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Parametric Vector Modelling of Laser and Image Surveys of 17th Century Classical Architecture in Dublin

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Abstract
The product of a laser scan survey of a building or artefact is a point cloud which defines the geometry of the object, and when combined with image data the object edges and material textures can be identified. The point cloud survey is useful for visualisation and also as a record of the 3D surfaces of an object. Where conservation or restoration work is to be carried out on the object conventional orthographic or 3D survey drawings are required. Survey drawings can be created by mapping vectors on to the point cloud or textured point cloud. This is a complex process as the data size of the point cloud is usually very large; also mapping in 3D space onto a point cloud is intricate due to difficulties in locating correct object planes and the detection of object edges. These problems have been overcome to a large extent using software platforms and plug inns which interface between CAD and point cloud processing software programmes. A method to improve automation of vector mapping by plotting parametric vector objects on to the point cloud is examined in this paper. This study is based on a laser scan and image-based survey of 17th century classical architecture in Dublin. The parametric objects are created from the geometry of the point cloud correlated with the historic design principles of classical architecture and then directly mapped on to the point cloud survey. The laser survey can only record the surface of the object; construction details behind the surface can be detected from historic data, thus producing a full 3D and orthographic vector survey of an object or building.

Categories and Subject Descriptors J.6 Computer-Aided Engineering, Computer-aided design (CAD)

1. Introduction

The current body of research work concerning advanced automated surveying for cultural heritage objects has concentrated on the identification of suitable hardware for terrestrial laser scanning and digital photogrammetry in addition to the required accuracy in the collection and processing of data ([B 2004], [B 2004a], [BDM 2006], [BHM 2001]). As a result, the main output of current research is the accurate 3D modelling of a historic structure or artefact. An example of this is the laser scan survey of the Cathedral of Saint Pierre de Beauvais carried out by the University of Columbia Robotics Lab [A 2003]. The resultant survey data can be interpreted as both 2D and 3D data but only contains information concerning the outer fabric or the surface of the structure. The textured point cloud survey is useful for visualisation and also as a record of the 3D surfaces of an object. Where conservation or restoration work is to be carried out on the object, conventional orthographic or 3D survey drawings are required. The drawings are created by mapping vectors on to the point cloud or textured point cloud as detailed in figure 1. This is a complex process as the data size (density of the point cloud) is usually very large. In addition mapping in 3D space onto a point cloud is intricate due to difficulties in locating correct object planes and the detection of edges which define objects.

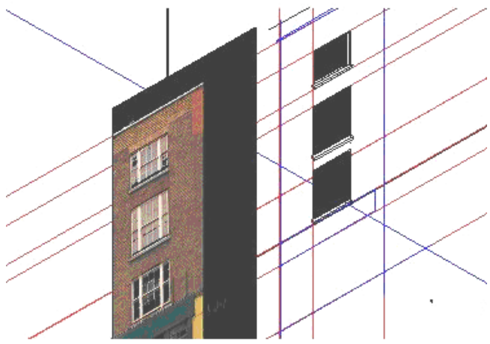

Figure 1: *Vector plot of a Laser Scan Survey*

A method to improve automation of vector mapping by plotting parametric vector objects on to the point cloud is examined in this paper. This study is based on a laser scan survey of 17th century classical architecture in Dublin. The parametric objects are created from the geometry of the point cloud correlated with the historic design principles of classical architecture and then directly mapped onto the point cloud survey. The laser survey can only record the surface of the object; construction details behind the surface can be detected from historic data.

2. Data Collection and Processing

The survey data was collected using a terrestrial laser scanner combined with digital photo modelling. The terrestrial laser scanner used for the surveys was combined with a digital camera, which captured corresponding images to the scan, appropriate software was later used to combine the image and scan data. Digital photo modelling was used alongside the laser scanning for independent data collection.

The initial data set consisting of the point cloud was preprocessed to register the separate data sets and artefacts were removed. A structured 3D model was created by meshing the point cloud followed by texturing from the image data, this process is illustrated in figure 2.

