Design of a Computer-based Frame to Store, Manage, and Divulge Information from Underwater Archaeological Excavations: the Pepper Wreck Case

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Abstract

In recent years archaeologists have been using a variety of computing technology to speed up research and make information much easier to access, manipulate, and analyze. I propose a Digital Library framework that will assist nautical archaeologists in their research work, enhancing the dissemination of archaeological findings and seafaring related information to the general public. In this essay I will attempt to outline the main characteristics and goals of my approach, which is based on a National Science Foundation grant for the creation of the Nautical Archaeology Digital Library.

Introduction

For millennia seafaring has been an important activity that not only enabled traveling and trading, but also generated the exchange of ideas, ways of life, and knowledge among people from a variety of races, cultures, religions, traditions, and geographies. This exchange in turn, influenced people's lives and facilitated advancements in science and technology that had otherwise not been possible.

Several aspects played key roles in the development of seafaring; an obvious one is shipbuilding technology. Enhancements in design and construction of ships made it possible to build bigger, safer, and faster vessels.

Bigger ships, for instance, enabled more cargo space, thus improving the owner's profits. Similarly, design improvements made vessels more stable, reducing the probability of capsizing and above all, reducing voyages' duration.

Evidence of the evolution of ships through history can be found in different sources. Paintings, frescoes, and drawings, for example, provide a graphic depiction, but one that is typically not very accurate of the real ships they depict. Historical narratives, although not rich in illustrations, also provide descriptions of the characteristics of the vessels. Ship remains from shipwrecks are without doubt the best evidence of this evolution. However, time, nature, and looters damage and quite often destroy this precious evidence, making ship reconstruction a difficult task.

Shipbuilding treatises on the other hand, are a major source of information about ships. Researchers use them as aids in the reconstruction of ships; they can also be used to compare shipbuilding techniques from different traditions, or their evolution in a span of time. Treatises, however, are a complex source of information. For instance, a researcher analyzing futtocks will be interested in finding relevant images in the illustrations contained in the collection of treatises, as well as their corresponding descriptions within the text. One illustration, however, can – and most of the time do include – several components; thus, the need to segment the treatises' contents to allow access to individual elements.

Digital Library in the Humanities

In recent years archaeologists have been using a variety of computing technology to speed up research and make information much easier to access, manipulate, and analyze. *The Perseus Project* (Crane 1988 and 1996) is an example of a digital library in the context of cultural and historical heritage material, focused originally on ancient Greek culture, and currently including Roman and Renaissance collections provides a variety of visualization tools for its contents, as well as several access mechanisms to its collection of texts and images. *The Digital Atheneum* (Brown 2000 and 2001) hosted at the University of Kentucky has developed new techniques for restoring, searching, and editing humanities collections with special emphasis on technical approaches to restoring severely damaged manuscripts. *The Digital Imprint*[1] at the Institute of Archaeology, University of California at Los Angeles proposes a project to design standards for the electronic publication of archaeological site reports. *The Petra Great Temple excavations* (Joukowsky 1993; Egan and Bikai 1999) located in Jordan, is a joint archeological excavation conducted by Brown University and the Jordanian Department of Antiquities, which illustrates the development of new technologies based on the archaeologists needs. *The Brown University SHAPE Laboratory* (Shape, Archaeology, Photogrammetry, Entropy)[2] (Hadingham 2000; Acevedo et al. 2000 and 2001) has developed several techniques and tools that can be applied to Archaeology; their multidisciplinary team designed software that enables archeologists to model and reconstruct columns, buildings, statues, and other complex shapes from photos and video. The *Theban Mapping Project*[3] (Reeves 1992; Reeves and Wilkinson 1996) based at the American University in Cairo, Egypt provides a comprehensive archaeological detailed map and database of every archaeological, geological, and ethnographic feature in Thebes.

With the use of computer-based tools, The *Canterbury Tales Project*[4] has collated several of the manuscripts written by Geoffrey Chaucer with the idea of reconstructing the history of the text. Using some techniques from evolutionary biology, it is possible to find relationships among the manuscripts.

The *Rossetti Archive*[5] is a hypertextual-based collection of the painter and writer Dante Gabriel Rossetti. The project includes access to Rossetti's original works both pictorial and textual, along materials from critical studies about his life and work. These materials are encoded, enabling structured search and analysis. The archive includes digital images, manuscripts, drawings, paintings, and designs. It also provides an advanced search option.

