THE APPLICATION OF CLOUD-BASED PHOTOGRAMMETRY IN THE STUDY OF THE BUILT HERITAGE

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Abstract. This paper considers the use of cloud-based photogrammetry to collect and process 3D information pertaining to the built heritage. Although modern surveying technologies such as laser scanning are available, their application may be prohibited by cost and the need for specialist knowledge in all but the largest projects. An argument in this paper is for a wider understanding of a holistic approach to the development of better documentation techniques to study historic buildings of variable size and form. The research utilised cloud-based photogrammetry to record and present aspects of the built heritage (examples from vernacular architecture in a rural setting), and suggests a suitable workflow to assist in the collection of heritage case studies. Recording the intact built heritage in this way provides a rich data set, and one which can be readily incorporated within mainstream architectural and information modelling packages. The paper concludes with a critical discussion of the issues inherent in the method, including those of accuracy, storage and application within established CAD packages.

1. Introduction

Highly sophisticated modern surveying techniques support the collection of highly detailed geometrical surface data with regards to buildings and their landscape. However, the use of such techniques (e.g. laser scanning) to record vernacular architecture is problematic due to location, scale, accessibility and costs associated with the technology and post-processing of data.

An argument in this paper is for a wider understanding of a holistic approach to the development of better documentation techniques to study historic buildings of whatever size. Many buildings in the countryside are now functionally obsolete (Brunskill 2004, Glendinning and Martins 2009), but now is the time to aid in, if not their preservation, their documentation before they disappear (Brunskill 2004). Maudlin (2009) highlights that architecture of this form creates the' identity of place' much talked about in heritage circles and, in the housing industry, in modern 'sustainable' developments. Brunskill (2000 and 2004) also highlights that (predominantly rural) small buildings are, "essential background for the great architectural works". Maudlin (2009) adds that these forms of buildings are largely being ignored. Brunskill (2000 and 2004) alluded to the creation of 'vernacular architecture' – structures unique to local areas – as being derived from small buildings. The argument here is to consider the area rather than the building. Naismith (1985) details that the small buildings of the countryside, (and the not so small as the total number of buildings collectively in a farm can be numerous), deserve more attention than they are currently given. Naismith continues that, "*out of proportion to their numbers*" they should be considered collectively and they can cover a wide area. Considered collectively, they create 'places' and form 'relationships' with people ancestrally (Maudlin 2009, Laing and Scott 2011) or through societal links, often romantic links, such as with the likes of Wordsworth and Burns, both synonymous with their areas and places.

The techniques explored in this paper are of particular relevance to the work of the Architectural Technologist, as they bridge a gap between the actual geometry of the extant built environment and a need to incorporate such detail within architectural models. Within the design team, the Technologist in uniquely equipped to transform the use of the resultant 3D models, such that they can be utilised as model components, provide information regarding the suitability of new design features, and the manner in which they can be transformed for extraction to digital fabrication processes. The techniques, then, offer a mechanism through which the skills of the Technologist can be enhanced when dealing with the existing built environment, and the built heritage, where materials, geometry and scales may be significantly different to those encountered or utilised within new build projects.

2. Documentation Methodology

The purpose of the preceding section was to highlight two main points. Firstly, that small buildings, under the umbrella of vernacular architecture or built heritage, should be considered of high importance but also holistically and not on the scale of one individual building or complex of buildings. In other words, one building does not make a place; one place does not make a society – the study of societal and economic history, therefore, requires study of more than one building.

Secondly, doocots are a particularly good exemplar for the proposed surveying techniques highlighted in the consequent sections of this paper. Doocots have a high importance historically, a unique and (almost) alien form to modern eyes yet are now completely obsolete and at high risk of vanishing from the landscape. Their very uniqueness and importance is counterproductive to their survival in that they are difficult to convert to modern use – they are oddly shaped, large for a single use yet too small for many modern functions. In this context uniqueness simply means they are different from each other but also their various forms and the fact that most are built ad-hoc (that is unlikely to be built with 'straight' lines!) results in a very difficult conundrum when it comes to surveying. Their size may be small, but that does not mean they are easy to survey. The argument here is that they are a worst case scenario from a methodological point of view, and represent one which would be extremely challenging when using traditional manual surveying techniques.

