CONDITION.2015

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CONSERVATION AND DIGITALIZATION

CONFERENCE PROCEEDINGS

NATIONAL MARITIME MUSEUM in Gdańsk

GDAŃSK 2015

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BACKGROUND

The idea of organizing the international conference *CONDITION.2015 Conservation and Digitalization* was initiated by museum's team while preparing project titled "The Shipwreck Conservation Centre with Studio Warehouse in Tczew – construction of a cultural infrastructure of the National Maritime Museum in Gdańsk". The investment started summer 2014 and its completion is scheduled for April 2016. The project is conducted within the programme "Conservation and revitalization of cultural heritage" supported by the EEA Grants and Norway Grants and cofinanced by the Minister of Culture and National Heritage in Poland. The project involves partners from Norwegian sector of culture: Norwegian Maritime Museum and University in Oslo: Museum of Cultural History.

The CONDITION.2015 Conservation and Digitalization Conference covered issues of conservation of objects discovered during the exploration of the seabed and during land archaeological excavations as well as digitization of large objects outside controlled studio environment. *CONDITION.2015* was organized both to promote the new cultural infrastructure and as a great opportunity to establish cooperation and present to international audience the trends in fields of conservation and digitization.

National Maritime Museum in Gdańsk beginnings date back to 1960. Nine years later first underwater archaeological excavations were initiated. For years museum's employees have been looking for effective ways of preservation and conservation of both organic and inorganic objects excavated from aquatic environment.

Conservation part of the *Condition.2015* conference was devoted to the conservation of waterlogged archaeological wood and allowed exchange of knowledge and experience among European specialists in field of conservation. Furthermore, theme scope of the conference was chosen to highlight the fact that properly managed conservation process requires properly made documentation. Digitization, both as a tool and a documentation process, begins a new era of application of modern multimedia technologies in culture and significantly influences the perception of archaeological objects by the museums' visitors.

The conference took place between 19 and 22 May 2015 and consisted of thirteen sessions with thirty seven speakers. During the first two days, delegates had an opportunity to learn about the latest trends in the field of conservation of archaeological objects excavated from aquatic environment as well as to establish a forum of exchange of good practices with conservators from the leading museums and scientific centers in Europe. In addition delegates had a chance to visit Conservation Department located in Maritime Culture Centre. The theme of the second part of the *Condition.2015* conference were the challenges and good practices in digitization concerning the objects' physical dimensions and environmental conditions in which they are digitally documented.

On behalf of the Organizing Committee we would like to thank members of the Programme Committee who supported the selection process of submitted abstracts and the programme of the entire conference. We would also like to express my gratitude to the National Institute for Museums and Public Collections for official patronage and support of *Condition.2015* conference. Last but not least, we would like to thank all delegates and speakers for creating a great atmosphere and making the conference programme interesting and inspiring.

The Books of Proceedings was prepared as a result of several months efforts and cooperation between Ars Nova Publishing House and the National Maritime Museum in Gdańsk. I hope it will constitute the source of knowledge in terms of the latest developments in area of conservation and digitization of cultural objects.

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CONSERVATION

Conservation of archaeological waterlogged wooden finds from the pile-dwelling site "Serteya II" (excavations of 2010)

Nataliya Vasilyeva

INTRODUCTION

Since the ancient times, the humankind has extensively used wood for various purposes. Both huge constructions as well as miniature objects used to be made of timber. Archaeological finds testifying to the wide use of wood in the past are usually discovered at sites where specific environmental conditions provided preservation of this material.

For example, wooden archaeological artifacts preserve well immersed in water or in wet ground. Condition of waterlogged archaeological wood depends on several factors:

1. composition of ground or water in which an object has been preserved,
2. duration of stay in a wet environment,
3. object's material (part of tree trunk it is made of, tree species, presence of jointed parts).

There are a several types of natural environment where waterlogged archaeological wood can be discovered: sea, wet ground, wells, pits, ditches, clayey soil, ice, peat bogs, lake bottom, river bottom. Once waterlogged, wood can perfectly preserve for thousands of years. This is clearly evidenced by the wooden objects discovered at the *Serteya II* archaeological site that dates from the 3rd millennium B.C.

The site is located in the sapropel deposits of the Subboreal period through which the river Serteyka in the Smolensk region flows today. The excavated part of the site is located in the riverbed of Serteyka. Pile dwelling of *Serteya II* was discovered by A. M. Miklyaev in 1972. At present, the Northwest Archaeological Expedition of the State Hermitage Museum, headed by A. N. Mazurkevich, is investigating the monument [1].

In 2010, several wooden objects were discovered during field works on the site. Sapropel sediments of the paleobasin preserved the wooden finds for five thousand years. The nature has formed there anaerobic environment with stable humidity, minimum temperature difference, absence of sunlight and conditions neutral towards organic materials. The wooden finds of 2010 were waterlogged, soft in substance, with losses at the edges and individual micro-cracks.

The discovery of waterlogged archaeological wooden objects requires taking immediate measures aimed at ensuring the maximum preservation of the finds after lifting. The evaporation of water in the air causes contraction of cell walls, resulting in cracking and warping of wood, its shrinking and deformations. Since the size of the 2010 finds from the *Serteya II* site was quite small (2 to 7 cm), evaporation could not only affect the shape of the objects but threatened to completely destroy them.

After the wooden artifacts had been lifted from water, they were packed into tightly sealed plastic bags filled with water. They were then delivered to the camp and treated with a biocide, sealed back into plastic bags and placed in the plastic containers in order to prevent possible drying. After the field works were completed, the objects were transported to the State Hermitage Museum and delivered to the Laboratory for Scientific Restoration of Objects Made from Organic Materials for further conservation treatment.

Before the conservation treatment, preliminary analysis of the objects was done, i.e. identification of the wood types and microscopic examination of the fibers condition. Identification of wood species was made by Mariya Kolosova, Cand. Sc. (Biology), a researcher at the Department of Examination and Authentication of Works of Art at the State Hermitage Museum. She used the microscopic method based on the anatomical structure of wood. The analysis revealed that five objects were made of hardwood, two – of soft type of hardwood, and one – of softwood (conifers).

Hardwoods are often used to produce small objects of plastic art and is more resistant to decay. Thus, the predominance of elm can be explained by the properties of this wood which has long durability and is resistant to decay in water. Elm wood is heavy, solid, and viscous, with beautiful pattern. This type of wood is widely used in timber constructions that get in contact with water (bridge pillars, ship parts and so on) [2].

Condition of wood fibers has been examined with a Leica MZ 6 microscope. Wood fibers were deformed, peeling off in some places, with losses and minor surface dirt. No signs of biological destruction were detected.

The main conservation goal in the case of waterlogged objects is to stabilize the material, preserving its shape and size. In waterlogged archaeological finds, water provides basic structural support to wood cells and cannot be removed (dried out) without being replaced by some other chemical substance. According to most researchers, the best results are obtained using polyethylene glycols. PEGs are widely used as preservatives in treatment of waterlogged wood.

In the State Hermitage Museum, the method of stabilizing waterlogged archaeological wood with synthetic water-soluble polyethylene glycols has been employed since 1963 (according to the method described by R.E. Moren and K.B.S. Centerwall) [3]. Methodology of working with polyethylene glycols was introduced into the Hermitage practice by Nina Gerasimova and Clara Nikitina [4]. For the first time the method was applied to the objects uncovered by the Nevel Expedition of the State Hermitage Museum headed by

Alexander Miklyaev from a similar pile dwelling *Usvyaty IV* (excavated in the village of Usvyaty, Pskov region) [5].

The size of waterlogged archaeological wooden finds often poses a problem for conservators. In this particular case, the small size of the artifacts makes them more sensitive to deformations – not only when they were lifted from the water but also in the process of treatment when they were removed from the conservation solution. Before immersing them in a PEG solution, the finds were placed into small plastic bags with holes to ensure their safety when lifting them back from the solution.

The finds of the year 2010, from the pile-dwelling site *Serteya II*, were treated according to the method described by R.E. Moren and K.B.S. Centerwall [3]. In order for the archaeological objects to preserve their shape and size, it was necessary to fully replace water with polyethylene glycol. At the first stage, the objects were immersed in a water solution of PEG with molecular weight 1500. At the beginning, the solution concentration was 10%. The water level was kept constant; fresh 10% solutions were added as the water evaporated. Thus, the concentration of the solution gradually increased. The water solution was warmed up with 500W reflector lamps, fixed on tripods over the basin since an increase in temperature reduces the viscosity of a solution. The temperature was maintained at the same level and corresponded with the concentration of the solution. At the next stage, the objects were treated with a water solution of PEG-4000. At the end of treatment the temperature did not exceed 70^0 C.

The items remained in the molten PEG for three days, then they were taken out. After the conservation, excessive PEG was carefully removed from the surface of the objects with a water alcohol mixture (1:1). The artifacts were weighed and placed in sand for slow drying. The drying process was controlled by periodic weighing. As the weight stabilized, it signaled that the drying process was completed. After drying, the objects were taken out from the sand and cleaned with soft brushes. The duration of impregnation was eight months, drying time was five months.

The amount of water in the wood could not be determined due to the size and state of preservation of the objects. The degree of filling the wood pores with polyethylene glycol has been calculated, the results are shown in the Table.

As a result of the treatment, the objects were consolidated, they preserved their shape and size as well as features demonstrating the way they were produced. Two round objects had several minor cracks. The cracks on the find 1 were left for further observations, while the crack on the find 2 was filled in with mastic consisting of molten PEG-4000 with a filler (wood powder). Now when the conservation is completed, the artifacts can be used as a source of archaeological information and exhibited in a museum.

We have already listed the woods used in production of the artifacts; all identified species are local. This fact is supported by other scientific research on the paleolandscape of the Serteyka valley. Identification of woods for various types of household goods demonstrated that during the Neolithic period preference was given to broad-leaved trees – majorly ash and elm, less frequently – oak. Palynological and antracological studies testify to the prevalence of broad-leaved trees in this part of the micro-region [6], [7].

After the conservation treatment had been completed, possible purposes and functionalities of the artifacts were researched. As a result, the objects could be divided into three groups according to their shape: 1. tools – finds 1 and 2, 2. weapons – 3, 3. pieces of jewelry and clothing – 4-9.

Two elm artifacts might be fragments of one object. Residents of the Neolithic pile dwellings used elm to make dishes, corner handles, and oars [8]. Most likely, these finds are fragments of an axe (or crank handles), examples of which are known from *Usvyaty IV* [5] and the Mesolithic site of *Lower Veretye I* [9].

A wooden arrow also originates from this site, object 3 presumably being its analogy. According to S. V. Oshibkina, a researcher of the *Lower Veretye I*, wooden arrows with solid heads and blunt ends could be used for "hunting small fur-bearing animals whose skin a hunter would try to keep intact, or for hunting birds". Already in the Mesolithic period, "hunting with a bow and arrow acquires specialized nature." [9].

Of particular interest are objects 4-9. They have been divided into two groups according to the shape and location of the openings: 1. objects of irregular oval-like shape with neat round cross-cutting transverse holes in the center. 2. objects of regular oval-like shape with neat round cross-cutting longitudinal holes in the middle (or without it).

The first group is conventionally referred to as "buttons" as the method of making holes is similar to the well-known Eneolithic amber plaques, such as those from the site *Sahtysh VIII*, burial 5 (Ivanovo region) [10]. Perhaps, threads made of plant fibers were used to attach such objects to clothing. At *Serteya II*, fragments of artifacts made of willow bark [11] were found – they could be used in combination with these "fasteners".

The objects from the second group are analogous to the oval amber beads (site *Naumovo*) and cylindrical amber beads (site *Sahtysh VIII*, burial 5) in their shape and drilling method [10].

The discussed wooden beads illustrate several stages of jewelry production. Thus, find 8 is an unfinished object of an oval-like shape in which a hole hasn't been drilled yet. Find 9 is a wasted object: a hole has been drilled off-center, too close to one of the bead walls causing it to break. Finds 5 and 6 are examples of completed objects. The miniature size of these beads emphasizes the advance of woodworking techniques in the 3rd millennium B.C. The shape of the holes indicates that drilling was performed from two sides, which is typical for making holes in amber or gemstone beads.

Thus, the shape of beads and the method of drilling holes are similar to the techniques applied to amber. Wood is a more affordable and easily processed material than amber. Consequently, the wooden jewelry could be used as substitution for more expensive or unavailable materials.

Types of wood, control weight before treatment, weight after treatment, weight after drying, the degree of impregnation by PEG

FIND	TYPE OF WOOD	WEIGHT (G)			DEGREE OF IMPREGNATION BY PEG N (%)
		BEFORE TREATMENT P1	AFTER TREATMENT P2 (G)	AFTER DRYING P3 (G)	
1	Elm (*Ulmus sp.*)	22.8	29.52	24.3	69
2	Elm (*Ulmus sp.*)	25.27	29.75	26.86	57.9
3	Maple (*Acer sp.*)	8.79	10.81	9.09	74.8
4	Pine (*Pinus sp.*)	1.36	2.46	2.06	33.3
5	Ash (*Fraxinus sp.*)	0.49	1.01	0.53	80
6	Elm (*Ulmus sp.*)	0.46	0.74	0.51	71.9
7	Willow (*Salix sp.*)	1.68	2.08	1.71	82.2
8	Poplar (*Populus sp.*)	0.73	1.05	0.80	69.4
9	–	0.39	0.84	0.66	93.98

Fig. 1. *Finds 1, 2 and 3 after restoration*

Fig. 2. *Finds 6, 7, 5, 4, 8 and 9 after restoration – front and rear view*

Conservation of waterlogged archaeological wooden objects, even those of small sizes, requires significant efforts from specialists. That is why it is so important to carefully consider available conservation capacities, possibilities of a preliminary analysis and technological research, as well as exhibiting conditions before lifting large finds from their usual aquatic environment. All archaeological finds made of wood, regardless of their size, functionality and artistic quality, are important sources of information on the ancient times, and preservation of not only spectacular large constructions but also of miniature object is of great importance for our research and understanding of the antiquity.

CONCLUSION

Sapropel sediments of the paleobasin ensured preservation of wooden finds for five thousand years. Proper measures taken in the field, followed by conservation treatment with a polyethylene glycol solution performed in the laboratory allowed to preserve the wooden objects discovered at the *Serteya II* archaeological site in 2010 and to retain their shape and size as well as characteristic features demonstrating the way they had been produced. These artifacts became museum exhibits available for exhibiting and further research.

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Sugar conservation of waterlogged archaeological finds in the last 30 years

András Morgós
Setsuo Imazu
Koji Ito

INTRODUCTION

In the last 30 years, our research team has been focusing on sugar conservation of waterlogged cultural heritage remains. The team consists of four members: A. Morgós (Hungary), S. Imazu (Japan), G. Strigazzi (Germany), and recently K. Ito (Japan). Our first paper on sugar conservation was published at the ICOM CC conference in Sidney in 1987 [1]. Our activity pushed at that time fast and cheap sucrose conservation in Europe into motion. Over the last 30 years, we have conducted extensive research on the use of sugars to conserve waterlogged wood and developed several alternatives to the sucrose conservation method, namely the lactitol methods: lactitol (pure), lactitol mixed with 10% trehalose, and the recent trehalose (pure) method.

BACKGROUNDS OF SUGAR CONSERVATION

Crucial backgrounds of sugar conservation are: type of sugars used, size compatibility, solubility and concentration of impregnation baths, hygroscopicity, and reversibility. The characteristics of sugars used in our conservation methods in comparison to PEGs are included in the Table.

SIZE COMPATIBILITY

In conservation-restoration **treatments**, the size of the constituting units (molecules, particles, aggregations) of conservation materials (chemicals, products) **should be compatible with the size and the size-distribution of the pores of the heritage material under conservation**. This can be called the (pore) size compatibility in treatments. Sucrose, lactitol, trehalose and PEGs are size-compatible with wood structure; below we compare sizes of conservation chemicals with capillaries and voids in sound wood on different structural levels.

Size of sugar and PEG molecules used in wood conservation and water: water (0.275 nm), sucrose (~0.4 nm), lactitol (~0.4 nm), trehalose (~0.4 nm), PEG 200-400 (~0.5 nm), PEG 4000 (100 nm);

Size of capillaries and voids in sound wood structure:

- in a cell wall:
  - up to 4 nm: capillaries **within fibrils** (intrafibrillar capillaries) 4 x 4 nm. The diameter of microfibrils is 2-20 nm; sucrose, lactitol, trehalose, PEG 200-400 (all smaller than 0.4-0.5 nm) are compatible in size,
  - 10-80 nm: capillaries **between fibrils** (interfibrillar capillaries); PEG4000 (100 nm) is not size-compatible and therefore cannot enter a cell wall. Sucrose, lactitol, trehalose and PEGs lower than 4000 all are size-compatible;
- Pits on cell wall:
  - 50-150 nm: pores in **pit membranes of hardwoods** – all conservation chemicals listed above can pass through,
  - 0.1-1 μm: pores in **pit membranes of softwoods**,
  - ~1 μm: **pit channels;**
- Cell lumen:
  - 2-5 μm: **lumen of fiber cells in hardwoods,**
  - 5-20 μm: **lumen of tracheids in softwoods** (larch latewood and larch earlywood of the annual ring of 5 μm and 20 μm, respectively),
  - 10(30)-500 μm: **lumen of vessels in hardwoods** (oak latewood of 10(30)μm and oak earlywood of 300 μm of annual rings).

Degradation increases the size of pores and the overall porosity of wood, therefore in such a case, larger conservation chemicals will be compatible.

SOLUBILITY AND CONCENTRATION OF IMPREGNATION BATHS

Higher degraded wood requires higher concentration of an impregnation bath with more deposition (lumen filling) of a conservation chemical in wood structure, while low degradation requires lower concentration of an impregnation bath and bulking of cell walls, and not so much deposition in cell lumens.

SOLUBILITY DEPENDS ON TEMPERATURE

Higher temperature results in a higher maximum concentration of an impregnation bath (higher solubility in water) and faster penetration of a conservation chemical into wood, i.e. shorter time of impregnation. A maximum impregnation temperature is determined by the heat stability of a conservation chemical and the sensibility of a treated wooden object. Generally, sucrose has low thermal stability, PEGs – medium, and lactitol and trehalose are thermostable sugars. The highest impregnation temperature for sucrose is 60°C, for PEGs – 60-70°C, and for lactitol and trehalose – 95°C.

THERMAL- AND PH-STABILITY OF SUGARS

High thermal- and pH-stability is required for successful conservation. Low stability causes degradation and consecutive discoloration; as a result, treated wood changes its color and becomes unnatural and darker.

Lactitol and trehalose have high thermostability and a wide pH-stability; they belong to the most stable saccharides. When 4% trehalose solutions with pH 3.5 to 10 were heated at 100°C for 24 hours, no degradation of trehalose was observed in any case. Being non-reducing sugars, these saccharides do not show Maillard reaction (a kind of chemical reaction causing browning of sugars) with amino compounds such as amino acids or proteins.

HYGROSCOPICITY AND DELIQUESCENCE

If a conservation chemical is too hygroscopic, its crystals become liquid in high humidity conditions (like rainy season, humid depository etc.); the surface of wood becomes sticky and attracts dust particles, therefore, in high relative humidity, low hygroscopic conservation materials are required. This behavior can be characterized by deliquescence points at 25°C. Trehalose is least hygroscopic – it liquefies in relative humidity > 94%, lactitol in RH > 90%, and sucrose in RH > 85.7%.

REVERSIBILITY

Sucrose, lactitol and trehalose treatments are considered to be totally reversible, if necessary, since a sugar preservative can be easily removed by dissolution in water.

SUGAR METHODS

Sugars as alternatives to polyethylene glycols has been playing an increasing role in conservation of waterlogged archaeological wooden remains in the last 30 years. Conservation techniques include using a heated sugar solution (the **"warm"** conservation method) or an unheated one (the **"cold"** conservation method), being the cheapest impregnation method. The latter method is particularly suitable for large wooden objects, construction elements of buildings and ships, however it can be used for smaller objects too. Sugars can also be used as pre-treatments for waterlogged wood before freeze-drying

Conservation of archaeological waterlogged wood with sucrose started in Italy at the beginning of the 1970's. After about a 15-year break, in the late 1980's, studies on strengthening waterlogged wood by impregnation with sucrose aqueous solutions began in United States and Hungary.

The first conference dealing exclusively with sugar conservation of waterlogged archaeological wood was organized in Stade, Germany in 1991. The first conference dealing solely with the lactitol conservation of waterlogged wood was held in Kashihara, Japan in 1999. Nowadays, there are more than 250 papers on sugar conservation of waterlogged woods. Sucrose is the most popular type of sugar, however some publications describe the use of mannitol, sorbitol and recently lactitol, and trehalose.

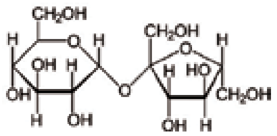
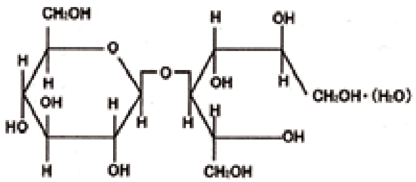
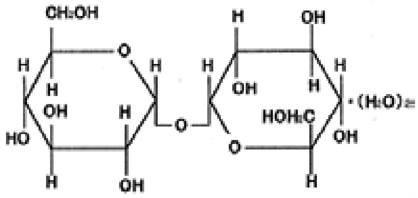
Sugars have many advantages: they are non-toxic, non-corrosive, have very slight hygroscopicity in normal air humidity, can be used for treating composite objects (made of wood and other materials such as textiles, metal etc.); this is also a low-cost method. Impregnation of wood can also be completed without heating; due to low molecular size of sucrose, lactitol and trehalose, diffusion (penetration) of the sugars into wood structure is acceptably fast also without heating. The strength-increase and dimensional stabilization achieved after such conservation is excellent. Conserved wood has a natural color and can be cleaned and glued easily. Sugars pose no fire, explosion or health and environmental hazards, except for those caused by biocides. Sugars can be easily extracted from treated wood by water so conservation treatment can be reversed if necessary.

SUCROSE METHODS

Two types of sucrose methods are possible:

- **"Cold" sucrose method** (at the temperature of the environment) [2]: first wood is placed in water containing a biocide. In order to prevent any possible biological degradation of the wood and the conservation material (sugars) within the wood and surrounding solution, this is recommended to add Kathon CG or Microbicides DP III (based on methylchloroisothiazolinone, a non-carcinogen, antibacterial and antifungal products of the Rohm & Haas Co. used in household items, cosmetics and water treatment) [3]. The bath is checked regularly in 2-day intervals; when it becomes cloudy or smells badly, the mentioned biocide should be reapplied. Please note, that the previously mentioned biocide reacts with microbes, therefore their concentration will decrease in time. If there are too much microbes present, the whole amount of a biocide can be consumed quickly and biological activity of microorganisms can develop. When there is no biological activity for 3-4 weeks, conservation can start in a 50g/L sucrose aqueous solution with a new addition of a biocide. The concentration of sugar is increased stepwise up to 1050g/L at a room temperature. Regular checking and adding a biocide is required under the whole period of impregnation. We still use this method – if we need cheap conservation of a large object, no other method can compete economically with the "cold" sucrose method. Recently we completed treatment of a 9 m long oak dug-out boat.
- **"Warm" sucrose method** (heated max. up to 60°C): according to our experience, under long-term impregnation, it is difficult to avoid breaking down of disaccharide sucrose into a non-crystallizable monosaccharide mixture even at 60°C. This is probably due to impurities in wooden finds that may catalyze the reaction. We don't recommend the use of the warm sucrose method.

Crucial measures and conditions are required under the sucrose impregnation period in order for successful conservation: using an efficient biocide and continuous checking the biocide concentration (we recommend an isothiazolinone type biocide such as Microbicides DP III, *Structural formulas and characteristics of sucrose, lactitol, trehalose and PEGs used in this paper*

	STRUCTURAL FORMULA	FORMULA, MOLAR MASS, HYGROSCOPICITY, MELTING POINT	SOLUBILITY IN WATER
Sucrose (Glucose + Fructose)		$C_{12}H_{22}O_{11}$ 342.30 g/mol Deliquescence point: 85.7% at RH(25°) Mp: None; decomposes at 186 °C	2000 g/L(25 °C)
Lactitol (monohydrate) (Galactose + Glucitol)		$C_{12}H_{24}O_{11}$ 344.3 g/mol 362.3 (monohydrate) Deliquescence point >90% RH (25°) Mp: 146°C (anhydrous), 98˚C (monohydrate)	572 g/kg (20 °C)
Trehalose (dihydrate) (Glucose + Glucose)		$C_{12}H_{22}O_{11}$ (anhydride) 342.296 g/mol (anhydrous) 342.3 (monohydrate) 378.3 g/mol (dihydrate) Mp: 203°C (anhydrous), 97˚C (dihydrate) Deliquescence point >95RH (25°C)	689 g/L (20 °C) Trehalose is less soluble than sucrose, except at high temperatures (>80 °C)
PEG 200-400	HO- $(CH_2 - CH_2 - O)_n$ -H n ≈ 4-9	$C_{2n}H_{4n+2}O_{n+1}$ ≈ 200-400 g/mol Mp: 4 to 8 °C (PEG 400)	freely soluble
PEG 4000	HO- $(CH_2 - CH_2 - O)_n$ -H n ≈ 91	$C_{2n}H_{4n+2}O_{n+1}$ ≈ 4000 g/mol Mp: 53-59 °C	660 g/kg (20 °C)

Kathon CG or WT by Rohm and Haas Co.) to control biological activity of microorganisms in the impregnation bath, and adjusting the pH of the impregnation solution to pH=7-9, and not exceeding the temperature of 60°C in an impregnation bath.

LACTITOL METHODS

Lactitol is chemically more stable than sucrose and withstands high temperatures and alkaline conditions. Lactitol is microbiologically rather stable and has low fermentability; termites don't like lactitol-treated wood. Hygroscopicity of lactitol is smaller than that of sucrose and PEGs. The properties make lactitol a good conservation material.

Lactitol conservation methods have been developed since 1994 for conservation of waterlogged wood and lacquer–ware. Now, over thirty separate organizations (museums and private conservations labs) use lactitol with success in Japan, Hungary, Mexico and China. Three conferences (Kashihara, 1999, Osaka, 2000, and Osaka, 2001) and two courses (Zurich, 1999, Osaka, 2001) have been organized solely on the subject of the lactitol conservation. The number of participants of the last conference exceeded 70. A comparison of the effectiveness of lactitol, sucrose and PEG4000 treatments can be found in one of our publications [4].

Four variations of the lactitol conservation method are possible:

Pure lactitol methods:

- **"cold" lactitol method** – impregnation at an ambient temperature; concentration is limited to 50-55%. If either impregnation or drying is carried out at a room temperature, this leads to formation of large solid lactitol trihydrate crystals on the surface and inside wood. Crystallization of trihydrate causes high volume increase that may crush weak wood structure. If impregnated wood is dried at 50°C, no dangerous trihydrate will crystallize and no damage will happen. Due to the concentration limit, this method is suitable for conservation of low and medium degraded wood.
- **"warm" (heated) lactitol method** – at a temperature between 50° C and 80(85)°C; the concentration of an impregnation bath is limited to 75% at 50°C and 85% at 80°C Impregnation is faster than in the cold method. After impregnation, heat drying at 50°C has to be used to avoid trihydrate crystallization. Wood of all degradation categories can be treated with this method.

Lactitol + 10% trehalose mixture method: by adding trehalose formation of lactitol trihydrate crystals can be prevented and instead of heat drying at 50°C, normal air-drying can be used and therefore a lot of money can be saved [5].

- **"cold" lactitol + 10% trehalose** mixture method at an ambient temperature; maximum lactitol concentration is 63%. It is suitable for low and medium degraded wood.
- **"warm" (heated) lactitol + 10% trehalose** mixture method uses temperatures between 50°C and 80(85) °C; maximum lactitol concentration is 80% at 50°C and ~90% at 85°C. It is suitable for wood in all degradation categories.

An example of conservation with the "cold" (pure) lactitol method

Conservation of 4 m long elements of a 5th-century AD pipeline from the Nango oohigashi site, Nara Prefecture, Japan [6].

Treatment time: pretreatment/decoloring and washing – 1 month, lactitol impregnation – 3 years, heat-drying at 50°C – 1.5 months, surface cleaning and consecutive drying – 0.5 month. Total time of conservation was 3 years and 3 months.

An example of conservation with the "warm" (pure) lactitol method

Conservation of a 3rd-century AD 6 m long timber coffin [7].

Concentration limit of the impregnation bath is 75% at 50°C and 85% at 80°C. Maximum water content of the wood on the surface was about 300-400% and about 200-250% inside. First, a one-month pre-treatment was done: one-week decoloring in tap-water with 1% EDTA-2Na and then washing in tap-water for next 3 weeks. Subsequently, the lactitol impregnation of the waterlogged wood started in a 40% concentration at 50°C and was gradually increased to 60%. The time of impregnation was about 13 months. Thereafter, the coffin was dusted with pulverised lactitol crystals to initiate crystallization, followed by drying at 50°C that took about 2 months. After drying, superfluous crystallized lactitol from the wood sufrace was removed with warm tap-water, and the wood was again dried at 50°C. The total time of the conservation was about 16 months.

An example of conservation with the "warm" (pure) Lactitol method – application for painted waterlogged wood

Conservation of 15th-century Aztec wooden polychrome objects from Mexico [8].

Wooden small masks and false vessels decorated with "Maya blue" (composed of an indigo dye and palygorskite) and carbon black were found in a waterlogged condition inside a stone container deposited as an offering in the 15th-century Aztec archaeological site of Templo Mayor (Great Temple), Mexico City. The deterioration level of the artefacts was from intermediate to low.

The initial lactitol concentration in an impregnation bath was 5% and contained an isothiazolinone biocide (Kathon 1.5 LX). The concentration was gradually increased in 5% increments at a room temperature up to 55%. Later, temperature was raised to 70°C, followed by an addition of lactitol in order to reach concentration of 80%. Drying was completed at 50°C. After conservation, no major changes were detected, neither in color qualities nor in the wood surface appearance. The final color of the wood and paintings was natural. The total procedure time was 8 months.

An example of conservation with the "warm" Lactitol + 10% trehalose mixture method

Conservation of the 1st-century BC extremely degraded waterlogged archaeological wooden figures and painted (lacquered) objects excavated at the tomb of one of the kings of the ancient Shisui Kingdom in China [9].

In 2002-2003, an excavation discovered the grave of one of the five kings of the ancient Shisui Kingdom (Han dynasty, 1st c. BC) in Shanzhuang village, about 150 km North of Nanjing (Nanking), China. Over 700 unique waterlogged objects were found, including 300 wooden figures (30-40 cm high), 90 wooden horses, 20 wooden animal figures, and many lacquerware, iron, bronze, ceramic and jewelry items. In many cases, the degradation of wood was extremely high – water content reached even 1400%.

First, a 1-2 week procedure of removing iron substances was conducted in tap-water with 1% EDTA-2Na followed by a 3-week washing in tap-water; water was changed every 2-3 days. The impregnation solution contained lactitol and 10% (w/w) trehalose in water, and 0.01% Kathon CG biocide. Impregnation started in a 15% (w/w) solution at 50°C. The lactitol concentration of the bath was increased stepwise to 30% and 50%. The temperature was raised to 60°C and the concentration up to 65%, 75% and 80%. The total time of impregnation of thin (few centimeter thick) objects was about 3 months, for thicker objects (up to 10 cm) – about 6 months, and for thickest objects (over 10 cm, e.g. figures, soldiers, animals) – about 18 months.

After the impregnation, the objects were removed from the bath and the wood surface was dusted with pulverized lactitol monohydrate crystals for generating crystallization of lactitol. Crystallization and drying was performed at the temperature of the environment. After the drying, the surface was cleaned with warm tap-water to remove superfluous crystallized lactitol, and dried off with soft paper tissues. The result of the conservation was nice and the paint decorations were all saved.

An example of conservation with the "warm" Lactitol + 10% trehalose mixture method

Conservation of waterlogged wood core lacquerware finds [10]

The lactitol + 10% trehalose method is especially suitable for the conservation of archaeological Eastern lacquerware objects. It is also successfully used for the conservation of usual waterlogged finds.

TREHALOSE METHOD

Two varieties of **trehalose methods** (pure trehalose without lactitol) can be used:

- **"cold" trehalose method** (at the temperature of environment): the maximum trehalose concentration in an impregnation bath at 20°C is only 41% – not enough for the conservation of highly degraded wood; it is suitable for low and medium degraded woods. No heating under impregnation is economically preferable.
- **"warm" trehalose method** (heated to maximum 85°C; lacquerware – 55°C). The trehalose concentration limit is ~90%/85°C; wood in all degradation categories can be treated.

The trehalose method is a unique and revolutionary one in the conservation of waterlogged wood. The drying step is totally different from the previous methods: forced air-drying is used to initiate fast crystallization of trehalose in wood structure. The duration of the "warm" method, including the required drying-time, is the most rapid among methods available today. It is considered to be totally reversible if necessary.

The trehalose conservation method is faster, safer and less expensive than previous treatments. It is very effective and results in a cross-sectional shrinkage below 2%. Even woods in high degradation states can be treated successfully with this method. We have to note, that the trehalose method is a ”strange” and ”unconventional” method since in the drying phase, the opposite to what was strongly recommended in former methods should be done, i.e. slow drying should be replaced with fast drying.

Why is trehalose method so efficient? The efficiency of the treatment is improved by the fact that a large amount (43%) of the total absorbed trehalose crystallizes in the degraded wood tissue immediately after impregnation, in the cooling phase, while the temperature of wood is decreased from the impregnation temperature (70-85°C) to the temperature of cooling, before any drying begins. The solid crystals protect the wood against collapse, shrinkage and distortion in the consecutive drying phase when water is evaporated from the wood. Thus, the efficiency of the trehalose method is based on three crucial facts:

1. partial stabilization and partial liquid water removal caused by the formation of hard solid dihydrate crystals on cooling take place before any drying occurs. In the cooling phase, nearly the half (43%) of the total trehalose that had entered the wood structure under the impregnation will crystallize and stabilize the degraded wooden tissue, and simultaneously **11.4%** of the total liquid **water** in the wood will be combined (removed) into a trehalose dihydrate crystal structure. Unlike to lacticol, trehalose drying produces only dihydrate crystals at a room temperature so there is no need to control the hydrate generation.

2. in the drying phase, the remaining 57% of the total trehalose amount will crystallize and bind **15.4%** of the total water as **crystal water**.

3. finally, about **three quarters (73.2%)** of the total liquid **water** will remain for removal by evaporation under drying. Evaporation is a liquid-vapour transition of water and the main cause of dangerous and irreversible cell collapse and deformation of degraded wood. In the trehalose method, 73.2% of the total liquid water will evaporate in the drying phase after the wood has been previously substantially strengthened and protected against collapse by the crystallization of 11.4% trehalose dihydrate.

In traditional (non trehalose) conservation methods, the dangerous liquid water removal (drying) by liquid-vapour transition of water takes place simultaneously with the consolidation of degraded wooden tissue, while in the case of trehalose method, a part of water (11.4%) is removed prior to drying by the crystallization as crystal water in the trehalose dihydrate. The crystallization of dihydrate is not a dangerous liquid-vapour transition. The principal difference between traditional conservation methods and trehalose method is, that in the latter strengthening happens first and evaporation of liquid water only thereafter.

The recommended “warm” trehalose method for an object about **1 cm** thick starts with multi-step impregnation in aqueous solutions of increasing trehalose concentration in four 5-day steps: 1. 30%/20°C, 2. 41%/20°C (room temp.), 3. 58%/50°C, 4.72%/70°C. (All % concentrations are in w/w and calculated as trehalose anhydrate.)

In order to prevent any possible biological degradation of the wood and the trehalose within the wood and the surrounding solution, this is recommended to add at least 0.02% of Kathon CG or Microbicides DP III.

The next step of conservation is the fast cooling and partial crystallization of trehalose, immediately after impregnation, by electric fans or placing the objects in a refrigerator. The fast cooling and crystallization of trehalose are preferred since they enable the production of fine, small crystals.

After cooling and partial crystallization, air drying and further crystallization follows. Unlike this is with lactitol, drying produces only dihydrate crystals at a room temperature and there is no need to control the hydrate generation.

Other conservation methods prefer slow drying to avoid drying stresses and collapse. The trehalose method involves faster drying because the cooling phase is separated from the drying phase, and solid crystals have already been precipitated before any drying begins, in a quantity sufficient to withstand drying stresses and collapse. After drying, superfluous adhered trehalose crystals on the wood-surface can be removed with hot water.

Examples of conservation with the ”warm” trehalose method

The trehalose conservation in practice can be applied to different types of archaeological objects, such as wooden finds of all degradation conditions, wood-core lacquerware, wood finds with paint remains, rope and basketry.

The detailed description of the method can be found in our WOAM Istanbul paper [11].

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Conservation of wooden wrecks from the Baltic Sea

Irena Jagielska

INTRODUCTION

The mission of the National Maritime Museum in Gdańsk, which has been in existence for 55 years, is the protection of cultural and technological maritime heritage through, among others, collecting and preserving artefacts; many of them come from the bottom of the Baltic Sea exploration. Since 1969, archaeologists and divers have been conducting regular underwater explorations. Several dozen wrecks were located during them and some were lifted from the bottom of the sea. Wooden shipwrecks were raised in parts which facilitated their storage before conservation as well as the conservation process itself. These were typically constructional elements like frames, stem, stern post, knees, rudder, keel, floor timbers, girders, transoms, planks or entire plating strakes, often with the sealing or metal parts which had to be conserved with the wood. "Gifts of the sea" – parts of shipwrecks found on the shore after stormy weather, were preserved and conserved too.

PRESERVATION AND CONSERVATION OF WRECKS

The process starts with securing wooden objects which means spraying them with water and covering with foil. Samples for testing are taken at this stage. Stainless steel tanks or tanks specially built to size are used for storage; they are built of wood, plate and lined with a thick foil, e.g. swimming pool foil, secured against disintegration by straps and crossbars. For storing keels, baths as long as several meters were built. Biocides are added to water in tanks; Kathon LXE is used for wood without metal and boric acid/borax for wood with metal elements.

COPPER SHIP

The biggest challenge for our laboratory was the shipwreck of the Copper Ship, a medieval merchant ship of a holk-type [1]. Its name comes from the copper ingots which, together with bundles of iron bars, iron ore, wood tar, wax, and potash as well as a large cargo of all kinds of planks, were to be transported to the west of Europe. Planks such as wainscots and barrel staves had different lengths and cross sections [2]. Unfortunately, after leaving the port of Gdańsk, the ship caught fire, which caused the vessel to sink [3]. The Copper Ship went down to the depth of 14-15 m and lay submerged in a layer of moderately medium and fine-grained marine sand [4].

Fortunately, the wood of wreck that had lain nearly 567 years in the sea water was in a very good condition, mainly for two reasons. Firstly, the ship had been operated at sea only for 8 years, secondly, during the fire it was covered with pitch and tar leaking from the barrels, which over time, combined with corrosion products, sand and iron ore formed concretion protecting the wood. Pine pitch was also an impregnation substance for a part of the wood from the Copper Ship (Fig. 1)

The wood from the Copper Ship was characterized as follows:

– water content in plank: 144%-283%, in frames: 114%-248%,
– medium cellulose content: 44% (contemporary wood: 46%),
– medium content of substances soluble in alcohol-benzene: 5.4% (contemporary wood: 2.8%).

After the concretion had been removed, 10 tons of wooden parts from wreck and cargo of the Copper Ship were conserved by two methods [5]. The wood impregnated with pitch was slowly dried and coated with a mixture of linseed oil and turpentine (Fig. 2).

A large part of the wood was impregnated with different types of polyethylene glycol (PEG). Individual parts of the wreck were sprayed for several years with 10% to 35% solutions of PEG 1500 and 4000. It was a kind of controlled drying because PEG entered only to the small depth.

A better method – a two-step impregnation – was used for the conservation of a part of the starboard. A special chamber was constructed of wood and foil with a humidifier placed in the middle to keep the humidity high. The object was sprayed first with a 10-40% solution of PEG 300, and next a 40-50% solution of PEG 3000. The PEG penetration was much better. (Fig. 3).

The "print off" method developed by P. Hoffmann showed that PEG 1500 and 4000 entered only to the depth of 1 cm. The TLC chromatography method used in a two-step method showed deep penetration of PEG 300 and little penetration of PEG 3000 [6].

The pioneer conservation of the Copper Ship brought satisfying results. There were no cracks or deformation noticed on the boards up to 6-7 cm thick. There were noticeable longitudinal cracks in elements with larger cross-sections, especially in those conserved with the use of linseed oil and turpentine. Fewer cracks were recorded in the elements treated with the method of spraying with PEG solutions. The best results were obtained using the two-step impregnation method with low-molecular-weight and high-molecular-weight PEGs, however in this case, the surface was more hygroscopic than in the previous methods. The shrinkage of cross-sections after conservation ranged from a few to several percent, depending on the method used.

Fig. 1. *Constructional elements of the Copper Ship coated with a layer of pitch; photo Leszek Nowicz*

Fig. 2. *Reconstruction of the inner stern post; photo Bernadeta Galus*

Fig. 3. *A part of the starboard after conservation; photo Bernadeta Galus*

Table 1. *Species of wood in the P2 boat*

PARTS OF BOAT	SPECIES OF WOOD
Keel, keelson, stem	oak
Floors, frames, and beam knees	oak, alder, hornbeam, birch
Planks, rowing thwarts	oak
Treenails	pine

Table 2. *Maximum water content and conventional density of hornbeam, alder and oak*

SPECIES OF WOOD	SAMPLE	MAX. WATER CONTENT (%)	CONVENTIONAL DENSITY (%)
Hornbeam	G	782.1	118.7
Alder	O	803.9	115.3
Oak	D1	410.2	209.7
Oak	D2	297.7	276.5
Oak	D3	210.3	361.7

Fig. 4. *The tank for conservation of the P2 boat;photo Irena Rodzik*

Fig. 5. *The keelson from the P2 boat after conservation; photo Bernadeta Galus*

P2 BOAT

The P2 boat from the 10th century was found in the Puck Bay, in the area of early medieval port [7]. The wreck was lying at the depth of 2 m, partially buried in the bottom sediments. The clinker boat is a unique find due to its specific structure combining both Scandinavian and Slavic construction features. It was originally used as a combat vessel which had a spindle - like shape [8]. For a thousand years, the P2 boat has been destroyed by biotic factors, pollution, waving and freezing of the Puck Bay; eventually 2.5 tons of wood (60% of the wreck) were saved in 400 elements.

Optimally, the elements of the P2 should have been divided into 4 groups, depending on the type of wood and degree of degradation; every group should have been conserved separately. It was a challenge to develop a method that could be used for the conservation of all types of wood at the same time. The boat was built mainly of oak, but many parts were made of different species of wood – see Table 1.

Analyses of the metal content showed a large amount of copper (0.12-0.21% of dry wood) and strontium 88 (0.26-1.25%). Iron content ranged from 0.1% to 0.3 % of dry mass in different kinds of wood. The properties of wood from the P2 boat are presented in Table 2.

The best method of conservation was developed based on microscopic, physical and chemical analyses. It was a two-step impregnation worked out by Hoffmann [9]. The first step of the conservation started from a 10% solution of PEG 400 with 1% mixture of boric acid and borax, and ended with a 41.5% solution. The temperature of the conservation solution was 42˚C, and the process lasted 20 months. The second step began with a 42% PEG 4000 solution, increased to 75% within 21 months [10]. During the conservation, the temperature of the solution circulating in the tank was maintained at 58˚C. After the impregnation, all parts were slowly dried. Parts of the P2 boat (except for the keel) were conserved in a stainless steel tank with a lid and removable shelves. The tank had two systems: one with circulating warm water and the second for preparing and circulating of a PEG solution, vapors were removed by a discharge channel (Fig. 4).

The oak keel was conserved in a 12 m long tank made of wood and chipboard, and lined with a thick foil. The tank and lid were insulated with a polystyrene foam. The first step started from using a 10% solution of PEG 400 with 1.5% mixture of boric acid and borax. Within a year and a half, the concentration of PEG was increased to 25% by adding a liquid PEG, whereafter an installation for heating and mixing the solution was used. Subsequently, the concentration was increased to 40% at 42˚C. The second step started from using a 42% solution of PEG 4000, increased to 70% within 16 months. After the conservation, the keel was dried in a long wooden box covered with foil to ensure slow drying and prevent distortion of the keel.

Quantitative analyses of PEGs 400 and 4000 during and after the conservation of the P2 boat were made with the use of method developed by Hoffmann based on high-performance liquid chromatography (HPLC) [11].

The conservation of the P2 boat was successful. The elements of the boat made from different types of wood with various degrees of degradation were effectively conserved. The wood of the P2 boat was hard, did not undergo warping or deformation (Fig. 5). Some elements had single cracks, caused probably by the lack of access of the circulating solution of PEG in the loaded bath. An average cross-section shrinkage of the conserved wood was 8%. Planks could be easily formed by being heated slightly after the impregnation.

"COG" FROM ROWY

The wreck named “Cog”, a type of a cog-built vessel from Rowy dated to the 13th century, is being conserved now. Four tons of wood undergo impregnation with a solution of PEG 200 (15%) and PEG 3000 (10%). Impregnation is going to be a long process because the constructional elements are very large. After the impregnation, the parts of “Cog” will be dried in a freeze-dryer with a chamber 1 m in diameter and 5 m long.

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"Code 04". Tarry substances on historic ships – do we need a strategy to preserve its information potential?"

Inger Marie Egenberg

INTRODUCTION: THE WATERPROOFING OF WOODEN BOATS AND SHIPS

Different kinds of tar and bituminous products, manufactured, modified or naturally occurring, have been used on wooden ships throughout maritime history, a practice that is also reflected in maritime myths. In the following quotation from Genesis 6:13-14, God may well have referred to a naturally occurring material: "And God said to Noah… Make yourself an Ark of gopher wood; make rooms in the ark, and cover it inside and out with pitch…" In the Middle East as well as in other parts of the world, for instance in La Brea, California, naturally occurring tar lakes are described [1].

"Tar" and "pitch" are technological terms applied to a broad group of materials [2]-[4]. They consist mainly of hydrocarbons and have various complex chemical compounds in common. Their compositions are not well known, and they vary considerably [5]. Bituminous materials may be subdivided, like Mills and White do, into Natural products on one side, consisting of *I. Bitumen*, *asphalt* and *II. Pyrobitumens: peat*, *lignite and coals*, and on the other side *Artificial products made by pyrolysis of wood, coal or resin*, with *III. Tars (distilled)* and *IV. Pitches (undistilled)* [6].

Pine tar production is by technological terms defined as dry distillation or destructive distillation – as one distils a solid material (resinous pinewood) to gain a distillate (pine tar). A by-product of tar kiln production is charcoal. One may derive tar from any kind of wood, and from peat and different kinds of coal. However, in Sweden, Finland and Norway, it is almost only *pine* tar that has been made. Particularly resinous wood from Scots pine (*Pinus sylvestris*), constitutes the raw material.

Caulking material does not consists of tarry substance alone, but of animal or vegetable fibres soaked in tar or pitch. Caulking is placed between the planks during construction in a clinker built boat, like the Norwegian and Danish Viking-ships. That is why the information one might derive from these contexts are particularly interesting.

Since the most likely kind of wood tar you will find applied to shipwrecks in Europe is pine tar distilled from resinous pinewood in traditional kilns, the article will address this kind of tar.

PINE TAR AND PINE PITCH

The connection between pine tar and pine pitch is clearly defined in the Nordic tradition, since pitch is a semi-solid matter achieved by boiling of tar. This definition does not fit altogether with Mills and White's sub-divisions above [6], where point *IV.Pitches (undistilled)* are understood as the *residue*, i.e. what is left after distillation. Boiling or seething of pine tar to pine pitch in the traditional way would not be regarded as a distillation since the volatiles simply evaporate out in the open air, and are not collected as a condensate or distillate. The contents of volatiles in the tar are reduced in order to gain a much more viscous liquid or sometimes a semi-solid or solid matter, depending on time intervals and temperatures involved. An experienced pitch maker will finish the boiling when the right consistency appears. One way of assessing whether this has been achieved, is, due to a local tradition in the valley of Gudbrandsdalen in Norway, to put a drop of burning hot pine tar into a cup of cold water. When the pitch-maker makes a bite mark in it, it should not stick to his teeth nor leave any mark on them. Then is it ready for use.

The word for (pine) pitch in Swedish is "beck", and *Beckholmen* is the name of an islet approximately one hundred meters from where the Vasa ship sank in 1628. A pitch boiling trade was however not established at this particular islet in Stockholm until 1633 [7]. It was advisable to conduct the boiling and seething of pitch on a safe distance form building activity [8], and preferably in a place surrounded by water, in order to avoid fire.

Stockholm tar is a trade name originating from the early 17th century when Finland and Sweden were united as a Great Power (1611-1718). This was a period in the Nordic history when pine tar was mainly produced in the northern parts of Finland and Sweden, traded in large quantities via Stockholm, and partly via other Finnish-Swedish harbours. In certain periods, *Stockholm tar* monopolized the tar trade in the region. In Norway the tar export never reached anywhere near the quantities of the neighboring countries, but it was nevertheless an important product manufactured in most parts of the country where Scots pine were to be found. Both its utilization and trade were regulated by early medieval laws, as was the tarring and upkeep of ships [9] as well as the wooden, medieval churches.

CONTRIBUTIONS FROM IMPORTANT ARCHAEOMETRY STUDIES

Primarily investigations concerning archaeological and marine finds have contributed to the record of chemical analysis on tar and pitch. The main issues have been the identification of materials, their provenance, age, production technologies etc. [10]. All these studies within the field of archaeometry seem to address analytical-methodical issues in addition to the specific questions of identification etc. However, in this overview, the latter will have the focus.

On board of the Cog of Bremen (from 1380 or after) a barrel content resembled the chemical characteristics of those from a 20th century kiln-produced pine tar sample [11]. Dr. Per Hoffman in Bremerhaven provided the reference sample, and Werner Lange concluded that the barrel found inside the Cog of Bremen contained medieval pine tar.

Evershed et.al showed that the GC-MS analysis of six pitch-samples from Mary Rose (1509-45) resembled that of a reference sample referred to as Stockholm tar, i.e. "good-quality pine tar obtained by the destructive distillation of *Pinus sylvestris*". The samples were described as follows: "Six samples of pitch and pitch-impregnated material from the Mary Rose were selected for analysis. These included pitch from barrels found in the hold "luting" from the main deck, caulking from between the timbers of the outer frame of the ship, tarred anchor cable and a tarry solid (possibly intrusive) found in a box of longbows". This collection of samples indicates the varied use of pine tar and pine pitch in maritime context [12]. Robinson et.al. much the same group of scientists as involved in the latter study, compared the six pitch samples from the Mary Rose with one from an Etruscan shipwreck (600 BC) found on the seabed close to Giglio in Italy. It was confirmed that also this old pitch sample, from an amphorae carried as cargo, was of a pine wood origin [13].

In 1989 a Finnish group of scientists published an article on pine tar analysis of samples collected from the wreck of Frigate St. Nicolai, which sank in 1790 [14]. Samples were taken from an undamaged tar barrel within the shipwreck, and from tarred twine and ropes. The authors refer to the history of pine tar production in Finland, and state the hypothesis that the barrel tar was made of pine tar and meant for maintenance of the ship during sailing and that the ropes had been tarred with the same kind of tar. They used a freshly produced sample from a pine tar company in Finland as reference, and found that their hypothesis was confirmed, although mentioning that the reference sample had a higher content of fatty acids compared to the barrel tar. Moreover, they found that the tar sample from the rope was in another state of degradation due to thermal degradation products, which they thought were the results of the process where the ropes probably had been soaked in very hot tar [14]. In another article one year later [15], they argued that they probably had been wrong concerning how these thermal degradation products had appeared. In this new study, they compared the barrel tar form St. Nikolai with a barrel tar from another wreck, St. Mikael (which sank in 1747). The tar barrel from St. Mikael's was damaged, and the tar that was left had therefore been exposed to the seawater and the marine environment for about 250 years. They differentiated between tar samples by collecting a highly exposed sample on the surface of the barrel content, and another sample from the interior of the barrel content (as little exposed to seawater as possible). Analysis showed that this exposed surface tar sample had similar components as the exposed tar sample from the rope in the former study [14]. The tar sample from the interior of the damaged tar barrel was very similar to the tar from the undamaged barrel from St. Nikolai. Instead of explaining the more degrades state as a result of previous heating of the tar, they found that it was probably a long-term alteration of the pine tar caused by the marine environment of which it had been exposed to [15].

A RESEARCH PROJECT REGARDING TRADITIONAL TARRING OF STAVE CHURCHES

In Norway, we have 28 wooden medieval stave churches left, and it is assumed by the Norwegian Cultural Heritage Authority that their exteriors were originally tarred with pine tar from Scots pine, *Pinus sylvestris* L.], produced in traditional kilns like those that the ones described above. The same authority wants to apply the considered authentic maintenance practice on the about 20 stave churches, which still have tarred exteriors. That principal statement made clear by the Directorate for Cultural Heritage, No: *Riksantikvaren*, during the 90s, defined the starting point for a research project on the characteristic properties of pine tar. The studies on pine tar by the author referred to here is mainly results from that project.

In the first phase of the project, participation in, and recording of three different kiln productions, was accomplished. Series of 5-8 samples from each production were obtained and investigated. This was done in order to increase our knowledge of this kind of material.

Moreover, an approval norm for kiln-produced pine tar was developed during the study. The laboratory associated with the cultural heritage authorities, assessed tar samples according to this norm. If a tar-maker wanted to sell his kiln-produced tar for stave-church use, he had to fill out a form to describe the production and send inn at least two samples for assessment. The development of this norm was based primarily on the sample series from the three productions, comparing specific weight, percentage of volatile parts, percentage of water-soluble parts, viscosity, visual appearance and general impression regarding smell, consistency etc. These physical appearances and properties of the tar samples were correlated with the temperature measurements from the kilns and correlated with chemical analysis by combined gas chromatography and mass spectrometry (GC-MS). In a traditionally performed pine-tar production, the tar is filled successively into a number of barrels. It turned out that the tar samples varies significantly both physically and chemically through productions, and *the patterns of variation* appeared similar from one production to another. The samples were analysed by GC-MS at the analytical laboratory of the National museum of Denmark by the collaborating chemist Jens Glastrup, and written up in an unpublished master thesis in conservation by the author, at The Royal Danish Academy of fine Arts, the School of Conservation, in 1993. The results were published later [16],

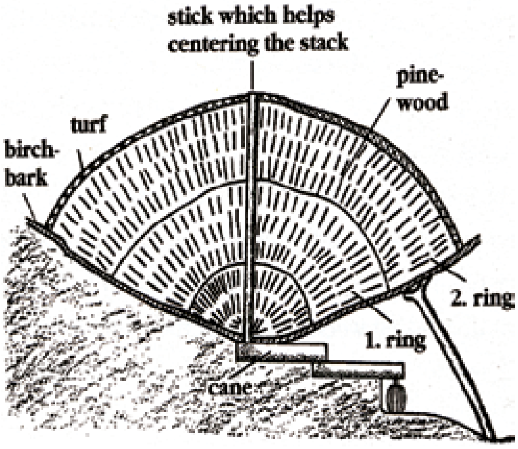

Fig. 1. *Large piles of pinewood sticks, stacked on a funnel-shaped platform, covered with turf and ignited from the periphery, in order to burn inwards. The turf layer on top is used to control the access of air i.e. oxygen. There is a wooden drainage underneath, which allows the tar to be drawn successively from the kiln into barrels or other containers; ill. D. Eldne*

Fig. 2. *Resinous pine wood carefully stacked according to the tradition of pine tar making*

Fig. 3. *A burning kiln in an early and late phase, left and right accordingly*

[17]. It became clear that the chemical changes occurred due to an increase of production temperatures within the kiln as combustion proceeded. The GC-MS data of an initial pine tar sample obtained from a kiln production when the production temperatures were low; consequently resemble those of a pine resin sample. The tar in the initial barrel also has a physically different appearance to the tar in the final barrel of a production. It is more viscous at the start than in the middle and towards the end, and the colour gradually appears to become slightly darker during the process.

DISCUSSION

It is not obvious that stave churches and Viking ships have much more in common than being important cultural heritage of national and international interest. Additionally they are made of high quality wood, pine and oak respectively, and coated with pine tar.

It is well known that boat-builders generally heat the pine tar and boil it to pine pitch to tighten the boat, in particular. There is a need for a pitch-like substance between the planks in a clinker-built boat.

Archaeologists or conservators generally detect tarry substances on shipwrecks during excavations or examinations afterwards, since traditional wooden boats and ships were generally waterproofed by tar coat on the boards and tightened with pitch between them. One might also find holes and cracks filled with pitch for repair purposes. Samples are sometimes collected, however quite random, and for the record only. Very often, the coating on the timber as well as the caulking material are removed and sometimes even thrown away.

What is the reason for such a practice? Is this practice based on a belief that the only information possible to derive from chemical analysis is that of identification of raw material i.e. wood specie? After all, the origin of the tar substance probably turns out to be resinous pine wood. One probably will have to be aware of the information potential to ask further questions.

The second phase of the research project regarding traditional tarring of stave churches, involved a PhD-study [18]. Due to church accounts from 15th and 16th centuries it is clear that pine tar was boiled also prior to application on stave churches. Seething of tar to something called "stir tar" (No: *rørtjære*) and to pitch was mentioned in the accounts, indicating differentiated degrees of boiling. One aim of the PhD-study was therefore to investigate how kiln-produced pine tar alters during the processes of boiling, followed by exposure and weathering. These experimental and analytical issues are dealt with in greatest detail in the papers III and IV [19], [20] of the dissertation, and summarised and discussed in greatest detail in chapter 3 in the main text [18].

In order to distinguish between complex pine tar samples of great compositional similarity, GC-MS was once again selected as the most suitable analytical technique. The pine tar samples were analysed, not only during the course of production, but also after boiling, and after application on test panels, and at intervals during accelerated and natural weathering. It was demonstrated that a significant distinction between newly produced tar samples from a kiln can be made by GC-MS analysis [19]. Further analytical evidence established that boiling of the tar below 200°C does not result in greater similarities between the tar grades, i.e. made the tar samples from different barrels more alike. Even after 30 months of weathering, it was still possible to distinguish between tar samples originating from different barrels deriving from the same kiln production [20].

Another reason for the neglect of the information potential of tarry substances might also be the restricted number of conservation scientists, preferably chemists, working within the field of cultural heritage. It is also important to underline that GC-MS is not normally a tool that conservators are skilled to use. One has to accomplish real interdisciplinary collaboration.

