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Towards a digitised process-wheel for historic building repair and maintenance projects in Scotland

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**Towards a Digitised Process-Wheel for Historic Building
Repair and Maintenance Projects in Scotland**

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Article Title Page

Towards a Digitised Process-Wheel for Historic Building Repair and Maintenance Projects in Scotland

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Purpose – With the increasing demand for high quality economical and sustainable historic building Repair and Maintenance (R&M) allied with the perennial problem of skills shortages (PM-project management and on-site practice) investment in new technologies becomes paramount for modernising training and practice. Yet, the historic R&M industry, in-particular Small–Medium sized Enterprises (SMEs) have yet to benefit from digital technologies (such as laser scanning, virtual reality (VR) and cloud-computing) which have the potential to enhance performance and productivity.

Design/methodology/approach – A qualitative participatory action research approach was adopted. One demonstration project (Project A) exhibiting critical disrepair, showcasing the piloting of a five phased digitised ‘process-wheel’ intended to provide a common framework for facilitating collaboration of project stakeholders thereby aiding successful project delivery is reported. Five semi-structured interviews were conducted with industry employers to facilitate the process-wheel concept development.

Findings – Implementing only Phase 1 of the digitised ‘process-wheel’ (e-Condition surveying incorporating laser scanning) resulted in an estimated 25-30% cost and time savings) when compared to conventional methods. The accrued benefits are two-fold: (1) provide a structured standardised data capturing approach that is shared in a common project repository amongst relevant stakeholders; (2) inform the application of digital technologies to attain efficiencies across various phases of the process-wheel.

Originality/value – This paper has provided original and valuable information on the benefits of modernising **R&M** practice, highlighting the importance of continued investment in innovative processes and new technologies for historic building R&M to enhance existing practice and in form current training provision. Future work will focus on further piloting and validation of the process-wheel in its entirety on selected demonstration projects with a view of supporting the industry to digitise its workflows and going-fully digital to realise optimum process efficiencies.

Keywords - Historic Building, Repair and Maintenance, Digital Workflow, Demonstration Projects, SME

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Introduction

Scotland has a residential and commercial building stock of over 450,000 pre-1919 buildings where stone is an integral part of its construction. An estimated £600 million is spent annually on the repair and maintenance (R&M) of pre-1919 buildings, whilst Historic Scotland (currently known as Historic Environment Scotland -HES) invested £133million between 2002 and 2013 to support historic building repair projects (Historic Scotland, 2014). In addition, there is a plethora of industry guidance, governmental legislation and standards, such as: The Scottish Historic Environment Policy (SHEP) (Historic Scotland, 2011) and British Standard 70913:2013 (Guide to the conservation of historic buildings). Nonetheless, the recent Scottish House Condition Survey (2016) reported Scotland's combined building stock was exhibiting over 90% of levels of disrepair. This presents a critical period for Scotland's uniquely diverse stone built heritage.

A key shortcoming of existing guidance and legislation is the tendency to be generic in focus. Given that the majority of historic building R&M is delivered by Small-Medium sized Enterprises (SMEs) (professional and contractor level) there is little relevance to carrying-out and managing on-site operations for SMEs. For example, SHEP (2011) calls for appropriate technical knowledge, materials, skills and methods of working to retain historic character and future performance of older buildings, yet does not stipulate specific guidance for carrying-out and managing on-site operations. Moreover, British Standard 70913:2013 states the project management process should be as simple as possible and sufficiently robust enough to ensure supervision, inspection, communication, and documentation are seen as key elements of high quality R&M, yet does not specify a defined process for project management (PM) of historic building R&M.

In the absence of specific guidance and standards targeted for carrying-out and managing on-site operations particularly for SMEs (See McGibbon and Abdel-Wahab, 2016a), the industry tends to adopt an ad hoc approach for managing on-site processes relying heavily on subjective knowledge, expertise and subsequent judgement. For example at the project appraisal stage, the building's condition survey data tends to be captured in an unstructured manner using traditional pen and paper which is not necessarily agreed and communicated with other project stakeholders. Common industry practice involves either the Architect or the Building Surveyor passing on their assessment of the proposed work to the contractor through 'a scope of work' which is often in a generic form. Invariably the 'scope of work' relies on the contractor to provide their own interpretation of the specific work to be executed along with developing robust method statements for on-site operations. A discrepancy between what the Architect or the Building Surveyor specifies and what the contractor actually finds-out on-site is often the case. This discrepancy is evident through many projects which experience cost overruns and poor quality of work because of in-adequate project specification (McGibbon and Abdel-Wahab, 2016a).

