The Conservation and Management of Historic Vessels and the Utilization of 3D Data for Information Modelling

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Abstract

The increased use of laser scanning and photogrammetry has given rise to new opportunities in disseminating information about historic maritime assets and are of great use in conservation management initiatives. This chapter discusses the current state of 3D survey of historic vessels and how this has been applied more recently for historic vessel conservation management. Key questions such as how this data is utilized, and what it is that the capture of such data is trying to achieve for the conservation and management of historic ships and vessels will be explored. In addition, this chapter will introduce information modelling, most commonly seen as Building Information Modelling (BIM) as an approach for furthering the effective management of historic ships and vessels, as well as other historic marine and maritime assets. It will demonstrate that the majority of attempts at utilizing BIM in the heritage sector have been limited to buildings, and that the full potential of this technique has not been realized. Through the use of the 'VIM' project at HMS *Victory* the chapter will then explore how information modelling can be applied to a highly complex historic ship.

Keywords

Historic ship · Conservation management · Information modelling · BIM · HMS *Victory*

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7.1 Introduction

The increased application of 3D datasets in the heritage sector in recent years has significantly improved the ability to optimize how we visualize and disseminate information about underwater and intertidal archaeological sites (Sanders 2012). It is also the case that the utilization of 3D data has increasingly formed an element of the survey and recording strategies for extant historic ships and vessels, either as stand-alone projects, or as part of conservation management initiatives.

Conservation Management for historic vessels follows the more general heritage conservation principles set out in the 'Burra Charter' (Australia ICOMOS 1999) first adopted in 1979 and updated in 2013; the seminal work undertaken by Semple Kerr (2013); and the 'Barcelona Charter' (Heidbrink 2003) which outlines approaches to best practice for the conservation and restoration of operational historic watercraft in Europe. In the United Kingdom, national heritage bodies have also published guidance on conservation management, including Historic Environment Scotland (2000); Historic England (formerly English Heritage) (English Heritage 2008); and national funding bodies such as the Heritage Lottery Fund (2012). In essence, these publications provide the benchmark for effective heritage conservation planning and management, and this formed the basis for dealing with the same considerations in relation to historic vessels in the United Kingdom, delivered through guidance developed by National Historic Ships (NHS 2010) in the UK. Connected to extant historic ships are those that represent examples of largely complete ships that have been recovered from the seabed. A good example is the *Vasa* ship (1628) in Sweden where the real need for effective conservation management planning has been clearly stated (Malmberg 2003).

The traditional approach to historic vessel survey is based very much in the 2D world and previous publications outline these traditional approaches that could be employed by the

investigator (Anderson 1994; Kentley et al. 2007; Lipke et al. 1993). The outputs comprise the traditional expression of the line drawing, in addition to plans, elevations and sections of a vessel. While more generally, advances in technology and surveying techniques and the resultant outputs in recent years have demonstrated the effectiveness of 3D survey, it is only in the last 10 years or so that 3D survey has begun to be utilized more fully for historic vessels; the details for which are more commonly found within unpublished papers and client reports. Indeed, until the last 5 years or so, the 3D outputs created for historic vessel survey have generally followed the aims of the traditional 2D outputs, these being the expression of hull shape, line drawings, and associated elevations, plans and sections. Developments in integrated modelling and data management software, particularly in a BIM context, has demonstrated the importance of accurate survey data for the effective management of complex projects (for which historic vessels certainly form a part). Whilst the primary focus for software developers has been the Architecture, Engineering and Construction (AEC) sector, the benefits such software, and the processes which the AEC sector has developed to underpin its use, are now being explored more fully within the heritage sector.

For such a new concept, there is a surprising amount of literature about heritage BIM, including a recent edited volume devoted to it (Aracyici et al. 2017); however, there is little that fully addresses BIM as software and process. The majority of the academic literature on BIM and heritage focuses on single aspects of BIM, be that storage of heritage information (Counsell and Edwards 2014; Edwards 2017; Simeone et al. 2014; Yajing and Cong 2011; Zhang et al. 2016); 3D representation of historic buildings (Brumana et al. 2013; Fai and Sydor 2013); or automated modelling (Dore and Murphy 2012a, b, 2013). Whilst these approaches no doubt have things to offer, they do not exploit the full benefits of BIM as a project and asset management tool (Breedon 2015, 2016; Campbell-Bell 2015, 2016 for an introduction to how BIM could be fully utilized in the heritage sector). It is these aspects of BIM that have the most to offer complex conservation management projects; and this is certainly the case with historic ships, given the inherent challenges that large and extremely complex artefacts pose.

This chapter discusses the current state of play with 3D survey of historic vessels and how this has been utilized more recently for historic vessel conservation management, focusing on experiences in the UK. Key questions will be explored such as: how this data is utilized; what is it that the capture of such data is trying to achieve for the conservation and management of historic ships and vessels; and what mechanisms developed for other sectors can be utilized to best enhance the effective conservation management of historic vessels—especially given their inherent complexity and heritage value? The chapter will then focus on the applica-

tion and integration of 3D data into information modelling (such as BIM) as a useful management tool, and on the concept of BIM and its application to historic ship conservation management in the UK. We explore how the opportunities presented in 3D realization can be employed to best effect in relation to the conservation management of historic ships and vessels—ultimately using the iconic HMS *Victory* as a case study to demonstrate mechanisms that can be employed for effective conservation management, and to highlight some of the limitations of existing systems.