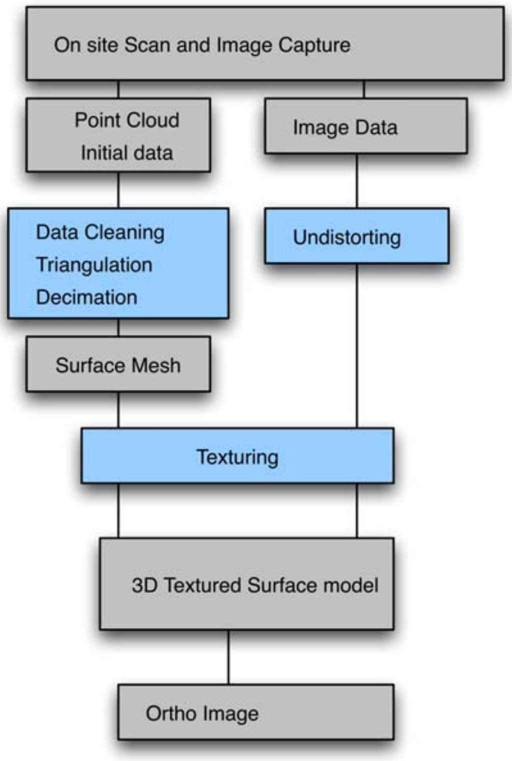

Figure 2: *Survey data collection and processing.*

3. Parametric Modelling

3.1. Definition

The basic parameters which describe vector objects are shape and volume expressed as coordinates and its orientation as an angular value. A cube can be defined with only two sets of coordinates, one for each of two diagonally opposite corners. The definition also requires three angular specifications, one to indicate the angle of the base side in the x-y plane, one the base angle in the x-z plane, and one the base angle in the y-z plane. The specification for the

The height and width are dependent on the connection of the wall at its ends to other walls or objects. The height materials and colour can accompany the numerical data. The cube as a parametric model can then be edited to change any or all of its parameters of construction and orientation [C 2005]. Parametric modelling is defined by Eastman [E 2006] as 3D or 2D solid object shapes which can be described according to parameters some of which are user defined and others which relate to position in a 3D environment relative to other shape objects.

3.2. Building Information Modelling

The parametric objects are brought together as building components to create or form the entire building, a system referred to as Building Information Modelling (BIM). The BIM can automatically create cut sections, details and schedules in addition to the orthographic projections and 3D models (wire frame or textured). The parametric building objects are not defined singularly but as systems using interaction with other objects and their own values (shape, texture etc.) within a BIM [E 2006].

In building parametric objects the problem of file format and exchange of data has been overcome by ArchiCAD (software platform) [A 2007] by using a geometric descriptive language (GDL) which is a basic language. The scripting in GDL allows for sharing and editing of the parametric objects at different levels. In figure 3 below an example of a column with a capital and base is constructed using a GDL script [A 2007].

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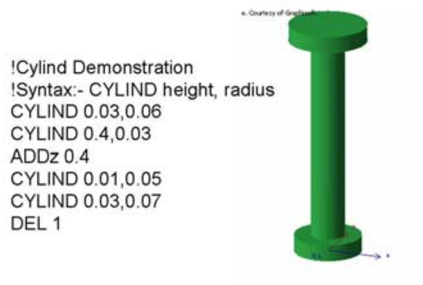

Figure 3: *Example of GDL object and script.*

3.3. Plotting Parametric Models from Laser Survey Data

Mapping parametric vector objects on to the point cloud can overcome the slow task of plotting and locating every vector onto the cloud surface. The parametric models can also introduce the opportunity to develop detail behind the object's surface concerning its methods of construction and material makeup.

Eastman [E 2006] illustrates an example of the parametric wall, which is defined by its volume (height, width and length) and its position in a co-ordinate system relative to other objects. The thickness of the wall will depend on its composite construction, the materials and techniques that make up the walls construction are represented in layers. relates to the connection to its formation level (floors) and finishing level (roof) which can be included. Other parameters are defined by the opening sizes and positions of doors and windows.

