheldon Church Ruins, constructed in 1725 on Edisto Island in South Carolina, has a French-inspired design unique to the American colonies that illustrates

French-Huguenot influence. In 1929, a fire destroyed much of the building, leaving only the brick masonry walls and chimneys. However, even in ruins, the Sheldon Church Ruins (or Brick House ruins) were deemed of great enough historical importance to be designated a National Historic Landmark. Unfortunately, after 85 years, weather and deterioration have left the Brick House ruins in a precarious state. Preliminary structural evaluations have indicated that portions of the walls and chimneys are close to failure, and if they fall, they are likely to destroy much of the original historic material around them. Recognizing the potential loss of this architectural treasure, the Preservation Society of Charleston listed the Brick House ruins as one of the “seven-to-save” sites in 2013, committing to help support efforts to save the building.

Figure 33 Colonial Era Church Ruins, source: http://blog.pix4d.com/post/137289919546/preserving-american-history-colonial-era-church

Data Acquisition

Both data sets were composed of nadir, oblique, and terrestrial images: nadir images were acquired with a DJI Phantom from two different flights using Pix4Dcapture (an mobile flight planning and execution app); oblique images were taken by manually controlling the drone, ensuring at least 60% image overlap; and terrestrial images were shot from a GoPro camera, held by hand or mounted on a tripod, giving close-up details for the 3D model texture.

Figure 34 Data acquisition process, source: http://blog.pix4d.com/post/137289919546/preserving-american-history-colonial-era-church

Achieved Results

The models were completed for the Preservation Society of Charleston and Historic Charleston Foundation. Images from various shooting angles - nadir, oblique, and terrestrial, were processed together in Pix4Dmapper, a photogrammetry software. With some clean-up of sky points, a clear 3D model was generated.

Figure 35 The point cloud of Colonial Era Church Ruins, source: http://blog.pix4d.com/post/137289919546/preserving-american-history-colonial-era-church

The picture below showing how architects used point cloud in REVIT to design a support structure proposal for saving the Brick House Plantation.

Figure 36 Make a renovation plan by analyzing point cloud data, source: http://blog.pix4d.com/post/137289919546/preserving-american-history-colonial-era-church

4.4 Case Study: Application in Dougong components

Dougong is the unique wooden structure in Chinese architecture which is composed with square wood of Dou and elongated wood of Ong and is located on the stigma and beams. Dou and Ong can be used together to undertake the roof and transmitted the weight to the beams. In the traditional architecture, Dougong is an important node which has different components and combination based on different structure. W.B.Yang from China University of Technology and his team designed an AR digitalized navigation system for different Dougong components.

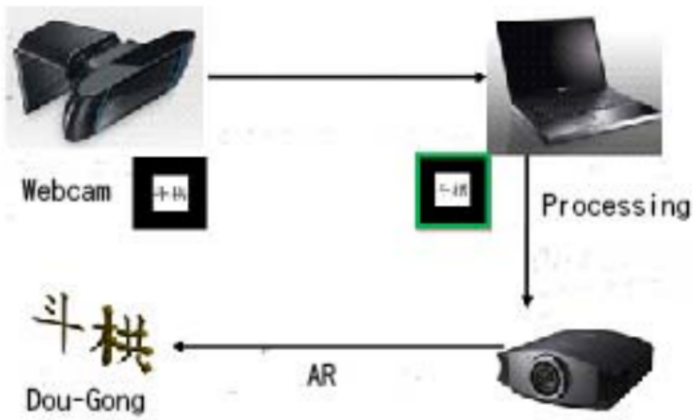

Figure 37 AR digitalized navigation system for Dougong

With the advantages of AR system, users not only can experience the most authentic environments of historic heritages, but also can obtain intuitive, interactive visual navigation information. Augmented Reality System provides a new, convenient and digitized choice to combine 3D objects in a single window for experiencers to navigate the presentation of pictures in a convenient and easy way. This application helps users to understand each link and assembly methods of the traditional wooden Dougong and enhance users' understanding in the "shape" and the "composition" of the Dougong (Yang, W. B., Yen, Y. N., & Cheng, H. M. 2015).

Figure 38 Tao-Wan Dou and Chi-Hu Gong

Figure 39 Zhu-Tau Dou and Guan-Dao Gong

Chapter 5 – Thesis Project

5.1 Overview

This project is a mixed reality mobile application that enables people to see and learn about iconic Chinese historical buildings using a smartphone phone with Google Cardboard. This mobile app integrates 3D reconstruction, augmented reality and virtual reality. This project is an exploration in digital documentation for the purpose of heritage conservation and education. This mobile app project is also an experiment in testing the viability of mass adoption for this combination of technologies.

Modern 3D digital reconstruction can be used to generate professional models. Compared to traditional modelling methods using CAD software, modern 3D modelling techniques using 3D reconstruction from multiple camera images can produce very accurate 3D mesh models and very detailed texture rather easily. Models generated by the photogrammetry software will be displayed through augmented reality, a medium which provides rich interaction and introduces a very intuitive user experience. I also integrated an augmented reality application with Google Cardboard to provide a more stereoscopic effect than traditional AR. This project also incorporates a virtual reality application, which plays the important role of providing an even stronger immersive experience. By combining AR and VR into a single application, this project enables users to have a more interactive, immersive and empathetic experience. This strong feeling will improve their understanding of the Chinese historical buildings and finally raise their consciousness regarding heritage conservation.

This project focuses on two very important traditional buildings: The Nanchang temple and Guangji Temple. Users can start from choosing one of these two buildings in the main menu. After entering into the scene, each historical building has two main components: the 3D model display under the AR scene and the panoramic virtual tour under the VR scene, respectively. Users can switch between two scenes by changing the direction of their eye gaze.

In terms of the visual experience, it should be noted that the size of the 3D model is directly proportional to the size of the image target. To enhance the visual experience this project uses a 1M*1.5M large image target. Therefore, the actual model size that users can see is about 1M*1.5M*1.2M. This size enables users to see more details of the model and also to make the scale appropriate for multiple users to share the virtual space together. Users can observe the model at any angle by walking around the image target while sharing their feelings with other users. The yellow tag in front of the building is a switch, and when users look at this tag its color will turn to green. After 1 second, users will jump into the VR scene, which presents a series of panoramic images about both the interior and exterior of the building. All these images constitute a virtual tour. Each time a user pulls down the magnet button on the Google Cardboard, it will switch to another panoramic image. By switching through different panoramic images users will have a deeper understanding and experience of the historical building and the environment around it.

The two different display modes (virtual reality and augmented reality) reveal to components of the application's content - 3D model and panoramic images work, which work collectively to deepen the user's understanding of the historic buildings. By integrating three technologies together, my project is an attempt to record and display these valuable cultural monuments using digital technology. The ultimate goal of this project is to encourage people to understand and realize the value of these cultural monuments, ultimately increasing their awareness for the need to protect these structures from decay.

Figure 40 Users are experiencing the project under the AR scene

Figure 41 Users are experiencing the project under the AR scene

Figure 42 Users are experiencing the project under the VR scene, source: http://tech.thaivisa.com/vr-on-the-cheap-how-to-watch-without-a-headset/14345/

This project moved through the stages of preparation, field production, digital production, and finally, development of the app.

5.2 Preparation

5.2.1 Equipment Selection

Drone and Photogrammetry software

There are two ways of creating 3D digital reconstruction, one is 3D scanning and the other is photogrammetry. Although 3D scanning is easier to operate and less time consuming than photogrammetry, 3D scanning equipment is much more expensive. Considering the budget of this project, I chose to use the image-based method to accomplish this task. In order to capture enough images to properly model an entire building, this project needed a consumer drone with a mounted camera. I thus chose the DJI phantom 3 as my scanning tool. This drone has a gimbal stabilized 4K Camera, which can take 12MP still-photos and shoot 4K video. It also comes with a controller that has two individual buttons for image shooting and video recording respectively. As for software, I chose to use pix4D as my photogrammetry software. Comparing to other free online photogrammetry services, which can only generate 3D models from images, such as Altizure and AUTODESK Memento, pix4D is more professional. Apart from generating professional models, pix4D also provides an entire set of data of the scan object for future projects, including point clouds, orthomosaics, etc.

Panoramic Camera

In recent yeas, VR has become a buzzword in the technology field. Due to the growing popularity of virtual reality, a number of companies have begun to launch VR development kits and shooting gear within the last two years. From professional customized VR cameras to consumer level shooting gear, the price of VR cameras can vary from several hundred to more than ten thousand dollars. The ideal VR shooting setup for this would have been a customized camera which combined 6 goPros and a 3D printed camera rig, but the cost of this setup exceeded the budget of this project. Through further research, I finally chose to use Ricoh Theta S as my shooting camera. Theta S has two 12M CMOS sensors which can take 5376 * 2668 pixel still VR images and shoot Full HD 1920*1080 VR video. Another advantage of this camera is its small size and light weight. Because of its small size, it can be tied to the drone and take aerial VR images and VR video, allowing for more shooting possibilities. The camera also supports

Bluetooth, allowing me to control the camera shutter speed, ISO, and exposure times from my cellphone. This may seem like a small benefit but they in fact allowed me much greater flexibility, which was very useful during later shooting periods. I will explain these details later when discussing my creative process.