Dedicated to the life and work of Pablo Ruiz Picasso, The *On-line Picasso Project*[6] is a digital catalogue reasonee of paintings, sketches, drawings, and sculptures created by this renowned Spanish artist, along an extensive historical narrative documenting his life and time. It also provides a collection of critical commentary about his work by scholars and art critics. Some of the features in this project enable the synchronization of the art gallery and the textual narrative. The use of visualization tools and interactive maps allow users to find patterns, relationships or facts in the collection.

Despite the use of computers and software tools by archeologists, I believe—based on my experience with nautical archaeologists and other scholars in the humanities – that the full potential which information technology can offer is still being underused. This is a common phenomenon present in other disciplines in the humanities too. Some reasons include – but are not limited to: a) humanists see problems differently from computer scientists, b) needs, goals, and priorities of scholars in different disciplines do not necessarily match, and c) lack of funding for particular research areas. Thus, I propose a Digital Library framework that will assist nautical archaeologists in their research work, enhancing the dissemination of archaeological findings and seafaring related information to the general public. This is, however, a major enterprise. In this essay I will attempt to outline the main characteristics and goals of my approach, which is based on a National Science Foundation grant for the creation of the *Nautical Archaeology Digital Library*[7]. I will start with a general description of the digital library and its components; followed by a commentary on shipbuilding treatises and ship timbers recovered from the excavation site, will elaborate on managing the collection of artifacts, and conclude with some ideas about this approach.

General Description of the Proposed Digital Library

Information about underwater archaeological sites and the study of shipwrecks can be classified in seven large groups of data, pertaining to: a) the characterization of the site where the ship sank, b) the characterization of the historical period under analysis, c) the specific shipwreck under study, d) the site formation process, e) the excavation, f) the reconstruction of the site, and g) history of the ship, its voyages and crew.

The complexity of the relationships among these sources is not limited to the ability of relating objects in the collection, it also requires establishing a robust protocol that enables scholars to properly identify, catalog, and describe artifacts. Furthermore, it must address the problems involved in mapping the excavation site, building models of the site and ship, as well as identifying and classifying the components of the vessels under study.

Studying and analyzing the components of a ship requires a model that enables researchers to correlate timbers such as keel, frames, planking, rigging elements and any component of the ship with a large collection of shipbuilding treatises, known shipwreck remains, and historical descriptions of shipbuilding techniques. Treatise contents vary depending of the time they were written, the author, the intended audience, provenance, and the kind of vessels they describe. Typically they include text describing the shipbuilding process, proportions a ship should have, illustrations of timbers and components, and instructions about how to assemble them. In some instances they describe cultural, social, and historical environments related to shipyards and shipbuilding.

As with many areas of scholarly activity, a comprehensive digital library providing immediate and interlinked access to the artifacts digitally generated will provide a critical resource to Nautical Archaeology with the potential of transforming the activities of the domain's researchers. Primarily changing the way in which research is carried out as well as how educational information is conveyed.

Digital artifacts from an underwater excavation include texts, photographs, drawings, videos, and 3D models (drawn from the excavation site, and acquired from historic sources). Another characteristic of the collection is that it is a dynamically growing one, as new artifacts and timbers are recovered. In this context, this approach will serve as a repository where information stored in the library will be used as the basis for research analyses. Thus, the infrastructure should also support rich interlinking of heterogeneous elements and the easy addition of new ones. Strongly related to the archeological evidence is the ability to handle, quantify, and represent uncertainty.

The proposed framework should support digital library replication and synchronization, since the nature of archaeology fieldwork requires that domain specialists travel to a variety of geographical locations. Therefore, data and information gathered at the excavation site should be properly transferred to a centralized or distributed repository, to be later integrated into the digital library. Conversely, archaeologists should be able to bring stored and processed information to the site. This replication raises obvious questions of maintaining data consistency and integrity.

Shipbuilding Treatises

Shipbuilding treatises are documents, either printed or manuscripts – especially the old ones – describing the components of a vessel, its dimensions, proportions, and in some instances the assembling sequence, and properties of the materials to be used in the construction of ships. Two major difficulties associated with treatises are language and time. Provenance of treatises ranges from a variety of countries, kingdoms, and empires, in a span of several centuries, mainly between the 15th and 19th centuries. When searching for descriptions and illustrations of components of a ship, researchers have to find that component in the treatises' collection, which often leads to descriptions on the way to assemble them. However, given the fact that ship components have different names in different languages, and in some instances even in the same language in different periods of time, this task is extremely time consuming, often leading researchers to miss important facts or draw inaccurate conclusions. Additionally, since illustrations in treatises are not included in the standard indexes, archeologists have to spend much time searching for them. Thus, a multilingual glossary is required, which should not only include definitions of terms and concepts but also spellings and synonyms.