For example, when auditors Deloitte (2014) reviewed Edinburgh's statutory repairs system, a legislative system introduced in 1991 to protect Edinburgh's historic tenement buildings, they discovered original compulsory repair works to almost 700 projects had vastly grown in scope. This had resulted in the final repair costs far exceeding expectations, on average an increase in work between 25-50%. In one project, repair work amounting to more than £1m was carried out, with about £500,000 worth of work done which was not on the original specification. Clearly, the risk of carrying-out on-site operations is transferred onto the contractor and it becomes unsurprising that delivering value for money for building repairs is a common industry problem. This problem emanates from a number of issues such as the: bespoke and specialist nature

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of the historic building R&M; lack of communication and collaboration between project stakeholders; structural composition of the construction industry which is skewed towards SMEs; prevalence of specialist sub-contracting (with its long-tail of micro-businesses); and the perennial problem of skills shortages (PM-project management and on-site practice), skills development and training (McGibbon and Abdel-Wahab, 2016a; Abdel-Wahab and Bennadji 2013; Pye Tait, 2013).

Clearly, there appears to be a gap between industry practice, guidance and legislation which is manifested in the recurring levels of disrepairs mentioned previously. These are not solely Scottish issues, various European and US studies have echoed similar issues (Vandesande et al., 2016; Baars, 2012; Finke, 2008). Vandesande et al., (2016) reported for the R&M of Belgium's historic buildings, the challenge was to improve the current management frameworks in order to reduce improper repair decisions and interventions as well as combat the lack of knowledge and information. Moreover, these challenges are not limited to the Western world (see Atakul, Thaheem and De Marco, 2014). However, to maintain focus the scope of the paper is on the Scottish context.

With the current proliferation of digital technologies (such as laser scanning, virtual reality, thermal imaging and cloud-computing) a great opportunity now exists to incorporate these technologies into practice (see McGibbon and Abdel-Wahab, 2016b). They can provide objective data capturing for informing high quality repairs and optimise on-site processes and performance, which can ultimately offer value for money to the client. For example, 3D laser scanning, is particularly relevant for the scheduling of R&M; offering typical deliverables such as accurate measured surveys, structural and condition monitoring, producing health records, 2D elevations and plan drawings in AutoCAD, in addition to a detailed 3D model (Laing et al., 2014; Wu et al., 2013; Smits, 2011; Barber et al., 2006). Visualising data in both 2D and 3D format can provide a deeper evaluation of the performance of various previous and current historic masonry repairs as well as being an effective monitoring tool for preventive diagnostics (crack configurations, structural failures, state of decay, residual moisture and humidity problems) (Costanzo, et al., 2014; Kylili, et al., 2014). Several studies (such as: Janvier-Badosa et al., 2015; Stefani et al., 2014) called for the need to promote the use of structured 2D/3D data in order to permit establishment of digital health record as well as logical project scheduling/programming of R&M work. However, in the absence of a common framework for objective data collection and dissemination amongst project stakeholders, the application of objective-data capture becomes piecemeal and disjointed. Therefore, there is an urgent need for a common process that engages all relevant project stakeholders to aid successful project delivery.

We present a 'Digitised process-wheel', which is intended for facilitating a multi-disciplinary and collaborative approach for historic building repairs. In effect a structured digital workflow that is aimed at supporting Integrated Project Delivery (IPD). IPD refers to the multi-disciplinary collaboration of various project stakeholders to ensure process efficiency and maximisation of resources for successful project delivery in-line with the client expectations (Garcia et al., 2015). Indeed, adopting a common structured process (for data capturing and dissemination) for building repairs, whilst incorporating relevant digital technologies that transcends the boundaries of traditional professional roles, is paramount for fostering genuine collaborative approach for successful IPD. Our Digitised process-wheel aim is two-fold:(i) to provide a structured approach for data capturing in a standard form that is shared in a common project repository amongst relevant stakeholders; (ii) to inform the application of digital technologies to attain efficiencies across various phases of the process-wheel.

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Current Frameworks for Construction Process Management

