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Built heritage modelling and visualisation: The potential to engage with issues of heritage value and wider participation

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ABSTRACT

Modelling and visualisation of the built heritage is an area where the use of digital tools and techniques have become pervasive. This extends across all stages and aspects of heritage projects, and has come to include the culture of data pertaining to physical objects and environments, the subsequent uses to which that data may be put, and the manner in which stakeholder groups engage in debate, discussion and participatory decision-making. This paper provides a critical discussion of the implications of these developments and the associated technologies, and argues that what might appear to be 'stages' of a project should be regarded as a cycle, which embeds social and qualitative aspects of the built heritage as key components. The paper aims to contribute to the debate regarding how we can embrace developing technologies within heritage study, and how application of the technology can help to foster deeper engagement in heritage, and across society.

1. Introduction

The last two decades have borne witness to a transformation of the manner in which we use digital tools to model, present, analyse and collaborate within the built environment disciplines. Although it was certainly the case at least as far back as the 1980s that strategies and plans emerged to support and facilitate deeper forms of information sharing - through data formatting which remains consistent across disciplines - it has only been in more recent years that digital technology (in terms of both hardware and software) has genuinely enabled digital data capture and reproduction which can be applied within the field of built heritage and architectural conservation. In itself, one might argue that some of the central aims of conservation and heritage studies can be and are being embraced by such emerging methods and tools. However, the central issues and themes of built heritage studies are often as related to the social and cultural values and meaning which may be associated with architecture (the complexities of which are explored by Jones, 2017, who also refers to the work of Waterton, 2005, who drew attention to the complex relationships in heritage between ownership, power, knowledge and the "public"). This aspect of conservation practice must not be lost within an assessment of where the state of the art may lie in the present.

The paper aims to contribute to the debate regarding how we can embrace developing technologies within heritage study, and how application of the technology can help to foster deeper engagement in heritage, and across society. The core objective of the paper is to draw together various strands of research and enquiry which have been undertaken in the related fields of heritage digital data capture, associated heritage modelling, representation of those results and data sets, and the increasing prevalence of societal engagement in both the practice and conservation of digital heritage, and especially in the past five years. In so doing, one can apprehend how these diverse fields, which have developed along separate research parts, must now be seen to be operating as a system, albeit one which is to a large extent self organising and which has developed not only in response to the availability of new technologies, but which has also developed to embrace innovation by a wide and disparate community of participants.

One area of digital heritage study and practice which is especially notable is that of community and public engagement – with regards to both perception of models, and involvement in their construction (Themistocleous, 2016; Bustillo et al., 2015; Guttentag, 2010). The study and practice of built heritage conservation, and aspects of technical conservation, have been heavily and of course rightly dominated by work undertaken through established scientific disciplines, including material science and aspects of technical conservation which relate to the environmental and practical performance of old or older buildings and artefacts. Two aspects of digital heritage which have arguably begun to impinge upon the manner in which such technical practice engages with end users and the wider public have included the collation, informal

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cataloguing (Carboni, de Luca, 2016; Younan, Treadaway, 2015) and sharing (Nishanbaev, 2020) of digital built heritage through social media. Many of these examples have tended towards the study of buildings which hold particular social or cultural significance for the participants, and to a great extent the underlying motivations for doing so provide extensive meta data which can be associated with multi-dimensional digital models. Related to this has been the emergence of relatively low cost yet technically effective methods which can be employed to capture and model heritage objects. For any particular case study, these could range in size from small artefacts to entire buildings or streets, where the models themselves can be constructed using digital photographs as the key data source (via photogrammetic methods). What has emerged from many studies has been the extent to which users who have viewed or engaged with the resultant data and models have 'gained new perspectives' of the built heritage which has been captured (as discussed in Tait et al., 2016).

2. Context

2.1. Data and meaning

The context within which this paper resides is one which has seen rapid change, due in part to the emergence of new digital data capture technologies, but also due to the demand for those technologies across sectors, and not necessarily limited to use within what may be regarded as solely professional disciplines within architecture, construction and the built environment. Fig. 1 serves to illustrate the relationships between users, digital data capture (discussed in this paper in relation to laser scanning and photogrammetry) and the route towards establishing meaning.