Tar coating is true enough a laborious and sticky material to handle and the appearance and the smell of it in archaeological contexts are not very pleasant. Moreover, it might be difficult to define where the "waterlogged" tar coat stops and the surrounding soil, mud or silt begins, as they physically may have been mixed. In order to get rid of impurities that have been fixed in the tar coat, one might have to scrape off some of the tar as well. Even applied to buildings, old tar coats does not have stratigraphic layers of any kind. Based on practical tarring experience, it seems that the latest applied tar layer solves, melts into, the underlying layer, and become like one, combined layer instead.

Still, tar layers and caulking material are indisputable and inseparable parts of wooden shipwrecks when they appear, and bearer of cultural significance and technological information from when and where they were made. To my knowledge, it has not proved to be destructive or to hinder the preservation of the shipwreck timbers. Nevertheless, tar coats tends to fall off after PEG-stabilisation and freeze-drying, according to my own experience from the Barcode conservation project at the Norwegian Maritime Museum.

I think we need a common strategy to be able to preserve and of course *utilize* the information potential of these tarry substances, provided they consist of pine tar. The pine tar has due to a remarkable chemical stability, proved a bearer of a lot of information. By improved knowledge of the conservation scientists regarding pine tar chemistry, and by systematic, thorough and conscious recording and collecting of tar samples from shipwrecks by conservators, i.e. before any chemical treatment, a potential for better knowledge of ship building technology, wood technology and the authentic boat building tradition clearly exists.

A common conservation and research strategy can lead to:

1. Improved conservation procedures by preserving not only the wooden parts of the boats, but also what is left from original coating and caulking material, preferably kept in its place.
2. To confirm or alternatively invalidate the pine tar contents of the waterproofing agents applied to shipwreck finds,

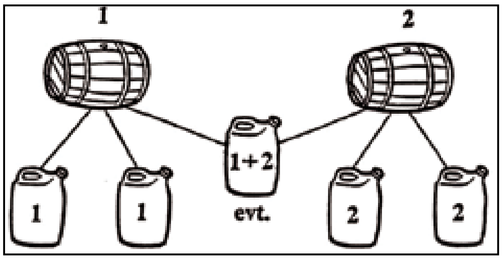

Fig. 4. *One fundamental assumption for the project was that different tar qualities were kept separate, and dedicated to differentiated use*

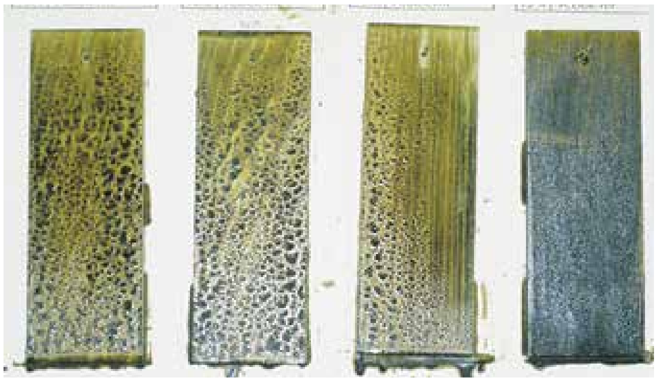

Fig. 5. *Tarred pine wood panels after exposure in weatherometer*

and chemically characterise the samples in ways which are comparable to previous studies or to current projects which is relevant to refer to. To do this, a good quality reference collection is of vital importance.

3. To chemically characterise pine tar samples from an experiment in seawater to find out whether pine tar coating on oak boards will prevent attacks from shipworm under the wooden surface and other wood borers on the surface (for instance *Teredo navalis, Limnoria lignorum* etc.). Is it possible to detect from shipwreck records, that tar-coated wood has been better protected from shipworms and other woodborers than un-coated wood?

4. Did the boat builder differentiate between tar qualities used for surface treatment and caulking? This is a question of cultural historic meaning, and can lead to new information about the authentic material knowhow of the boat-builder or in the tradition of boat building.

5. To chemically characterize pine tar samples boiled to pitch in various degrees of boiling (applying various combinations of time and temperatures) to be able to contribute to reconstruction projects of traditional wooden boats or ships.

CONCLUSION

There is a need to do research on tarry substances in maritime contexts in general, and on pine tar and pine pitch in marine contexts in particular – how it was used during ship construction and to which items and in which ways it was applied. The significance of tar and pitch as protection towards shipworms, and its significance relating to the sailing abilities of ships are matters of interest when it comes to reconstruction projects of individual shipwrecks. It is probably possible to gain more knowledge by systematic chemical analysis and by means of experimental archaeology.

Clearly, a well-developed collection of reference samples is vital in order to reach to conclusions, but there is still a good possibility to achieve such series of samples from traditionally accomplished tar kiln productions in Norway. To those particularly interested, it is even possible to go there and join such a tar manufacturing during summer season.

Pine tar and pine pitch has proved to be chemically quite stable even after long time exposure, both on tarred panels [20] and in marine environments [11], [15] and it probably hides a lot more information yet to reveal.

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Conservation of a 17th century boat, Barcode 6, for exhibition

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INTRODUCTION

In order to implement a major building project in Bjørvika in Oslo, several sites were examined archaeologically in 2008 and 2009. What was hidden under the ground was a former waterfront of the Middle Ages and Renaissance town of Oslo. The city was previously located on the east side of the Bjørvika bay until the Danish-Norwegian king Christian IV decided to move the town after a devastating fire in 1624 that almost burnt the whole town to the ground. The town was rebuilt (with broad streets and houses constructed out of brick) on the west side of the bay, and the old central harbour lost its importance. Over the years sediments from nearby rivers have accumulated in the harbour, together with isostatic uplift, contributing to making the harbour useless. The area was completely filled in the mid-19th century to give the town more space [1] but as it turned out the remains underneath were left almost undisturbed, protected from oxygen and harmful organisms by clay, until the present day.

The excavation was performed by archaeologists from the Norwegian Maritime Museum (NMM) who revealed what was initially thought of as 15 boats, and became the biggest collection of boats from the 17th and 18th century in Norway. (Later analysis showed that two of the "boats" where in fact dislocated sections from other boats, so the final number was reduced to 13). The boats were found in connection with several wooden constructions, and all were stripped down without any rig. Several factors point towards the boats being flattened and lowered on purpose, maybe as a foundation for something. [1] The area was named after the architectural style that was chosen for the new buildings, slender and tall but with different heights, namely *Barcode*. The excavated boats carried the same name followed by a number.

The excavations were performed simultaneously as, and mainly dictated by the construction work, which took place over the entire year. It resulted in several challenges, including more extreme conditions like snow, frozen ground and short daylight periods. [2] In less than 13 months, the excavation was complete, including dismantling and moving of all the boats. What was revealed exceeded all expectations, and the museum had to make several adjustments in order to receive all the material.

One of the projected Barcode buildings was going to house the headquarters of a private bank named DNB, and they expressed interest in exhibiting one of the boats in their building. The Savings Bank Foundation DNB funded the project, and the museum was given the opportunity to reconstruct one of the boats.

The project started in 2009 and was scheduled to end in 2015. In the newly erected buildings housing the DNB headquarters, a specially designed display case with climate control was completed in 2012. The boat is scheduled to return to Bjørvika in October/November 2015. An iceberg inspires the design of the display case and the peaks are rising up through the ground at street level, to allow the boat to be admired by passers-by. The whole process of getting the boat from the ground to the location of the exhibition required a multidisciplinary approach with several parallel processes, involving experts within the fields of archaeology, boat building, conservation, mount making and more (Fig. 1).

Knowing from the start that the boat would be exhibited, influenced the whole process and in particular the decisions related to the conservation. Having a tight time schedule and a limited budget also influenced the project. The project is not yet completed, but this is a presentation of some of the aspects that we have encountered so far. This article will not go in-depth into the ethical considerations around reconstructing the finds into a boat, when its final use might have been something completely different. Still, it is appropriate to mention that it has been a deliberate choice, as a boat is generally easily recognizable and more interesting than a structure with uncertain function.

BARCODE 6

When deciding which boat should be exhibited, considerations such as size and how complete it was counted as important factors. The choice fell on the boat *Barcode 6* (BC06), a clinker built and well-used small ship. The boat is 7.8 meters long and 1.9 meters high. It is relatively complete, consisting of 215.7 meters lengths of wood which together make up about 85% of the boat. It was mainly constructed in oak, with a few parts in pine, and wooden nails made of several different types of wood. It is dated by dendrochronology to ca 1595, and ended up on the bottom of the harbour some time before 1624. Both wooden rivets and iron nails, in some places in combination, in other places one or the other held the planks and parts together.

The wood is soft and degraded on the surface while the core consists of sound and well-preserved wood. Maximum water content (wet weight – dry weight/dry weight x 100) from 5 samples taken from two different oak planks (x039 and x047) varies from 116% to 260%. These samples are not representative and cannot say much about the condition of the boat as a whole, since they are taken from a very small area. The variation might just as well be wider. However, they do show that the condition varies within a range, and that some parts are well preserved, while other parts are more deteriorated. Typically, the surface is the most deteriorated while the wood in the core is more protected and hence sound [3].

DOCUMENTATION

Documentation in the field was done with both photographs and drawings of the boats in situ. The boats were unearthed part by part and stored in large water tanks between excavation, documentation and conservation. Digital documentation of ship findings with a graphic tool, FARO Arm, has been an established method at NMM since 2006, and there was never any doubt that this should be the method of choice for the Barcode boats[4]. Every boat part was documented digitally in a 1: 1 scale, and assembled in the program *Rhino 5.0* to create a digital 3D image.

The drawings contain information about the shape, wear and tool marks that are essential in the reconstruction work. The strakes were originally treated with tar on the surface. During the documentation process only the tar that distorted the traces on the surface and the shape of the boat parts were removed when it was necessary for the documentation process, if not it was left undisturbed.

Removal of iron salts from the wood was considered in the early phases of the project, but due to the time and financial limitations of the project, the removal of irons salts was not prioritized.

MODELS IN CARDBOARD AND FULL SCALE COPY

The boats were found on the old seabed, weighted down by more than 3 meters of clay, wood chips and filling materials. This flattened existence for 400 years, followed by a relatively rough dismantling during excavation, might have led the parts to lose their original shape. Boat parts were drawn digitally in the form they had after dismantling in the field. In order to recreate the shape each part had while the boat was in use, the boat parts had to be interpreted and a reconstruction of the boat made.

The digital drawings from the documentation were scaled down to 1:5 and printed as parts on cardboard and in 3D plastic. Together with a boat builder, the archaeologists used these parts to construct a cardboard-model of the boat. Archaeologists have experienced that it is more suitable to reconstruct boats physically than digitally. It is easier to manipulate parts in a desired manner. The cardboard planks and plastic parts were pinned together using needles and small screws where the printouts indicated the position of rivets and wooden nails [5].

During reconstruction, when going beyond the 4th strake, it became clear that the boat had a transom, although it was not found in the excavation. It was also obvious that the boat had been rebuilt during its lifetime [6]. The model was therefore made with a transom, and the missing parts were replaced. The complete cardboard model was again measured with the FARO arm to obtain a digital model that could be scaled back up to full size.

The physical cardboard model with the digital drawings and the digital model were then used as the basis for building a "floating hypothesis", a full-scale copy of the BC06. The original material was also consulted during the process. With traditional methods as a starting point, attempts were made to find production working procedures of the period. The replica was given the name *Vaaghals* (*Daredevil*) and launched on 11th September 2011.

IMPREGNATION AND DRYING METHOD

Although excavated on land, the boat consists of waterlogged wood and a conservation treatment was necessary before the BC06 could be exhibited. The condition of the wood varied throughout the boat, but in general the surface was more deteriorated than the core. Tool marks and imprints visible on the surface of the wood can tell how the various parts of boats were constructed as well as how it was used. When deciding on an impregnation method for the boat there were several different requirements that needed be taken into account.

The aim was to dry the wood while maintaining the shape, volume, tool marks and traces of wear on the surface, as well as the visual appearance of the wood. In addition, there were several restrictions, like financial and other resources, available equipment, expertise and experience.

To fulfil the requirements within the limits, impregnation with Polyethylene glycol (PEG) 2000 as the main bulking agent in room temperature was chosen. The impregnation started with a 4% of the low molecular PEG 200 intended for the better-preserved core of the wood [7].

The vast amount of boats and boat parts that were revealed in Bjørvika offered an opportunity for the museum to acquire a vacuum freeze dryer with a size that would allow drying boat parts of some length. The freeze dryer arrived early in 2012, and measures six meters in length and 1,2 meters in diameter. With freeze-drying a 40% concentration of PEG 2000 is sufficient [7]. A 40% concentration of PEG would leave some of the visual appearance of the wood, the downside being that it would not be possible to shape the wood for reconstructing the boat in a safe way after drying. Therefore, a method of shaping these parts before freeze-drying needed to be applied.

BC06 was impregnated in an acid resistant steel tank, covered with plastic sheeting and a lid of formwork panels. The tank was insulated on the outside with Styrofoam sheets. Following the initial 4% PEG 200, the solution was increased with 10% PEG 2000 every 6 months until 40% was reached and kept for another 6 months. A handheld

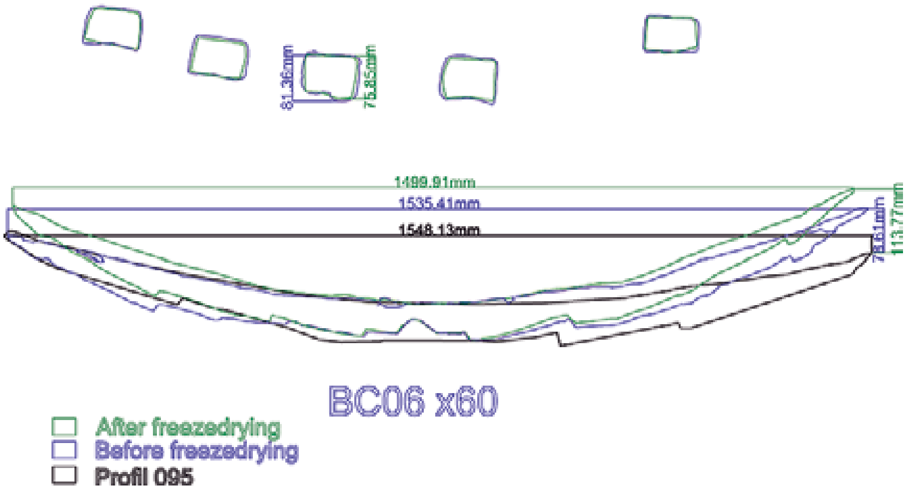

Fig. 1. *Comparing documentation of the shape of BC, part number 06x60 from different stages shows that the shape changes; illustr. Sarah Fawsitt/ /NMM*

Fig. 2. *The steel beam with profile sections attached*

refractometer was used to monitor the PEG concentrations. The PEG bath was heated up to almost 60 °C over several days on 3 occasions to facilitate the shaping of the keel and some of the more twisted planks.

Despite the size of the freeze dryer, it took several rounds to get the whole boat dried. It was initially thought to require 6-8 turns for the whole process, starting with the settings on -30 degrees Celsius (temperature sensors located in the freeze drier showing below -40), and gradually increasing the temperature in small steps over a period of 5-6 months for the planks and 9 months for the keel and the thicker parts. The vacuum varied with the temperature, but was typically within the range of $2{,}5 \times 10^{-1}$ to $5{,}0 \times 10^{-2}$ mbar.

Due to the time limits of the project, the reconstruction had to start before the whole boat was ready and dry. Drying the boat parts in the right order was therefore essential to get a good result. The first round was used to develop the method for the shaping of the boards. The second round was for the keel and the ribs. The rest of the rounds were repetition of the first, with small refinements and adjustments of the method.

For space efficiency inside the freeze dryer tank, a cardboard model of the shelves in the freeze dryer and cardboard models of all the planks in 1:5 was an appreciated tool. The exact placement of all parts were thus planned in advance. The longest planks from the first strake had the highest priority, second the planks from the second strake and so on. Broken planks or planks that were cut due to a dendro-sample were treated as separate parts and were not shaped together. The dendro-samples were returned after the dating, and treated together with the rest of the material. Even though much effort was put into the planning, transferring the plans to reality always led to some changes. However, the extra work invested into filling the freeze drier in an efficient manner paid off when the process could be reduced to 5 turns.

SHAPING OF THE KEE AND STRAKES DURING DRYING

The wood of BC-6 had to be shaped before it could be freeze-dried because it would be stiff and brittle after the treatment and hard to manipulate into place in the reconstruction of the boat. The risk of damage due to mechanical stress would also be high if the wood was to be shaped after the freeze-drying.

The shape of each part was determined by the cardboard-model made by a skilled boat builder and it showed that the keel needed to be lifted in the aft and bow and lowered in the middle. It also needed to be straightened and slightly twisted. It was of great importance to get the keel into the right shape and control it during and after drying. The entire reconstruction actually uses the keel as a fundament. Small errors in the shape could therefore potentially lead to big problems when it came to fitting the strakes of the boat. The error would add up higher in the boat and cause problems fitting the strakes together. These concerns led to a discussion of how to stabilize and shape the keel in a manageable way, causing minimal damage and loss of original material. The decision was made to mount the keel to a steel beam with bolts through the keel. This solution implied drilling seven holes through the keel, a method considered to control the shaping with relatively little damage.

The steel beam had to be strong and stiff enough to withstand the forces from the wood when being shaped. It also had to be stainless steel since the PEG is highly corrosive. The steel beam was made out of flat steel 100 X 10 mm, and a square tube steel 60 x 40 x 4 mm. These were screwed together and steel bricks welded on both sides of the beam at each attachment point for the bolts. A support frame was then screwed to the steel bricks and used to support the jig when drilling the bolt-holes, and anchor the keel to the steel beam while drying. It was important to keep the keel in the right position when drilling the holes, so profile sections of plywood were put in place at each point as guidance. These gave the right height and angle of the keel, as shown in Fig. 2.

After drilling the holes, the steel sleeves were mounted and u-shaped steel with steel sleeves of different lengths supported the keel. These steel sleeves kept the u-shaped steel at the right height and gave the keel its new curve when it was placed on top of them. After mounting the bolt trough the keel and support system, a flat steel bar secured the keel in place.

With this support system, one could manipulate the keel into shape and keep it in shape through the freeze-drying process (Fig. 3).

The three-dimensional shape of the individual plank was given by the reconstructed model, and every angle was based on the measurement made with the FARO-arm. By using this system, it was possible to get precise drawings of the planks and the measurements needed to shape them. A base line was defined, equivalent to the shelf in the freeze-dryer, and one could measure the height on both sides of the plank every 50 cm, or where needed, to get a profile of the plank. Wedges and profile sections of 18 mm plywood were used to give the planks the right shape. The wedges were used to lift the plank up to 5 cm and plywood sections from 5 and above. The wedges were just put on the shelf and the plywood sections were screwed to the shelf. It made it quite easy to use when working with the shaping of the planks. The planks were fixed to the shelf or sections with plywood and thus pressed into shape. The method was adaptable and gave the required pressure to shape the planks, and some of them demanded quite a lot of shaping (Fig. 4).

The shelving-system and use of profile sections allowed for an open structure inside the freeze-dryer tank, which is important in order to get an effective transmission of heat/energy during the process [8]. The PEG bath was heated to 60°C in order to make the wood more flexible, before working with the most challenging parts. Experiments to test the impact of heating prior to the work had shown that the wood became more flexible when it was heated. By heating the wood, it became easier to shape thus needing less mechanical pressure than without heating.

The experiment was performed with fresh oak to test the bending strength with a weight load within the elastic range of oak. The samples had been immersed in water for nine months to assure that the wood was completely waterlogged. The oak samples were taken from the same plank and 16 pieces 55 x 4 x 2 cm were tested at 20 °C and 60 °C. The weight load was 20 kg and was calculated on the basis of the test samples size. It was within 20 % of the estimated load to fracture. Each sample was tested three times and a micron meter was used for measurements (Fig. 5).

The load was applied for 15 seconds before reading the value and the test series went from 1a, 1b, 2a etc. through the series once, before the next measurement. The samples were kept in water at the right temperature in-between testing. An average value of the measurements at each temperature range was calculated, and the difference between the two temperature ranges.

Looking at the difference in the physical measurements, the heating did not have a very big impact. The difference in flexibility between 20 °C and 60 °C is from 0.70 mm to 1.59 mm for fresh oak, but converted to percent shows an increase of flexibility for fresh oak in the range from 21.9 % to 43.3 %. The results are presented in the Table.

This increase in flexibility was quite obvious when working hands-on with some of the challenging parts. The first one was shaped at room temperature and wooden clamps had to be used to twist the plank into shape. When a comparable plank was heated and shaped it was possible to do this only using hand power and it felt more controllable.

The impregnation solution was also tested to investigate any influence the heating might have on it. Several samples of PEG-2000 from the impregnation bath and clean solutions of PEG-2000 were heated to replicate the conditions of BC06. These samples had been analysed with FT-IR and MS for signs of degradation of the polymer. The conclusion of these analyses was that the heating procedure has no effect on the stability of the PEG 2000 [9].

RECONSTRUCTING THE BOAT

The boat was documented, impregnated and shaped at the NMM, but will be exhibited in Bjørvika. In the beginning, the vision was to build at least parts of the boat directly in the display case, but due to the distance and all the adjustments that had to be made on the support frame, it soon became clear that this was not an efficient way to go about it. The display case is located in the conference part of the buil-

Fig. 3. *The freeze dried keel*

Fig. 4. *Mounted planks*

Fig. 5. *Weight load of test sample*

ding, with meeting rooms on both sides. Both the museum and the workshop where the custom made metal stands and frames are produced are located at some distance. It would have been challenging to work on display in the exhibit case all the time, and the extremely careful planning needed to get efficient days and avoid disturbing meetings would have been a burden on the project.

It seemed more convenient to carry out the whole reconstruction at the museum and build it in such a way that it would be possible to take it apart again and transport it to the display case for another reassembling. A room with the possibility to adjust the relative humidity (RH) behind the temporary exhibitions was reserved for the purpose. After the reconstruction picked up pace, the air conditioning was set at 50% RH. A door that opens up into the exhibition was inserted into the wall, so the visitors can follow the work in progress. For security reasons the door is only opened when work on the boat is in progress or in connection with guided tours.

Because the wood most likely had a sound core, there was a chance that the planks would twist and bend even after drying. To avoid misshaping after drying, a rig was set up with wooden bars with the same distance as the interior setup for the freeze-dryer. The suspended planks were transferred directly from the freeze-dryer to the rig, only released for the transfer, and during cleaning excess PEG from the surface. In that manner, the planks were kept under tension and retained their shape until it was time to position them in the boat, or at least to let them acclimatise.

Since *Vaaghals* was built at the museum just prior to the reconstruction of BC06, it was expected that a lot of the experiences and methodology from the boat building could be directly transferred to the archaeological material. A set-up inspired by a traditional boat builder's workshop was constructed. Resting on pillars in front and behind the boat, was a solid beam with a T-shaped cross section. As a base to construct the boat upon, a deck joist was laid on the floor, as shown in Fig 6. The floor was very uneven and adjustments had to be made to ensure that the base for the steel beam was completely levelled, to avoid problems when relocating it to the display case.

The building of a boat starts with the laying of the keel. The same goes for reconstructing an archaeological boat. Unlike the planks, the keel was never released from the steel beam; it retained strength and tension and if released, it would have been impossible to return it. Once the keel was in place, the stern and the strakes could be positioned. The reconstruction work took place bit by bit, with required pauses awaiting the freeze-dryer to be ready and provide more building parts.

When the reconstruction started, it soon became apparent that additional supports were necessary. Inspired by the system of plywood moulds for shaping the planks, 1:1 cross sections, with intervals adjusted to the deck joist on the floor, were retrieved from the digital model of the complete boat. The cross sections were cut out in plywood, and mounted on each side of the keel, as a temporary exterior framework. They functioned as a base for resting and supporting the planks while fixating them in place. The cross sections were only seen as guidelines for the strakes. Adjustments were done with wedges or a Fein saw, whichever was necessary, to get the plank in the right position.

Having the cardboard model of BC06 as a template, and a set of customized pre-shaped boat parts, it was easy to think that reconstructing BC06 would be like having a big 3D puzzle that simply needed reassembling. Unfortunately, there was a bit more to it than that. The cardboard model was built with printouts of documentation made on waterlogged boat parts that had been subjected to the weight of overlying masses. The ribs and frames where not manipulated during the building of the cardboard model, nor were they in a fixed form while freeze-dried. Documentation of the shape from one of the ribs done both in situ during the excavation, later with FARO-arm at the museum and once again with the FARO arm after freeze drying, showed that the shape had changed (Fig. 7). It raised the question which of these stages, if any, was closest to the original shape.

Re-drawing of four of the planks after drying with the FARO-arm showed that the shrinking in the width of the boards was more extensive than the longitudinal shrinking. This is a well-known behaviour of wood [7]. In practice, when aligning the planks using overlap of the original nail holes as a definitive, the strakes needed to be placed increasingly lower than envisaged. Larger and larger sections had to be cut from the exterior plywood support to get the planks into the right position. The strakes and the ribs did not necessarily shrink in accordance to each other, which together with the shape alteration of the ribs resulted in the original parts not fitting as well together as the printouts did on the cardboard-model. However, the deviation was not so big that it prevented the parts from being placed in their right positions.

Some of the planks were already fractured and in several pieces when excavated, some had parts broken along the way and some had dendro-samples cut from them, so several of the planks consisted of more than one piece. Some of the smaller parts ended up at the bottom of the impregnation tank, and were only taken up for the last round in the freeze-dryer. Reuniting smaller pieces to their respective planks already positioned in the boat required extra work and sometimes a few planks had to be temporary loosened. Even though empty spaces have been left awaiting the dendro-samples and some of the smaller parts, it would have been easier to reassemble them before they were placed in the boat.

BC06 was supported by precisely fitted exterior bars in acid resistant steel up to the 4th strake, anchored in the steel beam holding the keel. The basic idea for the support construction was that the steel should carry the whole weight of the boat, and that the original parts' main job was to keep things in the right place. Exterior support legs disturb the visual impression when exhibited, and efforts were made to keep them to a minimum. The planks were held together by reusing the original holes where there had been wood nails, using modern bolts in acid resistant steel. Some of the original ribs that fitted well enough for the original holes to match the planks were also suitable and used to hold the planks in the right position if they retained enough strength. The development of the framework above the 4th strake is still in progress.

When considering whether or not to leave the areas with missing parts open or replace them with something representing what could have been there, several factors had to be taken into account. Building the cardboard model showed clearly that BC06 had a transom but it was not found, and we do not know exactly what it looked like. From the 9th and topmost strake, only one of the planks was preserved. Initially the idea was to show where the lines of the missing parts had been, to facilitate interpretation of the boat. As the reconstruction evolved, the idea moved towards not replacing or substituting anything, only adding what was necessary to hold the boat upright and together. *Vaaghals* already showed what the original material is interpreted to have looked like when it was in use and floating.

CHALLENGES AHEAD – RETURNING BC06 TO BJØRVIKA

The display case that awaits the boat has some limitations. There is not much space to work inside it. The initial opening was quite narrow, but it was made larger by removing a bigger part of the glass front than initially planned.

We are planning to move the keel, the four bottom strakes and some of the ribs as one part. This has to be carried down a long flight of stairs, through several doors, with only 11 cm clearing at the narrowest part, and finally eased into the display case. The sides, the 5th to the 9th strake, will have to be constructed as separate sections that can be removed from the boat at the museum and reassembled inside the display case.

The steam was not shaped or fixed during drying, and has twisted to such a degree that it does not fit into the boat without invasive measures. An ethical and visually satisfying solution is yet to be found.

CONCLUSION

The conservation of Barcode 6 is still in progress, and the treatment of some of the other boats has just started. We are still learning and there are still challenges that are yet to be solved.

In an ideal world, all the planks would have been dried and shaped before the reconstruction started, and all loose parts attached.

The reconstruction of BC06 would not have been possible without the initial work done with the cardboard model, and the construction of *Vaaghals*. All the work that followed was drawn from this experience, even though not much of it

*Results from the flexibility test**

NO	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B	6A	6B	7A	7B	8A	8B
Diff, mm	1.46	1.40	1.15	0.70	1.41	1.59	0.79	1.28	0.73	0.75	0.96	0.86	1.09	0.74	1.16	0.94
Diff, %	41.1	40.3	36.7	21.9	36.8	43.3	31.1	41.3	25.0	26.3	27.4	27.6	36.6	25.3	33.7	30.3

* The calculated difference presented in millimeters and present.

Fig. 6. *The laying of the keel*

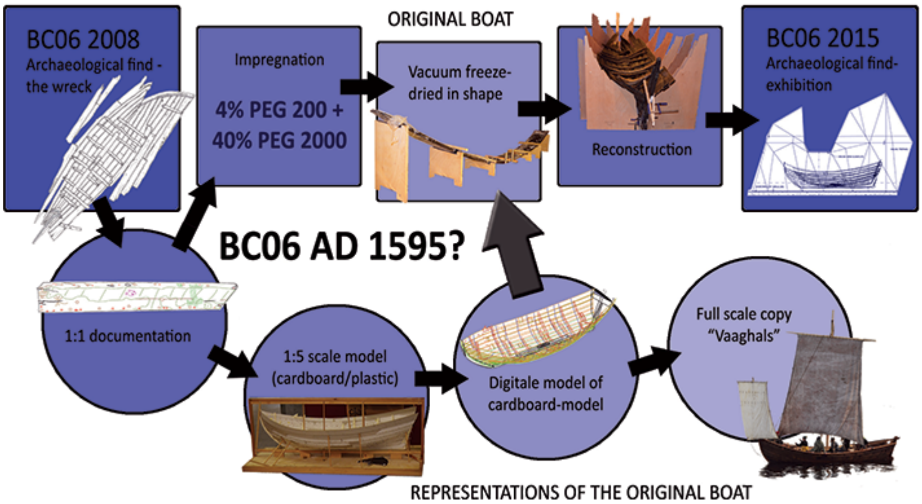

Fig. 7. *The different processes and stages of the conservation of BC06; illustr. Tori Falck, Monica Hovdan/ /NMM*

was directly transferrable. The project has depended on continuously adjusting existing methods and partly developing new solutions. It might not sound professional, but even though everything is planned in detail, small improvisations are sometimes what gets you there.

The changes happening to the archaeological wood during the conservation process most likely prevents it from ever being returned exacly to its original shape. Nevertheless when using original holes for attaching parts together and when allowing the traces of production and wear in the original material guide the reconstruction, the boat will become as close as it gets to the original shape.

The flexible interior rack in the freeze-dryer, with an easily adjustable shelf system where plywood moulds could be firmly fixed, was crucial to the success of the work. The heating of the PEG bath to 60 °C before shaping the keel and the more challenging planks eased the process.

All parts critical for reconstructing the boat, like the stern and the steam would have benefited from being secured during drying. In case forgotten, wood keeps confirming that it is a natural grown material, sometimes behaving unpredictably.

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The ArCo Project – ageing study of treated composite archaeological waterloged artefacts. Preliminary results

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INTRODUCTION

The problem of unstable reduced compounds in wooden archaeological artefacts from submarine excavations has been investigated in famous case studies, such as the Vasa, Mary Rose, Batavia and Bremen Cog shipwrecks [1]-[3][Fors, 2006 #506]. In these particular studies, the presence of S compounds potentially dangerous for wood preservation was proven to be mainly related to the action of specific sulphate-reducing bacteria in the marine environment (anoxic water). The reduced sulphur, originally in the form of hydrogen sulphide, spreads in the porosity of the wood to form either deposits of elementary sulphur, or of iron sulphide FeS_2 (pyrite) in the presence of dissolved Fe II resulting from the iron corrosion. Moreover, after removing from the burial environment and drying, the concretions stability is affected by contact with oxygen and humidity. Sulphur compounds can thus undergo oxidisation to produce iron sulphates and some sulphuric acid, and these reactions are catalysed by the presence of iron ions. The final result is the occurrence of mineral rashes on the surface of objects which can cause cracks and deformations (Fig. 1) and an irreversible acidic attack of the cellulose and lignin in the wood by hydrolysis [4]. Recently these observations have been confirmed also for other important shipwrecks found in the Baltic sea [5].

Conservation treatments are often needed for archaeological waterlogged wood, mainly to prevent the collapse of the structure during evaporation of water. Polyethylene glycol (PEG) treatment followed by freeze-drying or controlled air drying remains the worldwide standard for preserving degraded waterlogged archaeological wood [6]. Nevertheless, its main limit is the excessive sensitivity of PEG to moisture, making it necessary to install expensive air conditioning systems to control temperature and above all, air humidity. Furthermore, sensitivity to moisture may increase the corrosion of iron and the instability of salts-based concretions in the case of composite artefacts [1], [4]. Recent innovative ideas about consolidating agents aim to create an open porous structure instead of a solid bulk, lighter in weight, with available volume for future re-treatment without removal of the old consolidant. The proposed materials are an 'artificial wood' type, e.g. using lignin and cellulose mimic compounds to obtain a material which could possibly stabilize/neutralise the dangerous inorganic compounds present in wood [7].

In the framework of the Oseberg's research, biomimetic materials such as bakelite, crystalline cellulose, chitosan, synthesized lignin have been taken into consideration as possible wood consolidants [7]. In 2006, ARC-Nucléart studied fatty acid systems with the aim to stabilise soft degraded archaeological wood. Azelaic acid was tested because of its resistance to both hydrolysis and oxidation, its hydrophobicity at room temperature and water-solubility at high temperature (> 70°C), as well as high consolidation capability [8]. Nevertheless, it was observed that azelaic acid was not suitable for stabilising degraded archaeological wood, due to the acidity of the treatment solution (lower than pH = 3) which together with high temperature leads to significant chemical attack of wood by azelaic acid [9]. An alternative was the use of salts of sebacic acid (HNaSeb, Na_2Seb). In this way, the acidity of the treatment solutions can be easily controlled. The obtained buffer effect leads to pH values between 4 and 7, i.e. close to the pH observed for PEG solutions [10].

The common aspect of these innovative materials is that no available ageing studies exists, and providing them is one of the main aims of the ArCo project. In fact, in the framework of the project different samples from several archaeological findings are under investigation: the alum-treated wood from the Oseberg collection (Norway) [11]; "L'aimable Grelot", the roman river barge of Lyon (France), originally treated with PEG and then post-treated with a solution of PEG 20% and disodium sebacate 10%; the Skuldelev and the Nydam ships (Denmark), respectively treated with PEG 4000 and PEG 2000.

A wide range of analytical techniques were used to investigate both the organic and the inorganic components present in these treated composite archaeological wooden artefacts: pyrolysis coupled with gas chromatography and mass spectrometry (Py-GC/MS), infrared spectroscopy (FT-IR), scanning electron microscopy-energy dispersive X-ray analysis (SEM-EDX), X-ray fluorescence (XRF), X-ray diffraction (XRD), inductively coupled plasma optical emission spectroscopy (ICP-OES). The analyses have been performed on archaeological wood samples "as they were", and they will be repeated after about a year of ageing in a climate chamber where the relative humidity is periodically changed.

This paper reports some SEM-EDX, Py-GC/MS and FT-IR results obtained on the non-aged samples. The final aim of the project is to investigate degradation patterns in composite materials and to provide a list of recommendations for the preventive conservation of treated composite wooden artefacts.

The list of the samples analysed and their description is reported in the Table.

METHODS

SEM-EDX: a JEOL JSM-840 scanning electron microscope was used at the Museum of Cultural History, University of Oslo (Norway). The samples were sputtered using carbon before observation. The accelerating voltage was 20 KeV.

FT-IR: spectra in ATR mode were recorded on a Thermo Fisher FT-IR spectrometer (Nicolet iS50) at the Museum of Cultural History, University of Oslo (Norway). 64 scans and 4 cm^{-1} resolution were adopted. The range was 4000-400 cm^{-1}.

Py-GC/MS: analytical pyrolysis was performed at the Department of Chemistry and Industrial Chemistry, University of Pisa (Italy) using 1,1,1,3,3,3-hexamethyldisilazane (HMDS; chemical purity 99.9%, Sigma Aldrich Inc., USA) as a silylation agent for the *in situ* derivatisation of pyrolysis products. The instrumentation consisted of a Multi-Shot Pyrolyzer® EGA/PY-3030D (Frontier Lab) connected to a gas chromatograph 6890 Agilent (USA) equipped with an HP-5MS fused silica capillary column (stationary phase 5% diphenyl and 95% dimethyl-polysiloxane, 30 m x 0.25 mm i.d., Hewlett Packard, USA) and with a deactivated silica pre-column (2 m x 0.32 mm i.d., Agilent J&W, USA). Before instrumental analysis the samples were dried in the oven for 24 hours at 50-60 °C, and after that they were ground with a ball mill. After analysis, the pyrolysis products were identified by comparing their mass spectra with spectra reported in the Wiley and NIST libraries and in the literature [12], [13]. The peak areas were normalised for each chromatogram, and the data from three replicates were averaged and expressed as percentages, in order to calculate the relative amount of wood components and evaluate the degradation state.

RESULTS

SEM investigations were useful to observe the preservation state of the morphology of wood and the distribution of consolidating materials. Fig. 2 shows some SEM images from six samples taken from the Oseberg collection, the Lyon, the L'Aimable Grelot, the Skuldelev and the Nydam Bog ships.

In sample 1C-AP (internal part of fragment 1C, alum poor region) a partial collapse/shrinkage of the wood cell wall was evident. The middle lamella appeared to be the only part of the cell wall which survived. In sample 1C-AR (external part of fragment 1C, alum rich region) the structural integrity of the cell walls appeared almost completely compromised in some areas: the detachment of cell walls was evident, and some cells were completely collapsed. Spare fragments were also noticed in the cavities, attributable to alum crystals. Similar observations were obtained for the other Oseberg samples.

In sample Ly-A1, treated with PEG 20% + $SebNa_2$ 10% solution and freeze-dried, the structural integrity of the wood was quite well preserved, even if partial detachment of the cell walls was noticed at higher magnifications. The wood resulted just partially impregnated. Sample SM-A4 was the only sample from L'Aimable Grelot which showed a non-homogeneous impregnation. Where the wood structure was visible, it appeared highly compromised as highlighted by shrinkage of the cell, thinning of the cell walls and detachment phenomena. The samples from the Skuldelev ships were fully impregnated, as shown by sample Sk-3, in which the cell walls were completely covered by a PEG film. Similar observations were obtained for samples from the Nydam Bog.

Using EDS, it was possible to record some mapping of the most abundant elements present in the samples. Regarding the "alum poor" Oseberg samples, K and S were distributed quite evenly and appeared to be penetrated in the cell lumen (Fig. 3). No Al was detected, due to the low sensitivity of the technique. Nevertheless, preliminary ICP-OES measurements showed that Al is indeed present in the "alum poor" Oseberg samples, even with less abundance than K and S. This suggests that alum has undergone decomposition or that differences in penetration/diffusion occurred [14], and further investigations are needed to clarify this aspect. Regarding the "alum rich" Oseberg samples, the observations were similar, with the exception of the general detection of Al, which was mainly present in the same areas as K and S, indicating in this case the presence of recrystallized alum.

The samples from the Lyon and L'Aimable Grelot ships showed some partially mineralised areas. The EDS mapping highlighted the presence of Fe, S and Ca as major elements (Fig. 4) and crystals with different shapes were observed. Some preliminary XRD analyses confirmed pyrite and gypsum to be present in these samples, likely formed as products of reactions occurred in the marine environment.

In order to assess the chemical degradation state of the wood, Py-GC/MS with *in situ* silylation was applied. 113 pyrolysis products were identified in the samples and attributed to the wood components they derived from (H-holocellulose, L-lignin, G-guaiacyl lignin, S-syringyl lignin). The areas of the peaks were determined, normalised with respect to the sum of the areas of all the identified pyrolysis products and expressed as percentages. The sums of the percentage areas of the pyrolysis products from holocellulose and lignin were also calculated, together with their ratio (H/L ratio). This parameter is indicative of the degradation degree of waterlogged wood, especially in terms of variation of the chemical composition e.g. preferential loss of holocellulose in the waterlogged environment, when it is compared with

Fig. 1. *An example of efflorescence in archaeological waterlogged wood*

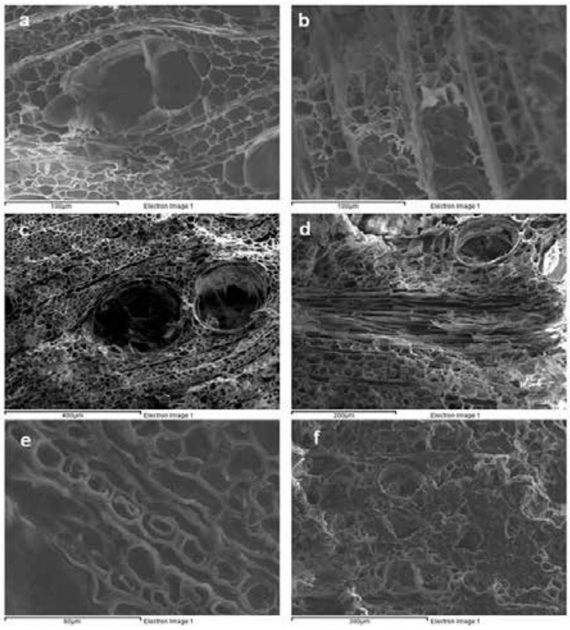

Fig. 2. *SEM images for sample a) 1C-AP, b) 1C-AR, c) Ly-A1, d) SM--A4, e) Sk-3, f) Ny-2 The images are taken at different magnifications. Bar scales are reported under each image*

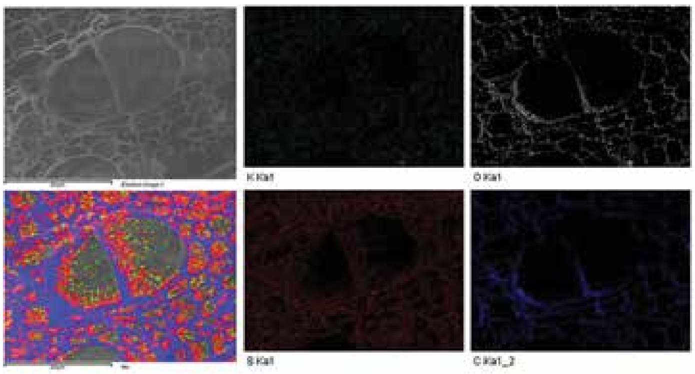

Fig. 3. *EDS mapping for sample 1C-AP*

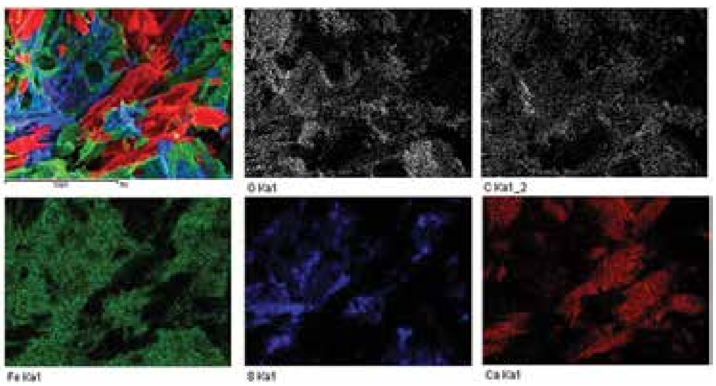

Fig. 4. *EDS mapping for sample SM-A2*

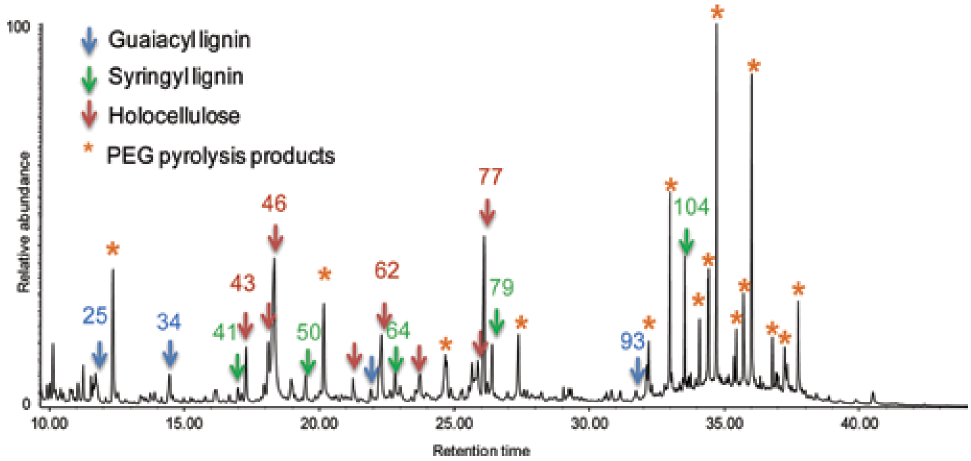

Fig. 5. *Py(HMDS)-GC/MS profile of sample SM-A0*

List of samples analyzed

PROVENIENCE	SAMPLE NAME	DESCRIPTION
Oseberg collection	5-AR 5-AP	Alum rich (AR) and alum poor (AP) samples taken from fragment **5** Probably birch wood.
	1B-AR 1B-AP	Alum rich (AR) and alum poor (AP) samples taken from fragment 1B. Probably birch wood.
	1C-AR 1C-AP	Alum rich (AR) and alum poor (AP) samples taken from fragment 1C. Probably birch wood.
	1D-AR 1D-AP	Alum rich (AR) and alum poor (AP) samples taken from fragment 1D. Probably birch wood.
Lyon	Ly-A0	Softwood contaminated by iron salts, untreated
	Ly-A1	Oak wood contaminated by iron salts treated with PEG 20% + $SebNa_2$ 10% solution and freeze-dried
	Ly-A2	Mineralised softwood, untreated
	Ly-A3	Iron nail with concretions
L'Aimable Grelot	SM-A0	Oak wood contaminated by iron salts treated with PEG 4000
	SM-A1	Oak wood contaminated by iron salts treated with PEG 4000 and post-treated with PEG 20% + $SebNa_2$ 10% solution and freeze-dried
	SM-A2	Mineralised oak wood sample treated with PEG 4000
	SM-A3	Mineralised oak wood sample treated with PEG 4000 and post-treated with PEG 20% + $SebNa_2$ 10% solution and freeze-dried
	SM-A4	Oak wood contaminated by iron salts and with beginning of acidification treated with PEG 4000
Skuldelev	Sk-1	Oak wood treated with PEG 4000
	Sk-2	Oak wood treated with PEG 4000
	Sk-3	Oak wood treated with PEG 4000 (dark part)
Nydam Bog	Ny-1	Oak wood treated with PEG 2000
	Ny-2	Oak wood treated with PEG 2000
	Ny-3	Ash wood untreated and freeze dried.

the same parameter obtained for a sample of sound wood of the same species analysed in the same conditions [15], [16]. Most of the samples were composed of oak wood, which in these analytical conditions showed a H/L ratio ca. 3.3. In addition, for the first time this coefficient was calculated for PEG-treated wooden samples. In fact, no significant overlapping between wood and PEG pyrolysis products was found in the adopted conditions, as shown in Fig. 5.

The Oseberg samples showed an almost complete loss of the carbohydrates component, resulting in H/L ratios around 0. In addition, lignin pyrolysis products with acidic functionalities were detected with high abundances (40-80

%), indicating a high extent of lignin oxidation, which was even higher in the alum rich regions. This confirmed the poor conditions of wood in these samples. The H/L ratios for the Lyon 2nd samples were 0.47, 0.02 and 0.20 for samples Ly-A0, Ly-A1 and Ly-A2, respectively. This indicated that sample Ly-A1, post-treated with PEG 20% + $SebNa_2$ 10% solution and freeze-dried, was the most degraded in terms of loss of polysaccharides. Further investigations are needed to understand if the treatment itself could have played a role in promoting this type of degradation.

Regarding the L'Aimable Grelot samples, no pyrolysis products from wood were detected for samples SM-A2 and SM-A3, which showed an almost complete mineralisation. Sample SM-A0 had a H/L ratio 2.76, indicating a very good state of preservation of this sample, in which the carbohydrates component was almost entirely preserved. Samples SM-A1 and SM-A4 had H/L ratios 0.59 and 0.79, respectively, highlighting a worse state of preservation.

An interesting observation was obtained comparing the results for samples Ly-A1 and SM-A1, both post-treated with PEG 20% + $SebNa_2$ 10% solution and freeze-dried. For sample SM-A1 a peak corresponding to sebacic acid was detected in high abundance. For sample Ly-A1 no such peak was detected, in agreement with Py-GC/MS results obtained in the analysis of pure disodium sebacate, which produced a few pyrolysis products (mainly ketones) with very low abundance, since carboxylates have very low volatility. This suggested that in the sample Ly-A1 disodium sebacate was present in the carboxylate form, while in the sample SM-A1 it has been transformed into sebacic acid, as a consequence of protonation in acidic environment.

To confirm this observation FT-IR analysis in ATR mode was applied to these two samples and to pure disodium sebacate. For both samples Ly-A1 and pure disodium sebacate, an absorption band around 1560 cm^{-1} was detected, corresponding to the typical C=O stretching of carboxylates. This absorption band was not present in sample SM-A1, which instead showed an absorption band around 1730 cm^{-1}, corresponding to the typical C=O stretching of carboxylic acids. This was taken as a proof that the disodium sebacate was completely transformed in the corresponding sebacic acid in sample SM-A1. This was likely due to differences in acidity between the samples and further investigations are needed in order to understand if this reaction could correspond to a positive effect of the applied post-treatment on the general acidity of wood.

The samples from the Skuldelev ships showed different results: for sample Sk-1 the H/L ratio 1.44 was indicative of an intermediate state of degradation with a partial loss of carbohydrates. For sample Sk-2, visual observations and SEM images highlighted a significant difference between the core and the surface of the sample, which were analysed separately. The H/L ratio of the core was very high (6.24), indicating a very good preservation of holocellulose and on the other hand, a preferential degradation of lignin, whereas the H/L ratio of the surface was very low, highlighting depletion of holocellulose in this part of the sample. Also sample Sk-3 showed extensive loss of carbohydrates. Finally the samples from Nydam Bog showed similar results with H/L ratios ca. 0.2, highlighting extensive degradation of carbohydrates.

CONCLUSIONS

This paper summarizes a part of the SEM-EDX, FT-IR and Py-GC/MS results obtained for a series of samples from several archaeological shipwrecks and wooden artefacts, investigated in the framework of the ArCo-JPI project. The analyses will be repeated after artificial ageing of the samples.

SEM-EDX enabled differences in the wood structural integrity of the samples to be highlighted. In addition, the efficacy of the impregnation was assessed as well as the presence and distribution of inorganic compounds.

Py-GC/MS permitted the authors to establish the preservation state of the wood in the samples analysed by calculation of the H/L ratio, highlighting a significant variability of degradation /preservation conditions. The calculation of the H/L ratio was successfully obtained also in co-presence of organic material different from wood, such as the consolidating agent (PEG). Finally, the disodium sebacate post-treatment was observed to behave differently after application on different samples: for the Lyon ship no alteration of disodium sebacate was detected, whereas for the L'aimable Grelot ship disodium sebacate turned into sebacic acid, which was observed as one of the most abundant pyrolysis products. This observation was also confirmed by FT-IR analysis.

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Metal ions in archaeological wood from the Oseberg find – a complex issue?

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Hartmut Kutzke
Susan Braovac

BACKGROUND

Artefacts from the Oseberg burial, housed at the Viking Ship Museum in Oslo, Norway, represent one of the most comprehensive collections of Viking Age wooden objects in the world. After their excavation in the early 1900s, many of the objects were treated with alum ($KAl(SO_4)_2.12H_2O$), which was widely used in Scandinavia up until the 1950s to conserve waterlogged wood.

Though various drawbacks of the alum treatment have since made its use obsolete, consequences of its use are still being faced today. Many alum-treated objects from the Oseberg collection now demonstrate extreme deterioration, the full extent of which has only been realised in the past decade. The release of sulfuric acid during the alum treatment is believed be a key factor in the ongoing deterioration of these objects [1].

However, other chemical influences must also be considered, such as the influence of metal ions. Al(III) is of course present in the objects due to the alum-treatment, and literature suggests that this can accelerate acid-catalysed hydrolysis of cellulose [2]. Furthermore, the highly fragmented objects were heavily reconstructed with nails and pins made from iron and copper, corrosion of which form ionic compounds that can migrate into the wood and promote wood degradation via radical Fenton reactions [3]-[6]. Other metal compounds have also been absorbed into the objects over their long lifetime from sources such as the ground soil in which they were buried, and metal tanks used for their treatment and storage.

The Saving Oseberg project aims to elucidate reasons for the extensive decay exhibited by the Oseberg artefacts, and develop strategies for their future preservation. One focus area is consideration of the metal ions present in the objects: how do these affect the condition of the objects, and how can we stop them from causing problems.

INORGANIC COMPONENTS OF THE WOOD AND THEIR POTENTIAL EFFECTS ON DEGRADATION

To date, analysis of the inorganic components of the objects has involved using X-Ray Fluorescence (XRF) and Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) techniques. These analyses can give semi-quantitative and quantitative information about the elements present.

For example, Fig. 1 shows the XRF spectrum of a fragment of object no. 250, an alum-treated carved board from the Oseberg collection. Two fragments had come away to reveal a metal rod, and the XRF spectrum was taken of the inner part of one of these fragments that had been adjacent to the metal rod. XRF analysis showed the rod to comprise mainly iron and copper, with a small signal for manganese. Accordingly these elements were all observed in the adjacent wood. Furthermore, sulphur and potassium are present due to the alum treatment (note that aluminium is difficult to detect using the XRF instrument, and thus cannot be observed). The presence of zinc is believed to be due to storage of the objects in zinc vats of water prior to conservation treatment. Calcium, which is naturally found in wood, was also observed.

While XRF analysis is convenient and non-destructive, it cannot give reliable quantitative data for these types of samples. Quantitative elemental analyses of several samples of alum-treated wood from the Oseberg collection were obtained using ICP-AES [7]. In particular, a series of six alum-treated wood fragments (185-1 to 6), originally thought to fit together in a loom, were analysed. These fragments had varying states of preservation, as assessed by visual observations and analytical pyrolysis-gas chromatography/mass spectrometry with in situ addition of the silylating agent hexamethyldisilazane (Py(HMDS)-GC/MS) [8].

Some correlation between iron content and the extent of degradation was observed. This was somewhat anticipated, given that the fragments were highly acidic, and iron-catalysed degradation tends to be efficient at low pH [9]. It was also noted that fragments with significant levels of calcium as well as iron seemed to be less degraded. Some evidence of inhibition of iron-catalysed Fenton degradation by calcium has been previously reported [10], but in general research into such an effect has been limited to date.

It will also be important to determine what types of compounds these metals comprise, in order to gain better insight into the potential influences on the condition of the wood, and whether or not these elements are inert in their current form. It is hoped that including X-ray diffraction and X-ray absorption experiments in future analysis will allow us to identify specific metal compounds.

MULTI-FUNCTIONAL MATERIALS FOR METAL ION TRAPPING

Dealing with problematic metal salts, such as iron corrosion products, in archaeological wood commonly involves extraction assisted by an electric field or chelating agents.

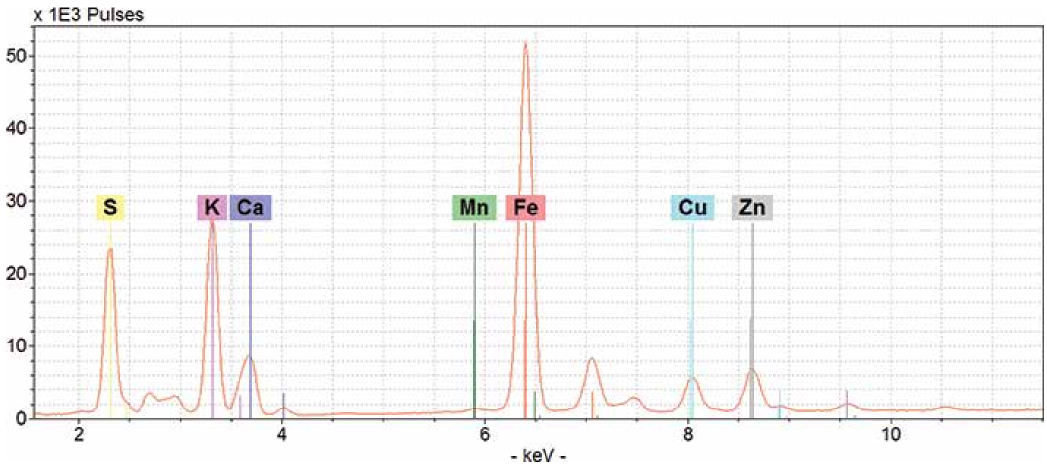

Fig. 1. *XRF spectrum of fragment adjacent to metal rod in object no. 250*

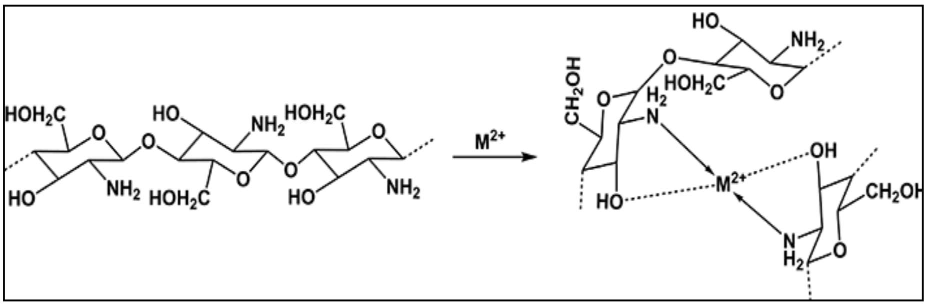

Fig. 2. *Proposed binding of chitosan to metal ions via coordination of amine and hydroxyl groups*

These methods generally involve immersing the wood in aqueous solution. However, many of the objects from the Oseberg collection are extremely fragile, and the water-soluble alum with which they were treated is a major structural component, so it is unlikely that they will survive immersion in aqueous solution. Thus we must explore alternative treatment options. Given that much of the collection is in dire need of a new consolidating treatment, one promising area involves combining structurally enhancing materials with chelating agents, to give a multi-functional treatment that is both a consolidant and a metal-trapping agent.

The polysaccharide chitosan is a potential component of such a consolidant. This is obtained in large quantities from crustacean shells via alkaline deacetylation of the naturally occurring polymer chitin [11], thus is cheap and readily available. Amongst other attractive properties that make it an interesting candidate for the treatment of archaeological wood [12], its ability to complex metal ions is well-documented, particularly with respect to removal of heavy metals from wastewater [11]. Binding of metal cations by chitosan is believed to mainly involve interactions with the amine groups, though the hydroxyl groups may also take part in complexation (Fig. 2) [13], [14]. Furthermore, chitosan may be chemically modified at the amine groups to give derivatives with enhanced and more selective metal binding capabilities.