Currently, the Chartered Institute of Building (CIOB's) Code of practice for Project Management and Royal Institute of British Architects' (RIBA) plan of work provide frameworks for pursuing construction projects which are designed to promote a more collective approach to project delivery(see CIOB, 2014; RIBA, 2013; British Standard PAS 1192-2:2013). However, a recent industry wide report by internationally renowned law firm Pinsent Masons (2017) on the theory and practice of collaborative working in construction, argued that the industry's fragmentation and its numerous bodies and organisations makes it difficult for a clear lead to come from any one consistent source. Moreover, the report concluded these frameworks have a tendency to promote silo-working as they are more suited to their relevant professional organisations. In addition, SMEs lack awareness of these PM frameworks and question their relevance for true collaboration given the industry's risk averse culture (Pinsent Masons, 2017). It follows that there is a disconnection between current PM process frameworks for construction as they are not integrated with on-site practice undertaken by SMEs (Poirier et al., 2015). Whilst current PM frameworks, such as RIBA and CIOB include maintenance as part of their agenda, they are not explicit and only infer that they can be adapted for the historic building R&M, refurbishment, and conservation sector. As such, Council on Training in Architectural Conservation (COTAC) (2016) have attempted to address this gap, by developing a historical building information modelling (HBIM) framework to guide the digital documentation of historic buildings. This overlaps the current wider construction industry frameworks; however it is very much in the conceptual stage and has yet to be piloted on a project. Furthermore, the definition and naming of the work stages in the HBIM framework does not reflect the terminology and work-processes that are undertaken by the historic building R&M SMEs, for example, describing the project appraisal stage in unfamiliar terms such as the identification, research, and options stage. Therefore, the historic building R&M sector requires adopting a more industry relevant framework that promotes not only a multi-disciplinary approach but also provides a defined delivery structure which accurately reflects R&M practice for optimised project delivery.

Thus adopting an integrated project delivery (IPD) approach can remove the contractual silo walls that separate the key participants, and collaboratively involves key participants very early in a project timeline and can result in optimal project outcomes (i.e. time, cost, quality and sustainability) (Garcia et al., 2015). Many protectionist and redundant processes that do not add value can be eliminated as it has been shown to achieve statistically significant improvements in project performance (Asmar et al., 2013). IPD has the ability to provide a collaborative platform for enhanced communication and sharing of tacit knowledge between team members, resulting in increased connectivity and interdisciplinary knowledge (Zhang et al., 2012). As such, IPD projects typically use some form of Cloud computing to facilitate the free exchange of ideas and project data (Cooley and Cholakis, 2013). Moreover, IPD contracts are known as "relational" contracts as consideration is given to not just to the end product but the process itself (Ghassemi & Becerik, 2011). However, "traditional" contract project delivery processes are still used in the majority of historic building projects and their adversarial nature presents troubling questions that hinder organisations from exploiting the full benefits of these types of collaborative technologies (Crompton et al., 2014). Yet, current innovative surveying, monitoring and evaluating technology such as 3D laser scanning and IRT along with digital tools such as NBS Create and Building Information Modelling (BIM) are specifically intended for multi-disciplinary centralised collaboration of the kind advocated and absolutely relevant for R&M (McGibbon and Abdel-Wahab, 2016a). Moreover it has been intimated that combining BIM tools, such as 4D modelling with IPD can further enhance the project delivery (Umar et al., 2015).

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Digitisation trends in construction

As previously mentioned, there is growing research evidence for the accrued benefits of embracing digital technologies for enhancing project performance and realising process efficiencies for historic building R&M. COTAC (2016) suggested that digitisation could enhance work prioritisation, project scheduling; programming and monitoring work progress. Whilst, McGibbon and Abdel-Wahab (2016a) in their study of repairs to two historic building located on the outskirts of Edinburgh, reported using a digital laser scan combined with traditional methods of survey had provided invaluable data, aiding visualisation of the required scale of maintenance (material and skill requirements). Shaughnessy (2015) argued that the ability to communicate within a unified platform, through the use of mobile Apps and cloud computing, could enhance the documenting and monitoring of a restoration project from survey to project closeout. Studies by Ouimet et al. (2015) and Hayes et al. (2015) surrounding the restoration of Ontario's Parliament Hill buildings explored further the potential uses for 3D data such as 3D printed scale models, CNC carved maquettes, robotic stone carving and digitally-designed replacement elements, resulting in the development of a digitally-assisted stone carving process. There are undoubtedly great benefits, in terms of enhancing process efficiency and performance.

Despite the aforementioned benefits for embracing digital technologies, the current approach could be described as piecemeal and sporadic. Moreover, the attainment of a fully digitised workflow for construction processes is hampered by the absence of a common structured industry process for carrying-out building repairs. Therefore, we call for both a structural digital workflow that will incorporate or integrate relevant digital technologies for achieving optimum process efficiencies. With the current processes for carrying-out construction work tending to be for generic construction projects, as set-out by professional bodies (RIBA and CIOB). These processes are inclined to reinforce the lines of demarcation between different professional roles as opposed to facilitating collaboration which is paramount for the multi-disciplinary and sympathetic approach required for the repair of historical buildings. The next section discusses our approach for the development and piloting of our process-wheel.

Research Method

We adopted an action research strategy with the intention to solve an industry practice problem and to produce guidelines for best practice (Denscombe, 2010). Specifically, we are adopting a qualitative participatory action research approach through proactive engagement with relevant industry stakeholders. The problem we are addressing is the lack of structured and collaborative approach for building repairs – as discussed above. As action researches involves pursuing research into practice undertaken by those involved in that practice, with an aim to change and improve it and produce practical, useful knowledge (Connaughton and Weller, 2013). One of the researchers applied their 30 years' experience in the field as both a practitioner and lecturer in historic building R&M to evaluate the challenges of new technology and innovative practice adoption on the demonstration project, to be able to formulate appropriate conclusions.

