

VISUALIZING HISTORICAL SITES – A CASE STUDY OF THE U.S. CAPITOL

by

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DEDICATION

This thesis is gratefully dedicated to all my family and friends, who give me spiritual support and encourage me to achieve my goals. This is also dedicated to those who inspire me to go forward in the hard time.

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LIST OF ABBREVIATIONS

Area of Interest	AOI
Augmented Reality	AR
Enhanced Reality	ER
Global Positioning System.....	GPS
Gross Domestic Product	GDP
Three Dimension.....	3D
User Interface.....	UI
Virtual Reality.....	VR
Software Development Kit	SDK

ABSTRACT

VISUALIZING HISTORICAL SITES – A CASE STUDY OF THE U.S. CAPITOL

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Tourism is a major industry, not only in the United States of America. Visitors from all over the world visit cultural heritage sites, national parks, entertainment venues, and other points of interest. Mobile devices and applications help with finding landmarks, routing, information retrieval and communication via social media. Thus, location-based services are often the key to providing useful and usable tourism information to many travelers. Washington DC is one of the prime tourist destinations in the U.S. with several historic landmarks. Thus, this thesis investigates how Augmented Reality can enhance the experience of visiting historic landmarks, i.e. the U.S. Capitol building. Several historic models of the U.S. Capitol were developed and embedded in an Augmented Reality App for Android.

1. INTRODUCTION

1.1 Background

Tourism as an international industry is also the biggest provider of jobs on the planet (Buhalis & Law, 2008). It has been rapid developed in recent years. With the popularity of the tourism industry, leisure travel is no longer a luxury privilege for a few consumers. More and more ordinary tourists could travel domestically or internationally. A copy of data from The World Bank shows that from 2010 to 2014, the number of worldwide international tourists increased from 967.194 million to 1.161 billion (World Tourism Organization, n.d.). Meanwhile, the share of the tourism industry in the global economy is also gradually expanding. A research report of the World Travel & Tourism Council in conjunction with Oxford Economics shows that the continuously growing tourism industry has contributed \$7.2 trillion dollars to the world GDP or 9.8% of the total GDP in 2015 (World Travel & Tourism Council, 2016). The importance of the tourism industry has been widely acknowledged by both government agencies and commercial communities.

With the advancement of personal navigation, information and communication technologies, the tourism industry has undergone substantial changes. Traditional pattern of tourism is facing challenges. Visitors are no longer satisfied with the old-fashioned tourism, and turn to seek various, flexible and customized tourist experiences

(Stamboulis & Skayannis, 2003). Therefore, the purpose of travel is potentially varied. In comparison, tourists in the past hoped to relax in their journey while temporarily escaping the pressure of daily life. Modern visitors are eager to pursue different life experiences, broaden knowledge and widen their field of vision (Krippendorf, 1986). As a result, cultural heritage tourism is becoming considerable popular. In the traditional historical building visiting tour, tourists can only take a glance of historical and influential events related to the historical building through photos, public dashboards and video recordings. This visiting mode is static and provides lack of interest (Park et al., 2006). Though these historical sites try to exhibit many historical records to the visitors, they fail to provide an attractive and novel visiting experience for modern visitors. Hence, requirements for new historical building tour experience are emerging. Going back to a certain period of history and observing historical events from the first perspective is becoming an expected traveling pattern for many tourists. In response to this demand, an immersive tour experience by means of accelerated developing technologies was proposed (Park et al., 2006). The purpose of this concept is to supply realistic environmental experience for the tourists, which makes them feel like they are placed in the historical situation.

Augmented Reality as a rising information display technology can provide this immersive experience to tourists. Due to its development, Augmented Reality is catching lots of attention from researchers, technicians, and consumers (Zhou, Duh, & Billingham, 2008). Taking advantage of the Augmented Reality technique, pre-constructed 3D animation models can be mixed with the real environment and be displayed on a viewing screen. Different from Virtual Reality that directly builds a virtual

external environment, Augmented Reality does not separate viewers from the real surroundings. Instead, it enriches the realistic environment with virtual models in the display interface. Augmented Reality technique bridges the gap between the real world and the virtual environment. It has the ability to reproduce historical buildings in a certain place via the visual form. Now, Augmented Reality is widely being applied in maintenance, advertisement, entertainment, education and so on. Six main potential AR research fields such as medical, manufacturing and repair, annotation, robot path planning, entertainment and military aircraft have been studied since 1997 (Azuma, 1997). Based on its outstanding characteristics, Augmented Reality is regarded as a suitable technique to achieve an enhanced tour experience. Some Augmented Reality historical building tour applications have been developed. However, the existing Augmented Reality historical building tour applications cannot satisfy the needs of broad visitors. When using an AR application to experience an enhanced historical tour, tourists have some requirements such as:

- It is compact, convenient, pocketable and easy to preserve.
- It is user-friendly. Users do not need additional knowledge, skills or trainings. Seniors and children use it easily.
- It requires no extra cost. Visitors do not need to buy or rent particular equipment for implementing the immersive tour experience.
- The Augmented Reality app is not limited to use inside the historical buildings. Visitors can get the immersive experience when they are roaming outside as well.

- It integrates multiple information sources. In addition to visualization of historical buildings, tourists also enjoy the convenience by sharing and communicating information between each other.

Furthermore, due to natural disasters, regional wars and urban development, many historical relics have been ruined, rebuilt or extended in their history (Xue, 2005). For tracking changes, recording history and conservation, preservationists are searching for a low-cost method to reconstruct and virtually display the different periodical historical buildings.

To sum up, an intelligent historical building tour AR application would be a benefit for tourists who are seeking for novel tour experiences, as well as satisfies the demands mentioned above.

1.2 Scope

This research is trying to contribute some efforts to the whole Augmented Reality field, especially in historical tourism. It tries to take advantage of a historical storytelling format to display 3D Augmented Reality models from different historical periods in an Android application. In addition, it attempts to integrate multiple formats of data such as 3D objects, 2D images, video, text and open source data like Wikipedia and TripAdvisor to enrich display content.

1.3 Research Questions

Facing these challenging problems, it is urgent to develop a personal user-related application to help tourists in their historical traveling tour. There are several big concerns driven in this article. First, what are suitable 3D modeling techniques for

historical buildings visualized in AR systems? Second, what are opportunities and limits for object recognition-based historical building visualization? Third, how can historical building changes be described in AR-based storytelling? Last, how can social media data enhance the content of historic building visualizations?

1.4 Thesis Outline

This thesis consists of five sections. Section One shows the new trend in the tourism industry and new requirements from the tourists. It describes the core needs of a historical building tour AR application and explains its limitations. A potential scope of influence of this research and several research questions are also proposed in this section. Section Two reviews the related research work in the past, including multiple approaches in rehabilitation of 3D historical buildings, object recognition-based historical building visualization and the effects of social media data integrates with 3D models. Section Three outlines the steps of this research as well as introduces the research data and study area in this research. This section then, details the methodology used in rebuilding 3D historical building models, tracking outdoor objects in the AR application, constructing an Android AR application, as well as linking Wikipedia to the AR application. Section Four presents the results of this study. Section Five concludes the whole research and presents the work in the future.