Figure 43 My equipment

5.2.2 Site Selection

Shanxi has thousands of historic sites, and to select the most iconic monument for this project I decided to perform a field study before my real production trip. I contacted the researcher Tang Dahua as my tour guide and advisor. Mr. Tang has a strong reputation regarding the protection of rural historic sites. He spent last 2 years finding obscure and badly damaged historic sites in Shanxi and discovered more than 300 unprotected historical buildings in need of renovation and protection. Mar. Tang posted what he had seen on social media and attracted many reports and raised social awareness. For this project, Mr. Tang, me and another 9 heritage amateurs went to Shanxi in November. We visited 4 cities and 9 iconic historic buildings in 5 days. During the trip, I tried to communicate with the local government and explained my project plan. After receiving 5 initial oral permissions and making considerations for various objective factors, I finally chose the two temples, Nanchan temple and Guangji temple, as my final scan targets.

Figure 44 Nanchan Temple

Figure 45 Map view of Nanchan temple

Figure 46 Guangji temple

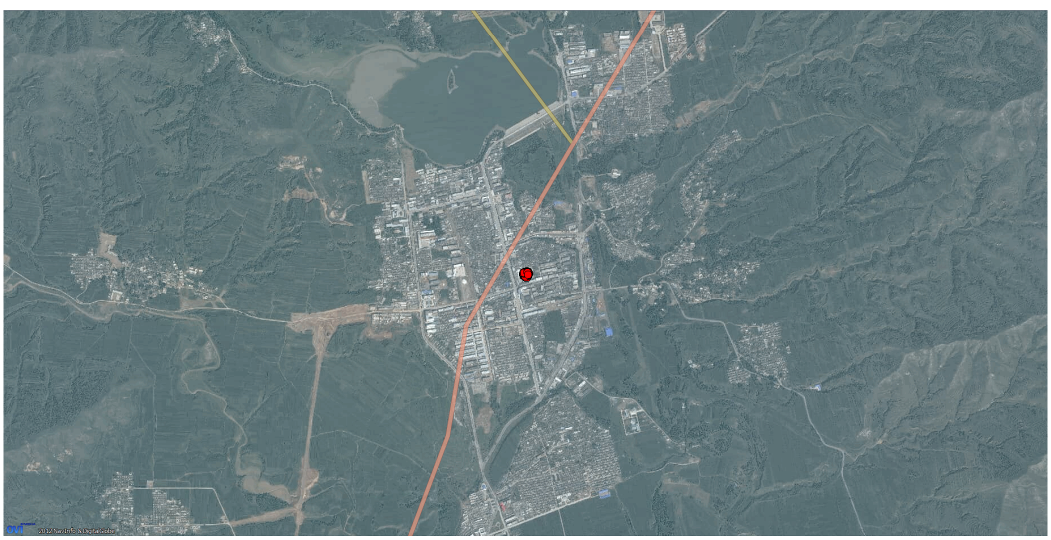

Figure 47 Map view of Guangji temple

5.3 In the Field

5.3.1 Scan Process

The first step of using an image-based scanning method in a generating 3D mesh is to select an appropriate image acquisition plan type (Pix4D). This procedure will guide the user on how to configure, position, and orient the camera towards the imaging subject in a way that provides the most useful information to the processing software while minimizing the uncertainty of the resulting measurements. For example, if a project has a very large scan area but a low requirement for scanning detail (e.g., scanning a group of buildings or creating a 3D map), then the best solution will be to use the Nadir plan. This scanning solution requires that the camera can maintain as constant a height and orientation as possible while shooting the camera images with a regular grid pattern. The image overlap should be at least 75% frontal overlap and at least 60% side overlap.

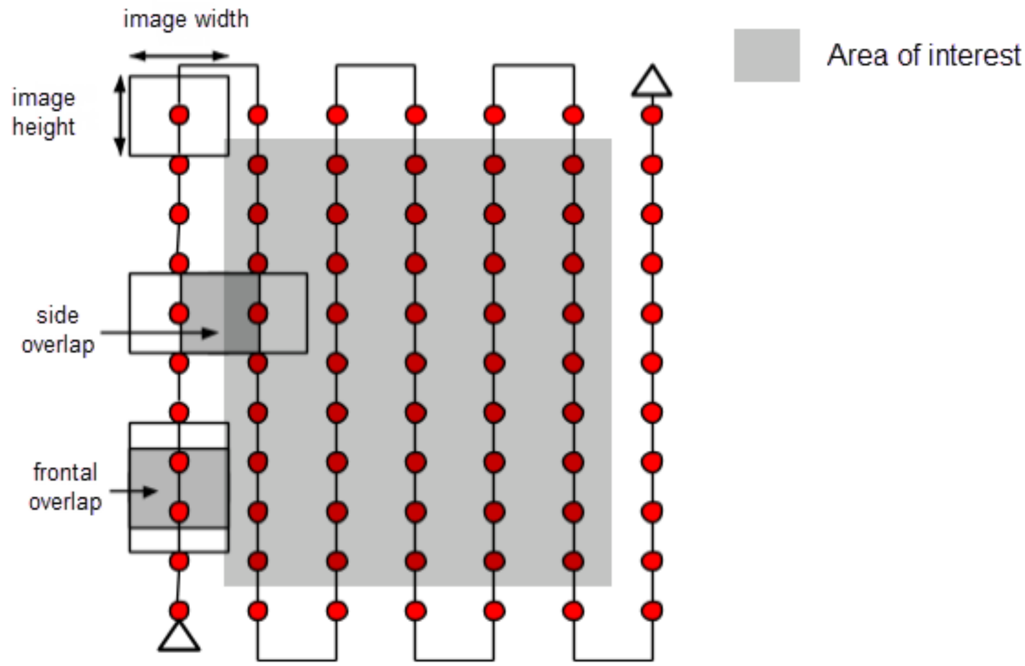

Figure 48 Nadir plan, source: https://support.pix4d.com/hc/en-us/articles/202557459-Step-1-Before-Starting-a-Project-1-Designing-the-Image-Acquisition-Plan-a-Selecting-the-Images-Acquisition-Plan-Type#gsc.tab=0

However, if a project requires scanning of an individual building, such as an old temple in my case, then the project requires another specific image acquisition plan. For achieving a better scan result, the entire scanning process needs at least 3 rounds of shooting. In each round, the drone needs to fly around the building and take oblique images rather than nadir images (Pix4D).

In the first round, the camera should maintain a 45 degree shooting angle and altitude should remain relatively low. To ensure sufficient overlap, each image should be taken within every 5-10 degrees of each other. This also depends on the size of the object and the distance between each shooting. Shorter distances and larger objects will require images be taken even closer to each other. In my shooting process, based on the size of Nanchan Temple, I took around 100 pictures for the first round.

After the first round, the shooting angle needs to be changed to around 30 degrees while also increasing the drone's altitude. During this period, images must be taken within every 5 degrees for enough overlap. In the second round I also took around 100 pictures.

In the third round, the drone should keep the same camera angle but continue to increase altitude compared to round two.

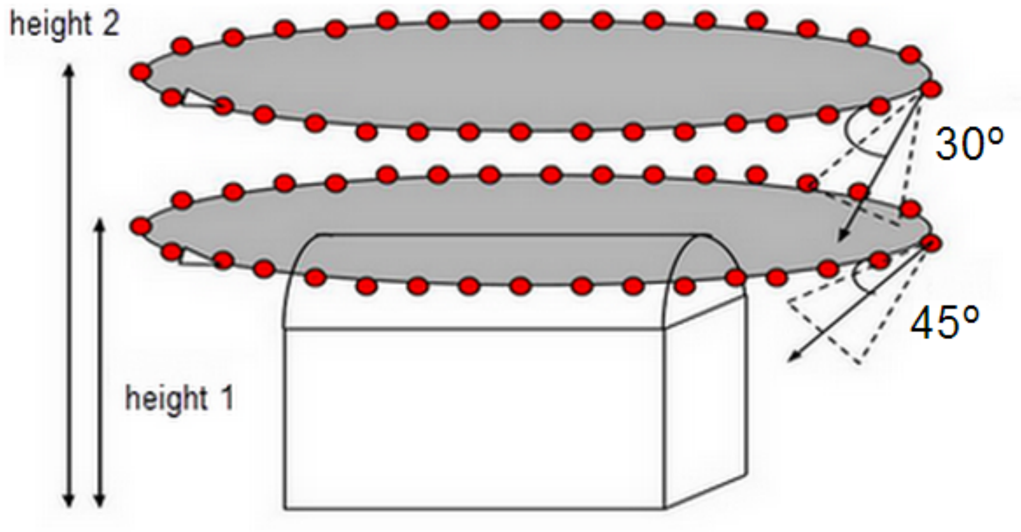

Figure 49 oblique plan, source: https://support.pix4d.com/hc/en-us/articles/202557459-Step-1-Before-Starting-a-Project-1-Designing-the-Image-Acquisition-Plan-a-Selecting-the-Images-Acquisition-Plan-Type#gsc.tab=0

Theoretically the altitude should not be increased more than twice between flights (Pix4D) as different heights will lead to different spatial resolutions. However, I found a special problem in my scanning process. Due to the unique shape of Chinese timber-structure buildings, if the drone only scanned the building following the standard scanning route, the final result would lose an important part of the data, which is the eave and the extensional wooden structure below it (FuZuo in Chinese) because taking photographs downwards cannot capture that part of the building. Thus, in order to cover all details of the temple I needed to walk around the building and use a digital camera to take another group of eave images after the third round of shooting. To entirely scan the Nanchan temple, the drone accumulated around 3 hours of flight time and took around 450 images in total.

Figure 50 Shoot at a low angle to capture the detail under the eave

Figure 51 450 images taken from different perspectives

In the 3 hours of shooting I found another important factor was the consideration for natural light. Because the day I shot was a cloudy day, the sunlight was very intermittent in the afternoon and lead to a lot of variability in light exposure. Therefore, during the shooting process I kept reminding myself to manually change the ISO and shutter speed in order to keep a consistent image color tone.

