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Original article

3D digital documentation for disaster management in historic buildings: Applications following fire damage at the Mackintosh building, The Glasgow School of Art

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ABSTRACT

3D digital documentation generates accurate spatial data. This data can be processed and developed for use in a range of different applications. Within the cultural heritage sector, the use of 3D data is becoming more established to aid conservation. However, little work has been done to investigate the role of scanning surveys for postfire inspection of historic buildings with timber components. The Glasgow School of Art and Historic Environment Scotland have been working collaboratively on digital heritage projects for almost a decade. When the fire at the Mackintosh building occurred on 23rd May 2014, the joint team immediately began a programme of emergency 3D digital documentation in the fire-affected areas. Prior to this, The Glasgow School of Art had undertaken a laser scan survey of the exterior of the Mackintosh building in 2008. Subsequently, comprehensive laser scanning has been carried out throughout the whole building. This paper outlines how and why 3D digital documentation was carried out, highlighting the immediate benefits for disaster management and immediate decision making in an emergency situation and additionally, demonstrates the ongoing research benefits for the longer-term conservation and restoration of the Mackintosh. The results of the documentation produced an accurate and high-resolution 3D spatial record of a significant historic building despite the challenging material properties of the postfire interior environment. Analysis of the data provided conservation teams and building control with valuable metrics for building access, health and safety and structural deformation.

1. Introduction

3D digital documentation, commonly undertaken using laser scanning or digital photogrammetry (also known as structure from motion), can quickly and accurately create a 3D survey record containing billions of x, y, z coordinates representing the surface geometry of a target object. Archaeological landscapes, buildings and artefacts are now routinely recorded in 3D, with complex architectural and engineering structures benefitting in particular from these methods of non-contact survey [1,2].

The Mackintosh building at The Glasgow School of Art (GSA) was designed by Charles Rennie Mackintosh and built in two phases between 1897–1899 (east wing) and 1907–1909 (west wing). It is widely regarded as an internationally important historic structure and Mackintosh's iconic architectural masterpiece ([3]: 153 and [4]: 1). On 23rd May 2014, fire took hold in the basement level of the west wing and very quickly spread upwards and outwards. There was considerable fire damage, notably to the iconic library (Fig. 1), Mackintosh furniture store, the glazed 'Hen Run' corridor and studios of the western wing. The immediate response from the Scottish Fire and Rescue Service is credited as having saved the building from significantly further destruction ([5]: 5). Following the fire, there has been considerable debate amongst architectural and heritage communities on proposals for reconstruction (e.g. [6]: 26), that has stimulated new research into the architectural history of the building (R. Calvert pers. comm. and [7]), both out of the necessity of conservation efforts and through new discoveries learned through this process.

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Fig. 1. The Mackintosh building library, before and after the fire on 23rd May 2014. Before image © McAteer, Glasgow School of Art, CC BY-NC-ND 2.0.

The GSA and Historic Environment Scotland have a long established collaborative partnership in 3D digital documentation and digital heritage projects, developed through the 'Scottish Ten Project' [8,9], which involved laser scanning and data processing of large and complex sites such as Mount Rushmore National Memorial and the Sydney Opera House. Other joint projects have created 3D datasets that have been used in multiple ways for conservation, accessibility and interpretation [10,11]. This partnership enabled the joint team to mobilise almost immediately after the fire to embark on a programme of emergency 3D digital documentation. The collective experience of working on a range of highly challenging historic buildings and heritage sites around the world had generated unique expertise in health and safety considerations, which was of significant benefit to digitally documenting the Mackintosh in the difficult postfire circumstances.

Previous work on postfire survey of buildings via laser scanning chiefly focuses on structural assessment in terms of deformation and stability of the masonry or concrete (some examples include [12,13, [32]]). There has also been some adoption of scanning tools for recording historic wooden architecture in response to previous incidents of fire affecting similar structure types [14]. However, there has been little work to show the application of these techniques to historic buildings with significant timber components in postfire circumstances, particularly with the aim of digitally documenting them for conservation purposes. The programme of data capture at the Mackintosh building was intended to record as much of the original fabric of the affected areas of the building, establishing a dataset prior to anticipated remedial work. This paper documents the data capture methodology and identifies outputs and applications that were instrumental in the immediate postfire decision-making process. It also highlights findings produced from the work, including the performance of the scanning equipment in the context of fire damaged materials and further use and reuse of the data.

2. Methodology

2.1. Data acquisition

3D digital documentation of the Mackintosh building was carried out in three phases, using terrestrial laser scanning and supplemented by high-resolution high dynamic range (HDR) photography. Where circumstances allowed, data acquisition was carried out following Historic England's Metric Survey Specifications for Cultural Heritage [15]. In each phase of documentation, data was saved in both proprietary (.imp) and non-proprietary ASCII formats (.xyzi), to ensure it could be opened in future by various software programmes.

2.1.1. Phase 1: prefire

In 2008, the GSA undertook a medium resolution (6 mm point spacing) laser scan of the exterior of the Mackintosh building using a Leica Scan Station 2 laser scanner. This was for internal GSA use in a 3D visualisation project to virtually simulate the placement of the newly designed Reid building, which now sits opposite the Mackintosh. An open traverse was carried out around the exterior of the building, capturing all exterior facades and the streetscape. As it was not part of the project remit at the time, no internal digital documentation was undertaken within the Mackintosh.

2.1.2. Phase 2: immediate postfire

On 24th May 2014, one day following the outbreak of fire, a programme of rapid 3D digital documentation was begun, with the objective to record as much of the building as possible. Over the course of six days, the team carried out over 230 individual scans of fire-damaged internal areas and the full exterior of the building.

At this time, the building was under the control of the Scottish Fire and Rescue Service (SFRS) and the team worked closely with fire fighters to access as much of the interior as was safe to do so. Many safety challenges were evident, including the possibility of fire re-ignition, the presence of potentially hazardous materials, poor lighting and visibility, and slip and trip hazards. The fire service ensured the team's safety at all times and any areas where there was a threat of collapse or other hazard were not accessed. At one point, the team was evacuated from the building as a small re-ignition occurred. Added to this, the team faced technical challenges including laser scanning wet, fire-damaged and smoke-blackened timber (Fig. 2).

The Leica ScanStation C10 and Faro Focus3D 120 laser scanners were used for this phase of recording. Both scanners are time-of-flight sensors, which calculate distances and angles using a controlled laser and analysing the reflected light [16]. Both systems use Class 3R lasers that operate at different wavelengths and power levels. The Leica C10 is a pulse-based time-of-flight sensor, which directly measures the time taken for the laser light to reach the object of interest and reflect back to the scanner [17]. The Faro X120 is a phase-based time-of-flight sensor, which emits a continuous wave of laser light and measures the phase difference between the emitted and returning signals [31]. Using this combination of laser scan equipment had advantages. While the Leica C10 has demonstrable high positional accuracy (6 mm) and low noise (2 mm) [17], it weighs 13 kg and best results are obtained when the scanner is levelled during set up. The Faro Focus 3D 120 operates at a significantly higher speed than the Leica C10. This allowed many more scans to be carried out using the Faro scanner in what was a time critical situation. The Faro Focus 120 also has the advantage of being considerably lighter (5 kg) and does not need to be levelled before scanning, meaning more rapid set-ups, often on uneven floors covered in debris and in small confined spaces.

Externally, a nine-station traverse was undertaken using permanent survey markers and targets to establish survey control.