2. LITERATURE REVIEW

2.1 Three-Dimensional Historical Building Models

As the visualization technology develops, 3D information plays an important role in protecting and displaying culture heritages (Dore & Murphy, 2012; Remondino et al., 2009). Utilizing 3D data to reconstruct historical buildings provides a possibility for researchers and visitors to understand history intuitively. How to rapidly construct accurate and photorealistic architecture models has been the focus for researchers (Allen et al., 2003).

The primary task of relic protection is to obtain accurate data. Traditional geometry-based approach requires field observations to acquire data, and then manually positioning the elements of the scene. This approach is easy to learn and implemented in commercial software such as Sketch Up, ArcGIS Pro and so on. However, this method is really time-consuming and labor intensive to digitize 3D data. On the other hand, it is difficult to evaluate the accuracy of resulting 3D models.

A few years later, with the development of imaging technology, image-based modeling technique appears, which makes fast obtaining a wide range of precisely 3D model and virtual world construction possible. Image-based modeling technique has emerged as a representative. Since image-based approach is based on photogrammetry method of stereo image pairs to reconstruct historical architectures, it needs significant amounts of overlapped images of the scene to recover the spatial construction.

Meanwhile, it completes the transformation from 2D images to 3D texture mapping of the models. For large-scale constructions, images need to be captured by aerial photography.

The image-based modeling technique shows fine accuracy in building regular shape buildings, but in the face of complex structures, the accuracy of the digitized models seems poor (Pieraccini, Guidi, & Atzeni, 2001). Then range-based approach as another method is catching attentions from researchers. Range-based approach, which is a method of terrestrial laser scanner, can capture the 3D geometry of objects by resulting point cloud in a fast speed (Böhler & Marbs, 2004). Comparing to the image-based method, range-based approach acquires smaller geometric details (Guarnieri, Vettore, El-Hakim, & Gonzo, 2004). Considering the efficiency and accuracy of this method, it has been applied to record complex historical 3D models for preservation.

Though new technique are promoted, considering the variations of different period historical buildings, it is hard to answer which measurement technique is better than others (Böhler & Marbs, 2004). In many situations, in order to further improve the accuracy of 3D models and simplify the modeling process, researchers tried to construct 3D models in hybrid modeling methods. For example, a joint project between CIRGEO, IRST and VIT create a great number of 3D models of a room in Buonconsiglio castle by means of both photogrammetry and laser scanning techniques (Guarnieri et al., 2004). They first utilized image-based modeling technique to capture the geometric surfaces, then acquire the detailed ceiling information of the room by laser scanning technique. Debevec et al. combined geometry-based and image-based approaches to construct

models (Debevec, Taylor, & Malik, 1996). By combining these two methods, models are constructed directly from images and geometry details are recovered from photogrammetry. This method requires far fewer images than the image-based modeling approach when modelling large architectures. In addition, it is more accuracy comparing to resulting models constructed by geometry-based method. The 3D-Arch project started in 2005 utilized an integrated approach which contains laser scanning, photogrammetry and modeling from floor plan to reconstruct complex medieval castles in Trentino province in Italy (Remondino et al., 2009).

When choosing the method to acquire 3D data for historical architectures, researchers need to take particular requirements of the historical buildings into consideration and make a balance between several factors like accuracy, time expense, automation and cost. Since this study restores 3D historical building models that are no longer present today, this factor is applying as a particular consideration when selecting modeling methods (Table 1). Due to the memory and computing power of current smartphones, the 3D models built for mobile platform have to sacrifice some details for accessibility. Too accurate 3D models may cause a negative impact on display.

In light of the advantages and disadvantages of recovering methods, in this research, a hybrid method based on geometry-based method and image-based method is implemented to construct 3D models.

Table 1. Comparisons of multiple methods for 3D historical architecture design

Factors	Geometry-based approach	Image-based approach	Range-based approach	Hybrid approach
Accuracy	Low	Moderate	High	High
Time expense	High	Moderate	Low	Low
Data Volume	Low	Moderate	High	Moderate/ High
Cost	Low	Moderate	High	Moderate
Recovery from images	Yes	Yes	No	Yes

2.2 Augmented Reality Techniques

Augmented Reality is a novel research field. It seamlessly mixes virtual objects with the real environment. Different from Virtual Reality, which creates a totally synthetic environment for a user and separates the user from the real world, AR superimposed the virtual objects and information with the reality. Some researchers describe AR as a form of enhanced reality (ER), which is an intermediate stage between the worlds of fact and fiction (Bowskill & Downie, 1995).

The first AR prototypes appeared in the 1960s were created at Harvard University and the University of Utah (Tamura, 2002). At the early period of its development, the main research direction is VR instead of AR. AR technique was conceived but then quickly ignored. Until the early 1990s, the term Augmented Reality was first proposed by Caudell and Mizell (Caudell & Mizell, 1992). In 1997, Azuma stated an elaborate survey for AR. It provided a common definition of AR as a technology which (1) combines real

and virtual imagery, (2) is interactive in real time, (3) is registered in three dimensions in the real world (Azuma, 1997). Some key factors of AR technology including graphic rendering, real-time tracking technique, tracker calibration, registration and augmented reality display were summarized at that time. Later, a paper review of ten years' work of AR at the ISMAR conference by Zhou et al. (Zhou et al., 2008) found that tracking, interaction and calibration are the most highly cited topic papers.

In historical tourism, applications of AR are mainly used to reconstructed the ancient historical buildings for display. Specifically, it superimposes the 3D virtual buildings with the real environment. Serval historical augmented reality applications have been built for cultural heritage. Feiner et al. (Feiner, MacIntyre, Höllerer, & Webster, 1997) described a prototype mobile augmented reality application to explore the university campus of Columbia University. It was the first trial to install augmented reality application on a mobile platform. This application presented information about interesting targets in the real world and took use of GPS to track users' activity in outdoor. A big limitation of this application is the quality of tracking accuracy and loss of tracking. GPS signals are weak for outdoor areas shaded by trees or buildings. Only text information could be added as augmented reality images. Then one year later, Thomas, Bruce, et al. (Thomas, Demczuk, Piekarski, Hepworth, & Gunther, 1998) improved the tracking accuracy of wearable computers and expand the exploration to a larger extent. They built a map-in-hat application to show visual cues for the navigation task through a head-wear display. The portable computer used to receive GPS signals and display 3D augmented reality images was still cumbersome and needed extra display equipment for

