Virtual Reality for Existing Structures

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Through time, war, and other phenomenon, pieces from the history of our evolution have been completely erased. Archaeologists are working to combat this by excavating sites and designing 3D models to ensure their preservation. However, all of these models are isolated and non uniform, making it difficult to extrapolate a bigger picture of how cities interacted together as well as hindering collaboration between research teams. Thus there is a great need for a central repository that will encompass all archeological sites. Koller, Frischer, Humphrey confirmed this evaluation with their survey concluding that 90% of surveyed researchers in the field felt that there was definitely a need for one. Thus, this paper will explore and describe an ideal way to engineer such a central repository. It is concluded that Unity will be the ideal platform to use to build this repository and that the key requirements which should be incorporated are security, speed, ability to change time and location, and the seamless infusion of uncertainties into the 3D models.

1. Introduction

200,000 years. That is how long the modern form of humans have been on earth [Howell]. Through that time, we have evolved and developed different customs, art forms, and architectures. However, through time, wars, natural disasters, and even by human hands, this history has been broken down to just remains. UNESCO, has stated that "Deliberate attacks on culture have become weapons of war." However, in past years, we have made strides to put this destruction to an end. For the first time this past September, the destruction of cultural sites has led to a war crime conviction. In addition, more than just preventing future damage, we have developed the technology to uncover what was lost. For the past decade, we have been able to extrapolate things such as what a building in ancient Rome would have looked like, even though now all that remains is a mere foundation [Schindler]. Today though, we are looking toward the future and aim to do more than just conclude what a building looked like. We are combining our knowledge of the past with our cutting edge computer modeling technologies to create a virtual window to the past. We call this study of using technology to capture data gathered by archaeologists and historians *virtual heritage*. This data can include pottery, furniture, works of art, buildings, villages, landscapes, and much more.

In order to properly capture this data and ensure it is appreciated and preserved, there is a twofold process that must happen. First, a central repository must be created to store all the data as mentioned by Koller, Fischer, and Humphrey. This repository should be peer reviewed, digitally secure, searchable, and should clearly depict uncertainties in terms of structural models as well as time. This central hub for data is essential to ensure modeling is not repeated unnecessarily as well as to ensure that these models, with their accompanying metadata, are accessible to all in order to inspire new lines of research and methods of preserving. Currently no central repository exists, even though 90% of surveyed researchers in the field [Koller, Frischer, Humphrey] felt that there was definitely a need for one. There have been many projects where researchers have tried to create a repository for a specific geographical area. However, there is currently not a way to bring all of these research projects together—models are viewed in isolation from each other. This will be the primary function of the central repository in my project. In addition, many of these previous projects do not associate the metadata with the structures inside their model viewing environments. While the association of textual evidence or historic records is available through external links in these projects, my project seeks to make the viewing of metadata simultaneous to the viewing of a structure as to not decouple these interdependent parts.

Secondly, a virtual reality environment must be engineered, utilizing the repository to query buildings, topography, art, relevant papers, and other metadata from. Within the world, the user should be able to control the time period as well as the geographic location. Depending on these parameters, the scene will present the architecture accordingly. Through this virtual world, classrooms can explore history through life-like scenes rather than text books. Even citizens not in academia can appreciate and explore the past. This 3D world coupled with the central repository will enable wide dissemination and increased accessibility to the cultural heritage of our global past.

2. Related Works

Virtual heritage is a newly developing area of study. This field which combines archeology with technology is a constantly changing because technology is continuously advancing, hence there is always more to contribute. There have been many projects which build 3D models but they all limit themselves to a specific geographic location or time period.

2.1 Previous Requirements Outlined for A Central Repository

Previous works have sought to understand what a centralized repository could look like and what the associated research would need to address in order to solve some inevitable issues arising from this type of work. Letellier (2007)[10] mandates that a large and centralized information system must be: flexible enough to meet the needs of any project, adaptable so they can be adjusted to new situations, capable of storing large amounts of information, and able to be queried.

However Letellier (2007)[10] also discusses the disadvantages to these types of databases including the need for expensive proprietary software, trained staff to make uploads, maintenance services for a cost, and software upgrades on a regular basis for a cost.

