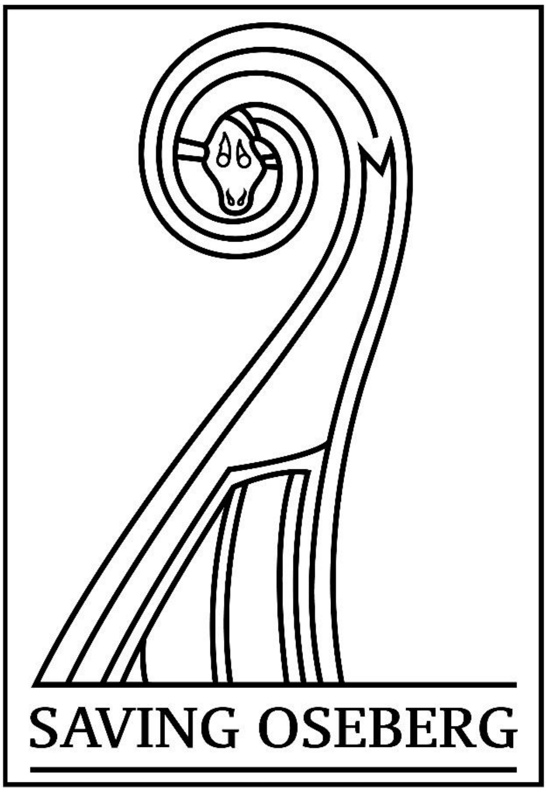
Saving Oseberg Phase II
Final Report 2017–2020



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1	15.4.2021	LB	First draft
2	30.04.2021	SO Team	Complementing information and discussion
3	30.06.2021	LB	Final Draft

Saving Oseberg Phase II Final Report 2017–2020
Saving Oseberg Team
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University of Oslo – Museum of Cultural History
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1 Introduction

The project Saving Oseberg Phase II (SO-II) was originally planned to run from 1/1/2017 to 31/12/2019. In the course of 2019, the MCH Board decided to extend the project with one year until the end of 2020, in view of delays and matching underspending. The project team delivered a large number of technical and administrative reports that detail the research methods and results as well as the administrative aspects, such as staff changes. All reports are archived in ePhorte under 2017/6982. This final report highlights the main findings from the previous reports, and refers to these for the details.

From 2017–2019, SO-II encompassed to varying extent the research on preventive conservation in the Viking Ship Museum in Bygdøy. These activities have been moved to other projects (Saving Oseberg Team, 2020b: 5), and are not covered by the present report.

Overviews of the project’s history and state of the affairs in 2018 were published during the project (Braovac et al., 2018, Braovac, 2019); see also the introduction section in Braovac et al. (2021). The aims of retreating alum-treated wood from the Oseberg collection are summarised in Tabel 1.

Tabel 1. Criteria for a successful retreatment of alum-treated Oseberg material. From Braovac et al. (2021:7)

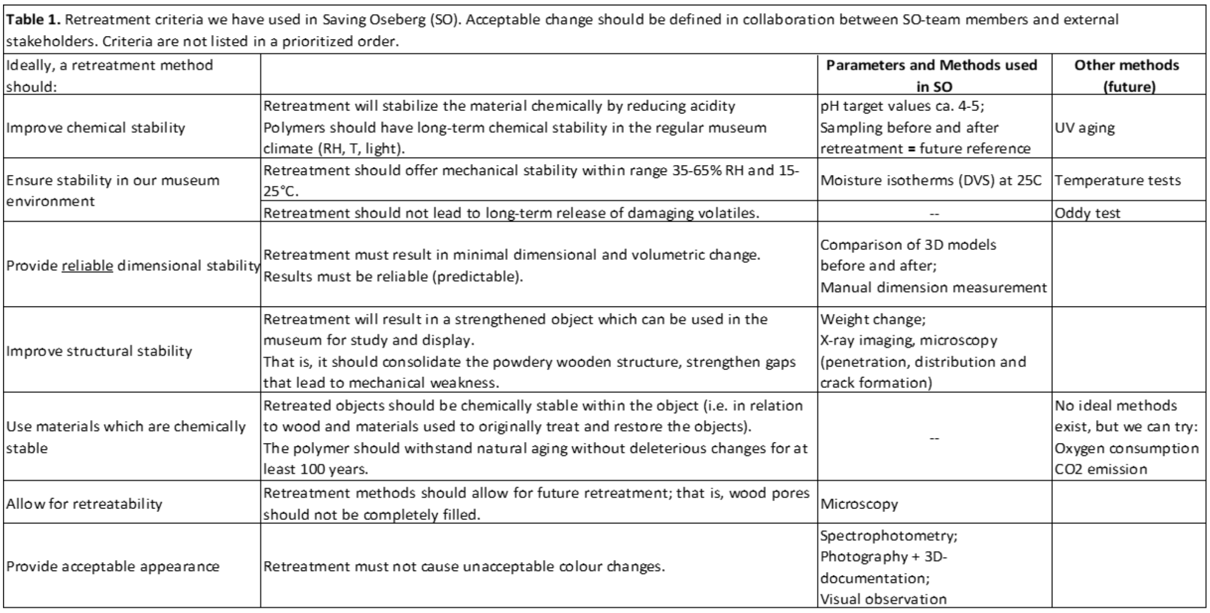

Table 1. Retreatment criteria we have used in Saving Oseberg (SO). Acceptable change should be defined in collaboration between SO-team members and external stakeholders. Criteria are not listed in a prioritized order.