MODEL EXPERIMENTS

In order to assess influences of various combinations of metal salts on wood, and whether chitosan has an appreciable inhibiting effect, model experiments are underway using pieces of fresh birch and Klason lignin from birch as substrates.

Wood pieces have been impregnated with various combinations of iron, copper and calcium chlorides and chitosan, and their relative degradation will be compared over a period of months and years using analytical techniques such as Py(HMDS)-GC/MS, Infrared Spectroscopy and Nuclear Magnetic Resonance Spectroscopy. Experiments with Klason lignin involve treating with a Fe(II)/H_2O_2 mixture (Fenton's reagent) with and without chitosan at varying pH, following the reactions with UV spectroscopy and Gel Permeation Chromatography.

CONCLUSION

The presence of metal ions in the Oseberg artefacts arises both from incidental migration from various sources and deliberate impregnation, and certain metals can potentially accelerate deterioration of the wood. Elemental analyses reveal a complex mixture of inorganic elements, though other types of analyses are required to elucidate their specific environments.

The use of chitosan as a component of new wood treatments is of particular interest due to its ability to form complexes with metal ions, and the potential for its chemical modification to optimise metal binding. Model experiments are underway to assess whether this potential for metal binding translates to significant inhibition of metal-promoted wood degradation.

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Chemical analysis of degraded wood by analytical pyrolysis-gas chromatography/mass spectrometry and infrared spectroscopy

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ALUM-TREATED WOODS FROM THE OSEBERG FINDS

From the mid-1800s to the late 1950s, conservation by alum salts (aluminum potassium sulfate dodecahydrate) – with some variations – was a common method for treating highly deteriorated waterlogged archaeological wood in many countries, especially Denmark and Sweden [1], [2]. At the Museum of Cultural History (KHM), a large portion of the wooden objects from the Viking Age Oseberg collection were treated with alum salts in the early 1900s.

The finds originated from a burial mound made for two women of high standing dated to 834 AD, and excavated in 1904 [3]. The deceased were laid to rest in a grave chamber decorated with sumptuous textiles and duvets of eiderdown. The chamber was erected on the ship, surrounded by objects and sacrificed animals they would need in the afterlife. It was then sealed with approximately 5000 tons of turf and large stones.

The Oseberg collection represents one of the richest, most complete collections of Viking Age wooden objects in the world. Many wooden objects bear intricate carvings, the collection's prime signature [4]. The find is exhibited at the Viking Ship Museum in Oslo.

The alum-treatment was mainly used on objects of diffuse porous hardwoods which were heavily degraded and could not be air-dried without extensive shrinkage and warping. Fig. 1 shows an example of an alum-treated object, the reconstructed Fourth Sled. A concentrated alum solution was heated to 90°C and objects were immersed between 2-36 hours. Heating alum solutions releases a significant amount of acid (pH of heated solutions are around 2-2.5) which is absorbed by the wood. It is uncertain whether there was awareness about the acidity produced in the bath at the time of treatment as it was not mentioned in the few surviving written accounts.

Over one hundred years after their original conservation, the alum-treated objects are in a precarious state of preservation. The wood is highly acidic (pH ≤2), chemically and mechanically weakened, surfaces are covered by numerous treatments and many objects are extensively reconstructed, some from thousands of fragments (Fig. 1). In many cases the wood has been reduced to a powdery mass (Fig. 2). X-rays illustrated that some metal fittings used in the restoration had corroded. All signs point towards active deterioration, however little is known about how this deterioration is reflected in their current chemical makeup.

CHEMICAL ANALYSES OF ALUM-TREATED WOODS

Two complementary analytical methods used to chemically characterize samples of alum-treated wood are briefly discussed: ATR-FTIR and Py-GC/MS. Pyrolysis was carried out after silylation using 1,1,1,3,3,3-hexamethyldisilazane (HMDS). Infrared analyses were carried out on samples first rinsed with distilled water to remove strong signals from sulfate.

The aims of the chemical analyses were to establish the effect the alum-treatment had on the wood after 100 years and to better understand how the observed variation in state of preservation of alum-treated woods was reflected in their chemical composition. In these analyses, samples of alum-treated woods from the Oseberg find were compared with sound woods (maple, aspen, birch), recently excavated archaeological woods (aspen, birch), one untreated sample of archaeological maple from Oseberg which was highly deteriorated upon excavation but left untreated and one sample of archaeological aspen treated in 2009 with alum to observe recent effects of the alum-treatment.

Py-GC/MS showed that the Oseberg alum-treated woods were highly depleted in their holocellulose (cellulose and hemicellulose) fraction, and in the most deteriorated samples the content was significantly lower than that found in the other archaeological samples analysed As Py-GC/MS can give detailed information about the lignin residues found in the pyrolysis products, it was also possible to observe the state of preservation of the lignin moiety.

For instance, Py-GC/MS demonstrated that the syringyl-derived lignin residues in the all archaeological woods (except for the archaeological aspen sample) were more degraded than the guaiacyl residues, based on comparisons of syringyl to guaiacyl (S/G) ratios relative to sound woods. Additionally, the alum-treated samples from Oseberg showed extensive oxidation of its lignin units to carboxylic acids (syringic, vanillic and p-hydroxy benzoic acids). These observations were also confirmed by infrared analyses, as signals assigned to carbohydrates were not detectable, bands assigned to lignin had broadened significantly

Fig. 1. *The Fourth Sled is alum-treated. It was reconstructed from over 1000 fragments. The varnished layers mask the deteriorated inner wood*

Fig. 2. *Alum-treated fragment exemplifying an extensively deteriorated state of preservation*

(indicating deterioration) and signals from carboxylic acids were present in spectra.

The possibility of secondary reactions during pyrolytic fragmentation is well known, which may give misleading results [5], however this may be significantly reduced by silylation with HMDS. Furthermore, as infrared analyses showed similar trends to that observed by Py-GC/MS, it confirmed that secondary pyrolytic reactions were minor, demonstrating that the results from Py-GC/MS reflect actual sample composition.

The extreme oxidation observed for the lignin in the alum-treated Oseberg samples is unusual: the untreated archaeological samples had only slightly increased lignin oxidation and of these, the untreated Oseberg maple sample showed highest oxidation – which was likely related to post-excavation ageing. Thus the oxidation observed in the alum-treated Oseberg samples is related to the alum treatment itself.

The lignin residues in the sample of archaeological aspen recently treated with alum did not show extensive oxidation, however the monomeric residues of lignin were significantly reduced after only five years. This was interesting as the chemical deterioration was not visible to the naked eye: the sample appeared as it did immediately after treatment (a pale beige colour). Although the reaction rate is difficult to estimate based on these results, it is likely that it takes several decades before this deterioration is visible on the wood (darkening and decrease in wood structural integrity). This may be one of the reasons that deterioration of the alum-treated Oseberg finds was only observed in the late 1990s, 80 years after their conservation.

Results from both Py-GC/MS and FTIR also showed a variation in the extent of chemical deterioration in the alum-treated Oseberg samples. This variation was possible to visually observe: increased darkening and powdering of wood fabric was reflected by an increased lignin oxidation to acidic residues. This variation is very likely related to the metal ions present in the wood, however this angle must be investigated in greater depth to understand which combinations of metal ions are in fact participating actively in ongoing reactions.

CONCLUSIONS

The two methods used here complement each other very well for the purposes of chemically characterizing alum-treated woods. The analytical results have shown that the alum-treated Oseberg woods have very little remaining cellulose and the lignin is highly de-polymerised and oxidised. The results thus confirmed that the extreme deterioration observed in these samples is related to the alum-treatment itself.

It was also possible to relate variation in chemical composition to what may be observed with the naked eye: darkened, less cohesive samples were generally more depleted in holocellulose and had a relatively high content of acidic lignin residues. This relationship between the visual and the chemical is an important point regarding further work related to developing reconservation methods for these finds, as they must be tailored to each object's properties, one of which is the extent of its deterioration. In other words, the results from the chemical analyses have taught us how to better 'read' our objects, as it will not be possible to chemically analyse all of them. That said, in future storage surveys it is nonetheless feasible to analyse 'some' objects by FTIR – now possible to undertake in-house at the Museum of Cultural History – which will likely aid in sorting into different 'preservation' groups. In this way Py-GC/MS, a more advanced (but, unfortunately, a less 'available') method has been very useful as it allowed for more specific interpretation of infrared spectra from alum-treated woods. It should also be mentioned that knowledge about current chemical makeup will allow us to better understand the reasons behind successes and failures of preliminary tests for re-treatment, which thus aids development of re-treatment protocols.

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The experiment of cleaning and conservation of archaeological textile in the field and in the laboratory

Nataliya Sinitsyna
Lena Sinitsyna

Only a very few specialists, apart from archaeologists, can imagine the state of textiles found in excavations. As a rule, archeological textiles reach conservators in an awful condition: improperly retrieved, overdried, and treated with perchloroethylene or other solvents. At some point, I realized that conservators should personally participate in excavating textiles, or, alternatively, archeologists should have some special expertise on how to work with textile finds.

First, a little bit of the history. In the year 1389, the widow of a Moscow grand prince founded a convent on the territory of the Moscow Kremlin. By the beginning of the 14^{th} century, it became the burial place of great princesses and czarinas. The convent was for female members of the royal family. In 1929 it was destroyed and all the white stone tombs transported to the Archangel cathedral.

Sixty years later, the restoration, study and research of the tombs and their historical periods were begun. For this purpose, and especially for restoring archeological textiles, a research group – "Historical necropolis" – a department of the Kremlin Museum, was set up in 1999. Our study provides important material for historical science, history of textiles and anthropology. Our scientific task is not only to study materials themselves but also to take part in their cleaning, restoration and reconstruction.

Over 12 years, we have worked out specific techniques of preserving archeological textiles. The work within the "Historical necropolis" program enabled us, for the first time, to carry out all the stages – from taking out fabric from a coffin to the final stage when it is ready for an exposition.

It is desirable to pre-process archeological textiles immediately after the material was delivered to the laboratory. The sooner the pre-processing starts, the better chances are to save their properties.

Pre-processing includes:

1. disinfection procedure and selecting samples for microbiological research,
2. careful cleaning of the surface of the whole processed complex,
3. sorting material which allows to pick out separate items from the mass of textile fragments; on this stage their identification is performed by only visually,
4. preliminary cleaning – each fragment is cleaned with a soft brush and given a name indicating where it was found,
5. a reviewed, detailed description of all textile fragments,
6. sampling for the purpose of the complex research.

The experience of the restoration and research group "Historical Necropolis" is interesting because the restorers themselves, in collaboration with an archeologist and anthropologist, extracted archeological textile material. In addition to restoration and research work, the group's task included developing methods of chemical-engineering and structural-technological scientific research for each burial complex. The research was conducted in two directions:

– microbiological research of textile material,
– complex experimental research of burial inventory.

It was the first such a complex research of materials discovered in burials in Russia.

The findings allowed us to navigate ourselves in choosing correct cleaning and conservation methods for different textile items from the burial complexes. Most of the methods used nowadays for textile restoration do not meet special requirements of archeological textile restoration so we had to adapt the known methods to specific tasks or, in many cases, develop new techniques. While developing a new restoration method for textile items from the Voznesenski monastery sarcophaguses, we were guided by ground principles of restoration:

- methods used in archeological textile restoration should be convertible to the maximum, i.e. we should be able to separate doubling materials from the original, if needed. (It needs to be emphasized: convertible to the maximum because 100% convertible methods do not exist),
- while conducting all restoration works (mostly it refers to cleaning), we have to keep in mind that it is a must to retain textile physical properties (structure, plasticity etc.) as much as possible, if they exist, or to restore them.
- chemical substances such as perchloroethylene are inadmissible,
- after restoration, archeological textile items should be made accessible for further research both from the front and from the inner side.

The archeological textile restoration process includes:

– description of samples' integrity and their condition after pretreatment, development of a final cleaning method, taking into consideration the results obtained from complex research,
– development of a doubling method,
– development of a reconstruction method.

The description of the integrity and condition of a sample brought for restoration after storage presents the state of a textile sample's integrity at this stage. Research results, especially structural and technological research results, enabled us to solve difficult problems of identifying small and, on many occasions, severely damaged fragments with certain item types; in order to assemble parts of clothes from many isolated fragments, we needed to have a clear picture of cloth types we could find in the burial. In this phase, we could already assume if the reconstruction of a certain item was possible.

Cleaning of an archeological textile is the most complicated and unpredictable process of restoration. Cleaning can be purely mechanical, without using water, or mixed when a textile item is submerged into a solvent and cleaned with the help of a soft brush. In some cases, if the integrity of a textile item allows it, it may be possible to use a vacuum table. Cleaning each textile fragment requires a careful, individual approach. Usually, the choice of a pretreatment method is determined by a collegial council of participating restorers.

As it was mentioned earlier, after the pretreatment including mandatory cleaning, an archeological textile can wait some time for the second restoration phase; of course it would be better if these two stages were not separated by a long waiting period. Unfortunately, sometimes it is not possible to accomplish, but we know from experience that if cleaning is correctly performed and certain storage conditions are met, an archeological textile can pretty well withstand long storage periods. For example, Maria Ioanovna's dress from a crimson obyar (fabric with large number of golden threads), trimmed with gold-silver lace, after pre-treatment was stored for more than twenty years before the final phase of restoration. It was a very interesting experience and it confirmed our supposition that golden threads from an archeological textile can withstand a long-term storage if they had been thoroughly cleaned.

At the same time, cleaning and conservation methods of golden threads must be corrected in each particular case, considering individual characteristics of each item to be restored. Depending on the composition of golden threads, the most appropriate solutions are:

– if the thread is of a homogenous composition – solely of silver or gold (so-called wire-drawn) – only careful cleaning is needed,
– weaved golden threads, where the textile base thread is weaved over with fine metal stripes (0.03-0.05 mm), requires a more careful approach to cleaning and conservation,
– for cleaning golden threads containing a large amount of silver – a 3% ftorlon solvent proved to be very efficient; threads are carefully covered with this solvent, with the use of a soft brush, and the process of patina initiation becomes significantly slower,
– a very positive effect can be achieved if spinned golden threads with a high percentage of gold are treated with a 1% ftorlon solvent (after the final cleaning)- threads like this are common for royal burials. One example of such a treatment was the restoration of the dress that belonged to Maria Ioanovna. This type of dress was traditional in Russia in the 17th century. It is amazing how well the red color in the fabric survived (Fig. 1).

While cleaning the dress, we eliminated deformations in the fabric. After drying we took measurements of the remaining details and reconstructed the original pattern of the dress. Since the fabric was weakened only at the edges of losses, it was decided not to support the whole dress. A thick silk gauze and transparent silk crepeline were dyed and then the adhesive was applied to the fabrics, as described below.

The support fabrics were cut slightly larger than the area of losses. The thick silk was placed under a loss and the area was covered with crepeline. The adhesive was then activated with a tacking iron. The most damaged areas (back and sleeves) were supported completely. A similar supporting method was used for most linen objects. In this kind of treatment, only a small area of an archaeological textile around a loss is subjected to the heat. The same principle was applied to the dress that had belonged to Maria Dolgorukaya.

On many occasions, the restorers succeeded in finding new ways and means of cleaning during the restoration itself, for example during the restoration of a silk dress with long pursed sleeves from Maria Dolgorukaya's burial complex. The dress belonged to the wife of the first Russian tsar of the Romanov family. It is a beautiful example of a lady's dress from the 17th century. This dress is extremely valuable, because it is only one left. The style has no analogues and is known only from written sources and pictures.

It was of the utmost difficulty to develop a cleaning method that would enable us to retain the original sleeve gopher. The mixed cleaning method was chosen, according to which the usage of a water solvent was reduced to the minimum and two and a half-meter sleeve fabric was cleaned the following way: the dirt from within twisted textile fibers was carefully removed with a thin needle under a microscope (not to damage fibers this work had to be done under a microscope or a strong magnifying glass). This work took five months to accomplish, but the result exceeded all expectations – the fabric acquired plasticity and glitter (Fig. 2).

When developing a method to be used for the final cleaning of the archeological silk and woolen fabric from Necropolis burial, research results for each burial complex had to be taken into account: the setting of materials in each burial, destruction grade of different types of textile, pollution types, and determination of deposits on the restored textile surfaces. Based on the obtained data, a strategy and specific cleaning and conservation method were developed for each textile item.

After analyzing results of this work, we arrived at the conclusion that on an archeological textile (especially silk) very often the presence of human pollutants can be detected; they resist mechanical pretreatment and after water cleaning, the dirt dissolves and dyes the fabric. As a result, the fabric acquires dark stains distinctive of archeological textile. The new method proved to be so efficient that we started using it quite often in our line of work.

Fig. 1. *The dress of Maria Iovanovna, before and after conservation*

Fig. 2. *Maria Dolgorukaya' dress, before and after conservation*

CHOOSING A DUBBING (REINFORCEMENT) METHOD FOR ARCHEOLOGICAL FABRICS

Some elements of the methods that we use to restore archeological textiles have been known for a long time, but we upgraded them and introduced many new innovations in the application of these methods. The basic method we chose for the archeological fabric reinforcement was dubbing it onto a silk fabric with the help of acrylic glue. We declined using paste in the very beginning because the long-term practice proved that after some time, a silk fabric glued with paste loses its elasticity, and if the restored fabric is incidentally oversaturated with glue, in a long while, it starts to destroy textile fibers; moreover, paste itself creates a perfect environment for mold and fungus. We use natural silk of different densities as a dubbing material – either Chinese Cho silk gauze or completely transparent Leon silk gauze. If there is a need, we also use other natural silk brands.

We cover the natural dubbing silk with glue that remains in the form of very small impregnations. The glue is spattered the following way: silk, preliminarily tinted in a required color, is smoothened and stretched on a wooden frame whereafter it is treated with acrylic glue, diluted to a required concentration with acetone (the concentration depends on the density of the gauze to be treated). The glue is applied with the help of a high pressure compressor that makes it possible to break the treating glue to a fine-dispersed state and with a great thrust delivers glue particles to the fabric where they settle (acetone later evaporates). As a result, what we are getting is not a solid film but rather a fine-dispersed net. Advantages of this glue application method are: 1. a doubling fabric retains its plasticity, 2. glue particles make the doubling cloth surface a little bit shaggy (not slippery as it happens when pure glue is applied as a film), which results in a better surface cohesion.

Archeological textile doubling was performed the following way: a thick silk (with spattered acrylic glue) was stretched on a doubling table with the glued side up. After that, textile fragments were placed upon the silk with thread direction. If a textile had a pattern (for example Italian Damask), then first a full-size ornament make-up was made; it was placed under the thick silk (transparent enough) and a restorer could spread out the textile fragments so that the ornament on them coincided with the make-up ornament. In some cases, when there were enough fragments, we could get a piece of a fabric of a quite significant size. It was assembled following the puzzle principle.

After all fragments had been carefully spread out, a transparent silk gauze was put upon them with the glued side down. In spots of loss, two spattered layers were treated with an electric heated palette-knife (temperature 60-70°C). The textile fragments were not subjected to thermo-treatment – they were squeezed between two layers of silk, and later on, two layers of doubling silk were stitched with a thin gauze thread along perimeters of all losses. When the textile integrity permits, we are making a "window" in the doubling silk on the front side and on the reverse side to make the real fabric accessible.

RECONSTRUCTION METHODS

Three dimensional archeological items like dresses, shirts etc. were doubled using the same methodology, but the doubling process was combined with the reconstruction process. Studying technological methods used in the production of different items found in the burials, was helping us greatly in choosing reconstruction methods; however, reconstruction is possible only if an item's construction is determined.

The reconstruction can be flat or three-dimensional; the latter is very complicated to execute. The three-dimensional reconstruction method was used to restore some items from Anna Mikhailovna Romanova's burial – a habit and mantle, dresses from burials of Maria Dolgorukaya and Maria Ioanovna, children's shirts from Feodor Belsky's burial and from an unknown burial #45 etc. For each of these items a unique method of reconstruction was developed.

We gained valuable experience in excavating and preserving a great number of textile objects in various degrees of preservation, and had an opportunity to elaborate the methodology of extraction, primary treatment and conservation of textiles. Later we used these methods while working with the textiles from the burials of Egypt and Noin-Ula.

As a member of the 2009 expedition of Archeology and Ethnology Institute of the Russian Academy of Science, I was really happy to take part in taking out and restoring textiles from ancient burial places of the 1th century B.C. in the North of Mongolia, in the Noin-Ula Mountains. A doctor of History Natalia Polosmak was the chief of the 2006 and 2009 expeditions.

It should be noted that the archeological expedition to the Noin-Ula Mountains in 2006 wasn't organized accidentally. The mounds of the noble representatives of the nomadic people of Hunnu have attracted attention of researchers since the beginning of the 20th century. Archeologists hoped that it would be a success and they were not mistaken, though the expedition was very long and hard. At the depth of 18 meters, they found a burial chamber filled with clay that covered everything around. It is not serious to think about full conservation treatment in the field, especially of textile pieces, but the proper preparation and taking-out of the textile objects from the burial is "the first step that costs". In the present case, the objects were very carefully prepared for the transportation by archeologists and conservators and brought to Novosibirsk, to the marvelous Institute of Archeology and Ethnography of the Siberian Branch of the RAS.

As mentioned before, all the items from the excavation of the mound were covered with a thick layer of clay and had been frozen for a long time. By the time our small group of Moscow conservators began working on fragments of an embroidered panel, they had already been partially washed away and came into our view as numerous pieces of cloths, big enough and covered with a layer of hard clay, under which we could hardly see the images of figures. There were also a lot of clots of clay in which one could hardly discern the fragments of a colored textile. To release the textile we had to wash the clay away very carefully, make it soft and then smooth it out fragment by fragment. During this process, the clay that remained on the surface of the textile and covered it with a thin layer made it very fragile.

The trial cleaning was carried out to work out a system of cleaning. The optimal way of cleaning, as it turned out, was washing textile items on a net with warm water. The treated fragment was placed onto the thin net stretched on a frame; for cleaning of larger fragments big frames were made. The frame was then submerged into a solvent (a 1% or 3% polyethylene glycol water solvent) for 2-3 minutes, whereupon the frame with a textile fragment was extracted (in that way the weight of wet fibers fell on the silk net) and the soaked clay was removed from the textile surface with a small spatula. After that, the frame with the textile fragment was placed into a bath in the leaning position. We rinsed it many times with a special sprinkler, with a warm 3% polyethylene glycol water solvent, with a soft brush used for cleaning of smoothed textile fragments. The remains of dirt were carefully removed from the weave with a thin needle with the use of a microscope (the process should be carried out under a microscope or strong magnifying glass in order not to damage fibers). This way we managed to clean even the most damaged textile fragments, while inflicting minimal damage to them.

Drying of the cleaned textile fragments was carried out on a flat surface between several layers of filter paper. We had the task of preparing the fragments of embroidery for transportation to Ulan Bator as soon as possible. That's why we chose the method of consolidation of the textile onto a silk gauze, sprayed with adhesive.

Another absolutely sensational embroidered item was extracted in 2009 from the bottom of the mound no. 31 from the depth of 14 meters. The textile covered the board floor of the burial chamber and was bound with clay from the excavation. Actually, one should have had great imagination to have seen embroidered pictures hidden in slippery clay stuck to the boards, but Natalia Polosmak believed in success.

First of all we had to separate the layer of clay with the textile inside it from the boards preserving the textile and leaving the clay stripe intact. The total length of the stripe was about 7 meters, and the width – 35-40 centimeters. Using spatulas of different sizes, we separated the stripe from the boards little by little, putting some narrow thin sheets of Plexiglas underneath. After that, one big sheet of it was

Fig. 3. *The embroidered panel after excavation*

Fig. 4. *The mechanical cleaning process*

Fig. 5. *The embroidery panel after conservation*

put under those numerous pieces of Plexiglas and the whole structure was lifted up carefully. To keep the clay wet we used a film of plastic to wrap up the textile, the clay and the sheet of Plexiglas many times (Fig. 3). In this state, the whole structure arrived in Ulan-Bator, and then in Novosibirsk.

It was difficult to believe that we could pull something out of this pile of clay. At first, we had to try to remove the upper layer of clay without damaging the textile fibers underneath (Fig. 4), and then to extract the textile; it was decided to wash out the clay and to smooth out the textile. This was needed to be carried out very fast, because the drying clay damaged the textile fibers, so we had to keep it wet by spraying it with water under the plastic film.

Subsequently, we had to take the decision about the way of removing clay from the biggest piece of the textile which was of a critical importance. We decided not to unwrap the whole

2-meter piece of clay at once; we divided it into 5 fragments, numbered and fixed. I couldn't imagine that the embroidered cloth would prove to be folded several times and the width of the embroidery would turn out to be 110 centimeters instead of 35-40; the embroidered figures were 60-65 cm high. Big net frames were made and the fragments of the textile were washed and smoothed on them little by little. The wet clay that covered the entire textile was abundantly moistened and became slippery and plastic, so it was possible to smooth out creases without damaging the textile fibers.

Cleaning was carried out according to the method described above, worked out for cleaning of the embroidered carpet from the mound no. 20. Conservators were extremely glad when they saw these fairy-tale faces and figures of handsome men in many-colored clothes. The carpet was several red woolen cloths stitched together, embroidered with colored woolen threads. The dye analysis showed that the main fabric of the carpet from the mound no. 31 contained mostly carmine acid and indicated the presence of laccaic acids in the threads of the embroidery. The same acid was present in the threads of the carpet from the mound no. 20. Thus, the special feature of the colored woolen textile pictures found in the Hunnu burial places in Mongolia was a frequent presence of laccaic acid in combination with alizarin and purpurine.

After the initial cleaning, when the dimensions of all the fragments had become clear, a consolidation cloth was prepared. We chose Indian cotton cambric, dense enough but transparent, and we dyed it in the color of the main fabric of the panel. Before consolidation, each fragment was re-washed thoroughly on a special table in a pacification solvent and all the threads were smoothed out and evened with the warp and weft direction.

The consolidation of the cleaned and smoothed textile fragments was carried out with a needle and a thin silk thread, without any adhesives. At first, the cotton was stretched and fixed on a frame and then the prepared fragments were placed on it. As a lot of the main fabric remained, all the fragments matched each other very well – like puzzles. Without using an adhesive, it was necessary to fix every thread. Taking into account the size of the embroidered carpet, it turned out to be a very difficult task (Fig. 5).

Much work was carried out for many months by a group of conservators, and the result of it are unique methods of cleaning, plasticization, fixing and consolidation of woolen embroidered fragments. Embroidered pictures from the Hunnu mound older than 2000 years, were restored to a new life.

Conservation and re-conservation of leather archaeological objects

Dawid Grupa

Conservation of archaeological objects made of organic materials has been problematic for many years. It also concerns leather artifacts due to factors influencing their state of preservation. Environmental conditions, connected with the objects deposition are regarded as the most significant. In proper environment, leather objects can preserve hundreds of years, although, if that stabilization is disturbed in some way, rapid material destruction takes place (sometimes the slightest change in the object's surrounding is enough).

It is observed clearly in the case of leather archaeological objects, where disintegration processes are doubled due to a rapid change of the environment. Hence, our constant care in selecting adequate methods enabling to protect these objects on the spot, before they are transported to laboratories for conservation treatments (Fig. 1). Elaborating new methods of protection and conservation, laboratory tests on organic objects create new possibilities for re-conservation of leather items, protected in former decades, and perform comparative studies on both – objects just excavated and those in museum collections. The tasks have been continued by the team of the Conservation Laboratory of Archaeological Heritage in the Institute of Archaeology of NCU in Toruń.

Conservation to protect the objects, strengthen their physical properties and restore their elasticity before they are reconstructed for exhibiting purposes, and selecting proper methods depends on objects' condition and structure of the material. Artifacts made solely of leather are easier for conservation, than multi-material items. Leather is often combined with wooden or metal elements, therefore the methods should protect the whole object, not destroying any component during treatment.

Even within one group of material, e.g. leather of various origin, many factors have impact on the final result of conservation work (Fig. 2). These include: kinds of leather, tanning methods, its usage history, deposition environment (dry, wet) and even the time, necessary for its clearing and impregnating before the stabilization process.

Basing on archaeological objects originating from sites from different periods, one could observe the differences between conservation processes of various objects. It was clearly seen in the course of conservation, comparing the objects from the sites in Gniew and Białystok with artifacts from the museum in Elbląg, subjected to re-conservation treatments. In these three cases, leather footwear was examined. Archaeological exploration in Gniew brought shoes excavated in earthen graves under the church floor. Owing to excavation works in Białystok prison, relics of leather boots (Fig. 3), connected with the prison functioning in 20th c., were obtained. Leather artifacts from Elbląg are dated from the late Middle Ages and were excavated during archaeological exploration from the 80s of 20th c. Comparing the three sites, we could verify relations between the influences of place and time of objects deposition, qualities of their manufacturing and protective methods used during exploration.

The leather shoes from the first site were overdried, because of being deposited in dry environment, but in a satisfactory condition (loam soil created stabilized conditions for the deposited objects). Preliminary works consisted of removing impurities, applying baths in a low percentage solution of citric acid (3%-5%), which enabled to loosen impurities on the surface and inside the footwear and remove iron-tannin compounds. The shoes were made of thin leather, which was also important for cleaning (it turned out quickly that leather began to split into separate layers). Mechanical cleaning was continued and the shoe relics were inserted in a water solution, being a composition of glycerol, PEG 400 and admixture of biocides.

The boots from Białystok were made of finely tanned leather with rubber soles, fixed with iron nails. The objects had been excavated from very damp, clay environment, therefore the material was not overdried and kept its form without significant deformations. The biggest surface destruction was caused by corrosion processes of iron elements' degradation.

During cleaning, at least two types of rubber were successfully separated – hard, compact, black rubber and brighter (currently pink), more flexible rubber. In the first case, baths in a citric acid solution helped to remove most impurities without damaging the construction of the boots. The other rubber kind, used in heels of high bootlegs, had different physical properties. The rubber was more flexible when touched and in contact with the acid solution it began to lose its consistency, splitting at its edges, which in turn caused its detachment from the sole. During mechanical cleaning, before placing the objects in a bath with a consolidant, we observed that the elastic rubber had been affected by the corrosion of iron more than the surface of the boots.

The third group of artifacts included objects excavated in Elbląg. Although their conservation had been performed two decades earlier, surface of some of them still remained greasy and seemed to be wet. In a few extreme cases, leather surface had clearly exposed spots of glycerol on it, not absorbed by its structure (Fig. 4). It must have been caused

Fig. 1. *Leather shoes before conservation, Gniew; all photos in the paper – Dawid Grupa*

Fig. 2. *Parts of the heel before conservation, Gniew*

Fig. 3. *Leather shoes before conservation, Białystok*

Fig. 4. *Fragment of a leather bag before re-conservation, Elbląg*

Fig. 5. *Example of a reconstruction of leather shoes, Frombork*

by improper proportions of the composition used for conservation and a wrong method of drying. The objects were selected mainly due to their state of preservation, quality of leather tanning, possibilities of reversing former conservation treatment and making comparative studies using new methods, consolidants and biocides. Working on all three artifacts groups, we took under consideration the possibility of reversing the process, if necessary, in future.

First every leather element was bordered and described in order to control, if they shrunk or deformed in the course of treatment. Next they were inserted in a bath identical to the one applied for Gniew and Białystok objects, where they stayed for 7 days. The purpose of bathing and rinsing was to remove the old consolidant, but during first three days we could observe how acid reacted with microorganisms present on the surface. It required introducing additional rinsing treatment under running water and mechanical surface cleaning. After repeating the treatment for the next 7 days, the objects were plunged in a new consolidant, where they remained for another 7 days. Afterwards, the footwear elements were taken out from the impregnating bath and prepared for freezing, which preceded the last stage. Having completed subsequent steps for all three groups of objects, the last stage started– freeze-drying.

Since the same processes were applied to all groups, it was possible to compare final results for objects coming from various environments and periods and verify effectivity of used procedures and chemical compositions for items treated for the first time and the re-conserved objects.

After drying, the objects were compared with their outlines. Owing to the fact that the procedures had been carefully followed, original footwear elements were preserved, their structure gained more elasticity, which enabled their reconstruction for exhibiting purposes (Fig. 5).

Careful analysis of the leather surface revealed a number of differences among objects. In the case of footwear from Gniew, its structure was strengthened and the preservation of leather elasticity prevented further mechanical damage. Flexibility of the boots from Białystok also improved, although iron elements should be protected in future as well, to stop the corrosion process. The best results were obtained in the case of leather elements from Elbląg, which was conditioned by the quality of leather and its tanning methods. As a result of removing excess glycerol used in original conservation, the leather surface changed its color from darker to brighter. It also helped to prevent microbiological attack, resulting from migrating glycerol to the surface and being perfect nourishment for microbes.

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Archaeometric methods for the analysis of historical objects made of metal complementary to the course of conservation work

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INTRODUCTION

All conservation and material analyses methods are characterised by different advantages and disadvantages, such as the scale of interference with the object substance, required instruments, expenses, the possibility/necessity for the execution of works *in situ* in the field and *ex situ* both in the conservation laboratory as well as in specialised analytical laboratories.

All these factors are prone to change with respect to the type of metals or their alloys used for the manufacture of the given object, its state of preservation, presence of other materials and/or objects bound by corrosion products, conservation works done in the past, storage conditions and possible use of the object for exhibitions. The application of archaeometric (material/archaeometallurgical) methods of analysis while carrying out conservation works and their design criteria require a research into these fields prior to the start of the complete programme.

The basic set of analyses include radiographic, metallographic, and spectral methods, which, if need be, can be complemented by others. It is argued that the best results of these treatments can be achieved at different stages of performing the conservation work, and that they can greatly increase the knowledge of the object as well as be beneficial for quality of the conducted preservation/conservation/ /restoration itself.

RADIOGRAPHY

Radiography is an imaging technique that uses electromagnetic radiation other than visible light, especially X-rays, to view internal structures of opaque and non-uniformly composed objects, with methods ranging from the most common, traditional film based X-ray imaging. On most occasions, best results are modernly achieved by means of industrial computed tomography scanning, but simpler (cheaper) methods often suffice.

Radiographic investigation should be viewed as an important pre-conservation (post-excavation) procedure, assisting the identification and interpretation of the finds, providing also their record in the conditions, in which they were recovered. This invaluable investigative technique is non-invasive, quick, and cost effective, enabling the form and structure of an object obscured beneath corrosion layers and deposition accretions to be viewed with no physical intervention to the item itself. In case of heavily mineralised metals, such as the ones made of iron alloys, a radiograph can provide information that cannot be gained by any other means, as the heavily corroded artefact can still bear an imprint of its original traits. Thus, this set of methods allow for the identification, classification, dating, and documentation of objects, which have already disintegrated beyond reconstruction [4], [12].

With sufficiently rigorous techniques of image capture and viewing, it is possible to identify the object, e.g. lifted from an excavation site in a solid soil block and/or densely covered with accretions (particularly ferrous artefacts), assess their form and size, the state of the surviving metallic core, discover surface features like decorations and ornaments (inlays, platings, damascening, enamel, niello, etc., made both with ferrous and non-ferrous metals), functional applications (tool finish, e.g. cuts on files, craftsman marks), mechanisms (padlocks, clocks) or even notice the survival of organic material through mineral replacement (handles, sheaths, scabbards). In addition, radiography can provide a range of technological information about the manufacture of an object (methods of forming and finishing, wrought or cast, construction of often complex artefacts like sword blades) (Fig. 1) [8].

As the subject is extremely vast and the article size is understandably limited, a decision was made to give examples of the presented methods when applied to historical swords. The usual complexity of the construction of these objects works in favour of this particular choice of illustration theme, and thus provides a proper and more than less complete understanding of the joint value of the discussed techniques.

The majority of artefacts intended for conservation made of metals and their alloys are good materials for conducting radiographic documentation and analysis. However, several categories of metal finds might not necessarily merit radiography. These include lead alloys and heavily-leaded copper alloys, simple copper alloy finds free of accretions, very thick pieces of metal, items of obviously modern origin, unstratified finds of clearly no archaeological or exhibition significance, large assemblages of clearly identifiable objects with no academic value (e.g. nails), and large architectural and structural items [4].

ON SURFACE INSPECTION (CORROSION INDICATORS)

It is a truism that naked eye inspection, supported – if need be – by stereo-microscopy, remains the basic method for conservatory evaluation of metallic historical objects. But material studies conducted during conservation can also immensely benefit from thorough on surface inspection, as the uneven and/or selective corroding can produce indicators of manufacturing techniques used in the making of a given object.

This is especially true in case of iron alloy artefacts of complex construction, where parting corrosion can enhance the contrast between different materials, mark weld lines, or evidence inlay borders or channels. Heavier rusting can expose construction details prior to any surface treatment to some extent (delamination, differential deterioration rate), but most corrosion indicators can be unveiled during (preferably) careful mechanical cleaning (Fig. 2) [3].

The amount of information gathered by means of on surface observation of corrosion indicators varies, and this depends heavily on the structural complexity of the analysed product, state of the surviving metallic core, and homogeneity of the utilised materials. Therefore, it gives little information in case of e.g. non-ferrous castings. Still, the bare eye and microscopic examination allow to identify mould flashing, casting seams, traces of soldering, remains of engravings, pressings, stampings, hammer marks, etc. and should not be omitted during conservation, where certain details can be lost due to procedures used.

Similarly to radiographic imaging, this method allows one to observe the object in its entirety, thereupon, it leads to a better selection of areas for possible further metallographic sampling and choice of surfaces most suitable for performing spectral analyses. It also helps greatly to reasonably assess the most suitable further conservation treatments [7].

METALLOGRAPHY

Metallography is one of the most useful tools when it comes to material and technological examinations of historical metals. This method is based on the study of polished and etched sections of metallic substances using optical microscopy (alternatively scanning electron microscopy and transmission electron microscopy, especially for higher magnifications, and additional EDS/WDS spectral analysis).

The principal difficulty with metallography of historical objects lies in the selection of best suitable sampling area, and usually includes taking of a small, representative sample for the purpose of said analysis. In certain situations, a section of the surface can be chosen for examination, thus omitting the removal of sample from the object. It is also worth mentioning that recently some neutron techniques have been developed, which allow to determine non-destructively some aspects of metal microstructure [5].

Metallography may present clues to the manufacturing processes utilised to produce a given object, give information on its thermal history (e.g. quenching, annealing, etc.) or on the possible presence of other metals/metal alloys (e.g. gilded or plated instead of pure cast). These can be identified based on the presence of different microstructural phases, type and size of grains, distribution of inclusions, weld lines, slag particles, and porosities, structure changes derived from casting and/or forging operations, etc. Conservation goals can involve assessment of the extent of corrosion, characterisation of the corrosion/patina, or the identification of remains of additional metallic or non-metallic elements/applications. Metallographic expertise can also be vital when searching for forgeries, be them ancient or contemporary (Fig. 3) [11].

Metallographic techniques frequently make it possible to retrieve microstructural information from totally mineralised fragments of artefacts. Corrosion products on historical metals should not be removed before sampling, as this allows one to discern the relationship between corrosion and metallic regions. After these observations are done, the preservation programme can be properly evaluated. Certain treatments may be deemed improper, especially the use of chemical solutions for the purpose of cleaning can in certain situations lead to the destruction of artefacts due to the dissolution or weakening of the corrosion products or the use of high temperatures can considerably change the microstructural composition of the metal [10].

SPECTRAL ANALYSIS

Spectroscopy in conservation and archaeology is most often used to determine the presence and concentration (qualitative and quantitative results) of atoms or molecules in a given structure, i.e. to determine the chemical composition of historical objects and materials. In case of metal, this knowledge allows to specify the characteristics of the alloy, its mechanical properties, and may also be helpful in identifying manufacturing methods applied in the making of a given object. Also, there is a certain usefulness of spectroscopic studies and analysis of trace element patterns and compositions of slag inclusions in the colligation of material groups and of raw materials with ore deposits (Fig. 4) [7].

For diagnosis tasks, many analytical techniques employ some kind of energy source to excite atoms/ions/molecules present in the sampled material to higher energy levels, from where they return to lower levels, accompanied with an emission of characteristic radiation, which can be collected and sent to a wavelength selector and finally detected for further material identification and analysis [1].

Selection of proper methods is mainly dependent on the character of the analysed material, the restrictions associated with the sampling or surface preparation, time needed to conduct the measurements, their interpretation, and general costs. The technique used most widely for chemical composition analysis is X-ray fluorescence spectroscopy (XRF). It involves stimulating the characteristic X-ray spectrum for a given substance by placing it in a stream of high-energy X-ray radiation. The acquired spectra with distinctive graph peaks correspond to the componential elements present in the metal [6], [9].

Highly satisfying results may be obtained by means of scanning electron microscopy (SEM) provided with an EDX microprobe. The latter is especially useful when analysing

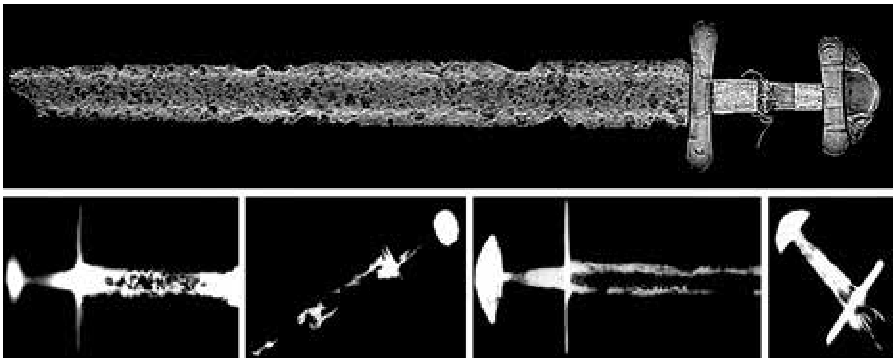


Fig. 1. *X-radiographs (below) and CT image (above) of different medieval swords; photo P. Kucypera, A. Majer, P. Pudło*

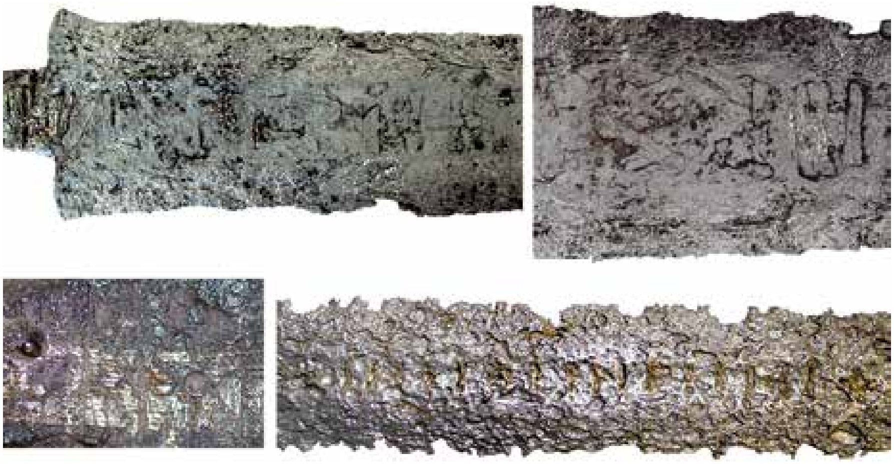


Fig. 2. *Corrosive indicators uncovered on different medieval swords; photo R. Kaźmierczak, K. Rybka, P. Kucypera*

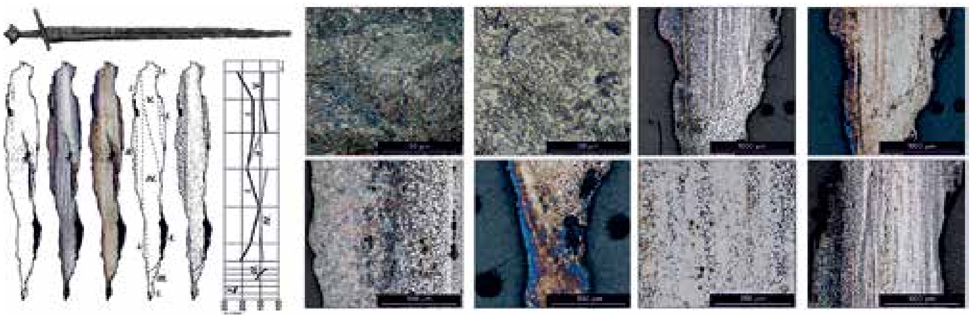
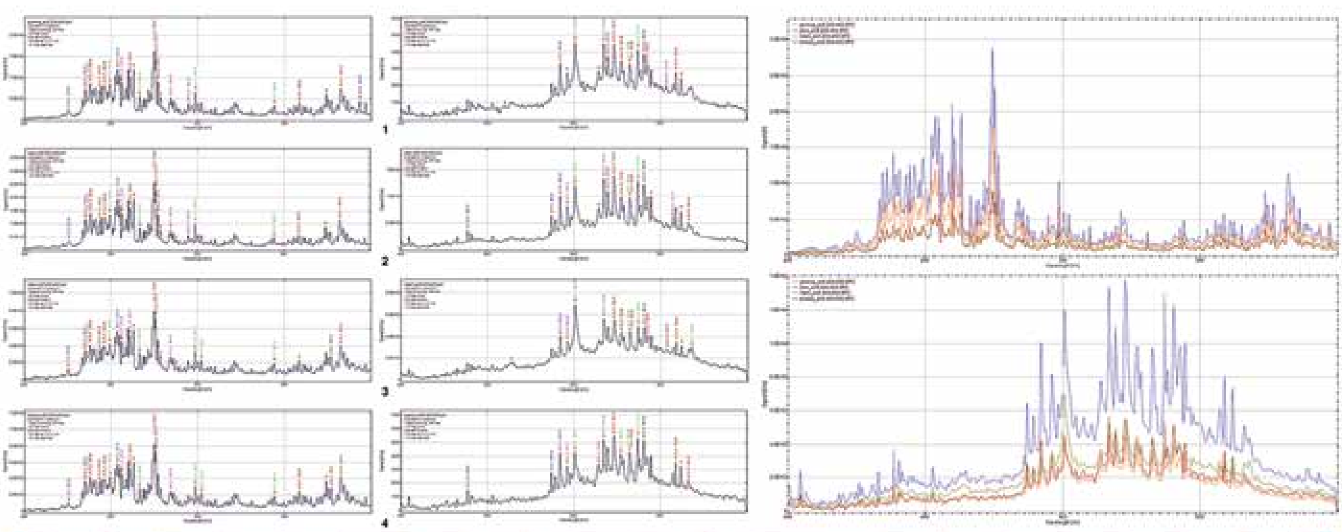


Fig. 3. *Metallographic examination of a medieval sword; photo J. Hošek, P. Kucypera*



C	Si	Mn	P	S	Cr	Mo	Ni	Al	Co	Cu	Nb	Ti	V	W	Pb	Sn	As	Ca	B	N	Fe
0.608	0.128	0.0283	0.0331	.00423	0.0291	0.0100	0.0145	.00100	.00898	0.0152	.00100	0.0100	0.0164	0.0100	.00100	0.0100	.00311	.00039	.00053	0.0456	99.06

Fig. 4. *Qualitative and quantitative spectral analyses of different medieval swords; elab. P. Kucypera*

structurally heterogeneous materials. The study of historical objects made of metals and their alloys can also greatly benefit from atomic absorption spectroscopy, electron spectroscopy, and mass spectrometry (AAS, ICP-MS, ICP-AES, XPS). These methods allow very accurate results and are best suited to the examination of homogeneous materials, and – with proper choice of sampled fragments of studied objects – also heterogeneous structures, like e.g. bloomery iron alloys. All of them are invasive, but nowadays, most require considerably small amounts of material to conduct the testing [2].

Non-invasive and rapid spectral analysis is made possible by laser-induced breakdown spectroscopy (LIBS). This method allows for fast examination of chemical composition and does not require any surface preparation or sampling. In general, it enables stratigraphic studies of metallic materials, along with measuring the thicknesses of the object's structural layers. It is, therefore, greatly suitable for identifying corrosion crusts and the depth of corrosion propagation [1].

CONCLUSIONS

With conservation being so often restrained to a pragmatic preservation of material culture products, its scientific and cognitional potential become belittled and detracted from simple but invaluable humanistic merit.

As highlighted in this brief deliberation and pointed out in the article's introduction, the performance of different, often basic material analyses can not only give highly detailed information about the character, properties, manufacture history, etc. of a given artefact, they can also make it possible – be it in addition or for their own sake – to most properly plan conservation procedures and their direction during conduction.

Once again, of great importance is the fact that in all aforementioned cases, these methods are always most suitably applied before and during the course of conservation works, i.e. that they are most beneficial (and cheap) when applied at given stages of preservation, always when it takes place, never afterwards.

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Various raw materials and large amounts of artefacts from New Market Square (Wrocław, Poland). A great challenge for the Minimal Intervention Laboratory

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INTRODUCTION

New Market Square is one of the two (the Salt Market being the other) auxiliary medieval and modern market squares in Wrocław. It is located in the centre of the modern city. In the south-west part of the square, from September 2010, archaeological excavations and architectural investigations have been undertaken by students and scientists from a few local universities, e.g. the Institute of Archaeology (University of Wrocław), with Professor Jerzy Piekalski, who was the head of the research [1].

New Market Square was founded about the second half of the 13th century. There had been local trade focused on the needs of the city's inhabitants, including the neighbouring New Town, as well as long-distance wholesale trade. In the written sources from the 13th and 14th century, we can find information that "poor peddlers" or "poor vendors" could trade three days a week in New Market Square. The bread stalls or parts of them were also housed there at least since about 1354. The preserved records mention the Baltic herring trade and shops (chambers) with suet operating near the square.

Because of the rich historical context of the square and the huge collection of artefacts retrieved during the fieldwork, advanced archaeological studies and conservation works have been carried out. The major problem discussed here is numerous organic finds (wood and leather that needs conservation intervention almost immediately) and items of iron, active metal with impaired equilibrium by excavation from soil.

MATERIALS AND METHODS

The artefacts catalogue includes above 12,000 inventory numbers. However, the total number of items is much higher. The collection contains all types of items usually found in urban excavations: pieces of clothing, shoes, containers, harnesses, kitchen utensils, tools, armour, toys, game pieces, and semi-products (also waste). The objects were made of various raw materials: metals, wood, leather, ceramic and were composites of them.

Artefacts recovered from the excavation in New Market Square were buried at a depth of 1-4 m below the ground level, in archaeological contexts that were enriched with organic substances and minerals, characterized by high humidity and low soil aeration. The first operation on the site was to protect waterlogged organic artefacts against moisture loss. They were packed in polythene bags and gradually brought to a laboratory. The items received included vegetable-tanned leather, wooden and textile items that were wet, dirty, with little signs of degradation, and sometimes infected by mould, which was visible as a white bloom. Metals were in a similar state of preservation. Many of the items were preserved only in fragments. A small percentage of organic materials were desiccated because of improper protection against water loss. Waterlogged and wet wood and leather usually shrink and deform during uncontrolled drying [2], [3].

The artefacts were conserved and selected objects were analysed with the use of physicochemical methods for the next stage of the research. Conservation works were entrusted to the Laboratory of Archaeometry and Conservation in the Institute of Archaeology (University of Wrocław). For this small, two-person team, and the Minimal Intervention Laboratory, it was a great challenge, due to the number and diversity of the finds.

During this work, several problems became apparent, ranging from conservation costs to intriguing and unexpected artefacts (e.g. a huge quantity of decorated everyday items). The other problem was organic artefacts (ca. 60,000 leather objects, 3,000 wooden items, and over 500 fragments of textiles), which all needed to be preserved as soon as possible to prevent microbiological degradation or uncontrolled drying (elimination of dimensional shrinkage). The conservation works are still in progress.

During conservation, an archaeometric investigation was undertaken. This requires two types of research: microscopic investigations and spectroscopic investigations. The microscopic observations were made by optical, metallographic and electron microscopes using an Olympus SZX9 stereoscopic microscope, a metallographic microscope, a NIKON Eclipse LV100 and EVO LS 15 Zeiss electron microscope. With these two microscopes, magnification from 6.3 to 10,000 times can be achieved. Further deployed analytical tools were spectroscopic: infrared spectroscopy, FT-IR (Thermo Nicolet 380), X-ray fluorescence, XRF (Spectro Midex) and a few samples were analysed by X-ray diffraction, XRD (Phillips X'PERT: PW 1830 generator, a voltage of 40 kV, a current of 30 mA, the goniometer 2θ was in the range of 3–100 °, at a scan rate of 2.0 s/step); XRD investigations were carried out in the Group of Analytical Chemistry and Chemical Metallurgy, Faculty of Chemistry, Technical University of Wrocław. Diffractograms were analyzed with the database ICDD PDF-2. These selected techniques are very helpful and can provide answers to several questions connected with conservation and further scientific investigations (e.g. the state of artefacts or techniques of decoration).

RESULTS

CONSERVATION OF ORGANIC MATERIALS

The conservation of wet and waterlogged organic objects normally consists of three phases: cleaning, impregnation and drying. The specific detail of these phases varies according to the type of organic material. Prior to washing, infected archaeological organic artefacts from New Market Square were disinfected with the use of a fungicide containing quaternary ammonium salts (Quats), i.e. Boramon and Daxol. Then, the artefacts were carefully washed by hand in warm tap water using sponges and soft brushes in order not to damage the surface and structure of items. Textiles (wool, silk and felt) were bathed in a temperature of about 30°C with the addition of surfactants. It was important to preserve construction elements, decorations, metal fittings and fastening, hoops of staved vessels, remains of thread, gilding and painting, wooden pegs in soles, applications etc. Any diagnostic attributes should never be removed.

Because of the huge number of leather artefacts and the need to make them available for a further study after conservation treatment, selection was necessary. The present state of knowledge of leather artefacts is such that the only categories of leather which should be considered for air--drying are scrap leather and waste from the manufacturing process. Conservation began with the most important complete wares such as shoes, purses, scabbards, belts, sheaths and gloves. Subsequently, their fragments, as well as waste that possessed diagnostic features, were conserved, as it provides relevant data on leatherworking. Important leather artefacts were measured and drawn before and after conservation treatment to determine the shrinkage. The primary aim of wood and leather conservation is the dimensional stability of artefacts to minimize shrinkage and consequences related to it (deformation, desorption cracks and leather delamination) as well as the consolidation of finds and protecting them from deterioration and microbial growth. It is very important that leather items retain suitable flexibility. This objective was obtained by using freeze-drying and solvent dehydration methods. They are the most common treatments and both can provide acceptable results [4], [5].

CONSERVATION OF LEATHER

Leather from New Market Square had a brown-black colour caused by the presence of minerals in the soil, especially iron ions forming hard black iron-tannin complexes [6]. Some pieces, especially the soles and waste, were delaminating badly. Sometimes there were considerable hard soil deposits and metal corrosion products (e.g. iron fittings) present. Most of the leather items (about 80% of the assemblage) were dried using vacuum freeze-drying. This manner is the most effective drying method (it is quick).

After cleaning, the next step was the decomposition of the iron-tannin complexes in 3% ortophosphoric acid in distilled water for 1 hour. Demineralization agents should be used very carefully for leather decorated with gilding and painting. The leather was then rinsed multiple times in tap water to obtain a pH value in the range of 5-6. After neutralization, the objects were totally submerged into a 20% water solution of PEG 400 with a 2% addition of a mixture of boric acid and borax (7:3) as a biocide for a period of 7-14 days. Glycerin (25%) was also used. PEG and glycerin act as humectants and prevent excessive shrinkage. All baths were kept at a room temperature. After immersion, the leather items were frozen to -26ºC (for 2 days) and then placed in a freeze-drying chamber under a vacuum for a period of 5-8 hours (the temperature of the shelves was 18°C, pressure was 1.4 mbar). Freeze-drying was also carried out without the vacuum, in a domestic chest freezer (average temperature was -20ºC) for a period of 8-10 weeks, but only leather waste was treated in this manner.

Freeze-dried leather is dry, light, soft and flexible with a natural colour, showing surface details extremely well. It retains its original dimensions prior to conservation; shrinkage is practically minimal (0-2%). It is sufficiently durable and supple to allow repeated handling, which is necessary during study and documentation. However, the long-term effects are sometimes unsatisfactory. Artefacts have been seen to be excessively dry and friable when the storage conditions are not optimal (RH in a range 40-55%).

The second treatment for leather waste was solvent drying. The water in the leather was replaced by acetone which was then allowed to evaporate. Next, the leather was impregnated by a 25-30% solution of glycerin and distilled water using a brush. This method has disadvantages. It can only be carried out in a work place with adequate fume extraction (acetone is a toxic agent). Dehydration using organic solvents should not be used for gilded and painted leather. Solvents can extract dyes, pigments, tannins and fats. The shrinkage is moderate (3-10%), but bigger than during freeze-drying. The low molecular weight polyethylene glycol is slightly hygroscopic and becomes moist at high humidity and, for this reason, the surface of the organic artefacts treated with PEG 400 was coated with a thin layer of 10% PEG 4000 water solution. It is very hard, not very hygroscopic, and was used for the protection of leather and wooden finds against the effects of humidity variations. A high molecular weight PEG 4000 tends to darken the surface of the organic artefacts, but it is not a disadvantage. In some cases, the leather became too rigid and brittle. If the leather was too stiff after drying, an aqueous solution of 20% glycerin was applied. This lubricant also reduces further shrinkage.

ANALYSIS OF THE DECORATION ON THE LEATHER ITEMS

During preliminary conservation work, several leather artefacts were recognized as decorated (even if the decorations are usually poorly preserved). Macroscopic observation indicated a few possibilities of ornamentation. Many items have yellowish dots or lines, several have metal mounts, a few have silver-grey dots and some had been painted. The decorations were analysed by XRF before further conservation, because the state of the ornamentation was rather poor (Fig. 1). XRF was the main analytical technique and with this tool, it was possible to identify the decoration's raw materials. Yellowish decorations were made of gold, but one yellow ornament was determined as lead. Silvery ornamentation was made of lead-tin alloys of various compositions. Together with the examination of decorations, the levels of iron and calcium contamination was measured, which are presented on the spectra (Fig. 2). The blue line presents the spectrum of leather only washed by tap water. The peaks from iron and calcium are strong. The demineralisation, made in an ortophosphoric acid solution (3%) in an ultrasonic washer (for 1 hour), showed significant decreases in the intensity of calcium and iron signals. This situation is noteworthy as chemical analysis before conservation may give false results in this case. The conclusion, after these analyses, is that XRF is an adequate technique to determine quickly the various types of decoration, especially those poorly preserved.

