

Linking Evidence with Heritage Visualization using a large Scale Collaborative Interface

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Abstract

The virtual reconstruction of heritage sites and artefacts is a complicated task that requires researchers to gather and assess many different types of historical evidence which can vary widely in accuracy, authority, completeness, interpretation and opinion. It is now acknowledged that elements of speculation, interpretation and subjectivity form part of 3D reconstruction using primary research sources. Ensuring transparency in the reconstruction process and therefore the ability to evaluate the purpose, accuracy and methodology of the visualization is of great importance. Indeed, given the prevalence of 3D reconstruction in recent heritage research, methods of managing and displaying reconstructions alongside their associated metadata and sources has become an emerging area of research. In this paper, we describe the development of techniques that allow research sources to be added as multimedia annotations to a 3D reconstruction of the British Empire Exhibition of 1938. By connecting a series of wireless touchpad PCs with an embedded webserver we provide users with a unique collaborative interface for semantic description and placement of objects within a 3D scene. Our interface allows groups of users to simultaneously create annotations, whilst also allowing them to move freely within a large display visualization environment. The development of a unique, life-size, stereo visualization of this lost architecture with spatialised semantic annotations enhances not only the engagement with and understanding of this significant event in history, but the accountability of the research process itself.

Categories and Subject Descriptors (according to ACM CCS): I.3.6. [Computer Graphics]: Methodology and Techniques-Interaction Techniques; H.5.2. [Information Systems and Presentation]: User Interfaces-Graphical User Interfaces; J.5. [Arts and Humanities]: Architecture; H.5.1. [Multimedia Information Systems]: Artificial, augmented and virtual realities.

1 Introduction

The 1938 British Empire Exhibition was a stunning display of architectural achievement and a reflection of the life and culture of Glasgow, the UK and the Commonwealth. As the last public showcase of the British Empire, the 1938 Exhibition was of huge international significance and continues to be a crucial event for the study of modernist architecture as well as British social and industrial history. Only one of over 100 innovative buildings remains on the site of the exhibition. Previous research was undertaken by the Digital Design Studio at Glasgow School of Art to digitally reconstruct the Empire Exhibition as a 3D scene using original sources (Figure 1). The main output was a robustly researched and constructed 3DSMax visualization, mapping the buildings and structures of the Exhibition to the topography of the original site at Bellahouston Park, Glasgow [JP07]. To achieve this, a large collection of related cultural artefacts (architectural plans, photos, drawings, and ephemera) was assembled and digitised, and

interpretation from people who had visited the Exhibition and architecture scholars was captured as video interviews.

This paper presents research which builds on this remarkable digital resource by linking the 3D scene of the Exhibition directly with the evidence on which the model was based and providing a customisable toolkit for the spatialised, collaborative annotation of 3D scenes.

Due to the paucity of original information such as architectural plans, a collaborative research methodology was critical to the original project's aim of producing an accurate 3D reconstruction via robust interpretation of incomplete evidence and the combination of a variety of sources, including testimony from direct witnesses and architecture experts. This methodology is expanded in the development of a tool which allows users to semantically connect 3D modelled data with their source(s) in an intuitive, discursive environment more appropriate for the visualization of large scenes such as those seen in

architectural reconstruction. The entire cultural archive on which the reconstruction of the Empire Exhibition is based is visualised within the 3D scene, along with research notes on the digital reconstruction, to enrich the building models and allow further interpretation via annotations.

2 Research Background

Semantic annotation, and the ways in which it can enhance engagement with 3D visualizations, is an emerging research area. The *EPOCH Research Agenda for the Applications of ICT to Cultural Heritage* identifies it as a crucial issue for development [AG08] as does the 3D-COFORM Consortium which deals with 3D documentation of tangible cultural heritage and states that 3D artefact models should be handled together with their context and interpretation represented by metadata, the modelled real world objects, and documentary sources [3D11]. *The London Charter for the Computer-based Visualization of Cultural Heritage* [LC11] brings together the most contemporary research issues in heritage visualization. Particularly pertinent to this research are Principles 3 and 4 which emphasise the need for transparent identification and communication of research sources in order to allow a robust evaluation of the purpose, accuracy, and methodology of the visualization and of visualization practice more generally. In particular this applies to datasets where there is by necessity, a level of uncertainty. Access to research sources and transparent methodology is now seen as crucial for the development of the discipline:

“Whilst it is unlikely that perfect reconstruction accuracy relative to an ancient monuments original appearance can be achieved for complex models, offering complete transparency about the underlying source data and decision making process determines the scientific authenticity of the resulting models. [...] One particularly interesting concern is methods for allowing interactive exploration of the relevant metadata displayed in corresponding locations in the 3D environment.” [KFH90]

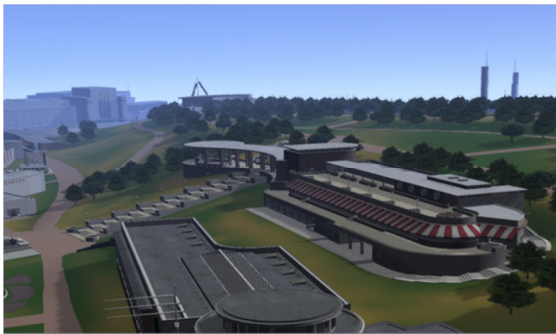


Figure 1: A view of the Empire Exhibition from within the real-time visualization

Previous research in this area has developed interfaces for adding textual semantic annotations to specific areas of visualizations, using an MPEG-7 framework [BGVM06], or for viewing information attached to specific parts of individual 3D models of sculptures, semantically described

with the CIDOC Conceptual Reference Model [SCU11] [RMA09]. Related disciplines have investigated immersive visualizations mapped onto CIDOC-CRM (for example the VENUS project's models of the archaeology of underwater sites [CBD10]).

Despite a defined need for tools for semantic annotation of 3D data by existing research in the field, there are no publicly available tools that can be used to connect visualizations of 3D scenes with cultural digital heritage artefacts in a variety of formats. Early steps have been taken in the development of scientific archives of 3D models presented alongside their metadata, such as the Digital Roman Forum [DRF11]. However, current examples make neither 3D models nor descriptive tools publicly accessible [KFH90].

One innovation of this research is to enable novel immersive interaction with the Exhibition 3D scene via a large-scale (13m x 8m), high-definition stereo projection, and the ability to annotate using separate tablet computers, connected to the 3D environment in real-time. The ability to present architectural sites at a life-sized scale allows researchers to gain a sense of immersion within the scene that would not otherwise be achieved using traditional desktop displays. Whilst this environment promotes immersion and collaboration it also renders traditional keyboard and mouse interactions inefficient and cumbersome.

One challenging requirement of this interface is to interact with the scene whilst also making relatively large textual inputs into the annotation database. There is a large body of research which addresses the issue of interaction within large-display environments [SS97], [KFAB04], [CRM*06]. However, many of these techniques either require direct interaction with the screen, tracked devices or do not offer practical support for large amounts of textual input. The recent resurgence of mobile touchscreen devices puts forward a number of interesting possibilities in terms of addressing these large-display interaction issues using a multi-device solution. Multi-device interaction techniques allow small groups of users to interact with the same environment each with their own versatile personal interaction device. The size and type of device can differ greatly, [MSG98] [DLM06] [JHKB06] show how small touch screen mobile phone type devices can be used to work collaboratively with a large display whilst [SGH*99] show how many different types of devices, both static and mobile can be combined to form a complex collaborative environment which allows data to be edited, viewed and shared amongst a group of users.

This paper discusses how previous research in the intellectual sustainability and transparency of 3D heritage visualizations has been extended by developing software to allow collaborators to add multimedia annotations to a 3D dataset and create both semantic and spatial relationships between the annotations themselves and the 3D models they document. The software is built on a CIDOC-CRM export-compatible data model and uses a variety of data

relating to the 1938 British Empire Exhibition as a demonstrator. At the end of the project, the customisable annotation toolkit will be made freely available, as will a downloadable visualization of the Exhibition and its related annotations.

3 Development

The following sections will outline the aims and objectives of the Empire system and the development that took place in order to meet those goals.

6.1 Objectives

The following objectives were outlined for the Empire system:

1. Optimize the existing scene geometry for real-time display.
2. Link elements within the virtual reconstruction with their related semantic annotations using the CIDOC Conceptual Reference Model as an ontological framework.
3. Provide users with the chance to experience the Empire Exhibition from a first person perspective using both a standard desktop PC and a large display visualization environment.
4. Allow groups of researchers to work collaboratively within the visualization environment, viewing, editing, and adding spatial annotations to the scene.
5. Provide support for multimedia annotations that may comprise of image, audio, video and textual information.