Emerging data collection techniques to support the capture of information about the physicality of existing structures and environments have included laser scanning, photogrammetry, virtual modelling and 3D printing. Where we wish to consider the subject of built heritage, though, we need to recognise that the context is arguably quite different to the consideration of architecture from a purely technical perspective. As discussed in numerous texts and examples of previous research (Fladmark and Heyerdahl, 2002), the notion and idea of heritage is that of something which might be regarded as culturally important, and which holds value as something which can be passed from one generation to another, and not limited to tangible objects (UNESCO, 2020). Connected with this manner of considering the constructed environment, we therefore need to recognise that the reasons for architecture and built artefacts being regarded as part of a wider cultural and social heritage may extend well beyond the physicality of an artefact, and may require close consideration of the meaning and values which have been associated with items, objects, materials and architecture, and which therefore make a contribution to our shared understanding of society and culture (for example, Al-Zoabi, 2004).

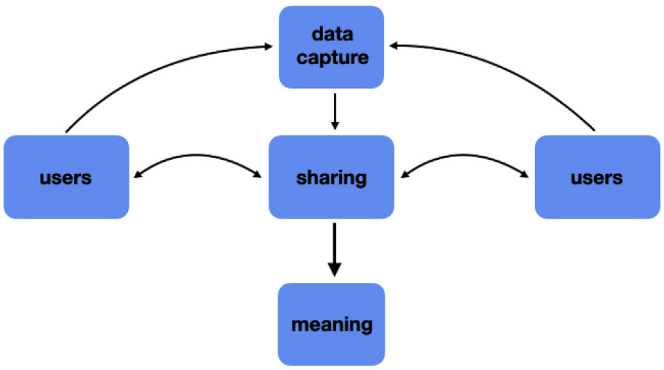

Fig. 1. Data sharing and meaning.

2.2. Qualitative considerations

It has been interesting, therefore, to observe the manner in which digital heritage research has begun to explore the connections between a largely quantitative data culture, and the equally important capture of social and cultural information. This has certainly extended towards the online sharing and debate of both digital and narrative encounters with the build heritage, as well as studies and research which have sought to explore how one may actually inform the other. In this sense, the development of research concerning digital built heritage has followed a key line of enquiry in relation to building information modelling. The practice of BIM is supported by possibilities which have emerged through the development of new software and office-based hardware, able to contain and facilitate the analysis of object based modelling data - where major data associated with objects is regarded and recognised as being equally important to geometric information about a building, where the software has in fact been developed in such a manner that objects like a meta data hold little value within the model itself. Therefore, this paper includes discussion of the manner in which digital heritage models and digital artefacts have come to play a part within the wider consideration of heritage, and as a core component within conservation management.

2.3. Public and user engagement

Clearly, a key aspect of the literature and research context which requires discussion and attention is that of public engagement in digital heritage modelling. This has in itself been a major area of research for many years, both within the disciplines which one would recognise as falling within the design team, as well as being a subject which has received attention within psychology, planning and environmental design (Bustillo et al., 2015; Tait et al., 2016; Laing et al., 2007).

Related most obviously and commonly to the use of photograph-based three-dimensional modelling, there has been an exponential growth in user-constructed digital models of aspects of the built heritage. The reasons for the popularity of this approach are rooted in the availability of free or inexpensive software, coupled with the ability through online platforms to share models with other interested parties. For example, the online platform Sketchfab reported having over 3 million users in early 2020, within which models of architectural built heritage, archaeological sites, heritage artefacts and cultural landscapes form a common part of what is a community led and community curated collection of models. Accessible methodologies and processes which can be followed by the non-expert are detailed in published studies (for example, Rahaman et al., 2019), as are examples of work studying the translation of heritage models for use within virtual reality (Bruno et al., 2010).

To date, it has certainly been the case that non-professional users have typically had to rely on such photograph-based modelling processes, due to the relative expense of using technology such as laser scanning. However, the availability of drone technology has extended the capabilities of such photogrammetric techniques, and it has recently become common for consumer level mobile devices to incorporate LIDAR and laser scanning, albeit at a lower resolution and specification (in terms of range) than dedicated scanning equipment. A valuable review of prior literature, and overview of the related workflow, is provided in Bakirman et al. (2020).

