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DEVELOPING HISTORIC BUILDING INFORMATION MODELLING GUIDELINES AND PROCEDURES FOR ARCHITECTURAL HERITAGE IN IRELAND

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ABSTRACT:

Cultural heritage researchers have recently begun applying Building Information Modelling (BIM) to historic buildings. The model is comprised of intelligent objects with semantic attributes which represent the elements of a building structure and are organised within a 3D virtual environment. Case studies in Ireland are used to test and develop the suitable systems for (a) data capture/digital surveying/processing (b) developing library of architectural components and (c) mapping these architectural components onto the laser scan or digital survey to relate the intelligent virtual representation of a historic structure (HBIM). While BIM platforms have the potential to create a virtual and intelligent representation of a building, its full exploitation and use is restricted to narrow set of expert users with access to costly hardware, software and skills. The testing of open BIM approaches in particular IFCs and the use of game engine platforms is a fundamental component for developing much wider dissemination. The semantically enriched model can be transferred into a WEB based game engine platform.

1. INTRODUCTION

1.1 Overview

As a multi-disciplinary and evolving system, Historic Building Information Modelling (HBIM) consists of the survey of existing structures using remote sensing followed by the mapping of parametric and information rich objects onto a geometric framework based on the remote survey data. The parametric objects which represent the architectural elements are graphically constructed or coded and are based on historic architectural documents (architectural rules and shape grammars). The resultant HBIM can then be used for automatically producing conservation documentation and analysis of historic structures in addition to visualisation. This paper addresses a series of questions to identify and develop Historic Building Information Modelling Guidelines and Procedures for Architectural Heritage in Ireland.

1. What are the prototypical standards for data capture based on laser scanning and digital photogrammetry for digital recording of historic structures and environments?
2. What additional processing is required to produce suitable documentation to assist the conservation process?
3. How can Historic Building Information Modelling (HBIM) ameliorate the digital conservation documentation dilemma, if it is an interpretive digital representation?
4. Can a combination of laser/photogrammetric survey data and HBIM (producing orthographic drawings and schedules) satisfy the requirements for the conservation documentation process?
5. Do WEB based, Game Engine and VR Platforms have potential to disseminate at appropriate costs the required conservation documentation based on HBIM to conservation experts?

1.2 Current Research

Digital Documentation and Recording Historic Buildings

International standards for recording and documentation for tangible and intangible cultural heritage and artefacts have been established by the Venice Charter and the London Charter which relates to the both the digital and paper based documentation of cultural heritage (CIPA 2011; ICOMOS 2012; Londoncharter 2012; RICS 2014; Stylianidis, Patias & Quintero 2011). The creation of digital 3D cultural heritage models include the use of remote sensing based on terrestrial laser scanning and photogrammetry in addition to the use of BIM, 3D CAD, GIS and other computing simulation techniques for modelling and adding intelligence to the objects. Models based entirely on remote sensing are limited to a record of an artefact encompassing data relating to geometry, texture and appearance. Cultural heritage researchers have recently begun applying Building Information Modelling (BIM) to historic buildings. The intelligent data or information contained in the model can range from geometric and spatial to material, structural, environmental, cultural and economic. The model is comprised of intelligent objects which represent the elements of a building structure and are organised within a 3D virtual environment.
Adding Intelligence

Building Information Modelling (BIM) is a virtual representation of a building, its structure, materials, and environment, providing the associated information (the "metadata") related to its design, construction and future lifecycle. The intelligent data or information contained in the model can range from geometric and spatial to material, structural, environmental, cultural and economic. The model is comprised of intelligent objects which represent the elements of a building structure and are organised within a 3D virtual environment. Historic Building Information Modelling (HBIM) is an extension of BIM for the physical and knowledge management and conservation of architectural heritage. HBIM involves the digital recording of historical buildings using remote sensing (laser scanning, digital photogrammetry) or combinations of digital surveying and manual techniques. The acquired survey data is then processed improving the data organisation and adding intelligence using BIM software platforms. Because of the difficulties in accurately representing the variety of complex and irregular objects occurring in historic buildings existing BIM libraries of parametric objects need to be rebuilt and coded. In addition as the building exists and is represented by a remotely sensed model, systems to map the intelligent library objects onto digital or other survey data were also developed (Fai et al. 2011; Murphy, McGovern & Pavia 2009; Dore & Murphy 2014).