CONSERVATION OF WOOD

As in the case of leather, for the conservation of wood the freeze-drying method was used. Its advantages have already been described above. The pieces of wood were first immersed in a 10% solution of PEG 400 in distilled water with a 2% addition of biocide (boric acid + sodium tetraborate, 7:3). PEG 400 replaces the excess water and adds support to the degraded structure following conservation. The time of impregnation was much longer than that of leather and depended on the dimensions, the degree of degradation and the thickness of the wooden objects (14-30 days). This rule also relates to the freezing time (a minimum of 2 days for small and thin pieces). Approximately 5% of a set of wooden artefacts, which consisted of small, slightly desiccated objects, mainly stave bowls, was dehydrated in acetone and then impregnated with a 10% solution of PEG 4000 or Paraloid B-72 in toluene (5-10%). For the consolidation of fragments of wooden items, *Dragon*, the polymer glue was used, which is a polyvinyl acetate solution in a mixture of alcohols (ethanol, isopropanol and methanol) with the addition of adhesion promoters.

CONSERVATION OF METALS

For metallic artefacts, the situation is different. The state of preservation of many items was very good; in most of them, the metallic core was preserved and the corrosion layer was not very thick. The biggest group that caused a conservation challenge was iron artefacts (the correct term is *wrought iron* or *steel*) because of the metal chemical activity and the number of objects (over 50,000 items, many decorated). Generally, the corrosion layers were created by oxyhydrooxides (e.g. for iron: α-FeOOH, *goethite*, β-FeOOH, *akaganeite* or γ-FeOOH, *lepidocrocite*), oxides (e.g. $\alpha\text{-}Fe_2O_3$, hematite, Fe_3O_4, *magnetite*), sulphides (e.g. FeS, *pyrrohite*; FeS_2, *pyrite*), phosphate ($Fe_3(PO_4)_2{*}8H_20$), *vivianite* [7]. The *green rust* which is sometimes visible was recognized as mixed ferrous-ferric compounds: $Fe^{3+}{}_aFe^{2+}{}_b(OH))_c(A_{(3a+2b-c)/z)}\ {*}nH_2O$, where A could be: Cl^-, Br^- [8]. This composition was confirmed by XRD analysis; Fig. 3 shows the XRD diffractograms of corrosion layers.

Conservation techniques, applied to metal objects are varied. Many articles and books [7], [8] are informative about the dilemmas connected with the selection of the conservation procedures from passive procedures (such as storage in adequate conditions and observation) to active treatments (e.g. mechanical cleaning or alkaline sulphite). The most important criterion, which should be considered in the case of the New Market Square items, is the number of items. The others, but no less significant, are the state of preservation, types of raw materials etc. For these reasons, we tried to adapt the conservation work to this quantity of items and the capabilities of our laboratory. Therefore, we had to plan conservation procedures to be as little labour-consuming as possible.

With thousands of artefacts, it is impossible to work only with manual mechanical methods (mechanical cleaning by prosthetic tools or air-abrasive techniques). The preliminary cleaning was always mechanical, but after the determination of the state of preservation, we continued further work with other popular conservation procedures: electrolytic reduction, alkaline reduction or chemical cleaning. However, for undertaking these tasks, standard laboratory equipment was insufficient; one laboratory dryer, two fridges, two freezers, three various-sized ultrasonic tanks, several prosthetic tools are not enough to progress conservation at an acceptable rate.

Efficiency can be modified in a few ways: first through preparing a list of the most significant artefacts from an archaeological point of view as well as the activity (or passivity) of their raw materials. Secondly, we can buy more equipment (e.g. laboratory dryers). The third possibility is the modification of conservation procedures to match the huge amount of items. During work with the New Market Square items, all the above options were exercised.

The conservation of iron items were made by various means. The single and rather big items were reduced by electrolysis in various solutions [9]. The efficiency of this treatment was satisfactory, as after a few hours, the preliminail cleaned artefacts became very black. The process conditions were various: for the electrolyte treatment, we mainly used a diluted solution of caustic soda (1% and 5% solutions) and washing soda (1% solution). The use of caustic soda (both solutions) is more effective, after 4.5 hours, the artefacts were covered by a black powdery layer (magnetite), below which the metallic surface was visible (Fig. 4). The current density was 2-4A for both solutions of sodium hydroxide. The electrolysis in a 1% washing soda solution is less effective, the maximum current density which can then be obtained is 2A, and after 6.5 hours in such conditions, the artefacts still had corrosion layers, not on all the surface, but in some places, there were deposits (lumps) of brown substances (Fig. 4). After mechanical cleaning with brushes, the surface became metallic except

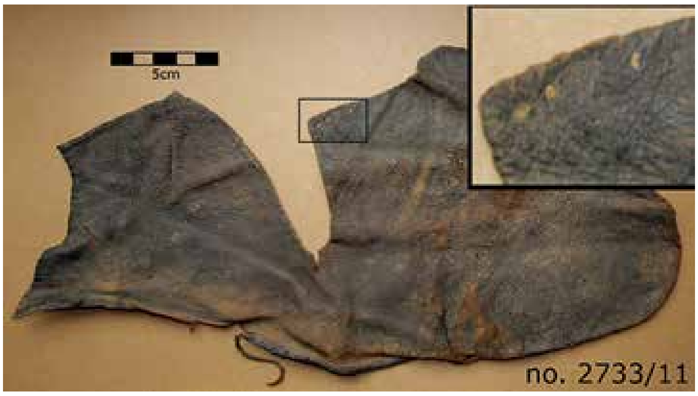

Fig. 1. *A photo of selected decorated leather (no. 2733/11); decorations are almost invisible*

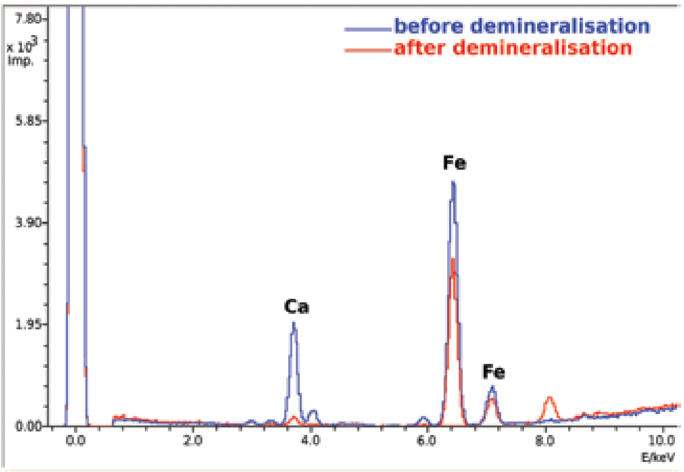

Fig. 2. *The ED-XRF spectra of a leather artefact before and after demineralization in orthophosphoric acid*

for the places covered by lumps. The artefacts were placed in a 5% solution of sodium carbonate to further chloride extraction and alkaline stabilization.

Next, we tested a cleaning procedure, an alkaline sulphite treatment in a solution of sodium sulphite and sodium hydroxide. This treatment in reducing conditions may prevent further corrosion by releasing chloride ions. The important thing is that the artefacts must be stored wet from the moment of excavation. Nowadays, after several investigations, it is known that magnetite is not formed by the direct reduction of ferric oxohydroxide (akagenite) by a solution of sodium sulphite. The process that takes place is more complicated. However, the effect is very visible. After a few weeks the artefacts are very black, their surface is covered by mixed iron (II, III) oxide (ferrous-ferric oxide). This conservation cleaning is definitely less labour-consuming (the changing of the bath is a quick treatment), but for this work, we needed special conditions: a reducing atmosphere and an increased temperature. For small amounts of artefacts these conditions are not onerous (glass containers could be placed in a laboratory oven), but for larger numbers of items, it is an extraordinary treatment.

We solved this problem buying a kitchen oven (several times cheaper than a laboratory one) and many plastic boxes. Polymer food boxes are often hermetic and come in various sizes corresponding with various artefacts' dimensions. This allowed us to perform the cleaning procedure at the same time for hundreds of items, especially smaller ones, such as knives, nails, wire and building accessories. However, this treatment has one large disadvantage: the reduction in the alkaline solution is dangerous for tin layers on iron items. Such artefacts are gently electrolysed. The chemical cleaning of an artefact in a 5% washing soda solution is a very time-consuming procedure. After several weeks and even months, the cleaning effect is almost non-visible (artefacts are coated by soft brown or red layers). The bath in this solution should be rather a support to other conservation treatments, because of the appropriate pH value to storage (sodium carbonate is an excellent alkaline inhibitor for iron items) and between conservation steps. Conservation with a disodium EDTA solution (10%) [8] has a similar effect, even if the corrosion products are removed more quickly, the chlorides are still present and should be extracted by boiling items in distilled water for several days [10].

CONCLUSIONS

In the case of the conservation of huge amounts of archaeological items, several parameters should be taken into consideration: first the expenses (e.g. costs of buying the chemicals, tools and energy use) and the second parameter is the profile of the conservation laboratory and its limits (especially in equipment and people). The Minimal Intervention Laboratory, a term used by Rodgers, has its own aim as a support for the archaeological laboratory [9]. Therefore, the possibilities of MIL are incomparable with those of a

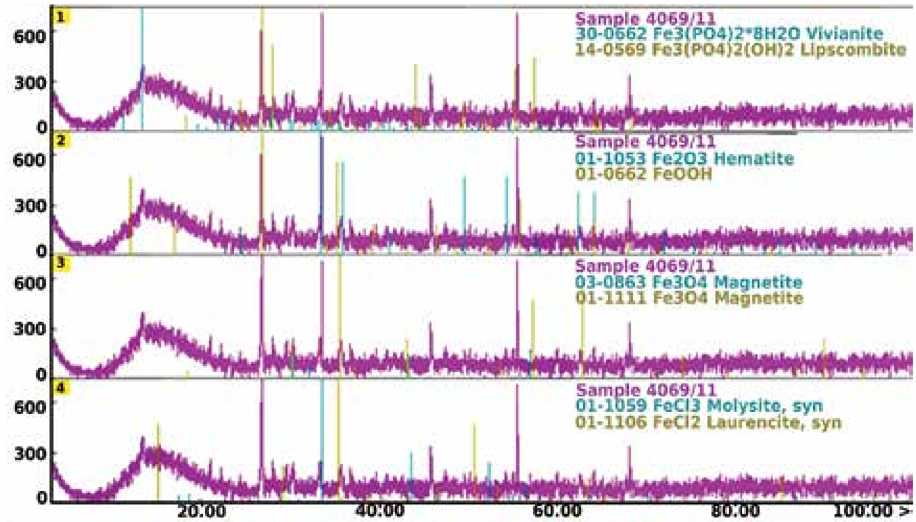

Fig. 3. *XRD diffractograms of corrosion layers from a selected iron nail*

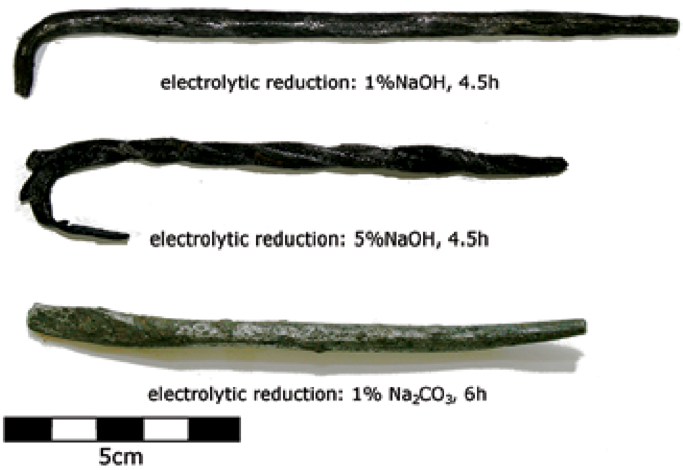

Fig. 4. *A photo of selected artefacts after electrolytic reduction in NaOH (1, 5%) and Na_2CO_3 (1%) solutions*

specialized conservation laboratory (e.g. comprehensive or mid-sized laboratories). Without large financial support and a multi-person team the conservation of thousands objects is a great challenge. This is the situation with artefacts from the New Market Square excavations.

During the conservation work, several problems became apparent: the large group of organic artefacts (mainly leather) and iron/steel objects, the decorations (tinning on iron items, ornaments on leather) and unknowns items (in both function and raw materials). Over the past four years, about 2,800 wooden, 16,000 leather, 480 textile and several thousand metal items excavated in New Market were conserved in the laboratory. Preservation work is still in progress. The effective treatment of organic artefacts was made possible by specialized equipment: a freeze dryer (Gamma 1-16 LSC, CHRIST) and a domestic freezer. Although a vacuum freeze dryer required a large initial outlay, in labour- and time-saving this method is much more cost-effective than other methods. Because of this, scientific investigation must be performed before and during conservation procedures. Conservation work can change the chemical composition of artefacts, therefore, samples for archaeometric analysis should be taken before conservation treatments, e.g. glues on artefacts (wooden utensils, knives etc.) and residues in ceramic vessels. Nevertheless, some investigation is possible after conservation is finished, namely the analysis of ornamentation on metal items (knives and swords) or leather decorated with metallic paints can be analysed after demineralisation. In our opinion, each stage of the research process is important: firstly, from the retrieval of archaeological artefacts during excavations, to the passive treatment, specialized analyses and conservation, to the examination of archaeological sources. The information gathered from these sources has a substantial impact on the final results of research.

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Evidence excavated from the ground – conservation problems concerning the archaeological objects excavated in the trenches of death of Polish officers murdered by NKVD in 1940 – Katyń Massacre

Małgorzata Grupa

In 1943, German Nazi Army representatives made a discovery in Katyń forest in form of mass graves of Polish officers, starting exhumation works, in the course of which many names were read from excavated documents, giving the beginning to First Katyń List. Nobody realized then, that there were much more places of that massacre and that they have been not known till today.

The most important tasks of archaeological-exhumation expedition in Kharkiv and Katyń were to obtain all the possible knowledge, concerning officers murdered there and collect evidence confirming or negating NKVD homicide in 1940. The state of human remains' preservation varied much. In Kharkiv, in four graves, the bodies were explored in skeletonization, while in the other eleven, the process was not completed – and remained in adipocere substance. In Katyń, on the other hand, all remains decomposed and only bones were reported. In damp graves – corpses and in dry graves – skeletons were deposited in several layers, as a rule, in 6-8, with density the moment of exhumation reaching about 70-80 cm. Burial pits in Kharkiv did not report, as in case of some graves from Katyń, arranging dead bodies in regular layers [1].

In the course of excavation, all found artifacts were carefully examined. However, not all the artifacts were brought to Poland. The team responsible for conservation protection made a decision after careful examinations, which were to be redeposited in burial pits together with excavated human remains and which could be transported to Poland.

Each object could have been a source of information of its permanent or temporal owner. The artifacts consisted mainly of personal belongings: outfit fragments (uniforms, caps, shirts, boots, belts, stockings, glasses, house keys and leather officers' bags), toilet articles (combs, shaving brushes, tooth brushes, soap dishes) and a number of small coins, wooden boxes, spools with thread, rosaries, medals and a variety of small objects [2]. Particular attention was turned to documents and all kinds of papers, which were found the most frequently, sewn between fabric layers of uniforms or thick military coats. Officers hid them due to persistent personal examinations and confiscating all things, which weakened mental toughness of the officers (constant interrogations outdoors in frost –40 degrees Celsius). Because of lack of basic writing material in the camps – paper – the archaeologists concentrated on detailed examination of metal and wooden objects, which could contain various notes and inscriptions. Metal objects, deposited in burial pits for over 50 years were subjected to substantial destruction, but still were regarded as precious sources of information. Each fragment was cleaned on the site and examined, if it did not contain any scratched information on its surface. Some of metal items had engraved notices from before the war period, like rings with wedding dates and names of wives, cigarette-cases and watches, frequently with dedications, rings with family coats-of-arms, medals and orders with identification numbers [3].

Part of these objects were burnt or calcined, because bodies of shot officers together with their equipment were thrown into pits and burnt, hence many deformed objects.

The first stage of work after objects' excavation was to arrange them into groups of dry and wet items and define their conservation process sequence. This division also specified two ways of preserving that historical substance. Artifacts from Kharkiv were placed in plastic bags, which helped to keep their humidity, while the objects from Katyń were put to paper bags, which unfortunately led to their over drying and irreversible deformation, particularly in case of organic materials.

Particular care was turned towards all kinds of documents, and the team members tried to decipher them during excavation works. They consisted of notes made on cigarette paper, scraps of Russian newspapers, calendars, notebooks and other printed documents, like, e.g. bank books, postcards, telegrams, etc., which were papers of different qualities. Notes written in ordinary pencil were in the best condition, while the ones written in indelible pencil dissolved (Fig. 1), leaving pink color on papers and ruining all inscriptions. All papers were rinsed in lukewarm water and cleaned delicately of adipocere substances, carefully, not to rub out the writing. After photo documentation, they were protected with thin foil and placed in thick plastic bags. In laboratory, next clearing treatment was performed and all inscriptions were read once again, verifying the earlier ones. After their disinfection, 1% of methylcellulose solution was applied and the objects were dried very slowly.

Damp leather belonged mainly to boots, officers' bags and belts. History of their using was relatively readable on the objects, e.g. repairs made during staying in prison camps, which are also reported in the diary of lieutenant Alojzy Babiński: on 12th of November (1939) he received from St. Pietrzyk a piece of leather for repairing his bootlegs, on the next day he informs that the boots will be ready in a week time, in fact the repair was made in later time, on 29th November.

In case of leather, we must identify its quality, type of leather, which animals' body part it was obtained from, what way and using what tannin it was prepared and how it was used – i.e. what damages and deformations are observed, what processes took place during deposition in the soil – these are important factors determining its condition. Leather in soil, silt or water, in the course of absorbing products of iron ions and tannins, obtains black color and becomes less flexible. Leather objects obtained from burial pits were usually made of high quality leathers, processed with mineral tannins, but in graves they got completely soaked with adipocere products, which in fact turned out to be additional protection against complete leather decomposition, although in conservation treatment its removing was very time consuming process. The leathers were frequently colored by metal joining particular elements salts: rusty-orange from iron products, green-blue from copper, which came from various clasps and rivets attached to footwear, bags and belts. Black stains, on the contrary, are caused by sulphates. Leathers were inserted in 3–5% solution of citric or phosphoric acids. In first stage the solution was transparent, but after 20 or 30 minutes it changed into yellow color. After 2–3 hours, the leathers were rinsed in running water until obtaining ph close to neutral. Adipocere mass slowly migrated onto the surface, but its removing lasted in several instances up to three months. Next, the objects were plunged into 3% ammonia solution in order to obtain neutralizing process and rinsed again. The following step was tanning leathers in 5% solution of sumac water-acetone (which treatment lasted from 3 to 5 weeks, depending on leather thickness) or in potassium alum and rinsed under running water again. In order to introduce lubricating substances into leather structure, first water had to be removed from it. Leathers were saturated with acetone and white spirit solution in proportion 3:1. Next, they were covered with composition of lanoline, wax, and neatsfoot oil in white spirit. Straightening them on bases, they were wrapped tightly in foil and placed in a laboratory incubator in temperature of 40°C. Higher temperature helps and hastens lubricating substances' penetration into leather structure. After one week deposition in the incubator, if it was necessary, the objects were cleaned of excess of the consolidant. The final treatment included very slow dryling. Appearance of microorganisms on cleaned objects turned out the biggest problem, slowing the work significantly. They forced to repeat the treatments each time and increase the biocides concentration [2], [4].

Cleaning wooden objects was relatively easier task, than leather ones, because during rinsing treatment, warm water could be used and that way it was easy to remove apodicere substances from the objects' structures quicker. Most wooden objects were made from locally grown wood. There was an orchard at the back of the monastery in Starobielsk, therefore a part of chessboards and pawns, tobacco boxes were made of that material (several of them have real artistic values). Boxes tops, both in Starobielsk and Kozielsk camps have images of the monastery entrance gate and outlines of the monastery buildings and dates of coming to the camp and after a hyphen – incomplete date 194… , with the last digit missing, which would indicate the end of imprisoning. In some cases there is a complete date – 1940, which might have been engraved on the train taking the officers to the place of extermination (Fig. 2). One of boxes bottoms had also several signatures etched, 9 of which were deciphered successfully.

Damp objects were impregnated in polyethylene glycol 4000, in raised temperature (50°C), bathing them in 10% concentration. Impregnation process lasted about half a year with systematic increase of consolidant concentration. Next, the objects were cleaned of glycol excess on their surfaces and dried very slowly in desiccators or plastic bags.

Wooden Dry wooden 'dry' items were cleaned on the surface and after disinfection they were saturated with Paraloid B72, and next again all the process was stabilized very slowly.

Textiles from Katyń and Kharkiv were very damaged and therefore only external clothes were suitable for conservation. The garments had signs of destructive fungi and bacteria activity in forms of colorful spots. Numerous traces of mechanical damages were also reported (torn fragments, holes made during using clothes, etc.), signs of repairs, patches and darnings. In majority, fabrics were stuck with adipocere mass, sand and corrosion products of soldiers' personal equipment, making compact mass. Corrosion processes in metals, leather and wood weakened additionally the textiles, making their cleaning difficult. Plant roots, growing throughout fabrics, tangling with fibres and tearing out their structures, contributed much to decomposing processes. Other irreversible changes in textile structures, like in case of leather and wood, were caused by varied environmental conditions, soaking objects with water, rapid drying, freezing. During these processes fibre dimensions change, what in turn leads to systematic decomposition [2[, [5].

Textiles from Katyń were very overdried, crushed and fragile. Some of them scattered apart under their own weight or when touched delicately. Many objects had signs of high temperature activity, what contributed much to weakening their mechanical elasticity and resistance. Their destruction increased, unfortunately, during transportation to Poland, because they had been packed in paper containers, through which the rest of damp evaporated, causing subsequent fibres splitting.

First, the state of preservation and methods for particular objects were defined. Damp textiles were moistened gradually and next inserted in lukewarm water with admixture of surface active agents, which treatment was to re-establish the fibres elasticity and soften all impurities. These were baths in water solution of polyethylene glycol 200 (PEG 200) and the material was rinsed afterwards, removing bulged impurities in the meantime with needles. These treatments were repeated several times, because only a small percentage of dirty substances was removed during every sequence. After each cleaning, the objects were disinfected in fumes of 5-chloro-m-cresol. Next, the textiles were saturated with composition, consisting of PEG 300 and Paraloid B72 in methanol and toluene and dried slowly.

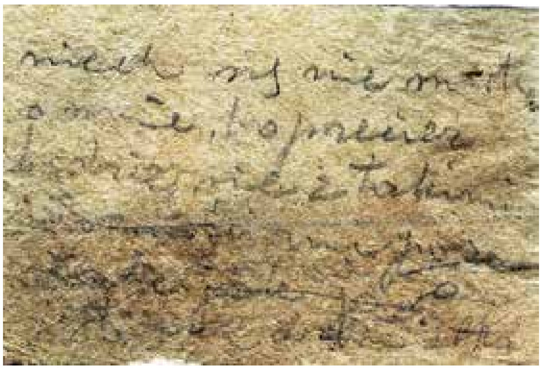

Fig. 1. *Cigarette paper with a fragment of the letter; photo Paweł Bielecki*

Fig. 2. *Wood cigarette case with inscription: "17-X-39 Starobielsk 7-IV-40" and with different monograms; photo Anna Drążkowska*

A cassock, excavated in Kharkiv was the most problematic in conservation, when we tried to increase and strengthen its fibres. It was found in the layer, where very high temperature must have been acting. Its fibres were practically calcined, therefore restoring its relative flexibility lasted over a year and its doubling and reconstruction – next 10 months (Fig. 3). That was the only cassock excavated in the homicide sites, because the Russians removed all the clergy of all the religions from the camps on Christmas Eve 1939 and their further destiny and places of burials are still unknown and wait for discovering. That priest might have been unable to collect and take with him all his belongings and the officers took care of his clothes and treated the cassock as a kind of relic. As early as in November holy mass services in camps were forbidden, which information is given by the careful annalist, Alojzy Babiński.

Next stage of work referred to reconstruction of selected uniform elements (Fig. 4), underwear and the cassock. Textile fragments were placed on base fabric, particular elements were sewn together. That way, military caps, captain and general uniform waistcoats and the cassock were reconstructed.

Conservation treatments are usually described in few sentences, which, however, do not reflect the time spent on working on particular objects. After four years of conservation work, 1020 historical objects from Katyń and 7500 from Kharkiv were protected, although the work on the found notes was continued. It is impossible to define univocally the research method of deciphering that type of documents, because we had to return to these texts again and again, getting used to individual handwriting. During separating about 200 cigarette papers, one was identified, containing names of 13 podpolkovniks (literally – sub-colonels). In another place, with the date of 10th January, Alojzy Babiński places information that 13 officers were brought from Stanisławów (present Ivano-Frankivsk) (Fig. 5). Another packet of cigarette papers contained names of 92 captains. Separating these numerous papers, glued and bulged with adipocere mass, paying attention not to destroy them, must have been the most difficult and time consuming work. In many instances there were no notes on them, but it was worth working overtime even for those deciphered names. In several difficult cases the papers were put aside for some time and we returned to them again [6]. That was work and effort of a big research team. We obtained the most detailed information from the pocket calendar of lieutenant Alojzy Babiński, who made his notes daily (2-3 sentences), delivering precious information concerning life in Starobielsk camp. He was imprisoned on 3rd October 1939. Travel to Starobielsk camp in a cattle truck lasted till 22nd October. He was taken to Kharkiv on 6th April 1940 and he managed to note down the time of the train arrival to Kharkiv station at 6 p.m. (Fig. 6). His further history is known from death pits, but it is said by evidence protected by archaeologists, anthropologists and conservators. All identified notes and information finish in April 1940. If Polish officers had lived longer, that careful annalist of the events would have reported it in his calendar, moreover, as he still had more than half of the empty book. Research in Kharkiv and Katyń confirmed once again that the genocide of Polish officers was committed by The Soviet Union authorities [3].

Fig. 3. *A cassock of fragment partly burnt (after conservation); photo Anna Drążkowska*

Fig. 4. *A military cap, four-corned cap with an emblem of eagle embroidered; photo Paweł Bielecki*

Fig. 5. *Page from small calendar from 1939 of A. Babiński with information that 13 officers were brought from Stanisławów (present Ivano-Frankivsk); photo Dawid Grupa*

Fig. 6. *Page from small calendar from 1939 of A. Babiński; the notes are ending on the day 6 IV 1940; photo Dawid Grupa*

During exhumation works in Kharkiv and conservation treatments in Toruń, total of 339 names were identified from all types of sources on our disposal (objects excavated from the death pits). This number also included 32 names, which did not find any confirmation on any list of prisoners from Starobielsk, made by either Russian or Polish party. Death pits in Kharkiv contained about 400 body remains, i.e. more than Russian lists inform. Our work initiated a list of officers, whom nobody cared for after the war. The officers' families may have been deported into Kazakhstan or Siberia, a part of which must have died during transportation and suffered the same fate as their husbands, fathers, uncles, leaving no trace [3], [8].

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Biochemical fingerprints in marine-archaeological wood – an overview of a research project

Yvonne Fors

INTRODUCTION

Underneath the water surface, our cultural heritage rest in form of archaeological shipwrecks, often interpreted as miniatures of contemporary society. Unfortunately, the seabed environment brings problems to the long-term preservation both at seabed (in situ) and in museum climate. The microbial wood degradation within marine environments has clear connections to the accumulation of inorganic contaminants in waterlogged wood, of which some result in the development of destructive acids and accelerated wood decay in recovered wooden objects after salvage [1]. Preserving marine archaeological wood has become even more challenging because of the discoveries of unforeseen amounts of detrimental contaminants of acids, sulfur and iron compounds. In addition to the museum shipwrecks *Vasa* (SW), the *Mary Rose* (UK) [1] and the *Batavia* (AU) (unpublished results), accumulation of sulfur and iron in varying amounts have been found in archaeological wood from aquatic environments around the world [1]-[3].

Waterlogged wood is degraded in marine sediments by erosion bacteria capable of decaying lignocellolytic material [4]. Also the enrichment of sulfides in wood embedded in organo-rich sediments is explained by microbiological wood degradation [5]. XANES analyses, X-ray and light microscopy studies, combined with isotopic analyses of archaeological wood from the *Vasa* and wood from simulated laboratory experiments made it possible to link the sulfur and iron accumulation to microbial processes in the seabed [1]. In low-oxygen environments sulfate reducing bacteria (SRB) forms hydrogen sulfide, which reacts to form mainly organic sulfur compounds in the lignin-rich part of the wood, or iron(II) sulfides in the presence of corroding iron [1]. After the salvage of the wood, the unstable iron(II) sulfides [6] start to oxidise with sulfuric acid as the end product. This process has been observed as acidic sulfate salt precipitates on the wood surface of museum shipwrecks. The formation of sulfuric and also organic acids in the wood may have long-term detrimental effects on the physical integrity of the hull and the fragile surface carrying invaluable archaeological information [1].

THE ROLE OF SEDIMENTS

Waterlogged archaeological shipwrecks are often considered relatively well-preserved in seabed sediments. The low salinity of the Baltic Sea water prevents destructive marine borers, and the seabed conditions often may seem to contribute to a preserving environment for the wooden material [7]. However, the general knowledge is rather limited about the actual influence from sediments on the degree of degradation on the archaeological organic material imbedded therein. Sediments are usually considered to have a protective effect by creating an anaerobic environment. However, sediments may also involve corroding forces of mechanical and physical nature. Moreover, the destructive effects on the wood explained by chemical and biological activities, both aerobic or anaerobic, can be associated to certain types of sediments [2], [3].

PREDICTING WOOD PRESERVATION STATUS

Different types of waterlogged environments involve a variety of natural processes, either in favour of preservation or acting to degrade organic material. The environmental parameters of most significance for wood preservation may differ also within the same geographical location. These parameters are interrelated, but also act upon the wood and wood-degrading organisms independently. The conditions and the mechanisms at the interface, such as the sediment-water interface are of specific interest because of their extreme variability of activities [8].

For improved understanding of the different biogeochemical mechanisms of most significance for wood preservation and to be able to connect them with key parameters in the wreck site environment, it is essential to have further insight of the seabed sediment interactions at different wreck sites. An important approach to investigate the role of the sediments involves documentation of the degree of degradation of waterlogged wood from different seabed environments. The preservation status should be classified in terms of both microbial wood decay progresses and distribution of inorganic contaminants, however not only for the concentrations of sulfur and iron.

SURVEY OF THE FIELD

INORGANIC FINGERPRINTS IN ARCHAEOLOGICAL WOOD

The sulfur and iron penetration profile from the surface throughout the wood has earlier been analysed and mapped in wood from several shipwrecks from the Baltic Sea. The results suggest the accumulation of inorganic elements to be strongly related to the successive microbiological decay of waterlogged wood. However, the degree of preservation of the wood and the distribution of accumulated sulfur and iron can differ significantly in waterlogged shipwrecks from different seabed environments, and sometimes also within an object or between wooden objects from the same wreck site [1]-[3]. This observation led to the hypothesis that the accumulation profiles of sulfur, iron and maybe also other inorganic elements throughout the wood cores may serve as a biochemical "fingerprint" of the (former or present) environment on the seabed wreck site.

XRF-analyses of wood samples from many wrecks display accumulation profiles which in many ways resemble those from the *Vasa*, where the timbers were bacterially degraded only in the outer wood surface. Sulfur and iron have also accumulated mainly in the same regions that show biodegradation. In addition to the Vasa wood, other shipwrecks from the Baltic Sea such as the *Kronan* (*Crown*) (Fig. 1), the *Svärdet* (*Sword*) (Fig. 2) and the *Spökskeppet* (*Ghost wreck*) (Fig. 3) display highest sulfur and iron concentration mainly at the ends of the analysed wood core samples [2]-[3].

However, earlier analyses of the *Götavraket* from the Swedish West coast and the *Batavia* from Western Australian (data not yet published) show more irregular XRF-profiles of sulfur and iron. These cores were more similar to the accumulation profile of the samples from the British *Mary Rose*, which was degraded in pockets all through the hull [1]-[3].

OVERVIEW OF A NEW RESEARCH PROJECT

The variations in accumulation profile involve significant differences for the conservation and long-term preservation of the objects, and need to be connected to key biogeochemical mechanisms in the environment of the wreck sites. Therefore, sediment samples were recently collected in the vicinity of strategically selected wreck sites in the Baltic Sea with varying degree of wood decay for full elemental analyses and ^{137}Cs analyses to date the sediments. Also, by XRF-analyses of the waterlogged wood the penetration profiles of other elements other than sulfur and iron were measured.

An initial observation was an increased concentration of inorganic elements in the wood and in fine grained sediments from accumulated seabed environments of fluctuating oxygen levels. Correlations were also noted between the penetration profile of sulfur and iron in the wood with the profile of other inorganic elements associated with natural seawater redox reactions (unpublished results).

Microbial decay of wood by specialized wood degrading bacteria and fungi in marine environments are well-known [4], [11]. Submerged wood provide environment-adaptive ecosystems of high microbial diversity and activity. These diverse habitats for microbial communities offer conditions suitable also for consortia of sulfur cycling bacteria [9]-[10]. The scavenging SRB depend on the previous activity by true wood degraders, such as erosion bacteria, commonly occurring in submerged wood [1], [4]. Sulfur recycling is in turn required for the complex symbiotic interactions associated with microbial decay of waterlogged wood [5], [9], and is likely coupled to the benthic nitrogen and manganese redox cycles in nearshore sediments [13]. SRB and the consortia of marine bacteria also seem to be very adaptive to the environment. Different species of sulfur bacteria have been reported to segregate and operate at different depths in wood [10], [13], probably related to decreasing redox levels. The interactivity between all these bacteria is mainly unknown but investigations of microbial communities inside the wood indicate a large number of bacterial species [10], [13], [14].

The depositional process of how wood is incorporated into the wreck site matrix is a geochemical key factor for the preservation of organic material in waterlogged environments [15], [16]. A systematic model in marine environments by Ward et al (1999) incorporates physical, biological and chemical processes in describing the wreck site formation with predictive and measurable parameters [17]. Apart from mechanical erosion by the physical transport of sediment, the decisive environmental parameters, directly or indirectly controlling the microbiological degradation activity as well as the number and diversity of microbial species are: redox potential (Eh), composition of organic matter, water input, depth of burial, moisture, oxygen, pH, temperature, salinity, conductivity, as well as the characteristics of the clay or sediment type, such as content, particle size and surface (ion exchange capacity) [4], [7], [14], [17], [18]. However, the degradation ultimately depends on the availability of electron acceptors and certain chemical species [14], [19]. The oxidants are consumed in order of decreasing energy production per mole of organic carbon oxidized (oxygen > manganese oxides > nitrate > iron oxides > sulfate). This motivates the analyses and mapping of inorganic redox elements in the wood other than sulfur and iron.

CONCLUSIONS AND DISCUSSION

Wood degradation and accumulation of inorganic elements in marine sediments are controlled by bacterial activities. Submerged wood provides strongly environment-adaptive ecosystems of high microbial diversity and activity. Earlier analyses indicate at least the sulfur accumulation in wood to be strongly associated with preceding microbiological decay.

The accumulation profile of sulfur and iron can differ significantly in waterlogged wood from different wreck sites worldwide. The variations in accumulation profile involve significant differences for the conservation and long-term preservation of the objects. To connect the variations to key biogeochemical mechanisms in the environment with the most decisive effect on the degradation within a particular wreck site, it is essential to possess a deep knowledge of the seabed interactions especially in the benthic environment of the water-sediment interface.

Initial analyses may give important clues about the key mechanisms and characteristics of sediments with largest consequence for the degradation and contamination of submerged wood in the seabed. The involvement of other redox systems coupled to microbial habitats associated with degradation of waterlogged wood need to be revealed. Understanding of the biogeochemical processes within the

Fig. 1. *XRF-scanning of the Crown samples 1a & 2b: (a) the more anaerobically preserved wood of sample Crown 1a shows lower accumulation of sulfur (but not iron) than the relatively aerobic sample Crown 2b (b); all images in the paper reproduced by permission of Nature Publishing Group*

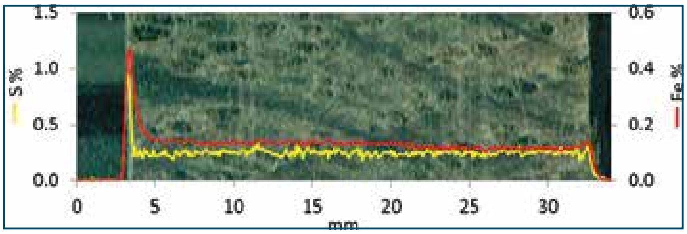


Fig. 2. *XRF-scanning of the Sword samples 1-1d & 1-2d: the samples from the Sword show closely correlated sulfur and iron accumulation profiles throughout the wood samples, however sometimes with a small shift between the larger sulfur and iron peaks at the surfaces*

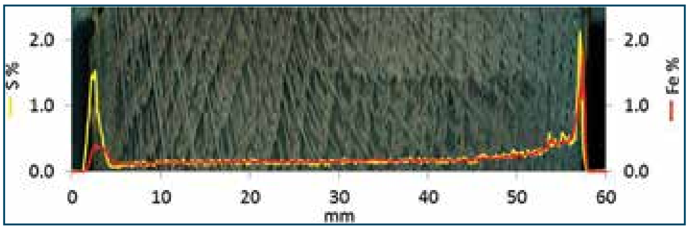
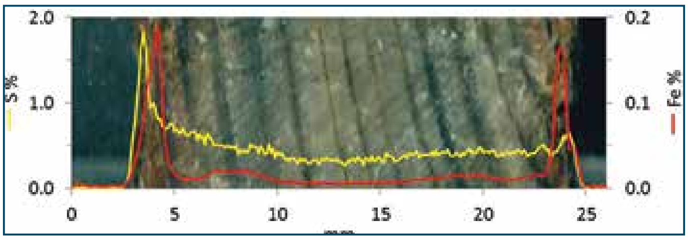


Fig. 3. *SXRF-scanning of the Ghost wreck samples 1c & 2b: (a)The iron and sulfur accumulation profile indicate fairly correlated profiles throughout the wood, although the larger peaks appear slightly shifted close to the surface region in sample Ghost 1c. The iron concentration in the inner parts of the wood is generally low: ~0.2 mass% Fe in Ghost 2 and <0.02 mass% total Fe in Ghost 1*



sediment and the interactions with wood in shipwreck timbers at different conditions will increase the possibilities for long-term preservation of these unique cultural heritage objects both in the seabed and on museum display in the form of well-adapted conservation procedures.

Conservation methods applied to waterlogged wood increasingly rely on combining modern analytical techniques to obtain new insights for improved actions for long-term stability for archaeological wood and shipwrecks. The overarching goal would be to develop tools for predicting local preservation prerequisites and status of wooden archaeological artefacts in different seabed environments. With this information at hand there are also implications for improving the long-term stability of wood in different environments. However, most shipwrecks will remain in their seabed environment due to the huge cost of salvage and conservation. Therefore a fundamental understanding of sediments, as a protective or destructive layer and the biogeochemical processes therein is essential for the long term security of the wooden cultural heritage still resting in marine environments. This information will improve the scientific basis for better predictions of wood preservation status, which would be invaluable when localizing yet unknown shipwrecks, and a support for the decision-making about suitable sites for in-situ-preservation and reburial of shipwrecks in line with UNESCO Convention 2011 (http://www.unesco.org/new/en/culture/themes/underwater-cultural-heritage/).

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Waterlogged archaeological wood from Biskupin site: multi-analytical approach for decay diagnosis

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INTRODUCTION

In 1933 a fortified settlement dating back to the Bronze and early Iron Ages (around mid 8^{th} century BC) was found in Biskupin, Poland. The site was situated on a marshy island, occupying an area of about 2ha. Several excavation campaigns were conducted between 1934 and 1974 [1] which highlighted that the village was abandoned after around 150 years of occupation, probably due to gradual flooding caused by violent climate change and the subsequent rising of the lake-water level [2]. At the end of the archaeological campaign in 1974, the findings included a considerable amount of oak- and pine-wood, as well as troughs made of lime-wood, a birch-wood ladle, an ash-wood disk wheel, a canoe hollowed out of a spruce tree trunk, and an alder-wood structural element from one of the houses. It was estimated that the construction of the Lusatian settlement in Biskupin absorbed at least several thousand cubic meters of wood.

In 1974, the excavation works were stopped and it was decided to adopt an *in situ* conservation strategy by leaving the wood remains in the environment in which they had been found, either in the ground or water. Today Biskupin is an open-air museum, where it is possible to visit a reconstruction of the ancient village, whereas the archaeological wood is still kept underground.

It is known that waterlogged conditions are ideal for the long term conservation of archaeological wood. Anaerobic conditions and low temperatures prevent the biodegradation of wood by white rot fungi, brown rot fungi and insects. However soft rot fungi and bacteria are still active in waterlogged conditions and can slowly degrade wood, resulting in alterations in the physical, chemical and mechanical properties [3]-[5]. In addition, since excavations started in Biskupin, and because of climate changes, there have also been changes in the burial environment, such as the lowering of the ground water and aeration of the soil. These phenomena could have contributed to accelerate the decay of the wood and it is therefore necessary to understand the dynamics of degradation.

Wood is a very complex material from a chemical point of view and its complexity is enhanced due to degradation [6]. Complementary approaches need to be used in order to assess the conservation state of wood from different points of view. Physical properties are very important, because they are related to the usability and the general strength of wood. Studying the wood morphology is also important, because it provides information on biological attacks and the structural integrity. Finally, the assessment of the state of degradation from a chemical point of view provides information on the components of the wood at the molecular level [7], [8].

CHEMICAL ANALYSES OF WATERLOGGED ARCHAEOLOGICAL WOOD

Samples: Eight archaeological oak wood samples were analysed, taken from five different fragments originally belonging to the pavement of the ancient settlement (Fig. 1). The fragments were taken from different areas of the archaeological site. Some samples were taken at different depth from the surface: A – outermost, B – middle, C- innermost part of the fragment. Fragment Oak 4 (A, B, C samples), fragment 199 (A and B samples) and the samples from fragment Oak 5, Oak 6, Oak 106, corresponding to the innermost part of fragment. The reference sample of 69-year old oak wood was also analysed and results were compared with those obtained for archaeological wood samples.

APPARATUS

In order to assess the preservation state of wood, three complementary approaches were applied.

- SEM was used in order to obtain information on biological attacks and structural integrity,
- The classical wet chemical analysis of wood components was performed using three independent standard methods. The determination of acid-insoluble lignin was assessed according to T 222 om-06 standard TAPPI method [9]. The analysis of the holocellulose content was conducted according to the chlorite method [10]. Cellulose content was determined according to the Seifert method [11],
- Analytical pyrolysis was performed using 1,1,1,3,3,3-hexamethyldisilazane (HMDS, chemical purity 99.9%, Sigma Aldrich Inc., USA) as silylating agent for the *in situ* derivatisation of pyrolysis products. Conditions of pyrolysis methodologies are described in [12].

SEM INVESTIGATIONS

One of the signs of the degradation process is structure deformation. It may also be the result of mechanical stress. In Fig. 2 are present the images recorded for all the analysed samples. In the samples taken from fragment 4 can be observe different level of degradation of the cell wall. The sample 4A presents important deformation of the cell wall and significant reduction of their thickness, indicating degradation of the secondary wall cells as a consequence of the degradation of carbohydrates. Slightly better preserved is sample 4B, however the cell wall presents deformation. Sample 4C appears better preserved with respect to the others from the same fragment. The same behaviour is observed also for samples from the fragment 199, A and B. More degraded is sample A, their wood tissue consists mainly of middle lamella, which confirms the high content of lignin in examined tissues with respect to holocellulose. The sample from fragment 106 presents some sporadic cracks of cell wall as in sample 4B. Samples 4C, 199B, 5 and 6 look similar, they seem to be slightly better preserved with respect to the others. In these samples the degradation can be observed from defoliation of the cell wall, which is a result of the loss of low-polymerized carbohydrates.

CHEMICAL CHARACTERISATION

Classical analysis

In order to assess the state of preservation of principal components of wood (holocellulose and lignin) from a chemical point of view we applied three independent classical wet methodologies. They are based on the separation, purification and quantitation of wood constituents by weight. Table presents the percentages of wood components, holocellulose and lignin. The ratios between holocellulose and lignin were also calculated. This ratio is a very important index as it constitutes information about the level of degradation in terms of loss of polysaccharides. It allows to evaluate the level of preservation comparing the ratio H/L of the reference sample with those obtained for archaeological wood samples. In fact the better preserved wood in terms of loss of polysaccharides with respect to sound wood are samples 4C, 106 and 199B, while the more degraded are samples 4A and 199A. This was in agreement with the fact that samples 4A and 199A corresponded to the outermost part of the analysed fragments, more exposed to the burial environment.

Analytical pyrolysis (Py(HMDS)-GC/MS)

In order to investigate changes in wood components in more detail and to understand how wood degradation can affect the polymers in the structure of wood, analytical pyrolysis coupled with gas chromatography and mass spectrometry was applied. Quantitative interpretations of complex pyrograms presenting a high number of peaks are often difficult, and results are semiquantitative. The summed areas of the relevant peaks were normalized to 100% and the data for the three repetitive pyrolysis experiments were averaged. The Histogram plot shown in Fig. 3 is very useful to compare sound and archaeological wood samples. As clearly shown in the graph, the strongest changes due to the degradation processes (e.g. low polysaccharides content) were observed in sample 5; slightly less with respect to sample 5 are samples 106, 4A, and 199A. Samples 4B, 4C, 6 and 199B appear to be only a little or not degraded in terms of carbohydrates and lignin content with respect to other investigated samples and sound wood.

In order to investigate the alterations of the single biopolymers more in detail we considered the various pyrolysis reaction pathways undergone by lignin and carbohydrates.

The pyrolysis of lignin lead to the formation of monomers (coniferyl and sinapyl alcohols) as the primary pyrolytic reaction, due to the predominant initial cleavage of the β-ether bonds between phenylpropane units. On the other hand, reactions involving conversion/alteration of the side-chain and the methoxy substituents on the aromatic ring are secondary reactions, which lead to the formation of guaiacyl and syringyl units with shorter side-chains and different functionalities [13], [14].

According to this categorization, we calculated the relative sum of these groups of lignin pyrolysis products. The most remarkable observations were the reduction of monomers, the relative increase in short chain and a slight increase in carbonyl and carboxyl (Fig. 4). Since monomers are the most abundant in sound wood, this reduction can be considered as an index of alteration (probably depolymerization). On the other side carbonyl and carboxyl are an index of slight oxidation of lignin.

The pyrolysis of cellulose and hemicelluloses involves chain scission and water elimination as primary reactions, leading to the formation of anhydrosugars as the most abundant pyrolysis products. Secondary pyrolysis reactions involve further decomposition and the rearrangement of anhydrosugars, which produce smaller molecules, such as furans, pyrans and cyclopentenones [15]. In sound wood anhydrosugars and cyclopentenones are produced in similar relative amounts (Fig. 5). We observed a general increase in cyclopentenones and decrease in anhydrosugars in archaeological samples, suggesting that the conversion of anhydrosugars to cyclopentenone is enhanced. This can be related to degradation of the carbohydrate structure because secondary pyrolysis reactions (conversion of anhydrosugars to smaller molecules) occur when the polymer is less coherent.

CONCLUSIONS

Results obtained for the samples from the Biskupin site confirmed how the chemical analysis of archaeological wood is a valuable tool used to establish its state of preservation and to compare differences in degradation for different artefacts and samples with a quantitative approach. The SEM investigations allow morphological study of wooden structure and provide information about structural integrity and biological attack.

Classical wet chemical analysis enabled us to identify the best preserved and the most degraded samples in terms of loss of hemicelluloses and cellulose and the decrease in the H/L ratio with respect to reference wood.

Py-GC/MS confirmed the results obtained by classical wet chemical analysis and permit to investigate changes in wood in more detail. The agreement between SEM, wet chemical analysis and Pyrolysis results were highlighted.

Fig. 1. *Fragments of archaeological waterlogged wood from Biskupin site*

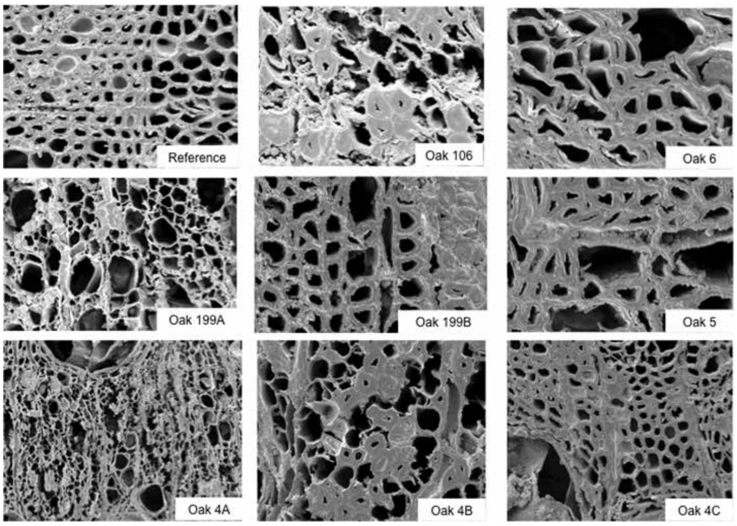

Fig. 2. *SEM images*

Percentages contribution of principal components of wood obtained by classical wet analyses

NAME OF OAK SAMPLE	HOLOCELLULOSE	LIGNIN	H/L
Reference	66.4 ± 0.4	25.5 ± 0.2	2.6
Oak 4A	26.1 ± 0.5	59.0 ± 0.4	0.4
Oak 4B	40.3 ± 0.5	44.2 ± 0.5	0.9
Oak 4C	48.4 ± 0.4	38.5 ± 0.3	1.3
Oak 5	42.1 ± 0.4	42.3 ± 0.1	1.0
Oak 6	47.1 ± 0.3	43.7 ± 0.5	1.1
Oak 106	50.9 ± 0.4	37.3 ± 0.1	1.4
Oak 199A	22.7 ± 0.6	64.1 ± 0.7	0.3
Oak 199B	57.0 ± 0.3	32.5 ± 0.3	1.7

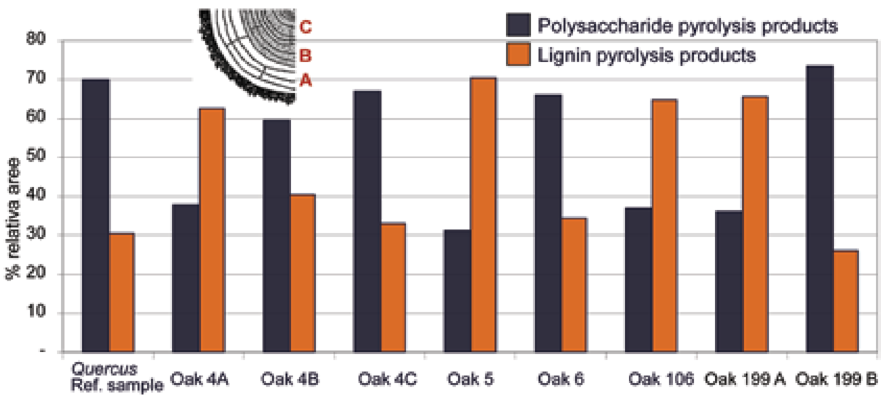

Fig. 3. *Semi-quantitative results obtained by Py(HMDS)-GC/MS*

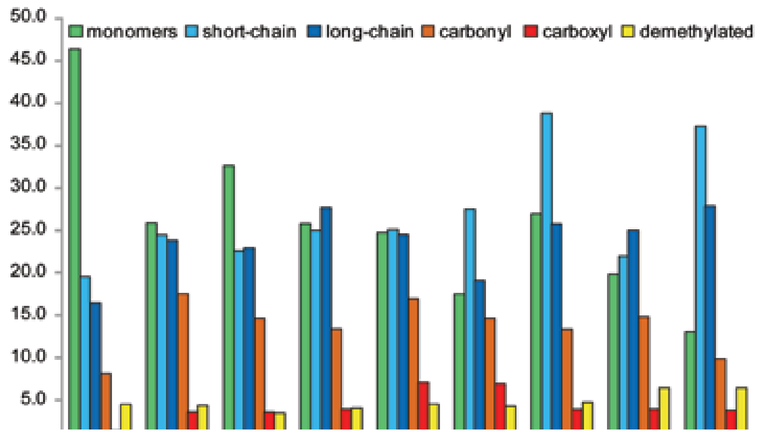

Fig. 4. *Distribution of lignin pyrolysis products*

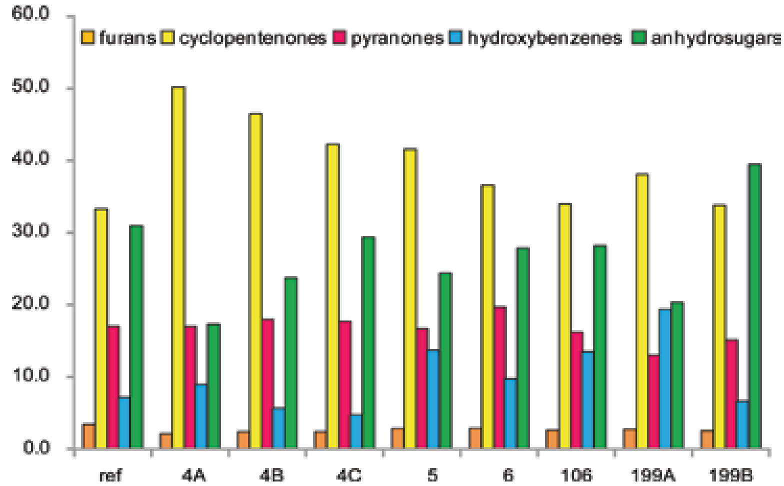

Fig. 5. *Distribution of polysaccharides pyrolysis products in Fragment 4*

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Research on physical and chemical properties of waterlogged wood

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INTRODUCTION

Wood under marine conditions, especially in direct contact with seawater, is exposed to many biological, physical and chemical destructive factors which in varying degrees and time lead to its degradation. Depending on the location of wood, the residence period in the sea, the intensity and type of destructive factors present, wrecks of wooden ships remaining at the bottom of the sea buried in sediments or just submerged in seawater show various stages of destruction. Knowledge about the rate and size of changes taking place in wood located in the sea, in wet archaeological sites, is incomplete and requires continuous studying. Issues related to the knowledge of properties of wood submerged in the sea, the level of its decomposition and further protection and conservation have become in recent years of growing importance in relation to the visible- especially in Europe- desire to save and preserve archaeological objects of cultural heritage.

In recent years, *in situ* protection of underwater archaeological sites has gained increasing importance. This is also reflected in the provisions of the UNESCO Convention from 2001 on the Protection of the Underwater Cultural Heritage [1]. According to this document, protection of Underwater Cultural Heritage *in situ* is suggested as a first option.

The Rules of this Convention described in detail the conservation programme for long-time preservation. It should involve many activities, such as preparation of documents including condition report, monitoring system and inventory (Rule 26) as well as underwater prospection (Rule 16) [2]. Particularly important are observations of changes in these environmental conditions and threats in the area of the underwater archaeological sites [3].

One of the methods for monitoring the degradation of archaeological wood, as well as the possible attack of marine-borer organisms, is the study of changes in modern wood submerged around archaeological sites [4]-[6].

In order to know the effect of the underwater marine environment on changes of properties of wood, contemporary wood samples after several years of exposure to underwater archaeological sites and selected sample from archaeological wooden shipwreck remaining on the seabed of the Baltic Sea were tested. The content of major and minor components of wood and the total content of minerals were determined. Some physical properties and strength of wood were examined.

RESEARCH AIM

The aim of the research was to determine the changes in physical, chemical and biological properties of wood caused by the submergence of samples for different periods of time in the Puck Bay (the Baltic Sea) in comparison with the properties of twin control samples, which had not been submerged in sea water. Chemical properties of modern wood after exposure in the Baltic Sea were compared with properties of oak wood sample from an archaeological shipwreck.

MATERIALS AND METHODS

Experimental samples (beams) with dimensions of (250×10×10) mm were prepared from sound oak heartwood (*Quercus robur* L.). The beams were placed at an archaeological site located in the waters of Puck Bay within the area of the medieval seaport in Puck, at depths of two meters [4].

In samples removed from the seawaters the following properties were studied:

- physical properties – wood density, the equilibrium moisture content, bending strength and compression strength along the grain,
- chemical properties – content of extracted substances (in ethanol), substances soluble in water, and in 1% NaOH aqueous solution (polioses), Seifert cellulose, Klason lignin, pentosans, mineral substances,
- resistance to *Basidiomycetes* fungi: *Coniophora puteana* (Cp) and *Trametes versicolor* (Tv) [5], [6].

For comparison of chemical properties, archaeological oak wood from sailing shipwreck (19^{th} century) remaining on the seabed of the Baltic Sea was selected (Fig. 1).

RESULTS

After exposure periods of one to three years, the test samples of oak wood were removed from the seawaters of Puck Bay archaeological site. Visual observation and photographic documentation were performed in the laboratory (Fig. 1). The tested samples were darker in comparison with control samples in wet and dried states. On the surface of the samples removed from seawater, *Balanus improvisus* and *Mytilus trossulus* as well as seaweed were present (Fig. 1).

The equilibrium moisture content in the wood under standard conditions 20°C/65%RH distinctly increased (Fig. 2.).

Fig. 1. *The samples removed from the Puck Bay after three years of immersion and the oak wood sample from shipwreck; photo Hanna Wróblewska*

Wood density and bending strength, as well as compression along the grain of the tested samples after conditioning decreased (Fig. 2, 3).

The amount of main components of wood – cellulose, hemicelluloses, lignin, did not significantly change during the periods of immersion in comparison to control oak wood samples (Fig. 4). The content of water soluble substances and extractives (ethanol) decreased (Fig. 4.). The amount of mineral substances (ash) significantly increased both in contemporary wood immersed in seawaters of Puck Bay and in the archaeological oak wood sample from the shipwreck.

Up to 3 years exposure of sound oak samples in marine environments caused changes in physical and chemical properties of wood in comparison with control oak samples (Fig. 2-4). These changes indicate a progressive biodegradation of wood in natural underwater conditions (Puck Bay).

The study showed (mass loss 7.7% and 32.3%) a significant increase in the susceptibility of wood to degradation caused by fungi *Basidiomycetes* (Fig. 5), the loss of mass caused by other factors than fungi were only 0.8-0.9%.