6.2 Optimisation of the Data

One of the challenges of this research is the size and scale of the dataset. The original 3D scene was intended for offline rendering and contains over 100 high resolution buildings (each made up of between 10,000 and 60,000 polygons) and a vast number of auxiliary features such as statues, benches, fountains, and vegetation – in total around ten million polygons. These models were all placed in an accurate geographical context, a digital representation of 175-acre Bellahouston Park, Glasgow. It was necessary to facilitate interactivity via real-time presentation as both a desktop application and a stereo visualization with remote data input. In the taxonomy dimensions defined by [FPM10], the new visualization provides interactivity with a negligible loss of precision and visual consistency, therefore a great deal of care was taken to optimise the scene whilst preserving as much detail as possible.

Data optimisation was performed in a number of stages and at each stage the performance was evaluated, using a PC equipped with an Intel i7 920, 6Gb of RAM and a QuadroFX 580 graphics card. Performance was deemed acceptable once the frame remained above a stable 60 frames per second. The first pass removed redundant elements such as hidden surfaces and structures. The second stage separated out the high detail decorative features such as lights, statues and furniture and simplified

them where possible. All of the high detail shrubbery and trees were removed in this stage and replaced with billboard variants. The third stage was to do an aggressive polygon reduction on the building models. The fourth and final stage was to generate alternative level of detail versions of each building model.

In the interest of preserving the models for future projects all of the processed models were exported and archived using the COLLADA, a freely available open standard digital asset schema [COL11].

6.3 Data Model

In order to ensure that the software would be usable by other researchers in the cultural heritage domain (and to increase the interoperability of existing research data on the Empire Exhibition) the CIDOC-CRM (official standard ISO 21127:2006) was chosen as the basis of the underlying data model for describing the 3D building models and scenery, the digitised archive of source material, and their inter-relationships. The CIDOC-CRM is “a formal ontology intended to facilitate the integration, mediation and interchange of heterogeneous cultural heritage information” [CDG*10] which provides detailed definitions of Entities and Properties for describing the underlying semantics of cultural heritage information and objects. Previous research has focussed on Persistent Items as the basis for semantic tagging [RMA09] in order to provide detailed descriptions for visualizations of real-world objects. The purpose of this research was not to implement a full CIDOC-CRM data structure for the Exhibition and all its related entities but to create explicit relationships between visualizations, the real objects they represent, and the evidence on which they were based. Therefore, a compact data model was designed which is export-compatible with the CIDOC-CRM, but condenses the core semantic concepts of the virtual reconstruction of a now-vanished architectural exhibition into a simpler structure. The naming conventions of CIDOC-CRM were maintained.

The two core concepts were that of real objects (modelled as *E22 Man-made object*) comprising the buildings of the Empire Exhibition and the real archive objects relating to them, and digital objects (annotations) which communicate information about the tangible objects via placement in the 3D scene (modelled as *E31 Document*, a specialisation of *E73 Information Object*). Relationships between real objects and digital surrogates or derivatives (for example a building and its corresponding digital model or a souvenir postcard and a scanned image) are represented through the *P70 Is documented by* property, demonstrating evidence for the visualization methodology, or the *P67 Refers to* property which allows the structured semantic modelling of non-documentary information such as multiple (potentially conflicting) interpretations of the architecture or the 3D scene itself. Both real and digital objects have associated information such as titles, creators (architects, photographers, 3D modellers etc.), and dates. This information was also semantically modelled to allow users to investigate implicit relationships, such as finding

all the buildings designed by a particular architect. A list of types was also created using the *E55 Type* property to increase search and interpretation functionality for this particular dataset; this types list is customisable to enable other instantiations of the software to fit completely different datasets. In this way, the data model allowed a clear focus on the core research issue of linking up visualizations with their source evidence, whilst also allowing future customisation and interoperability.

6.4 System Architecture

The visualization system was developed using the OpenSceneGraph graphics library, an open source, high performance graphics toolkit [OSG11]. The wide range of inbuilt functionality that OpenSceneGraph offers such as paged level of detail, occlusion culling and full shader support enabled the graphical element of the software to be developed very rapidly. Below this graphical layer the system uses a locally stored Compact Edition of SQL Server to implement and manage the database. Interaction with the Empire system is provided through two methods, the first is aimed at desktop PCs, consisting of a point and click 3D viewer with webpages in a separate window for creating and editing annotations. The second is a novel wireless tablet approach for use in large scale stereo projection environments. Remote control of the application is provided through an embedded web server and a series of interactive webpages. Consequently, bidirectional communication between the browser and the server is provided using an XMLHttpRequest protocol.