A summary of the technical requirements in order to have a system of this nature according to the *Principles for the Recording of Monuments, Groups of Buildings and Site*s[1] is as follows.

- Servers containing information for the system must be backed up to ensure availability

- The software must be available to all including those in academia and the general public

- There should be a standardized way to view the models and their associated metadata to increase ease of use and uniformity.

Koller et al (2009)[7] presents one of the more thorough lists of requirements for a large, centralized structures repository. Discussing the need for a repository which is secure and deals with the digital rights management of the 3D models, the concepts of watermarking and developing a graphics pipeline to prevent piracy are outlined in depth. Furthermore the idea that a model must be accompanied by metadata, a topic discussed in both Letellier (2007)[10] as well as the *Principles for the Recording of Monuments, Groups of Buildings and Sites* (1996)[1], is brought up. This metadata should include not only information such as the creator, subject, and publisher, but also commentary metadata where evidence for elements of reconstructions can be found as well as bibliographic metadata where all sources published and unpublished used in the model making process can be found. Additionally, Koller et al (2009)[7] mandates that a large, centralized repository must allow for the visualization of uncertainty in the the following: structural architecture, geometric dimensions, stylistic features –also discussed in Strothotte (1999)[12], temporal correspondence –also discussed in Zuk (2005)[15], and construction materials.

Finally Koller et al (2009)[7] also discusses the requirements for version control, future analysis, querying, interoperability, preservation of 3D models, and a peer review process for admitting structures to the database.

2.2 Rubric for Comparing Related Works

After considering the literature and requirements outlined above, the following rubric for comparing evaluated works was established in order to provide a uniform review. By looking into papers published, related websites, videos, and programs for each project, each project was measured on how it handled the following functionalities:

- Ability to change time period

- Scope of geographical region

- Flexibility and potential to be expanded

- Method of expressing uncertainties

- Ability to have multiple accepted versions of buildings
- Ability to view as a video, interactive walk through, or static database
- Window to view relevant metadata while still viewing the building
- Potential to query for a particulate building
- Cost to use program
- Operating system interoperability
- Ability to secure the digital rights of the 3D models
- Peer review board for 3D models

2.3 Evaluation of Related Works

A few projects that have done something similar to this were the Stanford Digital Michelangelo Project by Levoy et al (2000)[9], the Stanford Digital Forma Urbis Romae Project by Koller et al (2006)[8], and the UCLA Digital Roman Forum by Frischer et al (2006)[3]. For the purposes of this paper the four programs which exhibited features closest to those outlined above have been reviewed in more detail.

Gillam, Innes, and Jacobson (2010)[4] reconstructed an Egyptian temple in Unity which is set in a specific time period and location. Throughout their work, they do not discuss what security measures are in place. There are no indications of any uncertainties within the application. However, this may be due to the fact that the temple is not modeled after a specific building but rather it "embodies the key elements of a New Kingdom temple". Their metadata is not within the application itself but on the accompanying website. You can search these papers as you normally would with the find function in your browser. It is free to download for the public. The user is able to walk through the temple, accompanied by music, by using the arrow keys. It is not easily scalable to accommodate for more 3D models. The temple was hard coded into a specific position. For more buildings to be added, they would need to be added manually. This software is specifically for desktops only. In addition, the temple 3D model is based off published papers which have been accepted by a journal review board. This project meets the key criteria that it allows the user to freely walk through the 3D model rather than just showing video fly-throughs of it. This differentiates it from many other projects.

Dylla, Kimberly, Fischer, et al (2010)[2] took it a step further than the Egyptian project in their own 3D model called Rome Reborn by expanding their model to a whole city. However, like the Egyptian temple project, they are focused on a single time period. In addition, many of the models in Rome Reborn are not based on specific historical buildings but rather they embody what a typical apartment or other common building would have resembled and thus do not show any uncertainties. But the buildings that were based on historical buildings such as the Roman Forum still do not show any type of uncertainty. However many of them are from the time period 320 A.D and beyond thus there is less uncertainty because of the vast amount of the buildings which survived. This being said, due to the vast amount of detail including people, common buildings, and topography allows the user to fully immerse themselves into the experience. Rather than just having one historical building, this allows one to feel what a day in the life of a Roman citizen would have been like. Any relevant metadata cannot be found in the application but rather on the accompanying website. The key to the security of the 3D models is that they do not let the user download the software and freely walk around. Instead, they only give the user video fly-throughs. Due to this limitation, there is also no searching capability of the buildings. These videos can be played on any operating system. Similar to the Egyptian temple, this project does not hint toward it being easily scalable. The large geographic area and attention to detail this project covers differentiates it from many other projects.