Finally, the chapter will address the way forward, and the challenges and opportunities that lie ahead—particularly in relation to the practicalities of utilizing 3D data for information modelling in the effective conservation and management of historic ships and vessels more specifically, and indeed the wider maritime heritage resource more generally.

7.2 Historic Vessel Conservation Management Practice

The principles set out in the UK National Historic Ships guidance *Conserving Historic Vessels* (NHS 2010) outline the considerations for approaches to effective historic vessel conservation through ‘gateways.’ These gateways influence the priorities that face a vessel owner when establishing the way in which a vessel is potentially conserved and maintained into the future; essentially through *preservation, restoration, adaptation, and reconstruction*. The basis of the ‘gateway’ approach is established and realized through the preparation of Conservation Management Plans or Conservation Statements, which aim to highlight and understand the key significances of a vessel, and present ways in which the opportunities and threats facing the asset can be effectively managed into the future. Indeed, there have been a number of such plans and statements undertaken for a variety of historic ships and boats in recent years; select examples include SS *Great Britain* (1999); *Cutty Sark* (2005); *Lively Hope* (2007); *City of Adelaide* (2012); HMS *Caroline* (2014); HMS *Victory* (2015), and the *Scottish Fisheries Museum Fleet* (2017), some of which are discussed further in this chapter. Many of the earlier surveys, however, were produced at a time when 3D survey for historic vessels, and the understanding of its potential, was in its relative infancy, and due to a number of limiting factors—particularly in terms of data quality, processing, and the issues relating to time constraints and cost—survey initiatives were either not included (in the case of SS *Great Britain*), or where undertaken (for *Cutty Sark* and *City of Adelaide* for example), were not fully utilized for effective conservation management purposes.

It is also worthy of mention that whilst it is not the intention of this chapter to discuss the conservation management

of ships recovered from the seabed (such as *Vasa* and *Mary Rose*), and submerged archaeological sites in general, the interesting parallel alongside the conservation management of historic vessels is the use of conservation management plans and statements for wreck sites. While the approach is not new, national heritage bodies such as Historic England in the UK have recently commissioned the preparation of a suite of conservation statements in helping to understand the key management requirements for the protection, enhancement, and wider accessibility of designated wreck sites in English territorial waters (examples include Dunkley 2008; May et al. 2017). Allied to this is the increasing synergy between the management objectives outlined in the reports and the use of 3D survey imagery for sites, where investigators visiting sites are encouraged to use 3D outputs to provide information relating to ongoing monitoring and management. This is an important aspect of shipwreck conservation management, and while beyond the scope of this chapter, represents a clear avenue for future research and publication.

7.3 3D Survey for Historic Vessels

3D survey techniques, particularly laser scanning, and the increased use of photogrammetry, for the survey of extant historic vessels in recent years has resulted in a very broad based, and albeit fairly simplistic application. Early surveys, such as that employed on the clipper ship *Cutty Sark* (1869) in 2005, utilized hardware and software that has been improved in recent years—particularly in terms of factors such as data quality and processing, and the relative reduction in the time and cost associated with a project. The nature of the application aside, the objectives apparent in the utilization of the resultant data were primarily based within the realms of engineering, simple 2D outputs, or for virtual reality applications. Data acquisition for archaeological purposes during most historic vessel survey resulted in the provision of an accurate archaeological record, which in most cases was used for outputs such as the creation of basic wireframes, elevations, plans, and sections, or the creation of more traditional line drawings. This was perhaps without any real understanding of how the 3D data could and should be utilized for archaeological and heritage conservation purposes.

Perhaps one of the earliest surveys that prompted the question of archaeological enquiry and the use of the data for archaeological purposes was the laser scan survey of the ex-whaling vessel *Charles W Morgan* (1841), based in Mystic on the eastern seaboard of the United States (Classic Boat 2010). In this case, the resultant data was utilized for a number of key purposes, including gathering detailed information about the hull and the individual components during

each phase of the restoration, and the production of detailed plans of the ship, for which no historic archive was available.

The further use of laser scanning within an historic vessel context occurred around the same time as *Charles W Morgan*, in 2008, with the survey of the emigrant clipper ship *City of Adelaide* (1864) (also named *Carrick* during service as a Royal Navy Reserve Headquarters in Glasgow) whilst located at the Scottish Maritime Museum in Irvine, Scotland (Fig. 7.1). In this case the ship was under threat and the museum had limited options for the sustainable future of the vessel. As such, an application was sought with the national and local heritage curators to deconstruct the ship—in line with the National Historic Ships guidance *Deconstructing Historic Ships* (NHS 2007). The status of the ship as a protected ‘Listed Building’ meant that certain conditions were required to be met by the museum, prior to the final decision on the future of the ship. This included a full archaeological record of the ship hull and constituent parts, and a contextual record of the ship and the site to help aid engineering requirements (Figs. 7.2 and 7.3). In light of these requirements, a laser scan survey was commissioned which succeeded in providing an accurate record of the ship and the site upon which the vessel was situated (Atkinson et al. 2009). The ultimate use of the data however, was to help provide engineers with an accurate rendition of the hull of the ship in preparation for the design and fabrication of a bespoke cradle on which the ship was to be removed from the site in advance of transportation back to Port Adelaide in South Australia (Fig. 7.4).