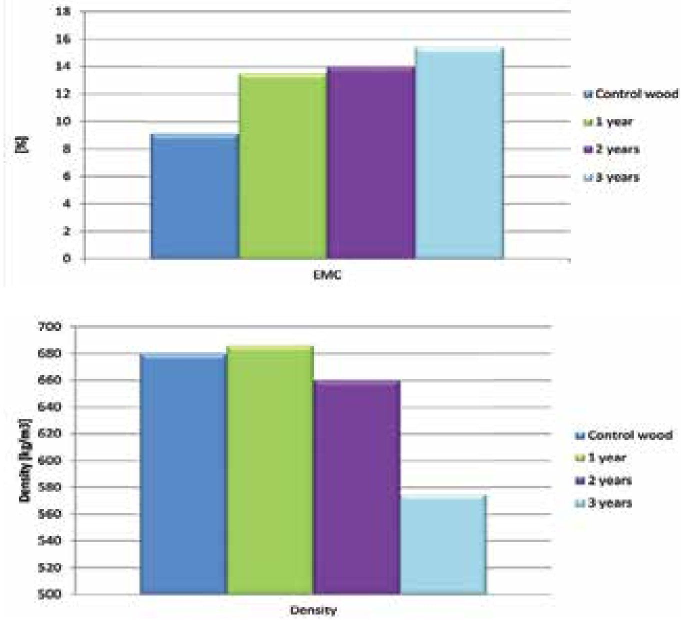

Fig. 2. *Equilibrium moisture content and wood density in the tested oak wood samples under standard conditions 20°C/65%RH*

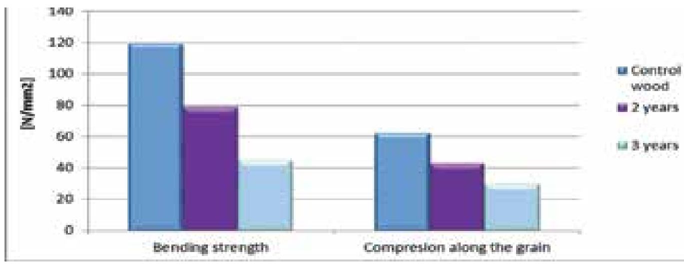

Fig. 3. *Bending strength and compression along the grain of contemporary oak wood samples after underwater exposition*

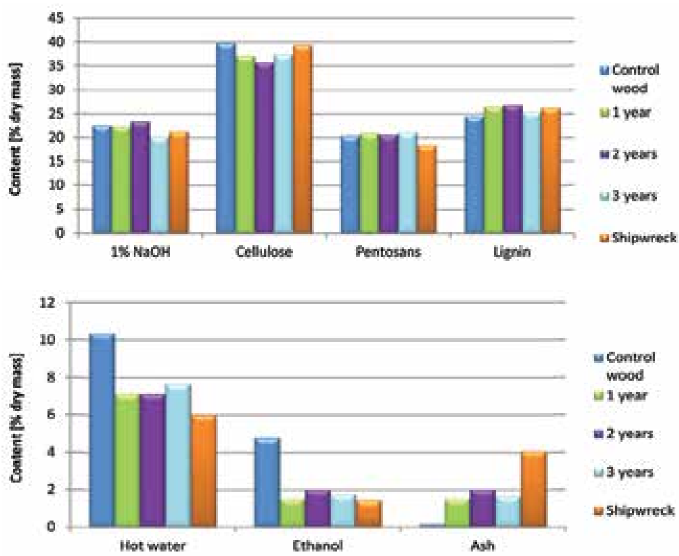

Fig. 4. *Major and minor wood components of contemporary oak wood after exposition in waters of Puck Bay and in archaeological oak wood sample from shipwreck*

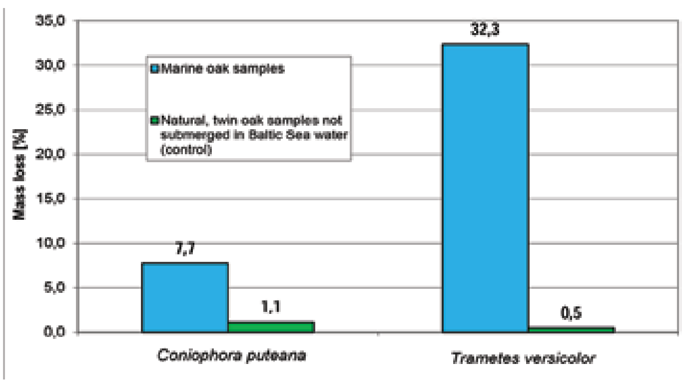

Fig. 5. *Mass loss of oak wood due to Basidiomycetes after exposition in Baltic Sea (three years exposition, Puck Bay)*

CONCLUSIONS

It was found that an immersion of oak wood in the waters of Puck Bay for a period from six months to three years caused significant changes to its physical, chemical and biological properties.

Further observations of changes occurring in contemporary wood, used as an indicator (bioindicator), can be useful in the monitoring of underwater archaeological sites.

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Learning from Nature – on the way to new materials for conservation of archaeological wood

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INTRODUCTION

In the 1990's conservators at the Museum of Cultural History in Oslo recognized serious damages of wooden objects from the Oseberg collection, conserved with alum salt after excavation in 1904. Today the objects are highly degraded and the wooden structure is widely destroyed [1], [2]. The artefacts are in an alarming condition and need to be consolidated. Similar observations were made in collections in Sweden and Denmark.

Which materials are suitable to consolidate the artefacts? Common materials like PEG or kauramin have some drawbacks; this lead us to look for alternatives and to establish a research project on "bio-inspired and biomimetic materials for the conservation of archaeological wood". The present contribution describes some thoughts around the potential use of biomimetic materials in wood conservation.

WHY ARE WE LOOKING FOR NEW CONSERVATION MATERIALS?

There is a rich choice of consolidants for archaeological wood available. However, many materials have clear drawbacks. Some materials are not resistant against metal ions that are present in the Oseberg wood as in many other wooden artefacts Other materials degrade over time or don't penetrate the wood completely. Some polymers don't cure sufficiently and stay in a viscous state over years.

Most striking, however, is the question of re-treatability. No consolidant will preserve an object forever. It will undergo ageing and degradation processes, and as conservators we have to consider how the condition of a treated object will be in fifty or hundred years. Therefore the conservation community has established that every material used to conserve an object has to be reversible. However, in practice removal of an old consolidant may be very difficult. The consolidant needs to be washed out using water, an organic solvent or supercritical carbon dioxide. This is not doable in cases of highly fragile objects such as like many of the Oseberg artefacts. The requirement for reversibility should be replaced by finding an option that ensures future treatments.

Re-treatment without removal of the old consolidant can only be done if there is enough space in the wood structure to allow the new consolidant to penetrate. However, most polymers used today form a 'plastic block' that does not allow future penetration. Therefore we aim to develop a material that exhibits an 'open' porous structure giving space for future re-treatment Moreover, a similar ageing behaviour of wood and consolidant is desirable. Biopolymers and their derivatives – bio-inspired materials – are promising candidates for future conservation materials.

WHAT DOES 'BIOMIMETIC MATERIALS' MEAN?

'Biomimetic' means to mimic structures and materials found in nature. It is more a concept and a way of thinking than a specific group of materials. The biomimetic approach is used in such different areas as architecture, medicine, material science, robotics, optics, catalysis and many others. It is probably one of the most successful concepts in material sciences and related fields, and we should try to use it in conservation science as well.

Development of biomimetic materials for wood conservation is based on the use of bio-polymers. The polymers may be modified or combined with organic or inorganic compounds, forming hybrid and composite materials. However, we are not only looking at the material by itself, we are also interested in structures formed by those materials and the functions they fulfil. Natural structures are very efficient and combine stability with flexibility. This can be achieved by combination of different materials, like the combination of inorganic and organic materials in bones. In spider silk fibres, the alteration of crystalline and amorphous domains results in the unique properties of this material. To ensure an efficient use of material but create stable structures at the same time, nature prefers open structures, as we are aiming for new conservation materials.

Natural structures are built up hierarchically: starting with single molecules, structures with an increasing complexity are built up. On every hierarchical level the material performs different functions. In the case of wood conservation desirable functions are, apart from consolidation, anti-microbiological properties, control of pH value in case of acidic wood or trapping of potential harmful metal ions. Hierarchical organised molecular networks, built up by units fulfilling different tasks and based on biopolymers, may be the future of wood conservation materials. Recently Walsh et al reported on the PolyCatNap a material built up from chitosan, guar, catechol and a crown ether, which is able to consolidate wood, trap metal ions and counteract micro-organisms [3].

ATTEMPTS TO USE BIOPOLYMERS

Cellulose as a natural wood component seems to be a promising candidate for a bio-inspired consolidant. However, the large size of the molecules makes it impossible to penetrate wood samples. Even the use of cellulose whiskers in the nanoscale range was not successful, due to flocculation of the particles [4].

More promising is the use of lignin and lignin-like materials. Attempts were made to use phenol formaldehyde polymers, like bakelite which is well-known as one of the first widely used plastics. Phenol formaldehydes exhibit lignin-like structures. They are very durable but brittle and probably not removable; it is very unlikely that a future re-treatment of objects conserved with phenol formaldehyde polymers will be possible. However, the penetration of wood with lignin monomers or oligomers and their polymerisation inside the wood seems to be a way to create a stable structure that is able to stabilise the wood [5].

Chitosan is a derivate of chitin and related to cellulose. First attempts to penetrate wood with chitosan were successful [6]. Chitosan may not only stabilize the wood but also chelate and inactivate metal ions.

HYBRID AND COMPOSITE MATERIALS

To combine biopolymers with other organic units or with inorganic compounds is a promising way to improve the properties and design molecules or networks for specific purposes. Metal-organic networks (MOFs) are of increasing importance in many fields, and we can again ask the question: how can conservation benefit from this development? Cellulose, for example, doesn't work properly as a wood consolidant but may be an excellent gap filler or may be used as protective coating in form of nanocellulose layers. The combination with inorganic compounds, for example with boron nitride, increases the stability of the material [7].

Silicon-based networks are currently under consideration. Very promising is the combination of silicon with lignin oligomers and with chitosan. Such hybrid materials do not only stabilize the wood but may also complex metal ions, forming multifunctional networks.

OUTLOOK: SELF-HEALING MATERIALS

One of the most impressive attributes of living organisms is their capability to repair damages. No conservation material will last forever. Wouldn't it be ideal to mimic self-healing and create a material that does not require re-treatment after a certain time but repairs itself? Many research efforts are currently going on to develop such self-healing materials for different purposes. In focus are self-healing polymers and concretes.

Most self-healing materials are made to hinder crack formation. The formation of cracks begins with forming microcracks on a microscopic level. Microcracks propagate through the material and merge, forming macroscopic cracks. A self-healing material is designed to stop crack formation as long as cracks are on a microscopic level. This can be done by implementing microcapsules filled with a healing agent into the material. Hits a microcrack the capsule, will the capsule be ripped and the healing agent be released. The healing agent polymerises, catalysed by a catalyst present in the the original material. The polymer fills the crack and further crack formation is prevented.

CONCLUSION

The present contribution gives only a first impression of the ongoing research within the scope of the 'Saving Oseberg' project. However, the authors hope to show the potential of the biomimetic approach in conservation science and to raise the readers' interest in the possibilities of new, bio-inspired materials in the field of wood conservation.

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Bio-inspired materials for the preservation of archaeological wood: Lignin

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INTRODUCTION

There is much need for new consolidants capable of preserving archaeological wood. Current materials include PEG (poly ethylene glycol), Kauramin (melamine formaldehyde), and sugars [1]. While PEG and sugars can be washed out of the wood given time, they often do not offer sufficient support for larger objects. Melamine formaldehyde on the other hand, cannot be removed but may not be evenly distributed. Even though these materials are used regularly none of them have ideal physiochemical characteristics required from a consolidant.

In Norway, the Oseberg Ship finds are of high cultural significance as a showcase of the wealth and power Norway possessed in the Viking age. The wooden objects were originally treated with alum ($KAl(SO_4)_2{\cdot}12H_2O$), which involved boiling the objects in a supersaturated alum solution at close to 100ºC. In the century which has passed since the treatment of the Oseberg artefacts, the objects have become increasingly unstable. Most are now unable to support their own weight and cannot be safely moved from their current display frames. Low pH (ca. 1) and metal ions present in the wood from both treatments and the numerous metal screws and nails used to fasten the many wooden parts to the metal frames, have resulted in degradation of even the lignin. If nothing is done, the most famous Viking Age find in Norway will be irrevocably lost!

When designing new materials for the conservation of archaeological wood it is vital that the object has an open structure after treatment, leaving room for future re-conservation of the artefact in case the current consolidant proves to be unstable. Additionally, the material must be compatible with the existing wooden structure (which shrinks and swells with changes in relative humidity) and be strong enough to support the finds despite having an open structure.

In order to develop a material that is able to fulfil all of these roles attention has been turned to nature. Biopolymers lignin and cellulose are responsible for the strength in wood and have an open structure. The solution to consolidation of archaeological wood could be found in biopolymers that can offer the support and flexibility needed and potential to serve multiple functions, trapping the metal ions present in the wood and preventing further degradation.

EXPERIMENTAL

Isoeugenol (1 w/v%) in water: ethanol (1:1, 4 mL), was added dropwise to a solution of water: ethanol (1:1, 8 mL), Cu(Salen) Na_2 (0.02 w/v%) and hydrogen peroxide (10 mol excess with respect to isoeugenol) with stirring. The mixture was then stirred for 48 h before quenching with water (15 mL). The polymers were extracted into ethyl acetate (3 x 20 mL), washed with brine (3 x 20 mL), dried over sodium sulphate and concentrated *in vacuo*.

RESULTS AND DISCUSSION

Synthesis of lignin-like oligomers has been carried out using isoeugenol. Initially a copper salen catalyst was utilised to carry out the polymerisation. The polymerisation reaction gave oligomers for all the analysed conditions, as shown in the Table. Reactions 1 and 2 were under the same conditions, only with and without the catalyst respectively to assess the efficiency of the catalyst. Unexpectedly the results show only a small difference in the molecular weight averages of the oligomers, with the polymerisation without catalyst giving slightly higher molecular weight averages by Gel Permeation Chromatography (GPC). Changes in pH showed an increase in range of molecular weight averages for both acidic and basic conditions and that acidic conditions disfavoured polymerisation. This suggests that *in situ* polymerisation within the Oseberg wood will not give large species under these conditions.

To evaluate *in situ* polymerisation, conditions **3** were used with a fragment of waterlogged Viking Age archaeological wood that had not been previously treated or dried. The reactions were carried out as for the normal reactions but with the fragment placed in the solution and occasional gentle shaking in place of constant stirring. As a result, the polymerisation took longer but it seemed to give the smallest range of molecular weight averages.

NMR was carried out on acetylated samples from all reaction conditions and compared to that of polymers with known lignin-like structure. C13 and HSQC enabled accurate labelling of the most common cross-linking observed between monomers. Species formed from reactions with and with-out the catalyst showed evidence of containing the same cross-linking across the different sized species. This suggests that polymerisation is occurring by a lignin-like mechanism and resulting in lignin-like species.

Conditions for polymerisation of isoeguenol using a bulky salen catalyst and the relevant GPC results

	CAT W/V%	MOL EXCESS OF H2O2	REACTION TIME, DAYS	PH	MN	MW	PDI
1	0.02	10	2	7	906.17	1268.69	1.4
2	None	10	2	7	993.22	1360.89	1.4
3	0.02	10	5	7	1012.92	1309.38	1.3
4	0.02	10	3	4	574.57	881.66	1.5
5	0.1	10	3	10	889.35	1320.95	1.5

A decorative animal head from one of the Oseberg sledges

Following this impregnation studies were carried out using the product from conditions **5**. Fragments of waterlogged archaeological wood were placed in a solution of **5** in ethylacetate or isopropanol with varying concentrations. It was found that saturation of **5** in isopropanol occurred at 2 w/w% whereas concentrations of 15 w/w% in ethylacetate were used without saturation being reached. Varying impregnation times from 7 days to 40 days were used to investigate the level of penetration achieved. Following impregnation the samples were allowed to dry in air for at least 24 hours before analysis by FTIR and SEM.

FTIR of an untreated piece of the same sample, the treated sample and the raw oligomer mix were taken and compared. For the wooden samples, flakes from the surface and the inner core of the fragment were taken to analyse the degree of penetration of the oligomer mixture. It was clear from the FTIR data that the penetration of the oligomer mixture could be traced by a distinct band not present in the untreated wood. Comparison of the core and surface of the fragments showed that the oligomer had thoroughly penetrated the sample and the intensity of the peak suggested that the penetration was even throughout.

CONCLUSIONS

Isoeugenol has been successfully polymerised to give low molecular weight lignin-like species. Performing the polymerisation without catalyst has been found to favour higher molecular weight species; however, there may be structural changes that will affect its ability to interaction with the existing lignin in the wood. NMR has been used as an effective technique to yield key information about the structures of the polymers, even in mixtures of different species.

Impregnation of the oligomers formed by this polymerisation reaction was successfully achieved on small fragments. The presence of the oligomer could be seen clearly by FTIR by comparison with untreated wood from the same sample. The data showed that full penetration occurred on the small samples and the intensity of the IR band was the same in the centre of the fragment as on the surface suggesting even penetration.

Further testing on larger samples is still needed to determine the degree of penetration possible for actual objects. The current oligomers offer no consolidation to the wood, but investigations are ongoing into *in situ* cross-linking to improve their consolidation abilities.

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Dimensional stabilization of oak and pine waterlogged wood with keratin aqueous solutions

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Magdalena Zborowska

INTRODUCTION

Keratin is a natural substance which includes over a dozen related proteins. This substance exists in different skin products such as hair, nails, wool, feathers, hooves, and horns [1]. Currently, keratin is mainly associated with the cosmetic industry in which it is used as an ingredient of shampoos and conditioners.

At the beginning of 2000s keratin was used in conservation of archaeological wood [2]. In a conservation process, Japanese researchers used feather keratin which is classified as hard keratin [3]. It includes protein β – structures with low mass amounted to 10.5 kDa and length of 3 nm [4]. According to Endo [5], feather keratin treatment provides wood with good dimensional stability. What is more, microscopic observations have confirmed that this substance penetrates into the middle lamellae reinforcing the cell wall. Other authors [6] have claimed that despite it is less hygroscopic than wood and similar in density to a cell wall of wood (1560 kg*m^{-3}), keratin made from duck hydrolyzed feather cannot be used for impregnation of low density waterlogged archaeological wood. Additionally, because its eutectic temperature is unknown, it should not be freeze-dried.

Feather keratin is produced in a limited range and consequently it is difficult to buy. Therefore, in our experiment we used wool keratin which is widely available and additionally has a similar structure as feather keratin. Wool keratin is best recognizable among keratins. Hard keratins that build wool keratin contain low-sulphur proteins with the mass varying 45-58 kDa and dimension amounting to 7 nm [4].

METHODS AND MATERIALS

Tests were performed on an approximately 600-year-old pine (*Pinus sylvestris* L.) obtained from Grudziądz (Fig. 1) and 1100-year-old oak (*Quercus* sp.) excavated in Poznań (Ostrów Tumski, Fig. 2). Both samples were deposited in wet environment with limited air access.

WOOD CHARACTERISATION

The wood from which the experimental material was prepared was characterized on the basis of macroscopic structure features (width of annual increments, percentage of latewood), selected physical properties (maximum moisture content, conventional density, shrinkage in the tangential and radial directions), loss of wood substance and chemical composition (concentration of holocellulose, cellulose and lignin).

The maximum moisture content (μ_{max}) (1) (the absolute wood moisture content after saturation with water in a vacuum chamber) was calculated according to the formula:

$$\mu_{max} = \frac{m_{max} - m_0}{m_0} \times 100 \tag{1}$$

μ_{max} – maximum moisture content [%],
m_{max} – maximum weight of waterlogged wood [kg],
m_0 – weight of oven-dried wood [kg].

The basic density (d) was calculated according to the formula (2):

$$d = \frac{10^5}{\mu_{max} + 66{,}7} \tag{2}$$

d – basic density [kg*m^{-3}].

Concentrations of chemical components were determined according to the methodology described in the Polish Standard (PN 92/P-50092). Ethanol was used as a solvent during extraction in a Soxhlet extractor.

WOOD CONSERVATION

To analyze the dimensional stability of the wood, four pins were stuck into each sample measuring 30 × 30 × 5 mm (T × R × L). The distances between the pins ranged from 12 to 21 mm, measured in the tangential and radial directions using a slide caliper accurate to 0.01 mm (Fig. 3).

The waterlogged pine and oak samples were impregnated for 10 and 12 weeks respectively with two preservatives: aqueous keratin and aqueous mixture of PEG 300 and PEG 4000 as a comparison. Experimental impregnation solutions of PEG were selected on the basis of the earlier investigation of the state of the preservation and PEGCON computer program [7]. The treatments were initiated with 10% aqueous keratin and PEG solutions. Every two weeks, the concentration was raised by 10% to provide the solutions with a total PEG and keratin content of 35% for pine and 49% for oak.

The samples intended for freeze-drying were frozen for seven days at a temperature of -27°C. Freeze-drying of the wood samples was carried out in a chamber coupled with a laboratory freeze-dryer and a vacuum pump. The samples were dried two days. The final pressure in the drying chamber amounted to 5.5 Pa.

The freeze-dried samples as well as the samples dried in ambient air in laboratory conditions had been seasoned for

Fig. 1. *A wooden road in Grudziądz and a pine sample excavated on this archaeological site*

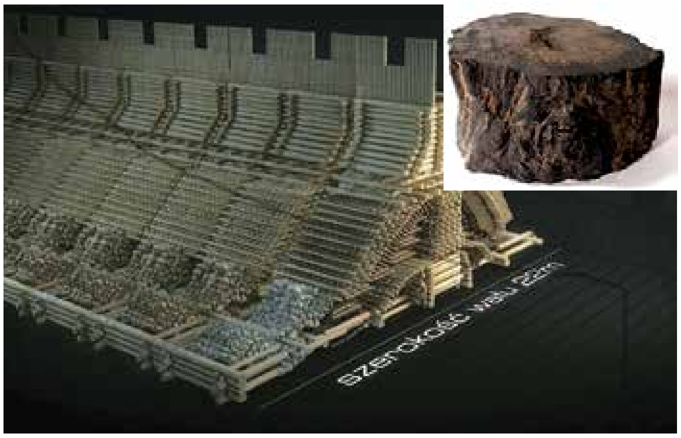


Fig. 2. *The defense walls of Ostrów Tumski (Poznań) and an oak sample excavated on this archaeological site*

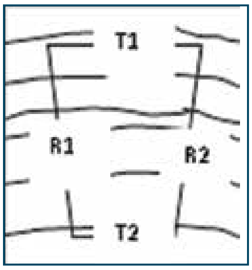


Fig. 3. *Appearance of the samples before the conservation process*

two weeks until they reached constant mass in the air at a temperature of 20°C and relative air humidity (RH) of 52%.

Wood shrinkage in the tangential and radial directions (β) of the samples (control samples and samples taken after conservation with keratin and PEG) was calculated with the following formula 3:

$$\beta = \frac{l_1 - l_2}{l_1}$$

(3)

β – linear (tangential or radial direction) shrinkage [%],

l_1 – dimension of the sample at the maximum moisture content [mm],

l_2 – dimension of the sample after drying and seasoning at 52% RH [mm],

The effectiveness of performed dimensional stability procedures was also assessed, irrespective of the wood species or degree of its degradation. For this purpose, the anti-shrink efficiency (ASE) was applied [4].

$$ASE = \frac{\beta_1 - \beta_2}{\beta_1} \times 100$$

(4)

ASE – anti-shrink efficiency [%],

β_1 – shrinkage of untreated wood, dried and seasoned at 52% RH,

β_2 – shrinkage of treated wood, dried and seasoned at 52% RH.

RESULTS AND DISCUSSION

The macroscopic analysis of the tested wood included a determination of the annual ring widths and shares of the late wood. The results recorded are given in Table 1. On this basis, it may be stated that both pine and oak wood exhibit macroscopic characteristics typical of narrow-ring wood.

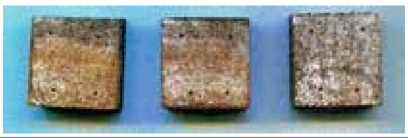
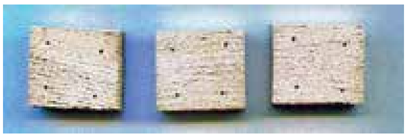
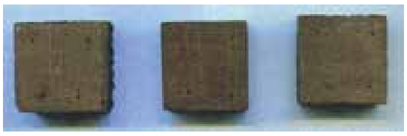
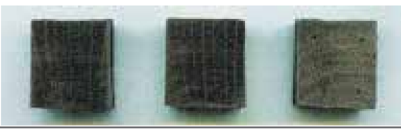
Table 1. *Selected macroscopic, physical and chemical features of the pine and oak wood*

WOOD	WIDTH OF ANNUAL INCREMENTS [mm]	PERCENTAGE OF LATEWOOD [%]	MAXIMUM WATER CONTENT [%]	CONVENTIONAL DENSITY [kg*m^{-3}]	HOLOCELLULOSE/LIGNIN COEFFICIENT
Archaeological pine	1.16	18	192	381	2.1
Contemporary pine [8]	1.51	38	141	483	2.6
Archaeological oak	0.56	30	124	524	1.6
Contemporary oak [9]	1.81	63	61	616	2.6

Table 2. *Shrinkage and anti-shrinkage efficiency of pine and oak samples before and after impregnation*

WOOD	SECTION	CONTROL SAMPLES	PEG 300/4000 – FREEZE-DRYING		KERATIN – FREEZE-DRYING		KERATIN – AIR-DRYING	
		β	β	ASE	β	ASE	β	ASE
		[%]						
Pine	T	8.4	-0.2	102.4	3.7	56.0	3.0	64.3
	R	4.1	0.2	95.1	2.1	45.8	0.6	85.4
Oak	T	15.4	5.9	61.7	6.8	55.8	10.7	30.5
	R	7.8	1.7	78.2	4.1	47.6	4.1	45.4

Table 3. *Appearance of the pine and oak samples after impregnation*

OAK WOOD	IMPREGNATE	PINE WOOD
	PEG	
	KERATIN + FREEZE-DRYING	
	KERATIN + AIR-DRYING	

In the case of ring-porous wood, such as oak, the more narrow annual increments are, the worse mechanical properties this wood has. Therefore the tested oak had probably lower mechanical properties in comparison to typical oak wood.

Based on the analyses of the physical properties (Table 1), it was determined that the pine wood had the mean maximum moisture content of 192%, while the mean basic density was 381 kg*m^{-3}. In view of the physical properties of contemporary pine wood amounting to 141% and 483 kg*m^{-3} respectively, it may be concluded that the examined characteristics changed slightly. Bigger changes of the described features were noticed in the case of oak wood. The maximum moisture content amounted to 124% while the mean basic density was 524 kg*m^{-3}.

The degree of degradation of the examined wood tissue was also assessed on the basis of the content ratios of the major wood constituents. The ratio of the holocellulose to lignin content (H/L) in the archaeological pine wood, which amounted to 2.1, was only slightly lower than stated for contemporary wood. The obtained results confirmed good condition of the examined wood. A lower value was gained in the case of the archaeological oak wood. Probably this wood degraded to a bigger extent and finally concentration of carbohydrates decreased.

Table 2 presents the shrinkage of the treated and untreated wood along with the ASE values for all the treatment variants. The moderate shrinkage of the control pine samples, amounting to 8.4% in the tangential direction and 4.1% in the radial direction, was determined. A slightly bigger shrinkage was detected in the control oak samples. After conservation, shrinkage values in all tested variants decreased. The pine samples after conservation were more stable in comparison to the oak samples. The best results were gained in the case of PEG conservation. The results were not so good after conservation with a keratin solution. In comparison with samples after treatment with keratin, air–drying gave better results than freeze-drying. Also for the oak samples, the best dimensional stability was obtained after impregnation with PEG, but after impregnation with keratin, smaller values of shrinkage were obtained for freeze-drying.

If upon completion of dimensional stabilization the ASE = 100%, it means that wood underwent no deformation. ASE values over 100% are caused by wood swelling, while lower values are equivalent to shrinkage. In conservation practice, ASE exceeding 75% is considered acceptable [10]. In the case of the pine samples after impregnation with a PEG solution, this condition was met. Values of ASE amounted to 100.2% in tangential direction and 95.1% in radial direction. Results obtained for the oak samples were lower and indicated that the conservation process should be improved. After keratin impregnation in each variant, ASE is too small, which means that this process needs changes probably in the case of keratin concentration, solution temperature or/and time of impregnation.

The samples after impregnation differed significantly in the range of appearance which is an important feature in the case of exposition of archaeological objects. Impregnation with a PEG solution caused important changes of the wood samples, both in the case of the oak and pine wood. The oak samples after impregnation with the solution had white stains, and the structure was invisible; the pine samples were totally white. After conservation with keratin and freeze-drying, the samples of oak had a natural color and visible structure. The pine samples had a partial white coating, but looked definitely better than after conservation with a PEG solution. Both the oak and pine samples had the best appearance, a natural color and visible structure after conservation with keratin and air-drying. Those samples needed neither cleaning nor improvement of appearance.

SUMMARY

1. The shrinkage of the pinewood and oakwood samples after conservation with wool keratin was decreased.

2. ASE of the pinewood and oakwood samples after conservation with keratin was lower than 75%. It means that the process did not meet the condition of good conservation.

3. The samples after conservation with keratin and air drying had the highest aesthetics.

4. If a conservator decides to utilize keratin in archaeological wood conservation, more detailed investigations should be performed on different species of wood with different state of preservation.

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CONDITION.2015

DIGITALIZATION

Digitizing a cargo ship – an in-house project of documenting the steam ship "Sołdek"

Marcin Kłos

INTRODUCTION

In 2011-2013 a team of four staff members of the National Maritime Museum in Gdansk conducted an inventory control of objects recorded from the coal-ore (bulk carrier) steam ship „Sołdek" which was originally launched in 1948. The survey was combined with digitization of the collection, including documentation with reviewed and extended descriptions for each object and a more structured and systematised metadata scheme, as well as digital photography.

Before the project began, more than 500 objects had only paper records from the 80s and early 90s of the 20th century. Numerous groups in this collection are objects which were manufactured in series (or mass produced), and are currently installed in a few dozen of the over 70 rooms in the vessel . The objects, such as various types of light fittings (luminaire) and hangers, have been entered in the museum's records as sets, each time under one main identification code with unique sub numbers. For example thirty table light fittings have identification code CMM/S/155/1-30. Up to 2013, when the revised electronic documentation was introduced, there were only single paper records for each set of objects with one representative photograph, thus not allowing for unambiguous identification of particular object in a set. Moreover, no proper movement information had been kept (there were some additional handwritten annotations indicating location, which had been recorded during previous surveys), and the available information (similar to comma separated values) had not been sufficient for clear identification of the location of each and every single object.

One curator from the project team was responsible for rewriting and verifying (including proper localization information) metadata from paper records as well as improving the quality and adding further information (context description, detailed information about manufacturers, checking vocabulary). Metadata work had been done parallel to visits in situ (ship), and after rewriting had been finished all the records were checked for errors by the Records Department. All comments were included in the revised metadata. During the process of gathering additional information about manufacturers, a contact was established with some of them (still active) with the aim of obtaining technical documentation. This contact was met with mixed response. Finally, it was possible to obtain documentation for one of the Duplex pumps from "GZUT" S.A. – Technical Equipment Plant Inc. More about manufacturers was gathered via the internet, for example from the University of Glasgow Archives Hub, information about steam boilers manufactured by the Scottish company A. F. Craig & Co Ltd.

Prior to photographic documentation, a control of compliance with the existing documentation for all the objects in the collection was performed. It had occurred already at that stage, that in case of sets of mass produced objects (light fittings, hangers, sinks, mirrors, etc.), it was really problematic to identify sub numbers for the objects and it was only possible to check the quantity. It was one of the reasons why it was decided to add an object id number on one image for every object, to ensure unambiguous identification. However, the downside to this solution during the whole project was the necessity of repeating photographic documentation due to reinterpretation of a sub number of an object in a set. This resulted from errors in paper (older) records or mistakes made by the project team performing documentation due to limited access to the rooms. An error in a sub number discovered after some time, caused mistakes in all subsequent objects of a set that had to be re-documented with proper (at that point) sub numbers. In some cases, some rooms were available only few days after mentioned discovery (resulting from watch-keeping system on the ship), so it was not always possible to make corrections or to control documentation compliance. As a result, some rooms had been neglected during documentation and the team returned to them when there was such a possibility.

The aforementioned mistakes were mostly caused by the architecture of the ship, where more than half (mostly sets of mass produced objects) of the collection is located in crew cabins, often similar to each other in terms of appearance and equipment. Moreover, due to the fact of almost seventy years of service (originally as a trading vessel and for more than thirty years as a museum), the room numbering system on s.s. "Sołdek" is not consequent (lacks continuity) i.e. in some cases adjacent rooms lack adjacent numbers. More importantly, id numbers of objects from a set do not reflect increment of room numbers (e.g. in room 14 there might be located an object with id number CMM/S/155/1 while in adjacent room 15 there might be located an object with id number CMM/S/155/25). As a result, there was surprisingly great difficulty in creating photographic documentation of sets of objects – some objects were documented several times – each time with current (at that time) id number.

Another challenge related with the ship's architecture is the location of the objects in the rooms, where often there was not enough space to make proper visual documentation. Key areas in this regard are the boiler room and the engine room of the ship, in which there are more than eighty objects, many of each covers one another making photographic documentation almost impossible. Therefore, compliance with visual documentation standards encountered a number of difficulties: (1) lack of necessary space (distance) for photography of a whole object, (2) density of devices covering one another, (3) insufficient lighting, and (4) lack of space for additional lighting to ensure proper parameters, (5) lack of space for scaffolding or other constructions to facilitate documentation, (6) necessity of taking photographic documentation without tripod due to lack of space to set it up, (7) accessibility to some elements of devices only from higher platforms or decks (engine room casing and boiler room casing).

Additionally, doubts concerned movable objects such as tools. The question was – whether it should be documented on site – where the objects are located within their context, whether in the studio, where optimal conditions for documentation are provided (however there is no context) – then visual documentation does not differ in terms of quality from documentation of other collections in the museum.

Finally, perhaps the greatest difficulty was the documentation of objects connected in a network of pipelines, often located very close to each other, which for the average viewer seem to be one complex object. These structures are so complex that a person without specialized technical knowledge has trouble distinguishing between individual elements (example shown in the Fig. 1).

GENERAL GUIDELINES ON DOCUMENTATION OF COLLECTIONS AT A MUSEUM-SHIP

The acquired experience during the project helped to identify key issues that needed to be specified before proceeding to documentation of the museum-ship's collections:

1. How to organize work in order to avoid errors due to the large number of documentation of serial objects in dozens of locations (rooms, hallways, decks)?

2. How to treat a ship – should we document the entire rooms or individual objects attached to the hull and decks?

3. How to create images of objects surrounded by other devices (objects), to the extent that it is not possible to accomplish photographic documentation of the entire object (therefore which documentation methods should be applied)?

4. How to document objects, which are mechanically connected with other objects (motor and pump) in such a way that it is difficult to distinguish between them/ set them apart?

5. Where should movable objects which are a part of a ship's equipment be documented?

ORGANIZATION OF WORK

Starting with documentation of a ship-museum one should be aware of its architecture and type of recorded collections, and that work on a large vessel requires knowledge of its architecture. For a member of museum staff, who for the first time enters a floating vessel, it may trigger an association with a multi-level maze. Such a feeling may be reinforced by the inconsistent numbering of rooms (which is the case on s.s. „Sołdek"), resulting from changing function (several rooms adaptations during service) and the traditional nomenclature (independent of the numbering). For example, there are rooms number 27 and 29, but there is no room number 28. This may also impede communication between employees – especially if one of the interlocutors uses only traditional names of the rooms, and the other only the numbers of rooms.

The recommended solution is to use up to date plans of the ship. This can be done in several ways, of which perhaps the simplest is a large print work – up to A0 for each deck (example shown in Fig. 2), on which all indications and comments are applied to, and a few smaller prints as handy reference material. IT solutions may be used for this task as well, however the available size of the displays may initially cause some perceptual restrictions (vs. print) in spatial orientation. In some situations (especially in the beginning of the project) it might be quite cumbersome. Creation of a mobile application specifically for audit and documentation should be considered as unlikely, due to time and resources requirements.

Unambiguous labelling of rooms may be implemented in at least a few ways, including labelling on a printed plan, use of a table in a spreadsheet/simple database, or generating reports from database management systems. In case of s.s. "Sołdek" the second method was chosen.

Equally important during the project was to use lists and summary sheets of objects that had been already checked and photographed. Moreover, it was crucial to (1) record all changes to ensure access to full change-log (all changes made in files, lists or sheets), as well as (2) to use a functionality allowing creation of comments for all amendments in cells/tables/sheets. This is all the more important the longer the process of documentation. In case of projects extended over time, there are often problems with reference to previous decisions and the reasons behind them. In case of s.s. "Sołdek", longer intermissions in access to the ship during the project were related to the periodic (which took several months) closure for winter – due to the very low temperatures.

In the case of the project, a problematic issue proved to be the management of image files created during documentation. It happened more than a few times that in a single day, a few dozen to over a hundred pictures were captured, however many of them were just illustrative photos. Division of created documentation to folders by dates, caused the difficulty of systematization of the material, especially that frequently there was no time to assign ID numbers to files because of day after day documentation on the ship. Moreover, within two years, some of the objects had several sets of images made with different identification numbers. It was an effect already brought to light during the initial control of compliance with the existing documentation, where lack of clarity in the numbering within sets of objects became problematic. As a result, in the final phase of work, a very

Fig. 1. *Engine room, view towards stern. There are four pumps visible in the picture and in total seven objects recorded in the museum's register; photo Wojciech Paweł Jóźwiak*

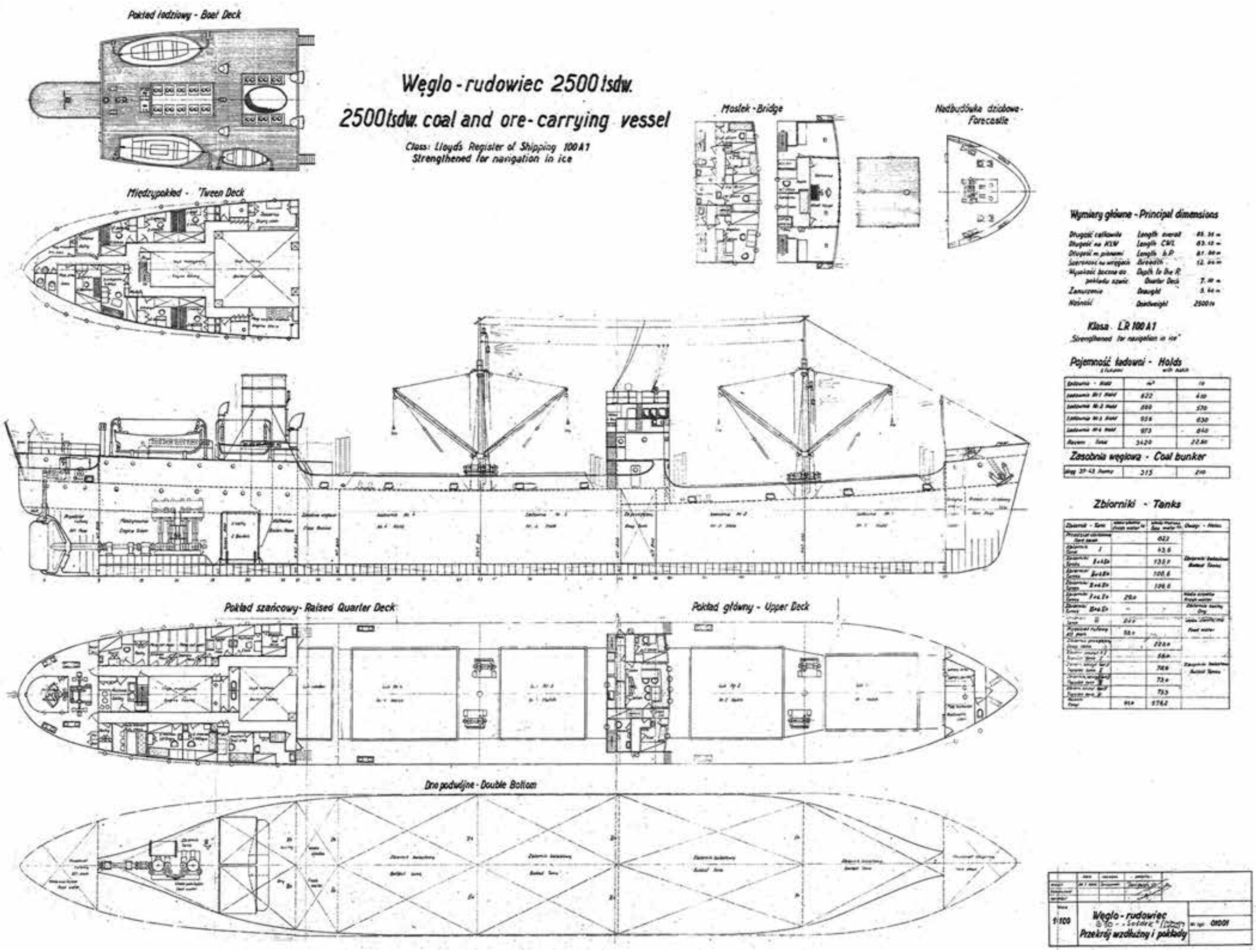

Fig. 2. *Drawing of longitudinal cross-section and decks of s.s. "Sołdek" made on 29.07.1946*

time-consuming verification of all the files was performed. After the first problems with the distinction of serial (mass produced) objects (shown on Fig. 3) and difficulties in finding where images of one object (fixed to a wall) from a set ended, and where other (from the same set on the same wall) began, the team began to document whole walls or even rooms. Additionally, location of objects in relation to each other (in the same room) were also often documented. Thereby mass produced objects were placed in the photos in a clearly identifiable space.

HOW TO DOCUMENT A SHIP

The fundamental question is how to treat a museum ship which is at the same time a museum object and a branch of a museum. If we assume that the entire ship – and therefore the hull and its interior – are one object (one record in a museum's register) and should be documented in accordance with good practices of documentation for museum objects like art (paintings, furniture, sculpture), then it means that we should conduct a detailed documentation of all available space in this ship along with the entire fitting and equipment. Thus, it imposes the obligation for detailed documentation of movable and immovable equipment not recorded in a register. This is a challenge in terms of marking such objects, since all of them should be treated as part of a vessel (and thus have one number). The other way is to treat the hull (Fig. 4) and interiors separately, then the corridors and cabins are in a sense beyond the records and do not require such detailed documentation. At the same time they constitute a part of the ship and as such are protected. The downside of this solution is that these objects usually lack detailed documentation and historical description in comparison to registered objects.

The answer to this question determines methods of documentation, so it is quite important to discuss it in a museum before starting documentation.

Two assumptions in this regard were made in the project. First, that documented objects are photographed with the broader context of rooms. Second, that full inventory of the entire interior of the ship will be carried out as a separate project. The outcome of the upcoming project will be a starting point to develop the full (detailed and exhaustive) documentation in this regard. For this purpose, it is planned to apply photogrammetry and computer graphics.

IMAGES

It has not been resolved within the framework of the project how to document objects surrounded by other pieces of equipment, mechanically connected to other devices or fixed to walls/hull. These physical limitations, related to the surroundings in which objects were used, cause some technical limitations in documentation but at the same time give an historical context to objects. This context enables the viewer to intuitively understand an object and its function in a way that is unattainable for an object exhibited in an exhibition room. Thus, documentation should not be an operation of "cutting" objects out of historical surroundings but on the contrary on documenting all possible aspects. In such cases, during the project, good practices of documentation for museum objects were omitted (no photographs documenting all sides of an object were taken) and the team strived for the best possible documentation, ensuring on the one hand unambiguous identification and on the other, general enough to give an idea of an object. Therefore, usually there were several photographs made showing as much of the object as possible and at least one photograph of an object within its surroundings. Furthermore, in some cases it was possible to combine both criteria i.e. identification and context in a single shot.

An alternative solution in selected cases might be a 3D point cloud scan (Fig. 5), which allows documentation of an object with the whole spatial context (surroundings) as well as abstracted from surroundings as an object – model. Currently, tests are being carried out by the 3D digitization team of NMM in Gdańsk.

Last but not least, is the issue of where to document moveable objects like tools. During the project, moveable objects exhibited in place of use/service were documented in situ, while other moveable objects (wire thimbles, flags, rubber stamps) were documented outside the ship. A preferred solution in this case is to document both on board (place of use/service) and in controlled conditions of a photographic studio.

PROJECT ASSESSMENT

Work on digitization and online dissemination of the collection led to the following accompanying activities, which were not included at the start of the project :

- conservation, especially cleaning of nameplates.
- query about manufacturers of equipment and machinery on s.s. "Sołdek"
- query for technical documentation of equipment and machinery on s.s. "Sołdek"
- query at the museum focused on the analysis of the documentation associated with the ship
- query and analysis of construction of ship's machinery and equipment, steam cycle and other technological issues in order to better understand documented tangible heritage and focus on important structural components.

CONCLUSIONS

1. It is a good idea to determine the order of documenting rooms at the beginning of the project(e.g. by decks, according to room numbers, according to type of rooms) and consistently note when documentation of a room was started and when finished, with a list of all objects documented in it. Then, another employee (than the one who made the list) should carry out verifications of results and approve it or return it for revision. The optimal solution for this process is to use a database management system for collections records and management, which provides collections control procedures.

2. It is worth the effort to implement naming/labelling for communication spaces in which objects are located and which so far have not been named/unambiguously identified in any way. In case of ambiguity (lack of clarity) of cabins and other numbered facilities, unambiguous nomenclature should be adopted for documentation and used consistently. Mentioned nomenclature must be compatible with metadata in the implemented database management system (it may be required to enter data into the system) which allows keeping information about the location as well as movement.

3. Keep in mind to record work progress in such a way as to be able to quickly generate a report indicating the status of implementation of the project and information about open and finished tasks. Yet again, the best solution is to use database management system used for collections recording and management, which provides control procedures.

4. Provide access to an overview as well as detailed information about each and every photograph created during the project. Remember to provide sufficient time for ver-

Fig. 3. *Corner of a room on s.s. “Sołdek” with five mass-produced objects recorded in museum’s register; photo Wojciech Paweł Jóźwiak*

Fig. 4. *.S.S. “Sołdek” on a dry dock in November 20**10** Rare occasion to document the whole hull; photo Mirosław Brucki*

Fig. 5. *Screenshot of partly postprocessed scans made by Piotr Dziewanowski and Janusz Różycki (National Maritime Museum in Gdańsku). Point cloud made from interior of the first and the second cargo hold on s.s. “Sołdek”. Look at the strengthening of the starboard*

ification of created material including name attribution to files. Worth considering are files description according to three criteria (e.g. using IPTC or other metadata): (1) date of execution, (2) location and (3) identification number. Use dedicated digital asset management systems (DAM) for this purpose. Keywords are useful as well but need control to avoid repeating values and synonyms.

5. Remember to consider various methods of documentation to ensure the best possible visual documentation. Take into account the existing conditions in different locations on the vessel (photography, photogrammetry, 3D scanning).

6. If there is such a need, you may consider developing intelligible plans of the ship for the purposes of dissemination of resources, allowing the viewers to see which room they are viewing and where is it located on the ship.

7. Think about preparing text description of each room on the ship, with function / purpose and historical analysis of changes in this respect during the service, to show the full context.

8. Be aware that full and comprehensive scientific description of a large ship (circa 100 meters and more), understood as the documentation of an entire vessel is an extremely time-consuming task and is associated with high costs of implementation.

ACKNOWLEDGEMENTS

The digitization of s.s. „Sołdek" would never be accomplished without the persistent commitment of: Brygida Sonnack, Wojciech Paweł Jóźwiak, Leszek Kostro and Przemysław Kwapisz. Thank you.

"Bremen Cog" – long term monitoring of deformation processes

Amandine Colson
Julien Guery
Maximiliano Ditta

INTRODUCTION

The "Bremen Cog" was discovered in 1962 in the River Weser close to the city of Bremen. It was successfully conserved and restored during the following years at the German Maritime Museum and since 2000 the ship is on display. This medieval vessel is 24 m long, 7 m wide, 4 m high and belongs to the largest archaeological ships exhibited in Europe along with the Vasa in Stockholm (Sweden) and the Mary Rose in Portsmouth (England).

Although the conservation treatments are completed, it is absolutely necessary to lead further monitoring measurements in order to regularly control the condition of the ship. Monitoring must include environmental control in the room, standards in Preventive Conservation (Temperature, Relative Humidity and Light), but also control of deformation processes. The environmental measurements are already on-going, but the deformation of the wood on the other hand was monitored only occasionally with analogue photogrammetry and 3D scanning. A systematic and multi-yearly monitoring system was to be designed.

According to Codes of Ethics of Conservation-Restoration, the chosen method should be non-invasive. Nowadays several technologies allow us to document Cultural Heritage, objects of various sizes as well as buildings. Unfortunately museum staff are not always aware of the diversity of methods and technologies and often choose through without having the overview.

A three dimensional monitoring system would allow the museum's conservator to keep an eye on the ship and observe wood deformation that occurred in the past as well as possible future deformation.

A closer look at examples in other museums was necessary to carry out further analyses and to combine with the museum's own resources (equipment, finances and manpower).

In 2015, the museum celebrates its 40th Anniversary and in September an exhibition has open to the public. In 2016, an extensive renovation campaign of the two Museum buildings: "Scharoun" (the historical building), and "Bangert" will begin.

Considering all these issues, it was relevant and urgent to set up a monitoring protocol. The question was only how and with what budget?

STATE OF THE ART

Since 2000 the Vasa [1] is monitored with a *Total station*, an electronic version of the traditional Theodolite, using different settings to get a 3D model, applied twice a year in average. The tool documents the target points and the data is compared with previous measurements in order to identify and try to understand deformation processes. This protocol was designed by the Royal Institute of Technology in Stockholm, under the supervision of, among others, Milan Horemuž Associate Professor Expert in the field of Applied Geodesy. The bi-annual acquisition is made by students and part of the University programme [2].

The Mary Rose follows the same model, although no support from a University was possible and the work is planned to be carried out by an external company [3].

As a matter of fact in the field of conservation-restoration, large scale objects represent a major issue, among them ships, buildings, entire sites and so on. Concerning ships, whether coming from archaeological, historical or even industrial context, the size of such objects, its buoyancy (when still floated) and its technical features are rising great challenges when they are to be displayed and preserved for next generations.

The "Bremen Cog" was conserved with Polyethylene Glycol (PEG), a method broadly used for waterlogged archaeological organic material, specifically for wood, and researched internationally by the Wet Organic Archaeological Material Group (WOAM) from the International Council of Museums – Committee for Conservation (ICOM-CC).

Nevertheless, at present no standardized procedure exists and the initiatives remain local and very unique. Every model is a combination of many factors. First of all the qualifications at hand, team and manpower on site, but also partners. Secondly financial resources allocated are also an issue that conditions strongly the equipment purchased and used, but also endowment for the necessary staff training.

SET UP GOALS

Considering the context and all the determinant factors, all potential trails had to be explored. The idea of testing different methods was regarded as a relevant approach, but required a network of experts with the appropriate qualifications and resources (equipment and manpower) to develop feasible protocols.

As a result, the "test phase" was set to start within 2 years. The results would be compared fairly in order to lead to a long-term solution. The comparison would focus on the technical issues as well as interpretation possibilities of the data and the costs. Therefore different methods were considered.

As the experience of monitoring was shown to give good results using a Total Station, this tool was to be tested. Actually the museum owned already a device.

3D scanners are recognised to be the most accurate tool to monitor objects three dimensionally and should also be integrated in the test. The third method has been under a tremendous expansion and development phase in the field of archaeology and conservation for the last 10 years: SfM Photogrammetry, and therefore also part of the test panel.

To summarize the test phase would include 3 methods: Total Station, 3D Scanning and SfM Photogrammetry.

EXPERTS' NETWORK

In order to maintain a high level of qualification, it was decided to call on different experts for advice.

Since late 2013, the museum has been part of the EU-COST-Action TD1201 COSCH (Colour and Space in Cultural Heritage), a network of 27 countries in Europe and composed of 5 Working Groups. The project promotes "research, development and application of optical measurement techniques adapted to the needs of heritage documentation" (www.cosch.info). The main goal is to try to put together engineers and technicians (Conservation scientists, 3D specialists) with museum professionals (Art Historians, Historians, Archaeologists, Conservators etc.).

During the first year and after carrying out a literature survey, the COSCH Network found out that limited literature was available explaining in detail how different techniques are used, in which conditions and for what reason. In March 2014, the Committee Meeting in Joensuu, Finland, decided to initiate "Case Studies", which would give more material and help to build up common knowledge.

In June 2014, Amandine Colson and Dr. Ursula Warnke, Director at the German Maritime Museum, decided to respond to the call and proposed the "Bremen Cog".

During the next COSCH Meeting in September 2014 in Belgrade, Serbia, seven case studies were chosen, one of which was the "Bremen Cog".

Through Short Term Scientific Missions (STSM), financial support would be provided from the COSCH allowing researchers to visit partners, covering travel and daily expenses.

COMMON FRAMEWORK

Testing different techniques lead us to the problem of having one system or framework to compare them all. Each technique has its own requirements and approach to the object, but our goal was to assure the comparison of the data three dimensionally. We wanted to be able to isolate and understand potential errors of one or the other and maybe to combine the advantages of them all.

To insure this goal we needed to build up a three dimensional space with reference points taken all around the ship and integrated in one Cartesian coordinate system (x, y, z) that would be recorded from each technique. In this way, every coordinate/measurement could be integrated in one system.

This network of references points has been established from the beginning and adapted for each acquisition.

PHOTOGRAMMETRY

The first test was carried out in October 2014, with the financial support of a Short Term Scientific Mission (STSM) from the Cost-Action and performed by Julien Guery, scientific consultant specialized in SfM photogrammetry, from France.

SfM photogrammetry consists of the definition of the shape, dimensions and positions of objects in space based on the analysis of photos [4].

The purpose was to set up an acquisition protocol and to produce a 3D model through SfM Photogrammetry.

The main objectives were:

– the production of an image-based 3D model
– the extraction of Digital Elevation Models (DEM)
– the identification of technical issues
– the determination of recommendations for future acquisitions.

Several photo acquisitions were operated during 3 days in order to define and to test a precise and reproducible protocol. This mission was technically challenging because of the surroundings: lighting conditions, concrete pillars from the building, metal structures supporting the ship and size of the object. One other issue was to try to keep the acquisition as simple as possible, to keep the eventuality of future acquisitions carried out by museum staff.

Thus various acquisition techniques and different cameras and camera lenses were tested on site. Subsequently a simple protocol was established and tested with the staff, in order to define where and how to take each photo around the Ship.

The datasets acquired were then processed in Dijon (France). Comparisons were made between the different datasets in order to confirm the protocol established on site. Different kind of results were extracted from the 3D models produced such as 3D animations of the "Bremen Cog" and digital elevation models of its different surfaces.

Further acquisitions could be operated by future operators or the museum staff thanks to the protocol developed during this STSM. The deformation processes will then be identified through the Digital Elevation Models (DEM) and the difference Δ will be calculated based on Model 1 and 2.

The last acquisition was made in March 2015 and is still awaiting to be processed.

3D SCAN

The Institute for Spatial Information and Surveying Technology from the University of Applied Science: i3 Mainz performed a 3D Scan. The Institute is experienced in the field of Cultural Heritage, more specifically archaeology, in Germany and abroad. They are also initiators and leaders of the COSCH Project.

Fig. 1. *"Bremen Cog"; copyright German Maritime Museum*

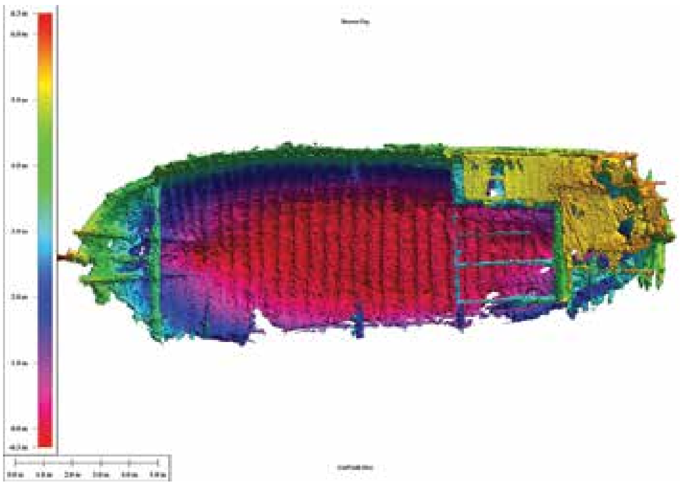

Fig. 2. *DEM COG; copyright Julien Guery*

Fig. 3. *Corina Justus in front of the cog; copyright i3Mainz*

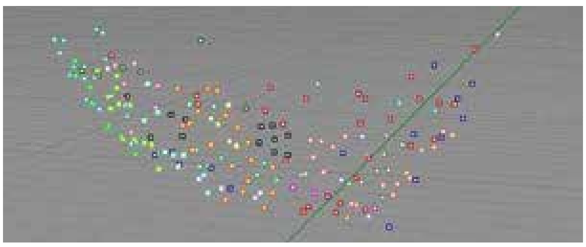

Fig. 4. *Point cloud after the total station recording; copyright Massimiliano Ditta*

In November 2014, Carina Justus and Stefan Mehlig, under the supervision of Prof. Dr. Frank Boosch and Dr. Stefanie Wefers visited the museum. The two experts operated the laser scan Leica ScanStation P20, provided by i3 Mainz, for 4 days. In total, 29 scanner positions were necessary to have a complete image of the ship. Additionally, more measurements were taken with Gom ATOS III (also provided by i3Mainz) of the bow close to the keel where the main weight is located and therefore most probably some deformations occur.

The same reference points used for the Photogrammetry acquisition were integrated in the 3D Scan.

A 3D Model was produced from the acquisition and delivered to museum staff as well as the viewer Mesh Lab, to visualise the model.

A second acquisition would be necessary to compare the data.

TOTAL STATION

The last technique implemented was the traditional Total Station. In fact the museum itself owns a Leica Flexline TS06. A Short Term Scientific Mission (STSM) was organized through the COSCH and carried out by Massimiliano Ditta, Guest Researcher at the University of Southern Denmark in Esbjerg, Maritime Archaeology Program. As a maritime archaeologist and experienced 3D Documentation operator, his understanding of the problematics was very high.

