Chapter 7

BREMEN COG: THREE RECORDING TECHNIQUES FOR ONE OBJECT

AMANDINE COLSON and LEVENTE TAMAS

ABSTRACT

The Bremen Cog is a ship which was discovered in the river Weser close to the city of Bremen in 1962. Based on dendrochronological examination, the cog was built in 1380. It was successfully conserved and restored with polyethylene glycol (PEG) at the German Maritime Museum in Bremerhaven and has been on display since 2000.

Despite its age, the cog was well preserved and the steerboard side was almost complete. The reconstruction of the missing parts seemed therefore possible and of interest to the public.

The museum wanted to give a new lease of life to the cog and allow the public to see it from different viewpoints, while also communicating research results. The case study described in this chapter focuses on the three-dimensional monitoring of the ship's current condition, the understanding of wood deformation that occurred in the past, and preventing future changes. Another objective was to make a 3D computer model, based on the same digital data, for the participatory education of the public. This model of the ship will enable its continued public presentation, through a virtual surrogate, during the building works. The case study involved different tests: photogrammetry and Structure from Motion acquisition, 3D scanning and total station. Data analyses were also carried out.

Keywords: Deformation monitoring, large-scale objects, conservation, restoration, laser scanning, total station theodolite, photogrammetry, COSCH

Introduction

The Bremen Cog was discovered in 1962 near the city of Bremen, Northern Germany, in the river Weser. The decision was taken to salvage the ship. Most timbers, together with finds, were recovered from the river bed between 1962 and 1965. Thanks to dendrochronology analyses, the ship timbers were dated to the second half of the fourteenth century. Following a six year reconstruction at the purpose-built German Maritime Museum in Bremerhaven, the Bremen Cog was found to be 24 m long, 7 m wide and 4 m high. Its conservation took almost twenty years before it was possible to present the ship to the public in 2000. About a year later, the first signs of deformation occurred. After different trials to design a new support system for the ship, the museum decided to work on a system that would feed information to the future support girdle. At that point the relevance of designing a non-invasive, long-term deformation monitoring system became clear.

Our study of the Bremen Cog was aimed at testing different recording methods on a single large-scale object to gain an overview of the expertise and the resources necessary to perform the challenging deformation monitoring over time. The study was conducted as an activity of the network, Colour and Space in Cultural Heritage (COSCH). It focused on testing three different techniques in order to compare their feasibility for a future deformation monitoring system. The expertise available within COSCH offered an ideal opportunity to gain new knowledge and benefit from feedback from the scientific community. Three techniques were chosen: photogrammetry, laser scanning, and total station. The approach was to compare, analyse, and fuse the data, in order to assess the advantages and drawbacks of each technique. Another aspect of this research was concerned with museum education, looking at digital visualization as a means to present the ship to visitors during renovation of the Scharoun building, where the ship is on display.

Earlier Research

Definition

The term monitoring is widely used in a range of fields. According to the Oxford English Dictionary, the elementary meaning is, "To observe and check over *a period of time*, maintain regular surveillance over" (emphasis added). Irrespective of the field of study, time is the central notion. In the field of conservation, we commonly differentiate between two types of monitoring that differ in methodology and in principle: one is concerned with preventive conservation and the other with remedial conservation. The ICOM-CC defines preventive conservation as "all measures and actions aimed at avoiding and minimizing future deterioration or loss. . . . These measures and actions are indirect—they do not interfere with the materials and structures of the items. They do not modify their appearance." Remedial conservation involves, according to the same resolution, "all actions directly applied to an item or a group of items aimed at arresting current damaging processes or reinforcing their structure. These actions are only carried out when the items are in such a fragile condition or deteriorating at such a rate, that they could be lost in a relatively short time. These actions sometimes modify the appearance of the items" (ICOM-CC Resolution 2008). Therefore,

- passive monitoring concerns the environment, climate and humidity changes around the object, while
- active monitoring concerns the deformation and degradation processes of the object itself.

Monitoring in Conservation of Cultural Heritage

Since the 1980s, control and monitoring of temperature, relative humidity, and light conditions have been recommended by preventive conservation specialists (Thomson 1986, 85). Ideal levels have been established and modern data-loggers enable conservators to take climate measurements at defined intervals and save the data digitally in spreadsheets. However, data analysis and visualization remains a challenge. Moreover the comparison to other decisive factors, such as meteorological data or the number of visitors is required (Michalski 2010, 355–56).

Modern technologies have helped make significant advances in the documentation serving different disciplines, including archaeology, history of art, and biology. The last decade saw intensive digitization campaigns in museums throughout Europe, among others in natural science museums[1] and in archives. In terms of active monitoring, most conservators are documenting the conservation state of objects using traditional techniques, such as drawing, photography, description, and sampling. Although coherent, these methods deliver less accurate information and become problematic for large objects.