6.5 Large Displays and Multiple Devices

The Empire Exhibition viewer is aimed at two different user groups. The first is the general public, primarily non-expert content consumers with the principal interest of navigating around the scene and reading/watching the various annotations. This group will typically be using the system from a desktop PC. The second group are researchers, or other cultural intermediaries such as architecture experts [FPM10], who are interested in contributing further annotations to the scene. This group of users could work alone at a desktop PC or in groups using the large stereo display and require the means to add further annotations by uploading media or simply entering text.

As they can stimulate the perception of real depth and communicate a higher level of overall visual consistency, stereoscopic visualizations can be considered superior to non-stereo 3D scenes [FPM10]. In the context of architectural research it is particularly important to present a realistic, full-scale view of buildings from ground level. By presenting the scene using the large scale stereo display available at the Digital Design Studio, it is possible to greatly increase a user's sense of immersion within the scene. The sheer size of the screen (13m x 8m) allows for the buildings to be rendered to scale, whilst the stereo projection enhances the perception of structure and depth.

In order to increase users' sense of immersion within the scene and appreciate the sense of scale it is important to allow them to be able to work together whilst standing in front the screen. As mentioned in section 2, there has been a lot of work based on interaction techniques for large displays however, many of these techniques do not consider inputting sizeable amounts of textual information. One alternative is to interface with the system using separate networked devices for example additional PCs. Due to the mobility requirement of users' interfacing with the system it was decided to experiment with using touch screen tablet PCs as interaction devices. By linking tablet PCs to host software it is possible to provide users with a customisable touchscreen interface whilst also granting the freedom to move around within a virtual space. Rather than develop custom software for the tablet PC it was decided to provide communication with the host application using an embedded webserver and a series of interactive webpages. Through the use of AJAX, these webpages are able to provide a wide range of functionality ranging from camera control and displaying annotations to more complex tasks such as data input. This approach puts forward two key advantages; firstly, it offers a great deal of flexibility in terms of the types of devices that can be registered with the host application since any device with a compatible browser can connect to the host system. Secondly, it means the system is highly scalable in terms of adding additional users.

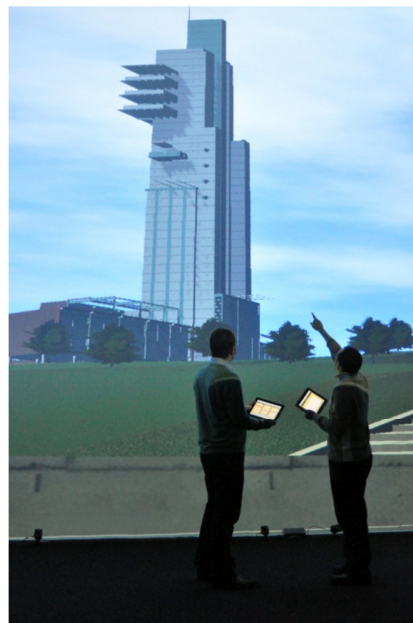


Figure 2: Two researchers using the touchpad interface in front of the large stereo display at the Digital Design Studio.

The tasks which users are able to perform with the tablet PCs can be separated into three groups; the first is camera control and navigation, the second is to display annotations, the third is to input annotations.

Managing the flow of interaction of multiple users can be very challenging. In order to prevent confusion, only one user is granted control of the camera and navigation tools at any time. Upon connecting to the host application each browser is given a unique ID enabling the host to differentiate between users. Using this ID, a control request mechanism was implemented which allows users to request control over the camera from the designated controller. Should the request be granted, control over the camera is passed to the next user. Although control of the camera is only accessible to a single user, the remaining tablet interfaces remain fully functional allowing other users to browse, search and input elements into the annotation database on their respective devices.