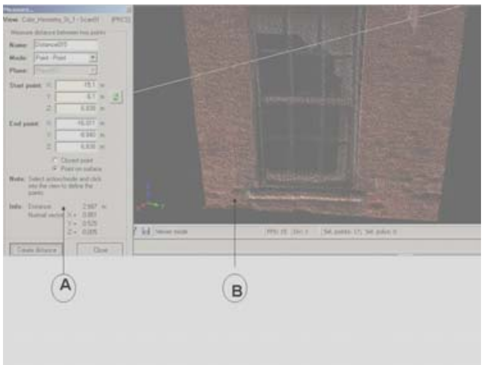

Figure 4: *Texture point cloud of a brick wall.*

In figure 4 above a section of a textured point cloud of a brick wall with an opening is illustrated, the dimensions and co-ordinates of the wall and opening are calculated using RiScanpro software [R 2006]. The dialogue box which calculates the dimensions is shown in A and the point cloud is observed in B. These dimensions can then be transferred into parametric modelling software, in this case ArchiCAD.

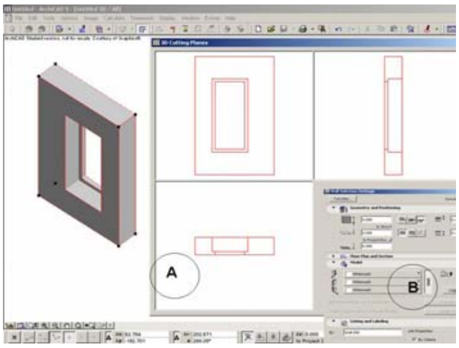

Figure 5: *Parametric Representation of the Wall.*

Figure 5 above illustrates the parametric representation of the wall built from the point cloud data as:

A – Shows the 3D model and the orthographic plan, elevation and section which is automatically created.

B –Shows a section of the dialogue box which describes all of the parameters of the wall and its opening.

The dimensions of the wall (height, width and length) and its position in a co-ordinate system were calculated using the point cloud in RiScanpro. The thickness of the wall and its composite construction were measured separately from the laser survey in this case. The materials and techniques that make up the walls construction can be determined from image data and the model can also be textured with the position image data. The opening sizes and positions of the windows were also calculated from the point cloud and are represented by a separate set of parameters.

3.4. Plotting Parametric Models from Historic Data

This research focuses on the recording and analysis of historic construction techniques used in post-medieval (from 1700 -1830) structures in Ireland. The arrival of classical architectural styles in Ireland in the early 1700s marked a change in technology and the beginning of the modern construction industry. Before the arrival of classical architectural styles, the buildings were mainly medieval in the form of fortified structures [R 1994]. The style and construction of Irish classical architecture which is based on fractal like components [C 2006], geometric proportion and a limited range of material and texture is an ideal subject for the building of parametric components.

3.5. Historic Data - Manuscript Sources

In the 17th and 18th century British architects studied Palladio's 1570 work Quattro Libri dell' Architettura and other renaissance manuscripts which subsequently have greatly influenced the architectural designs of the 1700s in Ireland and Great Britain. Palladio's principles and documentation of classical architecture were further developed by 18th century architects such as: *The Designs of Inigo Jones* by the William Kent (1727) and *A Book of Architecture* by James Gibbs (1728) [J 1986]. These later publications inspired the architectural pattern books which were published in the 18th century. The pattern books were based on the publications of the British architects mentioned previously rather than directly based on Paladio's work, creating a British and colonial Palladian style referred to as Georgian.

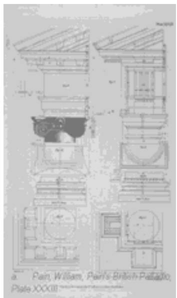

Figure 6: *Illustration from William Pain's Pattern Book*

Figure 6 is an example of an illustration from a pattern book showing Pain's 1792 drawing of the Ionic and Doric orders [P 1792]. The patterns books contained the historic construction techniques used in the 18th century such as: geometry and principles of the external and internal structure and fabric construction; positioning of openings; proportional relationship among the building's elements; and classical ornamentation.

