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HOW CAN CENTURY-OLD ARCHITECTURAL HIERARCHIES FOR THE DESIGN OF PUBLIC LIBRARIES BE RE-INTERPRETED AND RE-USED?

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Abstract
Purpose – The purpose of this paper is to describe a novel approach to inform heritage conservation based on the effective integration of documentation-based research with advanced survey methods for the creation of a sharable historic building information modelling (HBIM) objects database, specifically oriented to the study of Carnegie libraries whose designs in the USA and the UK were somewhat systematised by early principles of standardisation. The aim is to generate an exemplar developing new methodologies for the salvage, re-use and re-invigoration of shared inherited public buildings which have many common and standardized features.

Design/methodology/approach – This project will also involve the collaboration of conservation practice and digital recording together with library history. Digital laser scanning and structure from motion will be used together with archival documents to accurately build an information-rich framework for CAD and building information modelling applications.

Findings – By providing the base elements for the semi-automatic generation of a wide variety of morphological typologies and construction elements, this work ultimately promotes a shift towards the implementation of HBIM to support the conservation, maintenance and management of a high number of insufficiently protected public buildings from the turn of the last century.
Originality/value – The intention is that the resulting multidimensional parametric object library will provide suitable support for the faster generation of enriched 3D historic models and ultimately support the preservation of a large proportion of the huge but threatened public library building heritage in the UK and USA.

Keywords Heritage preservation, Architectural conservation, Twentieth-century heritage, Carnegie libraries, HBIM, Sustainable refurbishment

Paper type Research paper

1. Introduction

1.1 Scope of the research

As Joubert and Arayichi point out, the semantic data that can be provided by the designer of a new building at the point of creating a building information model are not generally available when looking at old buildings (Joubert and Arayici, 2017). The contribution of increasingly usable scanning techniques whether by 3D laser scan or structure-from-motion photographic methods are

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limited to providing data which record the surface finish and dimensional characteristics of a space or a building exterior. However, data generated through the systematic design review of Carnegie Libraries by the Carnegie Corporation, as well as detailed architectural trade literature of the time, offer a rich seam of information which could significantly assist in the documentation, comprehension and conservation of over 2,000 buildings which were constructed during a relatively short period of time between 1,889 and 1,910. The metadata for materials, their structural and environmental performance, their time and region of manufacture have long been classified in technicalindexes which are codified using transatlantic standards. It appears logical to re-trace the design process and adopt these regimes to build parametric constraints for new historic building information modelling (HBIM) elements (turrets, counters, revolving doors, etc.) according to the structure and ordering of information supplied where it is available rather than applying the given information to a new project in every instance. This paper presents the preliminary findings of a pilot study for creating an HBIM workflow towards defining a single but commonly standardized element of a building.

1.2 Relevance

Public libraries are under threat of closure across the world as the finances which support them are cut. Many libraries, not just those funded by Carnegie, were built at the turn of the last century often in "Queen Anne Style" (Girouard, 1984). This period, just before the catastrophic depletion of the First World War in the UK, carried with it the last full generation of tradesmen informed by tradition. The era of very high quality craftsmanship was further enhanced by new technology and the ample supply of good materials. Over time and through adaptation many of these buildings have developed serious defects in terms of leaking roofs and inaccessible entrances which tend to render them obsolete. Edwardian buildings, on the cusp of tradition and modernity, are as yet, often underestimated and so lack the support they require to be strongly protected in the UK. The Amenity societies that traditionally bolster protection leave a notable gap between the well-known Victorian Society and the Twentieth-Century Society. This gap leaves scope for neglect, expediency and rejection among decision makers who are pulled by market forces. There is an urgency to document, valorise and seek a sustainable future for these buildings. The British emphasis of this work, which will have numerous reference studies in the USA (Bobinski, 1969; Jones, 1997; Koch, 1907, 1917; Van Slyck, 1995), aims to redress an imbalance in terms of literature on Carnegie Library buildings in the UK. This work will aim to use the transatlantic basis of the Carnegie programme as an opportunity to re-invigorate discourse relating to comparable reflections of public space either side of the Atlantic today.

As the economic balance shifted from coal rich to carbon conscious in the twentieth century, light went from expensive to cheap and heat from cheap to expensive. This shift has precipitated the condemnation of many hundreds of public buildings which were engineered specifically to meet the lean targets of their day with bright single glazed roof lights to maximise daylight compensated by huge fossil fuel fired boilers. Very often the functioning aspects of decorative schemes and the way in which they covered structural joints or incorporated heating or ventilation equipment are deemed redundant because of ignorance of how these mechanisms were designed to work (Prizeman, 2015). Given that such features were standard elements of so many buildings, there is potential to make significant gains from identifying such patterns and enabling future projects to contribute to the enrichment of knowledge bases of building components. Since the 1840s, specifications determined a sequence leading from structure to finishes. It is proposed here that this archaic workflow may be used to advantage in augmenting the information relayed by surface scanning techniques.