Similar to the *City of Adelaide* survey, engineering requirements also formed part of a laser scan survey for the hull of the *Research*, an early twentieth-century first class Zulu sailing herring drifter, based at the Scottish Fisheries Museum in Anstruther, Fife. In addition to providing an archaeological record of the vessel, the data was used to help provide a control on which the hull could be monitored for movement as part of a static exhibit within the museum (Atkinson et al. 2010) (Figs. 7.5, 7.6, and 7.7).

A further example of the laser scanning of a large hulked clipper ship is that of *El Ambassador* (1868) located in Chile. In 2013, the *Instituto de Arqueología Náutica y Subacuática* surveyed the surviving hull of *El Ambassador* and succeeded in gaining detailed data about the nature of the remains, and the conditions and environment in which the ship survives. Like previous surveys however, the use and application of the data was limited to producing digital plans. It was a landmark survey representing the first laser scan survey of an extant historic vessel undertaken in Chile (Pollet and Pujante 2013).

These surveys were clearly successful in capturing the detail of the ship, and could be used for a range of purposes. This included providing control for the preparation of ship

Fig. 7.1 The emigrant clipper ship *City of Adelaide* on the slip at Irvine on the east coast of Scotland prior to survey and removal to Port Adelaide in South Australia (Headland Archaeology Ltd)

Fig. 7.2 Orthographic representation of the resultant point cloud acquired from the laser scan survey (Headland Archaeology Ltd.)

plans used in restoration works, in the case of the *Charles W Morgan*, providing an archaeological record and engineering control, for the design of a bespoke cradle, in the case of the *City of Adelaide*, and for ongoing structural monitoring in the case of the *Research*. The exploration of the conservation management potential of the data was minimal, however—mainly due to the difficulties in using the data for effective

archaeological enquiry and the financial constraints in integrating 3D survey techniques such as laser scanning into project designs at the time. Furthermore, the primary aim was to aid in the understanding of the priorities in stabilizing the shape and condition of vessels in the early stages of conservation, not to form part of an ongoing conservation management programme throughout the lifecycle of a

Fig. 7.3 External and internal long sections of the *City of Adelaide* as acquired from the survey data (Headland Archaeology Ltd)

Fig. 7.4 Examples of the resultant engineering modelling of the *City of Adelaide* developed during the design of the bespoke cradle used during transportation to Port Adelaide in South Australia (Clipper Ship ‘City of Adelaide’ Ltd)

conservation project. The same can also be said for projects where the principal aim was to provide data for virtual reality platforms and displays to augment educational dissemination; recent examples include the laser scan survey and

digital modelling of the Qatar Museums watercraft collection in Doha (Cooper et al. 2018); the RRS *Discovery* (1901) located in Dundee, Scotland (Digital Surveys 2014); *Edwin Fox* (1853) based at Picton in New Zealand (3-D Scans

Fig. 7.5 Plans and elevations derived from the laser scan data of the Zulu Research showing the main characteristics of the internal and external hull as surviving (Headland Archaeology Ltd)

Fig. 7.6 Laser scan point cloud from the survey of the builders' half model of a Zulu herring sailing drifter for a vessel built at the same boatyard (and period) as the *Research*. The model was scanned to provide a control from which to overlay the laser scan data from the *Research* to help understand the movement in the hull of the vessel to inform future conservation management and engineering considerations. (Headland Archaeology Ltd)

2017); and more recent work on the SS *Robin* based at the Royal Victoria Docks in London (SIAD Ltd. 2017).

More recent historic vessel conservation projects have included the preparation of Conservation Management Plans (NMRN 2014, 2015), a key part of which includes the use of 3D survey applications. The most notable is the laser scan survey undertaken for HMS *Victory* (1765) in 2013, which will be discussed in more detail within the following case study. Other examples include the laser scan survey in 2014 of HMS *Caroline* (1914) a British First World War light

cruiser and last extant survivor of the Battle of Jutland (1916), and the laser scan survey in 2017 of the Second World War era British submarine HMS *Alliance* (1945) (Fig. 7.8). In the case of HMS *Caroline*, a laser scan survey was undertaken with the principal aim of producing an accurate representation of the ship, its constituent parts and its internal spaces. This provided a basis for the production of accurate plans and elevations to assist with the recording phases associated with the ship's biography—essentially identifying parts of the ship relating to various phases of the vessel's life, from construction

Fig. 7.7 Sections along the vessel (bow top left, towards the mid-section, bottom right) denoting the data derived from the scan of the half model (in purple), and the corresponding section of the hull derived from the scan of the *Research* (black line). This clearly indicates

‘sagging’ and ‘pinching’ of the hull along the length of the vessel, providing important insight into future support strategies for the vessel in the museum gallery. (Headland Archaeology Ltd)

to decommissioning, following a long period of service as a Royal Navy Reserve Headquarters located in Belfast (Figs. 7.9 and 7.10).