Recently, advances in technology have moved dramatically, and have been critical in many diverse areas of construction, manufacturing and even the film industry. From a construction point of view, Arayici (2007) explains that digitisation, in a very practical sense, is an enabler for decision makers and planning. He highlights the use of digitisation for the regeneration of existing buildings overcomes many of the problems associated with them. Currently, there are now many approaches to the digitisation of the built heritage that may be adopted, and the adoption of the appropriate digitisation methodology is down to three key factors – accuracy, scale (of project) and affordability. Laser scanning and photogrammetry require skilled operatives / technicians; therefore it can be extrapolated that in building circles, an operative (to ensure accuracy is maintained) needs to know the fields of digitisation, heritage and construction. It is also arguable that the operatives should understand the wider built environment context within which scanning or photogrammetry is taking place, so as to ensure that the most relevant and useful data is collected.

3. Accuracy

The most central focus on the decision-making of any digitisation project in the built environment or heritage is the accuracy of the equipment. Accuracy dictates the detail taken in the project and the data storage capacity (that is more information, larger files). For example, data size for laser scanning can vary (depending on accuracy) from a couple of MB's to thousands. It is important to note that at the planning stage you need to know the accuracy required before you start – changing accuracy mid-way through a project is not an option unless at considerable time delay and expense. In other fields and in that of art history in particular, recent debate has concentrated on the need to consider storage in terms of both capacity and file type, with a need to consider file size and storage format. These considerations will affect the extent to which surveying is undertaken (meaning the geographical reach as well as level of detail), and may well influence the accessibility of files in the longer term, depending on storage format and stewardship of the information.

4. Affordability

Laser scanning remains an expensive, albeit highly accurate and reliable (El-Hakim *et al.* 2004). Quintero *et al* (1999) highlight this as a key issue – with the digitisation process, which usually is just a part of a larger project, taking up a lot of economic resource. As noted previously, laser scanning may not be appropriate in some locations – however, its accuracy and ability to cover a lot of ground easily and, predominantly, automatically –offers a low skill solution in large scale complex projects. Arayici (2007) confirms this by stating that laser scanning solves many problems associated with surveying buildings. Laser scanning can also encounter difficulties when faced with highly reflective surfaces (such as glass or water), which may bend or alter the path of the laser. Likewise, laser scanning in rain can be problematic, as the laser will detect water droplets, rather than the intended physical surface.

Other techniques such as photogrammetry offers less cost but is more time dependent and has a higher skill requirement. Latterly, stereo photogrammetry developments (in software) have proven to speed up the process at an affordable price, but this may be at the expense of accuracy.

5. Scale

In larger projects, economies of scale help to improve affordability, as the accuracy and speed enhance the advantages that laser scanning has over other surveying options. By scale, in this sense, it could mean the physical size of the project but also the timeline – that is scanning over several years to, for example, investigate and analyse the rate of decade on a stone monument or historic site.

Al-kheder *et al*, (2009) highlight several large-scale examples of the use of laser scanning and photogrammetry. This includes projects focusing on large heritage and archaeological sites. For smaller sites, the more cost effective but, arguably, more skill based photogrammetry is preferred. Figure 1 illustrates a still image taken from a series of scans undertaken in Scotland, showing buildings, elements of the streetscape and a large hill. To capture such data using photogrammetry would be extremely challenging.

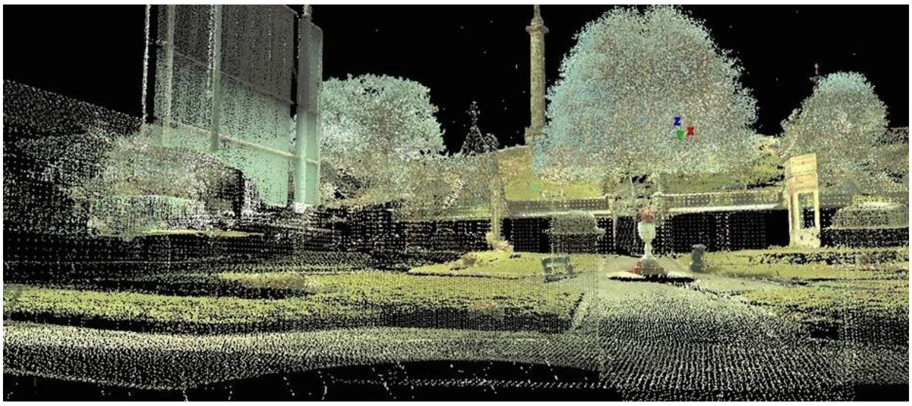

Figure 1. Excerpt from 3D high definition streetscape scan

El-Hakim *et al*. (2004) state that laser scanning is ideal for small projects, giving, "accuracy and complete details with a degree of automation". They go on to explain that cost and practicality preclude its use in small to medium projects. Arguably, small projects can be threaded together to become a collectively larger project so that laser scanning can become more cost effective. It is possible also to identify the detail achieved in small projects using a laser scanner on an ancient monument that required the need to avoid contact with the object studied (14).