1.3 HBIM and parametric object-oriented modelling

HBIM models and techniques are now making their first steps towards the achievement of better integrated and more efficient results. Building on original work of Murphy et al. established a method for the identification of construction methods through the use of pattern books correlated with 3D survey data (Murphy et al., 2005, 2009, 2013). Research to develop workflows for translating survey data for deployment in HBIM models is ongoing (Oreni et al., 2014), while others have explored the integration of HBIM within geographic information systems (Yang et al., 2016). The anticipated potential for HBIM to inform environmental retrofitting of historic buildings is explored by several researchers (Khodeir et al., 2016). Recent work explores the recognition and pairing of standardized plaster moudlings using 3D models from detailed scans (Echavarria and Song, 2016). Despite current limitations, HBIM appears to hold potential to be a crucial decision-making tool to support the formulation of judgments regarding the sustainable conservation of historic buildings, where observable patterns or standards exist. At present, the direct creation of 3D digital models for elements of an historic building can be extremely resource consuming or regarded as a dead-end process. An alternative is the adoption of a parametric object-oriented modelling method, based on the use of pre-constituted libraries of relevant construction elements where they are available. This could help to increase the efficiency of the modelling procedure, while adding precious information, useful for supporting stakeholders' decisions for the relevant building and for other buildings of the same construction period.

1.4 Towards an HBIM library for Carnegie libraries

This work seeks to identify standardized and common elements of Carnegie Library buildings and to classify them as such, in order to make a catalogue which is interactive and accessible as well as technically informative. The objects should contain information regarding their original purpose, aim and inception besides being constrained by a fixed range of parameter variability, which will be retrieved from historic specifications and contemporary technical literature identified through on-site surveys. Building information modelling (BIM) softwares such as ©Autodesk Revit, ©Graphisoft Archicad and ©Allplan are rapidly evolving and have started a process of adaption to the demands of heritage conservation by improving their ability to interact with point cloud data. This capacity enables the retracing of the surveyed profiles within the programme and therefore a more accurate construction of the base families. Nonetheless, a technical deficiency has been highlighted which affects HBIM when it comes to the modelling of the most complex, unique elements, which defy parametric characterisation (Tommasi et al., 2016). Here, the extensive study of Carnegie Library buildings offers the opportunity to identify a variety of construction techniques, geometries and elements which could be classified as resistant or recurrent in a bottom-up process, during a case-by-case evaluation. Finally, it aims to lead to the production of the parametric families with minimum risk of object simplification and will introduce interesting elements in the knowledge of these buildings and others of the same era. This might influence future conservation strategies, avoiding the risk that both private and public decision makers restrain scarce funding for a few isolated buildings instead of using their commonalities to develop a greater shared knowledge for technical preservation intervention where relevant.

2. Method

2.1 The stages of the process

The research will encompass four stages: production of a Carnegie Libraries map in a geographical information system (GIS) environment; photographic survey, laser scanning and photogrammetry of the libraries; archival research and document analysis; development of a gazetteer of building components common to Carnegie Public Library buildings in the UK.

2.1.1 The first stage.

This stage will involve the collation of GIS located extant Carnegie Library buildings across the UK (Figure 1). The lists of grants, existing websites and statutory lists will be used to accelerate the process. In the map, the libraries will be divided by zones within the Greater London area, Wales, Scotland, England and Northern Ireland.

The list of associated attributes will comprise an identification number, the address, name of the architect, grant date, built date, current use and references. This map will give a picture of the current situation of Carnegie libraries in the UK and provide a measure of the potential extent of the conservation issue. It will also furnish a base for future conservation interventions on a global scale, possibly promoted by the provision of the shared HBIM component library.

2.1.2 The second stage.
Once the libraries have been identified on a geographical base, a photographic survey of the remaining original buildings will be undertaken region by region. Buildings under particular threat or those that are of specific architectural interest will be scanned internally and have sufficient photographs taken externally to ensure the potential to process the data into a full digital model at a later stage without expending lengthy periods on site. Survey work therefore involves the use of digital laser scanning (DLS) inside the libraries and structure from motion (SFM) techniques for the facades.

This material will be collated both for the production of an illustrated book as well as for the proposed HBIM work. The GIS map will act as a base for efficiently organising the field visits and it will allow the organisation of the survey material on a regional base. This might help at the later stage to disclose latent local similarities, which might depend on the local architectural culture or on the specific geographical locations of the libraries.