Aside from laser scanning, 3D data has also been acquired using photogrammetry, and this is becoming an increasingly popular method of carrying out rapid and cost-effective surveys across the heritage sector (demonstrated in the various chapters throughout this volume). A good example of the use of photogrammetry in relation to conservation management for historic vessels was the production of a series of Conservation Management Plans and Statements associated with the fleet of vernacular Scottish fishing vessels based in the collection at the Scottish Fisheries Museum at Anstruther in Fife, Scotland (Wessex Archaeology 2017). Similar to the laser scan surveys noted above, the principal outputs were relatively simplistic, and in most cases provided data to enable the production of plans and elevations, and the ability to understand detail of the vessel components and construction characteristics (Fig. 7.11). In this case however, it is important to note the usefulness of capturing 3D data for smaller vessels and boats that, due to their vernacular nature, have no drawn record from which to undertake informative recording, assessment, and interpretation. Further effective

use of photogrammetry within historic ship conservation is the use of the technique to provide an accurate, quick and cost-effective means of recording areas of a vessel that are undergoing active conservation work. During the restoration works on HMS *Caroline* (carried out between 2014 and 2016), the technique was used to great effect in the recording of historic deck planking from the starboard waist area, and parts of the original floor in the former drill hall, introduced to the ship in the early 1920s when in use as a Royal Navy Reserve Headquarters. Despite working alongside contractors, it was possible to record and interpret the characteristics of the historic decking and the relict features on the deck plating below (Fig. 7.12). The resultant interpreted plans were then provided as part of proactive ‘live’ mitigation to help assist the ship’s managers with the Heritage Impact Assessment (HIA) process, and the means to understand how the significance of the historic ship fabric is retained.

There is no question that the capture of 3D data during the survey of historic vessels has proved useful, particularly in terms of providing an accurate archaeological record, assisting with the preparation of plans, elevations and section of vessels; particularly where documentary sources are limited or do not exist. The use of the data to assist with engineering

Fig. 7.8 Orthographic representation of the Second World War era submarine HMS *Alliance* following laser scan survey (Wessex Archaeology Ltd)

considerations has also proved very useful in many cases. In order to begin to realize the true power of the data however, opportunities to embed the data in more meaningful and long-term conservation strategies are now being realized—particularly with the development of information modelling applications.

7.4 The Concept of Building Information Modelling (BIM)

There have been a range of approaches to aggregating information and spatial data since the advent of computing technology, the most widely used likely being GIS. In recent years however, Building Information Modelling (BIM) has seen widespread adoption in the AEC industry and increased interest amongst heritage professionals. BIM is a term which has been used and understood in many ways since it was conceived, but perhaps the most useful way to consider it is

in terms of the UK Government driven push towards greater collaboration and data sharing within the construction industry. The aim is to reduce capital expenditure (CAPEX) by 20%, and to offer significant reductions in operational expenditure (OPEX) (HM Government 2011). Within this frame of reference, BIM can be seen as a collaborative process of project design, management and implementation, guided by common specifications and data standards. This combination of process and information management, along with the fully 3D nature of BIM is what distinguishes it from other computing approaches.

At its heart BIM is about more efficient working. Through early engagement of stakeholders, collaboration and careful documentation of the project timelines, responsibilities and deliverables, BIM aims to ensure that time is not wasted through reworking, mistakes, confusion and data loss. Whilst some people see it as such, BIM is not about software alone, it is a way of working within set guidelines. It is also important to note that the ‘Building’ in BIM, is a verb, not a noun.

Fig. 7.9 HMS *Caroline* in Alexandra Dock in Belfast in 2018, following the programme of restoration which aimed to re-introduce as far as possible the 1916 ‘Battle of Jutland’ appearance and configuration (Wessex Archaeology Ltd)

Whilst BIM was developed for constructing buildings it is increasingly being implemented in other areas, such as infrastructure. Whilst there have been calls to proliferate the process name, where associated with use in different sectors, this distances these use cases from the core elements of BIM and offers little in terms explanatory value. We could talk of Heritage BIM, or Ship Information Modelling, but prefer to follow the standard adopted by the many AEC industry special interest groups and use BIM for historic vessels.

By mandating its use on major government-funded projects and establishing the BIM Task Group to oversee its development (www.bimtaskgroup.org), the UK is one of those at the forefront of global BIM implementation. Specifications such as the CIC BIM Protocol, BS 1192:2007, BS 1192-4, PAS 1192-2 3, 5 and 6, and the upcoming PAS 1192-7, define standard ways of working which should be adhered to when using BIM on a project.

In addition to using these specifications, project documentation such as Employer Information Requirements (EIR) and BIM Execution Plans (BEP) are key, respectively, for defining project requirements at the tendering stage and for tenderers demonstrating how they will meet those requirements. After a contract has been awarded, a Post-

Contract BEP is created collaboratively to plan the project implementation.

Software is still very important to the implementation of BIM. There are many BIM authoring tools available, such as *Graphisoft ArchiCAD* or *Autodesk Revit* which allow the integration of 3D geometry and non-geometric information, facilitating the implementation of BIM in a way which will lead to the desired benefits. Again, it is important to stress that the use of these standard software packages do not make a project BIM compliant, nor is their use necessarily required.

These software packages allow the creation of 3D models with information rich objects, meaning that all the information about a construction project, including time scales, costs, responsibilities and attributes of each individual item can be included. By including this information, the model serves as a single source of truth for the project and can be used for the automatic generation of documents, such as schedules and 2D drawings. This model can also serve as a valuable asset in the future maintenance of the structure. The use of IFC as a standard data format allows this information to be interoperable, i.e. it can be shared between different software packages and maintain integrity, allowing different practitioners to work on the model.