3.6. Creation of Parametric Objects Based on Historic Detail

The following laser scan survey (figure 7) of a classical door-case constructed in circa 1730-1740 is taken as an example to illustrate the steps involved in parametric plotting of classical detail and proportional geometry.

Figure 7: *Point Cloud of Door-Case 1730*

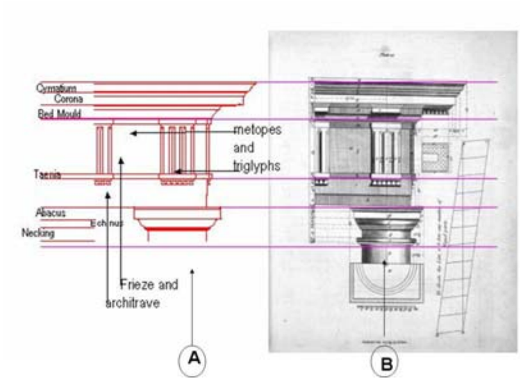

Figure 8: *Creating Parametric Objects from Historic Data.*

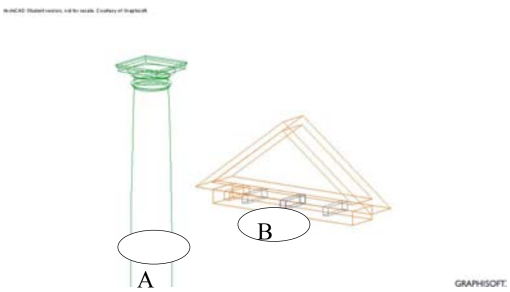

Figure 9: *Creating Parametric Objects from Historic Data.*

Initially the vector object A is modelled as a 2D parametric historic data B as detailed in figure 8. The historic data is taken again from William Pain's pattern book [P 1792]. The 3D parametric objects A and B (see figure 9) are created from the 2D vectors and the descriptive geometry of the historic texts, for example the capital and pediment are divided into modular components based on the diameter at the base of the column according to Palladian rules. The sub-component parametric vector objects A and B in figure 9 above are mapped onto the point cloud (figure 7) to form the partially completed object as illustrated in figure 10 below.

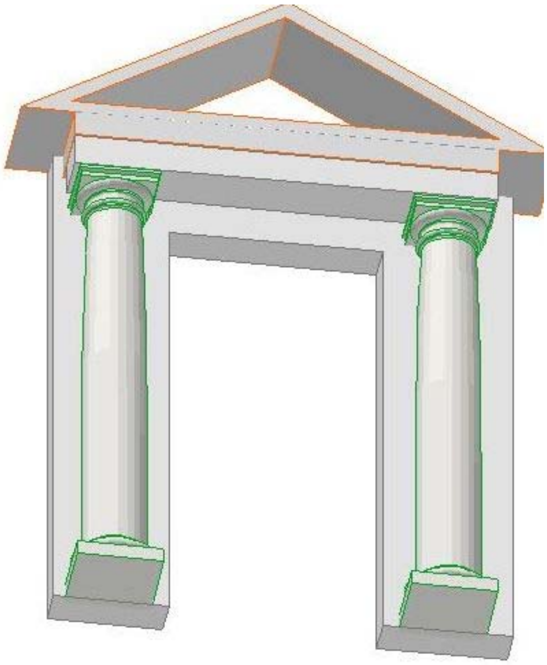

Figure 10: *Partially completed plotted parametric objects.*

The component parametric objects A and B (figure 9) which contain details of direction, x, y, z co-ordinate values and construction components (i.e. the capital, base and column can be separated) are modified to suit accurately the geometry, scale and rotation of the point cloud survey. The parametric objects were constructed using the software platform ArchiCAD. If the component objects already exist as whole or as primitive objects in a library or data base they are edited to match the requirements of the survey, otherwise they are built from GDL script as detailed in the example in figure 3. As new objects are constructed they can be contained within a database or library to be placed in the complete model of the building or as components within the elements of the building.