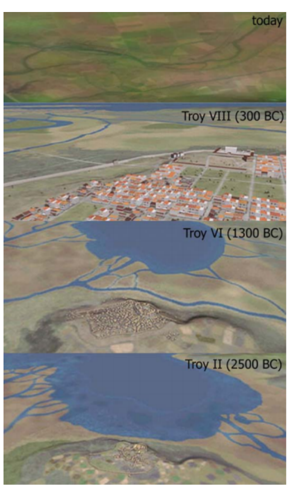

Figure 1. Time slices of the city of Troy

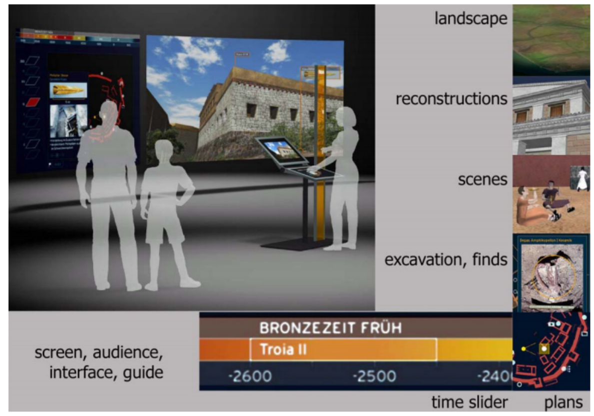

Figure 2. Different views within the city of Troy

Jablonka, Kirchner, and Serangeli (2002)[5] added even more functionality than previously discussed projects in their 3D model of the ancient city of Troy. Although they constrained themselves to a set geographical area, they did include a time slider to allow users to see how the city evolved over time as seen in Figure 1. They also included multiple versions of each building and artifact, as seen in Figure 2, including a pure topographical view without a building, a view of what was excavated, a view of an approximation of what it looked like when it was first built, and a view of what and where citizens would be gathered around. These different views allow the user to visually see a lot of the information that is in the metadata. However like the other projects reviewed here, they did not discuss how they were able to secure the digital rights of the 3D models. It does not use video fly throughs but actually allows the use themselves to walk around. This program appears to be for both museums to do interactive walkthroughs as well as for archeologists to aid in their research. This software requires a lot of memory and technical capabilities and is thus solely meant for desktops and laptops, not phones. The time slider and multiple views of an artifact and building differentiate this project from many others.

Kacyra, Kacyra, and Mooyman[6] attempted to expand geographically in their project, CyArk. They attempted to create an online repository for cultural heritage site data. They currently feature data from many prominent archaeological sites such as Pompeii and Ancient Thebes. These sites have been created through laser scanning, digital modeling, and other technologies. Each site has an accompanying interface which the user can use to search for information about the site. Each site can either be downloaded as a point-based plugin or as a Quicktime video. The goal of a central repository along with the searchable metadata differentiates this project.

3. Problem Description

There are two research questions that must be addressed if a database for 3D models of cultural heritage is to exist. (1) How should we store all the data associated with 3D models? This includes the 3D model itself, information about where it is located in the VR environment, content information such as materials used, as well as metadata about the user who created this model. (2) What should a functional 3D/VR environment for archiving digital models of cultural heritage sites look like? How should a user be able to interact with the data? What types of additional information will be included in the viewing environment? This paper in particular addresses these two main research questions that are crucial to creating a functional database for 3D models of cultural heritage structures.