Other Comparable Projects

The Vasa Museum in Stockholm, Sweden, houses a 69 m long archaeological ship. Laser technology has been used since October 2000 to measure systematically the changes in shape (Jacobson 2003, 186–88). The system was designed by the School of Architecture and Built Environment, Department of Geodesy of the

1 For example, the digitization of insect specimens by the EoS project at the Museum für Naturkunde in Berlin, see http://eos.naturkundemuseum-berlin.de/ (accessed 20 December 2016).

Royal Institute of Technology. Measurements are taken by the technicians twice a year. Over 400 points are recorded using a total station. This type of laser-based electronic theodolite, also called tachymeter, is used in modern surveying and archaeology to measure distances. The 3D data are processed and transferred to a dedicated software platform for visualization and comparison of the results (Horemuž 2003, 5). Work is ongoing to analyse the data acquired over the last sixteen years (van Dijk et al. 2016, 109) which will assist with the construction of a new support system.

The Mary Rose Museum in Portsmouth, England, is planning the same procedure to measure the sixteenth-century flagship of King Henry VIII. The Mary Rose is 38 m long (Schofield et al. 2013, 399–400).

The recent digitization of the fifteenth-century merchant ship found in Newport, Wales, shows the advantage of digital documentation of archaeological wood for assessing the deformation before and after a conservation treatment (Jones 2015). A Faro-Arm, a portable coordinate measuring instrument, based on laser technology was used. In fact, noticeable changes were detected by comparing the three-dimensional data processed in the commercial software Rhinoceros.

Impact on the Research Community

The participation of the German Maritime Museum in the COST-Action TD1201, Colour and Space in Cultural Heritage (COSCH), enabled the authors to undertake new research of the Bremen Cog. The COSCH case study consisted of preliminary tests on this fourteenth-century ship using 3D laser scanning, total station, and photogrammetry as pertinent methods to monitor three-dimensional deformation processes (see part 2, Methods and Technologies, for further explanation).

In response to a growing interest in underwater archaeological finds of this kind in Europe, a working group was founded in France in 2015. The initiative came from the conservation laboratory, Arc Nucléart in Grenoble, which is involved in the conservation of many wooden archaeological ships in France. The group is called *Groupe d'Étude et de suivi des épaves restaurées* (GEISER) and is led by Marine Crouzet of A-CORROS, Arles. Its expert members gather to discuss preventive conservation of ships, on display in French museums, treated with polyethylene glycol. Monitoring the temperature and relative humidity are central to this scientific exchange, as well as deformation monitoring. Following the publication of information about her research into the Bremen Cog on the COSCH website, the co-author Amandine Colson was invited to participate in this working group.

COSCH Case Study of the Bremen Cog: Description of Work

Significance of the Object

Archaeological organic material (remains of plants or animals) survives in one of two extreme conditions: wet or dry (Cronyn 1990, 243). Under European latitudes, we mostly deal with damp or waterlogged objects, found underwater in the sea, lakes, or rivers, but also in marshes or swamps. Preservation of such material is a real challenge for conservators and means long conservation treatments, from a few weeks to several years. A treatment of large pieces of wood, or a larger ensemble such as a shipwreck, can take up to several decades. Few projects have been carried out on large collections of archaeological organic objects and large-scale objects. High cost, problematic storage, and display are the main barriers.

Figure 7.1. Bremen Cog shortly after the opening of the permanent exhibition in 2000. Photo © German Maritime Museum.

The size of shipwrecks varies from a river barge to warship. They are rarely found and each discovery causes a public sensation, as well as excitement among the specialist community. A handful of wooden ships have survived in Europe and are preserved and presented in museums. Apart from the already mentioned Vasa in Stockholm and the Mary Rose in Portsmouth, England, larger ships include the Oseberg and Gokstad in Oslo, Norway, and the Skuldelev ships in Roskilde, Denmark. Due to the rarity of finds, only a few specialists deal with the preservation of archaeological wood, which contributes to the singularity of the field.

The Bremen Cog (fig. 7.1) was found in October 1962 downstream from the city of Bremen, during enlargement work of the riverbed of the Weser, opposite the Europa Hafen (Pohl-Weber 1982, 16).

The significance of the discovery was quickly realized and the decision was taken to dismantle the ship on site, taking it apart as much as possible before the arrival of first ice of the winter of 1962–63 (Pohl-Weber 1982, 17). The salvage of most of the timbers took place by December 1962. A diving campaign was organized in the summer of 1963 and a systematic survey of the area was carried out in the summer of 1965. A diving bell covering 24 sq. m for each position was used. All in all twenty-three working days and 274 changing positions were necessary to cover a global surface of 1400 sq. m of the river bed (Pohl-Weber 1982, 23–24) and around 2000 finds were raised (Bardewyk 1982, 5). In 1969 some wood samples were analysed through dendrochronology and established the medieval dating: the wood used for building the ship was felled in 1378 (Klein 2003, 157).