6. Photogrammetry

Photogrammetry and laser scanning arguably provide a more detailed and automated process of digitisation than that possible through manual surveying and measurement.

Photogrammetry is a tried and tested technique on heritage sites around the world on all types of heritage ruins and buildings, small to large (El-Hakim et al. 2004, Al-Kheder, Al-Shawabkeh and Haala 2009, Zhan and Pang 2007, Yastikli 2007). For accuracy and digital rendering, photogrammetry can be very accurate by also provides the geometric accuracy and texture mapping required (El-Hakim et al. 2004, Yastikli 2007). The basic premise is the detection of similar co-ordinates in a photograph, and thus overlapping several photographs to create a digital 3D image – although often quite basic. To get high accuracy often requires skill and a high knowledge base by the operator, however, and this work can be long, and require a skilled worker (Al-Kheder, Al-Shawabkeh and Haala 2009). Conversely, the technology is simple and lightweight, and modern cameras provide high resolution and ease of use in abundance. With more complex 'shaped' heritage sites, the accuracy of the technique does decline – 'shadows' will be created on complex shapes and some of the detail lost.

The issue with photogrammetry is that fine detail may be omitted, thus high accuracy, it is argued, is hard to achieve (El-Hakim et al. 2004, Zhan and Pang 2007). By this, it is meant that the millimetre or micro-millimetre accuracy required at some heritage and building sites, is sometimes omitted.

Yastikli (2007) provides a good overview of what digital photogrammetry and laser scanning is, while also introducing the terminology 'stereo photogrammetry'. This works much the same as traditional photogrammetry, but with many more images (hundreds instead of a dozen) thus can be adopted on more complex shapes. Further advances in software (for example, Autodesk 123D) and continued improvements in computers and digital cameras that remove the requirement for skilled operators and improve automation of the process of stitching hundreds of photographs together mean that photogrammetry will provide an accurate, affordable and simple platform for use on heritage sites in the future. Software available, utilizing the cloud for calculation of the point cloud and mesh (Autodesk 123D) allows for digitisation of an object, automatic detection of co-ordinates in photographic images (with little expertise required) and ultimately, the creation of a scaled model (digital or 3D printed) very quickly. The use of a cloud-based modelling system is important in the context of this study for two, perhaps conflicting, reasons. Firstly, the cloud based analysis means that the processing power of the user's computer does not need to be such that it is capable of running 3D modelling software. Whilst it is likely that computers used by most Technologists in practice in the office would not encounter such issues, when working in the field the opportunity to continue using photogrammetry processes could be beneficial. As a counter to this, the use of free-to-use photogrammetry packages tends to mean a lack of control on the part of the user, in terms of software processes and adjustment of the model. Desktop based software such as Agisoft Photoscan addresses this issue, yet carries an initial financial cost to the user.

7. Case study

Fetteresso Doocot[3] (Grade A Listed) is a 16th Century, 'Beehive' doocot on a slightly sloping site, access from the east near Stonehaven, South of Aberdeen. The shape of the building and materials used provide a complex and irregular shape, with features such as three rat courses and significant 'wear' (that is cracks and subsidence) meaning a complicated survey. Surveying this structure with conventional methods would prove to be difficult and, arguably, be inaccurate. Therefore photogrammetry proved to be the most sufficient and accurate solution available. Laser scanning techniques may struggle with the sloping site (that is, it needs to be level). Although a laser scanner would be able to accurately complete this survey, the act of setting up three or four times on this site would be cumbersome and may lead to errors. Also, the smooth 'cone' like shape of the doocot itself would increase the difficulty in stitching the subsequent scans, if using 3D scanning, where a laborious use of targets would be required.

The program of choice utilised in this case study was 123D Catch by Autodesk. This uses a cloud server to generate 3D models from pictures online. The reason for online generation is due to the amount of power required for combining these images (a problem, historically, for all stereo photogrammetric stitching). This program works by loading 100-150 images of a selected subject (in this case Fetteresso Doocot) sending all these images to an online server whereby it matches up key points from every image, thus creating a 3D model. With this surveying method, because of the 3D model output generated, these images can be scaled to size and it is possible to then measure intricate areas that may have been overseen in the site investigation. The photographs should be taken in two distinct phases: phase one, general photographs; phase two, detailed photographs.