Fig. 7.10 2D output of the lower deck of *HMS Caroline* derived from the laser scan data (top) as indicated in a traditional plan (bottom). This allowed the most current representation of the compartments and spaces

along the deck to assist with the detailed recording and interpretation phase during the compilation of the CMP (Wessex Archaeology Ltd)

Three key principles underlying the use of these models are:

1. Level of Detail (LOD)—the amount of geometric detail included in the model, ranging from a generic place holder shape of the right dimensions, to a fully modelled example of the actual object;
2. Level of Information (LOI)—the amount of information attached to an object, ranging from basic information such as what the object represents, and its dimensions, through to full specifications, and links to maintenance schedules and operating manuals for the object; and
3. Level of Definition (confusingly also abbreviated LOD)—a combination of Level of Detail and Level of Information.

Much has been achieved in driving towards BIM Level 2, but true BIM Level 3 (Fig. 7.13) remains out of reach at this time, due to technical, legal and procedural limitations. BIM's implementation within heritage however, has been patchy, and rarely meets its full potential, yet it is clear that this potential exists, particularly in the management of complex heritage assets such as historic vessels. As often very complex structures, both in terms of construction and history, there is a vast amount of information associated with these vessels. This information is important to understand and to manage the vessels, but it is often widely spread, inconsistently structured, and disassociated. Although in a different context, it was precisely these difficulties that BIM was conceived of to address, and so, as with operational management of a building through BIM, by combining all

Fig. 7.11 Vernacular fishing vessels from the Scottish Fisheries Museum fleet. Photogrammetric renditions of the Baldie class *White Wing* (top); the *Scaffie Maggie* (middle); and the *Montrose Salmon*

Coble Jubilee (bottom). Examples of the resultant construction detail drawings for each vessel are noted to the right of each (not to scale) (Wessex Archaeology Ltd)

the pertinent information into one place the conservation management needs of historic vessels can be much better met.

7.5 Use of BIM in the Heritage Sector

BIM development across the world has been firmly focused on new construction; heritage has been mostly ignored outside academic circles. This is despite calls, in the UK, for ‘all contractors’ to engage in the BIM process, and the importance of existing assets highlighted in *Digital Built Britain* (HM Government 2015). Over 90% of buildings which will be used in the UK over the next 25 years currently exist; many of these are, or will eventually become, historic

buildings. The result of this lack of attention amongst policy makers and the AEC industry is that there are no robust specifications or standards for BIM in the heritage sector.

Given the current lack of standards, it is unsurprising that BIM, as defined above has yet to see widespread use for heritage purposes. BIM has been applied in a number of projects, however, these all focus on historic buildings. Just as BIM is now being applied to infrastructure in the AEC industry, it can be applied to the operation of commercial archaeology projects and other elements of the built environment, such as ships, as is demonstrated below with *HMS Victory*. The lack of data standards and consequent limitations of software, as well as the broad array of heritage assets makes BIM’s utilization somewhat problematic at this time, but examples such as the Manchester Town Hall project show the benefits it can

Fig. 7.12 The outputs from a photogrammetric record of the historic deck structure and underlying deck plating from the starboard waste area of HMS *Caroline* (indicated in the red shaded area on the plan—top) (Wessex Archaeology Ltd)

bring (HM Government 2013). Heritage BIM projects have tended to fall into three broad categories:

1. BIM as Process—Renovation of historic buildings, using BIM as part of the project management, but not incorporating historic information which may be of relevance to the project;
2. BIM Model as Archive—Creating a BIM model of a building in order to serve as an archive for information about it. These may be used in the management of the asset, but there is no use of BIM as a project management process; and
3. BIM Model for Renovation—Creating a BIM model of an historic building with an emphasis on geometry over information, often for renovation or repair.

The first of these approaches gains the benefits of BIM as a project management process, but misses the fact that these buildings have particular planning needs that can impact work. This risk is therefore not controlled in the same way as others in the project. This also limits the model's future use in Facilities Management (FM) (or indeed conservation

management), it is however how construction professionals generally make use of BIM in a heritage context.

The second approach misses the core of BIM as a driver for efficiency in projects and looks straight to the technology as the latest method of storing heritage information. This view of BIM is widespread within the heritage industry and acts very much like an advanced GIS (see for example Counsell and Edwards 2014; Simeone et al. 2014; Yajing and Cong 2011; Zhang et al. 2016; Edwards 2017). Whilst such an approach could undoubtedly have value for the management and research of heritage assets, for many needs the data included is too much, and renders the model too large to practically use (Zhang et al. 2016).

The final approach is also very common within heritage circles, treating BIM modelling as a way to better understand historic buildings and either ignoring, or passing over the issue of historic information within the model (see for example Brumana et al. 2013; Fai and Sydor 2013). This can be seen as an extension of the use of 3D survey data discussed above. A similar underlying focus can be seen in the use of BIM modelling for virtual reconstruction of excavated buildings (Garagnani et al. 2016). The problem with this approach

Fig. 7.13 The UK BIM maturity model, detailing the basic requirements for each level of BIM implementation. Level 2 has been clearly defined with British and International Standards. Level 3 still requires technical, procedural and legal progress, and as such it is not currently

fully defined by standards and is unachievable. Some projects do exceed the requirements of Level 2 however (bim-level2.org- Derived from Bew and Richards 2008)

is twofold; it is the information which truly makes BIM valuable, and as the software packages were made for designing new buildings, representing the irregularity of historic assets is very difficult. A model will never be able to represent the geometry of a building as well as the laser scan data it is usually based upon, making attempts at exact reproduction redundant. Attempts to use the geometry of BIM models of historic buildings for designing renovations have therefore proven unsuccessful (Bryan 2015).