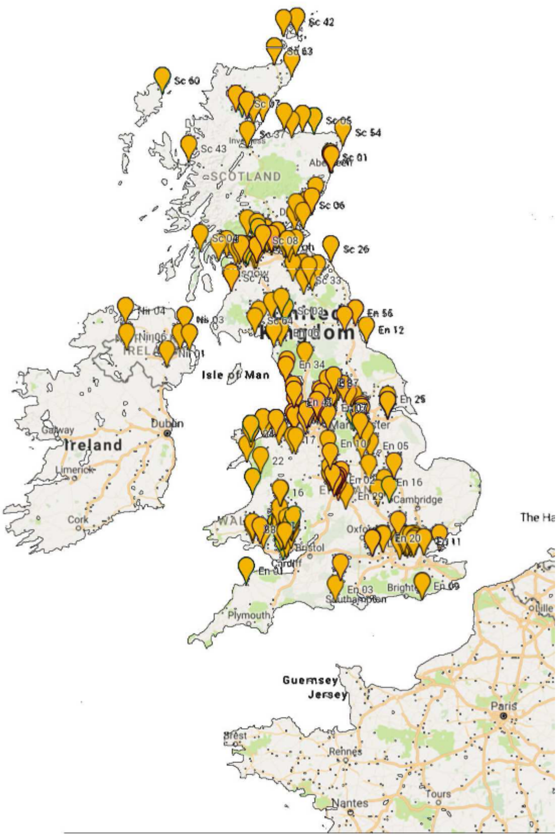

Figure 1. Carnegie Library GIS map of UK

2.1.3 The third stage.

Relevant heritage documents and archival information will be collated in order to implement the proposed integrated methodology in the following stages. This work will draw from both the Carnegie UK and US archives as well as local libraries, the Avery technical library in New York and the Royal Institute of British Architects (RIBA) library in London. The Association of Preservation Technology International (2015) has compiled a rich database of trade literature which is accessible to all. Furthermore, reviews of technical literature, in the form of annual Specification publications, and the architectural press held at the RIBA library and in many UK Schools of Architecture will add to the intensive investigation of the original design of these buildings.

2.1.4 The fourth stage.

Using archival material held in the Carnegie US trust at Columbia University and the Carnegie UK trust in the National Archives of Scotland, together with contemporary journals, a gazetteer of building components common to Carnegie Public Library buildings in the UK will be put together. From this initial review, key features of the UK libraries will be ranked by their commonality in order to develop a systematic record of components of Carnegie libraries. This will result in a new digital catalogue that outlines their original construction principles and purposes. This material will be translated into parametric elements required for inclusion in HBIM models for a selection of buildings. The project will also support a website with an interactive element. The final objective is the production of a parametric library of building object components for Carnegie libraries that can be used in HBIM (Logothetis et al., 2015). For this effort to be effective and to impact positively on current HBIM practice, it is crucial that further methods are developed to enable the sharing of knowledge. To this end, a web-based platform will be implemented.

3. Implementation of the method: some case studies

The proposed methodology was implemented in some preliminary sample case studies in order to test the effectiveness of different tools and workflows in creating a library of BIM objects, with specific attention to second stage. Initially, a few sample buildings were chosen, which were not necessarily Carnegie libraries. In the following paragraphs, a description of the different digital workflows is set out, which were developed according to the varying survey conditions. Additionally, the strategies used to develop them, as well as the various assumptions behind each decision are described. In this way, we illustrate how and when advanced contemporary survey techniques can be used as a framework to support a highly integrated HBIM heritage modelling process.

3.1 From DLS/SFM to HBIM objects

The first experimental application specifically addressed the problem of defining a digital workflow, ultimately able to produce a parametric BIM family, starting from the survey of an existing object. Furthermore, it sought to address the dimensional problem of the multiplicity of scales of the elements to survey and parameterise and the changing conditions of indoor and outdoor environments. In the end, two different pathways were tested: one starting from DLS and one starting from an ordered series of photographs, using SFM. The DLS method proved particularly efficient for the interior work, whereas the method based on SFM photogrammetry appeared more suitable for modelling the facades of the buildings or for reconstructing single monolithic objects. By using these techniques, it was always necessary to obtain a mesh that could be imported in ©Autodesk Revit software and transformed to a static HBIM object without further processing.

3.1.1 From DLS point cloud to HBIM: digital workflow.

The workflow was implemented using the internal spaces of the Bute Building in Cardiff University as a case study (Figure 2). Specifically, the open space occupied by the summer architectural exhibition was surveyed using a ©Faro Focus 3D X130 laser scanner. The process started with the indexing and registration of 16 digital laser scans of the space, which were then imported into ©Autodesk ReCap Pro. Editing the visible scene, it was possible to isolate a single element, specifically an exhibition panel (Figure 3). This element was then converted into a mesh through a point cloud application of the software. The meshing tool constitutes a distinctive advantage of the Pro version when compared with the open source alternative of the software, even though it is applicable just to the point cloud generated through DLS (the option is not available for a point cloud obtained through SFM).

Figure 2. Bute Building exhibition: point cloud of the panels

The mesh data generated in ©Autodesk ReCap Pro were downloaded and opened in ©Autodesk ReMake, where it was possible to amend errors including gaps in the continuity of the geometry and then to export the mesh in a version compatible with ©Autodesk 3d Studio Max, where it was converted into a .dwg file. Finally, a created generic metric family was created in ©Autodesk Revit where, importing the .dwg mesh, it was possible to generate a static BIM object. Subsequently, the BIM object generated through this workflow was successfully imported as a family into a sample BIM project (Figure 4).