![Figure 1: Scan to HBIM to Documentation (Dore & Murphy 2014)](image)

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HBIM was measured; data collection techniques, laser scanning, photogrammetry and other methods – software for survey processing - Parametric CAD, BIM and other software options. When asked to identify the different software systems used in their HBIM workflow, the following figure contains their responses.

The entire instrument and/or the recorded object are rotated to achieve, where possible, complete 3D point coverage. Time of flight scanners calculate range, or distance, from the time taken for a laser pulse to travel from its source to an object and be reflected back to a receiving detector.

2. PROTOTYPICAL STANDARDS FOR DATA CAPTURE - LASER SCANNING AND DIGITAL PHOTOGRAMMETRY

2.1 Data Capture

The terrestrial laser scanner is a device that automatically measures the three-dimensional co-ordinates of a given region of an object’s surface, in a systematic pattern at a high capture rate in near real time. The laser ranger is directed towards an object by reflective surfaces that are encoded so that their angular orientation can be determined for each range measurement.

Digital Photogrammetry

Most modern scanning systems are fitted with a CCD (charge-coupled device) digital camera and the image data that is captured can be used to colour the product of the laser scan survey data (the point cloud). Digital photogrammetry is based on hardware for data capture such as SLR digital cameras and thermal imagers or in some cases off-the-shelf cameras. The acquired data is then processed, fused and integrated using state-of-the-art photogrammetric and computer vision algorithms which are readily available with software platforms Autodesk Re-Cap and 123D-Catch, Agisoft Photoscan.
Microsoft Photosynth, Micmac, Pix4D, etc. Geo-referencing Image-based approaches are gaining momentum because they are much more cost effective than laser-based or structured light scanning methods. In digital photogrammetry stereo images are captured with multiple camera positions, pixel matching is used to locate similar points on the images and ray tracing to locate the camera positions. The geometric calculation of intersecting rays of light and the base line distance between cameras provides sets of triangles. From the triangulation process a point cloud is produced, locating the xyz points of the object. The point cloud is processed similar to laser scanning by meshing and texturing. The triangulation principle or bundle adjustments coordinates of multiple points on the object are measured in different images and are simultaneously used to calculate the 3D object coordinates by predicting the intersecting rays (Remondino et al. 2006;2011). The camera positions and the resultant 3D photogrammetric model of a Corinthian Capital is illustrated on the right hand side of the figure below.

![Figure 7: 3D photogrammetric model of Gallarus Oratory](image)

### 2.2 Pre-processing

The initial pre-processing stage involves cleaning and removing erroneous data or artefacts such as reflections of the scan through objects. These incorrect points can be eliminated before point clouds are registered. Once identified, reflections from objects in the background and in the space between the scanner and object e.g. trees and other objects in the foreground, moving persons or traffic and atmospheric effects such as dust or rain, can be largely removed by the introduction of range limits, or with the aid of graphical tools in a CAD software programme. Inaccurate points originating from multiple reflections can also be largely eliminated with this latter method. The point density on the object's surface can vary significantly due to the altering range to the object surfaces during acquisition. Re-sampling, by reducing the density of the data for overly dense point clouds, can reduce the amount of unnecessary data and file size. Software platforms, based on the organisation of all available data in an octree structure (which is a data structure useful for visibility of 3D data) enables the sorting of the data into an even point density on the scanned surface of the object. Signal noise can be eliminated, if the object is known to be smooth, by the application of a low pass or median filter. Filtering of point cloud data should be avoided where an object consists of smooth parts and edges as it will influence all object parts in a similar way.