Traditionally, the recorded data from Total Station are visualized in the post-processing phase. But instead, with the approach used during this STSM, it was possible to follow in real-time the acquisition of the data. Such workflow has a series of advantages otherwise not achievable with the traditional methodology. The core of that approach lays in the use of a 3D CAD software which can communicate directly with the Total Station through a specifically designed plug-in. Such software is Rhinoceros 3D and the plug-in Termite developed by Frederick Hyttel, a former student of the Maritime Archaeology Programme in Esbjerg (University of Southern Denmark).

Termite was conceived as a means of facilitating the operation and reducing the cost of real-time connectivity between Total Station and CAD software for application in maritime archaeology [5]. To achieve this aim, it has as a core feature the ability to instantly visualize and orientate data in Rhinoceros, and secondarily facilitates easy access to appropriate Total Station features, while naturally retaining all of Rhinoceros CAD capabilities.

The advantage of real-time visualization of data has some benefits: better, cleaner and more consistent data and a greatly reduced necessity for post-processing.

The reference points present around the Ship were integrated and some more were added to be able to fit to the requirements of the Total Station.

A total of 22 recording stations were identified and used for the recording phase.

Thanks to the work of Massimiliano Ditta, a protocol was established. For future acquisition it could be possible to perform it in less than 16 working hours.

Compared to photogrammetry and 3D scanning, the present methodology produces a limited amount of data. Instead of having a cloud of points for the entire ship, only a limited amount of points are recorded and can be constantly monitored. To understand the deformation processes acting on the Cog, the functionality of Rhinoceros can be exploited to compare different acquisitions in the same working space. Although the next Total Station acquisition will be carried out in the next 6 months, and therefore no data for comparison are available yet, a preliminary deformation assessment was performed. The advantage of using Rhino resides not only as recording software but also as analysis software. The shape of some elements of the ship were analysed through curvature analysis. A selected number of points at the same level were connected for three strakes at the starboard side, a bottom breadth section at amidships, and a portion of the sheer of the keel. The curvature analysis visually display in an exaggerated scale the curvature trends, and thus it allows to understand where forces are acting.

The next acquisition is planned in six months.

FIRST RESULTS

Through this experience we can already emphasize the importance of the multidisciplinary team and moreover multi-qualification profiles of the team members. It became also clear that such work could also be a very nice dissemination tool for our visitors. In fact, a 3D Model made for conservation issues could be shown to the public as an example of the work going on but also some other aspects of the objects. Here we can say, that the public experience the scientific work almost "live". The museum is planning renovation of the building and such a tool could be used as a chance to continue to present the ship during the building phase.

These three tests were very helpful to have a clear overview of the technical possibilities of each of them. Nevertheless further tests must be carried out to find out what is the best solution for long-term monitoring.

A table of comparisons will be established in the coming months and reported to partners in the autumn at the next COSCH meeting.

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We would like to thank Dr. Ursula Warnke, Director of the German Maritime Museum, the COSCH Network, Prof. Dr-Ing Frank Boosch and Dr. Stefanie Wefers from University of Applied Science: i3 Mainz, Dr. Christian Degrigny, Haute-Ecole Arc Switzerland, Jacob Jacobson, Curator at the Swedish National Maritime Museums, Milan Horemuž, Associate Professor at the Royal Institute of Technology in Stockholm, and Eleanor Schofield, Mary Rose Archaeological Services in Portsmouth for answering our questions.

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Use of photogrammetry at archaeological excavations in Norway

Magne Samdal

INTRODUCTION

Several archaeological institutions in Norway have started to use digital photogrammetry as a standard method for documentation of archaeological sites. This practice combined with the use of tablets, more accurate positioning-devices and an effective national documentation system (Intrasis) have pushed the archaeological fieldwork towards a more effective and better documentation practice. I will give an overview of the development of this method in Norway by presenting the institutions responsible for managing casework in relation to the Norwegian Law of Antiquities and excavating archaeological sites, and their practice in working with photogrammetry. I will tie this to the largest University-towns in Norway and the institutions situated here.

Some institutions and key persons have been leading the progress in implementing photogrammetry in archaeological fieldwork in Norway. They have taken a special interest in developing and testing this method in the field, and their experience and know-how have been shared in local meetings in the organisation Computer Applications & Quantitative Methods in Archaeology CAA-Norway (http://no.caa-international.org/). Another important factor to the development of the method is the cooperation within the university museum's IT-organisation MUSIT, (http://www.musit.uio.no/musit/musitweb/html/english.html), where all the museums and universities in Norway are represented. Here we have several types of workgroups, and one of them is dealing with archaeological field documentation. These forums have been crucial in developing and implementing this method in Norwegian archaeological fieldwork.

USE OF DIGITAL PHOTOGRAMMETRY

Photogrammetry can be defined as measurement in photographic images to determine geometrical characteristics such as shape and location of the photographed object. It is today the most known image-based method to collect detailed metric and semantic information from images in a 3D-model. Photogrammetry-software creates 3D models from multiple 2D images by establishing accurate geometric relations between pictures taken and the motive. This method requires at least two images of the same static motif taken from different angles to provide a stereoscopic view and thereby being able to extract 3D information in the overlapping areas [6: 63].

During recent years, development of software, hardware and techniques needed have accelerated, and made it easier to use digital photogrammetry with good results [1:18], [4: 26], [6: 64). In this article I will describe the use of compact terrestrial close range digital cameras, underwater cameras and aerial digital cameras (drones) in the process of creating 3D models and the development in the use of photogrammetry as a method in rescue archaeology in Norway.

TROMSØ

Tromsø University Museum (UIT), (http://en.uit.no/om/enhet/tmu) started to use digital photogrammetry in archaeological development/rescue excavations in 2011 [3]. A key person here is Erik Kjellmann (erik.kjellmann@uit.no) who introduced the method when testing several photogrammetry solutions in his master's degree (Kjellmann 2012). He ended up using the software Photoscan from Agisoft (http://www.agisoft.com/), and it is fair to say that Kjellmann's work on photogrammetry has influenced many of the key users at other institutions in Norway.

The method was in the beginning a replacement for older techniques concerning collecting and composition of geo-rectified orthophotos at the excavations (Arntzen 2008:12-15). Points for geo-reference are measured with Total-Station (TPS) and thereafter used in Photoscan to geo-rectify the model. The orthophoto is then exported and used as a base layer for drawing/further documentation on tablets or paper (2D). Later drawings are exported and processed in various software solutions for use in scientific studies and publications.

In 2012 photogrammetry was tested out on several different excavation sites by UIT (stone-age sites, rock-carving sites, iron-age settlement sites) and valuable experience about the software and best suited practice in collecting of data were gained. The development has gone from using different photo rig solutions (lift, Photo tower, trees, excavator buckets) towards use of light carbon poles and more compact digital cameras with built-in remote possibilities and transmission of live-views directly to tablets or phones. Thus the process of creating photogrammetry models has been easier and less time consuming, and as a result creating more accurate documentation of the excavation in shorter time than the traditional documentation system can provide. From 2013 the use of photogrammetry (Photoscan) was introduced as a primary documentation method in all of UIT's archaeological rescue excavations, and knowledge about the method and routines to gain good results have been spread to the rest of the staff through straightforward field manuals produced by Kjellmann and his team.

TRONDHEIM

At the NTNU University Museum in Trondheim (http://www.ntnu.no/) Raymond Sauvage (raymond.sauvage@ntnu.no) has been a key person in testing and implementing photogrammetry in archaeological fieldwork. They started in 2013 using this method on rock-art to document whole sites that later would be covered with protective materials. The goal was to get the best possible documentation of the rock-art context, using photogrammetry in combination with more traditional documentation techniques for comparison.

They started with complex SLR cameras and lift or photo tower, and experienced through the test year that this was unnecessarily complex and time consuming. From 2014 and onwards Sauvage and his team have used light carbon poles in combination with smaller compact cameras (Sony DQ100) with remote-function, and this has made it easier to implement. From this point NTNU have used photogrammetry on most of the sites excavated by the museum, and in many cases this has made the documentation better and far quicker.

A typical use of the method was to create overview models of whole sites, and detail models of bigger structures and objects as substitution for drawings (grave mounds etc). Agisoft Photoscan was used for processing models, Meshlab (http://meshlab.sourceforge.net/) for correction and ArcMap (ArcScene) for drawing on digital elevation models (DEM). Adobe Photoshop and D-strech (http://www.dstretch.com/) have also been used to analyse painted rock-art with colour manipulation to highlight colour pigmentation. Savage also used this method to perform mass calculation of structures. The experience with photogrammetry and the different software is positive so far at NTNU, but there is always need for development of better/stronger/easier guidelines and routines to achieve good results.

BERGEN

At the University Museum in Bergen (http://www.uib.no/en/sfyk), Thomas Bruen Olsen (Thomas.Olsen@um.uib.no) is responsible for implementing photogrammetry in archaeological field documentation. Olsen originally searched for a method to create simple 3D models of sites and nearby landscapes, and through input from meetings in MUSIT and talks with Kjellmann in 2012 started to experiment with Photoscan in Bergen. In 2013 he tested different equipment such as compact cameras and photo poles for obtaining good photos, as well as the limits with Photoscan.

From 2014 Olsen and his team have used light carbon poles and compact camera with wifi-transmitters (Sony RX) to obtain pictures for photogrammetry. After exporting the geo-rectified model from Photoscan to GlobalMapper (http://www.bluemarblegeo.com), drawings of structures etc. are made directly on the model in 3D. The results are then exported to the national documentation system Intrasis (http://www.intrasis.com/), web presentations, to researchers and for presentation in general. All excavations have access to this documentation equipment, as well as powerful laptops and software. They are now working towards a full implementation of the method, and are constantly improving their routines and manuals to make this manageable for the rest of the field-staff in Bergen.

Bergen Maritime Museum (http://www.bsj.uib.no/wordpress/?lang=en) is also using photogrammetry in documentation of maritime archaeological sites and objects, and has in several cases collaborated with the University of Bergen in creating 3D models from photogrammetry. They have also collaborated with the Norwegian Maritime Museum in Oslo (NMM) exchanging experiences with photogrammetry in maritime contexts. Since 2003 Photoscan has been tested on wrecks, ballast-cairns and smaller objects with good results. The visibility can be a problem due to algae resurgence, so from experience it has been better to take pictures during winter and have closer picture-overlap to obtain good photogrammetry-results in marine contexts. 3D models are primary applied for web-publication and lectures at the museum. The contact person here is Eirik Søyland (Eirik.Soyland@bsj.uib.no).

STAVANGER

The Museum of Archaeology (AM) in Stavanger(http://am.uis.no/frontpage/) has started to use photogrammetry in full scale. 2014 was an experimental year where this method was tested on seven different sites. A key person in this work has been Theo Gil (theo.gil@uis.no). The main goal with these tests was to get information and experience with the method and also to find out in which context the method was most suitable. How to implement the use of photogrammetry within AM documentation routine has also been a task for Gil.

In 2004 the staff at AM focused on two main tasks regarding photogrammetry. First the practical and technical aspects of the method, i.e. how to get the best pictures (drone/pole/ground), how many photos, degree of overlapping, favourable weather conditions, type of camera solutions and finally good software to process it all. The second task was to explore the possibilities with the method, i.e. what this method could do in a better and more cost-effective way rather than traditional documentation.

So far, Gil and his team have experienced that the use of photogrammetry is easy and useful in most cases. The method can replace plan- and long profile drawings, either by drawing directly on top of 3D models or on exported orthophoto (tablet). This is also the case at a larger scale, where stone-age sites and grave mounds are documented with photogrammetry, and details are drawn directly on the model instead of extensive use of GPS and total stations in the field. All information is later exported to the national documentation system Intrasis. Bigger 3D overview plans of a site taken with drones can also easily be made and distributed to researchers, media or web. AM have used the following programmes for processing data: Agisoft Photoscan, Global Mapper, Intrasis and ArcMap. For obtaining the data they have used small drones and photo poles.

Gil experienced that the new method needs to be implemented in the work routine (in the field and in the planning

Fig. 1. *Locations in Norway mentioned in the text*

Fig. 2. *Equipment used at KHM to obtain good photos for photogrammetry. Top left: DJI Phantom drone, middle left and bottom: Cinestar 8 drone, and top right: use of light carbon photo pole*

of fieldwork) to avoid bottlenecks in the process (both man and equipment). Powerful laptops with Photoscan need to be available in the field and the data collection and knowledge/use of this method must be integrated to the broader range of field-archaeologists, and not just to a few experts on the topic. Good field- manuals on photogrammetry with detailed workflow and check of data quality by leaders in different stages of the process can be a way to implement good routines on these topics.

OSLO

The Museum of Cultural History (KHM) in Oslo (http://www.khm.uio.no/english/) has used photogrammetry in archaeological fieldwork since 2012. Earlier the museum only did simple photomosaic-projects with different types of freeware (stitch etc) for presentations and publishing on the web. From 2012 Agisoft Photoscan has been used for our photogrammetry-projects. Initially heavy photo towers and lifts, trees and excavator-buckets were used to get good photos. Now lightweight carbon poles and drones, one octocopter (Cinestar 8) and a quadrocopter (DJI Phantom 2 Vision), are used in this process. We also observe an improvement in use of camera types as we started with large SLR cameras with remote trigger towards current use of light compact camera with wifi (Nikon 1 S1 and J4) and transferring of live-view to phone or tablet. Trimble Total Stations are used to geo-rectify the models.

From Photoscan the models are exported to Global Mapper or ESRI ArcScene, and details are drawn directly on the 3D model. The results are exported to Intrasis for analysis and storage. Our goal for the future is that the result of photogrammetry will be increasingly used for research, in publications and/or on the Web to supply documentation quality and data. The implementation of the method is only in its infancy at KHM. We have the equipment to produce good models distributed in our organisation, and are now developing routines for data-collecting and management, and creating a good work-flow from creation of photogrammetry models to integration of the results in Intrasis, as well as for better re-use of the results in research and dissemination.

The Norwegian Maritime Museum (NMM) in Oslo (http://www.marmuseum.no/en/) has also used photogrammetry over and under sea-level of both sites and objects. This season (2015) they are applying photogrammetry (Photoscan) as almost mandatory on onshore surveys in combination with surveying. A central person in this work is Sven Ahrens (Sven.Ahrens@marmuseum.no), who has also worked with this method in other archaeological contexts (Ahrens 2013: 18). The entire field-staff is now trained to use photogrammetry as part of the documentation process by NMM, and this work has gone smoothly from processing photo in Photoscan/Meshlab to drawing in Adobe Illustrator and later transferring it to ArcGIS. Traditionally NMM have used an FARO-arm (http://www.faro.com/home) and Rhino software (https://www.rhino3d.com/) in documentation of boat-parts and other objects in their laboratory, but they are considering whether photogrammetry could be a possible documentation technique on this material.

Like Bergen Maritime Museum NMM have experienced that low visibility is a problem when taking pictures underwater due to algae resurgence, and that it is best to do this during winter when visibility is good. Otherwise there are problems with getting good positioning of the control-points for geo-rectifying the model, but so far they have gained good results and will develop this further for underwater use as well. Until now, the models are used as the basis for drawing 2D illustrations for reports and publications, lectures and visualization on the internet.

The Norwegian Institute for Cultural Heritage Research (NIKU) in Oslo (http://niku.no/en/) has used terrestrial laser scanning and photogrammetry in their archaeological research in Norway for several years. Recently they completed a project where different techniques were tested such as terrestrial laser scanning and photogrammetry on standing buildings. These experiences show that the methods must be adapted to the object to be documented, and that one of the methods is not necessarily better than the other. Both these methods have drawbacks and advantages. The use of a scanner is complicated and the equipment is expensive, with complicated/long processing time and coarse texture of the object. However, this provides good accuracy and is suitable for large, complex structures and the surrounding environment. Digital photogrammetry does not require expensive equipment and software, and the processing is fast and automated. The texture of the object is also very good. Sunlight affects contrast performance and accuracy is however not as good as with scanning. NIKU plans to use photogrammetry (Photoscan) on a large scale in their rescue excavations, and work to implement the method. Contact at NIKU is Regin Meyer (regin.meyer@niku.no).

CONCLUSIONS

Development in the use of digital photogrammetry in documentation of archaeological sites within rescue-archaeology in Norway has accelerated dramatically during recent years. The reason is that development within software and hardware has made it possible to use the method as an effective tool in excavations and knowledge and experience has become known in Norway through extensive cooperation in MUSIT and CAA.

It is also quite clear that there are challenges with the use of digital photogrammetry. One needs good practices in order to implement the method in institutions, and have efficient operations and utility usage. It is also important to have a concrete plan for the use of photogrammetry, so it is not just a cool model suitable for web publishing. The method should be combined with other methods and the package should be customised to the type of site we are investigating. What is essential, at least within rescue-archaeology in Norway, is to demonstrate that the use of the method is resource-effective and the results have better quality.

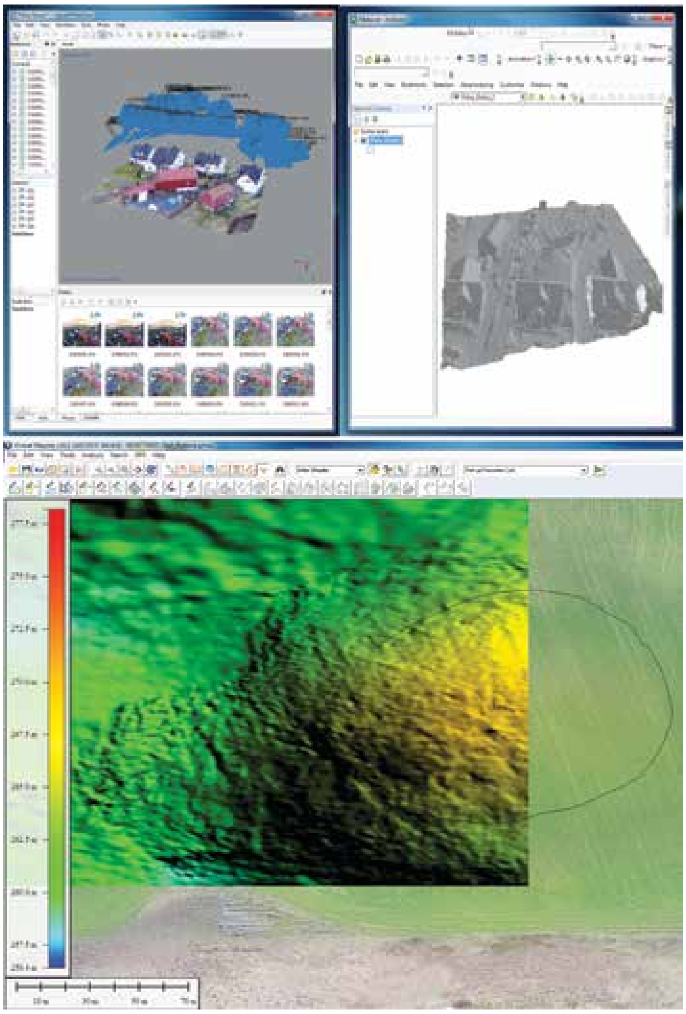

Fig. 3. *Photogrammetry-software used at KHM. Top left: Agisoft Photoscan, top right: ESRI ArcScene, and bottom: Blue Marble GlobalMapper*

It is therefore important that the result of digital photogrammetry is integrated as a basis for research, management and dissemination to a greater extent than today. Empirically, it has been easier to gain entry by showing successful pilot-projects where the use of digital photogrammetry and digital documentation have been set up against more traditional documentation methods. Tangible results makes it easier to assess the usefulness of the method in each institution.

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Large scale modeling in a day-to-day practice of a Heritage Inspector

Mariusz Wiśniewski

Article 29 of Polish Monument Care and Protection Act (Dz. U. 2014 poz. 1446 oraz z 2015 r. poz. 397, 774) allows the Voivodeship Heritage Conservation Officer (WKZ) to conduct research of a monument (or artifact) "on site" with its owner's consent. According to Article 30 of the said Act, the owner is entitled to grant access to the monument or artifact for the purpose of research. If a consent is not given, WKZ is allowed to issue an administrative decision forcing the owner to grant easement to the monument (or artifact) to conduct the aforementioned research.

The reality of the use of Articles 29 and 30, especially in the field of archaeology, is that in most cases an access is granted when research is in order. Usually these are an owner's actions or an expression of intention to act that warrant research, while WKZ and his employees only ensure that this takes place in conformity with law and good practice. Nevertheless, they have the power (however rarely used) to stop development plans in favor of preserving the site as it is or enforcing the owner to actively protect it.

WKZ rarely uses Article 30 and if so it is usually to let other bodies to physically conduct research on a monument or artifact. This may happen when an owner of a standing historical monument is allowing it to fall into ruin, while it is not even recorded, or when an archaeological site is going to be destroyed (entirely or in part) due to its location on a path of a major public purpose investment (i.e. a highway project), and current owners of the land do not agree to proceed with rescue excavations (for reasons that may be connected with the development itself).

WKZ and his employees rarely conduct research by themselves, usually due to the limited budget of their institution, time on hand, and a number of staff, as well as enormous amount of administrative tasks. The current state of affairs in this matter could be a subject for another discussion. For the purpose of this paper, it is important to note that research can be conducted within such an office, but it is not the only responsibility hereof and one conducting it should be mindful of realities of work in heritage protection environment.

Close-range photogrammetry is currently causing, along with other so-called "new" or "modern" methods (LiDAR, terrestrial laser scanning, pXRF, GPR etc.), a sort of revolution in archaeology. Photogrammetry, as a science of making measurements from photographs, is by no means a "new" method since its beginnings date back to the 19th century. However, it eluded archaeologists in the days of analogue photography and did not become a common practice during archaeological research; traditional methods of conducting photogrammetric analysis, i.e. specific knowledge, work regime and specialist equipment – needed to recreate conditions in which photos were taken and to align them as well as the costs of the method turned out too big an obstacle for archeologists.

Introduction and development of modern digital cameras and computers and, in recent years, advance in photogrammetric software reintroduced photogrammetry into archaeology. Especially new computer programs, now more user friendly, have made photogrammetry available to those who did not study it at postgraduate level and allowed to achieve reliable (or even professional) results after a relatively short training.

My personal experience with photogrammetry started before the year 2010, when AgiSoft PhotoScan was first introduced. I believe that some difficulty in mastering an earlier software version and limited computer power at my disposal were the reasons that only around the year 2011 I started achieving presentable results in photogrammetric recording with version 0.67 of PS program. At that time, I had the privilege to work as a photographer at the Wałowa Str. Excavation Project in Gdańsk (not far from the place where Condition 2015 conference took place). The excavation project preceded the development of land for future WW II Museum in Gdańsk and was the largest undertaking in Gdańsk at the time. My role in the project was to ensure "traditional" photographic record of the excavation, while 3D documentation of excavated structures by means of Terrestrial laser scanning (Faro Photon 3D Scanner) was conducted with utmost precision and great results by other members of the team, to whom I am still grateful for all the help and great professional experience.

In 2011, PhotoScan software still was, to some extent, a novelty among archaeologists and other professionals, but it quickly achieved a position of a "go-to" solution when 3D Photogrammetry is considered. This paper is not aimed at presenting detailed Photo Scan workflow since it was well documented in a published work as was the position and usability of this particular software solution in archaeological documentation (S. Campana, F. Remondino 2014; M. Forte 2014). It is only worth to note that all models presented here were created with the use of different versions of AgiSoft Photo Scan and Photo Scan Pro, and sometimes post-produced with the use of other programs that supplement my "digital toolbox" (Meshlab, Cloud Compare, Agisoft Stereo Scan, Blender, XnConvert, PSE 9 and PSE 13).

In December 2012, I started to work as a Heritage Inspector in the Department of Archaeology of the Mazovian Voievodeship Heritage Protection Office (WUOZ). Multiple tasks connected with the post create a situation in which conducting one's "own" research is not the highest priority. Thus, I myself firstly found close-range photogrammetry as a tool to supplement other tasks that had been assigned to me. That called for evolution of approach.

Photogrammetry is not "new" to WUOZ. This kind of documentation was conducted in the 20th century by traditional methods. An example of this may be the photogrammetric documentation of an early medieval stronghold Rokitno, near Błonie, west of Warsaw, conducted in 1963 with the use of specialist equipment – a stereoscopic camera setup "Wilda" (on a tripod), with a base line of 120 cm between cameras (T. Radecki 1963). However, the position and budget of the Heritage Protection Office has changed as has the legal background.

The Department of Archaeology (as well as other departments of the Office) welcomes use of "modern" documentation techniques during research, but currently can enforce only those methods that are described in legal Acts. Today, the list of required documentation is regulated by an appendix II to the Decree of the Minister of Culture and National Heritage from 27 of July 2011 (Dz. U. z 2011 r. Nr 165, poz. 987 ze. zm) that does not mention photogrammetry, laser scanning, environmental sampling, LiDAR, pXRF or GPR.

Thus, a Voivodeship Heritage Conservation Officer cannot enforce photogrammetry as a part of archaeological research documentation, but only suggest using it even if he can enforce conducting the research itself. The Office is often in power to commission photogrammetric documentation, but only within the budget, or carry it out with the available "manpower", but only when it does not hinder other responsibilities and tasks of the employee.

In a situation where an important monument, artifact or archaeological site is discovered to be in direct danger of destruction due to an accident, neglect or intentional misconduct, time is always short and budget restrains do not help, thus "horses for courses" approach proves to be the most appropriate.

PhotoScan is famous for the short time of data acquisition and applicability of the method and software package to almost every situation. I used it for the first time within the office, during a site visit to Ożarów Mazowiecki on 8th of March 2013. It was the first time I had to visit an archaeological site partially excavated in order to build a single-family house.

A primary responsibility of a Heritage Inspector during such a visit is to confirm that the excavation process is carried out according to law and conditions described in the research permit and to create a protocol describing the situation with all the details that ought to be improved or changed before next visit; an Inspector intervenes when the progress of works could endanger the subject of research. A protocol can be supplemented with a map, sketch or photographs. I decided that a simple 3D model of this relatively small archaeological trench would be in order. 33 pictures were taken from 8:58 to 9:03 – within 5 minutes I was able to gather data necessary to produce a 3D model of the entire trench.

A model of considerably high quality (accurate up to a centimeter), and in fact the only one so far from this particular archaeological site, has been created with the use of standard workflow, described in the Photo Scan manual, on "high" settings with the use of contemporary implementation of the software. This model, exported to popular formats (.ply, .obj and .pdf), was presented to my supervisors within the Office where it did get some attention as a novelty, but it was, nevertheless, included into documentation.

One could argue that a centimeter level accuracy is not the best that could be achieved and that a time-of-flight laser scanner could possibly perform better in recording of an open archaeological trench. I have heard these remarks and think that it is vital to the discussion to remember the purpose of 3D modeling during site visits or while conducting small-scale excavation projects:

- laser scanner can provide a millimeter level accuracy, but so can Photogrammetric 3D modeling. It is a matter of the number of photos, their quality (sharpness, resolution, distortion,) and quality of their alignment (projection, overlap),
- single context recording in Polish archaeology, as an idea, is slowly gaining popularity. Although well proven to be superior in most scenarios, it is still not the only and – though I am afraid to admit it – not the most popular method, especially in commercial archaeology. Quite often an archaeological feature is recorded as such ("object") rather than a Cut Feature and a subsequent Fill, or part of the Feature is excavated as a box-section and only the other part is excavated "as a single context". Moreover, extensive archaeological deposits tend to be excavated mechanically in set increments, usually in 10 cm "layers", not to mention topsoil and subsoil being stripped and cleaned very often to a table-flat surface which, one has to admit, is a creation of an explorer. In these conditions, 3D documentation represents an excavation process rather than an actual subject of excavation, and it does so to a far larger extent than it is the case with single context excavation and recording. A continuous triangle mesh and good quality texture are, in this case, a more appropriate tool than a point cloud from a scanner since its reception is more natural and it allows to better understand what part of the model actually represents an artifact/feature/subject, and which is a documentation of the process itself. One should also remember that quality is not the same as density of the model – while modeling a subject in situ, there is no point, in my opinion, in recording trowel marks,
- portability is always on side of digital cameras. During site visits, but also while conducting excavations, one is more likely to have an access to a camera (usually more than one) of a fairly good quality (and one should appreciate quite amazing capabilities of even the sim-

Fig. 1. *The first (simple) model created for MWKZ with AgiSoft PhotoScan, Ożarów Mazowiecki, 3.08.2013. An orthophotographic view generated from a 3D model*

Fig. 2. *A 19th-century gas lantern arm from Warsaw. An orthophotographic view generated from a point cloud*

Fig. 3. *Sieciechów, a fragment of Romanesque foundations of the temple. An orthophotographic view generated from one of 3D models*

plest of today's dSLR's and admit that a photographer is more likely to be the limiting factor.) A laser scanner, although these amazing instruments are increasingly getting smaller, more accurate and more capable, is still specialist equipment and with all additional paraphernalia (even if it only means a tripod) is not likely to fit into an Inspector's bag going on a site visit,

- cost of acquiring and maintaining a scanner (both laser and optical) is significant. Even if an institution is able to afford one, it wears out during usage and cost prohibits one from using it for assignments that at first glance seem "small "or "not very significant". In my practice as a Heritage Inspector, I am able to make it a rule to always carry a camera while "going into the field", and it would not be possible with a scanner, provided that the Office had one, since out-of-office insurance alone would make the operation cost unbearable.

While visiting archaeological excavations, an Inspector as much as in excavated artifacts or archaeological features is interested in the excavation process. 3D models potentially created during such a visit are not a competition to official documentation, but they may complement it. It is a responsibility of a research director to ensure to the highest standards of documentation. Moreover, a site visit may happen in time when the most important features have already been unearthed and, documentation having been made, subsequently removed – hence it represents the site of excavation at a particular moment in time. At the same time, a 3D model may be the only way of ensuring that some form of documentation is available if an archaeologist is unable or chooses not to deliver documentation in time.

Due to all mentioned reasons, I have made it a rule to always carry a dSLR while at work, the result being tens of 3D models created within last three years. It may not sound impressive at first glance, yet one has to remember that in the year 2013 just over 300 archaeological research permits (for all kinds of archaeological research including numerous excavations, some at a large scale) were issued in the central Mazovia region (excluding Warsaw city area), only 3 of which were issued for research projects (there were only 3 applications) and only once 3D photogrammetric documentation was created. This was in fact the only 3D on-site documentation of archaeological research that year and it was computed (not within a research project) with the use of 123D Catch free software. In 2014, the number of research permits issued (excluding Warsaw city area) was similar although slightly increased, only 3 of which were issued for research projects and no 3D models of any kind were created. Only one of the three research projects used advanced analysis of LiDAR data and another one of the three was accompanied by geophysical survey (electrical resistivity). In that sense, a Heritage Inspector has performed a bulk of 3D photogrammetric documentation of archaeological research in this part of the Voivodeship.

An ability to create models from "historic" photographs is another usable quality of modern Close-Range Photogrammetry, and was used within the Office on a few occasions with the use of archival photographs, taken by various employees of the Office over past years, and some research documentation. The full potential of this approach within the institution is yet to be exploited, but it seems that the major advantages are a possibility to supplement existing drawings with "ortho-photographic" views generated from models, recreating missing drawing documentation, and making past research available in an interactive form on the internet (M. Wiśniewski, 2014).

In late 2013, a new project of reinstatement of Historic Lanterns in Warsaw started as a Cooperation of MWKZ and the Office of Capital Monuments Conservator (BSKZ).

Gas and early electric models of lanterns illuminated the city of Warsaw in the late 19th and early 20th century. A number of models were introduced before WW II, but few actually survived the wartime. Since the lanterns are an important part of infrastructure, even those severely damaged were in first days after the war quickly salvaged, their parts put together, not always in a correct order, and then re-installed in the city. In the later years, newer and simple concrete models were introduced en-masse and most of the "historic" models actually often represented mismatched assemblages of parts (J. Zieliński 2007). To reintroduce accurate copies of some models in historic parts of the city, where they now belong, taking into account the fact that those few remained complete examples were scattered around the city, and original plans and moulds often didn't exist, one had to localize the best examples and document them in a way that later would allow for reproduction.

I was asked to carry out 3D documentation of eight examples and photogrammetry was selected as a method of choice. Beceause of high specularity of the subjects' surfaces and the need for a high density and high accuracy model, it was suggested not to use a laser scanner, and the fact that data acquisition took place on site, usually on more or less busy streets, spoke against use of an optical scanner.

Models have been completed although computing them, in some cases, turned out to be a challenge; luckily since the subjects were all accessible every day some photographs could be retaken. A key proved to be a substantial number of photographs for each model taken from a very short distance in a manual mode, carefully aligned and with plenty of overlap. A circular polarizing filter also proved to be a very useful tool for reducing reflections of modeled lantern posts and bases, while careful pre-processing of RAW files improved quality of the final models. The models of lanterns are now ready and awaiting the next step, when they will be used to make actual replicas.

By the end of 2013 I did realize that 3D photogrammetry used by myself generated some interest among my colleagues, also from other departments, so I decided to offer them a short training within WUOZ. Having the permission from MWKZ, I organized a one-day training: "Potencjał fotogrametrii trójwymiarowej w ochronie dziedzictwa kulturowego" (Potential of 3D photogrammetry in cultural heritage protection) on 15th of January 2014. It consisted of a theoretical and practical part – a short workshop explaining how to perform data acquisition in order to achieve a reliable 3D model. It proved very successful since weeks after Mr. Stefan Fuglewicz, working in the department of Monuments (Wydział Zabytków Nieruchomych WUOZ), during his visit to the Modlin Citadel (an early 19th-century military listed monument), where he was investigating progress of restoration works, took a series of photographs as earlier instructed. Based on the photos, a model of an exposed caponiere was computed.

Because the structure, normally hidden from the view, was visible for only one day and since it belongs to one of the most important monuments of military architecture in the country, the insight this short visit provided is invaluable and owing to Close-Range Photogrammetry it was well documented in context to the outer wall of the citadel.

In 2014, the use of photogrammetry within WUOZ grew to recording of artifacts, findings reported by people – unintentionally found at different occasions, from a morning jogging to construction works. These usually were characteristic objects like stone or bronze axes and happened very rarely, but were great exercises helping to perfect technique and workflow. Results of such work can be very rewarding and show how accurate photogrammetry can be, competing to some extent with a structured-light scanner, at least in resolution, if not in accuracy of a final model

In July 2014, Rafał Nadolny – MWKZ (the Mazovian Voivodeship Heritage Conservation Officer), who is actively supporting research projects within the area of the whole voivodeship, introduced me to a project carried out in Drobin.

Drobin is a small town in Northern part of Mazovian Voivodeship, and its artifacts and monuments are under the delegacy of MWKZ in Płock.

Drobin is now a municipality and a home to 3000 citizens, but its history dates back to at least 17th century and possibly as far as to the 15th century. One of the town's most important monuments are remains of a Gothic-style manor house dating back to 16th century (?). The excavation project, carried out by the Łódź University since summer 2012 proved that elements of the basement complex might be in fact older and correspond with the beginnings of the town. The basement complex in Drobin is now well known and important to the local community who took great interest in the research, yet due to many reasons the building fell into a state of dire disrepair; still preserved vaulted ceilings are crumbling and brick walls bear signs of some intentional damage.

The photogrammetric documentation of the Drobin basement complex took place on Friday 11th July 2014. Time is a crucial factor for this project since it coincided with the end of excavation season on site. I was notified about the possibility to make 3D documentation (on 08.07.2014) by MWKZ after his visit on site (on 07.07.2014) where preliminary results of research had been presented. Such a short notice required using well-established workflow and prevented from elaborate planning. In total 1560 photos were taken that day and during the processing phase less than 10 % photos were discarded.

During the processing phase, in order to be able to keep track of changes in the project and being aware that such a complex task will require many attempts to compute a satisfying model, I continued taking minute notes of taken actions and their duration.

A potential model could rival the laser scanner's accuracy, but would also count several GB in "size" so I decided, having at my disposal a powerful, but still standard computer, that several "small" models of particular rooms and details are "a safer path". Altogether, 31 models were created and made available to all parties involved in the research in Drobin. These models could be later merged in one and one "solid" model of the entire interior was created later this winter.

Documentation of the basement complex sparked an interest in Wojciech Ostrowski, M.A from Politechnika Warszawska (PW, Warsaw Technical University), Department of Photogrammetry, Teledetection and Spatial Information who proposed cooperation in that matter and kindly offered to analyze the model(s). Later in October 2014, a team of graduate students under his supervision used a laser scanner to once more record the Drobin monument. The goal was to record progress of decay (if any) and compare a point cloud with results of photogrammetry.

Photogrammetry gave equal results; it provided better quality at the X and Y plane and in the texture, while the scanner performed slightly better in the Z plane. Details of the whole process are available on request and will be presented in the upcoming publication.

Many of earlier mentioned projects have traits or attributes of "rescue" 3D modeling. A question now arises – does such a thing exist? Those working as professionals in heritage protection always notice a sense of urgency. Moderate budgets of institutions protecting monuments, fast pace of development (especially when large business is involved), lack of certain legal solutions, limited personnel and lack of involvement of general public are a reality.

This reality already created rescue archaeology. I do believe that photogrammetry has a strong role to play either as a part of rescue archaeological research, beside it or both, and due to all advantages of the method I also believe it can be successfully implemented within an institution such as WUOZ – not as a tool superior to a laser or optical scanning (these methods have their specific uses where they remain more effective in hands of specialists) but as a tool more flexible and affordable, and one that can be used today with equipment already at hand.

MWKZ and his employees certainly will, in near future, use Close-Range Photogrammetry.

On 5th May 2015 town house facades in Wołomin, Warszawska Str. 23, have been recorded to supplement the documentation provided by the developer aiming to re-erect a building that now is almost a complete ruin. The generated model will be a basis to watch over the reconstruction process and later this summer the most ambitious project yet to be undertaken within WUOZ is going to take place – the former monastery in Sieciechów, dating back to the 12th century and its still visible Romanesque and Baroque details await and deserve to be documented and later restored for future generations.

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Conservation and 3D-documentation of waterlogged wood from medieval mining

Philipp Schmidt-Reimann
Thomas Reuter

INTRODUCTION

The Ore Mountains are located on the border between the German federal state of Saxony and the Czech Republic. The region is well-known for its rich mineral resources. Already in 1168 first mining activities at Freiberg were documented. Through the centuries medieval mining relicts were overprinted by later mining, up to the middle of the 20^{th} century [1].

In 2008, during safeguarding activities under the town of Dippoldiswalde, approx. 30 km south of Dresden, the accidental discovery of archaeological features showed the presence of hitherto unknown medieval silver mines that survived almost entirely intact (Fig. 1). Thus, in 2009 a new research focus on mining archaeology was established at the Archaeological Heritage Office of Saxony a and supported by Saxon Mining Directorate,where exhaustive studies of medieval mines have been initiated [2]. To intensify research a binational German-Czech project ArchaeoMontan was started in March 2012. The Ziel 3-project was funded by the European Regional Development Fund (ERDF) and joined seven partners to coordinate research. ArchaeoMontan based on an interdisciplinary approach where archaeologists, historians, geologists, surveying engineers, conservators and museologists explore, document and research archaeological mining relicts in a cross-border cooperation.

During the three years that ArchaeoMontan was running, a wide range of new knowledge was gathered but a number of new questions were raised as well. A follow-up project is in preparation and will be submitted in the near future. The experience gathered in the first programme shows that the new project ArchaeoMontan 2018 will have to be focused on restricted regions to investigate the questions raised [3].

UNDERGROUND

THE MINES

For safety reasons a number of these medieval mines are currently being filled up with concrete by the mining inspectorate of Saxony. To this end the mines are excavated down to a depth of around 25 meters and all the finds have to be retrieved where possible. The exploited veins in Dippoldiswalde have been very thin and were running in a more or less vertical direction leaving deep but narrow stoops, mostly not wider than 80 cm, but often significantly narrower (Fig. 1) [1]. Because of difficult access and the restricted space in the underground medieval mines, the archaeological documentation and lifting of objects is hindered. The transportation of bigger wooden items out of the mines often poses a serious challenge.

The environmental conditions inside the underground works are characterised by constant low temperature, very high relative humidity or even waterlogged contexts. These conditions, combined with the fact that the mines have never been re-entered again since their closing, has led to the preservation of wooden artefacts.

THE FINDS

Most of the objects found underground are made of wood. This paper will therefore focus on the approach of handling and scanning large amounts of archaeological waterlogged wood. Only very few items made of leather, bast (rope) or iron have been found so far. Due to their rare occurrence those items will be neglected for the purposes of this paper.

Until now, more than 1000 individual finds made of wood have been selected for conservation. As research on medieval mining in the Ore Mountains is ongoing, the amount of finds will rise as soon as new mines are excavated.

The dimensions of the wooden finds range from wooden handles, which are only a few centimetres in length with a small diameter, up to massive drainage channels with a length of several meters (Fig. 2). Most objects are construction timbers and are made of coniferous wood with fir (*Abies alba*) being the majority of this group [4]. In contrast, tools are mostly made of hardwoods; especially beech (*Fagus sylvatica*).

Because of the climatic conditions mentioned above, the wooden installations, tools and other objects of daily work inside the mine are generally in a good state of preservation. To specify the state of preservation the degree of deterioration is expressed or maximum moisture content (u_{max}) [5], which is determined by weighing [6]. Fig. 3 shows the distribution of u_{max} – values based on the classification by Christensen [7]. As showed by u_{max} – values the degree of deterioration varies widely across the whole spectrum.

THE CONSERVATION PROJECT

The Conservation Department of the Heritage Office has ample experience with the conservation of waterlogged wood but is not equipped for handling the comparatively large amounts of objects of this category. Therefore it was necessary to set up a temporary workshop for the duration of the project. Additionally the workshop had to be self-sufficient owing to project guidelines.

The main challenge for the conservation of these waterlogged wooden objects was the logistical tasks of treating the great numbers of finds with the available resources. The time scale was three years, and the workshop had to be set from scratch, beginning with hiring new rooms, purchasing equipment necessary for cleaning, impregnation and drying of waterlogged wood, with the aim to conserve the waterlogged wood from medieval mining and present selected finds in an exhibition.

Fortunately, the financial support was adequate and the budget allowed for major equipment acquisition. For example, we were able to purchase large treatment tanks for impregnation (up to 2000 L) with appropriate pumps, facilities for de-ionization of tap water and other cost-intensive equipment such as a high-quality modern stereomicroscope (with a digital camera and a motorized focus unit allowing z-stack capture automatically). Furthermore, we increased the existing vacuum freeze-drying capacity and updated the necessary equipment significantly according to the general demands for vacuum-freeze drying of waterlogged wood impregnated with aqueous solutions of Polyethylene glycol (PEG) [8].

During the final stages of the project, an exhibition about mining archaeology presenting outstanding finds from the mines was to be organised. Therefore, the conservation of selected objects had to be accomplished before the end of the project.

Personnel were restricted to one conservator in the first year, and two conservators in the following two years. To ensure a successful project work within the given resources (time, personnel, financial budget) some project management tools were applied. Core elements were a work breakdown structure and Gantt charts, described in more detail by Schmidt-Reimann [9].

WORKFLOW

The close interdisciplinary collaboration of the team members was an advantage for conservation and allowed for an efficient workflow which is inevitable for the preservation of huge amounts of finds [10]. The workflow listed below was applied for bulk treatment. Specialised treatments were performed for unique single objects or features [11].

EXCAVATION

Site technicians record the freshly excavated objects generally underground. Afterwards, the finds are wrapped in polyethylene-foil in an unclean state leaving as much waterlogged sediment as possible adhered to the object. The wet deposit serves as a buffer for moisture and as a mechanical protection during transport especially from underground to the surface. The latter process sometimes posed a major challenge. Only occasionally, in the case of very fragile and outstanding objects, a conservator performed the recovery.

CLEANING AND STORAGE

After transportation to the Conservation Department, the finds are stored in a cool and humid temporary depot. Additionally, a permanently installed cold storage room (+ 1°C) at the Heritage Department can be used for selected delicate finds, although restricted by space limitations. However, to gain reliable dendrochronological dating of the archaeological complexes "poorly preserved material or wood without clear context or preserved tool marks is sampled for dendrochronological dating" [1]. The wooden finds are cleaned mechanically, while the degree and scale of cleaning is adapted to the size, condition and the complexity of the individual object. Small and/or delicate finds are cleaned under high magnification using a fine airbrush, whereas bigger and more stable finds are cleaned without magnification using hosepipes. Between each step, the finds are wrapped in PE-foil, inventoried in the temporary depot and checked regularly by visual inspection.

DOCUMENTATION

All finds are recorded once the object is clean. At this step of the process, photography is being substituted by 3D-scanning.

Since 2005, 3D object documentation is an important element in scientific research at the Archaeological Heritage Office of Saxony. With the excavation in 2008 of the Neolithic well of Altscherbitz and the first discovered medieval mining artefacts in 2009, 3D scanning of fragile wood started as a new area of activity. In the course of the ArchaeoMontan project, 700 timbers were scanned and documented. In total three close-range scanners are used for data acquisition. In 2012, a Konica Minolta VI-910 laser scanner (maximum resolution of 0,2 mm), was complemented by a Breuckmann smartSCAN3D-HE fringe projection system which achieves a maximum resolution of 18 µm (Fig. 4). Typically, median point distances are in the range of 0.4-0.6 mm. Experience has demonstrated that a resolution of ca. 0.5 mm is completely sufficient. A significantly higher resolution would cause the annual rings to show on the model, obscuring tool marks and rendering their determination nearly impossible.

Timbers with a length of up to approximately 1 meter can be scanned on an automated rotary table whereas larger objects have to be scanned using a manual step-by-step method. Nevertheless a complete scan is finished in an average time of 45 min. After the scan is finished every timber goes immediately back to the Conservation Department. For further processing and documentation of the scans a specialised software package, TroveSketch, has been developed in a cooperation between the Archaeological Heritage Office of Saxony and the University of Technology Chemnitz since 2006. TroveSketch provides functions to align, measure, render and intersect 3D models in a simple manner [12]. Standardised true to scale images are significantly improving the visual quality compared to traditional technical sketches. Now it is possible to publish complete catalogues in a very short time while the timbers are submersed in the preservation bath. Furthermore photorealistic renderings as well as virtual reconstructions can be done enabling archaeological research, although the objects themselves are still in conservation and therefore not accessible.

Fig. 1. *Impression of underground conditions in the medieval mines of Dippoldiswalde; photo Heide Hönig; all authors of figures – Archaeological Heritage Office Saxony*

Fig. 2. *Assembly of photorealistic renderings on the basis of 3D-scans showing the spectrum of finds; photo Thomas Reuter*

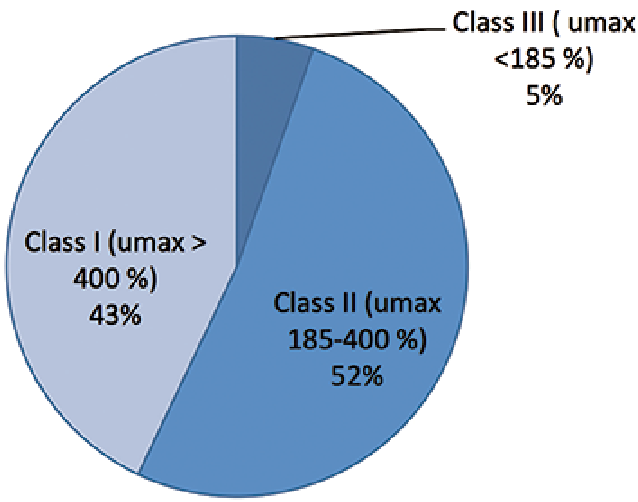

Fig. 3. *Distribution of umax – values based on the classification by Christensen respectively [7] (n = 352)*

SOAKING AND IMPREGNATION

Recorded objects are subsequently being soaked in several baths at room temperature. Tap water is used for the first baths, followed by repeatedly filling the tanks with deionized (ion exchange resin) and filtered (microfilter) water. Latter actions seem to reduce microbial activity considerably compared to the use of untreated tap water.

After several weeks or months of soaking, the finds are weighed both submerged in water and in air to calculate actual density and u_{max} – values respectively (see above).

Subsequently the objects are impregnated with an aqueous solution of deionized water and high molecular PEG 2000 prior to vacuum freeze-drying [13]. To prevent osmotic shock, i.e. avoiding too high osmotic pressure building up in the wood [5], the concentration is increased slowly and gradually during impregnation until the final concentration of 30 or 40 % (w/v) respectively is reached. During impregnation the tanks are checked visually as well as pH-measurements. The development of the concentration is monitored using a hand held refractometer. To this end, refractive index curves have been established as calibration curves prior to monitoring the refractive index of the actual solution to determine its concentration [14].

VACUUM FREEZE-DRYING

After the pre-treatment with PEG 2000 the objects are vacuum-freeze dried. During the process of freeze-drying the high surface tension and capillary forces normally occurring when liquid water evaporates can be avoided as the water is frozen and sublimes directly. The extended and updated freeze-drier was constructed according to the recommendations described by Jensen et al. [13]. A stainless steel tube of 2,80 m in length and with an inner diameter of 0.70 m is used as a vacuum chamber. The chamber is equipped with an external cooling unit allowing infinitely variable cooling of the chamber walls from room temperature to ca. -40°C. The ice condenser is cooled to -50°C during the process with a maximum ice capacity of 20 kg/24 h. A total of 16 thermocouples (type K) enable close control of the temperature inside the chamber (at the walls and in the air) as well as on the surface and inside the objects. The freeze-drying is mainly a computer-regulated process and can not only be controlled on the spot but can additionally be observed and, to a certain extent, regulated online as well.

Since aqueous impregnation solutions of PEG 2000 have got a certain eutectic temperature the knowledge of critical temperatures (eutectic and collapse temperatures respectively) of the actual solution is crucial for satisfactory results after vacuum freeze-drying [15]. Temperatures above the collapse temperature of the solution during the process can cause liquid phases and therefore shrinkage, cracking and collapse of the wood [8]. However, too low temperatures cause a substantially prolonged drying process, which is time-consuming and energy-intensive. Therefore the critical temperatures of the actual solutions are determined prior to freeze-drying by a simple but convincing method using stainless steel thermos flasks as proposed by Schnell/Jensen [15]. Thus the necessary parameters for the freeze-drying are known and ice temperatures inside the objects are regulated by adjusting wall-temperature during the process. Throughout freeze-drying the pressure in the chamber is lowered to 0,1 mbar.

The termination of the drying process is determined by the development of temperature inside the object, the weight loss of selected objects and especially by measurement of pressure rise inside the drying chamber after sealing it from the condenser. Subsequently the objects are removed from the chamber and excess PEG is cleaned off the surface.

3D-MONITORING AFTER DRYING

After freeze drying and final cleaning all finds are scanned once again. Thus, there are two datasets with detailed surface and volume information of the wood. This makes it possible to compare the 3D models for determination of volume change as well as deformation of the object itself. In Geomagic Studio there is a function to make a 3D comparison. It requires an alignment of both datasets as accurate as possible using the best-fit method provided by Geomagic Studio. Thus, the aligned datasets are ready to be compared. With the 3D model of the pre-preserved condition defined as reference, the distances between the vertices are calculated and visualised as a colour-coded texture on the 3D model of the treated find defined as test object (Fig. 5). The spectrum is chosen freely by the operator taking into account that the value of the median point distance will be considered as stable. The colour-code makes it possible to analyse the deformation. As all 3D-scans have been processed to provide watertight models the volume can be reliably determined.

CONCLUSION AND OUTLOOK

The waterlogged wooden finds of the medieval mines had been impregnated with PEG 2000 prior to vacuum freeze-drying in order to prevent shrinkage and to retain the original volume and surface structure. Scanning the finds before and after treatment has monitored volumetric changes. First results of the 3D-comparison are shown in the diagram [Fig. 6].

It must be emphasized that these results are not obtained by the use of standardized test specimens but by actual finds with individual reactions during conservation. Furthermore, available data is still limited to only a few finds. Therefore the results are of limited significance and no general statements about the treatment regarding its effect on waterlogged wood from medieval mining can be obtained at this moment. But it is planned to continue the 3D monitoring after conservation of waterlogged wood as a regular step within the overall workflow and collect more data about changes in volume. In addition to that a differentiation by wood species will be possible as soon as enough data is collected. This enables us to gain detailed knowledge of the results after impregnation with PEG 2000 and vacuum freeze--drying. This first application of the method on medieval wood from medieval mines in the Ore Mountains opens up a new and broadly adaptable approach to the conservation and monitoring of a wide range of waterlogged archaeological timbers and smaller wooden artefacts.

ACKNOWLEDGEMENTS

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Fig. 4. *Laboratory at the Archaeological Heritage Office Saxony with fringe projection system Breuckmann smartscan3D-HE, rotary table, daylight lamps and light box; photo Rengert Elburg*

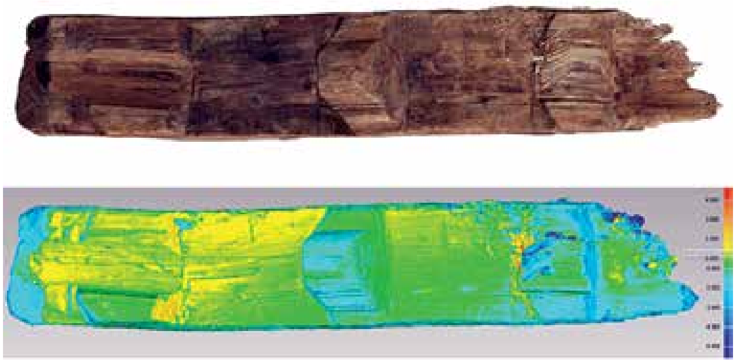

Fig. 5. *Comparison of a log ladder in Geomagic Studio. The coloured areas are showing changes in dimension (blue – shrinkage, red – swelling) of the object in preserved state compared to the original waterlogged condition*

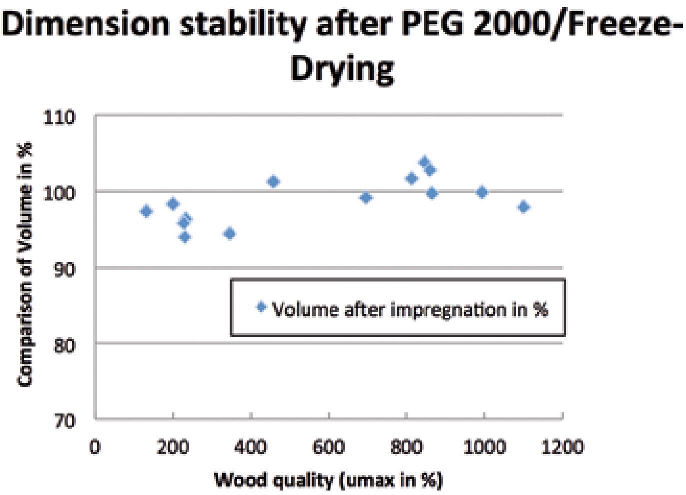

Fig. 6. *Dimensional stability of waterlogged wood from medieval mining after impregnation with PEG 2000 and vacuum freeze-drying*

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Making a digital inventory of a historic folk boat team from the collections of the National Maritime Museum

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From July to September 2014, the Architekci Gzowski & Gzowski design office, represented by Mateusz Gzowski and Marcin Kulesza, conducted Poland's first digital documentation of 14 historic boats from the collections of the National Maritime Museum in Gdańsk. We specialize in architecture and archaeology; years of experience in documenting historical relics gave us an assurance that we would cope with the task. We are the first architectural studio in Pomerania to start documenting monuments by using modern surveying methods such as laser scanning and orthophotography.The work was conducted in a close collaboration with the Ship Service design office, specializing in small and medium-sized vessels, especially yachts, boats and fishing boats. A substantive support was given by Dr. Jan Młynarczyk, a shipbuilding engineer, who specializes in small ships and yachts. The preparation and processing of 3D graphics were made by the Vikon Company, represented by Witold Hazuka. Such a selection of team of specialists gave us confidence that particular stages of the task would be carried out with due diligence and based on years of experience in the field of digital (laser scanning, 3D models) and marine technology.

Documentation of historic boats was technical documentation. At the beginning, we inventoried each of the boats. After that, we made marine technical documentation consisting of a series of calculations. Since this was the first such a document, all the work was preceded by a series of tests (scans, photographs, measurements) on the boats located on the Hel peninsula. Work guidelines were received from the National Maritime Museum.The documentation of 14 folk boats from the first half and early in the second half of the 20th century was prepared. All the boats were built in the area of today's Poland and was a testament to the tradition of boat building on the coast of the Baltic Sea.

The boats are a part of the Museum collection. They were subjected to scanning in the first place since they had been exposed to the open air and atmospheric conditions, which caused degradation of the material they were made of. All the boats were made of oak wood with additional metal elements (braces, crossbars etc.). The condition of individual objects was varied – from heavily damaged units, such as Hel27, to the renewed DEB5 unit. Five units had no external paint, while other ships' sides were painted in at least two colors.

The purpose of the task was to create complete technical documentation of the vessels for:

1. conservation needs – providing as complete as possible information about physical parameters of the boats and the state of the vessels as well as data for possible comparative and conservation works, including reconstruction. As a result, documentation was to provide a possibility to make and replace a single structural element in the event of damage or irreversible degradation,
2. registration needs – providing information about the physical and technical characteristics of the units for documentary, scientific and research purposes,
3. needs of sharing – using these data for popularizing knowledge about vessels in the society, including publication in online directories, creating animations, augmented reality, re-using etc.

The main objectives of the project were the directives included in the specification of essential terms of the contract and the recommendations of the London Charter[1]. The documentation of the boat made by the Norwegian studio, was the comparative material. Based on the design of the wooden oak boat and documented in the above-mentioned work, it was the only reference material for the preparation of the boat in Hel. It was considered that the visual effect should be similar to the result obtained in Norway. The progress was consulted on a regular basis with representatives of the National Maritime Museum and reports of each step were periodically sent out.

Presently, 14 historic boats are in the magnificently located Fisheries Museum at Bulwar Nadmorski 2, Hel. The Branch of the Museum is managed by Mr. Tadeusz Muza, who helped us greatly with carrying out the work. Words of praise and thanks go to the whole institution.

The schedule was divided into six stages.

The first stage of measurements (laser scanning) in the Fishery Museum, Hel. The measurements of three boats were taken inside the building and eleven boats were measured outside.

The problem of accurate measurements of each unit was their wooden construction that was subject to shrinkage and expansion due to the action of weather conditions.

