Lincoln Cathedral Interactive Virtual Reality Exhibition

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Abstract. This paper demonstrates a workflow converting terrestrial laser scan (TLS) data into an interactive virtual reality (VR) platform. A VR exhibition prototype of Lincoln Cathedral was created to validate the established workflow in terms of the technical and visual performance, usability, and functionality. It combined TLS data and storytelling to produce a shareable platform, inviting opportunities for public engagement, and to facilitate custodians with the tools to maintain the building's heritage. The paper discusses the use of open source software and suggests future work.

Keywords: 3D Laser Scan, Virtual Reality, User Experience, Building Heritage

1 Introduction

Lincoln Cathedral is a fine example of Early English Gothic style architecture; it displays a wealth of architectural craftsmanship, with historical significance embedded in its maze of linked and layered spaces. It survived a fire (1141) and an earthquake (1185) and was the tallest building in the world until 1549. The cathedral has, on average, four million visitors each year and it spends approximately 1.5 million pounds on annual repairs and restoration of the building's fabric [1]. A recent project to restore the Bishop's Eye window cost £400,000 alone. Many spaces inside the cathedral have restricted access due to narrow staircases, or due to a need to maintain the original building fabric. One way to increase audience participation at Lincoln Cathedral is to provide virtual access to such areas.

Over the past decade virtual 3D reconstruction and visualisation of historical buildings and heritage sites has become an efficient tool for analysing scan data, enhancing visitor experience, and contributing to the restoration of building heritage. Examples of virtual exhibitions include Roman heritage exhibitions [2] and Bronze Age exhibition at the British museum [3], or visualisation of industrial structure [4]. All utilise visualisation in the form of predetermined flyovers, or walkthroughs. Unfortunately, both forms of delivery rely on display screens and create a passive experience for the users, limiting their actions and experience.

This paper, instead, suggests an immersive virtual reality approach, combined with gamification, allowing users to fully experience virtual reality (VR) of a historical building.

Such virtual reconstructions have been enabled by improvements in terrestrial laser scanning (TLS) technology, including a large reduction in its cost over the last decade. TLS uses a low power laser to collect large 3D spatial point cloud data with millimetre precision; for example, Leica P20 collects up to a million points per second, each with 3mm accuracy. This technology allows for relatively quick conversion of real world objects into virtual space [4]. This capacity is deployed in projects such as Scottish Ten or Arc/k aimed at creating digital storage of all historically significant structures.

This paper aims to evaluate a new method for interpreting large scan data into a user- friendly platform, by utilising open-source and low-cost software. A prototype for an interactive virtual reality exhibition of Lincoln Cathedral was created, combining TLS data and storytelling to produce a shareable platform, inviting opportunities for public engagement. The method used, and the VR exhibition prototype produced, is evaluated in terms of technical and visual performance, usability, and functionality.

2 Virtual Reality Software and Devices

As one of the leading game making tools on the market, Unreal Engine 4 (UE4) was used as the main tool to develop the VR prototype in this research. It contains many advanced techniques and functions for creating interactive applications with high visual quality. The built-in visual programming tool, Blue Print, is easier to be handle compared with other gaming software on the market. For new users, its intuitive interface aids the integration of interactive functions, from grabbing and operating exhibits to teleporting the user between virtual scenes. The advanced material system and performance optimisation tools boost the high visual quality while saving the PC performance. Moreover, UE4 is an open source software and free with no condition in the heritage and architecture usage, which means the outcomes using UE4 are easier to be applied and pushed further by other researchers.

There were three available choices on the market during the time of this research; this research used a VIVE headset, developed by HTC. It was selected because its tracking technology is based on laser positioning, rendering it more reliable than other options that use cameras. It runs on a PC platform, which is more suitable for developing, researching and testing the prototype than game devices such as a PlayStation. The VIVE headset was the only VR device on the market available with two motion controllers – a vital feature for building and testing interactive functions in the prototype.