In our pursuit for the development of a process-wheel, a comprehensive data collection plan was adopted which included: (1) reviewing current industry best practice, guidance reports, and standards on construction processes; (2) researching appropriate digital technologies to be incorporated into the structured framework; (3) semi structured interviews with SMEs for validating our process-wheel; and (4) piloting and preliminary evaluating the process- wheel on a live demonstration project. Our process-wheel concept is intended to provide a common framework for facilitating collaboration of project stakeholders; in-particular

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3 SMEs, thereby aiding successful project delivery. As such the framework developed by the authors in
4 consultation with SMEs which allowed accurately capturing and reflecting the work phases of SMEs
5 operating in the R&M sector. Our process-wheel concept comprises of the following phases: Phase 1, Project
6 e-Appraisal; 2, Project e-Set-Up; 3, e-On-site Practice; 4, Project e-Handover; 5 Project e-Defects
7 Rectification (Figure 1). For each of these phases, a standard data capture e-form was developed with a view
8 of using on live sites. For example, for the Project Appraisal phase, an e-Condition survey was developed to
9 provide a structured and standard approach for data capturing by the SME contractor.

11
12
13 Figure 1. Structured Digital Workflow Phases

14 Whilst, our *process-wheel* was designed for the Scottish historic building R&M sector, the intention
15 was to develop a framework which could be both scalable to project size and definition as well as be
16 implemented across the wider UK and EU R&M industry. Therefore the *concept* was mapped and formatted
17 against existing wider UK construction industry leading organisations' PM guides, industry led digital
18 frameworks and a developing HBIM framework (Figure 2).

19
20
21 Figure 2. Process-Wheel mapped onto existing PM frameworks

22
23 To facilitate the process-wheel concept development a series of semi-structured interviews were
24 carried-out (in person, lasting approximately 60 minutes) with industry employers. To ensure the reliability
25 and quality of interviews, a purposive approach was adopted to select interviewees; minimum 15 years of
26 experience in historic building R&M sector; diverse professional experience; and held top-level management
27 positions within their organisations - see table 1. By drawing on their wealth of combined length and breadth
28 of industry experience a series of open-ended questions were posed surrounding; (1) the challenges facing the
29 R&M sector which confirmed our literature review findings that there is no common and structured process
30 for undertaking on-site operations in the R&M sector; (2) the general challenges facing implementing new
31 technology and processes.

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33
34
35 Table 1. Backgrounds of interviewees*

36 *In addition, the lead author of the paper has 30 years of experience as a contractor and consultant

37
38 Interviews were recorded, then transcribed and based on interview feedback qualitative thematic
39 analysis was used to identify, analyse, and report topics arising from the interview data (Denzin and Lincoln,
40 2011) Therefore, for the thematic analysis, Braun and Clarke's (2006) procedural guidelines; data
41 familiarisation; code generation; theme search; theme review; and theme definition and naming to allow it to
42 be grouped in a systematic way, allowing different themes and sub-themes to emerge from data. The final
43 stage of the research data collection was to pilot and evaluate the process-wheel on a live demonstration
44 project. For the construction industry when there is a high degree of unpredictability, pilot studies and
45 demonstration projects (PDP) are good means to add value to the research as they represent bridges between
46 basic knowledge generation and industrial application and commercial adoption on the other (Smyth, 2010).

47 The "live" project was selected for two key reasons; (1) relative complexity in terms of data capturing
48 with regards; the intricate nature of the repairs (planar, moulded and curved surfaces); variation in
49 architectural elements being replaced (lintels, cills, rybats); structural cracking to stone elements (2) need for
50 effective communication and collaboration between the numerous stakeholders involved in the project;
51 Building Surveyor, Structural Engineer, Contractor and Client.

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Due to project time and resources constraints the process-wheel was not implemented in its entirety, focusing on the project appraisal (surveying) phase and to some extent the set-up (project planning/logistics) phase. We piloted our proposed process-wheel (phase 1 and 2) in-tandem with conventional work processes, but on separate days in order to avoid disruption to on-site operations with a view of providing a comparative analysis for evaluation. We captured both processes using video recordings and digital images. The aim was to build-up the case for a 'digitised process-wheel' and raise awareness among the SME R&M community for both a structured work-process as well as embracing digital technologies. We set-up a 'Scottish R&M forum' as a platform for the dissemination of the digitised process-wheel as well as sharing ideas for modernising training and practice in the Scottish R&M sector. We held two events: one in September 2016 and another one in January 2017.

