Classroom Education Using Animation and Virtual Reality of the Great Wall of China in Jinshanling

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Abstract: The field of virtual reality (VR) has provided many useful aids in the academic setting due to the user-friendly control of realistically immersive 3D simulation. Some examples include virtual simulation (e.g., simulation of a medical surgery for medical students), component and environment construction (e.g., assembly of an automotive engine for mechanical engineering students), and data visualization (e.g., a virtual building site project for construction engineering students). However, certain specific avenues of study have yet to catch up with education as a whole with regards to such innovations, so rectifying this could be instrumental for topics where these innovations could be invaluable – especially in the engineering sector. For example, there is little research on the use of virtual reality in the education on ancient construction engineering, as most applications tend to focus on modern works of construction. For this specific reason, this research concerns a state-of-the-art virtual reality simulation of the ancient construction methods of the Jinshanling region of the Great Wall of China, which collects and presents the most up-to-date information regarding these processes, as a case study for classroom education. The virtual environment described in this paper allows the students to view the construction method of the Great Wall from different angles and analyze this process more clearly, compared to traditional photos or static digital modeling images. The use of VR is relevant to modelling the originally constructed structure from the currently damaged condition of the wall.

The Jinshanling section of the Great Wall is located in the Luanping County of Hebei, China. This section of the wall was first built in the beginning of the Ming Dynasty in AD 1368, and later renovated in approximately AD 1569; it comprised the closest section of the wall to Beijing (China’s capital during the Ming Dynasty), a mere 150 km away from the capital, thus requiring reinforcement against invasion. This explains the complex construction methods of this Jinshanling section – an outer layer of foundation stones and bricks and an inner layer of rubbles and rammed earth.

The data used for the modeling processes was obtained from measurements taken from both site visits and literature search. The authors used Dassault Systèmes SOLIDWORKS 3D CAD design software to reconstruct the damaged monument in a piecewise, bottom-up fashion, since SOLIDWORKS has an excellent display on curved surfaces and thus has an outstanding animated visualization of the step-by-step construction process. The SOLIDWORKS assembly also verified which sequences of construction were most logical. SketchUp (with Google Earth) was used for extraction of the existing terrain of the Jinshanling section of the Great Wall. The final 3D assembly along with the terrain were transferred to and coded in Unity (a gaming engine) to create a VR simulation using the Oculus Rift (a VR headset) and an Xbox controller, allowing students to examine the construction process in a virtual environment. A walkthrough of the wall would allow students to inspect the wall in a virtual environment. Thus, this study is expected to allow students to immerse themselves in the virtual erection process of ancient structures in a classroom setting.
Introduction

The advent of digital technology has given rise to a number of educational innovations, many of which involve the use of computer graphics and digital simulation of environments, processes, and objectives. One of the most well-known of these innovations is virtual reality (VR), which involves the recreation of a process or setting in a strictly virtual environment, without physical props or interaction. This enables learners to explore an environment in complete safety, and immerse themselves into settings that would otherwise be inaccessible or too complex to recreate in physical form. This is especially important in the various fields of engineering, which would otherwise entail exposure to hazardous environments, costly and time-consuming prop assemblies, and limited comprehension of engineering processes in general. Virtual reality presents the option of a safer and more immersive learning experience, be it through virtual task simulation (e.g. a simulation of the manufacturing process for a machine or building part), component and environment construction (e.g. the assembly of a complex structure from computer-modeled pieces), or data visualization (e.g. virtual building site projects for surveying and civil analysis). In the field of civil engineering, researchers demonstrated how VR can be implemented in modern construction (Fu, 2015; Sampaio, Rosario, Gomes, & Santos, 2013).

Despite the advantages provided by VR in the classroom, some academic topics have so far been slower to catch onto its use as an educational tool than others. If and when this is rectified, certain fields which would likely benefit from VR but have yet to implement it on a large scale could be moved forward significantly, especially in the engineering sector. This research uses historical engineering specifically as an example for demonstrating the value of VR used in this way, with the reconstruction of an ancient monument in a virtual environment as the main objective. The monument reconstructed here is the Jinshanling region of the Great Wall of China, which has been analyzed for up-to-date measurements which are used as the data set to be visualized by the simulation. Not only is this useful for bringing the construction of the Great Wall into the classroom in relative safety, but it can also present the original constructed appearance of the Wall as opposed to its current degraded state.

