Empire 3D:
A Collaborative Semantic Annotation Tool for Virtual Environments

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Abstract
3D visualization is a powerful tool to increase understanding and experience of the world's cultural heritage. However, where there is incomplete primary material on which to base visualizations there is a recognised danger that 3D models, as absolutist in their representations, can be misinterpreted as a totally accurate replica of reality. Good practice in creating digital reconstructions of non extant architecture leads to researchers meticulously documenting the process and outputs of heritage visualizations, however unless the research sources and methods are made explicit and visible, the danger of mis-reading visualized data remains.

This research describes the development of software that allows research sources, methods, and interpretation to be added as multimedia annotations to a 3D scene comprising the entire British Empire Exhibition of 1938. All real-world and digital objects are semantically described and given a spatial placement within the scene. The software is built on a CIDOC-CRM export-compatible data model and provides a novel interface which allows groups of users to collaboratively and simultaneously create annotations in an intuitive discursive visualization environment using remote tablet PCs. The development of a unique, life-size, stereo visualization of this lost architecture, with spatialised semantic annotations, will enhance engagement with and understanding of this hugely significant event in history.

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. The main output was a robustly researched and constructed 3DSMax visualisation mapping the buildings and structures of the Exhibition to the topography of the original site at Bellahouston Park, Glasgow [Johnston & Pritchard 2007] . 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.[1]

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 its source(s) in an intuitive, discursive environment more appropriate for visualization of large scenes such as architecture. The entire cultural archive on which the

[1] Low-resolution outputs of this research are available at the project website: http://www.empireexhibition1938.co.uk

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 [Arnold & Geser 2008 p.74] 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 [3D-COFORM]. *The London Charter for the Computer-based Visualization of Cultural Heritage* [2009] 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, particularly in 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 monument's 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." [Koller, Frischer, & Humphreys 2009, pp.10-11]

Previous research in this area has developed interfaces for adding textual semantic annotations to specific areas of visualizations, using an MPEG-7 framework [Bilasco et al. 2006], or for viewing information attached to specific parts of individual 3D models of individual sculptures, semantically described with the CIDOC Conceptual Reference Model [SCULPTEUR project; Rodriguez-Echavarria, Morris, & Arnold, 2009; Havemann et al. 2008]. Related disciplines have investigated immersive visualizations mapped onto CIDOC-CRM (for example the VENUS project's models of the archaeology of underwater sites [Chapman, Bale & Drap, 2010]).

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 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, however current examples make neither 3D models nor descriptive tools publicly accessible. [Koller, Frischer, & Humphreys, 2009, pp.5-6]

One reason for the slow development of modelling and visualization research specific to architecture is the scarcity of suitable visualization laboratories available to arts and humanities researchers. 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. Simulation of real movement within the scene, visualized at life-size, allows users to inhabit the virtual space and interact with it as a group, in addition to the more typical single-user, desktop mode of interaction.

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 packaged visualization of the Exhibition and its related annotations.

3 Software development

3.1 Optimisation of 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 Foni, Papagiannakis, & Magnenat-Thalmann, 2010, the new visualization grants *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.

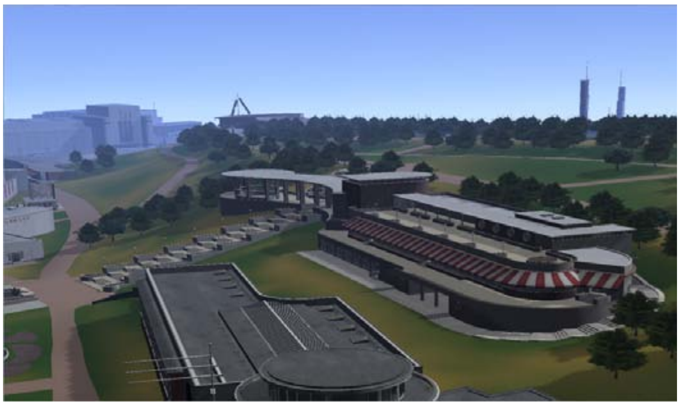

Figure 1 - A view of the Empire Exhibition from within the real-time visualization.

Data optimisation was performed in a number of stages and at each stage the performance was evaluated, using an PC equiped with an Intel i7 590, 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 [2010].

3.2 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 "a formal ontology intended to facilitate the integration, mediation and interchange of heterogeneous cultural heritage information" [Crofts et al. 2010 p.1] 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 [Rodriguez-Echavarria, Morris, & Arnold, 2009, p.123] 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.

3.3 System architecture

The visualization system was developed using the OpenSceneGraph graphics library, an open source, high performance graphics toolkit [OpenSceneGraph 2.8.3 2010]. 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 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 system is provided through two methods, the first is aimed at desktop PCs, comprising point and click 3D viewer with webpages in a separate window for creating and editing annotations. The second is a novel wireless tablet approach. 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 system.

3.4 Interface, navigation and immersion

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 [Foni, Papagiannakis, & Magnenat-Thalmann, 2010, p. 12], 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 [Foni, Papagiannakis, & Magnenat-Thalmann, 2010, p. 8]. 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. However, to use such large displays intuitively and effectively control methods that are not based around the classical keyboard and mouse paradigms must be considered.

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

Over the past year, there has been a rise in the availability of cheap, powerful and lightweight tablet PCs. This hardware presents many exciting possibilities in terms of interface development. By linking tablet PCs to host software it is possible to provide users with a customisable touchscreen interface whilst also providing the freedom to move around within a virtual space. Using this approach, a web server aimed at serving interactive webpages to the tablet PCs was embedded within the host application. 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 data input. The use of a web server also means that the system is highly scalable in terms of adding additional users. However, 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 at any time. Each tablet interface is then given a mechanism which allows them 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. Whilst control of the camera is only accessible to a single user, the remaining tablet interfaces remains fully functional allowing other users to browse, search and input elements into the annotation database on their respective devices.

Navigation and camera control methods were also used to increase immersion within the 3D scene. An extensive network 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. The camera then travels along the automatically calculated shortest route to the default camera view for the destination. Users can then use a mouse (desktop) or camera controls (tablet) to zoom and rotate around the focal point 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 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 yellow lines.

Within this interface, annotations must be displayed in a way that is easily navigable and communicates each annotation clearly. The annotations associated with the Empire Exhibition cover a range of formats: short textual references, high resolution images and video, audio, and longer text. Some building models are documented by over 100 annotations and there are thousands in total. 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 [Kadobayashi et al. 2005; Koller, D., Frischer, B., Humphreys, G. 2009] 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. At the point of being created, each annotation is assigned a default spatial placement based on its relationship to a modelled Exhibition building. By marking a point on the 3D model, it is possible to assign other co-ordinates to annotations if desired, for example if the annotation documents or refers to a specific architectural feature. Annotations with specific co-ordinates are shown as labelled, clickable pins in the 3D scene (Figure 4), 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. When clicked, another floating pane shows the full annotation (text, image, etc.) along with information about its relationships, creator and so on (Figure 4).

The tablet PCs implement annotation display through a series of webpages which allow users who are not currently in control of the main projected camera view to continue to add or view other annotations simultaneously.

Figure 4 - An example of a marker showing the reference point for an image annotation.

4 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 will have the opportunity to add further interpretive text annotations), the customizable software will be packaged in a form suitable for use by other content holders, i.e. with the option to create different *Types* and upload different data. The entire visualization with all annotations will also be packaged for download by content consumers, i.e. 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.

5 Conclusion

This paper has presented research to create an interactive, immersive visualization of the hugely 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 will be made freely available via the project website.

6 Acknowledgements

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