### Point cloud registration

Registration is the combination of two or more point clouds taken from different observation points or the referencing of the scanned object in a global or project coordinate system. This is achieved using tie and control points that are either features of the object (e.g. corners) or special targets (spheres, flat targets with high reflectivity), which are identifiable in the point, cloud at the processing stage. Software for registering point clouds usually facilitates registration by special targets or by overlapping point clouds or a combination of. In the case of large structures where the placing of targets is not always possible, known features on the object are used to fully transform and align the scans. GPS systems can determine the co-ordinates of the laser scanner position which can then allow for the scans from each position to be brought into a common frame of reference in a global or project co-ordinate system. Alternatively registration by cloud matching is carried out by selecting a pair of partially overlapping scans and transforming one scan into alignment with the other using appropriate algorithms.

![Figure 8: Point Cloud Registration](image)

### 2.3 Data processing

The range data in the form of the point cloud from the laser scanner can be considered as a skeletal framework for recording the geometry of the historic structure. This geometric framework is then mapped with the associated image data allowing for more precise identification of the structure’s texture and features. Polygonal surface meshing (creates a surface on a point cloud; the created surface is made up of triangles connecting the data points into a consistent polygonal model. The point cloud, illustrated in the Figure below is a series of random points, which are then linked by triangular networks using algorithms such as Delaunay triangulation (see Figure below). The function of smoothing modifies the surface structure of the point cloud by optimising the point data, filling holes and correcting edges. This can be followed by decimation which is a process to optimise the number of polygons and points in the mesh.
Ortho-image

The creation of an ortho-image from point cloud data allows for all of the image and geometric data to be exported for visualisation or further processing in CAD, or other modelling platforms. Ortho-images are photo realistic models containing width, breath and height of an object. The ortho-image represents the data for a particular plane on the x, y, and z-axis; this can therefore represent elevation, plan, or section of an object. The texture for the ortho-image is taken from the associated image data, the 3D geometry is supplied from the meshed point cloud. Both sets of data are for a particular segment and plane within the point cloud. Initially planes are created on the x-y, x-z and y-z axis.

3. HISTORIC BUILDING INFORMATION MODELLING (HBIM) - DIGITAL CONSERVATION DOCUMENTATION

3.1 Architectural Libraries

As previously stated, Historic Building Information Modelling (HBIM) incorporates a library of parametric objects, based on historic architectural data, and a mapping system for plotting the library objects onto laser scan survey data. BIM authoring platforms are mostly tailored for the modern architecture and their libraries of parametric objects are limited to basic components. To overcome this problem a design for a plug-in for BIM for complex architectural elements characterising existing and historical buildings was introduced by Murphy et al. (2013). A coding approach was applied for the design for parametric objects based on architectural rules from pattern books and shape grammars. The library elements (including detail behind the object’s surface) are accurately mapped onto a survey produced from laser scanning that represents the geometry and fabric of the building. The architectural elements can be coded or graphically produced. The design and detail for the parametric objects are based on architectural manuscripts ranging from Palladio to the architectural pattern books of the 18th century. The architecture of the Renaissance and the detail in architectural pattern books introduced and documented advanced scientific rules for the production of architectural elements, and these rules assist the design of parametric models. The use of historic data introduces the opportunity to develop the details behind the object’s surface concerning its methods of construction and material makeup.

Manual Methods

The parametric objects are mapped onto ortho-image and segmented point cloud data using a new system for mapping...
within existing software platforms and a newly designed web-based ortho-image scaling application. The objects can be placed manually onto the point cloud/scan data and adjusted within ortho-projections for correct angular orientation. Other applications can be used for extracting measurements from ortho-image and segmented point cloud data to size and place the objects. The figure below shows top left the automatic extraction of façade openings and dimensions to create the façade in the bottom of the figure. The door case is mapped from a segmented point cloud (left side of image) where the detail is more complex.