visualization. This limit also occurred in the study of Magnenat-Thalmann and Papagiannakis. They developed a real time integrated mixed reality system to recover the cultural heritage sites (Magnenat-Thalmann & Papagiannakis, 2005). They simulated the ancient scenes by mixing animated virtual human actors in the storytelling process. However, the AR system was running in a laptop workstation. It cannot be widely used in large cultural heritage sites. Vlahakis, VassilAndroid, et al. Vlahakis et al. (2001) presented a novel electronic cultural tour assistant at the archeological site of Olympia, Greece, in their project ARCHEOGIDE. The system presented the augmented reality views of reconstructed ruins combined with multimedia like 3D, video, and audio presentations. Additionally, it reverted the competing scenes in the stadium of Ancient Olympic Games. This project is an essential progress for applying augmented reality in tourism of historical building area. Though this application gives a remarkable experience for visitors, it isolates users from communicating and sharing with each other. Different from the previous AR applications for cultural heritage sites which were mainly used outdoor, Damala, Areti, et al designed an indoor mobile multimedia guide for the Museum of Fine Arts in French (Damala, Cubaud, Bationo, Houlier, & Marchal, 2008). Angelopoulou et al. designed a mobile AR educational game for iPhones to exhibit the archaeological site (Angelopoulou et al., 2011). It provided added information for users in an engaging way. In 2012, Haugstvedt and Krogstie developed a mobile augmented reality application to show information about a historical street. Using this prototype, they tried to investigate the usefulness and acceptance of common users. However, the

historical data they use is limit to historical images and texts only, which is less attractive for users to use.

2.21 Object Recognition-based Historical Building Visualization

To broad the use of AR, researchers have explored multiple tracking methods considering both indoor and outdoor conditions. Most tracking techniques fall into two categories that are sensor-based tracking techniques and vision-based tracking techniques. For sensor-based tracking techniques, sensors like magnetic, acoustic, optical and mechanical sensors have been explored (Zhou et al., 2008). However, until now there still are no reliable sensor-based tracking techniques. Recently, trials like building sensor networks for tracking are going on (Newman et al., 2004). Comparing to sensor-based tracking technique, vision-based tracking technique is more reliable. It takes advantage of image processing method to calculate the pose of the camera to the real environment. As a kind of vision-based tracking technique, feature-based method is a way to connect 2D image features with their 3D coordinate in real world. By analyzing the known feature, the camera pose could be reconstructed. Another popular vision-based tracking technique is model-based tracking method. It directly based on the lines and edges in a 3D model as markers to calculate the camera pose. Considering several factors, in this study, because of accuracy and stability, we choose feature-based tracking technique to visualize 3D historical models.

2.22 Augmented Reality Digital Storytelling

Materials such as pictures, descriptions, maps and audio guides are much widely used in traditional historical tours (Haugstvedt & Krogstie, 2012). With the common use

of digital devices, digital storytelling is becoming popular since it has the ability to continue providing information for users regardless of their locations and jump out of static narrative structures. AR application takes a further step and let the institutions give a livelier digital storytelling in a 3D approach (Page, 1999). By visualizing 3D models in this process, users obtain information effectively through rebuilding the scene in front of their eyes. Furthermore, it enables more interactivity for users to explore. Several researches have been done to explore AR-based new media experience. Kretschmer et al. created an AR prototype along with storytelling engine to assist historical sightseeing tour (Kretschmer et al., 2001). Bimber et al. applied AR technique in a digital storytelling components to build a virtual showcase (Bimber, Encarnação, & Schmalstieg, 2003). MacIntyre et al. made a trial to embed media theory into AR storytelling process and test the potential of AR as a new media form (MacIntyre, Bolter, Moreno, & Hannigan, 2001). However, social media as a new type media has been paid few attentions in few studies. In this study, we try to examine AR-based technique with rising social media data to describe historical building changes.

2.3 Social Media in Tourism

With the coming era of Web 2.0, the Internet has fundamentally reshaped the way tourism information is distributed (Buhalis & Law, 2008). Nowadays, web users become both the generators and consumers of the rich wealth content (Miguéns, Baggio, & Costa, 2008). The website is no longer a static page, but a dynamic platform for users posting or sharing their comments, experiences or emotions. Along with the blooming of web 2.0, a

wide range of application such as TripAdvisor and Wayn in tourism is also coming along. New form occurs for tourists to plan their trips.

TripAdvisor as the world largest travel website was founded in 2000. It aims to provide a platform for million travelers to offer reviews and advice to each other, as well as simplify their travel planning process to make decisions. Specifically, it offers links for booking hotels and activities for interested destinations. So far, TripAdvisor has provided 385 million reviews and opinions from travelers all around the world and shared 690,000 attractions and experiences. Now it successfully operates sites in 48 markets and 28 languages.

Wikipedia is an online encyclopedia contributed by volunteers around the world. It is available in multiple languages and open for anyone to edit. Comparing to traditional authoritative publications, this user-generated content is more up-to-date. Though at its early stage, the public continuously questioned the reliability of its content, due to the non-expert contributors and the constantly changing (Adler et al., 2008). Efforts has been done such as construct a trust system for Wikipedia content and rank the content in multiple trust level (McGuinness et al., 2006).

3 METHODOLOGY

3.1 Study Area

In this research, the Capitol Building will be used as a case study for examining the Augmented Reality app for historical buildings. Capitol Hill is located at the center of Washington D.C., United States. It is an essential political center for this country as the Congress, the House of Representatives and other important political committees work in this building. Figure 1 shows the south side of the Capitol Building. The Capitol Building has been ruined and rebuilt several times in its history. As a result, the Capitol Building we see today is a combination of different-period reestablishments.



Figure 1. An aerial view of the U.S. Capitol Building (Falbisoner, 2013)

On April 5, 1793, President Washington approved the initial version of the Capitol Building planned by Dr. William Thornton. The majority of the north wing of the Capitol Building was completed in late 1800 (Figure 2) and a temporary building known as “the Oven” which functioned as a meeting room for the House of Representatives was finished in 1801. This version of the Capitol Building will be the first model used in the app.

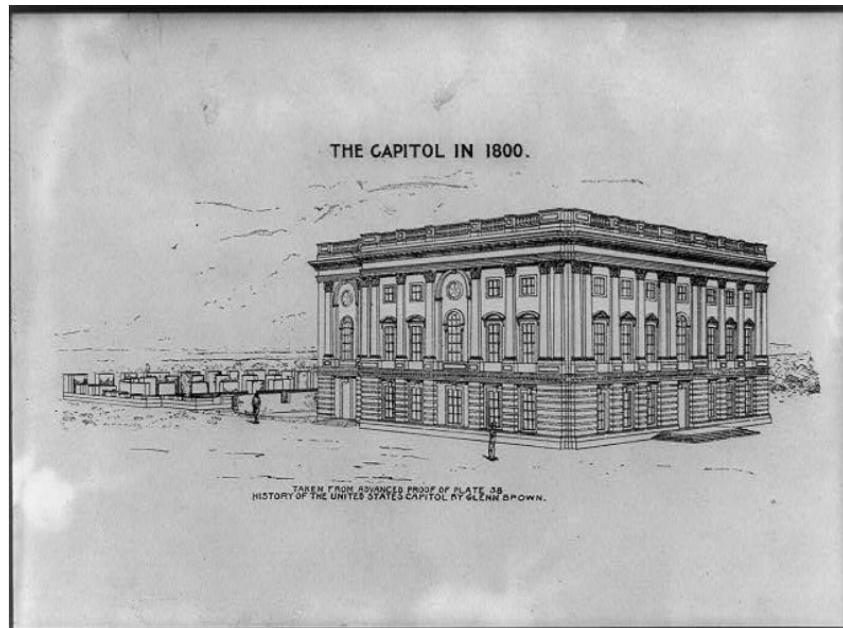


Figure 2. The Capitol in 1800 (G. Brown, 1800)

Then the reconstruction of the south wing took the place of the temporary building. However, on August 24, 1814, the British military set fire to the Capitol

Building, which led to serious damage. Figure 3 shows the scene of the Capitol after the conflagration of the 24th August 1814.