However, two major distinctions need to be made regarding the use of treatises, on the one hand, readers interested in browsing and navigating through the collection, or looking for specific components. And on the other, researchers working on the reconstruction of a ship, or looking for patterns in construction techniques. In the following paragraphs I will provide a brief commentary about some of the most important shipbuilding treatises from various provenances and ages to give an idea of their characteristics, similarities, and differences, which in turn will dictate the features the proposed architecture should include in order to make them available in a digital library framework.

Although ships have been built for millennia – the Uluburun[8] shipwreck for example, involves the excavation of a circa the 13th B.C. century ship – I will focus on treatises from the Renaissance until the 19th century. In this span of time, the development of shipbuilding techniques had a tremendous advancement. From an early oral tradition, where the techniques were passed from masters to apprentices, the evolution eventually led to sophisticated documents that included illustrations, detailed descriptions, glossaries, proportions, curves, designs, and finally, geometric algorithms and physics.

The 17th century witnessed major changes in naval architecture. England, France, and Holland were forced to improve their fleets due to the new requirements in transatlantic navigation. This time is also known as the *Golden Century of the Spanish Galeon*. A very important vessel, the Spanish Galeon, played an important role in the transportation of people and merchandises between Spain and America, which in turn, made the Galeon survive until the first quarter of the 18th century.

José Antonio de Gazstañeta, a Basque sailor with great knowledge of vessels wrote circa 1688 *Arte de Fabricar Reales* (Gazstañeta 1992) which can be considered the first attempt to compose a formal shipbuilding treatise in Spain. Gazstañeta was very familiar with five, seven, and eight-hundred tons galleons, which he sailed. A brilliant learner, observer, and self taught person, he wrote a manuscript describing the shipyard and construction of *La Capitana Real del Mar Océano "Nuestra Señora de la Concepción y las Animas"* – the Spanish flag ship.

In shipbuilding, Gazstañeta's manuscript marks the transition from and oral tradition to a more formal one. Although dated in 1688, it includes earlier events, and does not follow a consistent style. Certain sections are carefully written, while others are not. Also, several pages were left blank, which might suggest it was not written in a chronological order based on the stages during the construction of the ship. The meaning of certain segments is still unknown and codes are used extensively within the manuscript. However, it contains a rich collection of illustrations, and a comprehensive list describing all the pieces in the galleon, as well as calculations. For the first time also, he comments on difficulties at work, tricks from the master builder, and weakest points in building techniques.

It also describes how to measure and bend timbers, and once the ship is completed, how to measure and compare it with the original specifications to identify structural deformations. Gazstañeta introduced improvements to make ships more stable and allow the artillery to be placed at higher levels while maintaining stability – a key design concept in the defense of the vessels.

In Portugal, *O Livro da Fabrica das Naus* composed by Father Fernando Oliveira in 1580 (Oliveira 1991), illustrates the need to create formal guidelines in the construction of ships, in this case, driven by the extension of the Portuguese domains and interests (America, Africa, and India). The treatise begins by describing the characteristics of the wood used in the construction of a ship. Hard wood has to be used in the framing, since frames support the weight of the ship and are exposed to extreme forces, e.g., water and wind. Soft wood, on the other hand, is recommended for the planking; this allows bending and facilitates joining the planks to the frames. Another section provides information about the materials used in shipbuilding. Iron nails, for example, are preferable, due to strength and cost. For sealing purposes, oakum is recommended over wool and cotton.

Livro de Tracas de Carpinteria, a manuscript written by Manoel Fernandes and dated 1616 (Fernandez 1989), provides in the first section, a comprehensive list of dimensions for different vessels and the most important components to be used in different ship sections, e.g. keel, stem, and sternpost. For ships of different tonnage, it includes calculations, dimensions, and general guidelines. The second section of the manuscript contains illustrations depicting the construction of the ships.

A great source that depicts French galleys in the 17th century is the *Traitté de la Construction de Galéres* (Fennis 1983). The manuscript was written in 1691, and provides invaluable information about French naval architecture and technical terminology of galleys. This manuscript is divided into two sections. The first section describes timbers used in the hull, elaborates on the theory of the design of galleys, and the steps in the design of the galere senzille (simple galley).