Before starting phase one, the project manager for the survey needs to have some experience of the subject and software before a full survey is conducted to maximise efficiency and accuracy. For example, it is of critical importance that the sequence in which the photos are taken follow a pattern. A clear methodological approach to the survey is required (that is the photos should not be random). The survey should start by standing a set distance from the Doocot having the entire structure within the camera shot. Systematically walking around the building, while paying attention to the distance between camera and the building, the project manager should ensure the camera is a consistent distance throughout as figure 2 illustrates. This obviously requires space around the object, and a different methodological approach should be adopted if space is not available.

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[3] A *doocot* is a structure originally intended to house pigeons. The term 'doocot' is Scots. http://en.wikipedia.org/wiki/Dovecote

Figure 2. Systematic photographic recording process

The second photographic phase focuses on the detailed sections within the Doocot so that these images would be used to create a high quality model. The detailed photographs enhance the necessary need for texture mapping (see figure 3). In order to generate the best results, photos of the subject must be taken in a dull light so that reflections do not appear. Reflections will result in parts of the final model missing, because a reflection will only appear in one image in a specific form and therefore the program cannot match this with anything else. Also surfaces with high texture details will match together easier than monotone colours.

Figure 3. Detailed photographs from site work

The model generated from 123D Catch can then be exported in several forms depending on what use is required from the output. Figure 4 displays a point cloud formation generated in CAD from an exported model. Some detailed measurements using traditional methods were taken on site to corroborate with finished 3D model.

Figure 4. Point cloud generated by photogrammetry process

This methodological approach to the survey of Fetteresso doocot proved useful for storing large amounts of data at a high level of accuracy, which could have been missed visually on a site inspection. All information from the 3D generated model can then be analysed further, giving greater opportunities for in depth investigation. It should be noted that because of the buildings height, some elements of the model are 'missing' – however, this loss of data would also happen using traditional surveying techniques. It is an example, however, where traditional techniques need to be used alongside newer methods of surveying, and supports the notion that operatives must understand the underlying construction technology, so that intelligent decisions can be taking when undertaking modelling after site work is complete.

8. Discussion and Conclusions

Advances in Stereo photogrammetry is such that surveying and modelling is quick and low-skilled (than has been traditionally so) and it is quicker than any other technique used. It does require some digital expertise to create the model, but the software now available is such that the process is mostly automated. Accuracy using this technique once the model was created proved to be good, but not as good as the laser scanning. Very few problems were encountered using this technique and both the photogrammetry and laser scanning were utilised on more complex building shapes where traditional methods would prove difficult. These buildings were not regular – both techniques proved invaluable. The fact that Autodesk 123d catch also utilises point cloud data was one of the key reasons why it was chosen, as comparative data with the laser scanned point cloud could then be made.

This study aimed to explore the processes required to capture and model 3-dimensional information using photogrammetry, as opposed to laser can data. It is worth noting, though, that import of ‘native’ laser scan data has been supported by the main modelling and BIM packages for some time (including REVIT) and that outputs from the photogrammetry processes can be readily incorporated within 3D modelling packages as surface meshes. These would normally require ‘scaling’ to ensure that they match existing parts of a model, but this can be facilitated through taking sample physical measurements on site. Within the context of an educational brief (concerning for example the built heritage), one could imagine students being able to record the details of existing features or structures, either to support the creation of new design work, or as an end in itself.

In this sort of collective project, whereby hundreds of doocots are to be digitised and the object, although small, can be very complex to digitise and model, the planning of such means that the most complex (if small) building dictates the methodology for all. It is important to be consistent in the methodology, therefore both case studies illustrate provide a robust methodology and value to the end user. Integration of techniques is possible, as both case studies produce similar point cloud data, yet true integration remains unlikely on a small building type. Affordability would rule this option out yet individually, a combination of techniques could be utilised.

The usefulness of photogrammetry within the practice and discipline of the Architectural Technologist is of particular interest. Although a traditional area for Surveying and Surveyors, the heavy reliance on digital techniques and modelling/visualisation requires a technically adept operative holding those skills typically in the domain of the Technologist. The method provides a mechanism whereby viewable virtual models of real artefacts can be generated rapidly, yet the incorporation of those models within standard architectural packages remains a technical challenge.

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