2.4. Democratic access to technology

The application of technology in a democratic manner could refer to access to the technology for all, as well as use of the technology to actually serve democratic purposes. This prompts us to recall Arnstein's (1969) ladder of citizen participation, and perhaps begin to consider whether the user driven approaches to the collection of digital heritage data in some ways represents the Heritage community taken control of the digital agenda. Of course, we must also remember that the use of

photogrammetric methods has been a core component of some of the most genuinely groundbreaking technical research undertaken within the field of heritage surveying. For example, work undertaken by the 3D Survey Group in Milan (Fassi et al., 2011) has embraced the notion of there being numerous tools and techniques open to the practitioner, and where the choice of technique for any particular project or task needs to be driven by a combination of practicalities, access, cost and the anticipated purpose of the data once collected. Indeed, research undertaken pertaining to photogrammetry, and particularly within a heritage setting, has been able to establish that the method, when undertaken under controlled conditions, is capable of producing models and results of sufficient accuracy to be used within building maintenance planning, heritage recording and for communication to a wide audience. That models from photogrammetry tend towards photorealistic representations of buildings and artefacts also supports its use for these purposes. A useful review of this topic, with examples from the built heritage, was provided by Vitale (2018). Returning to the notion of the ladder of citizen participation one must also consider whether grassroots access to such technology can in time transform the heritage management landscape to one which is founded on a bedrock of widespread collaboration and co-design.

2.5. Mechanisms to support engagement

When considering and debating the built heritage of a city, participants may well be presented with a range of opportunities through which they can express opinion, or through which they can begin to fully participate in decision-making. Some examples of previous research have tended towards exploration of the ways in which the technology underlying digital heritage modelling can be used as a point of entry for participants, and act as a vehicle to encourage, stimulate and focus debate, and without there being a reliance on those participants holding expertise in either the technology or indeed in formalised ideas of conservation theory and management. Such an approach to multidisciplinary engagement, where participation may be based on experience and cultural or social background, as much as it may be based on technical ability, is arguably likely to be supported in increasing frequency in the future.

The European Commission has in the past noted that "collective awareness platforms"[1] are capable of supporting 'environmentally aware, grassroots processes and practices to share knowledge, to achieve changes in lifestyle, production and consumption patterns, and to set up more participatory democratic processes. Elsewhere in the literature (for example, Arniani et al., 2014), it has been noted that we might regard the topic and practice of collective awareness as being one which can help both individuals and communities to better understand the context in which they live their lives, make decisions and form opinions and feelings about the environment around them. This is especially important when considering the built heritage. Within efforts by the European Commission,[2] the importance of user engagement as a driver for the design and application of online platforms to support community planning is central.

3. Technology – laser scanning

Prior to the advent of digital data collection tools, the built environment and the associated construction industry has a far longer history of undertaking surveying using traditional techniques, and utilising analogue equipment which is highly accurate, albeit dependent on hands-on applications by experts, and lacking the speed of some digital devices. During the last decade or so, though, these traditional approaches to surveying (often used within site levelling, site setting out and suchlike) have been complemented through the rapid development and increasing availability of digital surveying and measurement tools, within which there has been study of applicability and complementarity of techniques, for example in Goodwin et al. (2016) and Wang et al. (2019).

Laser scanning has certainly been one of the more visible and impactful technologies, using equipment which is capable of collecting many millions of data points, and greatly outstripping the capabilities of traditional methods in that respect. However, and reflecting on the earlier discussion of democratic access to technology, the financial cost of adoption with regards to laser scanning has placed that outside the reach of many potential users, at least until recently.

Laser scanners operate by firing laser light, and in so doing recording (in the case of many scanners, at least) the time taken for the light to return to the scanner head. This enables the technology contained within the scanner itself to rapidly construct a three-dimensional representation of the space surrounding the scanner. Depending on the equipment used, medium to high definition scans will typically take less than 10 min to complete, including the collection of both laser data and photographic records of the nearby environment. Considerations for the practitioner will also include the capabilities of any given scanner in terms of its range, speed of operation, specified accuracy and performance under particular environmental conditions. Due to the fact that the scanner constructs a three-dimensional representation, the user of the resultant dataset is not limited in terms of viewing by the original position of the scanner. Where laser scanners are limited however is most obviously in the area of lines of sight, meaning that the scanner can only record the geometry of objects which can be seen from the scanning position.