4. Methodology

Based upon the success of previous projects using the Unity 3D Game Engine, we have chosen to build our 3d model repository and interface here [11]. Additionally Unity is a good choice for this project due to its industry-leading multi-platform support that includes but is not limited to iOS, Windows, and Linux. C# was selected to run the main program rather than javascript. Either language will have the same performance because both get compiled into CLI when building the game. Hence, there is no advantage of one over the other.

To enable the repository's models to stay up to date, a website will be used to insert and remove models from the repository. This website is built with HTML, CSS, and php. It has a simple form for the user to input different information such as the name of the structure, the years it was built and destroy, its coordinates, as well as the 3D model itself.

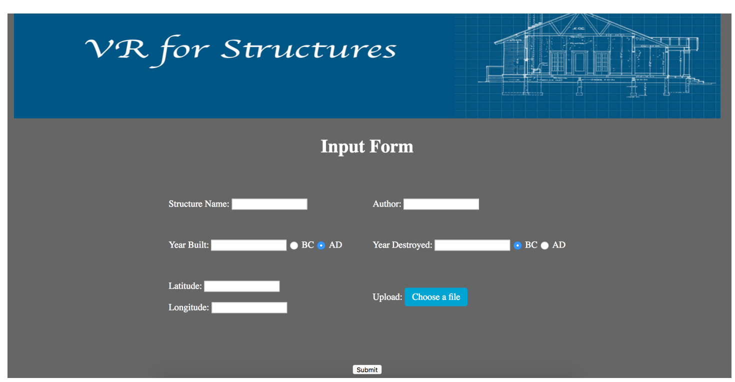

Figure 3. Capture of website

The textual data is stored in a sqlite database which is connected to the website. After checking to ensure that the information the user inputted is in the correct format, the program will attempt to insert the data. However, if the format is incorrect the user will be provided with useful guidance in order to fix their submission.

In order to store these 3D models in our webpage we have chosen to use Uploadcare which is a portable cloud storage which supports large file sizes [14]. Uploadcare has a widget that works as a simple form element in either a website or mobile application. This widget allows the user to upload any type of file from google drive, Facebook, Dropbox, Evernote, Onedrive, the user's desktop, and many others while supporting 20 different languages. Once the file is uploaded and the form submitted, the webpage will receive a CDN link from uploadcare with a universally unique identifier, UUID. A CDN or content delivery network is a "system of servers deployed in multiple data centers across the world". This allows for faster content delivery. This CDN link can be stored in the sqlite database and then later used to grab the model out of the CDN. The other textual metadata can also be easily stored in the same sqlite database and accessed in Unity.

Furthermore, in order to allow for automatic update to applications which have already been downloaded and are currently running on client's computers, UniFBX will be used to push updates to the repository.

For easy navigation, we also decided to incorporate the Unity package called OnlineMaps. This package grabs accurate data from different map services such as Google Maps, Bing, and Nokia and allows for game object to be placed on top of the maps in the viewing environment. This enables users to navigate to specific buildings using the map function as well as see and understand the building in the geographic/ contemporary urban context. For example is this building near a river? Is this building still in the center of the modern city?

There will be thousands of models in the repository, therefore to reduce the buffer time of the application, a method known as clipping planes [13] will be used. With clipping planes, new structures and aspects of the cities load as a viewer progresses/walks through the model rather than having all the models load at once.

In addition to being a repository, this interface offers many features which allow the user to gleam more data from the buildings were made with Unity as well. Some features in the toolbox include displaying geographic uncertainties and displaying the forces on a structure.

6. Results

In an overview, using the application, the user can navigate using an interactive geographic map which has intuitive zooming capabilities. The user can change the time period manually or by utilizing a slider for faster results. If the user has a specific geographic location they would like to explore, they can also input coordinates. Once a user has found their specific geographic area of interest, they can then explore the 3D models that are currently in that area that are stored in the repository. This repository will automatically update with any new structures that get pushed to the server, thus the models that display will always be the most up to date ones. These models can be found on the map through two ways. The first is by finding map markers which indicate an existing models on the map. The other way is by utilizing the search bar and inputting a specific building's name. Once a user has found their building of interest, they will be brought to a street view where they can walk around the building as if they were there in real life. A user can then use the toolbox of features to gleam more information about the model. They can click on the model to show images or records that would detail its history, construction, and other pertinent information.