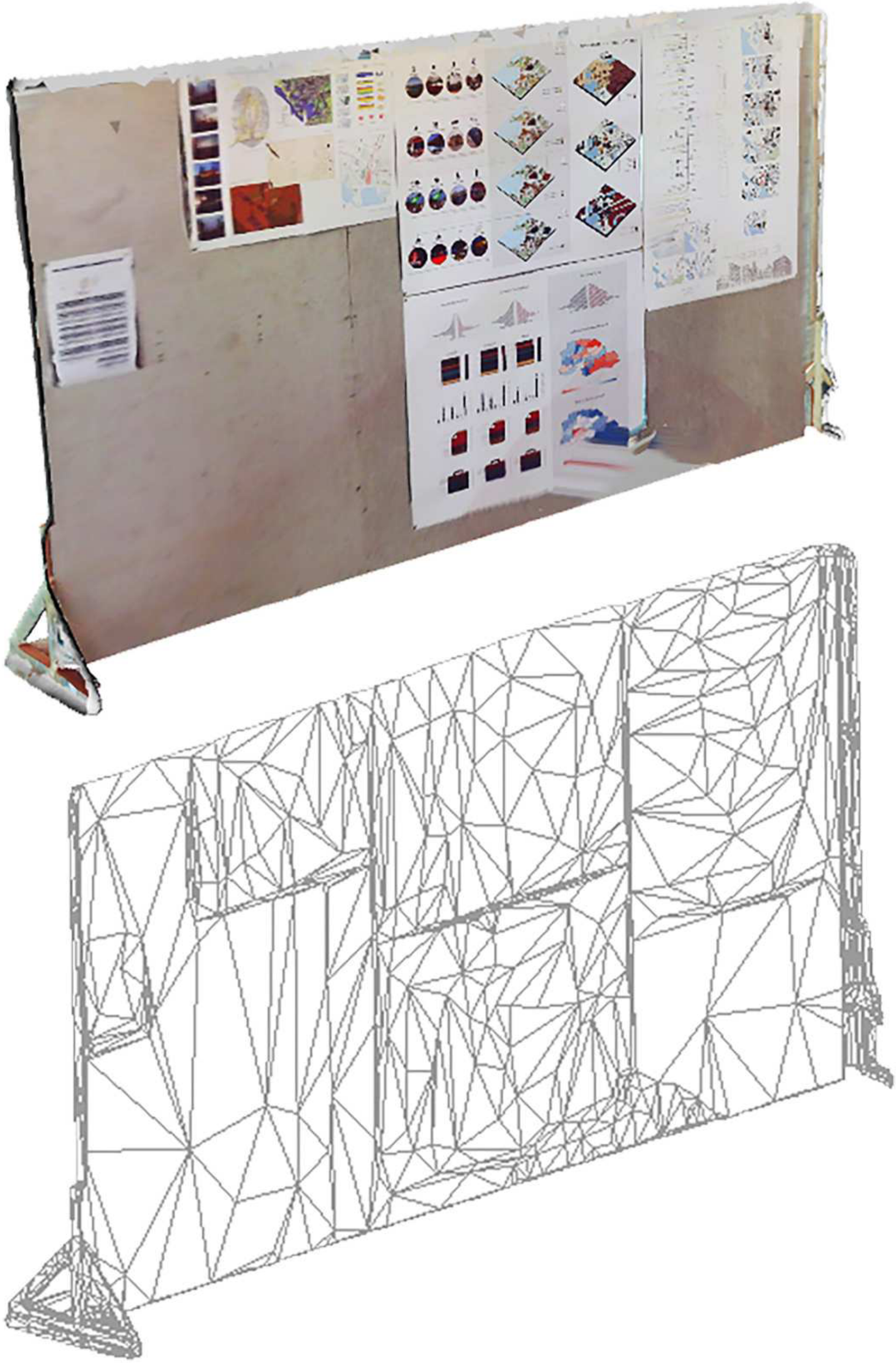

Figure 3. Mesh and BIM object of the exhibition panel

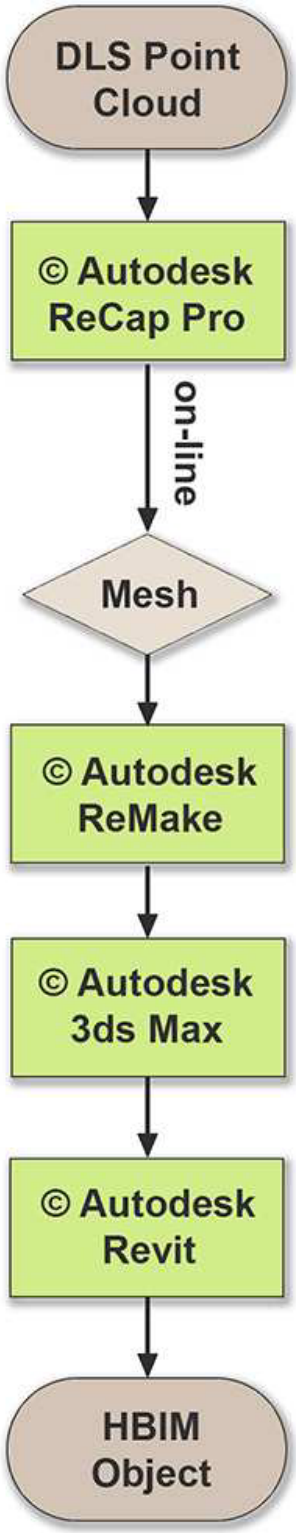

Figure 4. DLS flowchart

3.1.2 From SFM to BIM: digital workflow a (from point cloud) and digital workflow B (from mesh).

These workflows have subsequently been implemented using Cathays Library in Cardiff as a case study (Figure 5). Cathays Library is one of three Carnegie Libraries in the city. It was chosen as a test building in order to verify the suitability of the various methods proposed to survey the other Carnegie libraries in the rest of the UK. In this case, the survey concentrated on the main elevation of the building: its front facade. Due to some limitations arising during the experimental application, two parallel workflows have been developed: the digital workflows A and B (Figure 7). The first one started with the creation of a dense point cloud using professional photogrammetry software, ©Agisoft Photoscan in which 251 photographs of the Library's main elevation were aligned and converted into a dense point cloud. The photographs were taken using a Nikon D3100 at a constant focal length of 35mm.