Findings and Discussion

The Perceptions of Five Experts Involved in Historic Building R&M Practice

To gain an industry perspective on the challenges in modernising and enhancing R&M practice, the perceptions of five key SME players involved in Historic Building R&M (Table 1) were sought. The replies offered a number of challenges not dissimilar to the wider literature. However influenced by their background in an SME capacity, they offered deeper insights into historic building project management challenges namely; lack of effective communication and collaboration, project financing, skills development, enhanced data capture, cost/accuracy of technology. Despite these challenges, they did acknowledge that change was inevitable and all five respondents believed addressing the following two strategic process challenges were fundamental in attempting to modernise and enhance practice;

(i) *Silo working* remarking that "it is typical to work in isolation, particularly at the pre-project stage as there is a reliance on professionals (such as Building surveyor and structural engineer), when in fact the appointed contractor has a huge amount of untapped practical experience and knowledge that could be utilised so much more effectively and contribute value, in terms of project requirements/scope of the work; on-site quality and efficiency as well as provide better working relationships". They attributed this to the fragmented nature of the industry coupled with the restrictive and combative nature of 'traditional' procurement routes allied with clients' predilection to select the lowest price and not on who is most suitably experienced and qualified.

With the current construction industry frame works presenting a contradiction in terms of improved collaboration and communication. Perhaps, adopting an IPD approach is a way to circumvent these traditional ways of working and aid effective team working, given the main principle of IPD is to involve the trades early in the design process through the use of multi-party contracts (Garcia et al., 2015). Although implementing a more integrated approach, where a highly collaborative working environment in which shared values and goals are the vision, for some may mean 180° turn in terms of their current perspective. Therefore exemplars of the benefits (financial, efficiency, performance etc..) of adopting this type of collaborative approach will be fundamental in promoting its uptake.

(ii) *No defined R&M process* challenging the need for a cohesive structured approach to project delivery stating "the whole process seems very disjointed". However, they recognised that the propensity of the sector to use specialist SMEs at both consultant and contractor level coupled with the intensity and diversity of historic building R&M information makes it difficult to holistically PM. A perspective that is borne out in reality; recent research surrounding two case studies of historic building R&M found that both

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3 projects had encountered the PM challenges of an increase in project budget; planning; programming; as well
4 as difficulty in recruitment (McGibbon and Abdel-Wahab, 2016a). When questioned further they offered
5 alternative methods of working such as a technology linked pre-defined workflow as a way to enhance
6 communication and collaboration through the sharing of tacit knowledge between project members, believing
7 there was an opportunity to have a workflow pipeline which is readily accessed from survey, to procurement,
8 to manufacture to installation with the ability to react in “real time”.

9
10 With regards the implementation of new technology they believed there were three key themes that
11 required addressing; *raising awareness, resistance to change/industry engagement, skills development*.
12 Perhaps introducing new technology and processes at Further Education/Higher Education level by providing
13 a series of formal trainee and upskilling continued professional development courses for the existing
14 workforce (Abdel-Wahab and Bennadji 2013; Pye Tait, 2013). This could be a way for the workforce to gain
15 the necessary skills and knowledge needed to achieve the uptake of innovative technology. Furthermore this
16 could provide an opportunity to tackle the other two key themes identified and raise the image of the
17 construction industry by promoting that it is high-tech and not for underachievers (Abdel-Wahab, 2012).

18
19 Finally, when questioned about the developing *process wheel* they all agreed; it would be “a welcome
20 addition to our existing toolkit allowing us to gain a better understanding of previous projects, what went
21 right and what went wrong”. However, when questioned further they admitted they are inclined not to adopt
22 technology that requires too much investment as they view this as too much risk. This is consistent with the
23 findings of (Hardie and Newell 2011; Sexton and Aouad, 2006) who investigated the barriers of the uptake of
24 technologies by SMEs. Nonetheless, such was their interest they enthused they were more than willing to be
25 proactive partners to develop and lead the use of the *process wheel*, reiterating the need to create a raft of
26 demonstration projects showcasing the potential benefits.

27
28 In addition, they repeated the need for valid data on the capabilities of relevant new technology.
29 Evidenced by a demonstrable return on investment (ROI) particularly given workflow process digitisation
30 was very susceptible to efficiency gains at scale (the more frequently used, the lower the cost of each project
31 becomes) (Stroeker, & Vogels, 2012). Interestingly, Interviewee D and F offered an area that could be further
32 enhanced is the relationship between the supply chain, the design team and the contracting team. For
33 example, once the captured data is modelled and documented. The number of stones that are required for
34 each project can be extracted into an electronic cutting list and digital templates can be produced. This digital
35 information can then be sent directly to stone supplier for manufacturing which would result in a quicker
36 turnaround for all parties involved.