After some time in storage, the timbers were transported during the summer of 1973 to the German Maritime Museum in Bremerhaven, then under construction (Lahn 1982, 32). The reconstruction of the ship was carried out under high humidity by a team of up to five people. In the spring of 1979 the Bremen Cog was standing (Lahn 1982, 29) ready for conservation, which has been ongoing ever since.

The conservation of waterlogged-wooden objects is a very delicate matter (Hoffmann 2013, 3). The main challenge is essentially to replace the water lodged in the cells with another substance that can provide a support for the cell walls when the water is gone (Hoffmann 2013, 39). Only then, the shape and the original surface can be preserved to ensure that the structure will not collapse during the drying process. In order to prevent drying, the object must remain submerged or in 100 per cent relative humidity during the entire process. Therefore, the water substitute must necessarily be water soluble (Hoffmann 2013, 4).

Only a few replacement agents fulfil these prerequisites. One of the most popular is polyethylene glycol (PEG), an organic compound also used in medical industry (Horie 2010, 188 and 192). It was used, with promising results, in the late 1950s to treat archaeological wood in Denmark and in Sweden (Hoffmann

2013, 44). Over the decades, it became the most widely used method for the conservation of waterlogged archaeological objects (Hoffmann 2013, 44).

The Bremen Cog and the five Skuldelev ships in Roskilde were both found in the same year, and a year after the warship Vasa in Stockholm (Hoffmann 2013, 44), which led the teams to work closely together and form an international working group, that was to become the ICOM-CC Wet Organic Archaeological Material group.

After the north German discovery, a group of experts from the University of Hamburg (Hoffmann 2013, 80), in collaboration with Danish and Swedish colleagues, proposed a long-term conservation treatment, to last some thirty years, using PEG 1000 up to 60 per cent in water solution. This plan was re-evaluated by Per Hoffmann, when he took his office at the German Maritime Museum in 1979 and after carrying out some tests from 1979 to 1984 (Hoffmann 2003, 81 and 84). The conservation started with PEG 1500 up to 12 per cent and switched in 1984 to the so-called "two-step" method, developed by Hoffmann, using two different molecular weights: PEG 200 up to 40 per cent (Hoffmann 2003, 86) and PEG 3000 up to 70 per cent (Hoffmann 2003, 87), both in water solution.

The conservation ended, in accordance with Hoffmann's plan, in December 1999. After some months of work, the ship was presented to the public on 17 May 2000 (fig. 7.1). The conservation was completed, but soon new issues surfaced: the ship "had been floating nearly weightlessly between 1981 and 1999 and had regained her weight of ca. 40 tonnes . . . and began to change its shape" (Hoffmann 2011, 151).

From 2002 to 2005 an international experts group worked under the supervision of Hoffmann on a new support system. The decision was taken to correct the deformed hull and go back to the drawing by the shipwright who reconstructed the ship in the 1970s (Hoffmann 2011, 153). To achieve this, metal structures were built in 2006 and the ship was put back in position in 2007.

In 2008–9 a laser scan was carried out by the company involved in the new support system, to make a mathematical model needed to manufacture a new girdle. After a short break, the project continued in 2013 with a new team. New solutions for the presentation of the ship were considered. An evaluation of the situation and the data collected highlighted the lack of information about the state of the object and the deformation processes, thus hindering the conception of a new support system for the ship.

Monitoring the Bremen Cog

Since the beginning of the project, the ship's shape, considered as a construction, was under the responsibility of the shipwright Werner Lahn (until 1987) and the engineer Wolf-Dieter Hoheisel (until 1999). The timbers were individually documented during the reconstruction phase, using a stereoscopic camera. In 1982 a photogrammetric campaign was carried out by Hannover University, focusing on the vertical lines in order to establish profiles using a metric camera. A new acquisition, requested by the museum's scientific committee, was carried out in 2003. Over one hundred digital photographs were taken and compared with the profiles from 1982. At that point "a distortion in the range of ±10 to 25 cm" was attested (Wiggenhagen et al. 2004, 54).

In 2009, a laser scanning acquisition of the inner part was conducted, in order to plan for a new metal support. Although a couple of three-dimensional records of the Bremen Cog were created, these constituted isolated initiatives, aiming to address specific, temporal tasks. No permanent, long-term deformation monitoring system was implemented.

The main challenge, in order to preserve the ship for future generations, is to understand it from within its core. In 2014 the design of a long-term deformation monitoring system, measuring the Bremen Cog at least two times a year, was considered the most sensible approach. A new support system for the ship conceived without tangible information about the deformation would not be logical.

Objectives of the Case Study

The case study, Bremen Cog—when Science meets the public, had two main aims. First, the ongoing monitoring of the ship's deformation and, second, the development of a means of interaction with museum visitors. In 2012, the German Federal Ministry of Education and Research published a concept paper for the eight national research museums, in which their role was defined as "a presentation platform for research and a bridge to education" (BMBF 2012, 2).[2] By acquiring three-dimensional data, rather than using the traditional methods, more goals would be achieved (Howard 2007, 5): research, informing the public about ongoing work and explaining further details about the object.