The data processing lasted for three days, requiring 24 hours to align the 251 photographs and 48 hours to generate the dense cloud. Despite the result being generally satisfactory, the dense cloud lacked part of the façade, the central ventilation tower. However, this peculiar architectural element was present in the sparse cloud generated by the software.

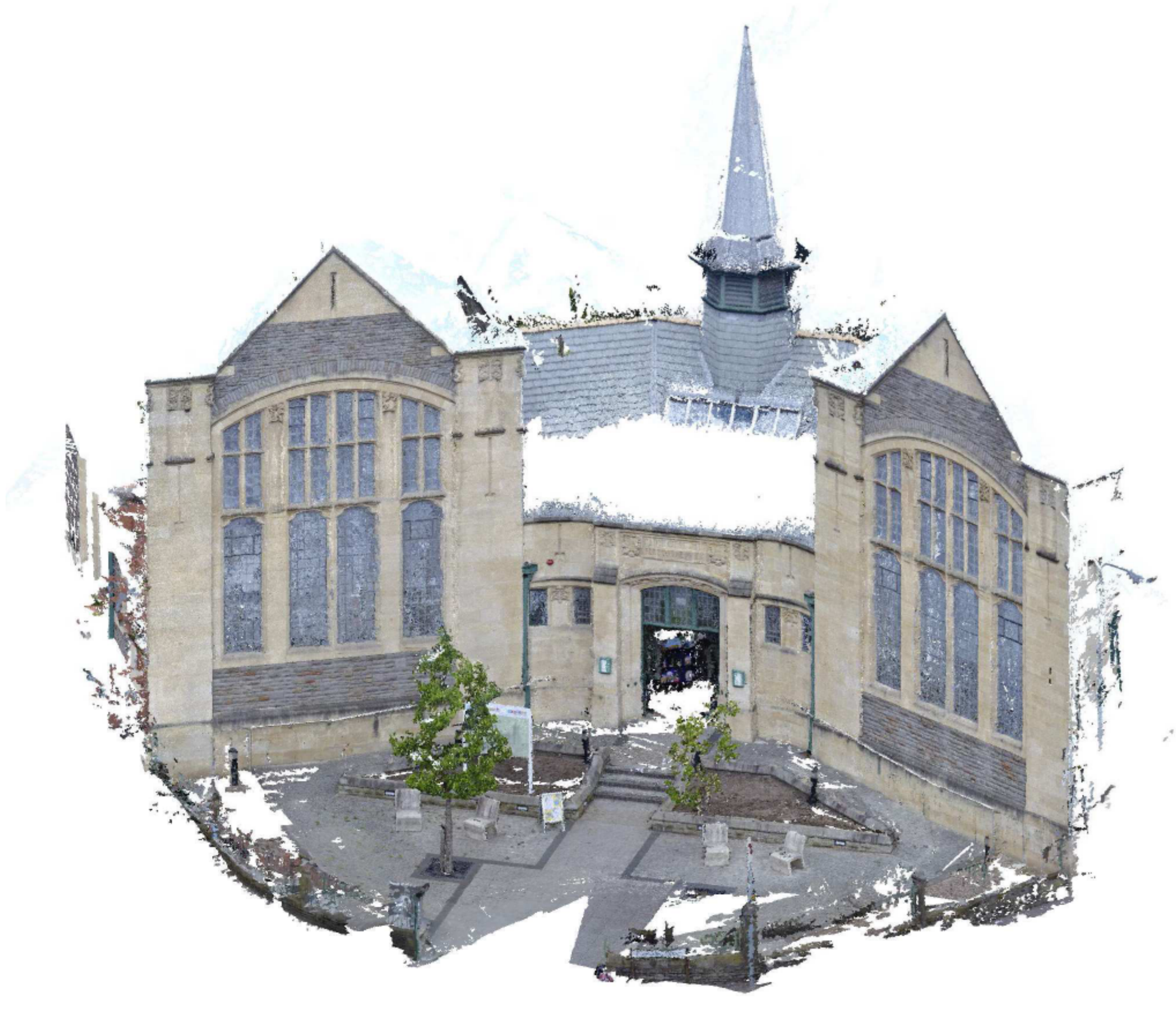

Figure 5. SFM: point cloud of Cathays Carnegie Library

In order to obtain a dense point cloud of the ventilation tower, the process was repeated another time, selecting only the pictures representing this element (about 50 photographs out of 250). This second attempt was successful and it produced an acceptable representation of the ventilation tower within ©Agisoft Photoscan. The two point clouds were then imported into ©Autodesk ReCap Pro, but it was not possible to merge the scans. Furthermore, ©Autodesk Recap did not allow the point cloud to be converted to a mesh which arrested the workflow at this stage. As a result, it was decided to create the meshes directly from the photographs by using ©Autodesk ReMake. In this case, 250 pictures of the library façade were uploaded, the maximum number allowed by the software for point cloud processing. Alternatively, the programme allows an optional off-line processing method to convert photographs into meshes. Using the cloud application, it was possible to download the mesh in a relatively short time (2 to 3 hours). The resultant mesh, however, presented considerable gaps in the continuity of the façade. Again, the process was repeated, using the previous selection of photographs, in order to obtain a detailed representation of the ventilation tower (Figure 6). The derived mesh was then imported into ©Autodesk 3d Studio Max and converted into a .dwg file before importing to ©Autodesk Revit as a generic metric family. In this case, however, the model was missing the dimensional information, so that the resulting BIM object was out of scale when compared to the one obtained from the workflow starting from DLS (Figure 7).