Figure 52 Control the drone and the camera to scan the building

Figure 53 The scanning process

Number of Calibrated Images	429 out of 466
Number of Geolocated Images	466 out of 466

Initial Image Positions

Figure 54 The scanning route of Nanchan Temple

The shooting for Guangji Temple was much more difficult. First, the communication with the local administrator consumed a lot of time. Fortunately, over two days of communication I could finally scan the building under the local staff’s observation. In terms of the size, the Guangji temple is more majestic and about twice as large as the Nanchan Temple. Moreover, there are some trees and buildings around the temple. These factors increased the scanning difficulty. In order to avoid these barriers, the drone had to sometimes be positioned really close to the building. Also, the time I scanned Guangji temple was in December and the local weather was cold and windy. The drone had great difficulty holding its position in the air under the strong winds and occasionally drifted out of control. This was doubly important because if the drone accidentally hit the building, the consequence would be disastrous. In order to keep the building safe, it was very important to control the flying posture at every moment and keep a safe distance between the drone and the building.

Because of the time-limitation, the building area, and the complexity of the environment, the results of the data acquisition were not as high quality as were achieved from the Nanchan temple shoot. This is seen especially in the insufficient point cloud generated in the final post-production stage. Less point cloud implies specific parts of the final model would be missed in the areas where the point cloud is rarefied. After this shooting, my experience was to be well prepared before scanning the large building. The weather conditions and scanning time had a great impact on the final scanning result. In addition, for a large scanning target, it is better to have a coordinated team to work with, as this could largely boost efficiency and the final result.

5.3.2 Panorama Documenting

The second part of the field production is the panoramic image shooting. This part will contain a series panoramic images about both the interior and exterior of the building.

In my original project idea, I planned to shoot a panoramic video for each historic building but during testing I found that the video format is not the best style of presentation. The first reason is the final image quality. If one is using the Ricoh Theta S to record a panoramic video, the highest resolution it can deliver is the Full HD resolution 1920p*1080p, which is much lower than the still panoramic image resolution (5376p*2688p) and can largely affect the viewer's experience. Secondly, because architecture itself is an unmovable object, this will result in little difference between taking a picture and shooting a video, as both final results are of the same stationary object. Thirdly, if I chose to shoot panoramic video, the image stability would be another problem. When covering the entire building, I had to hold the camera and move with it whereas with a still image this will not cause such a problem as long as I put the camera on a tripod. I can arbitrarily adjust the shutter speed and the aperture to control the image result. During comparison, I finally chose to use still images to show the building.

In order for users to see the building from different perspectives my shooting plan was to take each picture in every 20 meters around the building. As a result, users can switch between pictures by pulling off the magnet ring on the side of the Google cardboard to have the illusion of taking a virtual tour. In Nanchan temple, all panoramic images were taken at 5 meters above the ground. For the

Chinese historic buildings, this height will provide a better perspective to observe the details of extensional wooden structures. The solution for achieving this is to tie the panoramic camera to the bottom of the drone. After the drone must take to the air until it and achieved the predetermined altitude and stability, the next step is to adjust the angle of the drone to make sure the camera is perfectly facing the object. Next, I used the cellphone app to adjust the ISO, shutter speed, and the shutter. Because the panoramic camera is connected through Bluetooth, the flight height cannot be too high or the signal would lose connection. Through my testing, the highest altitude that camera can get is around 10 meters. Although this is not very high, it is enough to overlook the entire Nanchan temple. The advantage of this method is it can create an aerial panoramic image very easily, but it needs one or more people to control the camera while the pilot flies the drone. This process can unfortunately be time-consuming. In Guangji temple, because of the time limitation, I finally gave up this aerial image plan.

Figure 55 Panoramic aerial image taken by a combination of a drone and a panoramic camera

There were also a series of challenges shooting the interior of the building. The biggest problem was how to control the exposure. The traditional method for shooting indoor scenes is to let plenty of natural light to come into the room through windows and enable indoor objects to get enough exposure. This method does not work in the panoramic photography however. In panoramic photography the picture does not only record one side of the environment but every angle. Take Nanchan temple for example, if the statue of Buddha got the correct exposure, the front side of the building facing towards the Buddha would be seriously over-exposed. This will cause a very bad image result where one side has normal exposure but the other side is too bright. I therefore needed to come up with a new idea to take indoor pictures and keep the appropriate exposure for every angle. My solution was to put the camera on the tripod and place it in front of the status first. I then closed the front door and the entire space was in a closed condition. At this time, the room was almost entirely dark and only some weak light could come in through the seams of the door and windows. To make full use of the only light I had, I lowered the ISO to 100 and extended the shutter speed to one-half of a second. The picture taken in this way will get the same exposure at every angle. The details inside the temple such as the texture of the roof and the wooden girder are clearly visible. The low ISO also enhances the purity of the image. This shooting method needs to control the camera via Bluetooth after closing the door. Also, because the photographer was outside the door, this method can take a 360-degree image without any people inside the room.

Figure 56 The comparison between before and after

Figure 57 The comparison between before and after

5.4 Digital Production

5.4.1 Agent Modeling of Historic Sites

After the data acquisition stage, the remaining modeling work can be finished in Pix4D. Normally, we can divide the modelling process into two parts: data pre-processing and geometric modelling. In the data pre-processing part, the first step is to generate the point cloud. Point cloud data is a very important aspect in 3D scans and photogrammetry. This data represents points in a coordinate system. Normally, the way 3D scanners work is to measure a large number of points on an object's surface, and output a point cloud as a data file. The point cloud represents the set of points that the device has measured (Point Cloud). Because photogrammetry is an image-based 3D reconstruction method however, instead of directly measuring the points from an object the point cloud is the sum of measurements made from a series of overlapping photographs taken from a variety of vantage points. In this stage, the photogrammetry software will use computer vision to analyze and process each image uploaded to the software in order to identify and match thousands of key points. In pix4D, this stage is known as “Calibration”. In order to calibrate an image, enough key points of that image need to be matched accurately with other images. Each key point that is matched in at least two images allows the generation of a 3D point. However, some images cannot be calibrated at this stage in particular cases. One uncalibrated image is not calibrated because no matches with other images were found or because no matches have been labeled as accurate. Therefore, in order to enhance the accuracy of the final point cloud dataset, sometime in the pre-processing stage new matches between data sets must be manually set in order to calibrate images.

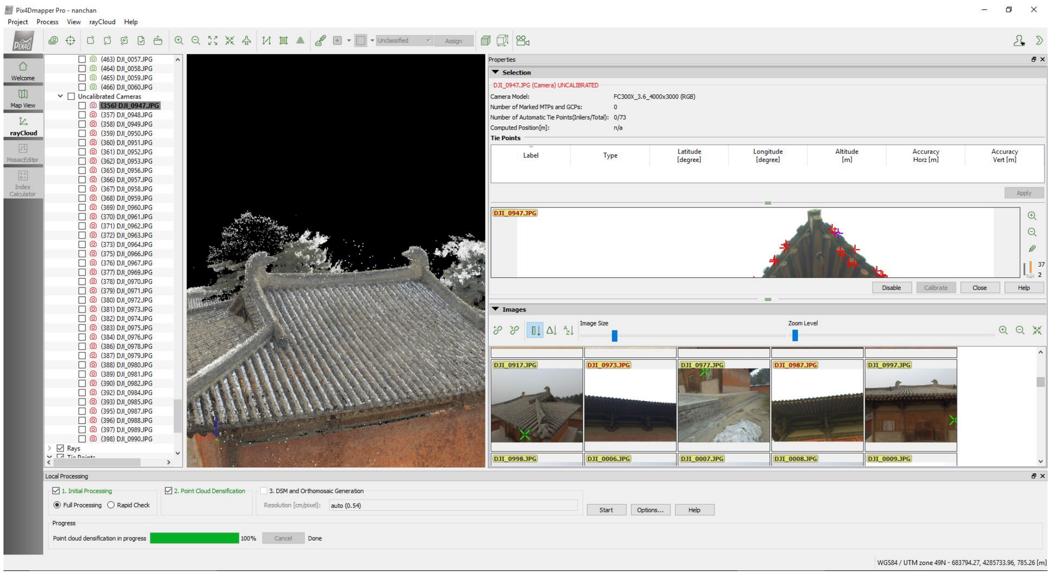

Figure 58 Calibrate process

After calibration, a point cloud dataset can be generated from the. Normally, the primitive point cloud data always includes some unnecessary data which we don't want to use such as the point clouds of trees and the environment around the building. At this point we need to simplify the point cloud by performing filtering and smooth processing for the original point cloud data.