The second section provides practical guidelines about the construction of galleys, including detailed descriptions of the timbers, wood, and their function in the ship. It also contains a sail plan and instructions to build the masts, the outfitting and lading of the galley. It is believed that the handwriting and illustrations were made by different authors. The manuscript is rich in illustrations, containing drawing curves, proportions, plan views, and individual components, such as keel, frames, futtocks, planking, blocks, tackles, and sails, as well as tools used in the construction of ships.

The Netherlands is also a country with a long naval tradition. In 1697 Cornelius van IJk published *Nederlansche scheeps-bouw-konst open gestalt* (van IJk 1697). In his book, van IJk describes step by step – from a practical rather than theoretical perspective – the design and construction of a complete vessel. Although not very detailed, the descriptions show the required steps in the assembling process. Cornelius' approach is known as skeleton-based, a technique extensively used in Holland during the 17th century.

Fragments of Ancient English Shipwrightry (Baker c. 1570) provides a glimpse to the English ship building industry in the late 16th and early 17th centuries. It is believed to have been started by Matthew Baker around 1586 and completed around 1630 by other authors. Its contents, although mostly unorganized, includes texts and diagrams on different topics, encompassing drawings, descriptions, and scales. Among other things, Baker established the methods for measuring the "tonnage" of ships, as well as the methods to fix the shape of the "midship bend," and extensively used arcs in the design of the curves of the ship. Circles and parts of the circles were used as basis for different shapes in the ship.

Dean's Doctrine of Naval Architecture circa 1670 (Lavery 1981) appears in a period of time that marks the transition of shipbuilding into a more scientific field. Switching from a learning method based on observation, Dean uses a drafting board. His work includes drawings, sketches, and other optical aids, providing detailed calculations, enabling to test the theory with real ships. Deane is also considered the founder of the scientific shipbuilding, as he introduces mathematical formulations in the manuscript.

Other examples in English shipbuilding writings are the *Scott's Manuscript* and *A Treatise on Shipbuilding* (Barker 1994). The *Scott's Manuscript* an anonymous and undated work – believed of having been written between 1600 and 1625 – contains mathematical, technical, and practical information. *A Treatise on Shipbuilding* circa 1600, copied by Sir Isaac Newton, includes drawings, sketches, and steps to conceptualize and build a ship based on the length of the keel. It describes the relationships between tonnage and stability and their effects on performance. In the case of rigging, it includes tables for masts and yards.

Treatises in the Context of the Proposed Architecture

To enable browsing and navigation in a digital collection of ancient shipbuilding treatises, the architecture I proposed will have the following features: a) browsing and navigation, b) transcription, translation, and illustrations, c) image segmentation, d) cross-language dictionaries, e) full text retrieval, f) visualization tools, and g) user interfaces. Using Lavahna's manuscript as test bed, the steps for processing the facsimile in order to be added into the digital library are depicted in Figure 12-01. In cases where modern transcriptions and translations are available, they can be easily converted into text files using OCR (optical character recognition). For other cases, manual transcriptions will be required, something that has been done in other projects in which I have been involved, such as the Cervantes Project and the Digital Donne, the former for Spanish literary works and the latter for XVII century English poetry.