Figure 6. SFM: mesh of the ventilation tower

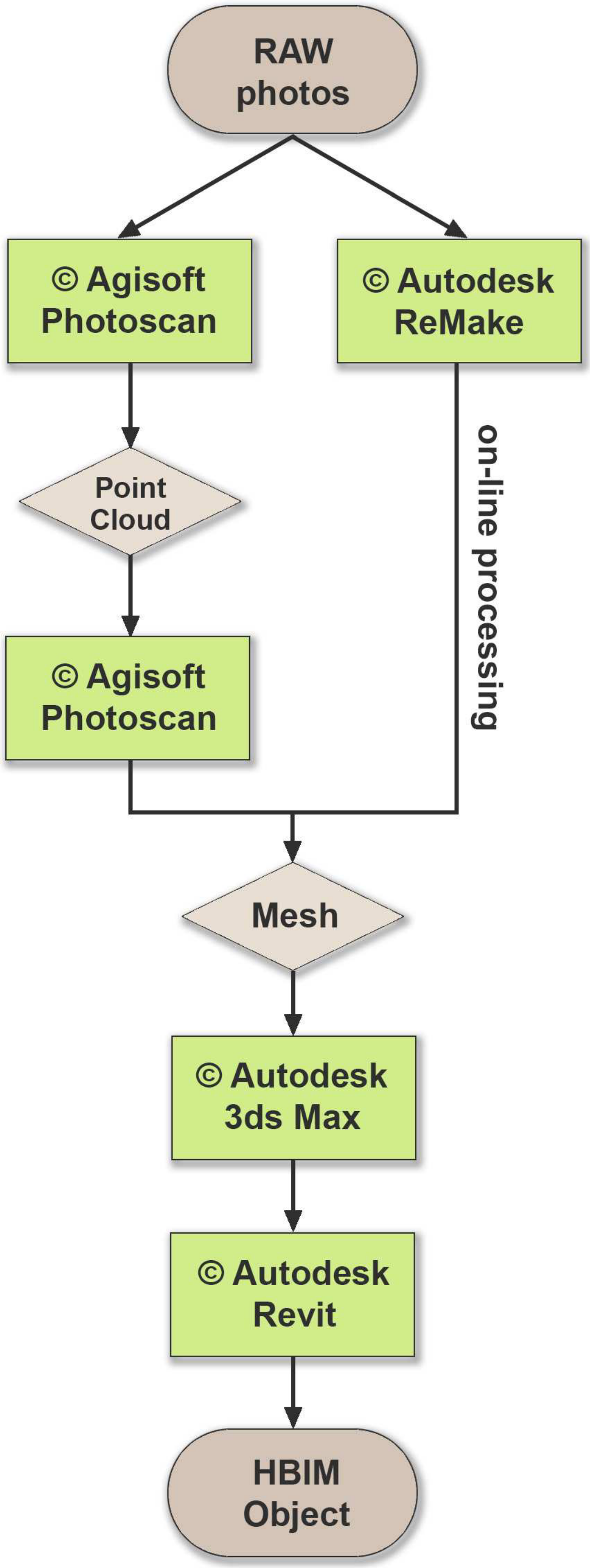

Figure 7. SFM A and B flowchart

3.1.3 From the Mesh (static BIM object) to the parametric BIM family.
The products of the DSL and SFM surveys were transformed into meshes that were then converted into objects when imported in ©Autodesk Revit. These objects became part of an experimental BIM library from which they could subsequently be imported, repeated and scaled within other projects in ©Autodesk Revit. Yet, these objects did not contain any information about the material or structural characteristics of the real elements they represented. To overcome this problem, it will be possible to assign to the BIM model the relevant information that will be collected through archival research an in situ observation. The aim will be to attribute the imported BIM mesh with data on the material and structural characteristics of the building derived from specifications and historic documents (Figure 8).

It should be noted that these BIM objects are static. This is because, when importing a mesh into the BIM environment, it is impossible to impose a system of constraints onto the object. This means that at this stage, it was not possible to define a system of parameters that would enable any variation to the dimensions of the object in order to generate a proper parametric family. As a result, attempts were made to convert the mesh into a solid, using programs such as ©Autodesk AutoCad and ©Autodesk Inventor. The hypothesis being that by importing a solid object instead of a mesh into ©Autodesk Revit, it would be easier to apply defensive constraints to the simplified geometry of the object. This could be one of the ways leading towards the definition of families of elements starting from an existing object. However, this solution still presents the problem that the final family does not contain any information about the material and structural characteristics of the architectural element. Again, it will be possible to overcome this problem with the help of the data collected through the archive research and on-site observation. Alternatively, it could be worthwhile to explore the possibility of creating a parametric family of elements containing the data (e.g. walls defined according to specifications where they are available), and then map them automatically to the mesh imported into ©Autodesk Revit.