Figure 3. A view of the Capitol after the conflagration (Strickland & Munger, 1814)

The committee of Capitol Building construction started repairing the ruined part of Capitol Building in 1815. Along with the restoration, the entire Capitol Building including a copper-covered wooden dome at the top of the central section was completed in 1826 (Figure 4). This form of the building will be built as the second model.

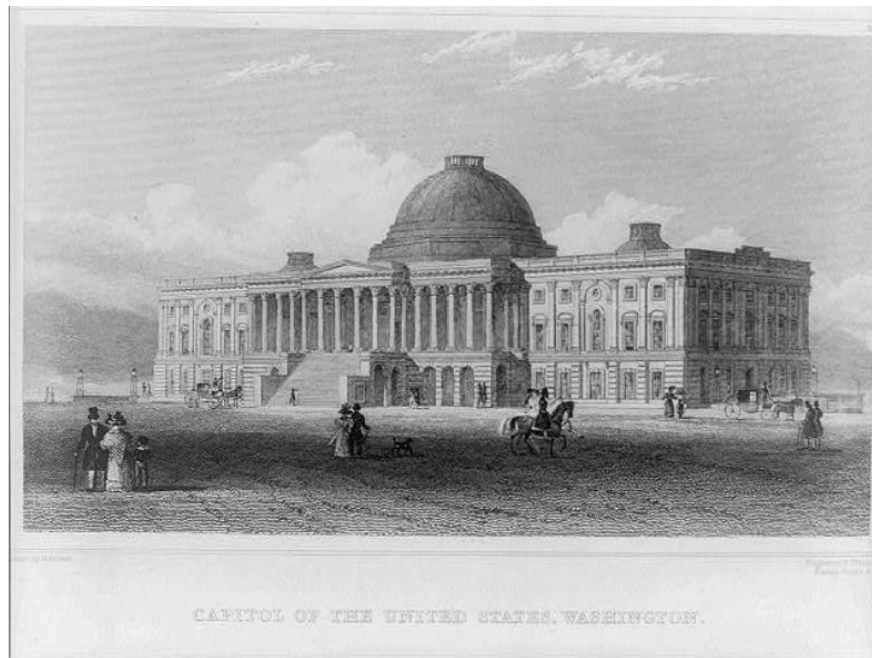


Figure 4. Capitol of the United States in 1831 (H. Brown & Sears, 1831)

With the increasing number of senators and representatives from newly admitted states, an extension plan for the Capitol Building was placed on the agenda. The Capitol Building extension project started on July 4, 1851, and lasted 17 years. The design of the new wings was compatible with the existing architecture style. After the completion of the extensional wings, the length of the Capitol Building had been stretched. Considering the proportion of different sections, the old designed dome looked unsuitable for the new Capitol Building. Therefore, a replacement of the dome was approved by the committee of the Capitol Building in 1855. The new dome was planned to be made of cast-iron and the Statue of Freedom was designed for the top. Later, the extension plan of the Capitol Building continued. The architects constructed marble terraces for its west sides and extended the old East Front. After these changes, the Capitol Building's exterior

appearance was what we see today. No more significant modification was made to it.

Thus, the exterior appearance of the Capitol Building in this stage will be the third model constructed in the app.

3.2 Datasets

This study utilizes the 3D model of the Capitol Building designed by CS3Design and uploaded to the 3D Warehouse as a prototype to rebuild the different time-period models (2014). Furthermore, several digital historical images obtained from the Library of Congress assist in constructing the Capitol architecture in early 1800s. The U.S. Capitol has been built, destroyed, rebuilt and extended several times according to its history. Hence, three main different out looking models will be built to show its variation in the history. In addition, Wikipedia record of the United States Capitol and TripAdvisor webpage of the United States Capitol will be linked to the app to enrich the content in display.

3.3 Workflow

The system architecture for the Augmented Reality Android app in this study is shown in Figure 5. The application consists of several modules that are part of the smartphone platform. Mobile units provide the ability of computation and object recognition to implement functions in the app. The app includes three main parts, which are 3D building models, Augmented Reality display and User Interface. 3D building models are pre-built and embedded into the app. Augmented Reality display, as the primary function in the app, is implemented by displaying different time-period 3D models of the Capitol Building. User interface enables users to interact with different app

functions and to switch functions from one to another. Wikipedia record and TripAdvisor data will perform as representations of web data to enrich the content of the whole app.

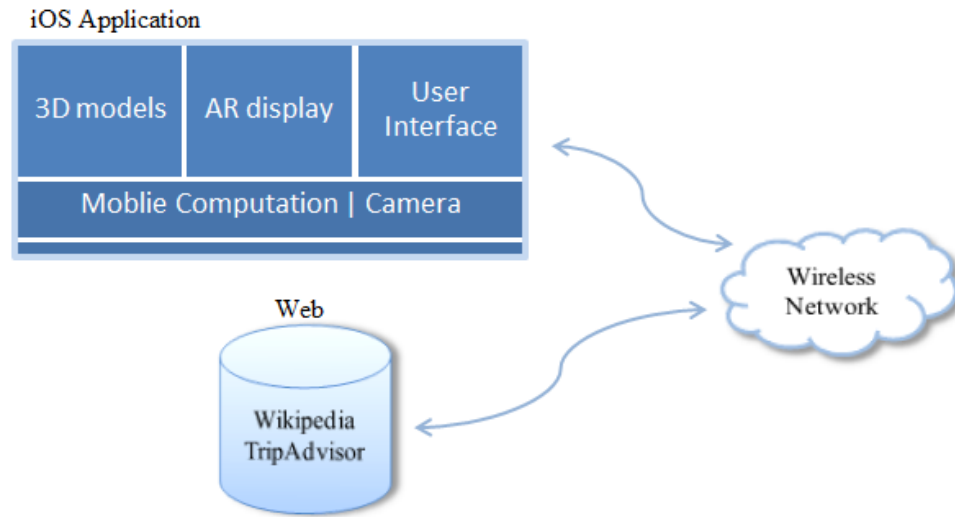


Figure 5. System architecture for AR app

We summarize four steps to complete the visualizing work. The workflow of this research is composed of four parts as showed in Figure 6. The first step is preparing visualizing models for the Capitol Building in different historical periods. 3D building models serve as the cornerstone of this app. Users would be more enthusiastic to involve in new tour experience if the 3D models are photorealistic. The second step of the workflow is to implement Augmented Reality visualization for the 3D models. It offers a novel way to show the various forms of the Capitol Building in the history to the tourists.