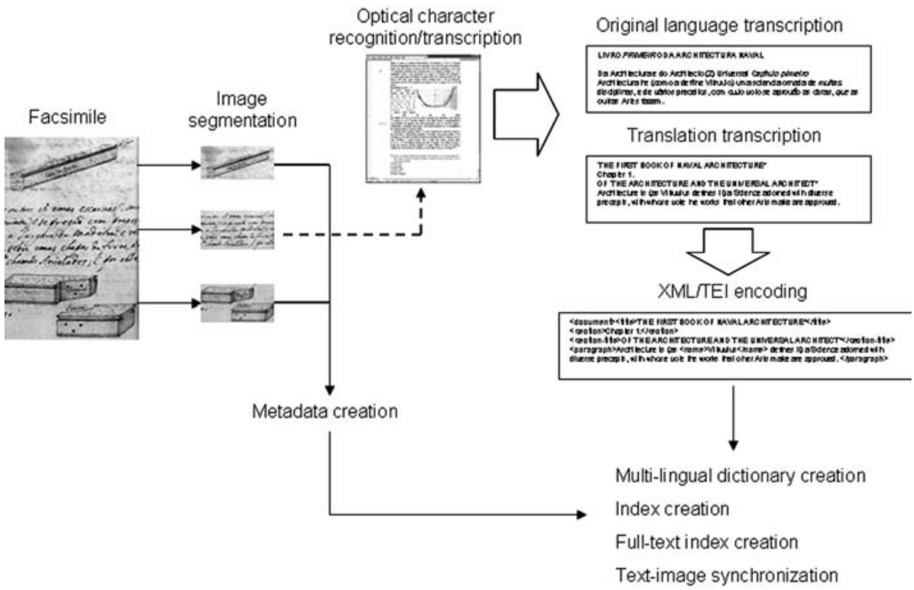

Figure 12-01 - The proposed architecture's workflow in the creation of a digital library of shipbuilding treatises. From the facsimile sources to integrated and interlinked information.

Semantic indexing and retrieval for images and texts will require texts and image metadata to be tagged. Tags within the texts not only provide semantic meaning to their contents, but also facilitates structuring documents.

Textual transcriptions will then be encoded into XML, which enables them to be transformed in multiple ways suiting a variety of requirements from different readers performing various tasks. Relevant terms and concepts within the texts will be identified, tagged, and linked to the multilingual glossary previously described. Thus, it will be possible to find definitions, multiple spellings, and synonyms of nautical terms, concepts, and scales in different languages. Compus (Fekete and Dufournaud 2000) illustrates the use of XML/TEI-encoded[9] texts to graphically visualize the structure of documents; as such, it has been used to analyze French manuscript letters of the 16^{th} century. Some of the features implemented in Compus can also be used to browse through the collection of shipbuilding treatises. Furthermore, the adoption of XML/

TEI as standard for structuring the documents allows the documents to be used in other applications.

Once the data sources have been processed, they can be used in different visualization tools. Figure 12-02 depicts the main browsing interface. Selection controls enable to choose treatises from the collection and sections within individual treatises. On the left, a display area presents transcriptions both in the original language and its translation into English. Using tab panes and scrolling area displays allows users to switch between the two transcriptions. On the right, the corresponding image from the treatise is presented. Since transcriptions and images are synchronized, users can click on the image to find the corresponding segment in the transcription. Conversely, selecting any text segment highlights the corresponding spatial coordinates in the image.

Figure 12-02 - Screen shot of the browsing interface for the collection of shipbuilding treatises in the proposed architecture.

Researchers studying individual components of a ship are presented with two visualization options. The first option is a montage-based interface (Figure 12-03) which presents a slide show of images. Users can control the speed, orientation, and mode of the slide show. For example, a user interested in keels, is presented with images from the collection depicting keels along its associated metadata. From the image it is possible to locate descriptions in the text related to that illustration. Images can be added to or removed from the slide show individually or based on a particular condition.

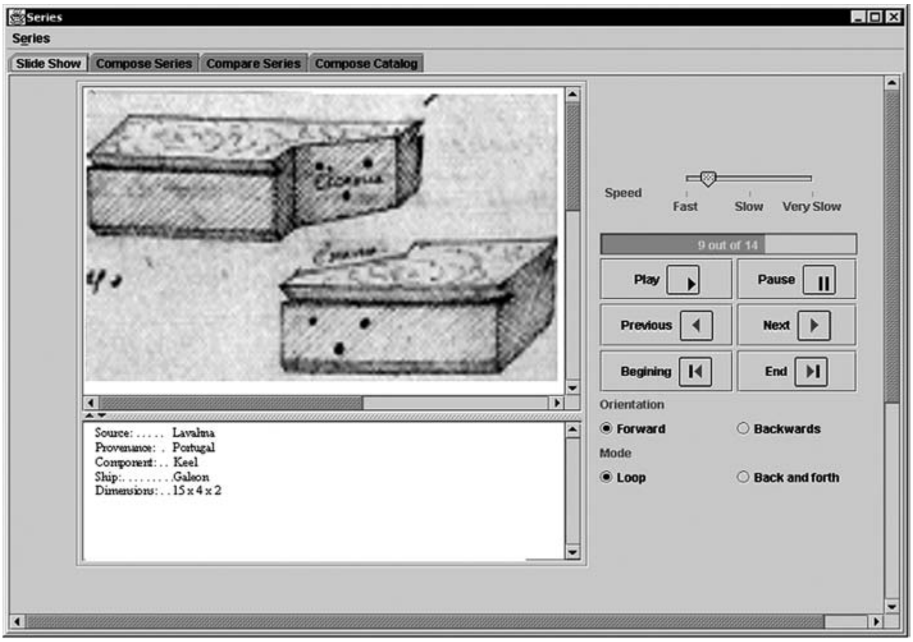

Figure 12-03 - Montage-based interface. Images are presented in a slideshow. Users can change the settings of the slideshow.