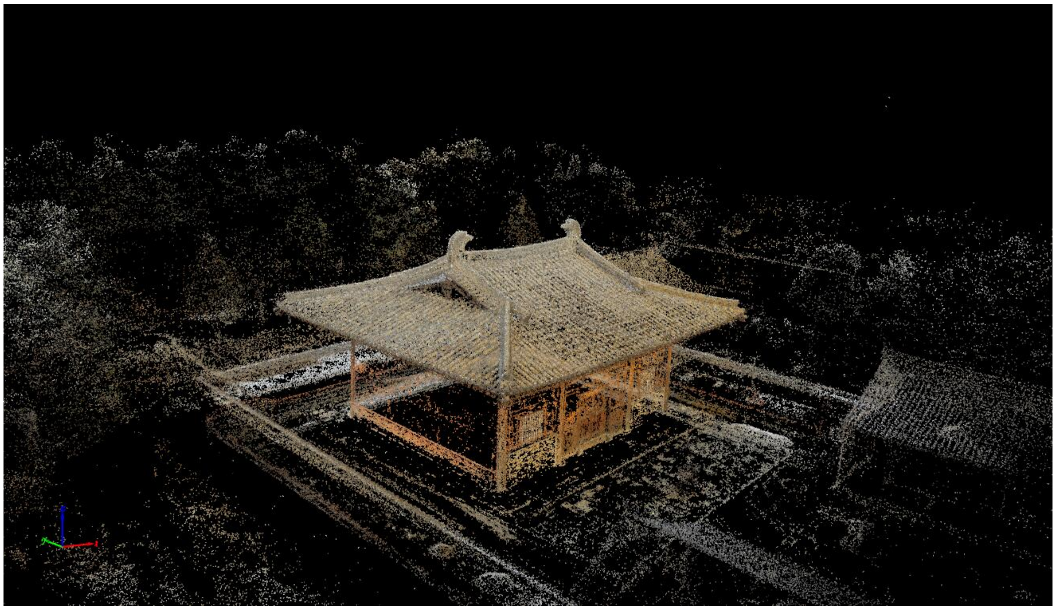

Figure 59 The primitive point cloud

The first step is to define the processing area. This step will keep only the subject's highlighted point cloud and delete all point cloud data outside the processing area.

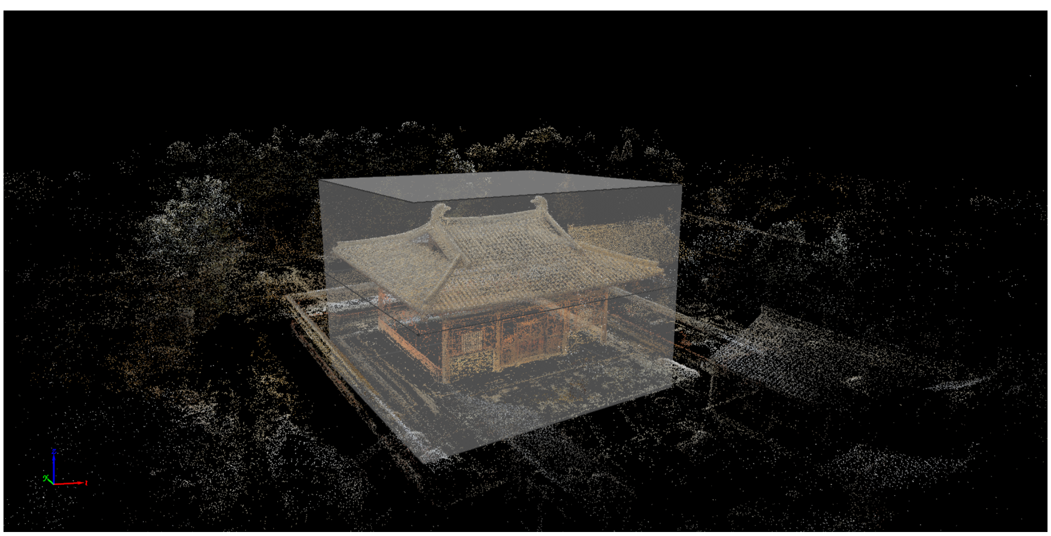

Figure 60 Define the processing area

After cleaning the data, we need to edit the densified point cloud to prepare for the next stage of 3D mesh generation because the subject's point cloud typically contains a number of "flying spots" around it such as tiny points from sky or trees. If these flying spots cannot be cleaned properly they will lead to the generation of a very strange 3D mesh at the final model reconstruction stage. At this stage we must therefore remove those "harmful points" by telling the computer which parts you don't want to generate the point cloud from.

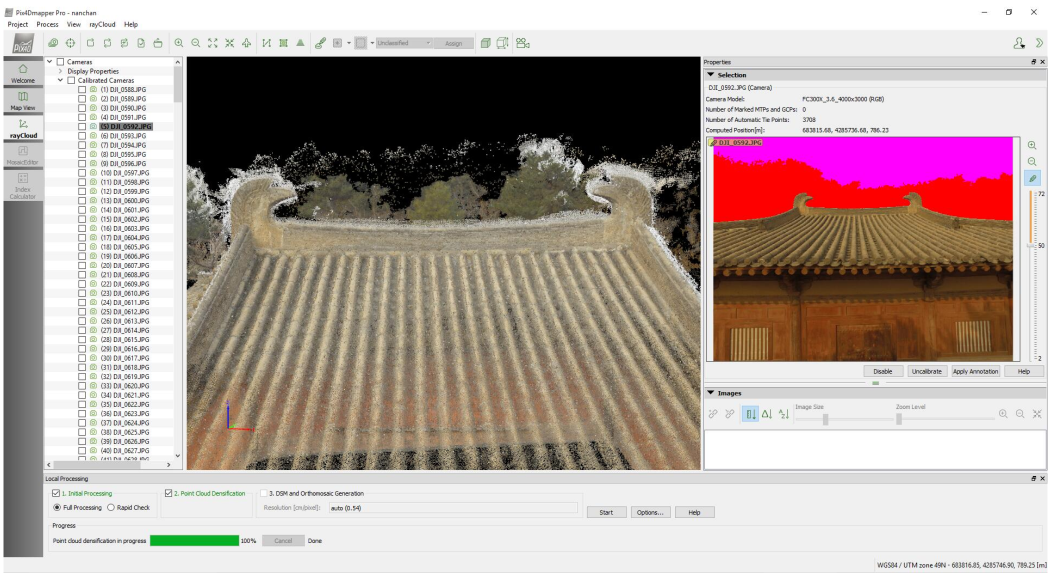

Figure 61 Edit the point cloud

Figure 62 The 3D mesh comparison between before and after the pre-processing

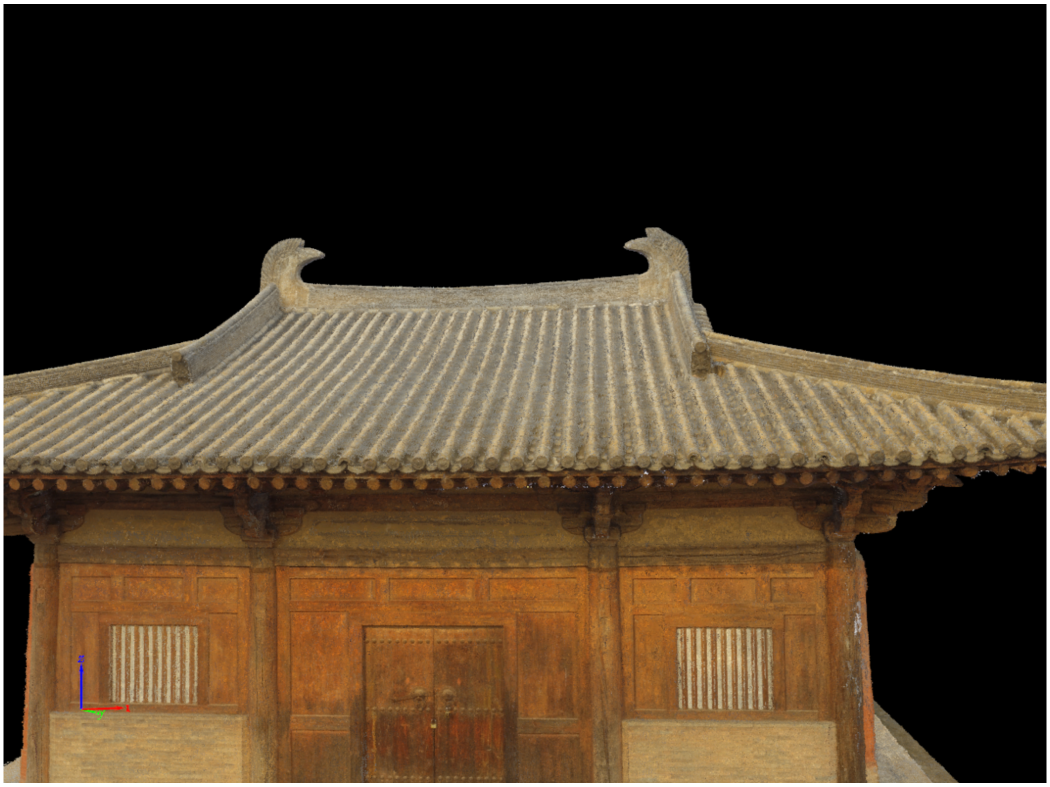

Figure 63 The 3D mesh comparison between before and after the pre-processing

After finishing all the pre-processing work. the second part is geometric model reconstruction. Model reconstruction is based on the preprocessed data and includes texture mapping in order to realize a realistic reconstruction. This stage is relatively easier than the first because the software will automatically generate the 3D mesh and the texture base on the point cloud and image data.

Figure 64 The final 3D mesh generated from point cloud

Figure 65 The final 3D mesh generated from point cloud

We can also import the 3D mesh we have into any other 3D software to further polish it. This part includes clipping and rendering until it achieves a design that meets your satisfaction.