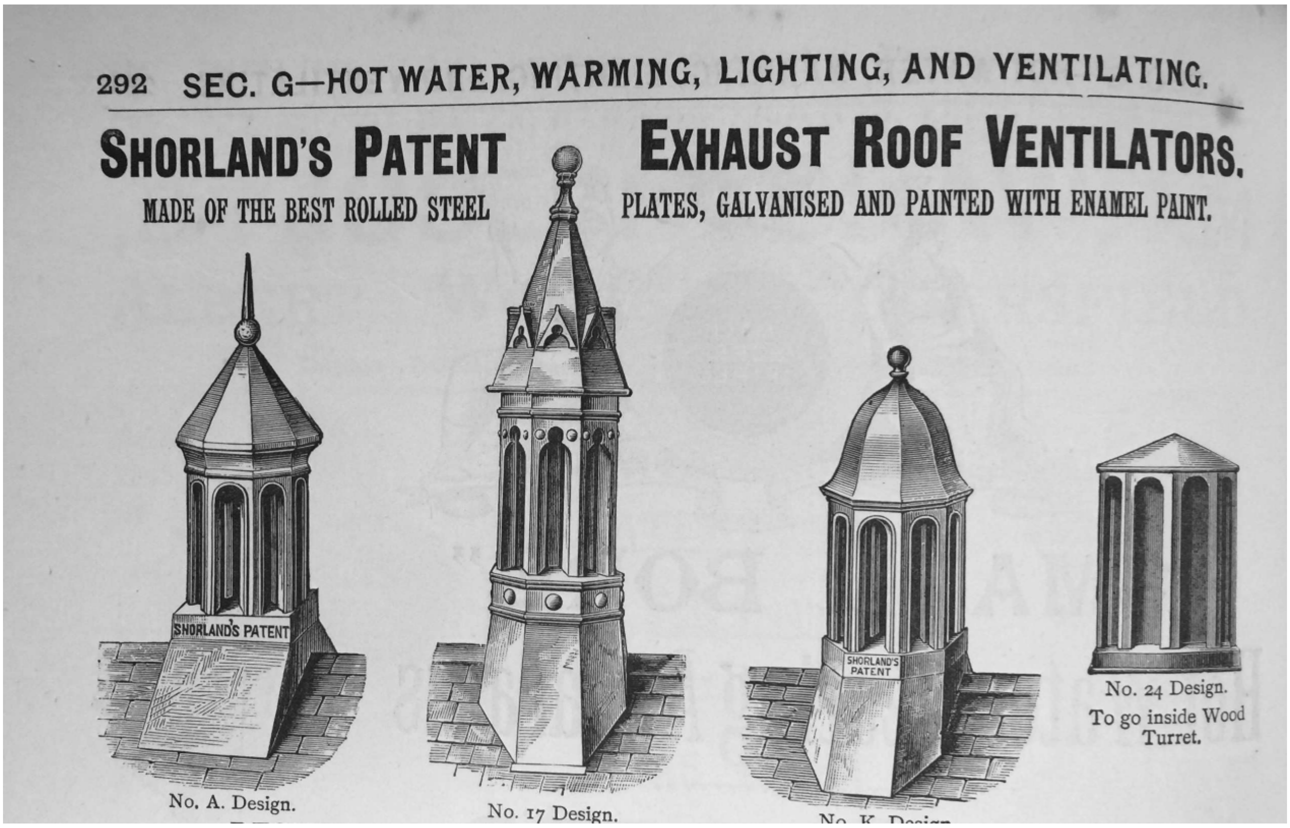

Figure 8. Advertisement for Roof Ventilators from the Architect's Compendium 1893

It is a goal for the future development of this ongoing research to address the issue of transforming a static object into a parametric and dynamic family. In this way, the aim is to generate a library of parametric flexible objects containing all the technical information suitable for re-use in the classification and modelling of other similar buildings. Furthermore, it is suggested that the creation of dynamic parametric families will improve the capacity of the library to adapt effectively to the circumstances of different cases; this will increase the level of automation in the modelling process. Furthermore, by using similar techniques, it is proposed to work in synergy with computer vision matching methods and point cloud mapping. In the next stages of research, tools such as ©Autodesk Dynamo will be tested in combination with ©Autodesk Revit, to reach this aim. To date, only a few preliminary experimental applications have been made within ©Rhino/©Grasshopper in order to test this idea (Figure 9).