Three different 3D methods were to be tested exhaustively. The comparison would focus on such technical aspects as accuracy, acquisition duration, post-processing duration, as well as the choice of software, cost of instruments, the operator's expertise necessary to conduct an acquisition, data formats, and data archiving. The fusion would combine different data sets to optimize the 3D model and benefit from the advantages of each method. A 3D animation would be produced to be presented to the visitors.

2 Citation translated from German by A. Colson.

User Needs

In the field of conservation-restoration, different techniques derived from chemistry, physics, and biology were developed over the time, called Conservation Science, in order to enhance knowledge about works of art. Some documentation techniques, such as digital photography, available at first only to prosperous institutions, became common practice. Nowadays almost every practitioner at a conservation laboratory has a digital camera. Unfortunately, not all cultural heritage objects receive equal attention. Some remain neglected and undocumented.

Monitoring and recording the condition of objects remains the central task of the conservator. First, it is essential to assess the current state of the object to identify a possible need for an intervention. Second, to keep a record of the conservation treatment of the object for future reference (E.C.C.O Professional Guidelines II, Code of Ethics, Article 10).

In this context, accuracy has to be defined by the conservator depending on the object's size and also the degradation to be documented. In the case of the Bremen Cog, it was decided to work at a level between 1.0 to 0.5 cm at first. After gaining a better overview of the deformation a re-evaluation would be made to see if more precision, around 1 mm if technically possible, would be needed.

As the conservator is required to document his or her work, the question of data sustainability arose. Would the data produced be accessible in ten, twenty and in a hundred years? Here lies the worry of working with digital instruments and tools, and maybe the reason why some professionals are still reluctant to use 3D technologies on a regular basis. The industry and engineering world charm the end-user with attractive case studies, promising very interesting results. But sometimes, reality appears to be more complex. End-users rarely engage directly with the technical field, unless they have some previous experience or an opportunity to address their questions in a specific research context.

Exploring different methods, or using different techniques to achieve a given objective, requires assessment of the costs involved. Following the project from start to finish and participating actively in the decisions is the only way for the end-user to gain a clear idea of the financial resources necessary.

The complexity of the hardware and software discourages the end-user from participation in the project. Working closely with the engineers and technicians plays an important role. More problems could be solved if conservators would be prepared to engage more with other fields, including with engineers from the information technology domain. In our case, if the deformation and climate data could be compared, patterns and similarities could be established and offer a factual basis for our theoretical assumptions.

Digitization methods

Location of the cog

The Bremen Cog is exhibited indoors, oriented towards the north, which means that starboard faces east. The ship is accessible on three levels. A large east window allows the visitors to look at the ship from outside, but constitutes a significant issue in preventive conservation, increasing the values of light on the object. Four pillars around the ship are made of concrete cubes, 60 cm in diameter. The temporary metal support is still in place and enables access to certain parts of the ship. On the backboard side, an elevator has been installed.

Common Coordinate System

Comparing three different methods requires a common coordinate system. The present recording project started in October 2014 with a coordinate system used for the photogrammetric acquisition conducted by Julien Guery. At that stage, eight reference points were installed around the ship, but none directly on it, exclusively on the ground floor. Together with colleagues from the Institute for Spatial Information and Surveying Technology, i3mainz, of the University of Applied Sciences in Mainz, the type of reference point was chosen and agreed upon. Black and white targets were printed on standard A4 paper (fig. 7.2).

Figure 7.2. Bremen Cog, east side. Target on a concrete pillar. Photo © German Maritime Museum.

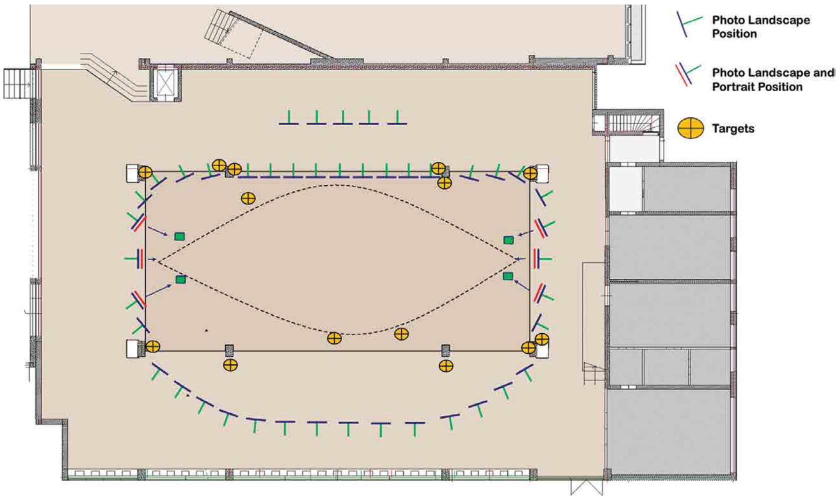

Figure 7.3. Bremen Cog floor plan, common coordinate system on the ground floor. © Amandine Colson.