6.1 Designing an interface

The main interface of the program is through the Unity game engine. A user interacts with a menu to select either a time period, geographic region, or particular building of interest.

Figure 3. User interface used to control environment

The user can then navigate on a 3D world map to the site of a particular building in order to view it in 3D/VR and see the associated data when they click on the structure. Some of the data that would be found in this tab could include the author of the model, the name of the structure, the year it was built and destroyed, any papers that are associated with the structure, as well as countless other pieces of information.

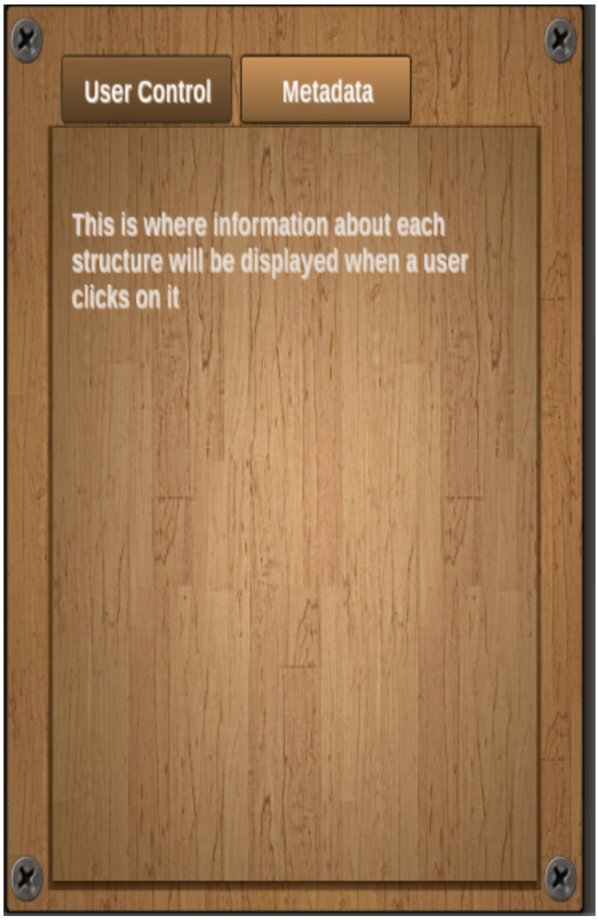

Figure 4. Metadata tab used to display associated data

As stated above, a complete database and model viewing environment should include methods of viewing temporal, geographic, and uncertainty data. Additionally this database should be searchable, widely accessible, secure, and academically rigorous. Our specific methods for dealing with these requirements can be found in the following sections.

6.1.1 Dealing with temporal data

As our rubric above states, a complete database and model viewing environment should include a method for varying the time. Through depicting environments in a static time period, there is much lost such as the ability to understand how individual buildings especially whole cities evolved over time. In order to accommodate for this need, we have designed our database to be time sensitive. A user can interact with the main menu to select a time period of interest. The buildings in the sqlite database are coded by time and thus, only the buildings associated with certain dates will appear. If a building existed from 200 BC to 400 AD, in the SQL database these dates will be associated with it. If a user, queries the program menu for a date outside of this range, the building will not be accessible. If a user queries the program menu for a date within this range, they will see this building as one of their options for viewing and interacting with. As can be seen in Figure 3, the user has two ways of changing the time period, either through manually inputting the time or by using a slider. The slider allows for the user to see how a city evolved faster and in broader strokes, while the manual input allows the user to investigate specific time periods.

6.1.2 Dealing with geographic data

Furthermore the scope of the geographic region is important to consider. To date the projects which have contained models have only considered their own environment, the particular city, town, or building limits that interest them. As more 3D models are created however, it becomes increasingly important to have a place where all can be viewed together. This broader view will give the user a better understanding of how different cities meshed together. Hence the environment must be flexible enough to handle structures from multiple different regions. As talked about before, this is where the Unity package called OnlineMaps comes into play. This functionality however can greatly affects the buffer time of the application depending on the number of models which are trying to load into the environment. We will address this idea by using an idea known as clipping planes.