Third, the Android application will be under construction. In this app, we try to perform a user-friendly interface and embed several functions such as taking photos, displaying augmented reality, interacting with the virtual models. The final step, Wikipedia record of the United States Capitol Hill will be linked to the app. It would allow users to have multiple approaches to obtain information sharing from other users who are interested in this destination.

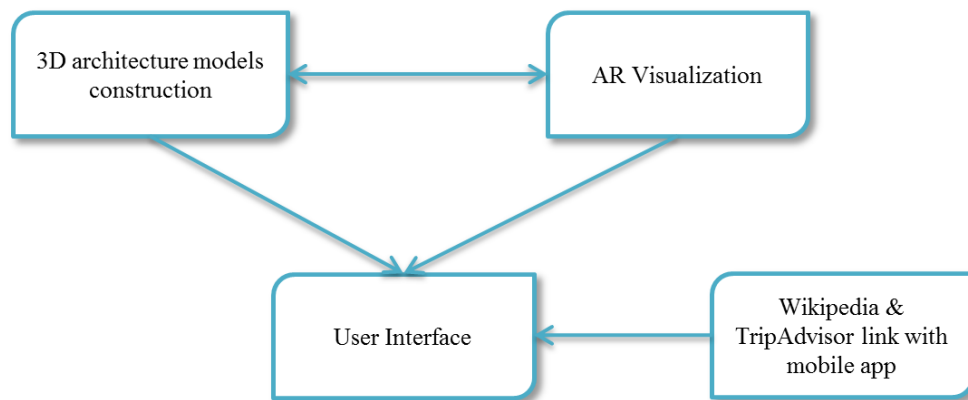


Figure 6. Workflow for building the AR app

3.4 3D Model Construction

Considering we are trying to recover buildings those do not exist today, we search their out appearance from the past images, photos, blueprints and drawings. To recover the outlook of Capitol Building in 1801, materials obtained from the library of Congress (G. Brown, 1800; Strickland & Munger, 1814) and the snapshot of the ancient Capitol

Building with “the Oven” extracted from The History of the United States Capitol (U.S. Capitol, 2010) are the mainly information we use. Importing the snapshot of the ancient Capitol Building with “the Oven” as the background image, then, we take use of the photo match method in Sketch Up to reconstruct 3D historical models. By manually adjusting the x, y, z coordinates of models in construction, we try to match the models’ 3D coordinate with the coordinate of historical buildings appeared in images. It provides the ability to restore virtual models directly from images. In addition, the photo match method will project historical images to the 3D models and show them as textures. Considering applying image to models instead of computer rendering shows an outstanding photorealistic result, we use the original texture as a priority. The oven and aisle in the first model are take use of computer-generated pattern. On the other hand, the images we found have been simplified and processed by the original authors. To recover the models based on historical facts, we photo match the exact parts in two images and package them together to achieve the first model. Figure 7 shows the process of photo match.

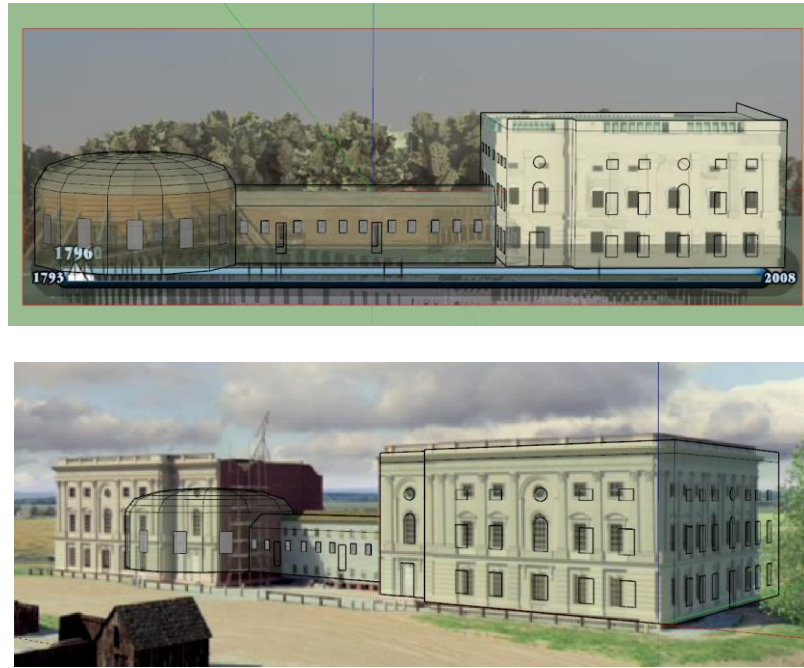


Figure 7. Photo match for early stage Capitol Building

The second model is for the Capitol Building in 1831, which is quite similar with the outlook nowadays. In this case, modification is based on the prototype of CS3Design Capitol Building model (2014) to obtain the second model. The third model is directly applied by the CS3Design Capitol Building model. Texture of these two stages is retrieved from realistic photos, thus it enhances the realism of the models. Figure 8 and Figure 9 shows the results of the second model and the third model.