Naturally, during different seasons, the shape of the hull may shrink even over a dozen millimeters. Another issue is protection of wood against environmental influences which means a new protective layer on the wood. All these

Fig. 1. *Hel Peninsula, the Fisheries Museum*

Fig. 2. *The Fisheries Museum, Hel*

Fig. 3. *Laser scanning inside the building*

Fig. 4. *Laser scanning outside*

Fig. 5. *Technical condition of the boat*

Fig. 6. *Point cloud processing – filtered analysis*

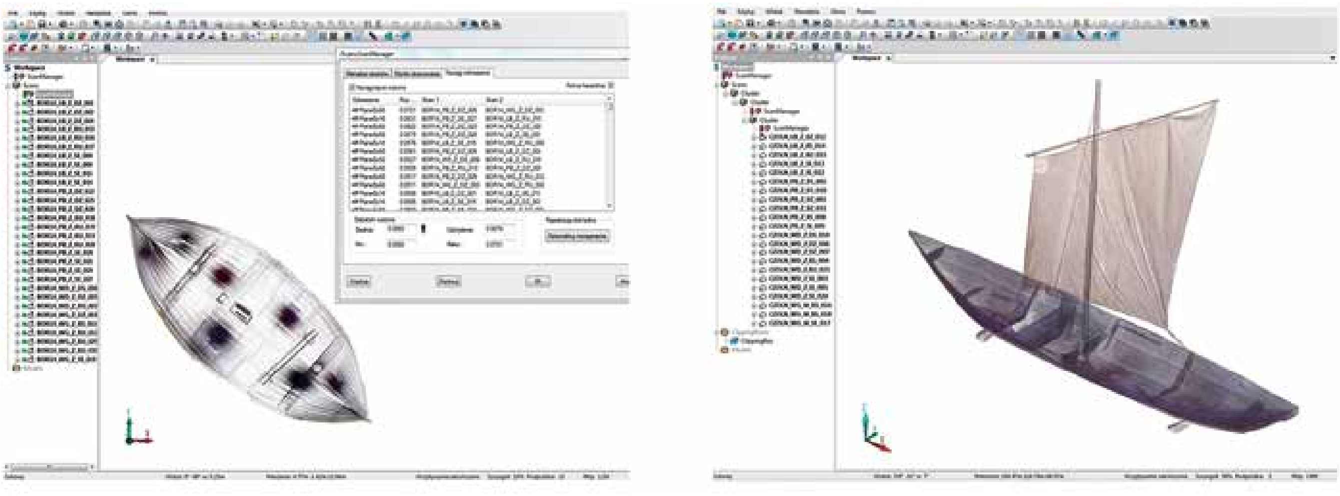

Fig. 7. *The filtration process and the registration of scans in Faro Scene software*

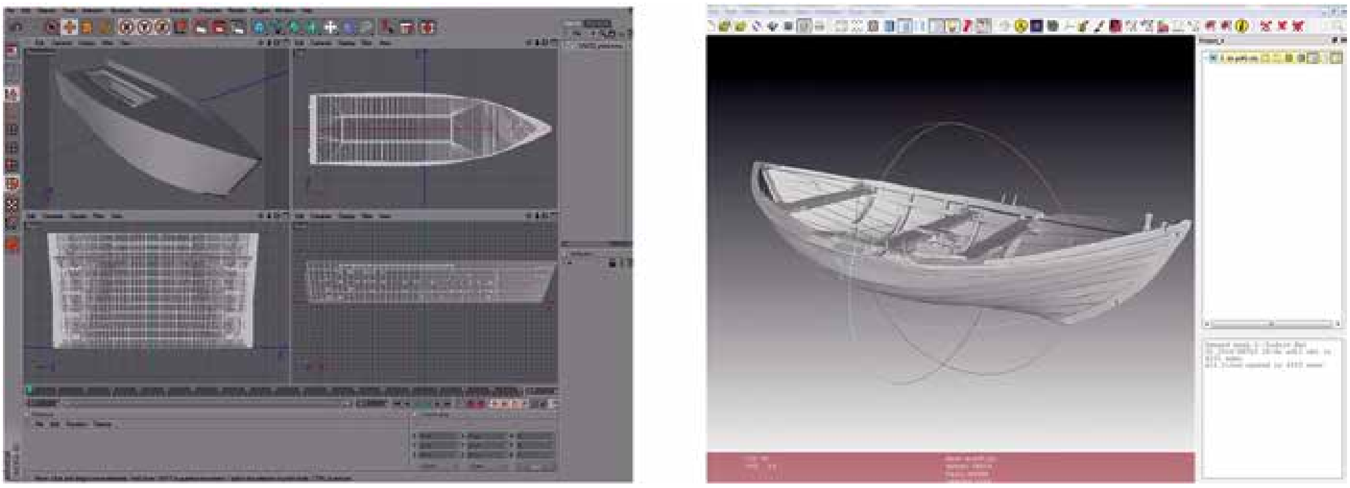

Fig. 8. *The stage of modeling of full solids of boats to improve their condition*

Fig. 9. *Czołn łebski*

factors point to the lack of rational justification for very accurate documentation of every square millimeter of the surface of the wood. Due to the materials used to build boats and, in particular, a thick tar layer that covered some units, we paid attention to a problem of possible reflection of a laser beam. To avoid a mistake that could significantly distort a scan, measurements were performed on completely dried and adequately prepared units (cleaned of leaves, branches and sand).

Scans were made in color, with the use of photo-quality 70 Mpx (megapixel) units integrated with the scanner. The total resolution of a camera is the result of the number of pictures taken by a scanner during a turn; from 15 to 35 scans were taken of each boat. The material obtained in the scanning process made it possible to accurately reflect the plasticity and geometry of each vessel.

The point cloud processing stage. Processed and filtered positional data were analyzed. Implementation of registration along with scans filtration and removal of erroneous single points gave us the density of point clouds from ~0.09 to 0.18 distances (millimeters) of the recorded points during the measurement. A given numerical value is the distance between neighboring points.

The next step was to analyze the collected data and classify each scan. Area scans were chosen carrying the highest number of source points, undisturbed and closest to one another. This lead to an increased number of scanning points, but the result was a more effective and efficient amount of

Fig. 10. *Boat HEL-7*

Fig. 11.*Boat KUZ-49*

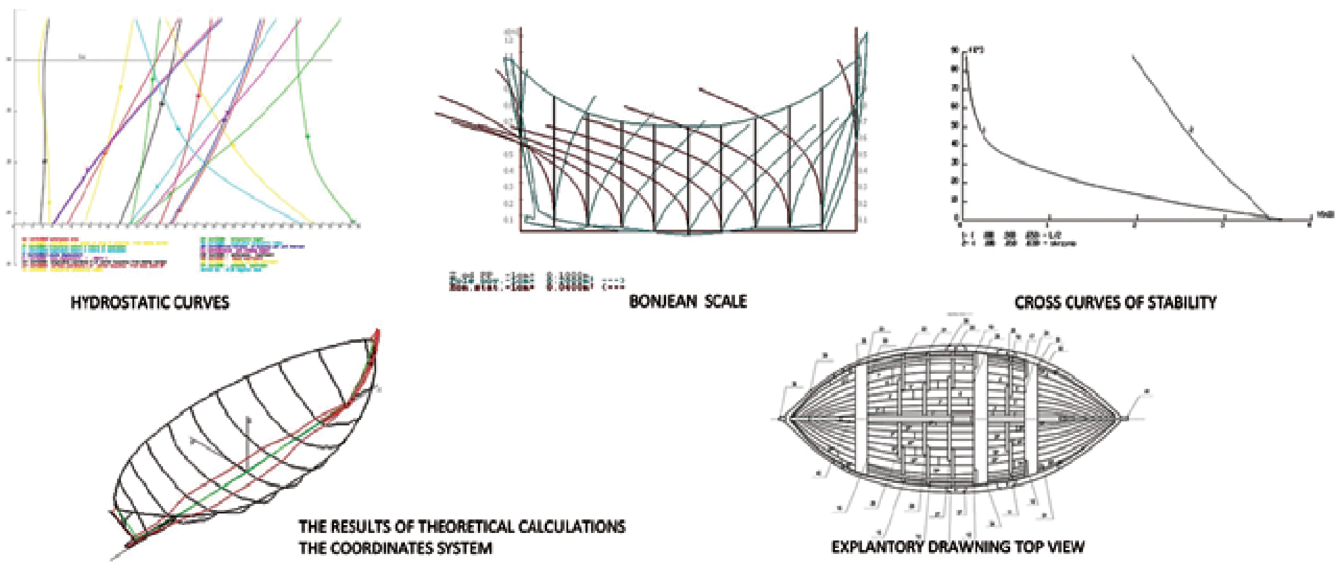

Fig. 12. *Drawings and calculationsr*

data. It was advisable to remove from the scans points that were more than 450 cm-600 cm away from one another.

The next step was data processing of a point of cloud; we cooperated with Vicon studio responsible for executing 3D models and conducted a tight boat models that were used by the Ship Service design office as the basis for calculations for individual units. The model was prepared in Cinema 4D software.

The stage of modeling of full solids of boats to improve their condition.

The model was prepared based on Meshlab software. Raw points were exported in the Faro Scene, in PTX format that allows to save raw data along with texture. A single scan in PTX format reached the size from 200 megabyte to 1.2 gigabyte. The scans in PLY format were exported from Meshlab program to Blender software for analysis and again filtrated.

Further process of submitting all scans together, creating a triangle mesh and UV mapping took place in the Meshlab program.

This process was partly automated. When a complex boat was being constructed, the process took place manually.

The final result was a mesh solid of a boat with a texture, based on a cloud of points obtained from a camera scanner.

The stage of ship calculations (drawings and calculations).

After receiving the material in the form of airtight solids, 3D solids and drawings based on scans, the marine laboratory processed the material.

On the basis of geometric data, calculations were made, specifying, among others, hydrostatic data, presented in graphical (hydrostatic curves) and tabular form.

HYDROSTATIC CURVES

– displacement (hull forms) in seawater,
– cross-sectional area waterline,
– location of the center of buoyancy,
– change in displacement per unit of immersion,
– midship section coefficient
– the Bonjean scale
– hull coefficient
– stability, including metacentric height and the righting lever curve

DIMENSIONING

– length overall, width in 3 measuring points (include maximum), height in 3 measuring points

The final step was the analysis of 3D marine materials and execution of technical and narrative documentation.

All in all, the method of laser scanning for measuring historic boats is faster and more efficient than traditional forms of measurement and documentation. The material obtained from the measurement and treatment gives a detailed picture of a boat, containing such information as color (texture), size and structure of an object. Such accurate results would be difficult to obtain using traditional forms of documentation. Moreover, owing to the method of documentation, reference material was created, that in a few years can be used for conservation analysis or for comparing states of preservation of monuments.

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Use of file metadata in dissemination of digital assets

Mikołaj Machowski

INTRODUCTION

In recent years, galleries, libraries, archives and museums (GLAM sector) have been producing digital assets on a massive scale. The simplest form of dealing with them is creating a system based on a folder tree and filenames, but it will be useful only to some extent and for in-house processing of assets. It will be useless for exchange of assets between actors and increasingly difficult to maintain when a number of files increases.

Everyone playing some role in digitization has had a situation when she or he was sure that somewhere – on a desktop computer, laptop or network drive – was the photo they were looking for and wasted minutes or hours to find it. Helpful in managing thousands of files is a specialized Digital Asset Management (DAM) system which should possess certain characteristics. The list presented with comments on next pages was prepared by the DAM Foundation formed to promote knowledge about how to manage digital files and stay sane [1].

UNIQUE ID

DAM systems ingest assets individually or in mass sets, and allow for the manipulation of those assets and their metadata individually or with mass actions. This is accomplished in part by assigning a unique identifier to each asset on ingest.

The easiest form of a unique ID code is a filename, but it has two main issues: it is very easy to change, and when creating a derivative of a master file (for example a JPEG thumbnail or crop), it is hard to generate a consistent naming convention that would be clear for everyone and easy to maintain. Embedding a unique ID into file metadata solves both problems.

When a digital asset is uploaded to a DAM, it needs to generate a unique identification code. This unique ID code, unlike the file naming convention, helps digital asset managers track assets through the system without the fear of accidental duplication. Furthermore, ID codes are infinitely expandable, meaning that a DAM can scale up over time. A system without this key attribute is doomed to remain small or become an organizational nightmare for those administering the system. Mistakes in file handling are inevitable without unique ID codes, and the ability to manipulate metadata on a large scale will always take twice as long. An ID schema can and should be designed in a way that will provide uniqueness on a global scale. Some ideas of how to implement it can be found in the description of Open Archives Initiative identifier format [2].

Unique IDs in a DAM make it easy to link particular assets not only when exporting files into external libraries, but even when connecting with other systems in one's own institution like museum inventory systems.

SECURITY

DAM systems secure the assets they contain. Security in a DAM extends to defining access control lists for assets and defining roles for users accessing the system.

Usually, in software systems access control is set by user privileges based on file permissions. In a DAM system it can be achieved by assigning keywords to files and rules of treating them. Users can be blocked from performing actions on files, viewing them or extracting files from archives. One should carefully consider how to name those keywords. A too descriptive name, when released outside of one's organization, can reveal things about one's internal procedures. When using metadata for this element, it is a good idea to scrub them before exporting. One should not forget to scan files from external sources – their metadata may bring interesting results.

A special case of security is the security of one's own data. Most DAM systems use indexing systems with various features, but museums and other institutions with long storage interests should take care of how information is stored internally. One should prefer systems where metadata are stored in files themselves or at least as XMP auxiliary sidecar files (they may be necessary when the file format doesn't support XMP data packet). With this system of storage, all data will always be accessible and easily transferrable to another software system. When data are stored only in a closed database where the layout of tables is very poorly documented or even proprietary, one may face a situation when one's own data becomes a hostage when one wants to change the software vendor, or even have problems when upgrading to a newer version of the software. Remembering about that is especially important today when the use of cloud systems or software-as-a-service model is on the rise.

FLEXIBILITY

DAM systems store assets as both binaries and metadata. A DAM system can store multiple file types, and allows for the customization of metadata fields and the metadata in those fields attached to the stored files.

All digital objects have the capacity to carry descriptive and technical metadata with them, and many do it within existing XMP records proposed by the International Press Telecommunications Council (IPTC) Photo Metadata Standard [3]. However, a true DAM allows for the creation of unique metadata models. Being able to add new metadata fields allows one's assets to become rich with information which has a knock-on effect in terms of being able to find, organize, structure, group and share your assets. We should remember that creation of additional metadata schemes can have the side-effect of limiting effective sharing. A metadata structure unique to one's DAM will not be visible in other systems. When making new hierarchies one should carefully research what data where should be stored. In one's own structure one should only store information which may be of lesser or no use for third parties. However, one should consider that only as a last resort – published metadata schemes officially supported by widely used software are enough to cover most of requirements especially in situations where a DAM system in museum is only an auxiliary one.

A special interest for museums is the IPTC Extension (latest version 1.2 published in October 2014) where the metadata structure *Artwork or Object in the Image* resides. It is possible to store extensive information about objects of art there.

I will present a selection of them with an example of how it could be used based on our own Cyfrowe MNW (Fig. 1).

***Portrait of John of Pernstein* – description** (Fig. 1)
Title: *Portrait of John of Pernstein*
Creator: unknown
Source inventory number: M.Ob.1764
Source: National Museum in Warsaw
Source inventory URL: http://cyfrowe.mnw.art.pl/dmuseion/docmetadata?id=21581
Copyright notice: public domain
Current copyright owner name: n/a
Date created: 16th c.
Style period: Renaissance
Physical description: oil, wood panel, 59 x 43

The names of the fields here are not just translations but were taken straight from the IPTC specs. Other fields are: circa date created, current licensor name, content description, contribution, description.

The IPTC Extension is fully supported in Adobe products and Open Source software like Exiftool or Exiv2 being the foundation of many programs or services.

Taxonomy or ontology of the above terms – while a fascinating problem – are not of special interest for us in the context of this presentation because metadata will come to us from inventory systems and we should not interfere with them more than fitting them into a proper metadata structure adjusted to photo management.

We should reserve at least one field for non-technical information related to a photo itself. It should inform an in-house assets manager and external users about special circumstances like: the fact that a photo was made with the help of ultraviolet, infrared light or X-rays, and provenance of a photo (not an object!) The metadata should be managed through controlled vocabulary and easily inserted from a user interface.

An example can be seen on Fig. 2 ("Special Instructions" in the center). As you can see, in the National Museum in Warsaw we don't yet fully support the IPTC Extension. Our software doesn't have this feature built-in, but its functionality is accessible through a flexible metadata system. We decided to use only the "Caption" field because it can be seen in the most basic file-management programs like Windows Explorer. In fully implemented workflow, both approaches can be adopted in parallel – the first one for more precise searches, the second for ease of use for ultimate users.

A special case of controlled vocabulary is a list of authors. Recommendation of a metadata standard is that this info "must be persisted and maintained" [3: 73]. In an older version, the standard recommendation was that when information was inserted by a photo creator, it shouldn't be touched at all. However, to include them in our workflow and utilize a full power of a DAM system, we have to unify formatting so all authors can be easily sorted and recognized. Photographers working alone have tendency to write their names as *name* and *surname*, but this makes it hard to find a name when working with photos from many sources. In our work, we have standardized the form as *surname* and *name*, and optionally an institution may be included.

WORKING DERIVATIVES

DAM systems render/transform assets on ingest into new forms, such as thumbnails or proxy files. The new forms generated on asset ingest via transformation should all be stored as asset parts of the original file uploaded.

This point is mostly about internal working of a DAM system – how to treat thumbnails or previews of files when using software. These files should never exist outside a DAM system and their metadata are mostly irrelevant. Sometimes those intervals are exported for external use in a form of web interface – digital museums. In these cases, we should try to retain as much of metadata as possible. Lately, museums have been using increasingly big files to better serve public and those files can be used for many purposes: republishing on websites, in presentations or even in printed publications. Metadata should be preserved to allow integration of files into users' digital libraries.

ACCOUNTABILITY

DAM systems enrich assets through the extension of metadata and metrics regarding the use and reuse of the asset throughout its lifecycle.

This goal is hard to achieve just through metadata, but keywords depicting provenance of a particular photo are useful. Many grants request reports about the use of assets created by their funds. Using chosen words in metadata will notify that this transaction should be added to a report.

This is the case for the portrait of John of Pernstein whose metadata are visible on Fig. 2. The creation of the photo was funded WPR Kultura+, second edition (2012) and when sold, the amount and invoice number will be added to a special report.

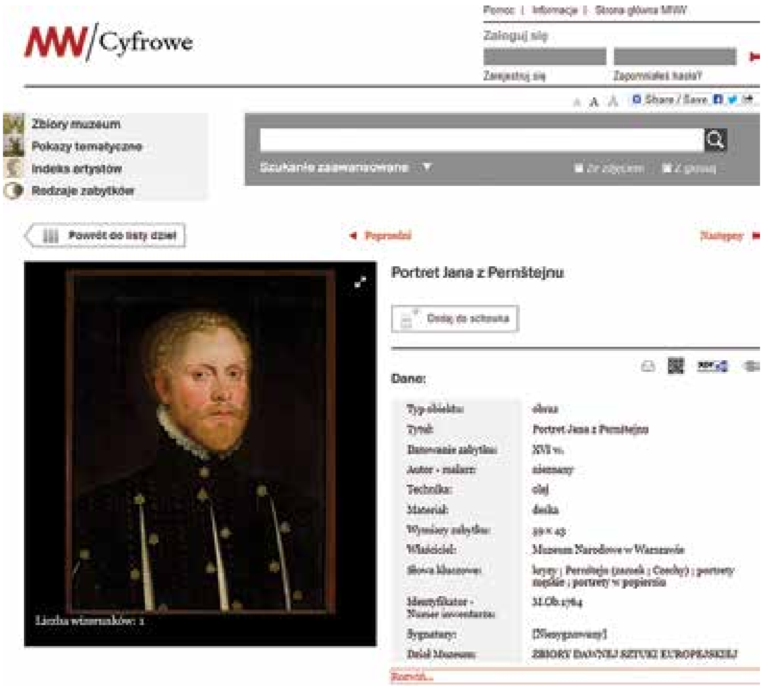

Fig. 1. *"Portrait of John of Pernstein" from Cyfrowe MNW*

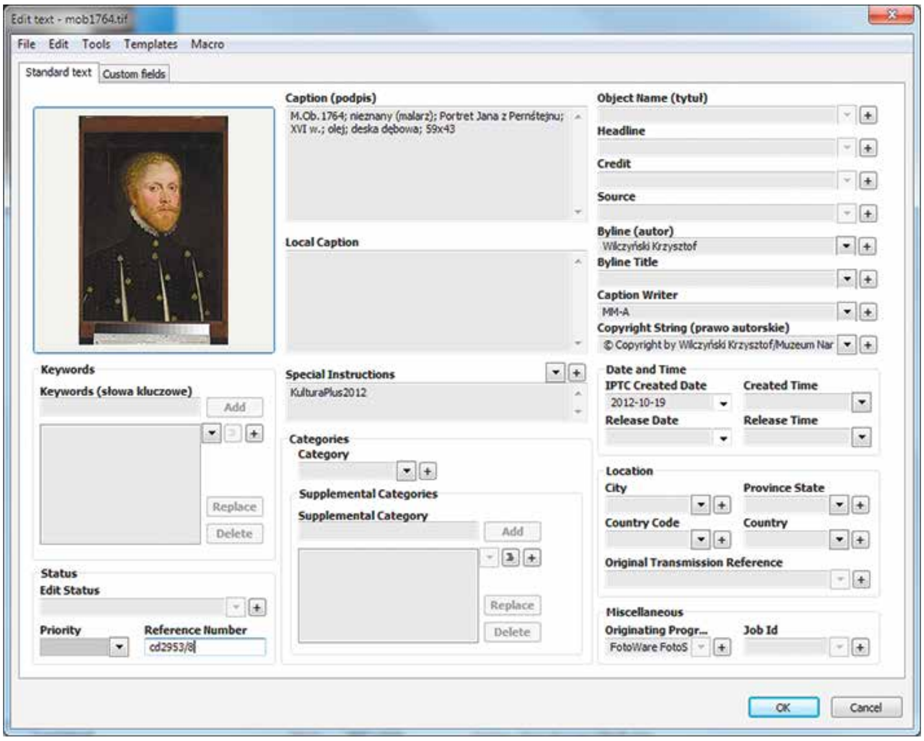

Fig. 2. *Metadata of a file with examples of a unique ID (a reference number) and special instructions*

VERSION CONTROL

DAM systems relate assets by tracking the relationships between and among an original asset and versions/variants of the original. Versioning and version control tools are central to an asset's life in a DAM system.

The ability to store and recall multiple versions of the same asset is a big deal in DAM systems. All true versions should have the same ID code and this should allow for updated versions of the same asset to be made over time. Some systems that want to be DAMs, mask versioning as parent/child relationships between files.

In museums, we rarely face a real problem of file versioning. Usually, when we get a file into the system, it is ready for publication of the final version of a digital photo. However, we have our special case when presented objects were themselves versioned in conservation processes, both with regard to documentation of a single conservation process itself and presentable states of an object before and after conservation. In file metadata, the state of an object should be clearly noted to enable easy finding of current visuals of paintings, sculptures etc. At least a notification "before conservation" for older photos of an object, in combination with the image creation date, should be enough to trigger alarm bells when one is looking at a certain photo.

WORKFLOWS

DAM systems regulate a structured process in the management, creation, and review of assets with workflow tools. Via programmed workflows, DAMs allow for a decentralized work force to collaborate together in a centralized system.

The main purpose of implementation is to save time and effort completing tasks involved in managing data we hold. It is easy to envisage how batch actions can save masses of time and effort compared to entering data on a purely asset-by-asset basis. This is in fact one of the most common reasons behind wanting a DAM system and so should not be ignored.

ADVANCED SEARCHING

DAM systems allow for users to find assets and to retrieve those assets by facilitating search through metadata, collections, workflows, and access control tools. By increasing the discovery of assets that may not have been easily accessible before an ingest, a DAM assists workers in leveraging existing content for maximum work potential.

Advanced searching should be achieved by splitting metadata in different, meaningful fields which allow to narrow the number of found objects. Categories are not only the obvious ones: author, name, but also more esoteric like provenance and special circumstances about creation of photo.

PREVIEWS

DAM systems have a preview function that allows users to view assets before downloading or opening a file on their own device. By allowing users to take a look at assets in search quickly, without download, DAM systems reduce the amount of time users must spend in search.

When setting up system configuration it is important to choose wise compromise. Previews should at the same time save time and users' resources but also offer good insight into the content. Note that mobile use of DAM systems increases all the time and what can be acceptable when browsing in a comfortable office may be daunting when preparing a concept on a mobile device in the field.

COLLECTIONS

DAM systems produce/publish content by providing methods whereby assets may be shared, linked to, or otherwise be distributed outside the system. This DAM function may be as simple as generating a URL on ingest or as complex as allowing users to build collections of items for sharing with a work group.

Once DAM users have found what they need in the system, they're going to want to share those assets or information, either individually or in groups. All that work on metadata and searching is for naught without the ability to form "private collections", lightboxes, and public kits and collections, with ways to link all these things. If a system can't form collections and share links, it's not a DAM. Links are especially important for sharing as file sizes increase. Useful are also smart searches when newly added assets, meeting certain criteria, are automatically added.

A DAM system centralizes one's data, allowing for a repository from which assets can be shared, edited and repurposed. It is therefore important to have the ability to share assets both internally and externally through various means. This might be achieved via an API or FTP, web interfaces set up to share a gallery of assets or perhaps just via email to an individual.

In order to make visual assets such as images, videos or audios usable, documentation must be attached to the asset in some way, either as a built-in child to the parent asset or at least contained in the same folder structure as the asset to which the document grants permissions – preferably in the form of an XMP sidecar file – to be easily integrated into the main DAM view without the help of an external program. A DAM must be able to take whatever one throws at it, asset wise, although whether or not one can view the asset may require a third party API.

CONCLUSION

One of the obvious questions for museums is: should we use a DAM system or rely on something built in our inventory system? Lately, inventory systems has started to include some DAM features, but it has been done only partially. Unless all of the above points are taken seriously, managing thousands of digital assets should be done by systems designed for this task.

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[3] *IPTC Photo Metadata Standard*, http://www.iptc.org/std/photometadata/specification/IPTC-PhotoMetadata [access: 30.3.2015].

Recording and online dissemination of objects consisting of many items

Weronika Grochowska

As far as digitization in museums is concerned, computer technology is still facing a challenge. Although to some problems technology has already came up with reasonable solutions, there are still some issues to solve. It needs to be reminded that digitization is not only about photos, scans, 3D scans and the like. Obviously, they are important but not more important than metadatas. It is significant to collect as much information about an object as we can to remember why this particular object was worth, for example, preparing a 3D scan of it (which is still more expensive than traditional photography). In Poland, museums are still facing the problem of dissemination in quite simple online collections catalogues. In some cases, even when high-quality photos and precise metadatas are collected, it is not that simple to disseminate objects correctly, especially when objects are recorded in museums' inventories with wrong numbering systems.

A problem with lack of unambiguous rules or standards for recording objects consisting of many items has become more and more important with implementation of Database Management Systems for collections in museums. In general, every museum has either its own standards or none, so it is difficult to build a universal database system for everyone. At some point, software can deal with objects numbered with Arabic numerals but has problems with letters, also Polish letters, which are very often functioning in an object number not only as part numbers, but in the main number as a shortcut from a museum's or particular collection's name.

Although now there are some rules or – more accurately – good practices of numbering objects, in museums with longer history and numerous collections, implementation of a new format is extremely difficult. Many museums have different numbering systems and even if a change is possible, it is suggested not to re-number the whole collection and start a new format only for new acquisitions. A number should link an object to information about it, so in practice, as long as every object has its individual number, it does not matter if the new numbering system disturbs the current order because a new numbering system for new acquisitions would not cause a problem with recognizing every particular object – the number would still be unique.

When it comes to disseminating objects from "old collections" with old identity numbers, no consistence, and sometimes also no logic, in a numbering system has a far-reaching impact on how a particular object will be disseminated in a museum's online catalogue. So it would have a real impact on how users will see this particular kind of objects – as a group or as a few individual objects. Of course it is not impossible to disseminate a group of objects in a proper way but to do that correctly, both a logical numbering system and fully functional collection management database are needed. This paper is an attempt to present difficulties with groups of object and several solutions for recording and disseminating them based on examples from different museums and their online catalogues.

According to the Collections Trust document, based on SPECTRUM standards [1], there are several commonly used types and formats for museum numbering systems. As far as numbering of individual objects is concerned, there is a simple solution. Items that are given to museums individually, should have different identity numbers [1: 2] but there are three solutions for numbering groups of items:

1. individual numbers for each item,
2. part numbers,
3. one number for a group of items.

An individual number for each item is the easiest solution for a group of objects, but in this case it is sometimes hard to make sure that every time objects are considered as a group and not as individual objects without a context.

Part numbers seem to be a reasonable solution, but it is important to obey one standard. A group of objects should be assigned the same main number and a suffix should be added to create a unique identity number for every item in the group.

One number for a group of items is a convenient solution, but in many cases, it is very risky because the number gives no information on how many items this particular group consists of. Where large numbers of similar items are physically grouped together (e.g. objects considered as industrial heritage), they can be numbered as one object but if there is a possibility that in the past some objects from that group functioned as individual objects or initially they were not inseparable unities (e.g. altars which consist of several sculptures and painting panels), this solution seems not to be the best idea.

Another issue is a problem with very complicated objects not from art or ethnography but from aforementioned industrial heritage, like engines or pumps. Although these objects consist of many elements, probably in every case they have just one number for the whole group, not part numbers for every screw, so at the end, recording and disseminating that kind of objects are not that complicated as the object itself.

In terms of their cataloguing and disseminating, one group of extremely complicated examples are altarpieces. Lamentation Altar (or St. Elisabeth Altar), originally from Church of Our Lady in Gdańsk, now in National Museum in

Gdańsk (Fig. 1), is a great example to outline a problem with disseminating objects form the old collections with illogical numbering system.

An altar consists of several components: corpus, three sculptures and two wings. In general, from the inventory point of view, this is a double-sided problem – it consists of items from different fields of art that could be created in different times and places; this particular example represents both. According to researches, the corpus was made in one of Gdańsk's carpentry workshops, wings were painted in another Gdańsk's workshop, and sculptures were probably imported from Bohemia or were created in a Bohemia-related workshop active on a territory of the State of the Teutonic Order. Moreover, the sculptures are dated around 1390 and paintings around 1400-1410.

Particular elements were not, for many reasons, entered to the museum inventory at the same time – the corpus and sculptures were listed before 1939, and wings after 1945. Later on, they were also rewritten to new inventory books with new numbers. The elements were recorded in the following way:

- corpus: MNG/SD/3/Rz/4,
- sculpture of Pieta: MNG/SD/3/Rz/1,
- sculpture of St. Elisabeth: MNG/SD/3/Rz/2,
- sculpture of St. Mary Magdalene: MNG/SD/3/Rz/3,
- left painted wing: MNG/SD/409/M,
- right painted wing: MNG/SD/410/M.

The symbols in inventory numbers: MNG – National Museum in Gdańsk, SD – Department of Ancient Art, Rz – Sculpture Collection, M – Painting Collection.

At first sight, two problems are noticeable – dividing one group of objects into two different collections (and two different inventory books) and no consistence in numbering. Above all, the corpus and wings were split between two collections with separate inventory books – Sculpture and Painting. The corpus and three sculptures were listed in the Sculpture Collection. They were treated as a group and they were entered under part numbers from 1 to 4. Two painted wings were listed in the Painting Collection as two separate objects with individual numbers, so they were connected neither with each other nor with the corpus or sculptures from the same altar.

The first choice during making the decision in which inventory book a particular object should be listed was the field of art it represented. Partly it had a logical sense – paintings were in the Painting Collection and sculptures were in the Sculpture Collection. The puzzling aspect is why the corpus was listed as a sculpture and not as furniture or even as a painting – after all, it has floral ornament painted on the sides and gold plating inside. It was disregarded that in practice the wings were more directly connected to the corpus by the hinges than were the standalone sculptures that, on a side note, are still considered by some researches as derivate elements of the altar. If someone does not know that this particular altar consists of not one, not four, but six elements split between two different collections, it is quite possible that the altar will be disseminated as separate objects or even will be disseminated partly.

Another problematic object for disseminating is a photo album. On the one hand, album is just one object, and on the other, it consists of many, sometimes even hundreds of, other objects – photos. There are the same solutions for numbering this kind of objects (mentioned before), but in this case, most often part numbers are in use. Although the strategy for numbering that kind of objects is known, there is still no consistence in using it. A reasonable solution for numbering photo albums is to give part numbers to all photos, no matter if they are attached to pages permanently (for example by glue) or just slid in there. Moreover, it is important not to forget to give a part number to a cover – the whole photo album itself (considered as kind of a book).

Lack of consistence in a numbering system or using different systems makes two risks more possible. First of all, when only pages have part numbers (and not every photo stuck to them), there is possibility that some photos could fall off and disappear. In this case, there will be a problem with starting an appropriate procedure when the lost object will have no number. Secondly, a common mistake is not giving a part number to the cover. It seems to be wrong because sometimes a cover or the whole album, considered as a book, have artistic values and are themselves works of art.

For recording and, in a long term, disseminating photo albums, the best solution seems to be recording both every photo in a photo album and the whole album into an inventory under part numbers, and the first number should be reserved for the album (as a book/cover of photos). This solution makes the dissemination of the whole album, with its contents, easier from the technical point of view. In the long term, apart from the statistical aspect, incorrect number of objects consisting of many items or sets could make correct dissemination difficult or even impossible.

Not always the way of numbering a group of objects has an impact on how the group will be disseminated in an online catalogue. This situation mostly follows from different technical possibilities or limitations of the database system used in a particular institution. It is important to note that, at least in Poland, almost every museum that has an online catalogue, uses different technology to disseminate objects. The choice of what technology should be used is very often directly related to the database system a museum uses, but database systems and dissemination technologies are not inextricably linked to each other.

Online collection catalogues show that every institution uses different solutions, very often without consistence. It might be a result of disseminating objects from old collections recorded with old and non-standardized or even wrong numbering systems. When every element of, for example, an altar is disseminated as a separate record, there is a risk that they will not be considered by non-professional viewers as parts of the same altar or as many photos from the same photo album. Thus it is strongly recommended

Fig. 1. „"Lamentation Altar" („St. Elisabeth Altar"), National Museum in Gdańsk, MNG/SD/3/Rz/1-4, MNG/SD/409-410/M

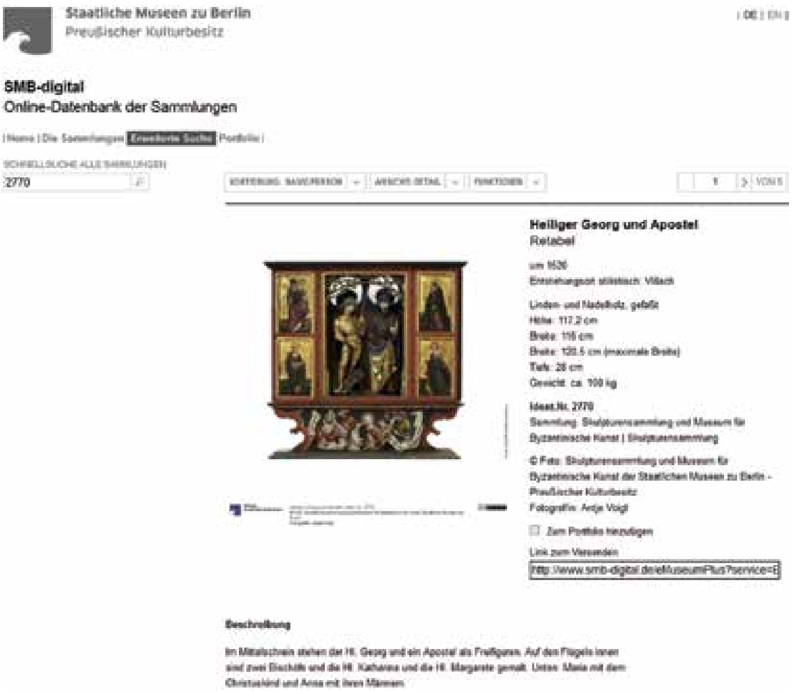

Fig. 2. *A record from the online catalogue of Staatliche Museen zu Berlin (www.smb-digital.de), ident. no. 2770*

Fig. 3. *A record from the online catalogue of Victoria & Albert Museum (collections.vam.ac.uk), id. no. 192 to D-1866*

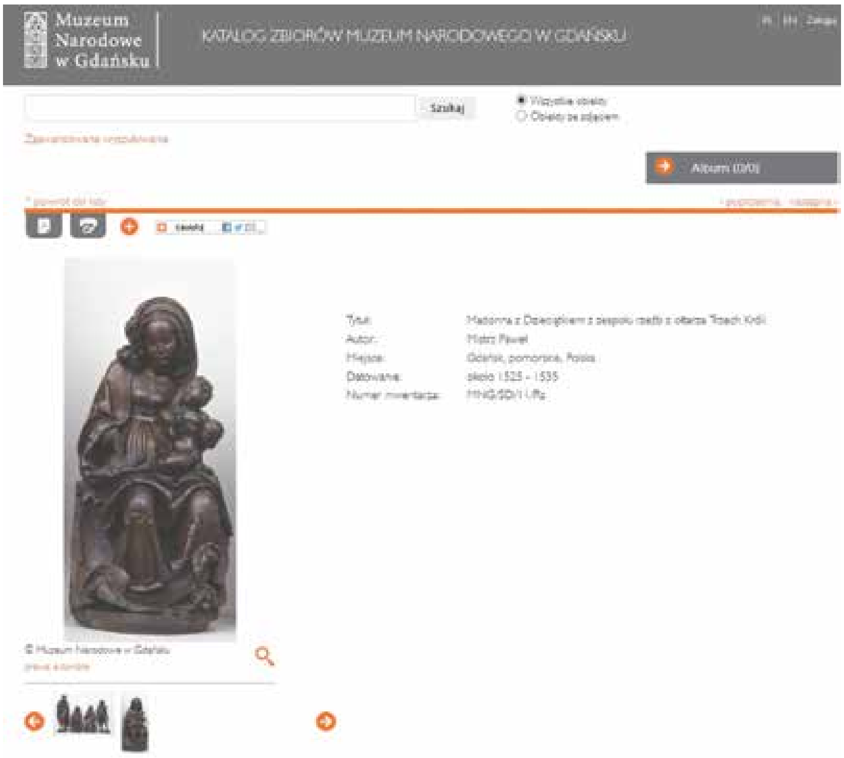

Fig. *4. A record from the online catalogue of National Museum in Gdańsk (zbiory.mng.gda.pl), id. no. MNG/SD/11/Rz*

to create one additional record to show these objects as a group. There are a few solutions for disseminating a group of items and all of them are already in use.

In a classical online catalogue, there are three main solutions for groups of items: dissemination as one record, individual records for every item and a combined solution – one record for a group and individual records for every object in this group. Dissemination of only one record for a group of objects is a good solution only if every item is inseparably connected to each other or all of them are very similar or even the same. As far as precise visual documentation is concerned, it is still possible to attach to this record a photo of every item from the group. However, in many cases there could be a problem with disseminating precise descriptive information that, in a long term, will be searchable correctly. In this case, altars are interesting examples. In many catalogues, an altar can be found by the term "altar" or "altarpiece" (or by the same term in different languages), but very often there is a problem to find – for example – sculptures from a corpus or paintings from an altar's wings with basic information about them because a different term has been used for describing the object than "painting" or "sculpture". For example, in one record for the whole altar there might be no precise information about the dimensions of every sculpture in this particular altar (but only information about dimensions of a corpus).

A good example of how groups of objects might be disseminated as one record and under one identity number in a wrong way and how important is to collect and disseminate precise metadata is a record of one of the altars from Staatliche Museen zu Berlin with the identity number 2770 (Fig. 2).

First of all, the title of the object is incorrect or incomplete. "St. George and Apostle" (Heiliger Georg und Apostel) is just a topic of the main sculptures in the corpus, not of the whole altar. The term "altar" (Retabel) is used only to describe the type of object, not as a part of the title. Secondly, information about the dimensions is also incomplete – dimensions are limited to the information about the whole altar. Next, the description, where the missing information could be caught, is definitely too general. Indeed, there is information about other elements of iconography, but there is nothing else (like information about dimensions of the sculptures).

An ideal situation is when we can disseminate the whole group, such as an altar, as one record but connect metadata and photos to this record, even archive photos, for every particular element from this group (Fig. 3).

Dissemination of a group of objects as an individual record for every item in this group is a solution that gives better possibilities for disseminating more precise information about every element of the group. Of course, sometimes there is no possibility to digitize every element as a separate object – in this case there is no other way than to photograph the whole group together and disseminate it as one record or to attach the same photo of the group to individual records. Individual records for every item makes sense also in the case when, for example, some elements from an altar are supposed to be derivatives or when the main part of an altar, like a corpus, is missing (Fig. 4). No matter which examples a particular object fits in, there is always a good practice to attach at least one photo to every record of the whole group of items. It makes it possible for users to notice that a given object is not an individual object, but it can be (or even should be) analyzed as a part of a group. In this solution, the risk is that every item recorded as an individual object, where no photo of the whole group has been attached to this particular record, will be seen as a separate object with no "group" context. And during the dissemination process, some elements from one group could be missed.

The most reasonable and probably the best solution for disseminating group of objects is to create one record for the whole group and also individual records for every item in this group. This solution lets users see both separate objects and the whole group. It allows to describe every item, for example sculpture from an altar, as an individual object, but at the same time it can be disseminated as a part of the whole group – an altar. One additional record for a group allows to describe the construction of an altar, which might be neglected when each particular object from an altar would have only its own record.

Finally, a useful solution to draw users' attention to both particular objects and the whole group at the same time is a section "related objects" or "see also" shown on the same page where records of every object form the group are disseminated. It also creates a simple connection between all objects from the group. This kind of links can keep users interested while they are browsing a museum's online catalogue for a longer time; owing to such a section, users do not need to search for every object separately. At the end, implementing more user-friendly and attention-grabbing options like "related objects" makes online catalogues more interesting for both professional and non-professional users.

A problem of groups of items is very complicated. Although a few solutions for numbering these kind of objects already exist, standards are not global or – more precisely – they are not used on a global scale. Sometimes even in one institution there are no rules for numbering objects consisting of many items. There are three options for numbering and disseminating this kind of objects: as individual objects with individual records, as part numbers for every item and as one number for the whole group. All of them could be used in one institution at the same time, but only when explicit standards and instructions (telling when a particular numbering system should be used) have been implemented. Owing to that, it will be possible to disseminate groups of objects from different museums together, based on the same standards from a similar or even the same database system to one catalogue. When the same standard will be settled, correct metadata will be useful not only for traditional way of dissemination, like simple online catalogues, but also for different, more advanced technology uses.

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Application of Survey Simulator for Museums

Cezary Żrodowski

INTRODUCTION

“Virtual Museum” is currently a very popular form of presenting museums’ collections of artefacts as well as an approach to archaeological research [1], [2], [3].

The term “virtual” can be understood in many ways – from a simple collection of on-line photographs, through multidirectional viewable panorama pictures, to complete interactive models of the real world, including 3-dimensional (3D) geometry, physical properties and many other features exceeding traditional graphics definition. The approach called “Virtual Reality” (VR) presented below uses the Survey Simulator application. The term VR was introduced by Jaron Lanier and Steve Bryson, and defined as: „the use of computer technology to create the effect of an interactive three-dimensional world in which the objects have a sense of spatial presence” [4]. In this case, 2 layers are equally important – hardware for multisensory interaction and software integrating entire simulation.

The hardware may be as simple as a standard computer (keyboard, monitor) or a highly specialized interface involving all human senses. The first specialized user-interface devices were miniature VR stereoscopic displays, mounted on glasses, connected to the sensors of head position (Head Mounted Display – HMD) and devices for manipulating virtual objects, usually in the form of gloves (VR Gloves), often with a haptic feedback. The purpose of these devices is ensuring most realistic interaction between a user and a model, and creating an impression of a full immersion in the digital model. In the case of simulations involving multiple users simultaneously, it proves convenient to use a common screen which significantly reduces computing power. The very popular solution to this type of a system is known as CAVE (Cave Automatic Virtual Environment [11]) that displays an image on a number of flat or spherical screens surrounding all users (Fig. 1).

Specific requirements of simulations containing movements over long distances led to the development of techniques for tracking a user in a virtual scene. Those most popular include optical tracking of a user’s position, whilst more advanced versions follow orientation and position of his limbs. A separate group consists of hybrid solutions, combining virtual world with physical dummy control devices, e.g. a bridge of a ship or an aircraft cockpit. Selection of an appropriate interface depends on the nature of the simulation, number of users and type of their interaction with the model (First Person Perspective – FPP, Third Person Perspective – TPP).

Another significant issue is the development of a simulation program. Compared to other graphics programs, VR systems are characterized by very high performance requirements, allowing to smoothly display complex graphics in real time. Currently, it is expected that the program is able to generate at least 30 frames per second at Full-HD resolution (1920x1080 pixels). Depending on the purpose of the simulator and the competence of programmers’ team, we recognize three dominant trends in the approach to software architecture and development strategy:

1. development of proprietary program, based on a low-level graphics library (usually OpenGL or DirectX). This approach is typical for student projects, research and early stages of industrial implementation. Usually due to problems with software maintenance or update, such programs are either discontinued or turned into commercial projects, which later provide other developers with high-level libraries or finished VR applications,

2. development of proprietary program based on high-level libraries. There are many tools on the market, supporting developers’ work on different levels. Most popular are platforms supporting creation of video games (game engines), with the leaders such as: Cry Engine, Unreal Engine and Unity [6]. Their usage can minimize the effort of developers who can focus on the substantive content of the simulator rather than low-level implementation of details, usually invisible to a user,

3. usage of existing, closed programs (Commercial Off The Shelf – COTS), which is the domain of teams with relatively low competence in software development. Typically, such systems allow a user to self-create scenes and scenarios, using the simplified tools. Often they limit a user’s work to building or importing 3D model geometry and defining simple relationships between the elements of the model. Such solutions are used for common tasks where the scope of the necessary functionality is well known and defined. This group can include simulators for industrial applications such as: PTC Division, 3D Via, Worldviz, as well as products of the world leader in the field of COTS simulation programs – PRESAGIS (STAGE, FlightSim, Vega Prime and VAPS) [5].

Programs may either include mathematical models, describing the behavior of physical objects or can be considered as the first step in the implementation of more advanced applications, including remote control, telepresence and augmented reality.

Presented Survey Simulator is an example of a single user program, first person perspective, built on the basis of the Unity platform [6], focused on the problems of photorealistic visualization of extremely complex objects in a stereoscopic mode. The details of the implementation are presented in the next paragraphs. Although the program was developed for a different purpose (professional trainings in the maritime branch), it presents many functionalities useful in museum applications, such as a very high level of photorealistic visualization, support for complex geometry, readiness for full immersion [7], [8] as well as gamification of a user's presence in an exhibition area.

PURPOSE AND ARCHITECTURE

Initially, the program was solely intended to assist in training of DNVGL inspectors, certifying ships and platforms structures. Its primary task was visualization of technical problems encountered on vessels, including a 150-year experience in their detection and evaluation. The main requirement was improvement of inspectors' competences by:

1. increased efficiency through a partial transfer of practical training from a vessel to the laboratory. There are several elements reducing effective time of training, such as access to yards, safety procedures or hard to reach areas. Additionally, inspectors' training is always carried out in the frame of standard commercial work, within the constraints of time and location – e.g. an inspected ship can be located in a very distant shipyard which requires long-distance traveling,
2. providing visualization of a wide range of possible defects and damages, found by inspectors during their works. Moreover, the simulator is expected to accumulate users' experiences and support corporate knowledge preservation against erosion resulting from personnel changes,
3. reducing the time needed for certification, by demonstrating rare and important issues required in a training program but occurring very rarely due to young age of fleet or its good technical condition.

Survey Simulator was created as a graphic program developed internally. The first updates, however, highlighted the need to utilize a professional development platform allowing developers to focus on the unique features of the program rather than the standard code, handling graphics features of the program. After several months of analysis and testing, a Unity VR engine was selected.

It is a very mature development environment, supporting the most important operating systems: Windows, MacOS, Android, as well as web applications running remotely on Web browsers. It is also optimized for supporting selected VR specific hardware. The most important are: a stereoscopic display and system for remote control of trainees' computers. The display is based on a Dolby 3D system allowing for presentation of a 3D simulation to wider audience in a standard cinema. Remote control allows for direct interaction between a teacher and a trainee without disturbing other participants. It enables presenting all students with new, unusual, correct and unacceptable solutions generated by participants and not provided by the developers. In addition, the possibility of recording such solutions allows for obtaining new cases from participants and including them into next courses.

The program includes a number of scenarios allowing for simulation of different types of inspection and parts of vessels. The basic version contains 4 types of vessels (bulk carrier, container ship, oil tanker and mobile offshore unit – MOU), and provides from 2 to 12 inspection scenarios for each, covering a variety of areas – from a deck to double bottom, from cargo holds to an engine room (Fig. 2).

Data describing a scenario contain mostly a 3D geometry model so the procedure for its preparation is one of the most important components of the entire system. An input 3D model comes from an external engineering application (CAD / CAE – Computer Aided Design, Computer Aided Engineering), however real-time visualization generates requirements beyond engineering software needs, so conversion of existing models is necessary. The CAD/CAE geometry is focused on providing a high-accuracy shape. In the case of real-time visualization, a simple shape ensuring the highest graphics performance and illusion of accuracy is a priority. The entire conversion process involves a series of steps:

1. conversion of parametric geometry (CAD/CAE) into a mesh of triangles, the logical structure of the assembly being preserved,
2. mesh optimization for increased performance and visual effects,
3. manual modelling of elements not present in the original geometry (damages, simplified Levels of Detail – LOD),
4. preparation and application of textures.

Due to very high requirements for visual realism and the size of models, a part of geometry optimization works must be performed manually by experienced graphic designers. Although there are number of programs capable of automatic geometry simplification, they don't guarantee obtaining desired visual and aesthetic effects. Fig. 3 presents the results of such an operation. The final reduction of triangles number from 256 to 58, after applying the texture and associated geometrical components (outer shell plating of the vessel hull), causes no differences in visual impression.

Particularly noteworthy is the process of preparing a model that presents damage and disadvantages of hull structure and equipment. Typical engineering software works well for correct structure design, consistent with the principles of design. Modelling of „non-technical" shapes, alike all kinds of damage (cracks, buckling and rupture), is very difficult. Complete model may sometimes contain even several thousands of modelled errors. It leads to an increase of the size of the model and immediate need to use much more advanced mechanisms of database management. Random displaying of various errors, in virtually unique sets, doesn't allow a student to „memorize" the entire scenario, thus forces him to maintain high focus all the time.

Training carried out in the Survey Simulator contains four different modes (Fig. 4):

1. ship knowledge mode – familiarization with the terminology and identifying parts of structures as the first step in professional training,
2. areas of special attention – more advanced training, designed for smooth converting of theoretical knowledge on the hull structure strength into practical skills,

Fig. 1. *An example of the CAVE visualization facility;* SOURCE *http://scifundchallenge.org/firesidescience*

Fig. 2. *Initial user menu presenting a complete range of inspected vessels*

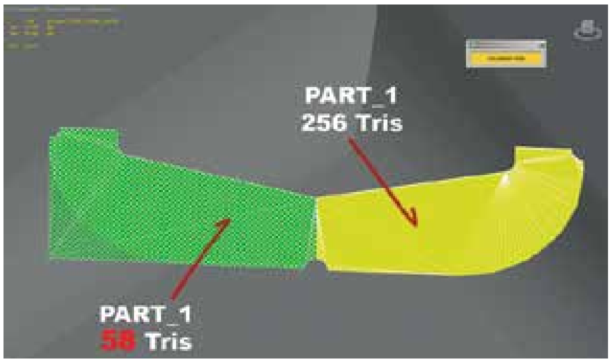

Fig. 3. *Exemplary result of manual mesh reduction*

Fig. 4. *Training modes in Survey Simulator*

3. survey requirements mode – designed for efficient survey planning. As vessels are very complex structures, in practice they are never inspected as an entire object on one go. Various inspections address only selected systems and areas,

4. findings mode – the last stage of the training is simulation of a real inspection. A user has to carry out tasks he had learned in the previous stages. Only a limited assistance from the program and teacher is allowed. It also covers the exam mode.

The program also simulates basic physical phenomena primarily used to control collision between moving components (including a virtual user's body). Collision control pushes a user to navigate around the site in an appropriate position reflecting real work conditions. The program allows for a quick switch between positions: running up, standing, bowing, kneeling, and crawling. The interaction with the environment may also include simulation of floating objects, refraction of light on transparent objects and, especially, manipulating movable parts (doors, valves, levers, as well as available tools). A typical inspection tool kit includes: a flashlight, hammer, spray paint can, camera, and smartphone.

Summarizing: Survey Simulator is a unique tool because of the powerful combination of a high complexity of a model with high level of visual realism, all being a result of specific process of data preparation based on a widely used Unity platform, and applying a practical approach to marine engineers' professional training.

PROPOSALS FOR APPLICATION OF SURVEY SIMULATOR IN MUSEUMS

Many of described functionalities can be used directly in applications supporting museums' activities. Some of them are straightforward and can be observed on many examples. The simplest one may cover a virtual extension of an exhibition area allowing for presentation of collections not accessible for wide publicity. It may contain artefacts stored in warehouses – either too fragile to expose or too large or placed in inaccessible/hazardous locations (under water or in buildings in poor condition). It can also cover exhibition of foreign artefacts gained through an exchange of virtual collections between different museums. In this case, however, standardization of digital data formats is a critical problem. Survey Simulator is based on the Unity engine, a standard for real-time visualization, and can be considered as a common platform for such cooperation.

More advanced usage can provide an extension to standard collection displays. An interesting proposal can be to connect a visual model with external database and to visualize database content on a 3D model. In Survey Simulator, such an approach is demonstrated in the survey requirements mode. Visual presentation of query results is a perfect tool for planning thematic tours as well as a support of research and collection management (e.g. visualization of searched artefacts and their location in a storage). Fig. 5 presents an example of a fire-fighting system (red) presented on a monochromatic background of the ship structure.

We can also consider extending the range of stored data. There are no obstacles for hyperlinking any additional information to 3D models of chosen artefacts, identical with those that can be seen in digital kiosks accompanying selected objects in physical museums. A 3D model, as interface for data exploration, is nothing new – a similar approach is presented by many applications like Google Earth or HD3D.

The educational potential of the described program is very important. Integration of implemented data bases allows for easy learning of branch-specific knowledge, including multilingual support, making virtual exhibitions attractive to foreign visitors. This option doesn't exhaust the list of teaching/learning opportunities. Presentation of results of engineering analysis seems to be one of most impressive. We can show much more than in the real world – from simple seating inside artefacts, through simulation of working machines explaining their operational principles, through their assembly/disassembly procedures, to advanced engineering analyses, including strength, fluid, body dynamics or ergonomics. Fig. 6 presents examples of simulation of corrosion caused by structure aging and Fig. 7 shows typical ship structure assembling in a shipyard.

It can also be a great tool for dissemination of research results. This leads to digital experimental archaeology, which can be both a research tool and a great educational adventure. Depending on the existing data, it can be implemented as more or less advanced games and quizzes for younger visitors or an interactive tool allowing for manipulating objects for older ones. In addition, it can also be used as a crowdsourcing platform for voluntary research (e.g. digital reconstruction of fragmented artefacts). This approach, called "gamification" [9], is currently considered as one of the most promising educational themes. Adventure, competition, attractive graphic form is everything we need to stimulate young people's minds. Digital archaeology, based on engineering simulation, also creates additional opportunities of cooperation between museums and universities. In most cases, the usage of advanced CAD/CAE software is limited to the educational purpose only. In the case of B.Sc. and M.Sc. theses, there are often doubts about potential commercial usage of such project. In the case of simulation related to museums' objects they are easily allayed. There are no obstacles to teaching modern technology using examples from the past, making such projects attractive for both sides. A good example can be simulation of nautical and sea keeping properties of a digitally reconstructed wreck of "Copper Ship" [10].

The last important proposal covers the usage of mobile platforms. The Unity engine allows for preparing simulation using many different operating systems, including main mobile platforms such as Apple and Android. Small "teaser" applications can be a great tool for attracting visitors as well as souvenirs from museums, downloaded from local access points. They can also be used for keeping in touch with visitors, informing them about new version of software, new exhibits and events in museums.