6.1.3 Dealing with uncertainties

Temporal, structural, stylistic, and all other uncertainties should be clearly depicted within the environment and not just in the additional data. By integrating these uncertainties into the environment and into the 3D models themselves it will avoid confusion for the user and will allow them to get a complete picture of what a site looked like without having to dig into the metadata. One way to integrate the uncertainties into the models would be to utilize a metadata tab. This tab would appear when you click on a building and it would display the main uncertainties. Thus when viewing a model you can see the uncertainties at the same time you are viewing the model to get a fuller picture.

6.1.4 Query system

There is also be an interface which allows the user to search for specific buildings within the environment and based off the results, their camera view will then bring them to that 3D model within the environment. Thus a user can search specifically for the Parthenon and be brought right to the model, even if they are not sure what country it is in. When the user queries the system, the software can do a simple look up in the database. If the building in fact does exist in the system, the coordinates in the database will be used to redirect the camera to the appropriate model. This functionality can be seen in Figure 3. Currently the Statue of Liberty is being searched for. This search interface should also extend to the metadata.

6.1.5 Issues of accessibility

This software should be accessible to all and from anywhere. Users should be able to access it from any medium including laptops, phones, and tables. Unity is the perfect platform for this because it is able to transform an application to be compatible with many different mediums. However the other problem is that in order to keep the application current it goes out into the internet to grab up to date models and data. However if an archeologist is at a site where they do not have internet, they will still wnt to be able to use the application. Hence two versions will be available, one version that automatically updates and goes to the online database to pull its information and another version which will have a local database which it pulls its information from. The application which has a local database will have to have have a new version every few months in order to insure that the models are all up to date in the repository.

6.1.6 Issues of security

Although we want the software to be easily accessible, security and digital rights management should be at the forefront. However, security should not come at the cost of the user not having as much mobility. Video fly-throughs give a great first impression, however they do not allow the user to fully immerse themselves in the environment. There are many different softwares and methods that exist which try to thwart the theft of 3D models. Some of them include a software called ScanView, watermarking, secure graphics hardware, and encrypted renderings. Currently we are just relying on the security that Unity has built in, as well as practicing good coding behavior such as not directly using variables for SQL statements to avoid SQL injections.

6.1.7 Issues of academic rigor

Most importantly though, any model should be thoroughly reviewed by a peer review board to ensure the data being displayed is the data that is widely accepted by the scientific community. This can be done by filtering through the already accredited archaeological journals for such 3D models. Once a handful are found, the authors can be contacted to for permission and for any missing information. There are many journals and organizations which already exist that receive and accredit models such as The Associate for Computing and Machinery, Computer Applications and Quantitative Methods in Archaeology, The Virtual Reality Society, and Virtual Heritage Network.

6.1.8 User Interaction

Virtual reality allows users to fully immerse themselves in the buildings to a degree where it is difficult to tell what is real and what isn't. This will give the users a better feel for what the building is like in real life. In addition, it will allow users better navigation of the space and to move around intuitively by simply walking around with their two feet and moving the view of the camera by turning their head. Hence our program will be developed and deployed in a VR environment, as well as desktop.

7. Conclusion

Hence by utilizing newer technologies, one can improve building documentation drastically. Specifically in the field of archeology, by using Unity and VR, we were able to not only develop an environment where all structures can be kept, but also create it in such a way that it showed pertinent metadata information and it was life-like.

This improvement of building documentation is greatly needed. As mentioned 90% of experts find a central repository extremely necessary. Furthermore, this is one of the main concerns at the CAA conference which is the conference for computer applications and quantitative methods in archeology. The move to virtual reality for the documentation also dramatically increases researchers abilities to analyze structures and cities as well as to get a better feel for scale.

8. Future Work

Since building documentation has so many different applications I would like to expand my project so that it has application outside just archeology. I hope to expand the toolbox so that it can also aid civil engineers in structural health monitoring.

Furthermore, I hope to build a web crawler which will find the models for me from these peer reviewed websites. This way no one admin must shift through all the papers published by archeologist to find the appropriate data.

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