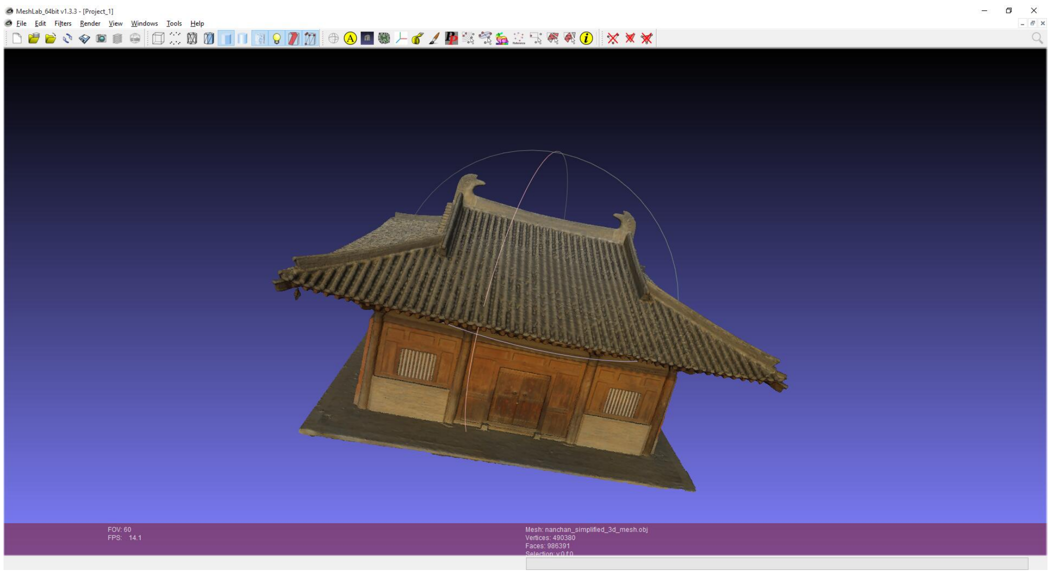

Figure 66 Polish the model in Meshlab

5.4.2 App Development

5.4.2.1 First AR Prototype

I used the Vuforia SDK to make my first AR prototype. Vuforia provides a comprehensive SDK for developers to create interactive augmented reality games and apps in a simple and fast way. Also, the content can be seamlessly deployed on the mobile platform (Android and iOS). My first iteration of the AR scene was a very simple one, which bound the scanned building with an image target. In this simple AR application, the user can make the building appear by using their smartphone to scan the image.

Figure 67 A simple AR scene

5.4.2.2 First VR Prototype

In the first VR prototype, I borrowed my friend's Oculus Rift and tried to make a 360 VR video app on it. I found the process was quiet simple. First I needed to create a sphere in any CAD software and then import it into Unity. In Unity, we can drag either a 360-degree video or a equirectangular panoramic image into the sphere as a texture. I then needed to write a MoviePlay script to play the video and create the sphere's shader. Finally, importing the Oculus Unity SDK, the rest of the work can be finished by the the OVRCameraRig prefab. This prefab is able to control the movement of the camera through the accelerometer inside the Oculus and finish the stereo rendering at the same time.

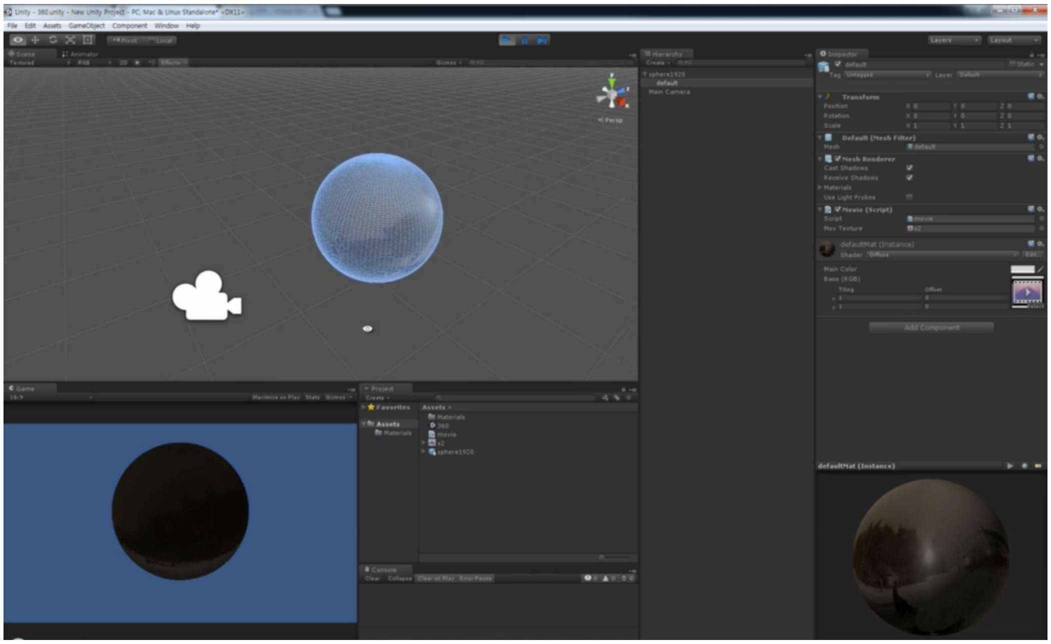

Figure 68 The first version of VR scene

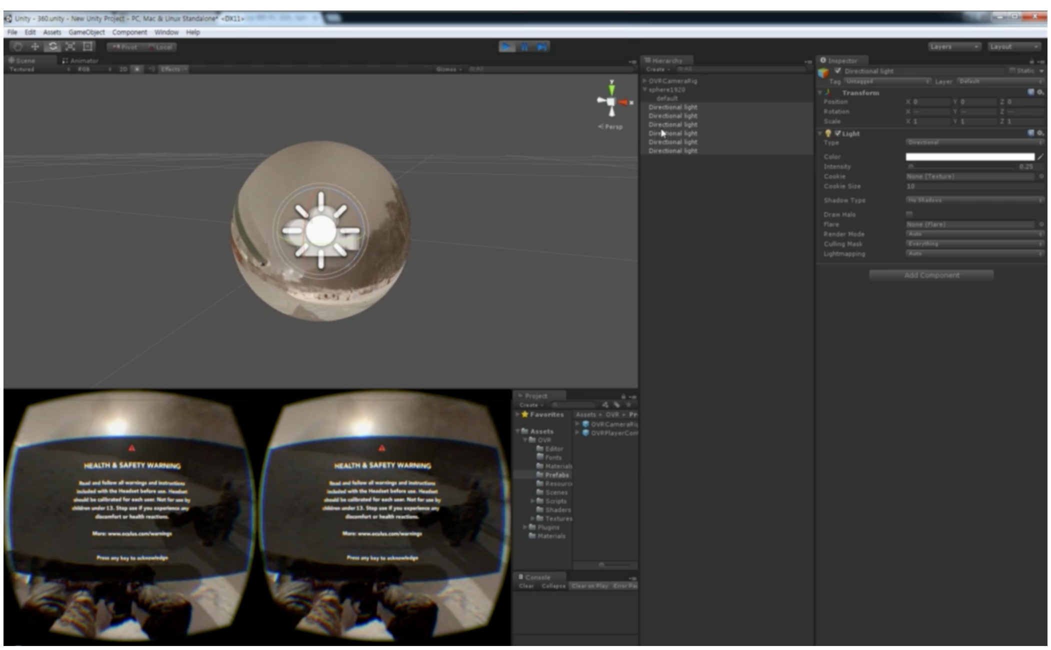

Figure 69 The first version of VR scene

5.4.2.3 First Mixed Reality App Prototype

After finishing all the data acquisition work, I started to make my first AR + VR app prototype. The app integrates both the Cardboard Unity SDK version 0.5.0 and Vuforia 5 SDK. Since Vuforia 5 version, Vuforia started to support digital eyewear developer kits such as Google Cardboard SDK and Oculus Mobile SDK for the Gear VR. This makes creating mixed reality apps possible for the video see-through devices. In Unity, the Vuforia AR camera prefab continues to drive the AR recognition work, but there is a new Vuforia Behavior script that provides a function which can bind another camera. With this script, we can import the Cardboard's Main Camera prefab from Google Cardboard SDK and bind it with the AR camera together to render a stereo view. The SDK also offers a Transition Manager script. By implementing this C# script, the transition function between AR and VR scene can be achieved. Users can switch between different scenes by orienting the direction of their eye gaze.