It is of course possible to collect information over a very large service area, and a key task undertaken either within the scanner itself or subsequently within desktop-based software, is that of registration, where numerous point clouds can be connected. Within the area of heritage culture, one could certainly argue that the ability of a laser scanner to capture the noise of constructed, inhabited and used human spaces in itself adds greatly to the data which is collected. Where a building or artefact which is deemed to hold cultural value is scanned, the technology will certainly collect information about the geometry of the object, and of the immediate surrounding environment. It will also, though, record information such as nearby (or even attached) vegetation, people passing by, vernacular traffic and animal life.

In the consideration of the built heritage, laser scanning technology can be utilised to collect virtual and highly detailed snapshots of buildings and sites at any given point in time. Fig. 2 illustrates output from an

Fig. 2. Example from laser scan of protected building in Elgin, Scotland (scan undertaken by Dr Marianthi Leon).

[1] https://ec.europa.eu/digital-single-market/en/collective-awareness.

[2] Including within the EU framework for action on cultural heritage. https://ec.europa.eu/culture/content/european-framework-action-cultural-heritage_en.

applied research study, for example, where HD scanning was used to capture and then represent selected examples of the built heritage as part of a heritage-led urban renewal project (http://elginheritage.scot/3d-mapping-project/).

In the case of some of the most prominent laser scanning initiatives – in Scotland one thinks of the ground breaking Scottish 10 and other associated projects (Historic Environment Scotland, 2020) – the technology has been used to populate and create a digital resource which will hold value and be useful from many centuries. That the resulting point clouds can also serve other purposes, perhaps in tourism or public outreach or access to information, illustrates that the compilation of digital heritage records may well be in the service of one particular task or project, but that the underlying dataset will most likely carry immediate value within other endeavours.

The technologies and techniques of laser scanning have developed, within the field of cultural heritage, to provide a solid technical base for the informing of heritage preservation techniques, the cultural interpretation and subsequent presentation of heritage (Hakonen et al., 2015), and within the field, specifically, of architectural heritage (Al-Kheder, Al-shawabkeh & Haala, 2009; Lambers et al., 2007).

When considering the importance of data collected through laser scanning over time, one must also be vigilant to remember that heritage itself is founded on the notion of things which may be passed from one generation to another. A key difference between architectural heritage and some other heritage objects is of course that architecture is not something to be placed in the museum, and the architecture will evolve over time. That laser scanning is also able to collect information about the physical environment surrounding an object being studied means that we also naturally and occasionally accidentally will record and model the built heritage within an urban setting which will be likely to change and evolve over time, in response to the needs and behaviour of communities and participants. Therefore it can be argued that heritage visualisation, supported by advanced digital data collection methods, begins to acknowledge the relationship between buildings, artefacts and sites, and therefore holds the potential to inform the urbanism and decision-making which recognizes the importance of place making and the genius loci[3] (Norberg-Schulz, 1980).

4. Technology – accessible techniques and technologies

As noted in earlier discussions of democratic access to and participation in heritage modelling, and with the emergence of financially accessible methods of digital image capture, wider participation in the surveying, recording and modelling of existing buildings and landscapes has become possible. That is, a participant no longer requires to have access to financially inaccessible equipment in order to collect data and produce usable 3D models of buildings, artefacts and sites.

The use and application of photogrammetry as a method to collect accurate and highly detailed heritage models has seen a wide use of the technology to record, study and in some cases share memories of buildings and areas. What is also notable is the extent to which recent research has captured the growth of a widespread interest in the study of 'abandoned architecture', accompanying texts and testimonies often referring as much to the social history embodied in the buildings and remnants, as to the architecture itself (Leslie, 2017).

One aspect of the growth of accessible technology (including the popularity of 'tilt shift' fake miniaturised photography, an example of which is provided in Fig. 3), and also engagement in the processes of 3D digital modelling, is that of the motivations driving such participation in the first place. With the example of tilt shift photography, for example, it would seem doubtful that most people participating in the manipulation of digital images to produce imitated examples of tilt shift photographs are doing so as a result of some desire to experiment with the notion of photography. Indeed, it seems more likely that the ability of the method to allow the user and the participant to experiment in a very playful manner with the ideas of the "real" has become a driver in itself.

Fig. 3. Example of a 'tilt shift' image (taken by the author, Vancouver).