41 42 43 *Preliminary findings from Demonstration Study*

44 45 *Overview of Case Study*

46
47 For the demonstration/case study, a project site located within a conservation area, on the West coast
48 of Scotland, (approximately 30 miles from Glasgow) was selected. The building is a typical pre-1919 red
49 sandstone block of tenement flats with a 10m high ashlar front façade undergoing a series of masonry R&M
50 interventions, such as stone replacement (Figure 3). The *Process wheel* was not implemented in its entirety
51 due to project financial and time constraints; the limited timescale allocated for the ‘live’ project (4 weeks)
52 whilst the small amount of available budget made it difficult to resource all the intended technologies within
53 the designed structured digital workflow. Therefore, it was decided to focus on phase 1; *Project e-Appraisal*

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(*e-condition surveying*); and to some extent phase 2; *Project e-Set-Up*. As part of the *e-condition survey*, 3D laser scanning of the building façade was incorporated to help capture and inform the proposed scope of works and identify the nature and scale of the stone repair required e.g. number of stones to be replaced and extracting accurate dimensions for creating templates. A 3D laser scan on-site was carried-out (using Leica 3D laser scanner: Laser class 1 in accordance with IEC60825:2014) with a remit of capturing point cloud data at various levels of scan resolution (Table 2).

Figure 3. 3D laser scan of Façade

Table 2. Scan resolution of Point Cloud data

This allowed the capturing of data from a global level to a regional level to a local level. The point cloud data captured at 1.6 mm of spacing at 10 m also enabled taking accurate measurements thereby eliminating the need for multiple trips to site (Figure 4).

Figure 4. High resolution laser scan of the ground and first floor

From the author's experience the majority of dimension recording at this stage of the project tends to be based on a ground survey process which relies heavily on the inherent tacit knowledge and experience of either the contractor or the consultant (Armesto-González et al., 2010) presenting a number of quality issues. However, this approach permitted the production of highly accurate and detailed measurements of only the architectural elements being replaced. The creation of a 3D model and 2D CAD drawings of each element (5 in total) using Autodesk Architectural Revit and AutoCAD 2014 generated highly accurate 2D section drawings of individual stones with each element drawing showing basic dimensions (length; breadth; height) (Figure 5 & 6). This allowed the creation of highly accurate stone carving profile templates of the decayed stonework without the need to cut into the façade, as well as providing a reference point for quality assurance for ensuring good workmanship.

Figure 5. 3D Revit model and 3D Point Cloud Data

Figure 6. 2D CAD drawings

In addition to the laser scan data, an *e-condition report form* held on an industry recognised cloud platform (Trimble connect) was populated (using an I-Pad) to provide a structured approach for capturing additional relevant information in relation to stone type and the nature of the stone repair required. Capturing structured data can also aid in informing costs estimates and supporting the development of *e-Risk Assessment and Method statements*. These in turn can facilitate the provision of an *e-Quality Assurance checklist* to ensure that the repairs have been carried-out to the required standards. As *e-forms* can be easily created and exchanged all the information was stored in electronic format, allowing the forms to be uploaded directly to the project information repository at the point of data collection and provided real-time information to project stakeholders.

Table 3 below demonstrates the benefits accrued from the use of conventional on-site processes compared to the SDW for the surveying process. For example, the *e-form* eliminated the need for duplication

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as currently on-site data (stone characteristics, scope of work, site logistics etc.), in the majority, are hand written then transferred to digital format off-site and it can take at least a full day or more, dependent on the scale of the project. This is borne out when comparisons with the conventional survey were carried out; a 25-30% estimated time and cost saving was experienced. These figures were based on the assumption both consultant and contractor rates were similar in nature.

Table 3. Conventional Survey Process and SDW Comparison

In order to better deal with dynamic environment of the construction site, 360° Virtual reality (VR) photos were captured using a free and readily available mobile App (Optonaut) and viewed using inexpensive VR headsets (Google Cardboard). By creating an immersive experience in order to support a higher level of spatial awareness of site constraints, visualisation of stone repair areas and inform site logistics. Using these low cost, easy to use devices allowed the visual and interactive transmission of project information without the need for sophisticated computer skills. Furthermore they enhanced collaboration between all stakeholders in the project, in particular client communication providing them with the ability to be immersed into the project, experiencing the work as it was occurring and enable real-time insights into project progress. Additional benefits of using digital technologies included reducing the health and safety (H&S) risk; particularly working at height e.g. using a laser scanner eliminated the need for a scaffold to be erected when taking dimension measurements. As the application of the aforementioned technologies, as part of the new process wheel, not only enhanced the quality of data captured; improved project communication they also highlighted possible enhanced productivity performance.