The positions of the targets were selected in accordance with the 3D recording scanning positions. At least three targets had to be recorded from a single scanning position. Furthermore, since several recordings are needed to document the whole cog, the individual shots had to be aligned. The alignment of the required standard requires at least three identical targets for all 3D data sets. All targets were measured through tachymetric surveying in order to have a global reference system available for all future recording campaigns. Altogether, six more positions were added on the ground floor—making fourteen points (fig. 7.3), plus seventeen on the first floor, and five on the second floor.

When Massimiliano Ditta prepared the total station acquisition, in April 2015, the instrument required more reference points around the ship, and between the ship and the instrument, for the resection/repositioning. Nineteen reference points were therefore added, making forty-seven in total (Ditta 2015, 11). These points were used during the acquisition, and also for merging the different data sets.

To have one system that could serve all the requirements and was technically suitable proved to be a challenge. Although everyone knew that this was a testing phase, from the aesthetic point of view, it was difficult to justify almost fifty reference points.

Paper targets can only be a temporary solution. During the renovation of the room, twenty points were selected and had their centres drilled with stainless steel survey marker nails. The accuracy of this procedure has its limits, but the position of some points was maintained.

Table 7.1. Bremen Cog: Comparison of all photogrammetric data acquisition campaigns. © Amandine Colson.

Date	October 2014	October 2014	March 2015	April 2016
Operator	Julien Guery	Julien Guery	Julien Guery	Massimiliano Ditta
Duration of acquisition (hours)	2	2	1.5	1.5
Duration of post-processing (hours)	3*	2*	4*	12
Number of pictures	197	115	235	675
Pictures ground floor	72	39	80	252
Pictures first floor	74	33	75	207
Pictures second floor	51	43	80	216
Daylight (yes/no)	yes	yes	no	yes
Camera	Nikon D300	Canon IXUS - NIR	Nikon D300	Nikon D300
Software	Agisoft PhotoScan	Agisoft PhotoScan	Agisoft PhotoScan	Agisoft PhotoScan

* this post-processing includes aerotriangulation and 3D point cloud generation but no Digital Surface Model (DSM) or orthophotograph generation

The Institute of Photogrammetry and Geoinformation in Oldenburg, Germany, partners of the museum since March 2016, plans to work on technical questions such as the coordinate system and the reference points. A new coordinate system is to be implemented in 2017.

Photogrammetry

Three photogrammetric acquisition campaigns were carried out between October 2014 and September 2016. Those in October 2014 and March 2015 were undertaken by Julien Guery and the campaign in April 2016 was undertaken by Massimiliano Ditta (table 7.1).

The first acquisition campaign took place during Guery's Short Term Scientific Mission in October 2014. A three-week Mission was supported by the COSCH

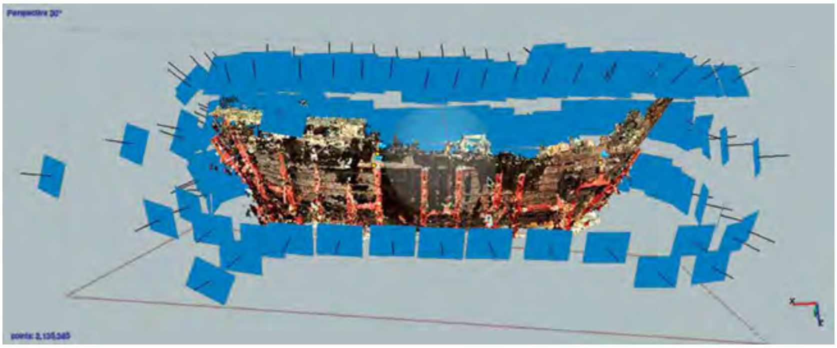

Figure 7.4. 3D photogrammetric model. © Julien Guery, 2015.

Action. Guery focused on local conditions, such as the daylight and the object material, a dark conserved wood (fig. 7.4).

After a couple of tests, it appeared that the best time would be late evening, when the sun goes down in the west or even later in complete nightlight. Other tests, using a modified camera to take pictures in the near-infrared range were promising. After solving these primary issues, the focus was on the acquisition itself.

Laser Scanning at i3mainz

In November 2014, the cog was recorded by Carina Justus and Stefan Mehlig from i3mainz using a Leica ScanStation P20. Twenty-nine scanning positions were needed to acquire a 3D data set representing almost the entire cog. The high number of scanning positions was needed due to:

1. the very complex shape of the cog: the inner and outer part both have many occluding areas;
2. as the inner part of the cog could not be entered due to its fragile conservation condition, the scanner had to be positioned outside the cog, on the ground level, to capture the outer part, and on the first and second levels of the exhibition room mainly to capture the inner part; and
3. the large size of the cog and the limited space around it (the field of view was small). Including the tachymetric surveying and laser scanning three days were needed.