Whilst a certain Level of Detail is important, it is Level of Information which is key for heritage application of BIM. For the heritage industry to gain the full benefits of BIM it must also incorporate the process aspects; this will allow the efficient and joined up management of conservation management projects and for data requirements to be clearly understood throughout. Doing so will bring the benefits seen

in other industries to heritage, and avoid some of the missed opportunities seen in early uses of 3D survey data. Before this can be fully realized however, the lack of data standards, interoperability and specifications must be resolved. Until then, terrestrial and maritime built heritage (archaeological works are somewhat less constrained) cannot explore the full value of BIM.

With respect to the use of 3D survey, in this case laser scanning, to help obtain accurate and up to date information about the condition of the hull and associated components, and for informing ongoing and future conservation management objectives, we now turn to HMS *Victory*. This is an example of a conservation project that aims to utilize integrated 3D data and heritage information, through information modelling, for effective ongoing conservation management.

Fig. 7.14 HMS *Victory* in No. 2 Dock at the Historic Dockyard in Portsmouth (National Museum of the Royal Navy)

7.6 HMS *Victory* (1765) and Information Modelling: A Case Study

The survival of HMS *Victory*, and the continued efforts to restore and conserve the ship throughout the twentieth century, are due in totality to its association with the Battle of Trafalgar and the death of Nelson (Fig. 7.14). Efforts to restore the ship to its ‘Trafalgar’ appearance were the driving force behind the initial restoration in 1922–1928, as well as the major repairs undertaken between 1955 and 1964, and the continuation of repair and restoration works through to the bicentenary of the Battle of Trafalgar in 2005. More recently, however, there has been a recognition that *Victory* is equally important as an object in and of itself. This is in no small part due to the attrition of the numbers of wooden ships of the line during the nineteenth and twentieth centuries. Increasingly HMS *Victory* represents an archaeological repository which can inform our knowledge of the history and technology used in naval architecture of the eighteenth and nineteenth centuries, while the extensive works carried out in its restoration and conservation during the twentieth century provide a narrative for the early conservation of historic vessels as well as providing essential information on the efficacy of various approaches used in the conservation of historic ships. HMS *Victory* is an extremely complex structure, with over 16,000 individual timber components used in its construction, few of which date to its initial build. Various phases of rebuilding, refitting and restoration over the ship’s 250-year life span have resulted in a mix of materials of different age, type and significance. In addition to the archaeological evidence contained within the ship’s fabric, a

large amount of documentary evidence exists relating to the restoration and conservation of the ship through the twentieth century. From the 1920s onwards drawings, plans and reports were created to chart alterations to the ship for the restoration to as close to the Trafalgar appearance as possible.

The next 15–20 years will see a large programme of works designed to stabilize the structure of the ship and ensure its long-term survival. Core to this is the preservation of significant parts of the structure to prevent further loss of archaeologically significant material. This approach requires the ability to understand the impact of works on the fabric of the ship, and to understand the significance of each component so that proposed works can be designed in such a way as to minimize impact on significant material. BIM serves as a potential management tool to assist in this analysis, by relating the information generated from both archaeological and documentary research with a 3D model of the ship. The use of BIM on HMS *Victory* therefore represents a fuller utilization than those discussed above.

7.7 Development of the VIM

In 2012 ownership of HMS *Victory* passed from the Ministry of Defence to the National Museum of the Royal Navy (NMRN), and work was undertaken to understand the current condition of the ship and underpin the conservation and planned maintenance of the vessel, established through the preparation of a comprehensive Conservation Management Plan (NMRN 2015). As part of this work a measured survey

Fig. 7.15 Frames of HMS *Victory*

Fig. 7.16 Plan and isometric view of the different components comprising the upper gundeck

was undertaken using terrestrial laser scanning to create a detailed 3D point cloud of the ship (Fenton Holloway Ltd 2014). The point cloud was used to create a solid surface model of each significant component within the ship's structure, resulting in a complex 3D model with over 15,000 individual elements (Fig. 7.15). This model was used to facilitate the structural analysis of the ship, generate accurate plans and sections and to form the basis of a 3D model for the management of information relating to each component within the ship's structure. This management model, which has been dubbed the VIM (or *Victory* Information Model), seeks to apply the concepts of BIM to the ship. The aim of the VIM is first and foremost to support and inform the ongoing conservation works of the ship by providing the ability to understand the significance of each individual component within the structure to ensure that planned alterations and interventions do not impact on the most significant elements

(Fig. 7.16). In planning the creation of the VIM, there were several key considerations:

1. The nature of information recorded:

A wealth of information exists on HMS *Victory*, but not all this information is relevant to the ship's conservation, and while the model could conceivably be used to collate and organize a lot of this information, the priority of the project is collating information that will facilitate the decision-making process in advance of HIA. This information can loosely be divided into three types:

- (a) Physical information contained in the 3D model itself, such as dimensions, shape and weight, along with additional material information such as timber species, presence of insect action and pest management (McCormack 2016), fruiting bodies, structural failure;

- (b) Archaeological information from surveys of the ship structure during the preparation of the CMP, shipwright's timber marks (Wessex Archaeology 2014), analysis of timber technology, dendrochronology (Nayling 2014), and paint analysis (Crick-Smith Conservation 2014); and
 - (c) Subjective values such as various types of significance (evidential, historical, aesthetic and communal) as identified in the CMP, and other research (Leggett 2016)
2. Longevity of data:

The VIM is designed to support the current 15 to 20-year programme of works to stabilize the ship, but aims to go beyond this into the long-term management of the vessel. In addition, the data contained in the VIM is potentially useful in other forms of research relating to the ship's fabric, and so should be easily exportable to other applications. The selection of software packages and data formats needs to ensure that all information entered into the database is futureproofed against software change or redundancy. Equally important for the long-term management of an asset which may have many different individuals and organizations working on it over its lifecycle is standardization of data structures and terminologies. Establishing this early on will allow the easy interrogation of data and less reworking of information at a later date. This also raises the importance of standardizing and checking (for completeness, accuracy and current relevance) data before entry, as it will have been generated over many years by different individuals and for different purposes (Historic England 2017).