The second option is a collage-based interface (Figure 12-04) which presents users with thumbnails of images related to a given component of the ship. Thumbnails can be rearranged by the user in the display area, clustering them based on characteristics the user is interested in. Items can also be added to and removed from the display. Mousing over a thumbnail pops up a window containing related information from the treatise. Visual aids, such as colors, shapes, and patterns can be used to depict additional information. For example, colors can be used to indicate provenance of the image, whereas a horizontal line can provide temporal context of the treatise.

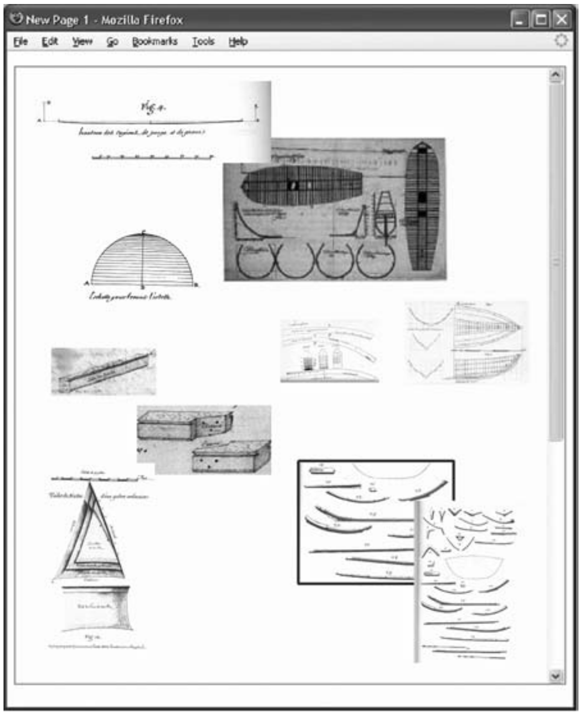

Figure 12-04 - Screen shot of the collage-based interface prototype depicting images from different treatises.

Combining collage and montage interfaces enables to search for patterns in the evolution of shipbuilding techniques; for instance, narrowing and rising of the ship in a span of time, or how keels and frames were assembled in different countries. A more advanced analysis is the identification of techniques and methods adopted from other shipbuilding traditions; for example, what Baltic techniques were introduced in Iberian shipyards. Advanced searching options allow looking for images of ship components based on different criteria in their associated metadata. In the case of the transcriptions, full text capabilities enable searching for terms in context within the transcriptions.

Text-Image Segmentation

The creation of a hypertextual-based Digital Library of shipbuilding treatises requires the documents to be segmented. Document segmentation is the process in which document components are identified and classified; for example, the separation of illustrations and text segments in a page.

Textual sections have to be transcribed; this is however, a very difficult task to accomplish in an automatic way, considering that it requires optical character recognition (OCR) processing and most of the treatises are old manuscripts.

OCR is a technique that works quite well for modern business documents, but produces low quality results when applied to old manuscripts or even ancient books. In my experience with the *Cervantes Project*[10], for example, some attempts were made to automatically transcribe the texts of Don Quixote using OCR. After some attempts, the results were so low that manual transcription was used instead. This illustrates the complexity of OCR applied to a printed book published in 1605; manuscripts are even more difficult since they are handwritten documents.

In the case where several components are depicted in one illustration, those components need to be individually identified and classified. To better understand this, let us take for example the case of searching for futtocks. Futtocks are usually depicted in conjunction with other components in the same illustration, thus the need to extract them individually. Also, images and descriptions complement each other. For example, reading a description in the text can be augmented by observing the corresponding image. Conversely, exploring an image while reading the description associated to it; can help to better understand the contents and context of that image. To accomplish this, text-image synchronization is required, which in combination with indexed texts will enable to search for terms in the texts and browse the associated images.