The processing of captured data sets (registration, alignment, outlier removal, etc.) in all twenty-nine scanning positions was based on the local coordinate system and lasted ten days. The resolution of each point cloud was 6.3 mm @ 10 m; accuracy: 3 mm @ 5 m. A Leica ScanStation P20 (2013) was used. A tachymetric surveying with an accuracy of ca. 3 mm (adjusted) was applied to generate the local reference system. The aligned point cloud had ca. 30 million points (areas of no interest, such as the floor and roof, were deleted) with a resolution / point spacing of minimum 5 mm. The processed data were provided in PLY and OBJ formats which can be visualized and analysed with the open source software MeshLab. Due to the point spacing of minimum 5 mm a comparison of this data set with a qualitatively similar data set recorded in the future would provide information of geometric deformation of greater-than-or-equal-to 5 mm.

Total Station Theodolite

The total station is an electronic distance measurement device (EDM) used on building sites and archaeological excavations. A laser is pointed at a target and the position is recorded three-dimensionally. Thanks to a grant obtained through COSCH for a Short Term Scientific Mission, Massimiliano Ditta, an archaeologist and expert in 3D recording, worked for three weeks on the protocol and acquisition, using the Leica TS06 owned by the museum.

Usually in context of a monitoring, reflective targets are used for each point. Recordings can be made without targets, but the reproducibility of the recording cannot be assured. Installing targets would have meant drilling into the original wood, and was at that stage considered ethically unacceptable. If a long-term method is chosen, this question will be re-evaluated. The stickers used in earlier 3D scans were reused on the outside of the hull. For the inside, so-called feature points were defined by Ditta and catalogued.

The accuracy of the technique was ±2 mm cu., meaning an acquired data set can be compared with another one giving precise results. Usually, the data recorded with the total station are only seen during post-processing. It was possible to control the data acquisition through Rhinoceros software in real-time.

Presentation

As planned, the 3D models were used in another context, to promote the ship and the work of the Institute of Photogrammetry and Geoinformation in Oldenburg within the museum, and also externally. The historians and archaeologists are relying on animation (a mov format) to present their research into the cog at conferences. The present case study is a pilot project that aims to connect research and presentation.

In autumn 2016, a digital exhibition was organized by the eight museums of the Leibniz-Association, to celebrate the 300th anniversary of Gottfried Wilhelm Leibniz's death. It made use of the 3D data acquired during the case study. The animation was shown on a digital screen, installed on a large table, located outside

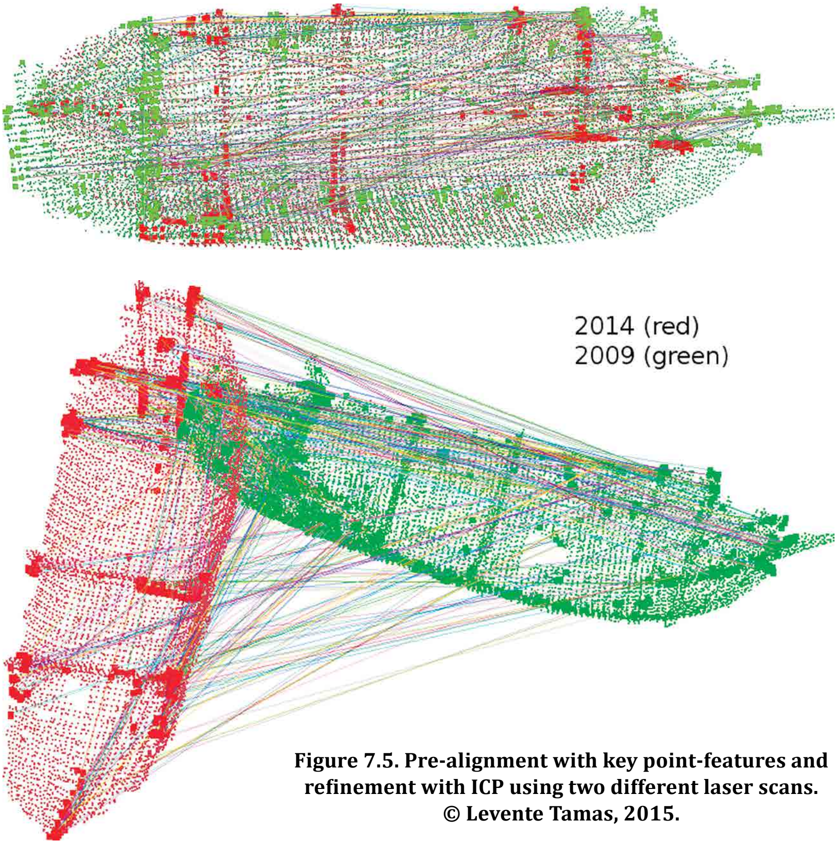

Figure 7.5. Pre-alignment with key point-features and refinement with ICP using two different laser scans. © Levente Tamas, 2015.

the conference hall of the German Maritime Museum. Historical and archaeological facts were added to complete the presentation. Visitors were given a chance to see the virtual ship, while the actual ship was covered during the ongoing renovation. In March 2017, the new exhibition surrounding the Bremen Cog opened. The digital models are used to present the ongoing research on the deformation monitoring.