3.3 Procedural Modelling
Semi-Automatic mapping from laser scan surveys

A procedural modelling approach uses a sequence of generation instructions, rules or algorithms that can be repeated with varying characteristics to automatically generate 3D geometries (Kelly & McCabe, 2006, Muller et al., 2006, Hohmann et al., 2009 and Thaller et al., 2011). While procedural modelling has many advantages such as automatic generation of geometry, great flexibility for variation and object hierarchy, a disadvantage of these methods for existing buildings is that they lack the detail and accuracy required for many applications in AEC or heritage sectors. Current software for procedural modelling also does not automate the production of engineering drawings and is primarily used for applications such as visualisation. In the work of Dore and Murphy (2014) design and conceptual framework for the HBIM procedural rules are based on concepts from shape grammars. A shape grammar is a production system used in procedural modelling to automatically generate two or three dimensional geometries from a basic vocabulary of shapes and a set of production or shape rules. The HBIM library of parametric architectural elements (Murphy et al., 2013) is used as a source for shape vocabulary on which the rules and algorithms are applied. Architectural rules and proportions are also used to assist the reconstruction process. Architectural rules and proportions outlined in pattern books relating to classical buildings are used to provide an initial estimate for the position and size of building elements on a generated building. This greatly reduces the amount of further editing required when modelling classical buildings from survey data.

In the figure below the result of the application of procedural rules designed for accurate and efficient modelling of curved walls that contain deformation is illustrated. As a result of deformation the walls which support the dome may not be perfectly vertical and may contain different levels of deviation at different heights and locations. Horizontal cut sections through a circular wall at different heights capture areas where the wall is bulging or warping.

Figure 13: Procedurally Modelled Dome and Drum (Dore & Murphy 2014)

Creating a surface from cut sections through the wall at different heights allows the variances of the surface to be accurately represented. This new procedural rule allows users to select a group of horizontal cut sections which are then used to automatically generate the irregular wall surface. The non-vertical wall is created by generating a surface between each horizontal cut section. This rule results in automatically generated geometry for a drum wall which represents the true condition of the wall with deformation based on scan data.

4. COMBINING LASER/PHOTограмMETRIC SURVEY DATA AND HBIM FOR CONSERVATION DOCUMENTATION

While the perfect geometric replication can be produced from laser scan and photogrammetric survey data the HBIM can be considered as an interpretation of the object or building. The integration of laser/photogrammetric survey data and HBIM (producing orthographic drawings and schedules) can then satisfy the requirements for the conservation documentation process. This approach is illustrated in the figure below.
While BIM platforms have the potential to create a virtual and intelligent representation of a building, its full exploitation and use is restricted to a narrow set of expert users with access to costly hardware, software and skills. The testing of open BIM approaches in particular IFCs and the use of game engine platforms is a fundamental component for developing much wider dissemination. OpenBIM is a universal approach for collaborative design, realisation, and operation of buildings based on the open standards and workflows (Graphisoft 2016). IFC provides a series of definitions for all object element types used in the building industry and a text-based structure for storing those definitions in a data file (Solibri 2016). WEB based, Game Engine and VR Platforms have potential to disseminate at appropriate costs the required conservation documentation based on HBIM to conservation experts. The proposed design in the final figure below combines Historic Building Information Modelling (BIM) with Game Engine tools and technologies as an active repository of associated knowledge and data.

Semantic WEB is employed to extract information and to relate digital content. The semantically enriched model can be transferred into a WEB based game engine platform. This enables not only interaction with the virtual building but allows users to access and query related information rich data contained in the model and externally. The user access and queries are linked to the geo-location of elements of the building and to geometry shape and attributed semantics facilitated by data flow between the game engine asset server and the 3D HBIM components server.

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