6.6 Navigation and camera control

Non-expert users have often been observed to experience great difficulties when navigating in a virtual environment [DANZ03]. Since the target audience for this system are not known to be typically well versed at navigating through virtual environments it was important to carefully consider the navigation paradigm that was to be used to ensure that it is intuitive and usable for all users. Navigation within virtual environments is well known to be harder than in the real world. Whilst modern virtual environments can provide close to photorealistic graphics, they are still unable to replicate the full array of sensory detail that the real world puts forward [Vin99]. Consequently, it is not uncommon for users to be disorientated and lost within a virtual world. In order to address this, the types of navigational task present in our system are examined. Navigation within virtual environments can be broken into three different types of activity; goal-directed, exploratory and maneuvering [BH97] [Kul09]. Goal-directed activities are concerned with finding a way to a particular destination; exploratory activities are less focused and more speculative as users navigate in a meandering, adhoc way. Finally, maneuvering activities describe behaviours which aim to discover more about a particular item [Kul09]. Our user base consists of two broad types of user; a researcher or a member of the general public. A researcher is more concerned with locating a particular building either for studying the architecture or examining and adding to the annotations. This type of activity can be described as both goal orientated and maneuvering since researcher will typically investigate an item once found. Members of the public on the other hand would also be interested in viewing a particular building and their annotations but generally speaking their engagement would be on an exploratory basis. There are many different techniques to enhance path finding within an environment, elements such as maps, landmarks and personal agents [DANZ03] can all aid in the process. However, giving users the ability to move the camera to any position they please increases the chance for users to become disorientated and requires a more complicated method of controlling the camera. Rather than complicate the system by allowing for this, it was decided to automate camera movement.

Extensive networks of footpaths were designed as part of the original Exhibition and were modelled along with the buildings. These tracks are used to provide a realistic, ground-level navigation between buildings selected by users in both the desktop and stereo visualizations. A series of camera tracks were created (Figure 3), linking each building, its default camera view, and the pathways.

To navigate the scene, users select their desired destination from an aerial map displayed in a floating pane either on the screen (desktop) or on the tablet PC (Figure 4). The camera then travels along the automatically calculated shortest route along the camera tracks to the default camera view for the destination. Users can then use a mouse (desktop) or camera controls (tablet) to zoom and rotate around a building or feature for closer inspection, without being restricted to pathways and ground level. This navigation method aims to convey a sense of physically inhabiting the space, and instead of ‘teleporting’ users to particular points, simulates real travel. This is not only highly intuitive but inherently communicates a sense of each building in the context of the whole Exhibition, and also reduces the chance of users becoming lost or disoriented within the scene.



Figure 3: An example of the camera tracks defined within the scene, shown as pale yellow lines.



Figure 4: A capture of the map that is displayed on the tablet PC. Users are able to zoom and pan the view and select their desired destination by touching an area on the map.

6.7 Viewing and adding annotations within the scene

The annotations associated with the Empire Exhibition cover a range of formats: textual references, high resolution images, video and audio, each of which may be linked to a particular spatial element within the scene for example a statue, mural or architectural feature. Some building models are documented by over 100 annotations and there are thousands in total. Given the large number of annotations care must be taken in presenting the information so as to prevent the user suffering from information overload. Given the spatial component to many of the annotations it is tempting to follow the route that other projects such as [KLM*05] [DCP*07] have taken and visualize annotation within the scene itself, floating above or around buildings. However, this number of annotations displayed within the scene by default would quickly cause symptoms of occlusion as the screen became more and more cluttered. Visual 'clutter' is a known user-interaction issue for visualization of annotations in 3D scenes [KFH90] therefore in order to present the annotations in such a way that they can be viewed, browsed and searched for efficiently; a building-centric approach was adopted.



Figure 5: An example of a photographic annotation viewed both on the large display (above) and the tablet interface (below).

Due to the multiple device approach that has been implemented, annotations can be viewed in two ways within the scene; firstly a windowed interface was implemented on the main display. Upon reaching a

building, a list of annotations is displayed on screen (Figure 5). Control over which particular annotation is displayed from that list differs depending on the interaction device. Within a large display environment where the tablet PC is used to control the system, the user with designated control selects the desired annotation from a list displayed on their tablet PC and their choice is reflected both on the large display and their personal tablet device. Users that do not have designated control of the system are able to view annotations of any building with their own tablet PC so that they contribute to any discussion or analysis of the building and its annotations. When interacting with the system using the desktop interface the user is able to click directly onto the screen using a mouse and select annotations from the list.

At the point of being created, each annotation is assigned a default spatial placement based on its relationship to a modelled Exhibition building. This was typically a point on the roof of the building. However, it is possible to define a local position within the building space in order to attach annotations to specific architectural features. Annotations with specific co-ordinates are shown as labelled, clickable pins in the 3D scene (Figure 6), however to avoid saturating the scene with thousands of annotation, those without specific co-ordinates are shown as a clickable list in a floating pane over the default building view.



Figure 6: An example of a marker showing the reference point for an image annotation.