3. Archiving standards:

HMS *Victory* is an internationally significant historic ship. Data generated as part of the ongoing works to the ship must be compatible with the guidelines developed by National Historic Ships, as well as heritage bodies such as Archaeological Archives Forum, ARCHES, ClfA and ADS.

In order to support both 2 and 3, a key requirement of any software is that it uses, or can easily export to, non-proprietary or open file formats. This is advantageous for a number of reasons: (1) Straightforward archiving of data; (2) Import/export to other software to minimize replication of work; and (3) Futureproofing by accommodating transfer of data to newly developed software.

Several significant issues were encountered when trialling BIM software. Firstly, Level of Detail (LOD) of the existing 3D data is not readily compatible with existing off-the-shelf BIM packages. Most BIM software is created to facilitate the design process, and simplifies and manages 3D data by using standard forms and set templates for elements of buildings. Entering 'as-built' information for historic

assets is much more difficult, with non-standard geometric forms (i.e. ships timbers) not being easily realized in the software. Secondly, the Level of Information (LOI) required was outside the remit of most BIM programs. Whilst material, dimensions, appearance and even cost are common factors, information such as condition, presence of rot, etc. as well as archaeological information such as timber marks, dendrochronology, evidence for reuse, value and significance are not attributes used as standard in BIM. This can complicate the process of adding this information. Thirdly, when this data is added, its interoperability with other programs is not guaranteed. This makes it difficult to directly import and export information to other software through the standard format of IFC.

	BIM	VIM
Level of detail	Simple 3D geometry	Complex 3D geometry
Structure	Buildings/infrastructure	Ship
Process stage	Design and operate	As-built
Future structural change	Minimal	Major
Level of information	Moderate, standardized	High, specialized

To satisfy the conditions required of the VIM, an alternative to an off-the-shelf BIM package had to be developed which could deliver the key concepts of BIM in the context of an historic vessel. This involved the combination of two key elements: (1) A 3D modelling software that allows the import of existing 3D data; and (2) A database program managing the key information needed for the ongoing works.

In the case of the VIM, Rhinoceros 3D was selected as the modelling software. This software was selected due to its ability to handle the complexity of the 3D data, its ability to both import and export to a range of open and non-proprietary file formats, and the availability of an SDK allowing the potential for a custom-built plugin to be developed. Microsoft Access was chosen as the database management program. To access the information held in the database from the Rhinoceros 3D model the object is selected and the Hyperlink option within Rhinoceros 3D is used to link to an html version of the database entry. Whilst this does not follow a standard BIM software approach, it was deemed the best way to implement BIM in this context.

7.8 Future Development of the VIM

Creation of the VIM is an ongoing process, and is by no means a finished product, indeed as the VIM is designed to support the next 15–20 years of work on the ship, it needs to be a fluid and responsive database. A large amount of time is

Fig. 7.17 Model of the rudder from HMS *Victory* in .stl format opened in simple viewer

needed to input a range of data, with over 100 years of reports and surveys, along with additional information from photographs and plans, many of which are now themselves historically significant items. Establishing data formats, standards and terminologies for digitizing this information, in response to the lack of accepted industry standards, will ensure that work is not replicated. In addition, an archaeological watching brief on the ongoing works on the ship is exposing previously obscured material which helps to establish the age and condition of the ship both now and in the past. This information will both inform the future management of HMS *Victory* and further contribute to an understanding of its history.

In the short term, the aim is to develop a plugin that better links the 3D dataset to the accompanying database, as well as allowing the filtering and display of elements by each of the database fields. One of the key reasons for using open or non-proprietary file formats is to ensure that the database and model are flexible enough to be transferred into new software packages as they develop (Fig. 7.17). BIM is a rapidly developing industry with an ever-increasing range of applications, and working within already well established open file formats, although not optimum, future-proofs the dataset for new developments.

7.9 Lessons from the VIM

The development of the VIM provides a single source of truth for the HMS *Victory* project, uniting a detailed model of the physical object with information necessary for conservation and management. The VIM straddles the categories of

Fig. 7.18 Model of a beam arm from the lower gundeck showing LOD of individual elements within the VIM

BIM usage in Heritage described above. It is to be used for archiving information, conservation (as opposed to renovation) and to a degree process management. The first of these is limited in scope, for the reasons described above, but it is nonetheless a living archive of important information about HMS *Victory*. As a process management tool, it is used to understand what work must be done and when, though not in the same detail as some of the 4D uses in the AEC sector. Its development was also not as tightly controlled with documentation, being driven more by an opportunistic use of existing data/knowledge rather than existing standards or future goals. The key learning experience of the VIM project has been to understand the purpose of an information model. Ultimately, this would allow for a better scope to be defined, especially in terms of what Level of Information and what type of information is required in any future project (Fig. 7.18). This in turn would lead to process changes in how data is gathered and incorporated in to the model, reducing costs and producing an easier to use model.