At a conceptual level, the process of photogrammetry refers to the construction of digital three-dimensional models using photographic images of an existing object or structure, to determine highly accurate representations. Through a combined application of photogrammetry with best-practice site surveying, the geometric accuracy and reliability of the resultant models is equal to that of laser scanning, and a combination of the methods can in fact provide clear benefits (as discussed in Fregonese et al., 2016; Valero et al., 2017; Yastikli, 2007). Therefore, and especially in locations where the use of regular terrestrial 3D scanning would be difficult due to access or safety, for example, the approach can be applied as either an alternative or as a complement to other approaches. Work undertaken in Milan[4] has demonstrated how the combined use of multiple methods of data collection has enabled data collection and modelling of the Duomo di Milano at a very high level of detail, coupled with a web-based interface to enable interaction with the data itself. The nature of the web interface is such that the survey can be used as a tool to support maintenance work, and to document changes over time (development of the digital model and the accurate use of multiple methods is described in Achille et al., 2020).

The example shown in Fig. 4 illustrates the results of a study undertaken in Orkney, where engagement with the local community (with that engagement led by the University of the Highlands and Islands) indicated a specific location in the town's High Street which held particular meaning and value to local residents. Researchers were able to use a combination of photographs and relatively low cost laser scanning technology to undertake a series of studies, during the course of a single afternoon.

Some researchers have noted that the outputs of photogrammetry can tend to be easier to interpret than the isolated use of two-dimensional drawings (for example, Núñez Andrés et al., 2012), and that the availability of three-dimensional representations of a building or structure makes the use of such data within reconstruction or redesign projects much easier. Reflecting on this discussion of a range of techniques and technologies, what has become clear in some work (Núñez Andrés et al., 2012) is that the combined use of numerous methods is likely to bring greatest benefit to the user.

5. Applications

It has been argued in this paper that various emerging technologies have found a place within practice, and can offer or facilitate ways in

[3] The prevailing character or atmosphere of a place.

[4] http://www.sitech-3dsurvey.polimi.it/?page_id=101.

Fig. 4. Example of photogrammetric model (tree) from Kirkwall (model prepared by the author)

which society can utilise the potential of digital heritage modelling to realise some degree of holistic engagement with the subject matter. Nevertheless, securing the value of this technology will require the co-development of methodologies to support storage and visualisation of data, and workflows to support widespread participation from all stakeholder groups.

It has been interesting to also witness, over a period of quite a number of years, the application of interactive and online technologies to support engagement with digital heritage. Some early examples of such research tended towards the use of such online platforms as "Second Life" (Börner, 2002), which supported online users to undertake some form of virtual visit, often to sites which no longer exist, including reconstructed sites from archaeological study (Themistocleous, 2016; Guidi et al., 2014; Butnariu et al., 2013; El-Hakim et al., 2004). Another example of

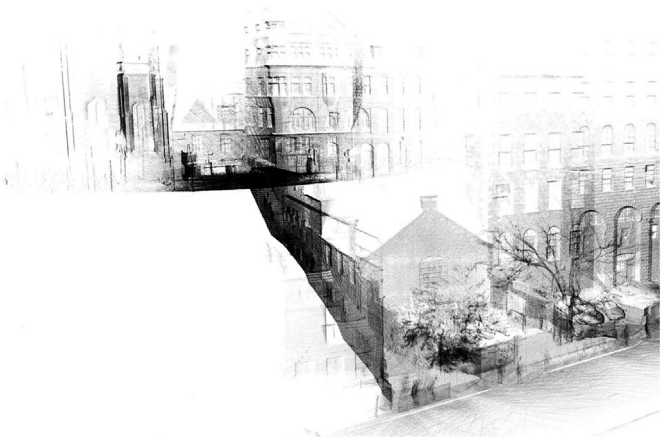

Fig. 5. Image of urban historical areas, capturing using mobile scanning (captured and produced by Daria Belkouri).

interactive digital heritage concerned a project which emerged from the study of vernacular built heritage in two towns in Northern Europe (Laing et al., 2007; Conniff et al., 2010). In particular, the study concerned the (photographic) recording and representation of a collection of heritage buildings located in the Faeroe islands, initially modelled by the team to illustrate unique building layouts, which appeared to have been dictated as much by the surrounding natural and open environments as they had been by architects and builders. Having undertaken that initial photographic study and modelling using mainstream architectural and design based digital tools, the team felt a distinct lack of immersion, and a feeling that the unique sense of place which existed on site was missing from a static, albeit attractive and geometrically correct, representation of the buildings. The research then extended to incorporate technologies which had been developed within the computer games industry, to support users interacting with models to freely navigate the space between buildings, and to view and experience the buildings in a manner which was much closer to an actual site visit. This aspect of the work was certainly reminiscent of much earlier research (Cullen, 1961), relating to the importance of movement, awareness of our surroundings, and our awareness of how those surroundings change as we move through an environment.