Managing Artifacts

Information about artifacts recovered from a shipwreck is subject to multiple representations, spatial and temporal will be two obvious ones. This ranges from the location where the artifacts were found at the excavation site, to the locations where they are stored during the different stages in the conservation process, to the place where they are exhibited or stored. Generally, artifacts are found in a location where they were not originally stored, thus recreating cargo distribution is a complex task given the combinations in which cargo could have been stored.

Artifacts are exposed to multiple changes from the moment the ship sank until its discovery; currents, tides, and time modify the site. Therefore, bathymetry maps, tides and currents, environmental information, and geological data, is information that helps researchers to understand how these elements have affected the site, and ultimately the ship and artifacts under study. Historical information about the site is also important; this includes ancient maps, historical texts about the site, and large collections of images.

In terms of temporal representations, once the excavation process begins, the site will be completely transformed. During the surveying phase, divers take extensive video footage, photographs of the ship and its surroundings; sketches and drawings of the ship and artifacts are made, along with notes describing the conditions in which they were found. A grid is then created that helps to map the location where pieces of the ship and artifacts were found. Further, divers have to record all the activities during their diving shifts, thus they have to keep a diving log, which can be used to recreate the excavation process.

The digital artifacts associated with underwater excavations include texts, photographs, drawings, videos, and 3D models from the excavation site, and also acquired from historic sources, as well as from other excavations. The proposed framework will serve as a repository of record; information stored into the digital repository will be used as the basis for research analyses. Therefore, it will have to provide fixed, stable reference points for content, even if materials are later updated.

Since the nature of Nautical Archaeology requires researchers to work at the excavation site, the framework has to provide the option of adding – on-the-field – information gathered during field work (as was previously discussed for timbers and ship fragments). Also, researchers should be able to download and consult information obtained from other excavation projects that have been stored in the digital library. I argue that access to stored and processed material at the excavation site can expand the ideas about the artifacts being recovered. At any stage the framework should allow linkage of representations of digital objects in different media to their corresponding physical counterparts in different contexts.

The Pepper Wreck as Test Bed

The creation of a digital library framework for Nautical Archaeology is a long-term enterprise given the complexity of the materials under study, the variety of media, the relationships among them, and the size of the collection. Thus, my approach will start by taking the Pepper Wreck[11] excavation as test bed, and will place it within the context of the broader, extensive collection available to us at Texas A&M University through the Center for Maritime Archaeology and Conservation. I believe that this approach will provide a standard framework that can be extended to other scientific and engineering endeavors.

Located in São Julião da Barra (Portugal), at the mouth of the Tagus river, The Pepper Wreck (Afonso 1998; Castro 2001, 2003, 2005a, 2005b) site is only a few miles away from Lisbon. Its excavation yielded a large collection of artifacts dated from the late 16th and early 17th centuries, and led to the identification of this shipwreck as the nau *Nossa Senhora dos Mártires* wrecked on September 15 1606 on its way back from India. The study of its hull remains – which include a portion of the keel, eleven frames, and some of the planking – yielded interesting results and a first glance at these largely unknown ships: the Portuguese *naus da India*.

Given our availability of Portuguese shipbuilding treatises, it will be possible to compare the timbers and fragments recovered from the excavation site with the descriptions and properties present in the manuscripts. As new timbers from other excavations are added to the collection, scholars will be able to compare ship remains from any excavation and treatises, providing an interesting scenario of missing physical damaged archaeological evidence with technical descriptions from the treatises.

Conclusion

On-going digital libraries projects show how advancements in information technology— especially computer-aided and hypertextual-based tools—have changed the way scholars work in the humanities. I believe that some tools, techniques, and methods in digital libraries fit the needs of users and researchers in Nautical Archeology, especially in the context of using shipbuilding treatises in the reconstruction of sunken ships from incomplete and damaged components recovered from the excavation site; as well as manipulating a large collection of artifacts.

I believe that this rich interdisciplinary effort between Computer Science and Nautical Archaeology will benefit both fields. Archaeologists' on-field work and off-field research and analysis can be accelerated; multiple representation and rich interlinking of digital objects will be possible. On the computational side, the unique properties of the materials, ship fragments, and artifacts, and the way archaeologists use and manipulate them, will require the development of new algorithms, and the implementation of interfaces and tools; which can in turn be applied to other areas within Computer Science.

Notes

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11 The Pepper Wreck excavation. Institute of Nautical Archaeology at Texas A&M University http://nautarch.tamu.edu/shiplab/projects%20pw%20index%201.htm Accessed on December 10, 2005.

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