4. Conclusion

The flow chart in figure 11 details the proposed new methodology, this process involves the following stages: collection and processing of laser/image survey data; identifying historic detail from architectural pattern books; building of parametric historic components/objects; correlation and mapping of parametric objects onto scan data and the final production of engineering survey drawings.

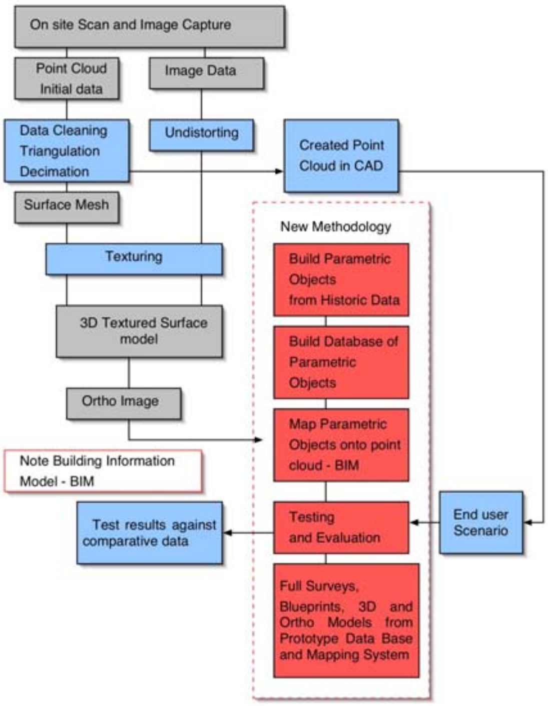

Figure 11: *Process flow chart point cloud to full survey drawings.*

Reverse engineering is the process of capturing an object's physical dimensions, geometry, and material properties to produce orthographic plans, elevations, and section and 3D models [C J 2006]. The object in this case is an element of a historic structure, an 18th century door case.

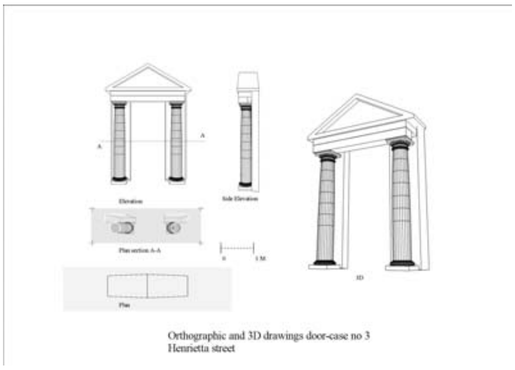

Figure 12: *Orthographic and 3D drawings*

The object is brought through the design process in the opposite direction, from the laser scan survey to the blueprint, revealing information about the original design and construction. The re-engineering process facilitates the analysis of the structure's spatial geometry, construction techniques and materials which can then be used for future conservation and maintenance planning. An example of the product of reverse engineering is illustrated in figure 12, the production of 3D vector model of an 18th century classical door case based on plotting of parametric objects onto a point cloud survey.

The process outlined in Figure 11 must be contained within a framework, this framework is proposed as:

A. A prototype data base of parametric objects based on historic data.

The following steps are proposed for the design of the prototype:

1. Identify a sample range of building components for historic structures 1700 – 1830 in Ireland
2. Identify corresponding historic detail from architectural pattern books
3. Build primitive parametric 2D objects
4. Identify the construction detail behind the surface of the historic structure using historic data
5. Build library of basic architectural components using GDL script or Boolean operation

B. A system for mapping the objects across platforms in CAD and laser/image processing software allowing for the plotting of the parametric objects onto the point cloud and image survey data.

The mapping system proposes the following user interactive stages:

1. Processing image and laser survey data.
2. Correlating laser and image survey data plotting the parametric objects onto the point cloud and image survey data.
3. Modifying parametric objects to fit accurately the geometry, scale and rotation of the point cloud survey.
4. Mapping more complex shapes as textured models onto their component parametric objects.
5. Creating the entire building, a system referred to as Historic Building Information Modelling (HBIM) i.e. full engineering survey drawings.

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