In the past few years it has been interesting to note the rapid development of mobile scanning devices (Zlot et al., 2014), coupled with the use of drone-based photogrammetry to record routes which may be taken by individuals or groups, and to survey parts of the environment which may be difficult to access by any other method. In Figs. 5 and 6, for example, one can see a still image from a scan which was undertaken to help record and (re)present walking routes within a mediaeval urban area. The scan is interesting from a technical perspective in that it was possible to collect information pertaining to a very large urban area and in a relatively short amount of time. The visual qualities of the scan are also important, as what is gained in terms of scale is perhaps lost in terms of detail. More importantly though is the appearance of the raw data cloud, which has visually much in common with the sketching of Cullen in the 1960s, and is sufficiently abstract in appearance to be genuinely useful in the generation of thoughts, ideas and debate.

We can also refer for a moment to the use of visualisation within communication of the built heritage to a wide audience. When formulating a method or protocol to model heritage buildings - which are arguably enriched by the appearance and presence of inaccuracies, movement over time, unique surface characteristics and suchlike – the value of such features should be embraced and valued. References within literature to this very subject by Till (2009), referring to comments by Laurie Anderson, drive our attention towards the fact that visual and material complexity in the real world extends quite significantly beyond notions of our surroundings being somehow defined or

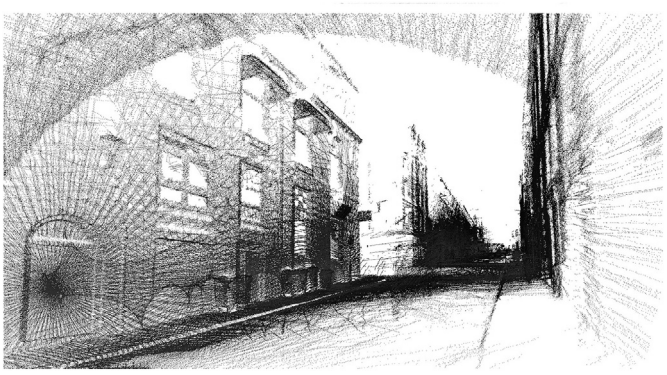

Fig. 6. Image of urban historical areas, capturing using mobile scanning (captured and produced by Daria Belkouri).

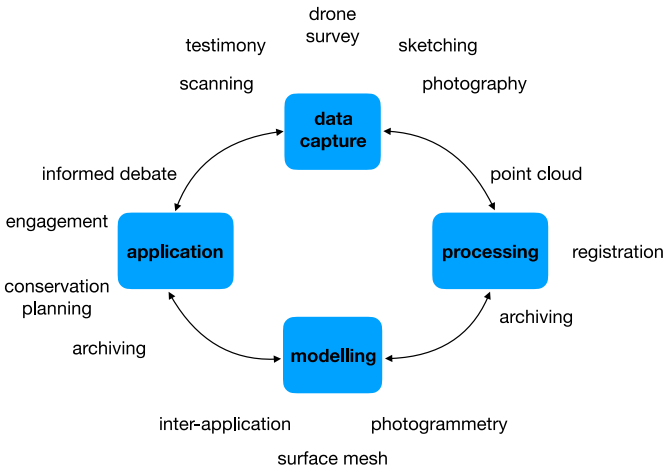

Fig. 7. Cycles within heritage digital modelling.

flavoured by "dirt" or imperfection (grit). In the real (non virtual) world, the user of a model is able to interact with space, to observe and test various (often controlled) effects of weather, light, and even the presence and behaviour of other people. In fact, the early examples of hosting virtual heritage within online settings was to a great extent focussed on the study of interactions between users. In other words, notions of what we might regard as a perfect environment are certainly not frozen in time – which is of course a central theme within conservation theory itself – maybe objects, buildings and materials will change over time. One could argue, in this respect, that a key challenge for the heritage modeller is to capture such complexities and 'imperfections', but in a way which allows for multiple viewpoints, users and evolution over time.