3 Interpretation of Scan Data to User-Friendly Platform

Many virtual reality exhibitions utilise traditional technology, such as freestanding displays, with interactivity limited to touchscreen devices. Our approach utilises fully immersive virtual reality, commonly used in the gaming industry and widely known for its entertainment quality. It has matured over the last five years, mostly due to OLED (Organic Light-Emitting Diode) development [6-7], reducing its main limitations: motion sickness and crude display [8]. The use of a head-mounted display (HMD) improves experience and navigation inside the virtual environment. The workflow for development of the interactive virtual reality exhibition can be divided into four parts:

1. Data collection
2. Data Visualisation: isolation; reduce complexity; patch & polish
3. Exhibition Narrative
4. Interactive functions: teleport, scale, slice, daylight manipulation, information text, voice over.

Our approach involves combining visuals extracted from the TLS data, using Geomagic software, simplified in Rhinoceros 3D (Rhino) software, and an interactive narrative curated using Unreal Engine 4 (UE4) software. This research differs from established research approaches [5] by integrating a gamification approach into the visitor's experience, and by introducing an interactive virtual tour guide and a spontaneous walk-through experience.

3.1 Data Collection

Data collection at Lincoln Cathedral was conducted using Leica P20 TLS (Fig 1), due to its speed and accuracy. TLS has almost completely replaced more traditional total station or photogrammetric approach [8]. TLS data - otherwise known as a point cloud - is very detailed, but it is a time-consuming task to remove outliers and spikes before the data can be used for a further production.

Fig. 1. Data collection at Lincoln Cathedral

3.2 Data Visualisation

Key architectural features were extracted and isolated from the main point cloud data and modelled independently (Fig 2), using global coordinates to maintain spatial relationship between objects.

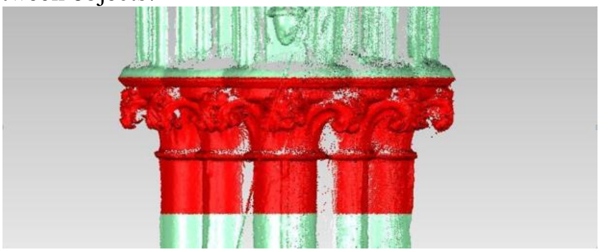

Fig. 2. Isolated column extracted from the main nave

Isolated features were then imported into Geomagic (a scan-based design and processing software) to retain geometric accuracy and improves visualisation, this was achieved by reducing noise (mesh complexity) and patching holes (Fig 3).

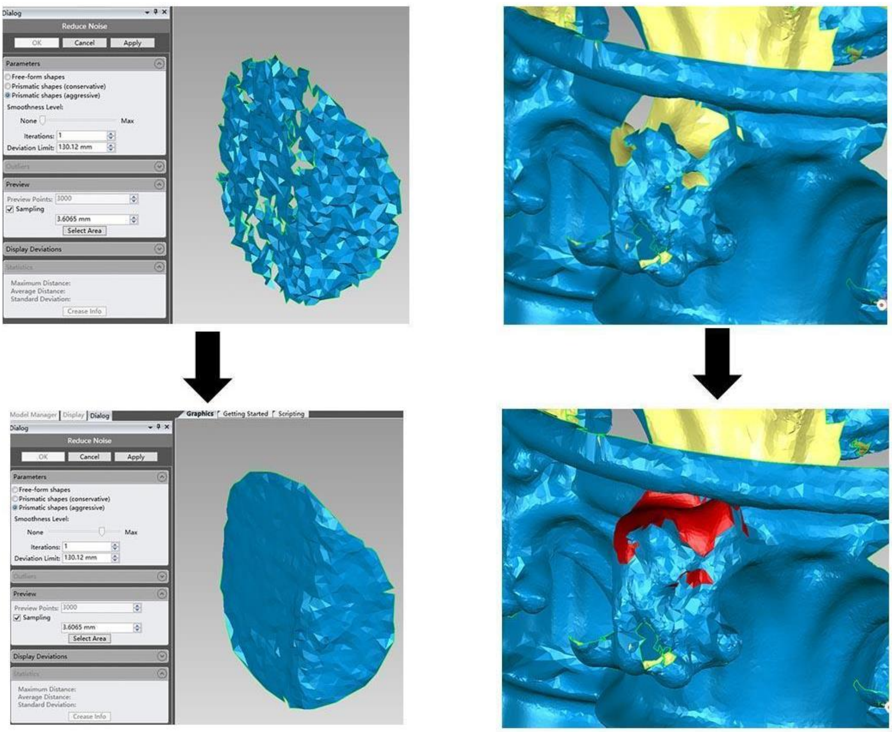

Fig. 3. Geomagic software used to reduce noise and patch holes.