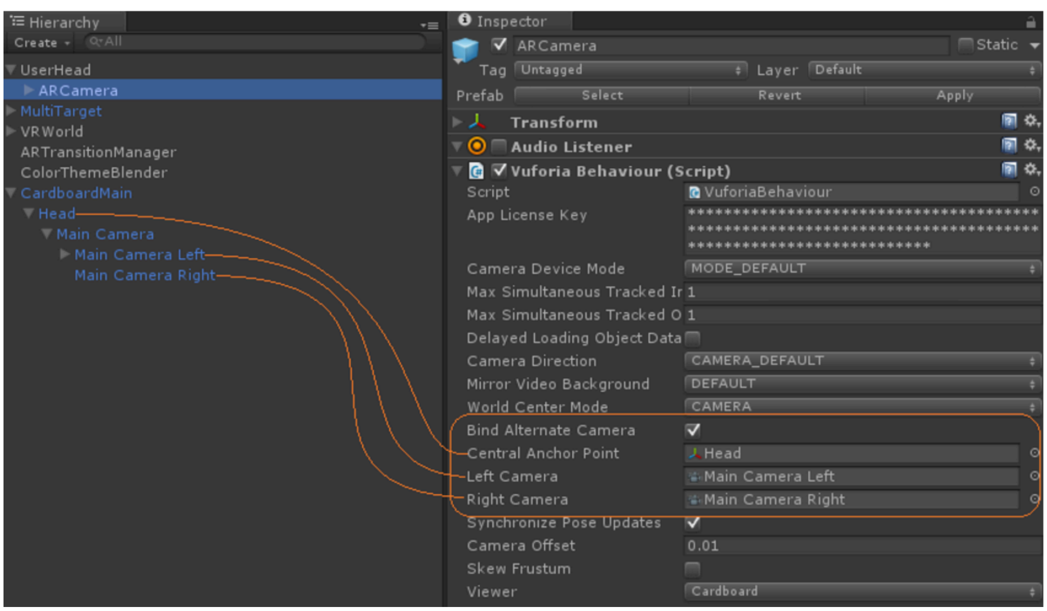

Figure 70 Bind the AR camera with the VR Camera

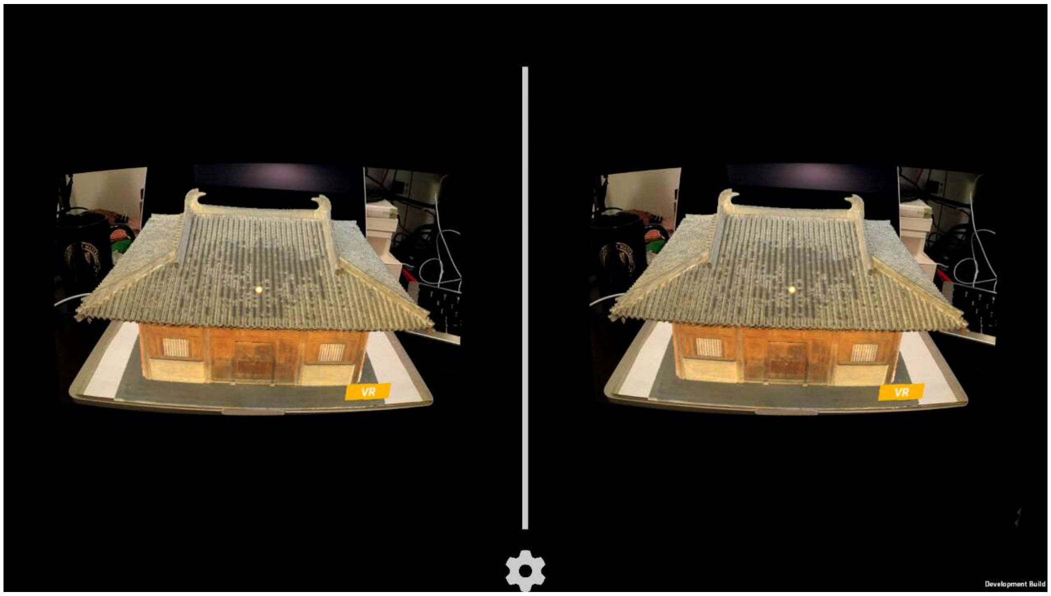

Figure 71 The Stereo rendering

In this version, I also tried to test different effects by using different sizes of image targets. I printed out a large image target with the dimensions of 1.5m*1m. The final result was better than I expected. The building looks larger and clearer and the stereoscopic effect is even stronger than the effect I saw on the A4 printing paper.