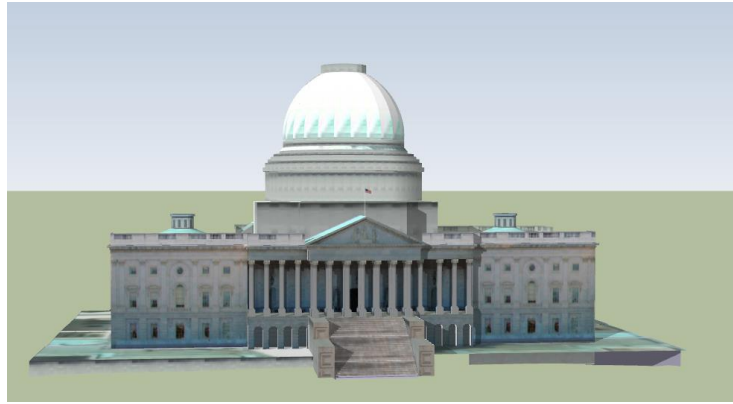


Figure 8. Second model for the Capitol Building

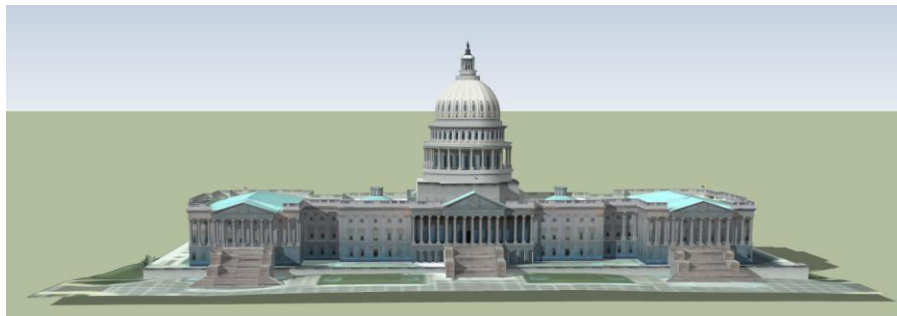


Figure 9. Third model for the Capitol Building

3.5 AR Technology

ARToolKit is an open source software development kit (SDK) library for implementing AR applications. It is relatively new, since it was first developed by Hirokazu Kato of Nara Institute of Science and Technology in 1999 (Kato & Billinghurst, 1999). The source code is organized in Github and available for common users to download. Until now, ARToolKit has been applied in a vast number of commercial software and has been downloaded up to 751,000 times (“ARToolKit download statistics,” 2016). In this study, we apply Vuforia-unity-6-2-26.unitypackage as an

extension in Unity3D to implement AR effect. To achieve the goal, users need to register in Vuforia website and get the license key for their project. After registration in Vuforia website, users could create, manage or download their targets database. Specific targets need to be embedded into Unity project for object recognition.

The object of this study is to achieve three AR functions, mainly the AR historic tour, AR video and AR virtual button (Figure 10). Through AR historic tour function, tourists can review different period pre-build Capitol Building models superimposing with real environment, and flexibly interact with the virtual objects. A cinema in a historic spot contains limited seats for visitors to see historical related movies at certain time. However, the AR video function overcomes this obstacle. Tourists can see the historical movies on their cellphones by using the phone camera to recognize the specific target. AR virtual button assists tourists to switch between multiple scenes.

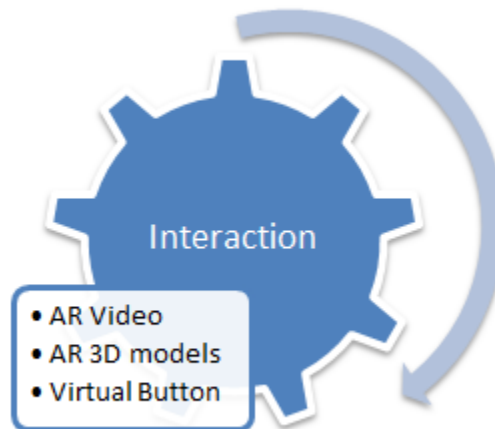


Figure 10. AR functions in app

When constructing the project, AR camera is taken advantaged of to mix 3D models in the real environment instead of main camera. To apply image-based target for object recognition, target database need to be created in Vuforia website and embedded into Unity3D. In addition, lean touch obtaining from the Unity3D Asset Store provides functions for users to interact with virtual objects showing on the screen, so users can transform, scale and rotate the models in the AR app. Figure 11 shows the process of creating AR visualization function for the first Capitol Building model.

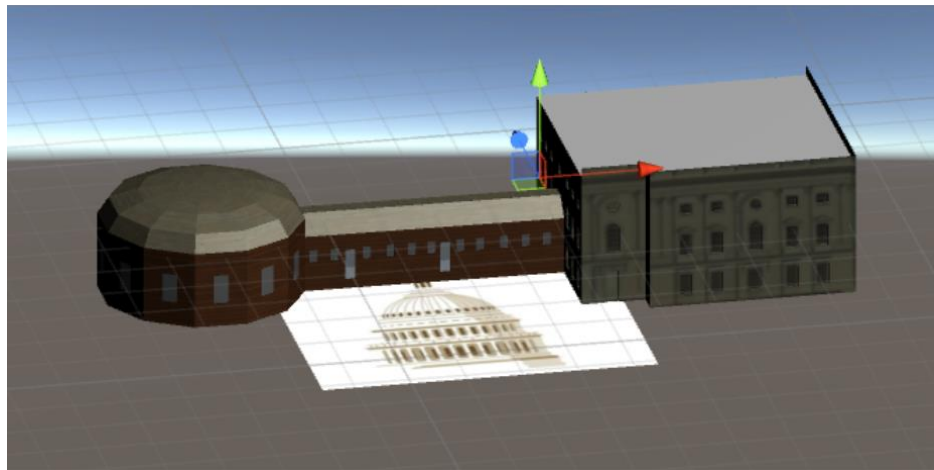


Figure 11. Creating AR visualization for the Capitol Building

AR video function is supported by Vuforia video playback plugin. It will display the video when camera detecting the image target. By tapping the start button on screen, the pre-embedded video will play in full screen mode. Considering that the user may

move around while viewing the AR video, it is not necessary for the user to always aim at the target with the camera of the mobile phone. Once the video starts playing, the AR video can play continuously, even if the camera moves away from the target. Figure 12 shows the appearance of an AR video in this research.

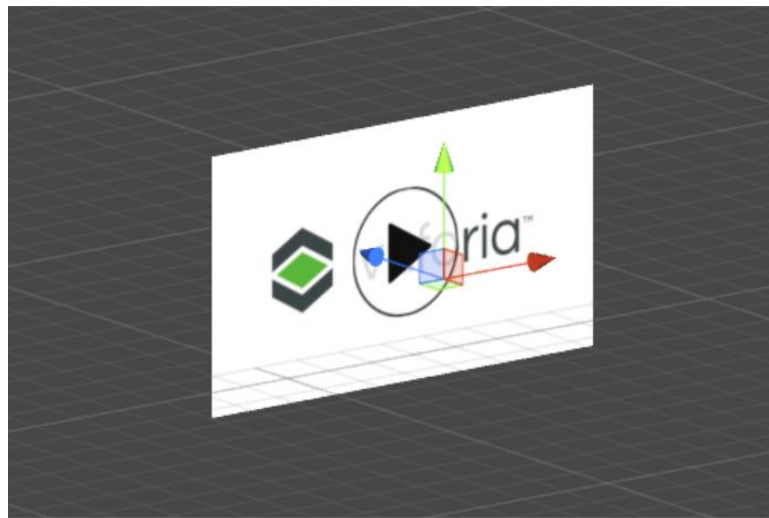


Figure 12. AR video building mode

3.6 Application Functions

The AR historical building tour application will be directly constructed in Unity3D software. When finishing building a Unity Android project, an apk project is automatically generated in the software. In addition, Unity3D provides multiple API scripts for users to access the multi-touch screen, accelerometer, GPS and so on.

The first function is AR Historic Tour. In this function, a time line of the Capitol Building in its history is showed. By tapping different historical periods, users could view the variation appearances of the Capitol Building. Here, multiple display effects are implemented. In the five historical periods, the first, third and fifth periods are 3D visualization, while the second and fourth periods we use historical image to show those historical situations.

A snapshot function is implemented with virtual 3D visualization for users to record the virtual object or take photo with that. By tapping the snapshot button, snapshot image will be saved in the app folder. The script to achieve that functions is written in C# obtained from Edgaras Art (Edgaras Art, 2015).