7.10 Discussion

Past historic vessel conservation has striven to understand the key significances that require to be retained, whether it is physical historic fabric, or maintaining elements or spaces within a vessel that magnify significance in other areas—essentially the different values that make the asset important. The opportunities to better manage the retention of significance and understand how conservation work throughout the lifetime of a project is best understood can be helped significantly through the acquisition of 3D data and effective information modelling. There is a real motivation and willingness of the wider marine and maritime heritage sector to engage with and embrace 3D survey initiatives; and where the key integration of 3D outputs in projects represents a central

goal. This is the case not only with large organizations such as the National Museum of the Royal Navy in the UK (examples include HMS *Victory*, HMS *Caroline*, HMS *Alliance*), but also smaller organizations such as the Scottish Fisheries Museum in Scotland (Fifie Sailing Drifter *Reaper*, the Baldie *White Wing*, and other small craft within the collection).

In relation to HMS *Victory*, the challenges inherent in the development of the VIM are clear to see, but more generally, there is also a real opportunity to push the adoption of information modelling in historic vessel conservation, as something that is seen as beneficial, rather than potentially seen as something that is costly and time consuming.

Further to this, the non-selective nature of 3D data collection techniques such as laser scanning and photogrammetry means that there is a wealth of data, which have already been collected, that may be used in the development of information models for historic maritime assets. This depends on accuracy and completeness, and some of the older surveys may fall short of what is needed, but importantly there is no need to start afresh, all of the previous work is still valuable.

The importance of early engagement in the development of maritime applications of information modelling cannot be overstated. In order to maximize efficiency and long-term value, real progress needs to be made on standards, both here and in heritage in general. The heritage industry has a long history of standardization to aid interpretation and research, with information modelling it has the added value of saving a lot of time and expense for individual projects. The best approach to conservation management needs to be further explored too. Whilst the VIM shows one way of taking conservation management forward into information modelling, it has developed under a very specific circumstance, with technical restrictions as they exist at this time. Going forward, with enough pressure, these technical restrictions may change, offering better ways to handle the uniquely complex assets we deal with.

A certain amount of education of the AEC industry and software developers may be required, but it need not be solely for our benefit. The assets we deal with have a long history. One day the new builds that are being managed with BIM will have a history to contend with too; considering the issue of history now could save a lot of trouble later. The immense Level of Information required for the management of an historic vessel will of course outstrip a new building for some time, but one day they too may be considered important heritage assets with associated restrictions on what can and cannot be done to them. It would be better to record information when it is current, and allow for its integration into BIM than to have to retrofit that information at a later date. This requires a long-term view certainly, but that is the purpose of BIM.

There is a need to be pragmatic about what is represented in an information model of an historic vessel. If the represented geometry is too complex it will serve to increase file sizes, making models more difficult to use, and greatly increase the cost and difficulty in creating them in the first place. The Level of detail does need to be sufficient for the needs of the CMP however. In the case of HMS *Victory* for example, it would be no good to represent the hull with a handful of objects since it has such a complicated interwoven history of conservation and repair. We may find however, that in the future dealing with complex geometry is made easier by the application of automated object generation from shape grammars, as demonstrated by Dore and Murphy (2012a, b, 2013) in neo-classical buildings, especially with the ongoing improvements in AI recognition. Recent work using procedural modelling to create parametric models of ships by Suarez et al. (this volume), for example, brings the 3D modelling process for historic assets more in line with that usually seen in BIM projects, and reduces the time and expertise required to create iterative models. Their focus is on reconstruction from partial information, rather than the creation of a digital twin of a fully recorded vessel, but the procedurally generated model could be used as a starting point for the geometry. This geometry could then be edited to adequately represent the vessel. The complexity of this task will likely scale with the required LOD, with more complete representations requiring more edits, as real vessels do not necessarily follow all of the rules, and can have very complex histories of modification. It may be that for the most complex models it is actually faster to start from scratch than to check and modify the many individual elements, but this procedural modelling approach would need to be tested upon a complex extant vessel.

7.11 Conclusions

Whilst it is still too early to gauge the long-term success of the VIM project, the easy access to information that it provides, as with BIM projects, should lead to significant benefits. These will include improving project outcomes through better management (whether on existing assets, new assets or through expanded opportunities for education), better use of resources, and ultimately, expanding our knowledge of historic vessels and their effective conservation management. Combining the principles of information modelling with a CMP, effectively embedding that CMP within a visual interface that makes access to information easier and more contextual than ever, remains the key challenge. 3D survey was once seen as too expensive to be used in heritage, but it is now common place in the industry. Information modelling is a costly process to kick start, both for an industry and

individual organizations, but its success within the AEC sector, and the benefits highlighted in this chapter show that it is worth the investment. In addition to extant historic ships, it is also important to stress the potential application for information modelling in the wider marine and maritime archaeological sphere. A key area of application concerns the ongoing management of wreck sites (either on the seabed or subsequently recovered), whether it is in the domain of research projects, or through the management perspectives and requirements of the national curator, particularly in relation to designated wreck sites. There is a clear window of opportunity, and the researcher, heritage practitioner, and curator alike has the opportunity to engage with the development of a solid platform on which to effectively integrate 3D applications through information modelling with the conservation management of the marine and maritime historic environment well into the future.

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