Brief History of the Great Wall

The Great Wall of China is a sequence of fortifications consisting of prominent watchtowers and the wall connecting them, the original purpose of which was to watch and defend the land against enemies such as the Mongolians, Japanese pirates (Chan, 1982) and Manchus (Waldron, 1990) during the Ming Dynasty. The Great Wall is approximately 13,000 miles long (Abbey, 2012) and the construction methods and materials varied from location to location. The construction of the wall was first started more than 2,000 years ago (Lovell, 2006); the wall was continuously expanded, built, and rebuilt throughout several dynasties since, with the major construction of the wall ending during the Ming Dynasty. However, the wall was not significantly expanded upon during the Qing dynasty (Luo & Zhao, 1986).

The scope of this study is the Jinshanling section of the Great Wall, which is located in Luanping County, Hebei China. The focus of the study is on the towers known as Unnamed Building 10 and Unnamed Building 11, as well as the wall connecting the two towers. These names are for tourist identification; the towers were unlikely to have been called as such during the Ming dynasty. Based on historical date information displayed on site, the Jinshanling section was originally built in the beginning of the Ming Dynasty in AD 1368.
and renovated later in the Ming dynasty, at approximately AD 1569. Because Beijing was the capital of China as far back as the Ming Dynasty (Luo, Wilson, Drege, & Delahaye, 1981), and this section of the wall was only 150 km away from Beijing (Google Maps, 2017), reinforcement against invasion was pivotal at the time. Therefore, the structure of the Jinshanling section is complex, with foundation stones and bricks comprising the outer layer of the wall, and rubble with rammed earth contained inside.

Construction Methods of the Towers and the Wall

Unnamed Building 10 is a wood column tower, while Unnamed Building 11 is a brick tower; thus, Unnamed Building 10 was supported by wood columns on the first floor of the tower, while Unnamed Building 11 is mostly supported by arches and vaults influenced by the Roman design, from bricks. The construction from the foundation to the first floor of the two towers is similar, however: in both towers, rubble and rammed earth are used for the inner core, and foundation stones and bricks used for the outer layer. While there are architectural variations of these towers, e.g., for numbers of entrances or windows and locations for arches or wood columns, their materials and erection sequence are still similar. Hence, modeling of these towers falls under two categories, i.e., wood column towers and brick towers whose dimensions vary. In this paper, these towers are represented by Unnamed Building 10 and Unnamed Building 11, respectively.

For constructing the base of these towers, workers would first have leveled the foundation by either cutting into the bedrock or filling it with rubble and mortar. For the outer layer, foundation stones would have first been stacked diagonally from the four corners of the building and eventually formed a square shape (the layout of the building). A different crew would stack rubble for the inner core while the first crew worked on the outer layer. After the foundation stones were laid, the crew would stack bricks for the outer layer. The inner core crew would have kept stacking rubble and rammed earth for the inner core to the desired height of the first floor.

For Unnamed Building 10, the crew would have erected 16 wood columns while another crew stacked bricks for the wall of the first floor of the tower, using framework for openings such as windows and entrances. Timber boards and beams were likely installed on the top of the columns to support the brick pavers on the second floor. The workers would then have stacked bricks and stones for the battlement of the second floor. Pavers of the floors would have been installed at the last stage of construction.

For Unnamed Building 11, the crew would have stacked bricks for the first floor, from the bottom up, to build the outer wall, the interior walls and columns. Temporary and permanent timber frameworks were used to make openings such as windows, entrances, arches and vaults. Once the first floor was complete, the construction of the mini tower on the second floor began, where workers would erect timber columns for both the mini tower and its portico. Another crew would stack bricks for the wall of the mini tower. Wood posts and beams were used for the roof structures and ceramic tiles were installed for the roofing. Similar to Unnamed Building 10, the construction crew would have stacked bricks and stones for the battlement of the second floor. Lastly, brick pavers were installed on the first and second floors.

The base of the wall connecting the two towers would have been constructed in a similar fashion to the base of the towers (from the bottom up), where foundation stones (one layer)
and bricks were stacked for the outer layer and rubble and rammed earth were stacked for the inner core. The key-in feature may have been used where more bricks were used for the outer layer and less rubble for the inner core at every other section of the base (see Figure 1 for the section view of the wall). Evidence of the key-in feature was found in eastern Jinshanling where pure rammed earth was used for the inner core.