Conclusion

Our digitised process-wheel is a means for attaining a multi-disciplinary and collaborative approach for building repairs which the wider industry has been yearning for in numerous government reports. As we said at the outset, there is no definitive procedure for the planning and execution of the practical work and we are not suggesting that the framework presented above is the only 'right' methodological approach to take. However with the increasing demand for delivering high quality building repairs and delivering value for money, the need for modernising, optimising on-site processes and effective project management becomes fundamental. The demonstration project revealed that a move towards a digitised process-wheel provides a good basis for heritage documentation (3D model generation) by demonstrating how a 3D model of the elements being repaired could be used to modernise on-site practice, such as extracting 2D-templates for stone-cutting. Yet to arrive at a deeper understanding of the challenges facing modernising and enhancing existing R&M practice there is a continuing need for similar demonstration project based data, which would be a welcome addition to growing data such as Historic Scotland's (2012-16) refurbishment case study series and contribute to the development of a wider knowledge of the major challenges to delivering successful historic building R&M in Scotland. Our future work will focus on piloting and validating the '*process-wheel*' in its entirety on demonstration projects. Identifying and incorporating the relevant digital-technologies (in the context of demonstration projects and the process-wheel) will be instrumental for showcasing the impact of a digitised process for streamlining R&M operations and enhancing both practice and training.

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Figure 3.3D laser scan of Façade

61x82mm (150 x 150 DPI)

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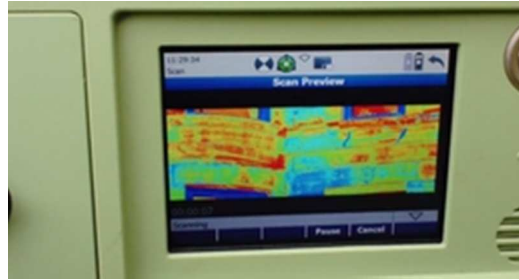


Figure 4. High resolution laser scan of the ground and first floor
43x23mm (150 x 150 DPI)

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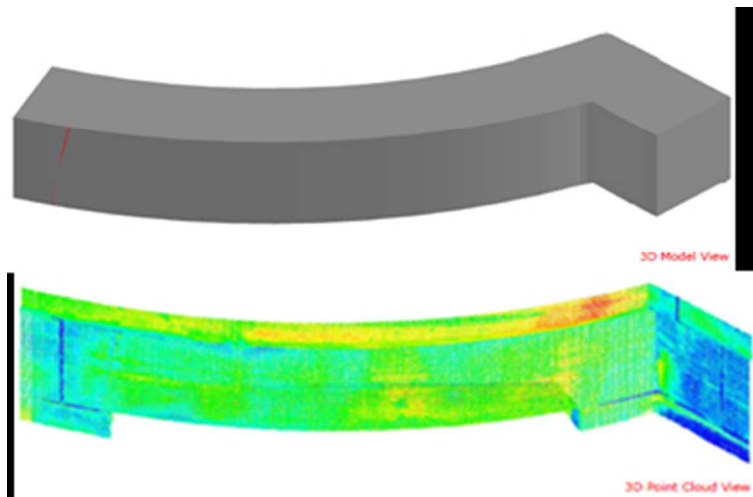


Figure 5. 3D Revit model and 3D Point Cloud

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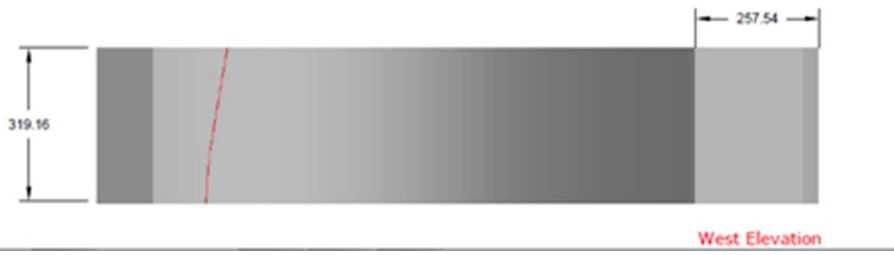


Figure 6. 2D CAD drawings

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Journal of Cultural Heritage Management and Sustainable Development