Quality Evaluation

Each method uses specific software and tools. Software viewers do exist to visualize the 3D data, but a comprehensive custom evaluation was only possible during the Short Term Scientific Mission of Levente Tamas, in September 2015. The data were evaluated and compared over a week.

Beside the visualization of different 3D data, the main purpose of this investigation was to compare the scans taken at different times and with different

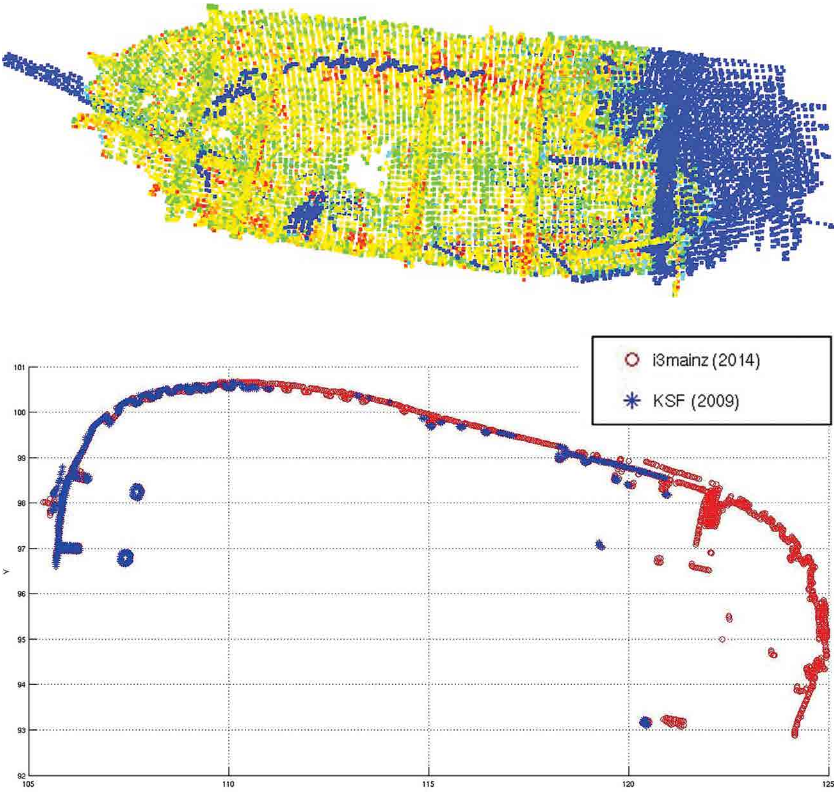

Figure 7.6. The entire body and the cross-section comparison of two different laser scanned measurements. © Levente Tamas, 2009 and 2014.

devices. The data collected prior to this case study were included, including a 3D scan completed by a private company in 2009.

Comparing heterogeneous data is not a trivial task. Adding a data set without geo-referencing makes it even more complicated. On the other hand, it was decided that it was relevant to test the comparison between similar acquisitions and continue with different ones. Each comparison method needs to be prepared for the next step. In the main literature for 3D data comparison purposes there are several methods for rigid body transformation estimation. From these we opted for the key point-feature-based pre-alignment and with Iterative Closest Point (ICP) refinement as shown in figure 7.5, where a scan from 2009 is shown in red and a scan from 2014 in green. This works well for the data of the same modality, and without non-linear distortion. However, for comparison of data of different modality (i.e., LIDAR vs. structured light) advanced non-linear deformation analysis has to be used.

For non-technical scholars an estimation of the entire 3D object, as well as the cross-section analysis, are both useful outputs of the comparison. Examples are shown in figure 7.6 where the entire ship is compared with local plane approximations, as well as a cross-section along the main axis of the object (green indicates small changes; red, bigger ones; and blue, no data).

Both visualizations have their advantages: the object level deformations are easily detected on the whole object visualization; however, for systematic analysis the cross-section can be more useful.

Handling Data and Metadata

In the course of this case study the data were stored in a shared cloud kindly provided by i3mainz. Each partner had easy access. At the end of the case study, all data produced will be stored at the German Maritime Museum. Metadata were not considered by the case study.

The data may be reused for further investigation by a Ph.D. project that started at the museum in March 2016.

Critical Discussion and Evaluation of Research

Different challenges arose during this project. The technical questions that had to be addressed included the pre-processing of data (e.g., conversion, including filtering), geo-referencing, registration of heterogeneous data, and comparison for deformation analysis. Articulating these questions was the first step towards finding solutions. The benefits of the chosen approach can inform other similar scenarios in the cultural heritage domain.

One of the technical challenges concerns the large size of the object whose view is obscured by surrounding objects, making the data acquisition difficult. The density and accuracy of the data, required to answer the initial question concerning deformation, were both important aspects of the volumetric data capture. The need to use the available older measurements and geo-reference them retrospectively was another aspect. A global overview and comparison of the different techniques may help other end-users to choose a method when working on similar projects.