Figure 1: Section view of the wall

Modeling of the Studied Towers and the Wall

For the authors’ earlier research (J. Yang, A. Tan, F. Tan, Parke, & F. Yang, 2016; Yang, Hadipriono Tan, & Tan, 2017), the modeling of the wall and towers was created using SOLIDWORKS, shown in Figures 2, 3 and 4. SOLIDWORKS modeling can show the construction sequence using static images and animation (Figure 4). The animation was created using the hide/show feature and saved to an .avi file. The SOLIDWORKS allows the user to perform a walkthrough if the user possesses a working knowledge of SOLIDWORKS.
Figure 2: Unnamed Building 10 on SOLIDWORKS

Figure 3: Unnamed Building 11 on SOLIDWORKS
SOLIDWORKS animations and models may be adequate for a classroom lecture using PowerPoint or video display, but the user friendliness of virtual reality enables students to be immersed in a virtual environment. This allows students to visualize the animation of the construction process from different angles using head movement. A walkthrough of the wall would allow students to inspect the wall in a virtual environment. Students can control both camera and directional movement using the headset and an Xbox joystick game controller.

Three different software packages were needed for this objective (VR of the Great Wall): SOLIDWORKS, Google SketchUp, and Unity. The hardware needed for the VR included Oculus Rift headset with sensor and an Xbox controller, shown in Figure 5. SOLIDWORKS is a 3D CAD design modeling software and it was used for the 3D modeling of the Great Wall. SketchUp is another 3D CAD design modeling software which, while not as powerful as SOLIDWORKS, was invaluable for the extraction of the existing terrain of the Great Wall. Lastly, Unity is a gaming engine that is compatible with most virtual reality hardware, and its role in developing the VR was for loading and rendering all the objects (terrain, wall and towers), programming dynamic interaction of the construction method, programming the camera views, and programming the hardware.
Figure 5: Oculus Rift Sensor, Headset and Xbox Controller (from Left to Right)

To achieve this objective, the actual modeling of the terrain was first extracted in Google SketchUp, shown in Figure 6. The satellite image was from Google (Imagery 2015 CNES/Astrium DigitalGlobe).

Figure 6: 3D modeling of the Terrain in SketchUp (the satellite image was from 2015 CNES/Astrium DigitalGlobe)
Next, the modeling of the structures (wall and towers) were created using SOLIDWORKS. The structure was separated into parts and reassembled for animation, which was necessary to support dynamic interaction in the VR.

After this, the terrain and the structure were rendered in Unity. The walkthrough of the wall and towers was then programmed using the first person view; the height of the camera is adjusted to 1.60 meters, assuming this was the height of the average Chinese male in ancient times. The VR modeling was programmed so that the directional movement of the camera is controlled by the right joystick of the Xbox controller and the head movement is controlled by the Oculus Rift headset. Lastly, dynamic interaction of the construction method was programmed in Unity. The dynamic interaction is similar to the animation in SOLIDWORKS, but the end user is able to control the camera view and movement via the Oculus Rift and Xbox controller. The construction method is programmed where the end user is able to see the sequence of the construction by pushing button A and B on the Xbox controller, as shown in Figure 7. The end user is also able to go back to the previous step by pushing the left bumper (LB) button on the Xbox controller. Similar to the walkthrough, the directional movement of the camera is controlled by the right joystick while the head movement is controlled by the Oculus Rift headset.

![Figure 7: Dynamic Interaction of the Construction Sequence using the Xbox Controller](image)

Classroom Setting and Usage

The 3D modeling (static images and animations) and VR are helpful to use in high school or college courses teaching ancient history of engineering. Examples of courses where this model was prototyped as part of instruction include CE 5860H, Sustainable Ancient Constructed Facilities, from the Department of Civil, Environmental and Geodetic Engineering, and ENGR 2361, History of Ancient Engineering, from the Department of Engineering Education at The Ohio State University. While an instructor could use actual on-site photos to explain the engineering and construction techniques, it is easier to do so with 3D modeling and VR. The reason is that most of the time, ancient structures are deteriorated,
such as the one shown in Figure 8, so the instructor would have to explain more and draw the missing and hidden components of the structure to explain the concept. 3D modeling and VR fill in the missing and hidden components, since they are a complete model of the structure. Nevertheless, actual on-site photos do have the advantage of being authentic and credible when presented to the students.