Article Title Page

Figures Research approach

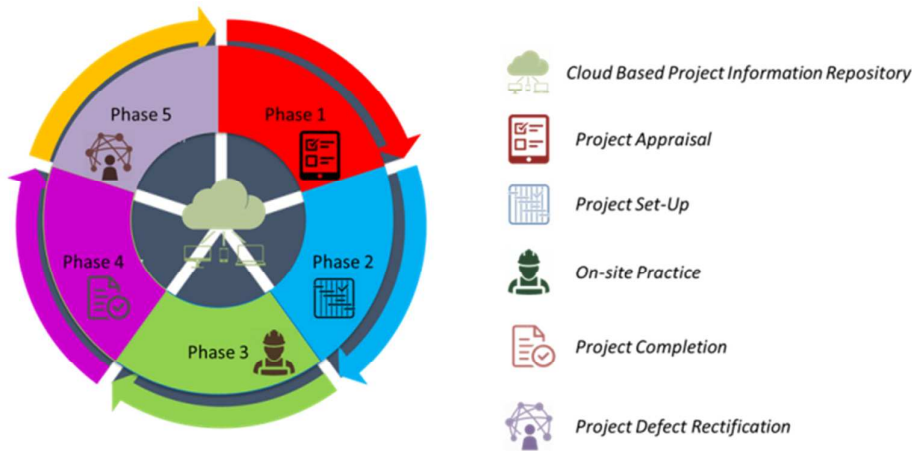


Figure 1. Structured Digital Workflow Phases developed by the authors based on data provided by industry

Structured Digital Workflow	Chartered institute of Building (CIOB); Code of Practice for Project Management 5 th Edition	Royal Institute of British Architects (RIBA) Plan of Work 2013	Council on Training in Architectural Conservation (COTAC) HBIM Framework- 2016	NBS; BIM Digital Plan of Work 2015	PD 6079-4:2006; Project management – Part 4: Guide to project management in the construction industry	BS 6079-1:2010; Project management. Principles and guidelines for the management of projects	Construction (Design and Management) Regulations 2015 (CDM 2015)
Phase 1 - Project Appraisal	1 Inception	0 Strategic definition	0 Identification of Asset Strategy	1 Strategy	1 Inception	1 Conception	Develop Risk assessments
	2 Feasibility	1 Preparation and brief	1 Research Legislation Preliminary Survey	2 Brief	2 Feasibility	2 Feasibility	Health and Safety (H&S Strategy)
	3 Strategy	2 Concept design	2 Determining Options	3 Concept 4 Definition	3 Outline design		
Phase 2 - Project Set-Up	4 Pre-construction	3 Developed design 4 Technical design	3 Define Detailed Survey 4 Determining Intervention	5 Design	4 Scheme design 5 Detailed design 6 Mobilization	3 Realisation	Safe Construction Methods + Strategy
Phase 3 - On-site Practice	5 Construction 6 Testing and commissioning	5 Construction	5 Physical Intervention	6 Build & Commission	7 Construction		H & S Strategies
Phase 4 - Project Completion	7 Completion, handover and operation	6 Handover & close out	6 Handover	7 Handover & close out	8 Testing and commissioning 9 Handover and Completion	4 Operation	H & S Strategies
Phase 5 - Project Defect Rectification Period	8 Post-completion review and in use	7 In use	7 Operation and Future	8 Operation & end of life	5 Termination	5 Termination	H & S Strategies

Figure 2. Process-Wheel mapped onto existing PM frameworks



Article Title Page

Tables

Research approach

Interviewee	Role	Position	Experience	R&M practice
A + B	Contractor	Director	25 Years	Masonry
C	Contractor	PM	25 Years	Masonry
D	Supplier	Director	25 Years	Masonry
F	Consultant	Director	15 Years	Masonry

Table 1. Backgrounds of interviewees*

*In addition, the lead author of the paper has 30 years of experience as a contractor and consultant

Findings and Discussion

Preliminary findings from Demonstration Study

Overview of Case Study

Scan Resolution	Point Cloud density	Area
Low-Medium	6.3 mm of spacing @ 10 m	Whole Facade
Medium-High	3.1 mm of spacing @ 10 m	Ground/First floor elevation
High	1.6 mm of spacing @10 m	Elements

Table 2. Scan resolution of Point Cloud data



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Survey Process	Existing	SDW	Benefits
Time in total	40 hours Inclusive of site re-visit	28 hours – no need for additional site visits	12 hours (25-30%)
Cost+ vat	£3000.00	£2050.00	£950.00 (25-30%)
Quality	Tacit knowledge/experience reliance Ground level survey Paper based data capture	Exact dimension extraction & element recording Digital accuracy to +/- 1mm 3d models and 2D CAD drawings of the identified repair areas	Benchmark comparison of the on-site work completed with the intended designed R&M Effective collaboration and communication Cloud based documents accessible to all project stakeholders through mobile devices.
H&S	Access issue; for extracting dimensions accurately H&S documents tend to remain static	No access issues e-H&S documents tailored to project specifics and site conditions.	Elimination of working at height when taking measurements e-H&S documents tailored to project specifics and site conditions.

Table 3. Conventional Survey Process and SDW Comparison

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