The Capitol Building Wikipedia webpage and TripAdvisor webpage are accessible in the output app. A C# script called url is created to drive this function. Here is the C# script:

```
using UnityEngine;

public class url : MonoBehaviour {

    public void urlLinkOrWeb1 ()
    {
        Application.OpenURL("https://en.wikipedia.org/wiki/United_States_Capitol");
    }
    public void urlLinkOrWeb2()
    {
        Application.OpenURL("https://www.tripadvisor.com/Attraction_Review-g28970-d143718-Reviews-U_S_Capitol-Washington_DC_District_of_Columbia.html");
    }
}
```

Here two functions are given. The `urlLinkOrWeb1` function will control the browser to open Wikipedia webpage while the `urlLinkOrWeb2` function will open the TripAdvisor webpage. It implemented by importing this script into a button object.

4 RESULTS

As an outcome of this study, it builds an Augmented Reality Android application and could be used in the U.S. Capitol building historical tour. Users could explore the history of the Capitol building by means of multiple media, such as historic images, 3D models, and videos. Users could use cellphone camera to track the image marker and recover the outlook of different periods of the Capitol building anywhere. At the same time, they can also use the photo function built in the app to take image of the mix reality scene. Touch methods like drag, translation and rotation are implemented. In addition, interaction between users and this app is supportive as users can switch to different periods, show AR results of the Capitol building, call out the Wikipedia description, and review other users' comments and sharing in TripAdvisor webpage. Therefore, users have the chance to have a better comprehension of the Capitol Hill when connecting to the social media platform.

4.1 Prototype Description

The outcome prototype was running in an ASUS MeMO Pad 7 LTE Android device for test. The Android system version is 4.4.4. In this study, 3D models are constructed in SketchUp which can be seen in Figure 13.

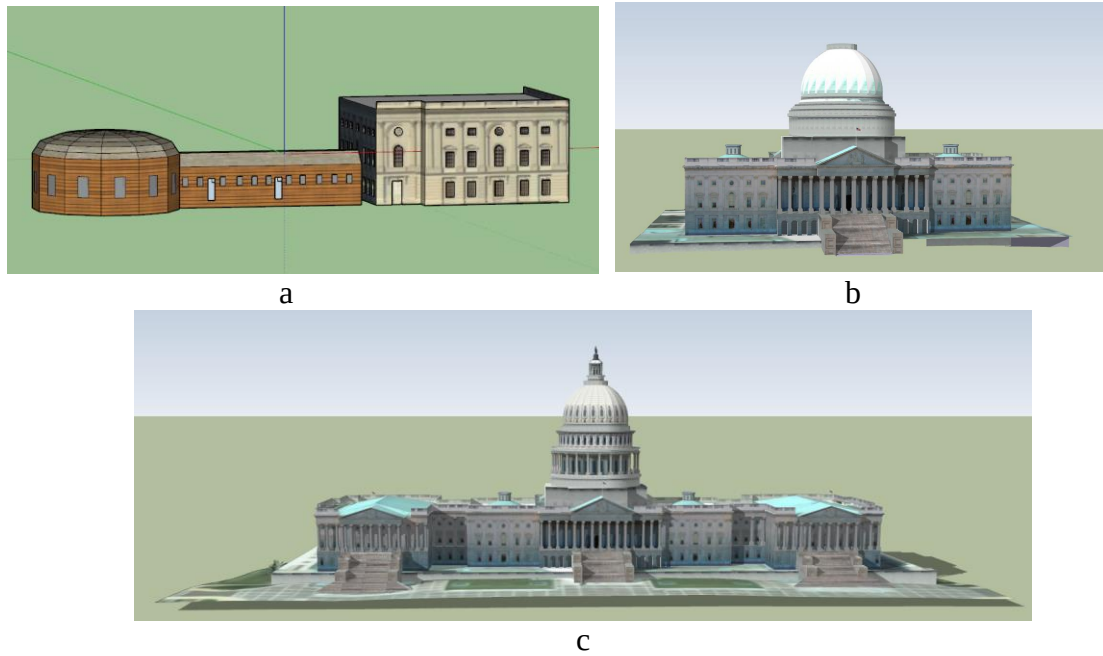
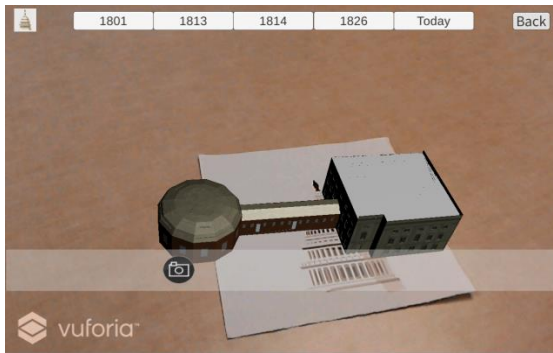


Figure 13. SketchUp: 3D models of The Capitol Building. a, The Capitol Building in 1801; b, The Capitol Building in 1826; c, The Capitol Building today.

The whole project is built in Unity3D with the assist of Vfuoria. Figure 14 displays the AR effect of the Capitol Building outlooks in its history. The timeline is located in the top of the screen for switch scenes. For each scene, it contains a Capitol Building logo on the left side, while a back button on the right side to go back to the main menu. For three AR scenes, the camera icon located at the bottom supports users to take images with the virtual historic buildings.



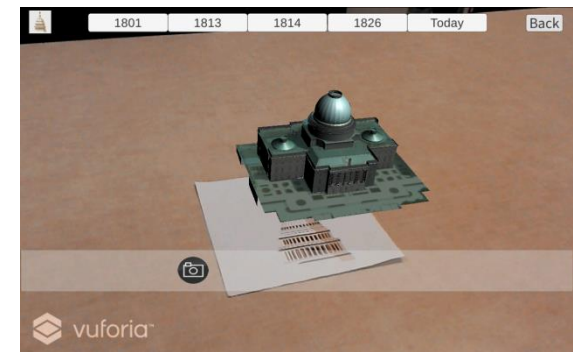
a



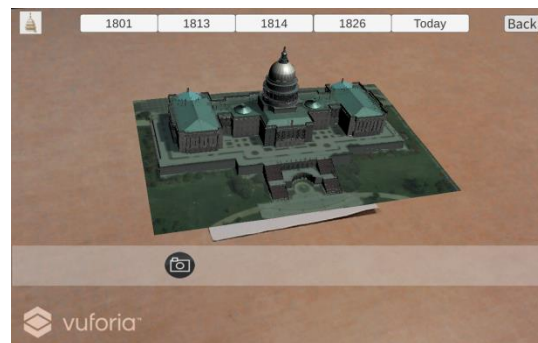
b



c



d



e

Figure 14. AR Display of The Capitol Building. a, The Capitol Building in 1801; b, The Capitol Building in 1813; c, The Capitol Building in 1814; d The Capitol Building in 1826; e The Capitol Building today.