Figure 8: On-site Photo of Unnamed Building 11

VR is a state of the art display compared to static digital images. There are pros and cons for each means of display: the main advantage for static digital images and animations is that they can be placed into a PowerPoint presentation, allowing all the students in the classroom to view it at the same time, while the main disadvantage is that the images and animations are not interactive as those provided by virtual reality and it may be difficult for some students to comprehend the construction method when the instructor goes over the presentation only once.

The advantages of VR as stated in an earlier section of this paper, are mainly because VR is a state of the art display where students can immerse themselves in, and walk through, the construction environment. This allows them to look at the walkthrough and construction sequence from different angles and go back to the previous steps of construction with a click of a button from the controller. However, VR is limited to one student at a time, since each student needs an Oculus Rift headset and an Xbox controller to view the walkthrough and dynamic interaction. This can be resolved if the classroom is equipped with an Oculus Rift and Xbox controller for every student. This solution does require individual computers (the recommended system for the Oculus Rift includes a Windows PC with internet access,
Windows 7 SP1 64-bit or newer, NVIDIA GTX 970/AMD R9 290 or higher, Intel i5-4590 equivalent or higher, compatible HDMI 1.3 video output, three USB 3.0 ports, single 2.0 port and with 8 GB or more RAM memory) to support each piece of hardware, so the classroom setting is similar to a college computer lab. This would require additional space compared to the traditional classroom setting sufficient for a PowerPoint presentation.

Additionally, while the Xbox controller is used in directional movement, some naïve end users may experience cyber sickness because they are not physically walking in the walkthrough. To solve this problem, a VR treadmill called Virtuix Omni is needed (see Figure 9). The treadmill allows the end user to walk, run, sit and perform other motions in the virtual environment as they would naturally, such as the walkthrough and dynamic interaction. The end user uses Omni’s special shoes to perform the motion on the octagonal shaped treadmill. The shoes are attached with a tracking device, Omni Tracking Pods, and the bottom of the shoes have a low friction sole to achieve smooth and comfortable movement. Omni is compatible with Oculus Rift and can be programmed through Unity. At the time of this study, the Omni was not available for purchase. More information on the specifications of Omni and the release date can be found at their website (Virtuix, 2017).

![Figure 9: Omni Treadmill (used with written permission by Virtuix)](image)

**Discussions**

The proposed construction sequence by the authors was based on the authors’ construction experience, logic, and other variables. For instance, by stacking bricks at four corners among other survey measurements, it would have been easier to form a square shape for the layout of the tower instead of stacking in a one-way direction at one corner and comeback in a
complete square direction. In addition, the floor finishing would have been the last step of the sequence to prevent floor damages from other construction steps, such as transportation and unloading of materials. Lastly, this sequence was based on the assumption that there were enough workers to work simultaneously. If there were fewer workers, then it is obvious that one could not stack bricks (outer layer) and rubble (inner core) at the same time.

The proposed construction sequence was also based on the assumption that it was a wholly new construction. Renovation or reconstruction would have different sequences, such as integrating the old wall into the new wall. In addition, evidence of the key-in feature was only shown in eastern Jinshanling; this may or may not apply to all sections of the wall in Jinshanling. If evidence is presented that the key-in was not used, the authors will update the design to reflect this.

There was also an inaccuracy in Google Earth’s satellite images of the terrain and locations of the Great Wall. When a placemark in Google Earth is placed in the center of the tower according to Google’s 2013 satellite image, the structure is no longer in the center in a later satellite image from 2015, as shown in Figures 10 and 11. The placemark is off by approximately 15 meters (for Unnamed Building 10). The inaccuracy may be attributable to the discrepancy between the Google Earth views of the wall from outside and inside China (Russon, 2016). This inaccuracy from Google Earth is explained later on how it affects the authors’ judgment in the creation of VR in Unity.