Adding annotations to the scene is achieved using the web interface (Figure 7). To add an annotation the user is required to fill in details about the annotation such as author, type, reference point etc. Selecting any element which requires textual input will present the user with an on screen keyboard which allows them to input textual information. External files are either stored locally within the tablet or can be referenced from a networked location and are then uploaded to the local database.

Registering an annotation to a specific point on the building however, must be done in three dimensions. Upon selecting the option from the annotation input screen the user is presented with a zoomed view of the building on screen. Using controls displayed on the tablet PC the user is able to translate and rotate the model, moving a crosshair to mark the desired position for the annotation (Figure 8).

Once confirmed the selected 3D coordinate will be stored within the database and linked to the annotation.

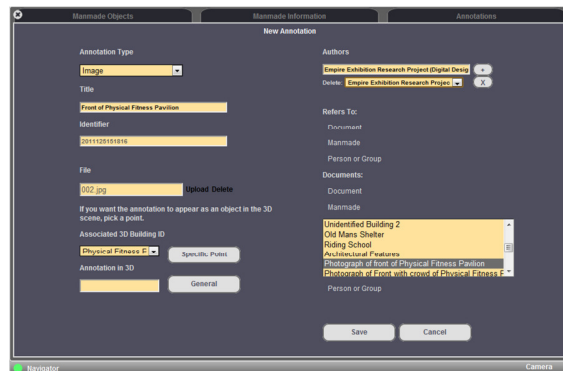


Figure 7: An example of the interface for inputting an annotation.

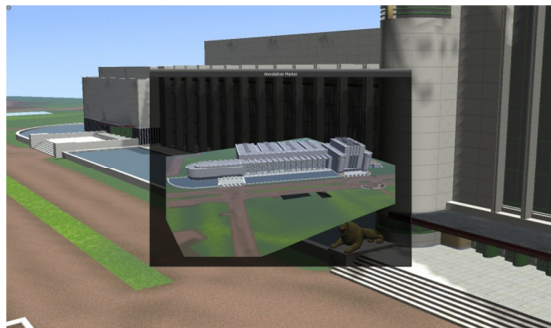


Figure 8: An example of the target marker used to mark a specific position for an annotation within the building's space.

7 Further Work

In addition to widely disseminating the 3D models and related cultural artefacts relating to the 1938 British Empire Exhibition, the primary purpose of this research is to enable further investigation of the methodology of 3D architectural visualization by other researchers. After a period of user-testing by experts including architects, historians, and 3D modellers (during which they had the opportunity to add further interpretive text annotations), the customizable software was packaged in a form suitable for use by other content holders for example, with the option to create different types and upload different data. The entire visualization with all annotations was also packaged for download by content consumers for example, with the 'add' and 'edit' functionality removed.

In the future, there is the potential to continue with the approach used by the initial modelling project and encourage contributions from members of the public, both in terms of interpretation of the Exhibition and in providing additional sources of evidence for Exhibition structures. Assembling information from disparate sources was a crucial part of the creation of 3D representations of the buildings and further information would allow this research

to progress with confirmations or contradictions of those aspects of the scene which were modelled with uncertainty. However, interaction of this level (for example, allowing members of the public to submit comments or images through a website, with the potential to make corrections to the 3D models) would require significant moderation and is therefore subject to further funding.

It is also hoped that the software is used by researchers on other similar projects and that in the future, the data can be integrated into a larger, interoperable collection of information on architectural history.

8 Conclusion

This paper has presented research to create an interactive, immersive visualization of the historically significant 1938 British Empire Exhibition which took place in Bellahouston Park, Glasgow with the functionality to explicitly link the digital 3D models with their research sources and interpretation, in 3D space. This was achieved by optimising existing 3D data designed for offline rendering and incorporating the 175-acre scene into a real-time application. A lightweight data model based on CIDOC-CRM was designed and a multimedia collection of research sources and methodological notes were semantically described and uploaded as spatialised annotations to the application.

Two interfaces are provided by the software, one aimed at general content consumers (using a desktop PC) and one with stereo visualization of the data and a novel method of annotating in collaborative groups, using remote tablet PCS. Both simulate real-world navigation to increase immersion. Annotations are shown in a non-obstructive way within the 3D scene either as clickable map pins or as a clickable list relevant to the current building view. At the end of the project the scene, associated annotations, and software itself was made freely available via the project website (<http://ddsgsa.net/projects/empire>)

Acknowledgements

Both this research and the initial project to model the Empire Exhibition were funded by the Arts & Humanities Research Council (AHRC).

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