The AR Capitol Building app includes a total number of eight scenes. The main menu as the entrance of this app provides a lobby for users to choose which function they would like to use. Through main menu, users have five options like showed Figure 15**Error! Reference source not found..**

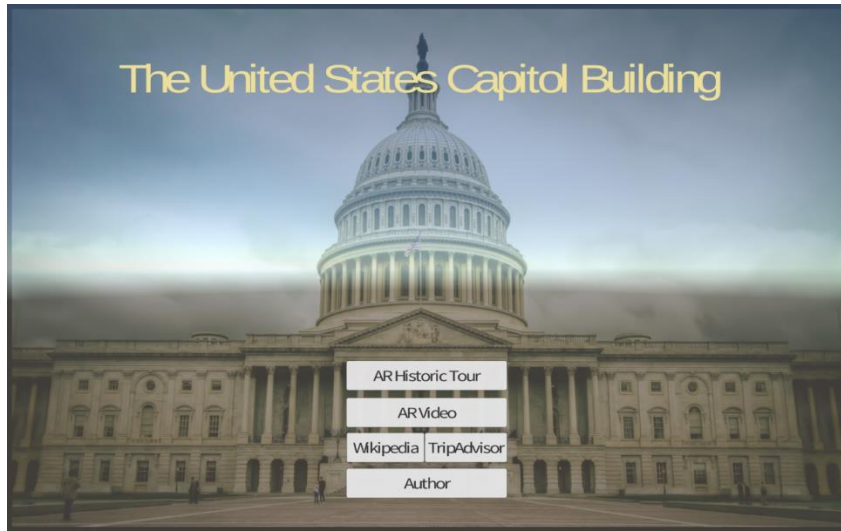


Figure 15. App main menu

The AR Historic Tour option will lead users to the timeline of different stages AR Capitol Building review page. When tapping the AR Video button, the AR camera will be set up and display the pre-embedded video if the target is captured. The video will play when tapping the virtual film. Figure 16 shows the scenery in real environment.



Figure 16. AR Video mode

17. The Author page contains the basic information for authority like shows in Figure

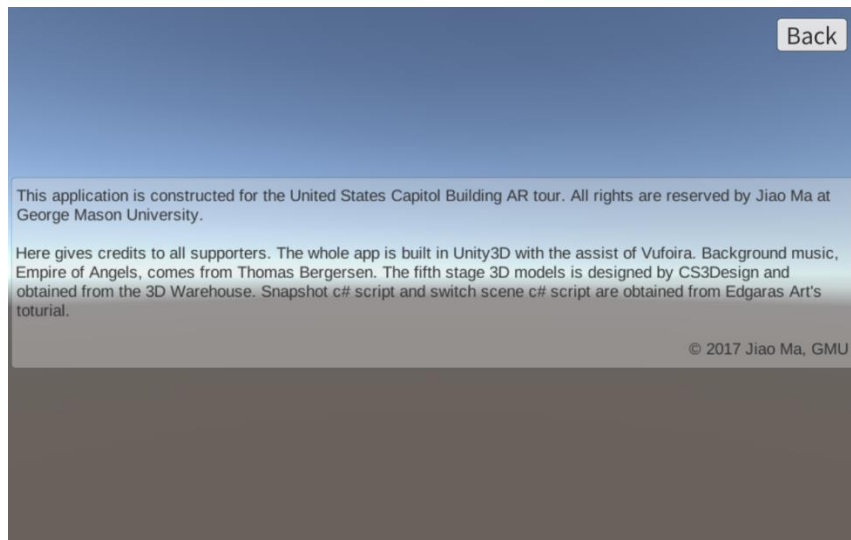


Figure 17. Author Page

5 CONCLUSION AND FUTURE WORK

5.1 Conclusion

To achieve the goal of providing an optimal immersive tour experience for the tourists, this study applied the Augmented Reality technology to visualize historical architecture sites by utilizing multiple formats of data such as 3D models, 2D images, video, audio, text and open source data like Wikipedia and TripAdvisor to take tourists back to the history. In the main while, it successfully identified the critical components in the process of constructing the AR application.

1. Discuss the suitable 3D modeling techniques for historical buildings visualized in AR systems.

This study compares different 3D objects retrieving methods from various different aspects. It indicates that the hybrid method based on geometry-based method and image-based method is a selection for visualizing historical building in AR environment, especially for recovery of 3D historical buildings models that are no longer present today. Due to the memory and computing power of current smartphones, the 3D models built for mobile platform have to sacrifice some details for accessibility. Too accurate 3D models may cause a negative impact on display.

2. Compare the opportunities and limits for object recognition-based historical building visualization.

As technology advances, new or enhanced tracking technologies appear increasingly. Although image-based object recognition method has been forwarded for a while, right now it is still more reliable than sensor-based tracking method to use for AR historic app considering of stability and usability. However, use of the target image limits the viewing angle of visitors and slightly reduces their immerse tour experience effect.

3. Utilize various data formats to describe historical building changes in AR-based storytelling.

This study broadens the way a historic building can be exhibited. In the storytelling process, it uses as many forms as possible to attract visitors. Through the use of 3D models, pictures, videos, open source data, visitors can have a spatial view of historical buildings and see the historical buildings in details. AR technology reproduces a complete history of different stages of the architecture.

4. Make a trial in integrating open source data into historic tour app.

This study extends the way information is received and transmitted. Through the Wikipedia link function and TripAdvisor link function, this study succeeds in connecting each individual user in a traditional historic tour app into the web. Information is grouped together and has no obstacles. Simultaneously, different from traditional authoritative information, which is objective and careful, comments, experiences or emotions from other tourists are more perceptual and valuable in terms of various tourists' requirements.

Overall, this thesis demonstrates the usability of Augmented Reality technology as a novel visualizing method to assist tourists in their historical tour. The integration of data in different data formats can enhance the visualizing content. As an increasing

number of tourists are seeking immerse tour experience to get more attractive, the AR historical app could have more broaden usability.

5.2 Future Work

Further research will expand on the knowledge gained from this study. First of all, optimize running fluency of this app and compress the size of that. The current version Android application is cumbersome which is up to 400M. The AR application delays when users switch scenes in the app. The video embedded into the Unity project is a main reason of it. As a result, video coming from website instead of containing that directly in the app will be an alternative method. On the other hand, a light-weight app may also attract more users to use.

Secondly, in this study, Object recognition by using image-based tracking technique is achieved. In the next step, trials in applying the sensor-based tracking method, specifically, GPS to recognize 3D models will be explored. Results considering accuracy and usability of comparing both image-based method and sensor-based method will be analyzed.

Thirdly, investigation towards satisfaction of user experience will be evaluated. Studies on what extent the use of AR technology enhances the interest of visitors compared to the traditional visiting modes will be driven. In addition, frequency of open source links used in the app will also be investigated.

In the future, more attempts in combing open source data and break the blocks between data coming from different source will be made.

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