For this purpose, a subjective comparison was made, allocating points to each technique. After different trials, the results could not provide complete consensus among the team and the comparison was abandoned. Moreover, the diagram showed that no technique offers a perfect answer and that either the methodology used during each acquisition campaign has to be questioned or it is simply impossible to compare different kinds of data sets produced through different techniques.

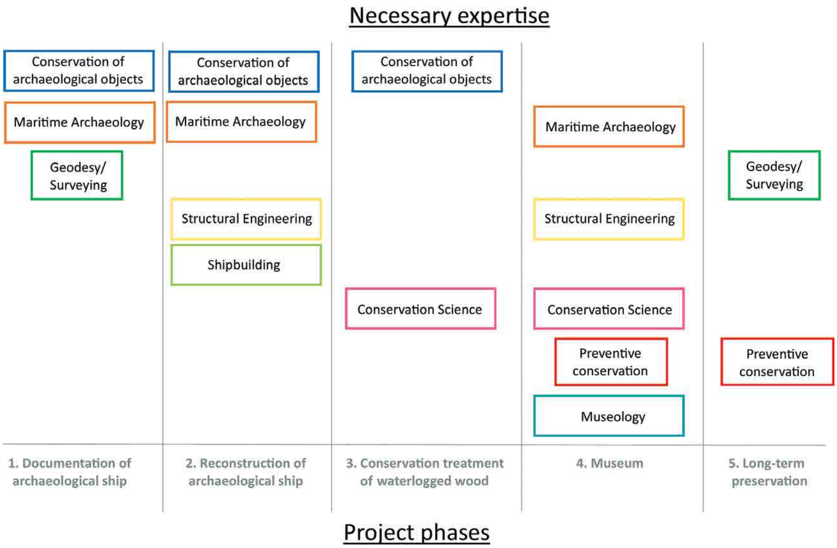

Figure 7.7. Expertise model chart. © Amandine Colson.

Last but not least, this project highlighted the considerable challenges to do with the different expertise involved. Interdisciplinary work is, without a doubt, the only way to solve such complex issues as deformation monitoring of an archaeological ship. Nonetheless the variety of backgrounds can lead to misunderstandings. Vocabulary misunderstandings were often mentioned as a central problem during the COSCH Action. This experience showed that the ways humanities and engineering researchers approach a problem vary profoundly. Cultural differences, connected not to nationality, but to the field of work, represented both an asset for the project and a challenge at the same time. Beside the intellectual challenge of understanding each other, planning work within the restricted timeframe and limited human resources was also an issue.

The contribution of interdisciplinary work was significant throughout the Bremen Cog project: from day one of fieldwork in the river Weser, to the reconstruction of the ship and the conservation treatment. Based on communication with colleagues involved in similar projects, a chart (fig. 7.7) has been elaborated to give an overview of the different fields involved in the project phases. This chart simplifies the fields of expertise required to answer the questions concerning the conservation and the presentation of an archaeological ship. It may serve as a reminder that such a complex project cannot be conducted singlehandedly, but is a result of decades of work involving various fields. The involvement of some fields is necessary during many phases, while others are only required once or intermittently. The chart presents the expertise involved and its impact on the dynamics of the project.

Conclusion and Future Research

This research continues as part of a Ph.D. project under the auspices of the German Maritime Museum, jointly supervised by Christoph Krekel of the State Arts Academy in Stuttgart and Thomas Luhmann of the Institute of Photogrammetry and Geo-information of the University of Applied Science in Oldenburg.

The approach chosen for this case study could be applied not only to other large-scale cultural heritage objects, such as wooden or metal ships, but also to larger sculptures and industrial objects exhibited indoors.

Photogrammetry will be tested further as a promising low-cost method. The partnership with the Institute of Photogrammetry and Geo-Information in Oldenburg is expected to help with the technical problems. A new coordinate system will be studied and a new acquisition protocol established in 2017.

Deformation monitoring of conserved ships appears to be an issue for other museums in Europe and so the creation of a specialist European working group is being currently discussed with colleagues in France, Norway, Great Britain, and Sweden. The first meeting is scheduled to take place in Bremerhaven in 2017. The problems raised during this case study will be addressed in other conservation/restoration networks or working groups and also amongst engineers. Possible solutions by other specialists should be investigated.

In order to build refined object models, based on non-linear shape registration methods, further investigations are necessary of the data treatment (including the SfM measurements) and advanced filtering of the heterogeneous data. Other interesting research includes the investigations related to the refitting of deformable object parts in an ensemble, that is, the separated planks in the deformed ship body, which is also a non-linear registration problem.

Basic education concerning digital technologies applied to the humanities should be discussed as part of any Bachelor's or Master's programmes. Limited training opportunities are available to graduate professionals, therefore the real experience and knowledge are gained through projects.

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