3.3 Exhibition Narrative

Unreal Engine 4 is a free open source gaming software; it enables reasonably easy VR development compared to architectural 3D modelling and visualisation software, such as Sketchup, Autodesk Revit or Rhino. In the UE4 platform, an Actor refers to objects that can be placed in the scene; subclasses of Actors include StaticmeshActor, CameraActor, PlayerPawn, and LightActor. Components are used to classify static meshes, cameras and controllers, and can be attached to an Actor. Each Actor has its own BluePrint - a visual programming tool in the UE4 - used to manipulate events and variables belonging to each Actor's BluePrint. The refined models were imported and assembled in UE4 to create each scene.

For the purpose of this experiment, three scenes were created in the interactive VR prototype. The virtual tour starts with the visitor in front of the Chapterhouse of Lincoln Cathedral; here they are introduced to the infamous Lincoln Imp and acquainted with the basic VR interactive functions, such as looking around, walking and teleporting in the virtual reality world. Users can navigate between each scene guided by the mini-map, or the advice given by the mischievous Lincoln Imp (Fig.4).

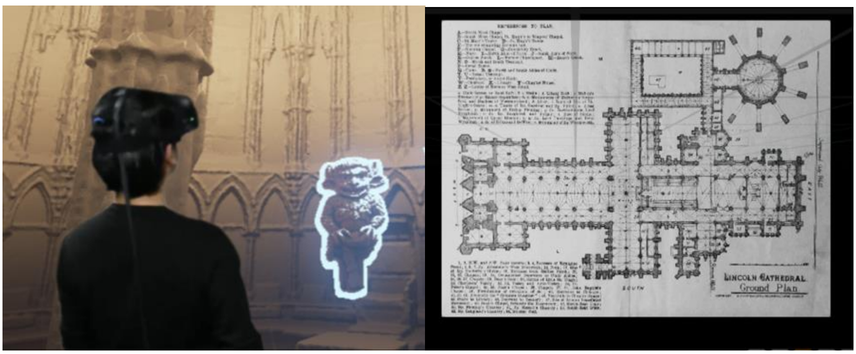

Fig. 4. Lincoln Imp and mini-map help the user navigate the VR environment

3.4 Interactive Functions

In the development of the prototype, six main interactive functions within UE4 were used: teleport; grab; scale; section; and appear/disappear. Transformative functions are new applications of VR of heritage buildings. In the Main Nave scene of Lincoln Cathedral, visitors can change the time of the day and interact with objects, such as columns, and obtain additional information (Fig. 5).

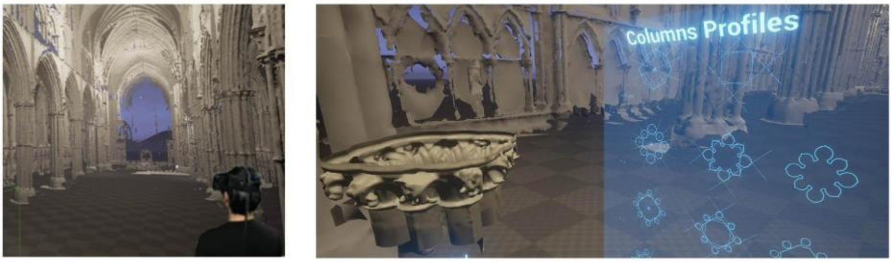

Fig.5. Main Nave scene of Lincoln Cathedral, with interactive information function

In the new Digital Model Exhibition scene, users can view architectural and historical objects isolated from their original location, offering various interactive functions, such as: grabbing, scaling, slicing (free sectioning) and rotating, to achieve an alternative perspective (Fig. 6).

Fig. 6. Digital Model Exhibition scene, with isolated objects and free section function

To study an object in detail, a visitor can grab an object, lift and scale it. It can be scaled to 1:1, allowing the visitor to walk through the object. Freely sectioning is a powerful function created in UE4, helping visitors to better understand complex architectural structures.

The dynamic mini-map (Fig 7) allows the visitor to navigate and teleport between the different scenes. Destination can be previewed before teleportation. The same mechanism allows historical documents and other media, such as videos seen in the VR exhibition scenes to be embedded into a scene, for users to interact with.