6. Digital heritage – an emerging conceptual framework

As stated at the outset, this paper aimed to explore and conceptualise the manner in which a range of digital tools and techniques can be employed to facilitate and support engagement and user participation with the concepts and practices of built heritage management, conservation and preservation. Within those techniques, there have been very significant advances in recent years with regards to hardware which can be utilised to assist with data capture. This has been rightly regarded as opening new possibilities for the heritage practitioner with regards to the scale and accuracy of information which can be collected. Associated with this, though, are the considerations which are discussed within the paper in relation to the democratisation of heritage data, modelling and sharing.

Therefore, it is argued that the subject of digital heritage and heritage modelling can be considered from the connected perspectives of the tools and technology which might be available to the practitioner, and the uses to which they might be put. It should also be recognised that the processes and practices of such data capture, and the subsequent visualisation of such data sets, could in fact be carried out and completed in the absence of a clear or final end goal. After all, once data has been collected, one could argue that the initial information could then be used for a multitude of purposes (visualisation, public engagement, archiving, later historical research).

Connected with this notion of data and the knowledge and understanding which can be drawn from the capture and modelling of heritage sites and artefacts is the additional consideration regarding the series of practical and intellectual activities not as a linear process, but instead to recognise that they operate in a cycle (Fig. 7). The importance of that cycle to individuals working within built heritage projects may be affected by the extent to which the participants are engaged in a collaborative working environment (some challenges of which were discussed by McGibbon and Abdel-Wahab, 2016), or where there are perceived barriers to, or risks associated with, collaboration (Hirsenberger et al., 2019).

Reference to Fig. 7 also draws our attention towards the multiple technologies available to capture and then represent data, and also to their numerous potential applications. As with the work reported by Achille (2020), the importance of considering heritage buildings throughout their life cycle inevitably draws one back to consideration of how sematic (non geometric) data can be incorporated within models (Simeone et al., 2019). As discussed in the introduction to this paper, heritage study has social, cultural and personal meanings at its core, and this is reflected in the suggested cycle.

With heritage modelling - at a technical level - we have now reached a stage where models can appear very close to representing reality, at least in visual terms. In so doing, we arguably find ourselves in danger of entering the uncanny valley (Mori, 1970), where even very small visual or technical 'imperfections' in a model can lead to perceptual rejection in the mind of the viewer or model user. Although one can be mindful of Magritte's (1928) observation that such models are never more than abstractions of reality, where the intention underlying the development of virtual heritage models is to incorporate them within stakeholder or other user engagement activity (as detailed in Laing, 2018), these dangers become quite significant. As noted in Jouan and Hallot (2020), recording and modelling of the built heritage must been undertaken within a context of mutual benefit with stakeholders, and the assessment of cultural significance.

7. Concluding remarks

There has been a significant growth in recent years in the prevalence of digital methods to capture, record and represent the built heritage. This has given rise to many examples of research activity whereby aspects of that heritage are documented, often in ways which could facilitate their inclusion in new design work, wider virtual city models, or as part of conservation work. One naturally wishes to explore the nature and significance of such work, in terms of fabric conservation, in that the record is an abstraction of reality, albeit one which may be aesthetically convincing and geometrically accurate. However, the potential benefits of holding such data in a form which documents and can portray the built heritage to expert and non-expert audiences alike are notable and could in themselves suggest a useful tool to further democratise the heritage conservation movement.

Returning to the suggested cycle of activity, the overarching message is that a successful development and use of digital heritage requires the interaction and collaboration of multiple disciplines, each of which hold specific and valuable skills sets. This will in turn require the application of multiple research and practice methods (surveying, data manipulation,

digital modelling online interaction, telepresence, environmental psychology, participation and co-design), which are collectively drawn from the physical and social sciences. Appreciating and acting upon this is both significant to the 'success' of an activity yet presents a clear challenge to the multi-disciplinary research team. The route to success may, in fact, lie in understanding that the cycle is not one with start and end points, but is instead one which will continue to evolve and change over time, much in keeping with built heritage itself.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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