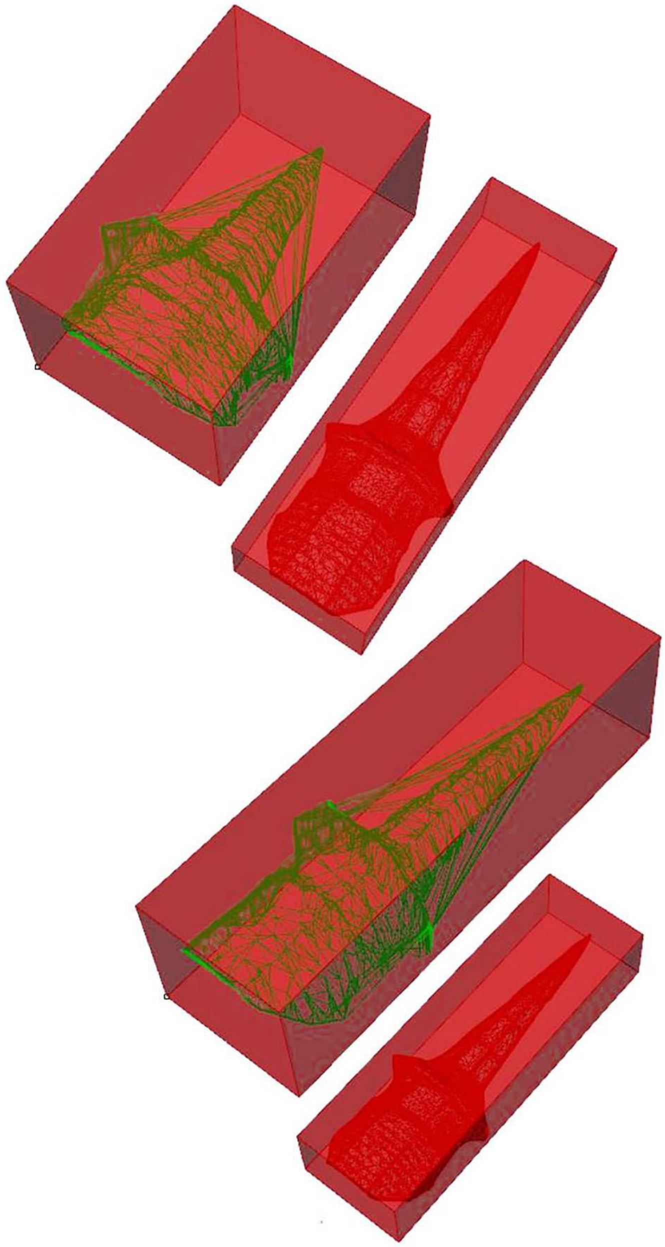

Figure 9. Cathays library ventilation tower: isomorphic transformation from the original bounding box to the target bounding box

4. Conclusions

4.1 Discussion of the partial results

A comparative analysis of the different parallel workflows has led to some considerations regarding the effectiveness of each method for the purpose of obtaining a detailed BIM object. First of all, the DNS workflow presented the distinct advantage of maintaining all the steps to obtain the BIM object inside a family of programs developed by the same manufacturer (©Autodesk). This minimised the compatibility problems between files, so that it was possible to obtain a detailed BIM object in few steps. On the other hand, when using SFM to generate a point cloud, the process started with ©Agisoft Photoscan software, which was not developed by the same manufacturer of the final programme intended for creation of the HBIM object, ©Autodesk Revit. This fact caused some problems when it was necessary to generate a mesh and import it in ©Autodesk Revit. In fact, even though it was possible to import the point cloud into ©Autodesk ReCap, it was impossible to export it in the form of a mesh. Attempts to overcome the problem were made in two different ways: first, by generating a mesh directly in ©Agisoft Photoscan, which was not successful due to the extremely long processing time; and second, starting the process using software from the ©Autodesk Suite, namely, ©ReMake. In this way, the mesh was obtained directly, and subsequently it was processed following the same steps of the DLS workflow. This second pathway, however, presents the disadvantage of imposing a limit on the number of images from which the mesh is generated, which may impact on the overall result. It is notable that the model of the façade obtained after using ©Agisoft Photoscan was much more detailed than the one created with ©Autodesk ReMake.

It is possible to conclude that the first workflow using Autodesk software and DLS was preferable for generating the digital survey of large elements, such as a façade, while the second is mostly useful to generate a digital model of small sculptural elements, such as the ventilation tower of the library. However, photogrammetry may prove preferable to DLS where, for example, there may be an opportunity to employ an unmanned aerial vehicle or drone mounted camera at significantly less cost than it would be to attempt aerial laser scanning for the capture of angles and points of view that are impossible to reach from the ground.

4.2 Future work

The state-of-the-art HBIM methodologies are limited in their failure to exploit available historic and technical documentation for the creation of highly integrated and enriched historic modelling. The original approach presented in this paper would make use of detailed design documents in order to create a gazetteer of building components able to support the evaluation of both typical and more visionary re-use strategies for Carnegie public Libraries and encourage dialogue regarding the future of these public libraries among disparate communities. Moreover, it would help to develop new protocols for public projects. Future work will include the development of a multi-modal matching strategy based on computer vision techniques. The intention is to perform automated matching between illustrations and historic technical literature and depictions of objects in photographs in order to speed up the feature cross-recognition process between the many standard elements used in the design of Carnegie Libraries.

The work will also serve to inform those who become engaged at a building scale in the alteration or conservation of Carnegie Library buildings. Architects, developers, designers, engineers (structural and mechanical) and conservators who are engaged in such projects will all have access to better means to assess and evaluate their design decisions, potentially saving money and delivering better outcomes from a conservation perspective.

The quantity of data available in terms of design direction for a single building typology held in the

Carnegie archives in the US and UK is unparalleled. This project will involve the collaboration of conservation practice and digitisation methods, education history and library history. It will aim to use the transatlantic basis of the Carnegie programme as an opportunity to re-invigorate discourse relating to comparable reflections of public space either side of the Atlantic today.

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The Arts and Humanities Research Council (AHRC) funds world-class, independent researchers in a wide range of subjects: ancient history, modern dance, archaeology, digital content, philosophy, English literature, design, the creative and performing arts, and much more. This financial year the AHRC will spend approximately £98m to fund research and postgraduate training in collaboration with a number of partners. The quality and range of research supported by this investment of public funds not only provides social and cultural benefits but also contributes to the economic success of the UK. For further information on the AHRC, please go to: www.ahrc.ac.uk

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