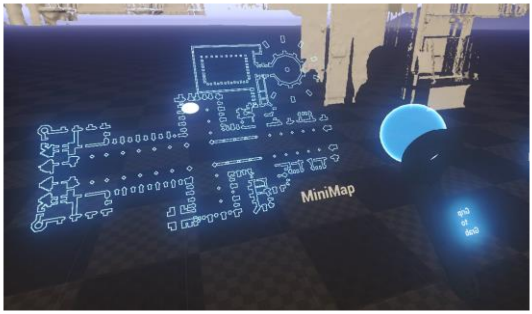

Fig. 7. Mini-map is used to navigate and teleport between scenes

4 Technical and Visual Performance

To improve the technical and visual performance of the interactive virtual reality exhibition, it was necessary to simplify the data, and control materiality and the level of detail.

4.1 Simplify Data to Increase Framerate

Once the interactive functions were operational, the first prototype was tested but it failed due to the complex meshes causing a low frame rate. VR displays require the graphics-processing unit to perform at a rate of 90 frames per second in order to avoid the screen juddering and causing motion sickness [8]. It was therefore necessary to simplify the meshes, using Rhino 3D software to reduce the mesh face count, and import back to UE4 to achieve a running framerate closer to 90 frames per second.

Simplification was an indispensable step to overcome the limited computer performance. This was completed in two separated stages (point cloud and mesh models) in manipulating the data during the workflow. Data had to be simplified to save time in the different stages, and to increase the display quality afforded by the limited computer performance. Simplifying the point cloud reduced the time required to process the raw data to a warped mesh model. Geomagic Studio software offered four commands under the sample section to achieve the reduction: Uniform, Curvature, Grid and Random. In this research, we found that Uniform was the most appropriate command to use, it allowed the designer to Keep Boundary, and provided a high control over specifying the different densities for the flat and curved areas separately.

Simplifying the mesh models helped to control the frame rate of the final product. Geomagic software was not as effective as Rhino software in terms of reducing the complexity of mesh models. More often than not, Geomagic resulted in “Not responding” during the reduction process, an outcome that never occurred with Rhino during the tests. Therefore, all the simplification of mesh models was completed using Rhino in the practical experiment.

4.2 Materiality

With modern laser scanners, color capture tends to extend data collection time by a factor or 2-3. In the case of Lincoln Cathedral, due to access restrictions and the visitors' schedule, color was not captured, with the exception of the wooden framework in an area of particular research interest - the Chapterhouse roof timber structure. In all other instances, material was applied to the refined models within UE4, which has an advanced, yet complex, material system. In UE4, an image applied on a mesh plane, or three maps (Colour, Specular and Normal) define material texture. The material system within UE4 is very powerful and goes beyond visually representing materiality; it helps minimize the amount of system performance required during an interactive function. For example, during the interactive function of sectioning a material texture can be reprogrammed to enable parts of the newly sectioned model to become transparent – making the sectioning effect without cutting and generating new models real time, reducing the amount of processing power required to run the function. UE4 is a leading platform in game design area and offers high quality visuals of materials used to represent historical buildings

4.3 Level of Detail

Due to the wide-angle perspectives in virtual reality, more objects have to be rendered compared to using a traditional display. Therefore, the complexity of the mesh models in the virtual reality scenes had to be controlled to a suitable level of detail (LOD). The effect of a shift in the level of detail can been clearly seen before and after the user focuses on an object (Fig 8). If the screen area is larger than a certain percentage (this value is set in the detail panel), the system will render the object in focus in full detail, and the background information will be distorted as a simpler version. The shift in LOD is dependent on the percentage of the pixels on the screen occupied by the object.

Fig. 8. Shift in level of detail, before and after focus on the Chapterhouse model

The LOD command helped to reduce the render load on the computer system. In general, the aim was to merge several mesh models, with different level of details, into one. Each object in the exhibit had many faces, and if those faces were not seen within a frame they were 'hidden.' This improves the performance. The shift in the

LOD is controlled by the user when they rotate their heads to observe something far from their vision center.