Figure 72 The giant image target

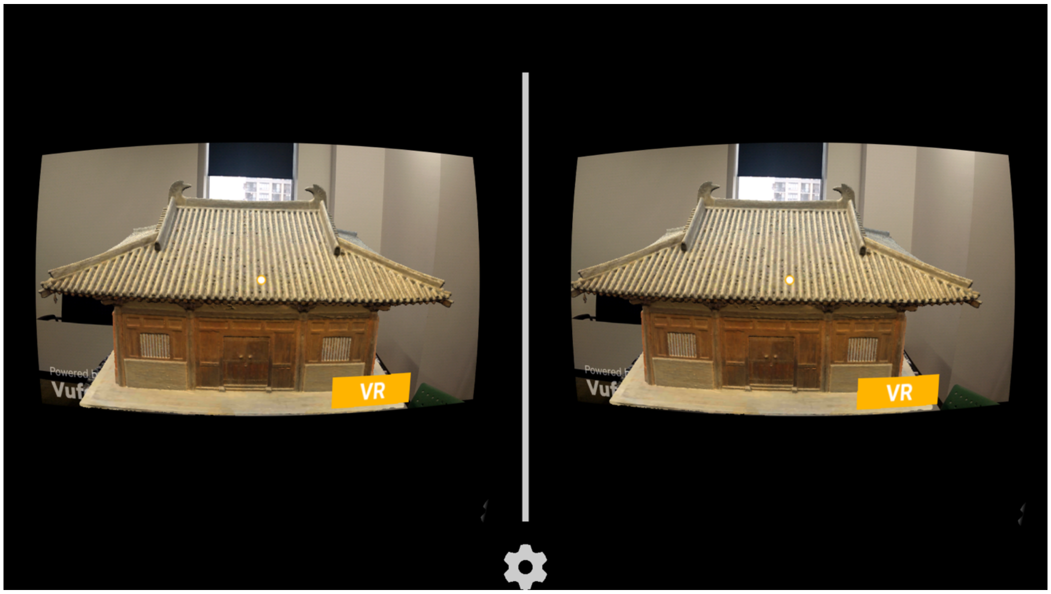

Figure 73 Front view of the building

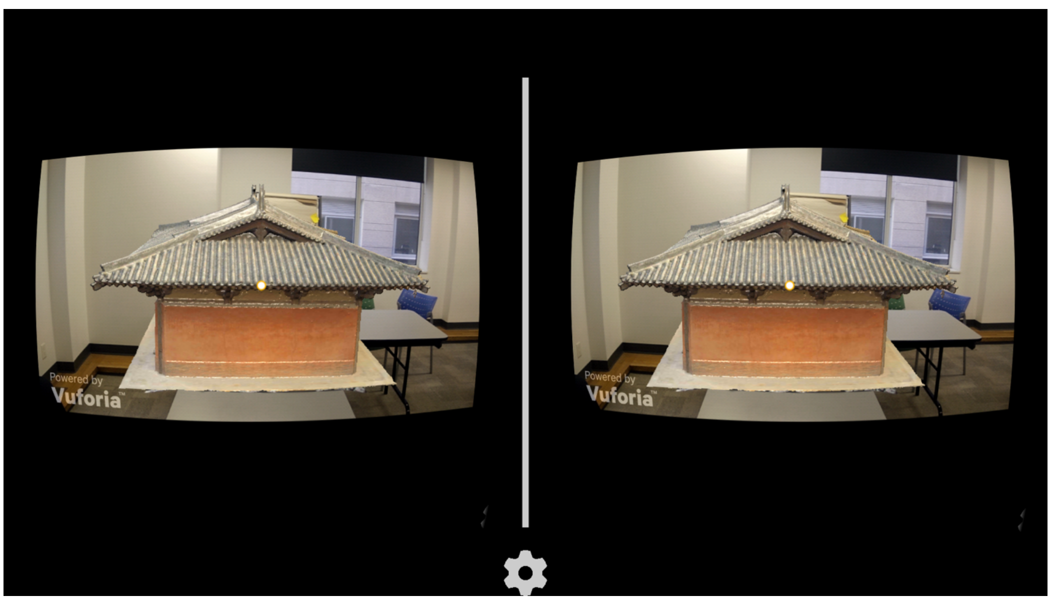

Figure 74 Side view of the building

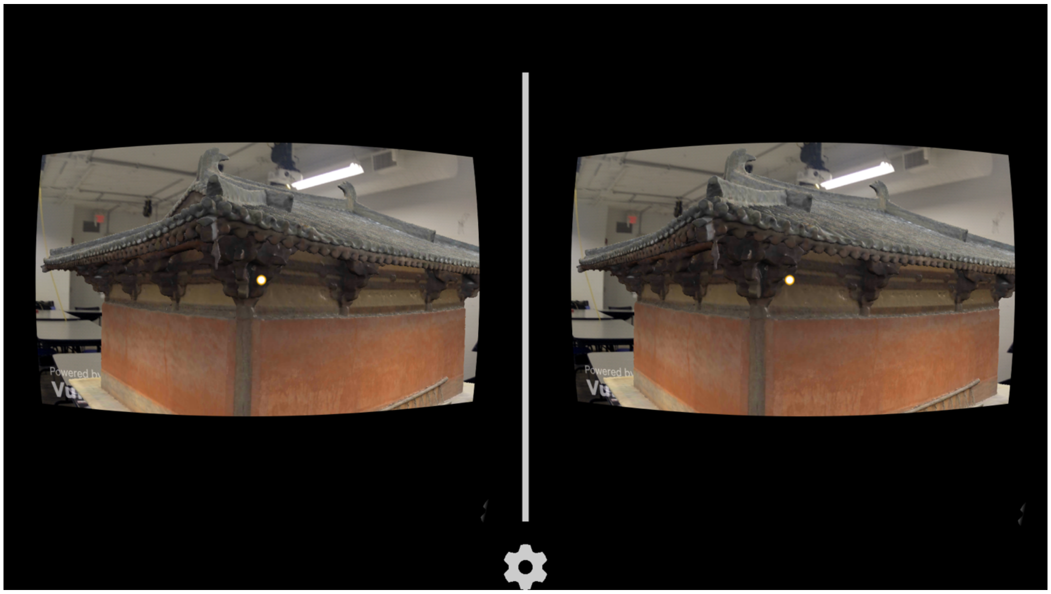

Figure 75 The timber structure of the building

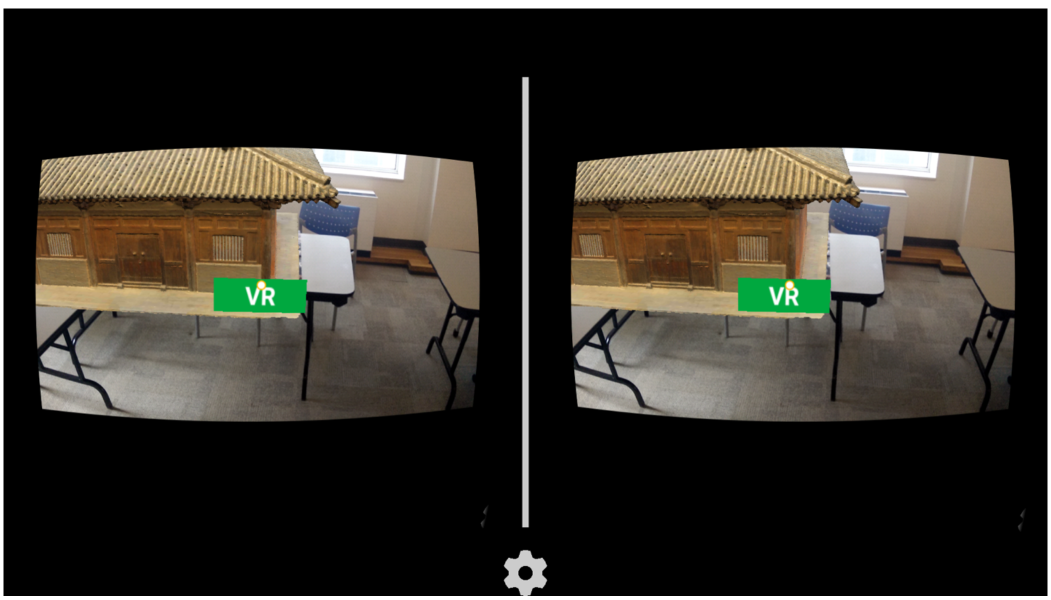

Figure 76 Trigger the VR scene

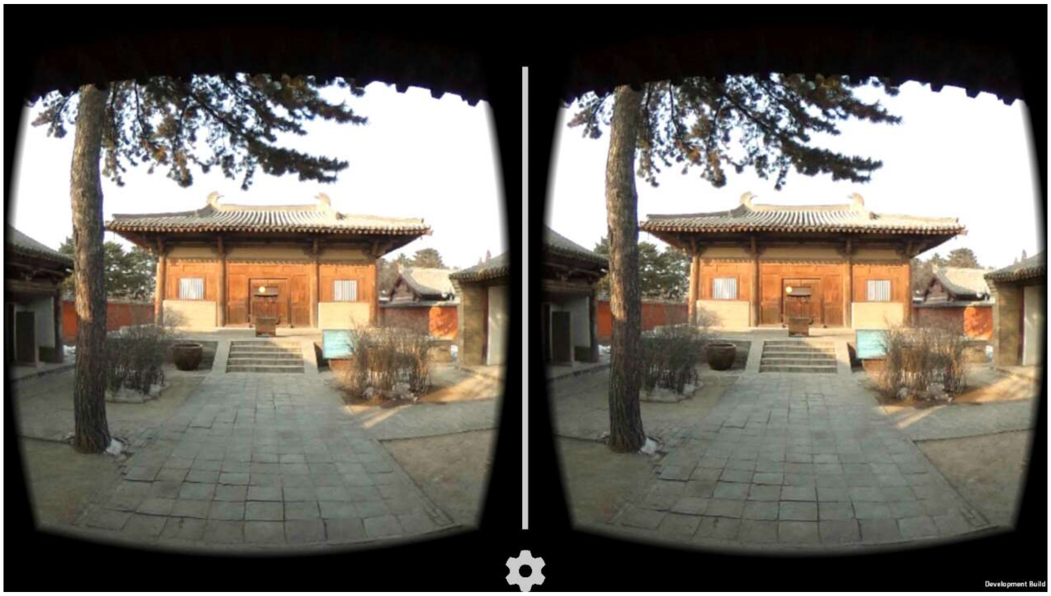

Figure 77 Inside the VR scene

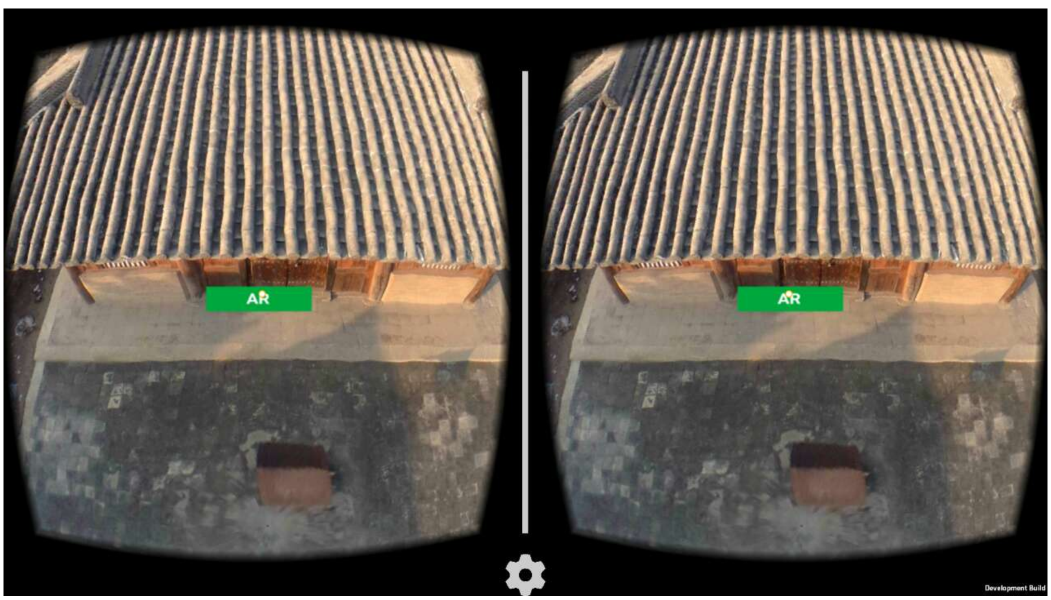

Figure 78 Trigger the AR scene

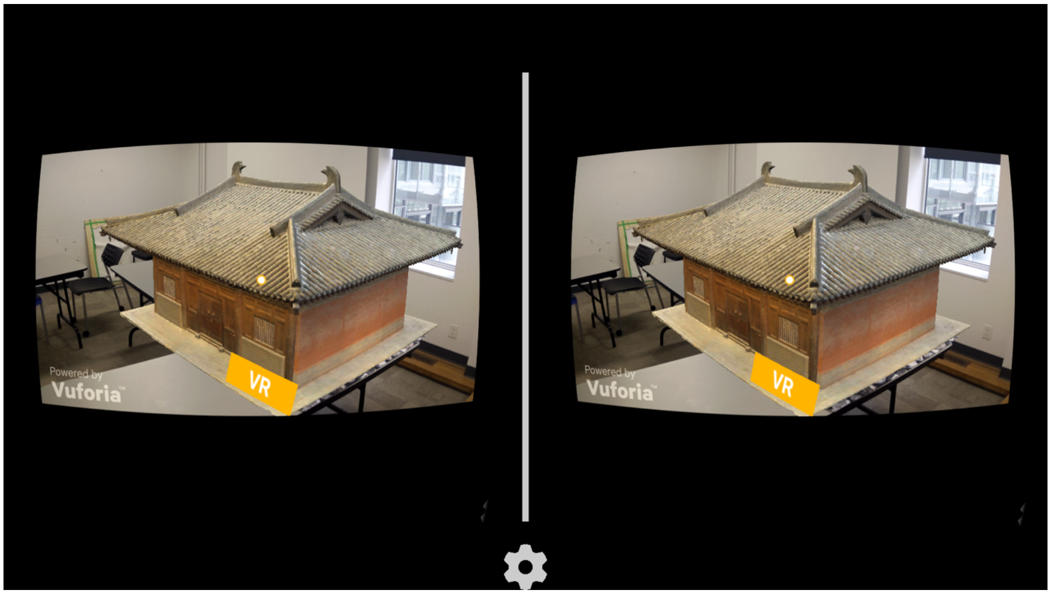

Figure 79 Return to the AR scene

5.4.2.4 Second Mixed Reality App Prototype

During the testing phase for the first prototype, some participants provided the feedback that the user experience was a little plain due to the lack of sound during usage. Participants revealed that it is very difficult to get emotionally involved with the scene if there is no music or audio immersion. To make the experience even richer I therefore added background music in the VR scene in the second prototype iteration. Another major improvement was that the second prototype enabled users to switch between different panoramic images by pulling down the magnet button on the Google Cardboard.