Figure 10: Satellite Image of the Towers and Wall taken in September 2013 (map data: Google Earth, CNES/Astrium)
The SOLIDWORKS animation was saved to an .avi file which takes a lot of space. For example, the animation of the construction method of the Wall was approximately 1.08 GB. The storage size could be reduced by converting the .avi file into an .mp4 file using any third party software, such as Free MP4 Video Converter. The animation was reduced from 1.08 GB to 3.81 MB by converting it to a high-definition (HD) Ready (720p) MP4 file. It would save space and processing time, especially if the data were to be embedded in PowerPoint.

SOLIDWORKS modeling cannot be directly placed into Unity, so a plug-in (add on) called Free SolidWorks OBJ Exporter v2.0 application was used to save the modeling into a 3D object (.obj) and transferred into Unity. The first author acquired the knowledge of the transfer between SOLIDWORKS and Unity from CAD-VR (2017).

As stated above, the inaccuracy in the Google Earth tracking system affected the placement of the tower in Unity. When the structure was placed based on the Google satellite image shown in Figure 12, both Unnamed Building 10 and Unnamed Building 11 were not on the ridge of the mountain. While it is true that there were a small number of towers and walls that were not built on the mountain ridge, there was only a small chance that they were built as shown in Figure 13. However, based on general site evaluation, it is more likely that the towers were built on, or as close as possible, to the ridge of the mountain. Therefore, it was a more reasonable and subjective judgment to move the towers as close as to the ridge of the mountain as possible in Unity.
In Unity, an asset called *FPSController* is needed for the first person viewing. This asset is used to adjust the height of the control. It is also needed to program the speed of the direction movement.

Java coding was used to create the dynamic interaction of the construction method, with hide/show features along with if/then statements being used to program the dynamic interaction. Another Java program was created to rotate the texture of an object (the structure) in Unity.
A completed walkthrough of the towers and the dynamic interaction of the construction method of the wall were both demonstrated to an audience comprised of 15 civil engineering graduate students in a weekly seminar to determine the realism of the VR models as well as the feasibility of the simulation for classroom use in general. The feedback on the simulation was predominately positive, especially the walkthrough of the structure, but the realism of the dynamic interaction of the wall was somewhat less favorable compared to the walkthrough; the latter can be improved with additional iterations of the modeling. The VR models were also presented and demonstrated to both graduate and undergraduate students in CE 5860H (Sustainable Ancient Constructed Facilities), and ENGR 2361 (History of Ancient Engineering). The students’ end-of-semester teaching evaluations were shown to be very positive. Their feedback on the preference towards learning construction methods like the Great Wall via VR as opposed to the traditional PowerPoint slide presentations with onsite photos demonstrates that this can be a powerful educational tool and an asset to classes about various engineering subjects.

Conclusions and Future Studies

The creation of a VR rendering of the Great Wall of China section in Jinshanling was derived from a combination of various packages of both software (SOLIDWORKS, SketchUp (with Google Earth), and Unity) and hardware (Oculus Rift and Xbox controller). VR allows the end user to participate in a walkthrough of the towers and the wall, specifically Unnamed Building 10 and Unnamed Building 11. The VR is a state of the art display in a classroom setting, compared to traditional on-site photos or static digital 3D models and animation. There are advantages and disadvantages of using each method (on-site photos, static digital images and animations from SOLIDWORKS and VR) in the classroom, and the overall students’ feedback on the feasibility of the VR method for classroom use was very positive.

While it took approximately one year as of this writing, this stage of the research, which included data collection from onsite visits and other sources, knowledge acquisition of the software and methodologies, creation of the modeling and writing of this paper, is still an ongoing research project. The next phase of the research includes human subject testing and additional iterations of the modeling. Human subject tests on the VR simulation, along with statistical analysis to evaluate the data, are needed to validate and improve on the feasibility of the VR models for classroom use in general. Additionally, while Unity has a basic rendering feature, it may be easier to use a rendering software such as 3DS Max or Cinema 4D to render the object. For instance, one has to write a Java or C# code to rotate a texture in the object, so it is not very developer friendly. In 3DS Max, one can rotate the texture with a drag and click of the mouse using a built-in feature, UVW Map Modifier. Therefore, 3DS Max, Cinema 4D or other rendering software should be used for additional rendering iterations to make the Great Wall more realistic. Overall, the authors hope that this study will enable students to immerse themselves in the virtual erection process of ancient structures in a classroom setting.

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