The LOD significantly improved the running performance of the interactive VR exhibition, yet maintained a detailed version of each single mesh model. Unfortunately, this function is sometimes problematic in its application to virtual reality due to the wide-angle distortion caused by wide field of view (FOV) in VR. This can mislead the LOD function into making incorrect shifting decisions. In VR cases, because of the wide-angle distortion, the further the content located from the image center, the more serious distortion will happen. As a consequence, the edge area on the screen is always dramatically stretched. That is to say, the objects will take more pixels when they are displayed near the edges of the screens. Meanwhile, content near the vision edges is not what the user attempting to see, but due to the area occupation is beyond set value, are likely to be shifted up to the detailed one as well.

5 Visitor Experience

The interactive VR exhibition prototype was evaluated to better understand its impact on the visitor's experience of Lincoln Cathedral. Initial observations from an empirical study of the prototype, involving four architectural students at the University of Nottingham, who compared their visit to the Cathedral with their visitor experience during the VR prototype. Additional feedback was gathered from Lincoln Cathedral Connected.

The empirical study of the prototype concluded that the interactive VR exhibition has potential to contribute to the conventional tour guide experience. It allows the audience member to inspect objects that are normally out of reach, or have limited visibility, such as the Lincoln Imp. The interactive functions provided a more illustrative method of visually exploring and analyzing the building, compared to traditional method of observing objects from a distance. Visitors get the opportunity to interact with the exhibits at a detailed level, which has the potential to enhance their understanding of the architectural and social history. The VR exhibition also has the benefit of being able to include archived material, such as scans of historical photographs, paintings, and video and audio recordings. The VR exhibition can also be accessed remotely, using a small floor space, which opens up the opportunity for user to explore the historic building from their own living room.

A video demonstration of the prototype was sent to Lincoln Cathedral Connected for review. Fern Dawson - Audience Development Officer of Lincoln Cathedral - stated:

'*I can definitely see the applications of this type of technology for visitor interpretation and the ability to access hidden spaces or features and to be able to zoom in and out and to rescale entire rooms or buildings.* '[9]

She explained that the public have been asking to see more of the traditional crafts like stonemasonry, joinery and glass, and praised the detailed model of the Chapterhouse roof structure. Being able to offer an interactive VR exhibition model was viewed by the committee as a potential outreach tool to engage with those who cannot visit the site in person. However, the committee felt that the prototype lacked a social aspect, and considered it to be an individual experience. They suggested that the prototype could be improved to cater for those who visit heritage sites for a more social experience.

6 Summary and Future Work

This paper demonstrates a workflow converting terrestrial laser scanner (TLS) into interactive virtual reality (VR) platform, which extends previous work in this area by promoting a more user-centric approach. The virtual reality enables curators to create rich narratives by guiding the visitor through virtual experiences, and custodians support in their endeavour to maintain the cathedral.

Use of gamification enables storytelling and guides visitor through Lincoln Cathedral in a similar way to traditional tour guides, making it easier for users to navigate the VR experience.

Such approach would be of most benefit to two groups: people who are unable to visit the Cathedral in person as well as current visitors. They can learn more about the building itself and interact with architectural features, mixing virtual reality experience with the normal visiting one. Both groups are also able to virtually access parts of the cathedral that have restricted access, such as Chapter House roof structure.

The demonstrated workflow has the advantage of being low cost due to a use of open source tools and standardisation coming with the use of common platform and approach. Use of detailed TLS data provides flexibility - the visual data can be simplified for a general audience (offering processing benefits for the general public as discussed above) and made complex and very detailed for specialised use (such as replacement of the architectural detail by stonemasons). This approach has received a positive feedback from Cathedral Fabric Committee. Colour information is very important for fabric maintenance and the authors of this research are looking at quicker and more inclusive data collection. Another improvement would be utilisation of a flexible moving data collection device (deploying an inertial system for self orientation) allowing for quick access to small spaces.

One of the limitations of the interactive VR exhibition is a lack of social interaction between members of the public. This aspect is missing from virtual reality, where each user is separated by the HMD. One way forward would be a combined virtual reality experience, where users can see and interact with each other, however this requires further work to fully understand all implications, including a better understanding of users interaction with the equipment. The next planned step in this research is to explore this concept in a VR exhibition, allowing the general public to both experience the technology and provide important feedback

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