So far, Survey Simulator has been implemented in the Norwegian Maritime Museum in Oslo (2014) as an educa-

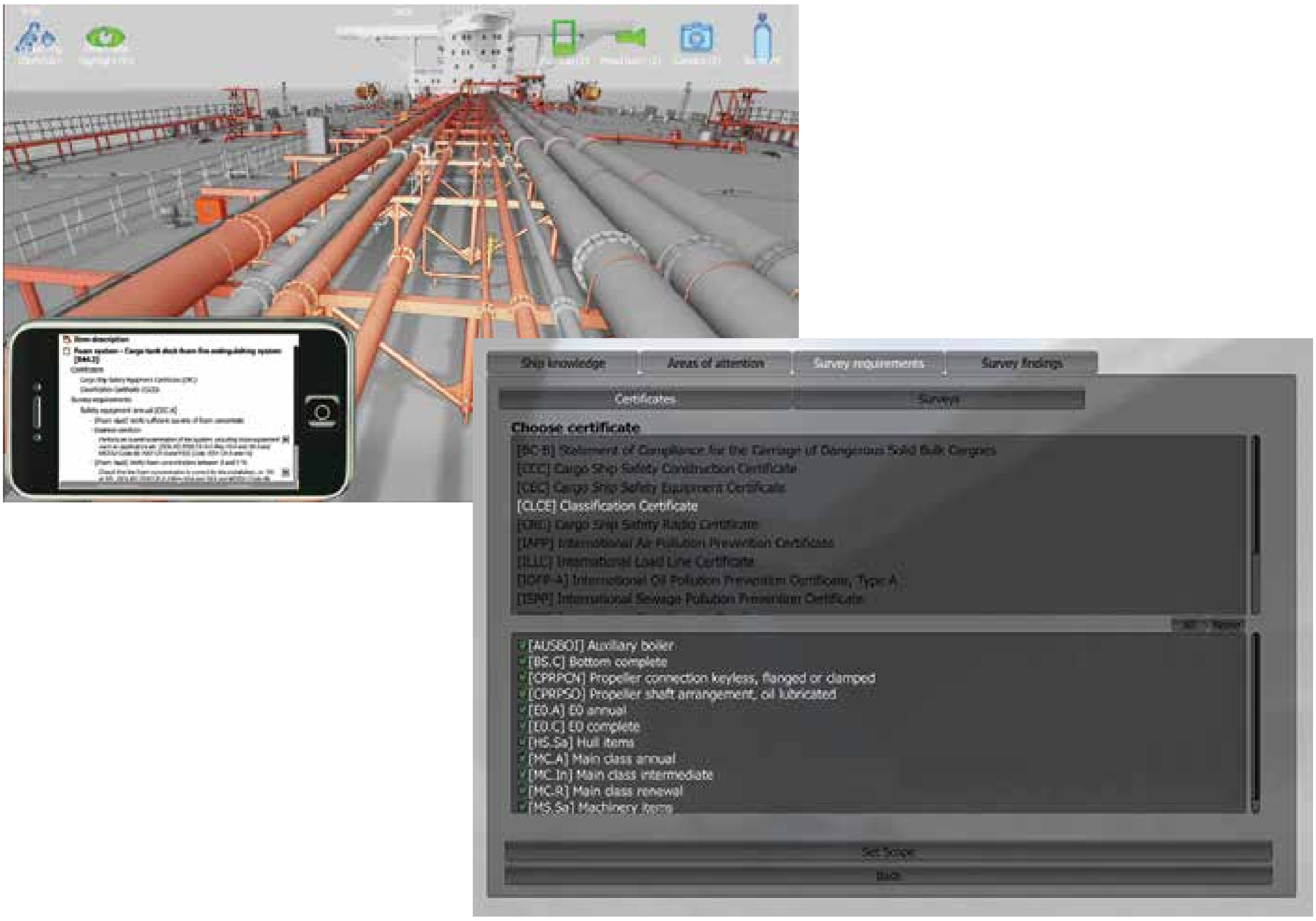

Fig. 5. *An example of visual data filtering in Survey Simulator*

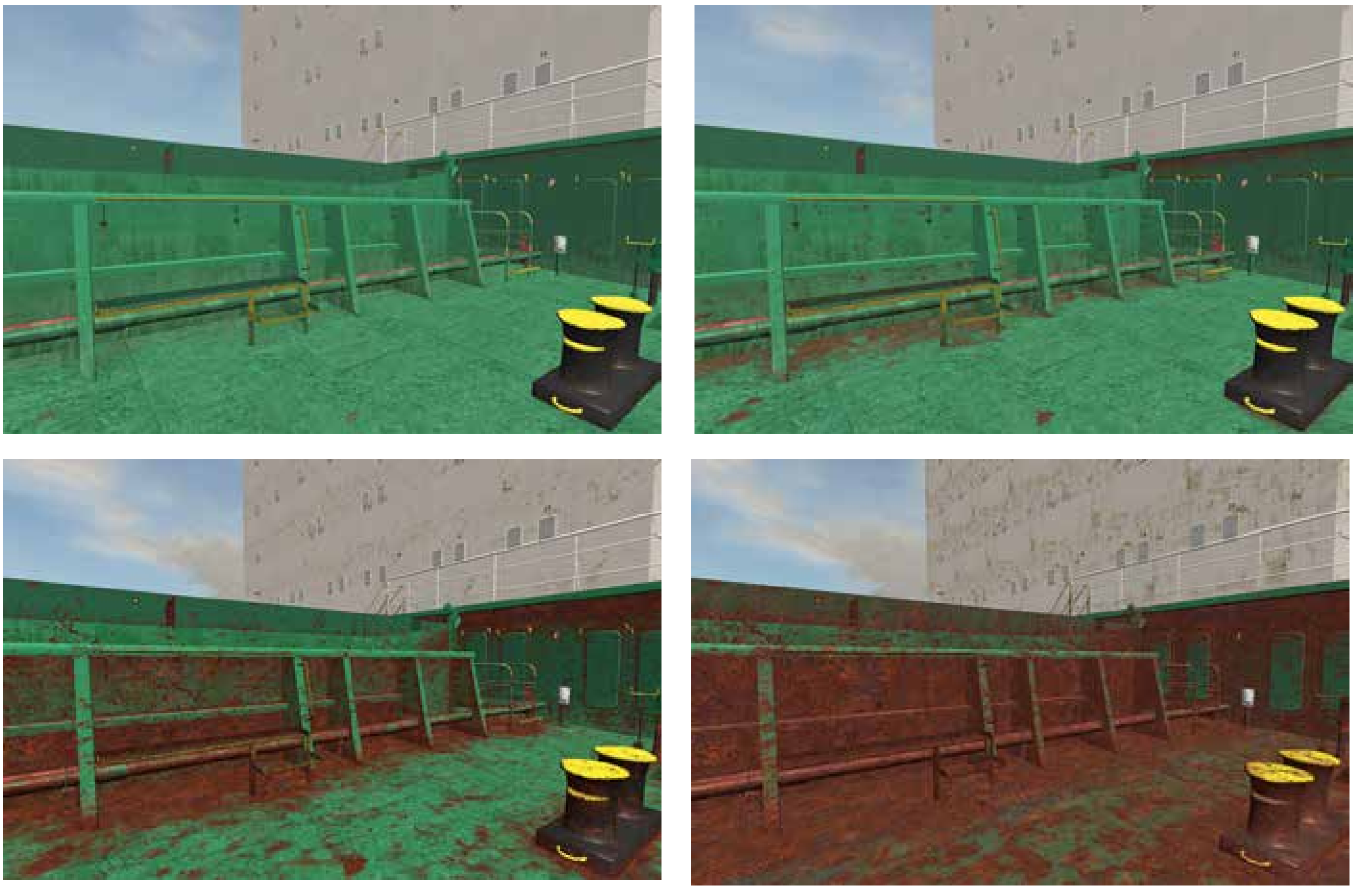

Fig. 6. *Simulation of ship structure aging*

Fig. 7. *Simulation of an assembly process of a ship hull structure*

tional tool explaining marine structures to wider publicity. The second installation is currently being prepared for the National Maritime Museum in Gdańsk.

CONCLUSIONS AND FUTURE WORKS

As it usually is in the case of software development, there is no such thinking as "a finished and completed version" and it is no different in the case of Survey Simulator. Future development covers some potentially interesting areas such as:

1. scenarios going beyond artefacts and history, describing processes of archaeological research, including very difficult cases such as underwater missions of remotely operated vehicles (ROVs) and scuba divers,
2. implementation of physical models allowing for simulation of a ship loading process and its nautical properties,
3. multi-user support, making educational games more interesting through direct competition with other users,
4. support of point clouds, allowing for real time visualization of models acquired by 3D scanning, without the necessity of expensive data processing,
5. extension of immersion level by introduction of physical objects allowing for full, all-sense interaction.

Survey Simulator is a multifunctional tool, able to replace many highly specialized applications and integrate different services related to digital exhibition of museums on one coherent platform. It can cover exhibitions, educational and research purposes, allowing for various synergies and interactions.

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Coins found in medieval churches – the challenge of digitizing and the (re)use of data

Steinar Kristensen

INTRODUCTION

Archaeological museums and archives are bursting with archaeological field documentation of a bygone era. The documentation accumulated in the archives derives from different times with different methods and different standards. The project "Religion and Money" reuses analogue data from 23 churches (Fig. 1). Data from the archives are unlimited; it's just a matter of questions to be asked. The documentation contained excavation plans, photos, reports and lists of objects found in the churches. The digitizing processes and some challenges will be presented and discussed below.

THE DIGITIZING PROCESS

THE DOCUMENTATION

The researchers in the project are engaged with several institutions in Scandinavia and in the United Kingdom. The first step for the project group was to select which churches and what type of documentation were suitable for answering the questions asked by the project. The chosen churches showed a large variation when it came to type of churches, excavations methods, level of documentation and the amount of coins found in them (Fig. 1). Each church has been subjected to analysis conducted by a researcher, either an archaeologist or a numismatist.

Plans, photos and reports were scanned with a minimum of 300 dpi. Analogue lists of coins and in some cases other categories of artefacts, have been typed in to excel sheets with predefined variables. Excel was chosen because most of the participants in the project were familiar with the software. The researchers themselves provided the documentation digitally. A cloud based data storage service has been used to share data effectively as quick and easy distribution of data has been essential for the process.

The GIS analyst evaluated the potential in the analogue documentation. For instance, it was important to determine the used excavation methods and to what kind of context the coins were related to. The related contexts are 1 x 1 m squares or larger excavation units. The coins can also be related to structures such as graves, cultural layers or postholes. There is quite a large variation in the resolution of the recorded find context, from exact coordinates to a whole nave of a church. This has to be taken into account when reusing the material. Different excavation and documentation practice has meant different strategies for the digitizing process. Evaluating the level of digitizing was also quite time consuming when deciding what to digitize and what to omit.

THE WORK FLOW OF DIGITIZING

In this paper digitizing means mostly re-drawing the old paper plans using vector data. It was done with the software ArcGIS [2]. ArcGIS handles several formats of input data as geographical files, tabular data and raster data. The vector data in ArcGIS is connected to an attributed table with information and fields created by the user.

Tabular data

Excel files with information about the coins were converted into Microsoft Access database and structured and cleansed for errors like misspelling and lack of spatial relations. Further different types of queries were prepared for use together with the digitized plans in the GIS.

Raster data

Excavation plans were converted from .pdf to raster file (.jpeg) before they were added to ArcGIS and georeferenced. Georeferencing means to associate the raster to a location in the real world coordinate system. The georeferencing process sometimes ran rather quickly and with a fair result of accuracy, but in other instances the raster contained errors and deviations which made it nearly impossible to achieve an acceptable level of accuracy. After reaching an acceptable level of accuracy the raster plans were used as background maps for the actual digitizing process.

The digitizing process

The digitizing process of the original excavation plans can be divided into two parts. One part dealt with the archaeological features like stone walls, cultural layers, burials, altars or postholes. The other group of objects to be digitized were the defined structures from the excavation such as trenches, sections and especially the grids used for relating the artefacts. The archaeological features were digitized by "drawing" the outer line and the digitized feature was instantly categorized during the process. One important tool for digitizing is the tracing function. When using this feature the pointer snaps and follows the raster lines. This reduces the digitizing time radically compared to just drawing on top of the plan. The time spent on digitizing varied widely depending on the level of details on the excavation plans.

In most of the churches some kind of grid has been used as context for the relation of the finds. In some cases a 1 x 1 m squares grid was used throughout the church, while other churches had a more complex non-regular grid with squares of uneven sizes and shapes ranging from 1 m^2 to 45 m^2. The squares were digitized and given a unique ID corresponding to the relation in the coin database.

Connecting the information of the coins to the digitized features or squares was the next step in the digitizing process. Some of the coins had precise coordinates within a local coordinate system. They were plotted in the real world coordinate system (WGS1984/UTM 32). The rest of the coins had its contextual relations either to features or squares. One of the main debates regarding the GIS in the project has been how to display the coins location in the churches. Three ways of displaying these coins have been discussed and are illustrated with an example from the church of Bunge in Gotland, Sweden. The first was to give the polygon of the related context a certain colour depending on the amount of coins found in that particular context. This meant that for every analytic level one had to make specific queries and then join the tables with the contexts through a unique id. The work with queries is time consuming and only one combination of attributes could be presented at the same time (Fig. 2). A second way of displaying was to show the amount of coins with a point of differing size in the centre of the related context. This would give the reader a stylistic view of the fact that the coin derived from somewhere inside the whole context, but not precisely in the centre even though it is displayed that way (Fig. 2). Arguments against these two methods are that they will increase the numbers of queries and limit the functionality in the project. Both methods would conceal the uniqueness of the coin itself. This is because every query is the total number of coins with identical properties. The choice for presenting the scattering pattern of coins was the "Random point" method [3]. This method produces a point randomly within the context´s boundary. The coin records in the table were then joined to the random points. Every coin (with its properties) has its unique coordinate, and all coins are visible in the map at the same time without overlaying each other (Fig. 3). It would also be quicker to do spatial analysis based on attributes in the table in ArcGIS by using different analytic tools. Objections to this method are that the presented maps can give the impression of a "true" placement of the coin, rather than an indication that it was found somewhere within the context.

This objection is truly important especially when the task is to do spatial analysis on the digitized documentation. The project did choose this "random points" method due to the benefit of having a point representing every single coin with all its attributes. The challenge is then to use the randomly placed coins carefully and to be explicit when discussing the method and the results of the analysis.

THE CHALLENGES

Within a project like "Religion & Money" different professions meet and mutually increase their knowledge of a specific topic. In the following I will shortly address some aspects of challenges experienced during the digitizing process.

THE PURSUIT OF ACCURACY

When georeferencing the excavation plans, the pursuit of accuracy begins. Getting optimal results is not always a walk in the park. The raster twists and bends, and sometimes it just doesn't want to fit the coordinates. It could be caused by measuring errors in the analogue plan or errors occurring during scanning of the paper plans. Another factor that's affecting the result of the georeferencing is the scale of the original plan. This becomes clear when you are trying to "squeeze" a relatively small scale map down to a "1:1 scale" in the GIS. The original plan of the church of Bunge on the island of Gotland in Sweden was 1:300. The drawn lines on the plan had a 0.3 mm thickness. This is equivalent to 9 cm in "real life". When digitizing in the middle of the drawn lines there would still be a minimum of 4-5 cm deviation depending on how one is interpreting the line in relation to in- or outside.

A similar example is another church from Gotland: Västergarn. This church is smaller than Bunge and the scale of the plan was 1:100 with line thickness of approx. 0.5 mm. For this church we do have accurate measurements from the excavation. Comparing those with the one on the digitized plan gave a deviation of 25 cm over a length of 27 meters. The 25 cm inaccuracy sounds a lot but in that scale this would be considered to be marginal. Plans with different scales are hard to merge into the same dataset. So one demanding challenge is to have a realistic expectation to the original data and the (re)use of it and to decide when to stop the pursuit of accuracy. The data will never get better than the original and should be treated as intended. The pursuit of accuracy can challenge your focus and be quite time consuming.

THE COMPLEXITY OF EXCAVATION UNITS

In some of the churches it has been hard to figure out how and why documentation was done the way they were. With our 2015 knowledge of GIS, it seems odd that the original documentation in some cases is missing what we today consider as necessary and crucial. Although we may allow ourselves to question the methods of our predecessors, it is still important to respect the way our colleagues did their documentation in their time. In stave churches like Høre and Ringebu, both in Norway, and also in the stone church of Aggersborg in Denmark, the coins were related to squares of different sizes and shapes. In Ringebu, excavated in he early 1980s, more than 800 coins were found (Fig. 5). The resolution of accuracy of placement of the coins ranges from precise coordinates to excavation units up to 28 m^2. The whole church is less than 200 m^2. The size of the area the coins derive from will of course affect the analytic possibilities and what kind of spatial analysis could be meaningful. It puts limitation to analysis like for example distances from certain objects like altars or baptismal fonts. The varying square sizes are not the only obstacle to overcome. The documentation shows that coins have been found and related to squares which are overlying each other to some extent. This gives a rather complex picture of the condition of the find situation (Fig. 4).

When using the random point's method this situation has to be taken into account as coins found in different contexts can appear too close or too far apart.

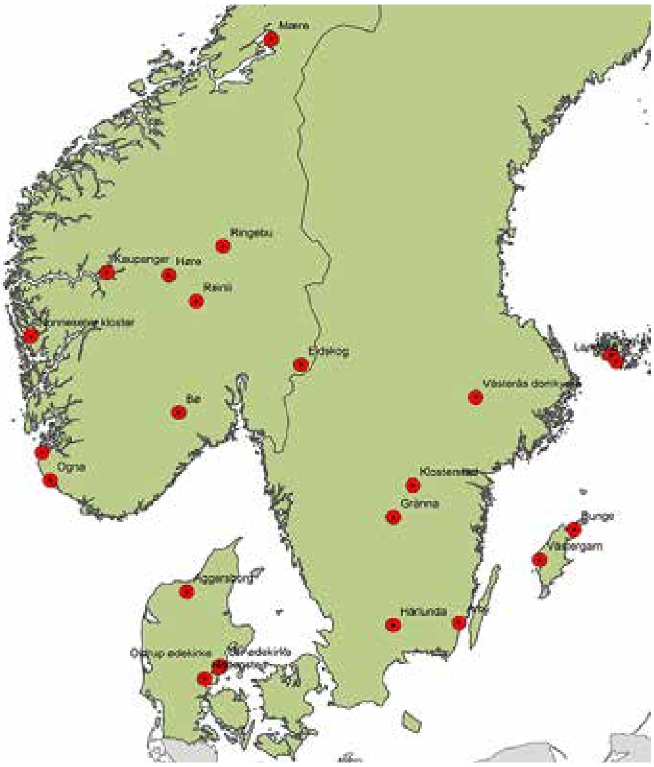

Fig. 1. *Scandinavian churches in the project; all maps in the paper – the author*

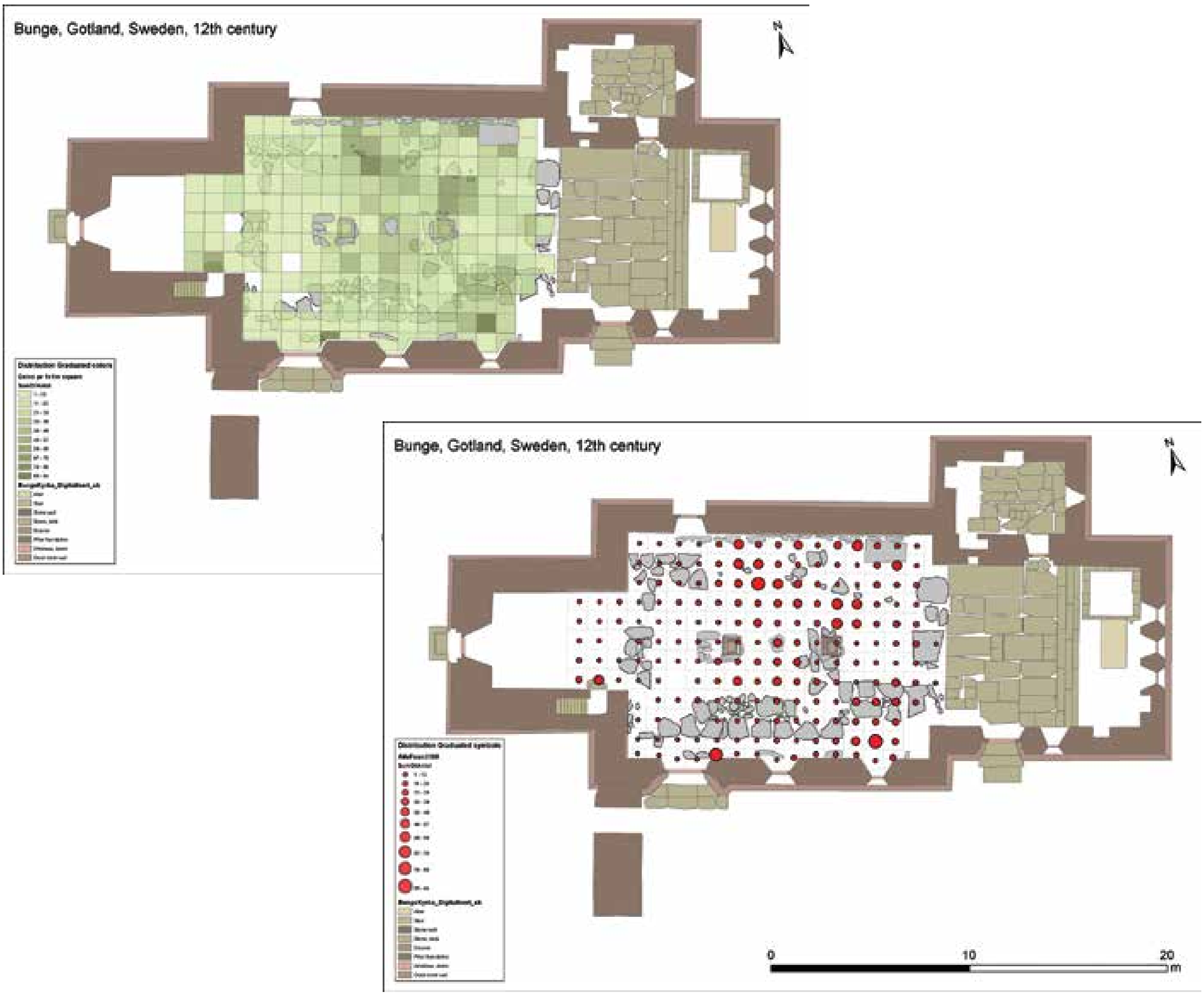

Fig. 2. *Bunge, Gotland, Sweden. Scattering pattern showed as filled squares (upper) and as center points (below)*

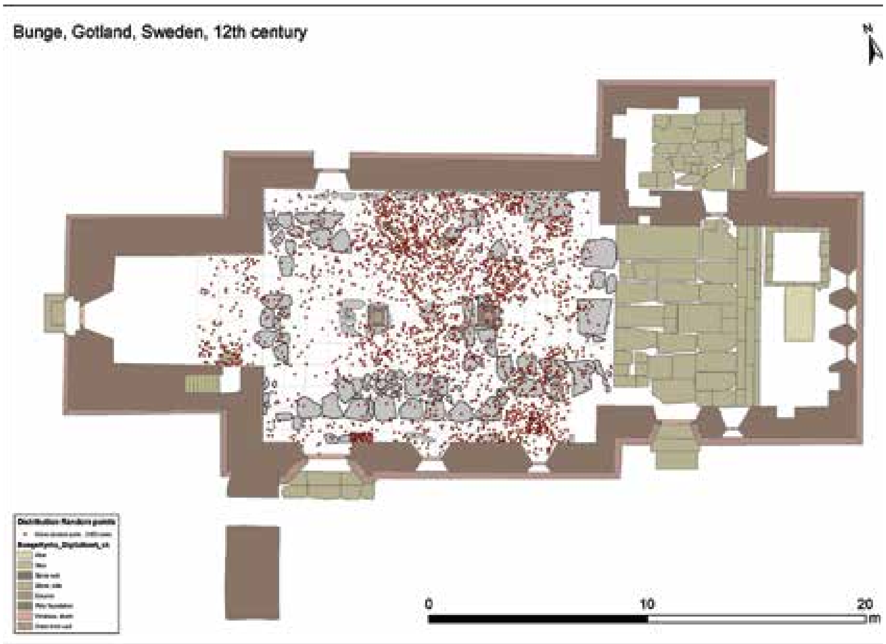

Fig. 3. *Bunge (Gotland, Sweden): scattering pattern showed as "random points"*

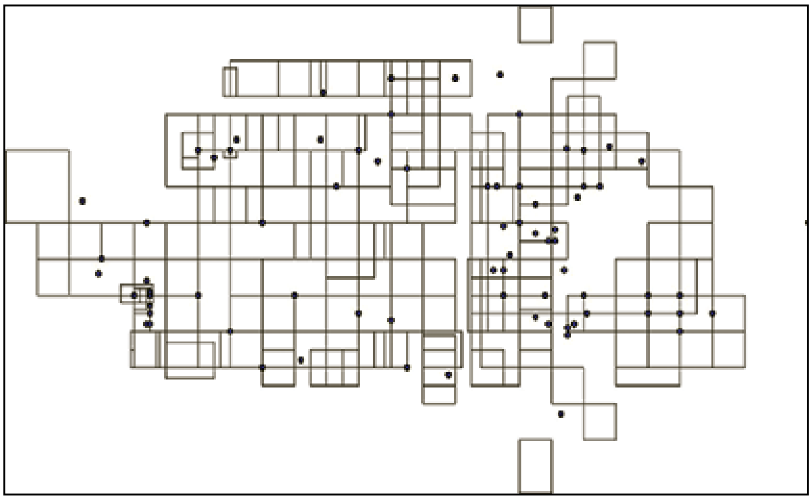

Fig. 4. *The complex grid of squares in the Ringebu staves church, Norway. The dots are coins with precise coordinate*

Fig. 5. *Excavation in the Ringebu stave church, ca. 1982; photo Museum of Cultural History*

CONCLUSIONS

The intersections between the disciplines in a multidisciplinary project like "Religion & Money" are rewarding. Through different approach and agendas the project evolves and new knowledge is gained, but there are also challenges due to the nature of different professions. The perception of a GIS person is not necessarily the same as of a numismatist and vice versa. This project has had several workshops where participants met and discussed aspects of the project including digitizing and GIS. Displaying coin location in the churches was one of the most debated issues in the GIS part of the project. The way the plotting is done will strongly influence the way the find distribution is interpreted.

It is important that the possibilities and challenges afforded by a GIS is communicated in a good way to the partners that are not familiar with this way of thinking. That is also a challenge to remember.

ACKNOWLEDGEMENTS

I wish to thank the participants in the Religion & Money project for their dedication in the discussions during the project regarding GIS and coins. I especially want to thank the project manager Prof. Dr. Svein Harald Gullbekk, from the Museum of Cultural History, The University of Oslo, for his belief in GIS and digital documentation as tools for research. I also wish to thank my colleagues at the Digital Documentation group at the Department of Collection Management: Espen Uleberg and Magne Samdal for all the discussions around digital challenges during the project.

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Digitizing archaeology in Norway

Mieko Matsumoto
Espen Uleberg

INTRODUCTION

Archaeological collections are the result of many years of *events* such as excavations, surveys, and accidental discoveries. Today, there are five university museums with archaeological collections in Norway; 1. Museum of Cultural History, University of Oslo, 2. Museum of Archaeology, University of Stavanger, 3. University Museum of Bergen, 4. NTNU University Museum in Trondheim, and 5. Tromsø University Museum, The Arctic University of Norway. Each museum is responsible for excavations and finds in their district (Fig. 1). The additions to the collections were published annually from 1866 till 1999, and this tradition of printed editions has been replaced by databases and online access. The digitized collections are big data that afford new possibilities for archaeological research. This paper describes the organization of the database development and the different modules in the system. Plans for further development are introduced, and the project Dynamic Distributions will be presented as an example of how digital resources can be used.

ORGANIZATION DEVELOPMENT

The first move towards a common database system for these museums was made in 1988 when a EDB-committee presented a design for archaeological databases in Norway. It was used for the sites and monuments records, and the databases in use for the museum collections today are developed from this design [1]. Two consecutive projects worked with digitalization and database development before the permanent organization MUSIT (*MUSeum IT*, www.musit.uio.no) was established.

Large scale digitalization started with the national Documentation Project (*Dokumentasjonsprosjektet*) in 1992 [2]. This project was a cooperation between the humanistic faculties at the universities, which at that time included the four university museums: Oslo, Bergen, Trondheim, and Tromsø. Several university institutes had large paper based archives which could only be studied by visiting the institutes. The extensive and diverse material included archaeological and numismatic collections, place name registers, Norwegian mediaeval documents, and folk music [3]. It had been agreed that this information should be more accessible to researchers and students as well as the general public, and that the best way to achieve this was by digitizing the material. A main purpose of the project was to convert these archives to electronically readable media. The motto was "From drawer to screen" – the scientific information should be taken out of the drawers and be readable on screens. Sub-projects were set up for different disciplines. Three of these were Archaeology, Runes, and Numismatics, all at what is now the Museum of Cultural History (*Kulturhistorisk museum*, KHM) at the University of Oslo. There were also archaeological projects at the university museums in Tromsø, Bergen, and Trondheim [4]. The Documentation Project was replaced by the Museum Project (*Museumsprosjektet*) in 1998.

The Museum Project was a cooperation between the university museums also including the collections of Natural History. The work on Archaeology, Runes, and Numismatics was continued, and the museum of Ethnography in Oslo got its own sub-project. By 2006, it was realized that the development and maintenance of museum databases were a permanent task, and accordingly the permanent MUSIT cooperation was established in 2007.

One of the important aspects of the MUSIT organization is the degree of user commitment it has encouraged. When a certain module or group of functions in the database is to be developed, a user group with members from each museum is started. The user group will discuss and suggest further database development, and work closely with the system developer. These groups are in principle temporary. Some of them, like the one for the archaeological database, are practically permanent. The user groups are also forums for discussion, and have contributed to a better understanding for joint database solutions at the university museums.

DATABASE MODEL

The conceptual model for the databases was object oriented, and the concept of an event was crucial. The model allows the integration of information from several disciplines. This was a brave approach, and is still a main goal for the database development and modelling. An event was defined as "something that takes place in time and space, perhaps on account of 'someone' or 'something" [5]. The concept of an event was also crucial in the development of the CIDOC Conceptual Reference Model (CRM). CIDOC CRM provides definitions and a formal structure for describing the implicit and explicit concepts and relationships used in cultural heritage documentation (http://www.cidoc-crm.org/index.html). CIDOC CRM has proved challenging to implement. One of the larger databases based on CIDOC CRM is the database for Ethnography at the Norwegian university museums [6] (http://www.unimus.no/etnografi/khm/samling/). The database for archaeology is also based on CIDOC CRM, and has been converging more and more towards the CIDOC CRM data model.

NATIONAL SITES AND MONUMENTS REGISTER

The Documentation Project took over responsibility for the development and maintenance of the National Sites and Monuments Register (SMR) in 1992. This register was at that time divided among the five university museums. The museums in Oslo and Tromsø used a system for free text queries developed in Norway called SIFT (*Søking I Fri Tekst* – Query In Free Text). Later, the project handled the conversion of the SMRs at these museums into one single database. At the same time the responsibility for the register was transferred to the Directorate for Cultural Heritage (*Riksantikvaren*), and the National Sites and Monuments Register is now named *Askeladden*. *Askeladden* has a version open to the public called *Kulturminnesøk* (Cultural Heritage Query, http://www.kulturminnesok.no/), which was launched in 2009.

ARTEFACT CATALOGUES

The first task in the field of archaeology in the Documentation Project concerned the artefact catalogues. The Norwegian university museums have 150 years of tradition of annually publishing artefact catalogues, and from 1992 the published artefact catalogues were transcribed and tagged using Standard Generalized Markup Language (SGML) [7]. The tagging used a syntax especially developed for the catalogue texts. This work on the artefact catalogues started in Oslo and was soon after extended to separate sub-projects at the other university museums. The tagged texts were published online and a web page with a map interface was launched as early as 1995. The map interface gave access to a limited part of the SMR and the archaeological collection.

The database for archaeology was implemented in Oslo in 2004. The SGML-tagged texts were transferred to the database, and from this time onwards new cataloguing was registered directly in the database. A special user interface for Stone Age followed in 2006, and soon after for Mediaeval period. In 2014, a digital acquisition protocol was ready, and in the same year the module for conservation was implemented. Photos, magazine facility, and events such as loans and laboratory analysis have been integrated, and the system now covers all aspects of curating. The artefact descriptions are published online through the Archaeological Portal (http://www.unimus.no/arkeologi/forskning/). This web site is freely available for all, and is continuously updated. As of 19. May 2015 there are 877 350 artefact entries published on this website.

ARCHIVES

The Norwegian university museums have topographically ordered archives. These archives contain information about sites and monuments as well as excavations conducted in the museum district and artefacts in the collections. The work on digitizing the archive material started during the Documentation Project at the University Museum of Bergen. All documents in the topographical archive were scanned and tagged. Later, NTNU University Museum in Trondheim started digitizing their archive, a project which is still ongoing. These archives are so far not published online.

The most time-consuming part of the process is to annotate the documents. Metadata has to be added to the documents to facilitate queries. KHM has started a project called Totally Digital Archive (*HelDigitalt Arkiv*, HDA). A web page with archaeological reports, documents from the topographic archive, and artefacts (http://app.uio.no/khm/topark/kart/) is developed in collaboration with the University Center of Information Technology (*Universitetets Sentrale IT Tjeneste*, USIT). The documents are scanned and uploaded in a way that they can immediately be accessed by cadastral unit. KHM is experimenting with crowd sourcing as a means to annotate the documents.

PHOTOGRAPHS

The university museums have also large photo archives. The work on the database for photographs started in Tromsø during the Documentation Project. Tromsø University Museum has a large number of photos documenting recent history in the Northern parts of Norway in addition to museum artefacts and excavations. The photo base is now used at all the university museums, including the Museum of Natural History in Oslo. The photos are published online (www.unimus.no/foto), and as of May 2015 more than 580 000 photos are published under Creative Commons licenses (http://creativecommons.org/). KHM has decided to use the CC 4.0 BY SA, which means that all photos can be used freely as long as they are attributed and shared under the same conditions.

The intention of the Documentation Project was a fully integrated system (Fig. 2), but the different parts, artefacts, photos, and archives were developed in collaboration with different university museums. Consequently, the different applications have existed in parallel more than as an integrated whole. The focus on integrated solutions has become stronger over the last years. One example is that the conservation module was integrated in the archaeological database from the beginning, and not originally developed as a separate application.

The first applications were built on technology from the 1990's, and after two decades it is now time for a renewal. MUSIT will over the next three years implement a new IT architecture. Central elements in the new architecture are scalability and modularity. The system shall be able to handle growth in the amount of data, and it shall be possible to separate and recombine the different elements in the system. The coming user interfaces will be web based and not applications that must be installed locally. A goal is that it will provide a complete system where all types of artefact documentation are fully integrated.

FIELD DOCUMENTATION

KHM started with digital field documentation in the early 1990's. The program PenMap has been used at KHM and at the Museum of Archaeology in Stavanger. ArcInfo was

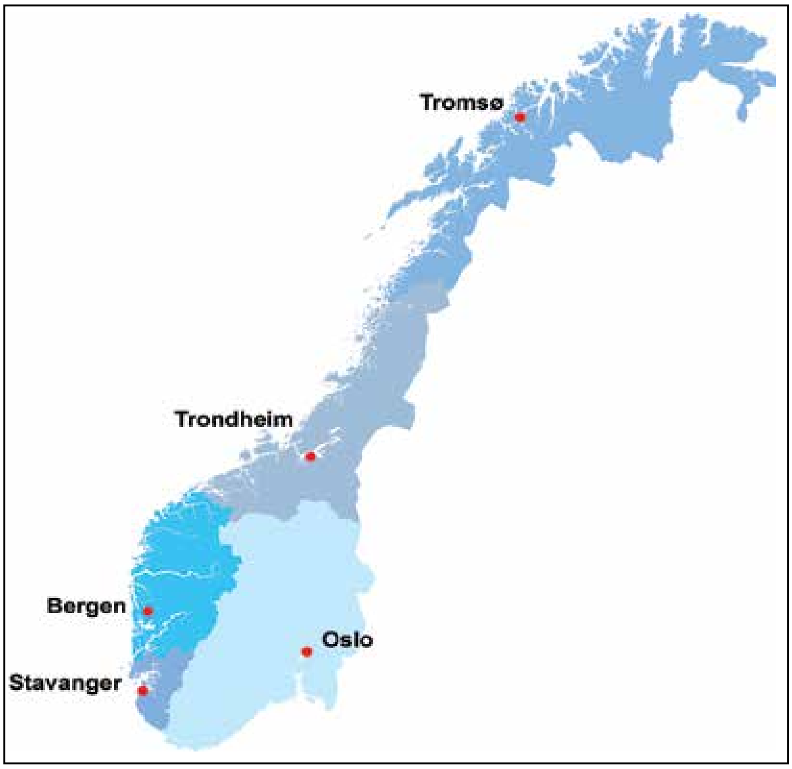

Fig. 1. *The districts of the university museums with archaeological collections in Norway*

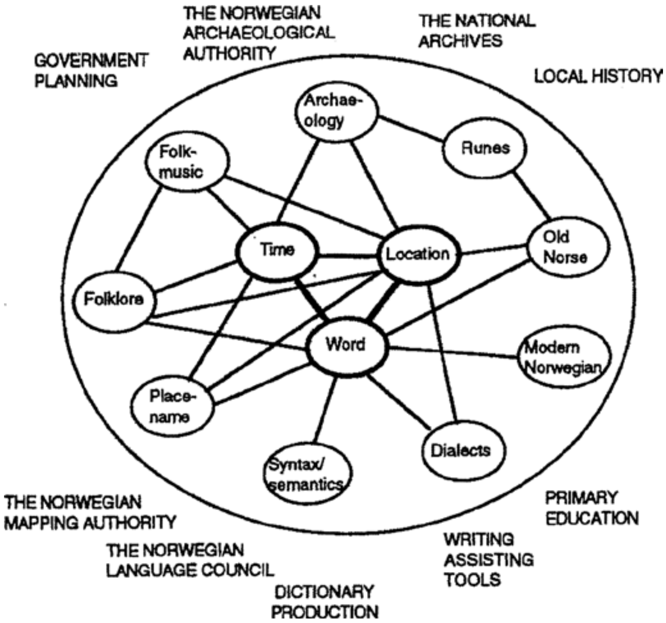

Fig. 2. *The university information system with its data types, their connections, and possible use (after [8: 278])*

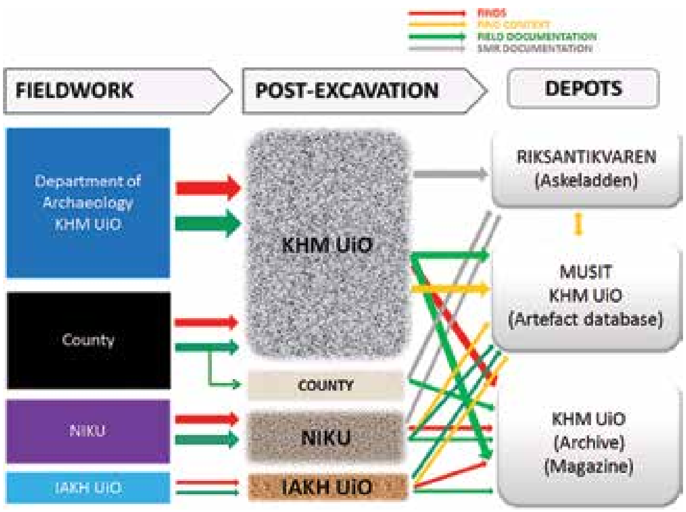

Fig. 3. *Overview of creators of archaeological data and the data flow from excavations and surveys*

introduced at larger rescue excavations in Oslo, Trondheim, and Tromsø.

Through the MUSIT collaboration, the university museums agreed on Intrasis as the common system for excavation documentation. Intrasis is a Geographical Information System (GIS) developed and maintained by the National Heritage Board's Contract Archaeology Service at the National Historical Museums in Sweden (http://www.intrasis.com/). The excavation documentation shall be integrated with the databases for artefacts and conservation, and common documentation standards have therefore been developed and implemented in Intrasis to make it compatible. This common standard for field documentation will also make it easier to combine results from excavations all over Norway in new ways and facilitate nationwide queries. This aggregation of excavation documentation will give new insights and create new possibilities for research.

DATA FLOW

The documentation created digitally has accentuated the need of a better flow of data among the different creators of archaeological excavation and survey data (Fig. 3). The university museums are responsible for the larger part of the excavations in their districts (Fig. 1). Surveys, and some smaller excavations, are conducted by the county archaeologists. The university institutes will carry out excavations as part of education and research in cooperation with the university museums. In Oslo, it is the Department of Archaeology, Conservations and History (IAKH), Faculty of Humanities at the University of Oslo. Norwegian Institute for Cultural Heritage Research (*Norsk Institutt for Kulturminneforskning*, NIKU) conducts excavations in mediaeval cities and churches. In southern and eastern Norway, the district of KHM, the Norwegian Maritime Museum (NMM) excavates sites under water both at sea and in fresh water.

The university museums store archaeological artefacts, and they will also archive excavation documentation in the form of excavation reports, drawings, photos, and GIS files. Lately, 3D documentation of sites and artefacts represents new formats, which will be archived and published by the university museums.

DATA MODEL

From the beginning, the intention of the Documentation Project was to create an information system where all collection information was interconnected and it was possible to do queries across different disciplines and databases. The system was always referred to as university research databases. The initial focus was also on conversion of written material. The ambition of interconnectivity still exists, but the advent of digital documentation has created a totally new situation for data curation, research, and publishing.

Since the different applications originated at different museums, they have been like silos with limited interconnections. Today the photo and artefacts are linked. The module for the acquisition protocol is integrated in the artefact database. The events created in the conservation module links also to the artefact catalogue module. In this way there is a steady development towards more integration.

One way of describing the system is to put the module for cataloguing archaeological artefacts in the centre (Fig. 4). New objects are first registered in the acquisition's module and then imported into the artefact application. Both of these are linked to a table with the cadastral units in all of Norway and to a magazine module. The artefact application is linked to the photo application and the conservation module. From this module it is possible to open windows with full text catalogues, high resolution photos, and geographical maps. All aspects of collection curation and artefact analyses can be registered in this system. However, detailed excavation documentation, like drawings and site maps, is even more extensive, and has yet to be incorporated.

The IT-architecture is based on technology from the 1990's, and time has come to build a new main structure for the database system. It should be a Service-Oriented Architecture (SOA) that can meet the demands for scalability and modularity. The future data system shall handle large sets of data, which are constantly increasing due to mass digitalization and large excavations. The new structure shall also give a possibility to define a central functionality linked to modules for specific parts of the collection. This functionality can be related to geographical references, collection events, storage and retrieval of objects. Examples of modules are descriptions of archaeological artefacts and numismatic objects. It is expected that the concept of modularity will increase the potential of research results linked to the main database.

OPEN DATA AND RESEARCH

The online MUSIT database with archaeological artefacts from all the Norwegian university museums will open new research frontiers that was unimaginable two decades ago. Geotagged artefacts and images published as open data will send the archaeology in new directions. Archaeological data from single excavations rarely qualify as big data. However, the accumulation of data over the life span of an institution like KHM is huge. Selecting a material from such a large collection can today be done through a few queries instead of spending weeks and months over written texts. It is also possible to generate a number of different types of maps from the information in the database. The data sets can be explored through the generation of maps combining and grouping the material in many different ways.

One example of such data exploration is our recent project Dynamic Distributions [3], [9], [10]. This project focuses on large stone artefacts like sickles, axes, and daggers, all typologically dated, from the Stone Age in southern and eastern Norway (Fig. 5). In the course of the project, the basic information is constantly updated in the database and immediately published online. The updates include the geotagging of older acquisitions. The specimens are grouped accord-

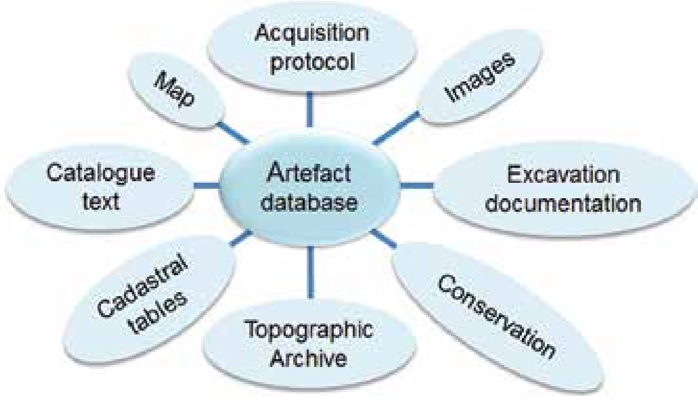

Fig. 4. *The modules of the data system*

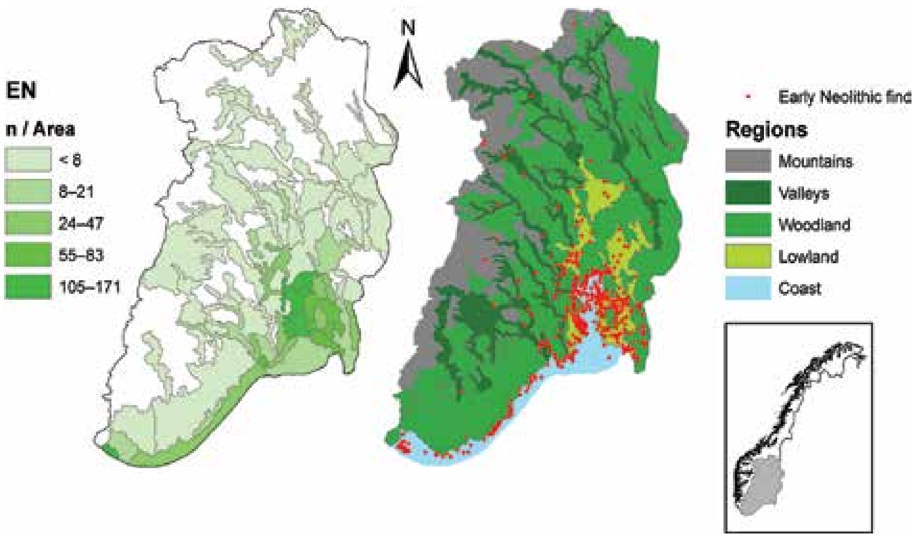

Fig. 5. *Stone Age artefacts and landscape types presented by the project Dynamic Distributions*

ing to artefact type and period, and studied in relation to landscape types and sea level change. The project Dynamic Distributions is in this way following two directions. One is to make all information available already during the project. The other is to explore the possibilities that are provided by archaeological big data.

The different landscape types rely on the work by Oskar Puschmann [11], [12], which is published as a downloadable data set. The divisions in Puschmann's landscape reference system are made on the basis of six variables: Major landform, Geology, Water and waterways, Vegetation, Agricultural areas, and Buildings. The Major landform is the dominant form of the landscape. The Geology takes both bedrock and deposits into consideration and adds geological detail to the major landform. The variable Water and waterways subsumes lakes, fjords, and sea as well as streams, rivers, and waterfalls. The Vegetation pattern concerns natural, semi-natural, and managed vegetation. The variable Agricultural areas concerns suitability for agricultural and land use; meadows, fields, and pastures. The variable Buildings also covers technical installations, and is perhaps the variable most reflecting modern use of the region and least relevant for an archaeological interpretation. The description of the regions is based on thematic maps and data registers. Puschmann's work is applied as the best suitable approximation to prehistoric landscapes at this scale.

Sickles, axes, and daggers were chosen because they are typologically dateable artefacts that were ascribed a meaning in relation to the landscape where they are found. Most of them are stray finds and the known find circumstances vary greatly. Some can be assigned a very precise coordinate, while others can only be attributed to a wider area. Different accuracy levels reflect the provenance of the artefacts. Most of the finds can be related to a certain cadastral unit. The degree of accuracy is decisive for the type of archaeological analyses that can be performed. The maps showing the distribution of artefacts in the landscape are based on the geotagging in the database. When the artefacts are placed within rather wide landscape categories, as shown in the following example, it is possible to use artefacts with a cadastral accuracy or better.

The map (Fig. 5) is one of the results from the project, and shows Early Neolithic finds from KHM's district. The Early Neolithic in this part of Norway is the period from 4000–2800 BC. Neolithic subsistence is by definition based on agriculture. However, there are very few indications of agriculture in Norway at this early stage. The map on the right shows the artefacts mapped on the five landscape types, illustrating the concentration along the coast with only few occasional finds in the more interior areas. The map on the left uses a finer landscape type resolution. It shows the relative number of finds by area of landscape types. The maps demonstrate how different presentations of the same information will give different impressions. The overall distribution image suggests a continuation from the preceding Mesolithic period rather than an abrupt change.

CONCLUDING REMARKS

The database systems now developed and maintained by the organization MUSIT has been developed since the 1990's. It is now time to rethink the IT architecture and create a system based on service-oriented architecture with better possibilities for scalability and modularity. The large amounts of data afforded by the databases have already created totally new conditions for research. A further integration of different types of documentation will give even better overview of the information and new understanding of prehistory.

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Possibilities of conservation and reconstruction of archaeological sites through digitalization

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INTRODUCTION

Archaeological sites are mostly preserved in their field documentation as plans, sketches, photos, descriptions etc. Nowadays, all data can be digitized, gathered and analyzed in Geographic Information Systems. GIS have many definitions. One may present GIS as a system designed to capture, store, manipulate, analyze, manage, and present all types of spatial or geographical data by users connected to the net [1]. Another definition sees it as sets of information for which databases are observations about spatially deployed characteristics, activities and events [2]. However, the definitions have common aspects such as spatial, digital information that can be post-processed and analyzed to gain new data.

In archaeology, GIS is used in Cultural Resource Management, landscape archaeology and spatial analysis [3]. In my master dissertation [4], I proposed that we should add also archaeological conservation of sites through documentation and digitalization as another possible way of using GIS in archaeology. Conservation of archaeological sites through their documentation, either paper or digital, is the main method of protecting archaeological data from complete destruction [5]. After reconsideration, I proposed not to treat archaeological conservation as one of the four ways of using GIS but treat it as a term that combines all three described aspects. The goal of CRM, landscape archeology and spatial analysis used in GIS, or more specifically – the Archaeological Information Systems, is to digitally preserve archaeological sites and try to gather new knowledge about it on the intra- or inter-site level.

I would like to support my thesis with three case studies from different parts of the world and cultures – Altdorf „Am Fridhof" from Germany, Gebelein region from Egypt and Castillo de Huarmey from Peru. All three sites have one thing in common: their documentation was changed to a digital one (or created as such) and constituted the basis for Archaeological Information Sysytem (AIS) followed by spatial analysis which helped to discover new data.

ALTDORF "AM FRIDHOF"

Altdorf "Am Fridhof" was a Celtic settlement. Excavations were conducted by the Warsaw branch of the Polish Academy of Sciences, Archaeology and Ethnology Institute, and the Bayerishes Landesamt für Denkmalpflege. I presented details of the documenting procedures as well as results of research and GIS analysis elsewhere [4].

The site was documented on sheets of paper about 2.1 m per 90 cm, and the artifacts were documented with all 3-dimensional data. During the process of creating AIS for the site, four stages of work-flow were formed: understanding documentation, digitalization, choice of software and creation of AIS. The fourth stage involved not only combining digital data but also creating unified vocabulary and preparing data for spatial analysis (for example selection of data, choice of a generalization level). The spatial analysis was based on the "average nearest neighbour" principle which provided information about distances between artifacts inside known archaeological features. With this data, buffers around different types of artifacts were created. This analysis was supplemented by a density analysis. The results showed areas in the excavation zone which might suggest the existence of unknown archaeological features (Fig. 1).

Digitalization of analog documentation, followed by a spatial analysis, opens new research possibilities. The analysis of spatial localization of artifacts conducted during my research gave the possibility to discover new features in the site, twenty years after the field works had been finished. The example of Altdorf clearly shows that proper documentation of the site gave us a possibility to reuse and reanalyze data at any point in the feature.

GEBELEIN

The second case study is from the Gebelein Region, a place of interest for the Gebelein Archaeological Project since 2013 [6]. Gebelein is localized south from Luxor, on the west bank of the Nile. It is an archaeological site complex with all types of sites in Egypt from the Predynastic till the Muslim Period (Fig. 2).

The field survey done in the site complex was so compound and collected so numerous different types of data that in order to fully describe its potential we had to describe it as a proper new method: "Comprehensive Field Survey". With six work-flow steps [7], it combined different type of surveys, not just those from the field, such as archaeological, anthropological, flint, pottery and geographical surveys but also epigraphic, archival and magazine surveys, maps and satellite image analysis, itinerary and landscape views. To help to reconstruct the past landscape of the region and the role of Gebelein in ancient Egypt, we used all available data collected in a non-destructive method. For the use of archaeological, anthropological and pottery survey we used Mobile GIS: a GNSS tool with a GIS application which had georeferenced archival data helping us to localize known sites and document previously unknown archaeological features [6]. Mobile GIS gave us an opportunity to create a complex database-documenting system for pottery and anthropological surveys and was a support for geophysical research. It turned out to be a very open, flexible and effective tool and in the matter of a field survey its precision (from 1m to 50 cm) was satisfying. Additionally, mobile devices gave us the possibility to verify in the field the results of analysis of archival maps and contemporary infra-red satellite image analysis (Fig. 3).

Mariusz Wiśniewski, in his article „Large scale modeling in a day-to-day practice of a Heritage Inspector" (published in this volume), proposed using 3D modeling as a tool useful for rescue documentation. The example of feature no. 405 in Gebelein, cut half way through by a bulldozer, shows how useful photogrammetric documentation can be in a field survey if one does not have excavations tools. The method gave the possibility to document and create a plan and profile drawings, which, with the use of an analysis made *in situ* by an anthropologist, led to the interpretation of the feature and the grave under difficult field conditions.

The research in Gebelein is a perfect example of the possibility to combine and use archival data in the field; it helps to find places researched by previous scholars or reconstruct past landscapes. "Comprehensive Field Survey", treated as a method that helps to gather all type of available information, shows that collecting digital data and reviewing archival data in the field is possible at the same time and can help to expand knowledge on the intra-site level. Effectively it may change the interpretation of the region from the past.

CASTILLO DE HUARMEY

The Castillo de Huarmey site is located 1 km east of the city of Huarmey, in the Huarmey province, Ancash department, Republic of Peru. The site is the largest site from Middle Horizon Period (AD 600–1050) in the southern part of the north coast of Peru and it is located at the top of an elongated rocky spur that protrudes into a valley [8], [9]. The research was preceded by the 2010 geophysical survey and mapping (with the use of GPS RTK) of mud brick structures found on the top of the rock [10]. The result of this work was a database and Archaeological Information System of the pre-Columbian center.

To summarize the basic information about discovery made in 2013, I would like to refer to the currently available best publications: "The significance of the imperial mausoleum of Wari, civilization, was based on the fact that it was the first unlooted imperial tomb of the Wari, the ancient civilization of South America predating Inca Empire" [11]. The burial chamber contained fifty-eight funerary bundles of noble women, six human sacrifices, two royal graveguardians, and over one thousand three hundred exceptionally rich objects that formed the ceremonial offerings and grave goods. The artifacts found include unique pieces that have no parallel in pre-Hispanic art in general, and provide important data regarding the identity of high-status women and the political structure of the Wari Empire [12]-[14].

The field documentation was conducted with the use of photogrammetric data, sketches and total station measurements. In the post-excavation process, raw photo data were changed into a 3D model with the use of the PhotoScan software. Subsequently, the exported GeoTIFF files were imported to the AIS of the site and used as the basis for sketches. The sketches served as a valuable source of information for spatial relations of the skeletons and finds. A bioarchaeologist conducted *in-situ* interpretations of the remains [15]. Vectorization of bones, done in ArcGIS – first from sketches, then from photos – was a long process that helped to create a plan of the chamber. The results of the work gave the possibility for the anthropologist to look again into spatial relations between the individuals and, for example, connect loose bones to a particular skeleton. The results of this work, done with the help of GIS, has been described elsewhere [15].

The next step was to analyze artifact finds from the burial. For that purpose it was necessary to combine two databases – the field and inventory database. They contained two common pieces of information: a field and museum number (both written down on the sketches) so it was possible to create a joined, relational database. This allowed us to divide artifacts according to their material and see their relations to individuals or to conduct a spatial analysis [16].

One of the first steps was to see if the skeletons interpreted as sacrifices created any kind of zones around them. However, the Thiessen polygon method results did not give such a suggestion. The Kernel's point density analysis gave two pieces of information about spatial distribution of artifacts in the chamber: the biggest amount of artifacts were put around the individuals A and C, and the highest density area was caused by storing artifacts in reed boxes [17]. Afterwards, for a visual effect, the skeletons were once again drawn by the anthropologist on a transparent paper, and with the use of vectorized bones as a base map, georeferenced. The black and white drawings were edited, their background made transparent, while bones themselves remained white. The rasters were combined in ArcGIS to present a 3D spatial effect of burial layers.

The almost fully digital documentation of Castillo de Huarmey enabled us to reconstruct spatial distribution of bones and artifacts, and to conduct analyses away from the site, during a computer-based process in the office. 3D models and interpretation sketches helped to create a plan and fill it with the Archaeological Information System of the site. In the result, it was possible to interpret and re-interpret data as well as to complement them with more detailed information from the site in following years and also to reconstruct this amazing discovery.

CONCLUSION

GIS turns out to be a powerful tool [3] that gives great opportunities to archaeology. The general digitalization process – one that considers not just archaeological data – has changed the process of interpreting data with different technical tools which may lead to technological determinism [18]. However, we cannot forget about the main

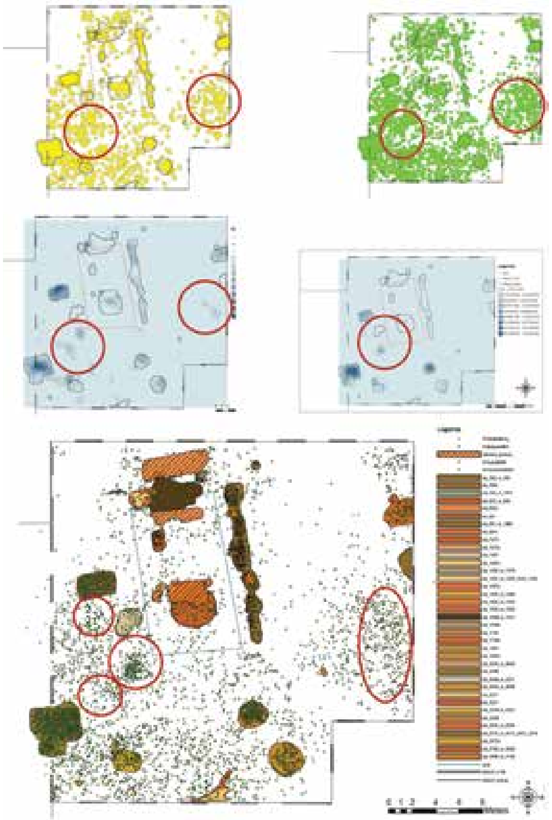

Fig. 1. *AIS of Altdorf "Am Friedhof" and results of the spatial analysis [4]*

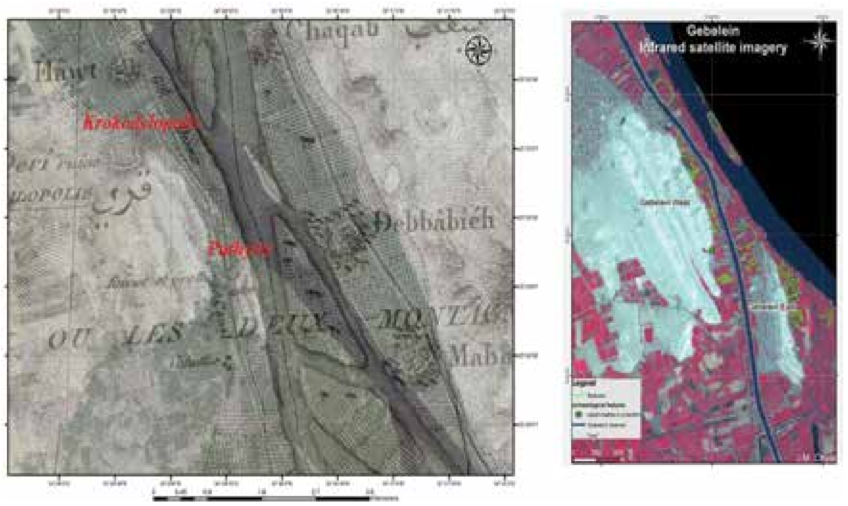

Fig. 2. *The Gebelein site complex – reconstruction of location of the sites were possible owing to Comprehensive Field Survey [6]*

reasons for applying such tools and processes: to preserve heritage. A proper process of gathering, manipulating and analyzing archival, field and digital data allows us to expand our knowledge about the past, manage collected data for future use, and reconstruct forgotten landscapes and present results to general population in an interesting and understandable way.

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