Figure 80 The magnet button, source: https://developers.google.com/cardboard/?hl=zh-tw

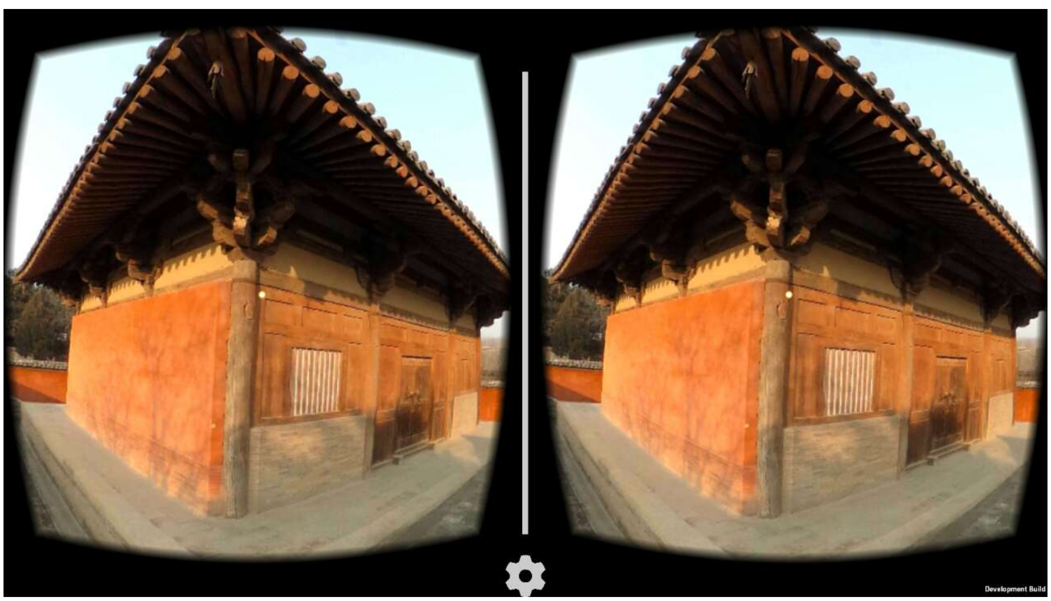

Figure 81 Switch between different VR scenarios by pulling the magnet ring

Figure 82 Switch between different VR scenarios by pulling the magnet ring

5.4.2.5 Third Mixed Reality App Prototype

In the third version, the content of Guangji temple was added in. In this iteration users have two temples available for them to see. Due to the number of changes to the content, I added a UI element (main menu) at the beginning of the apps launch to enable user to make the choice. The UI element also makes the app look more systematic and complete. In addition, because the magnet button is the only physical input on the Google Cardboard, in the third prototype I also added a return function. As long as users pull the button down when they are inside the AR scene, users will now be able to jump back to the main menu. This UI element allows the user to keep choosing and watching more content that can be selected from the main menu.

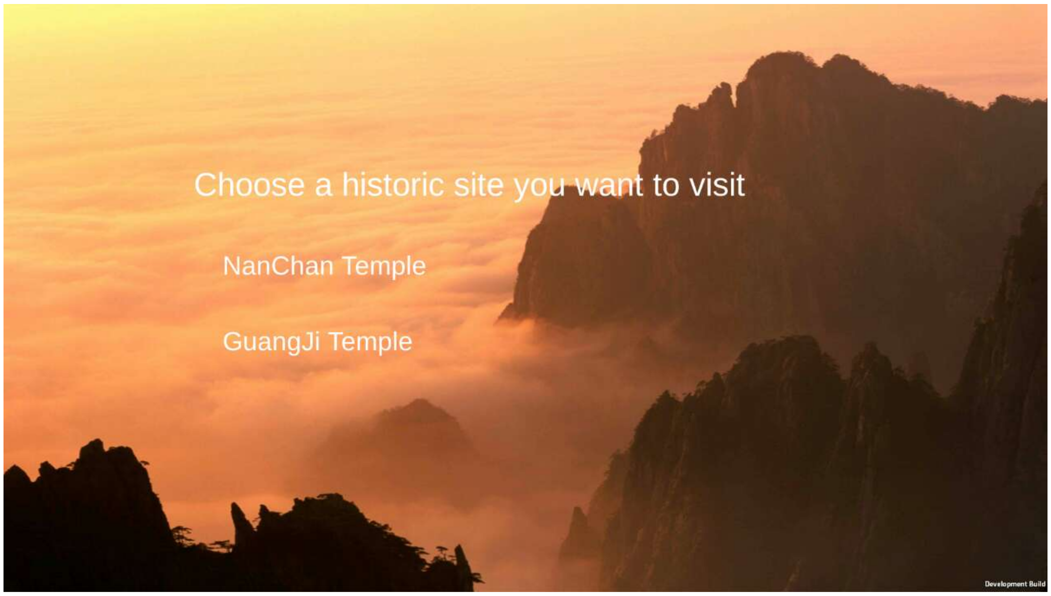

Figure 83 The main menu

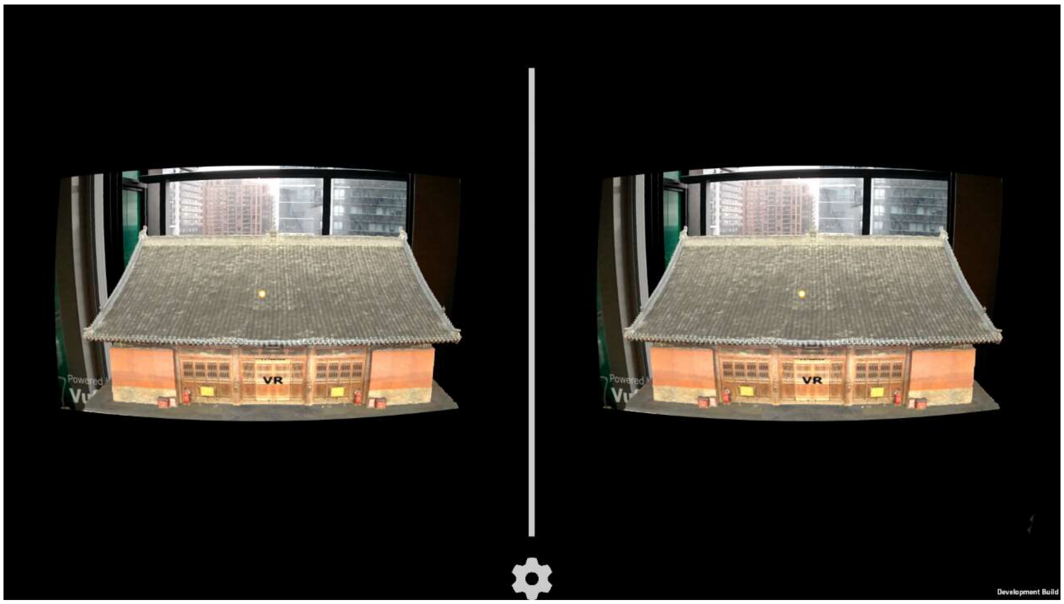

Figure 84 Add Guangji temple

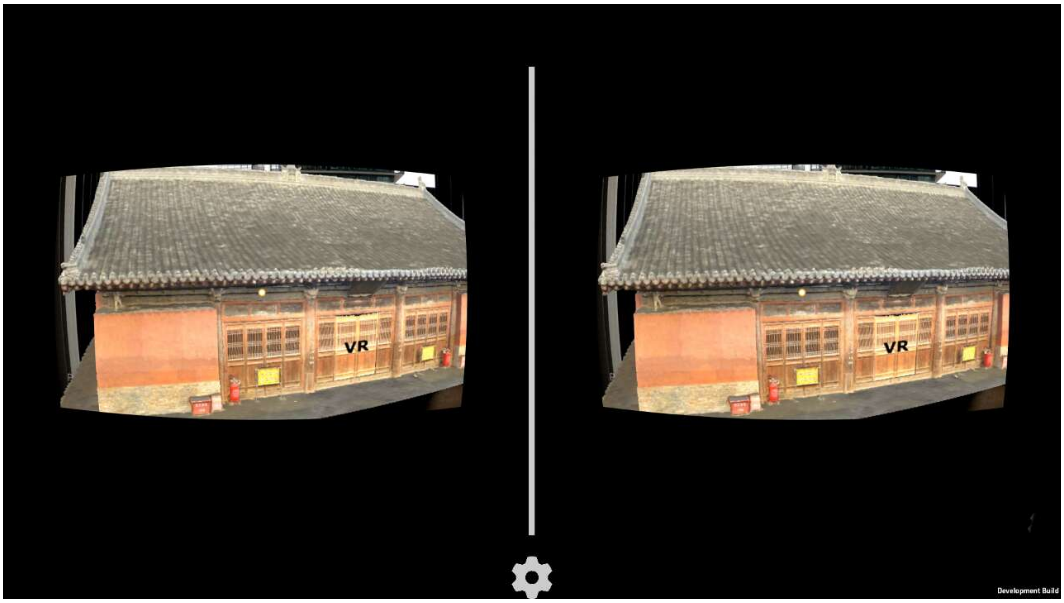

Figure 85 Side view of Guangji temple

Figure 86 VR scene of Guangji Temple

Chapter 6 - Conclusion

This thesis presents methods for using consumer-level technology as a means of documenting, disseminating and ultimately protecting Chinese historic buildings. By integrating 3D reconstruction, Virtual Reality, Augmented Reality and smartphone app platform, I created a mixed reality educational app can be used with a smartphone and Google Cardboard. This study began from researching the conservation state of Chinese historic sites. Through two field studies and a number of interviews this study has found several serious problems existing with Chinese heritage conservation. This thesis presents the idea of preserving Chinese historic sites through digital preservation and the concept and tools in 3D reconstruction, VR and AR respectively. Finally, the thesis project finished the mission of scanning, 3D modelling, data recording and panoramic shooting for two historic buildings by using a series of consumer tools and the final production of AR/VR application.

By letting 8 users participate in testing, I found the solution of using digital preservation technologies not only can provide detailed and comprehensive data of historic sites for the further research and study but also enable people learn about the information of historic buildings in an interesting and engaging way.

Consumer seems to appreciated this form of representation. They believed the entire user experience was very intuitive and not complex.

The final prototype indeed supported some of my assertions from the beginning of this study. Digital preservation technology can make the future architecture data archive more scientific and systematic. VR and AR can greatly improve the engagement between people and the information. The cultural heritage field can exploit the AR and VR technology by finding a new way to provide the information and offering new consultation methods of archaeological or cultural sites or museums.

This thesis project has been shown to have an effect in enhancing people's interests to historical buildings, facilitating their learning process and experience and ultimately arousing their awareness of Chinese historic building conservation.

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