Ideally, a retreatment method should:		**Parameters and Methods used in SO**	**Other methods (future)**
Improve chemical stability	Retreatment will stabilize the material chemically by reducing acidity Polymers should have long-term chemical stability in the regular museum climate (RH, T, light).	pH target values ca. 4-5; Sampling before and after retreatment = future reference	UV aging
Ensure stability in our museum environment	Retreatment should offer mechanical stability within range 35-65% RH and 15-25°C.	Moisture isotherms (DVS) at 25C	Temperature tests
	Retreatment should not lead to long-term release of damaging volatiles.	--	Oddy test
Provide reliable dimensional stability	Retreatment must result in minimal dimensional and volumetric change. Results must be reliable (predictable).	Comparison of 3D models before and after; Manual dimension measurement	
Improve structural stability	Retreatment will result in a strengthened object which can be used in the museum for study and display. That is, it should consolidate the powdery wooden structure, strengthen gaps that lead to mechanical weakness.	Weight change; X-ray imaging, microscopy (penetration, distribution and crack formation)	
Use materials which are chemically stable	Retreated objects should be chemically stable within the object (i.e. in relation to wood and materials used to originally treat and restore the objects). The polymer should withstand natural aging without deleterious changes for at least 100 years.	--	No ideal methods exist, but we can try: Oxygen consumption CO2 emission
Allow for retreatability	Retreatment methods should allow for future retreatment; that is, wood pores should not be completely filled.	Microscopy	
Provide acceptable appearance	Retreatment must not cause unacceptable colour changes.	Spectrophotometry; Photography + 3D-documentation; Visual observation	

2 Understanding chemical stability of alum-treated wood

Chemical characterisation of alum-treated Oseberg wood as well as other wood and paper used in the project is detailed in a number of technical reports (Łucejko et al., 2017a, McQueen et al., 2019b); Łucejko et al. (2021) list all the characterisations done at the University of Pisa using pyrolysis gas chromatography and mass spectrometry (Py-GC/MS).

Understanding acidity and Carbohydrate degradation patterns

The extremely low pH (pH 1–3) of alum-treated wood from Oseberg is identified as the main cause of the accelerated degradation. The acidity of dissolved alum is a round pH 3.5, which proves that much acidity is due to other acids. While this acidity is a result of the alum treatment, we cannot meaningfully separate acidity caused by H^+ and acidity caused by aluminium ions, or their relationship to wood degradation, based on analysis of Oseberg wood (McQueen, 2019: 8, Saving Oseberg Team, 2020b).

Acid-base titration experiments were performed on extracts from alum-treated wood from the Oseberg collection, in order to assess the relationship between pH, titratable acidity and other analytical results in these samples (McQueen and Braovac, 2019b). The titratable acidity (overall acidity) in these samples was found to be closely linked to the high Al content from alum, and information on this has already been obtained more accurately by ICP-OES. As a result, these experiments did not improve our insight into acidity caused by H^+ in Oseberg wood samples and its relationship to wood degradation.

Surface pH measurement is our most commonly used method of determining acidity in objects, but such measurements are not particularly accurate if linseed oil or varnish is present. Chapter 5 in McQueen et al. (2019b) presents a more detailed discussion of pH and acidity in objects. Links between pH values and other analytical results (e.g. ion content and wood degradation) remain unclear, also due to the demonstrated inconsistencies between solution pH and overall titratable acidity. We therefore cannot easily explain the variation in pH among objects. The variation in pH may also reflect difficulties of measuring pH in the presence of linseed oil (Braovac et al., 2021:6).

However, Py-GC/MS analyses of alum- and acid-treated wood model systems indicate that the action of aluminium in the hot treatment baths contributes to the unique pattern of degradation in alum-treated artefacts (Łucejko et al., 2019). We proposed that this could be due to both the action of Al(III) ions on the organic material and H^+ produced by aluminium species in water. The literature suggested that saccharide conversion and degradation reactions catalysed by aluminium compounds were most efficient in an acidic environment. In our experiments, the degradation caused by the hot alum solution was clearly distinct from that caused by hot sulphuric acid solutions at the same pH. There was some evidence of potential reactions with aluminium ongoing after treatment, but this was less clear, as changes to the wood after alum treatment appeared to be much less dramatic in model samples than during treatment (McQueen, 2019).

The mechanism of alum-induced wood degradation, while poorly understood, is thought to involve acid hydrolysis from the outset, caused by sulphuric acid introduced during alum treatment (Braovac and Kutzke, 2012). This is potentially accompanied by non-redox reactions catalysed by aluminium ions (Braovac et al., 2018, Braovac et al., 2016), such as isomerisation and dehydration of saccharide materials (Zhou et al., 2014, Gupta et al., 2017) and cellulose hydrolysis (Chamberlain, 2007, Baty et al., 2010, Baty and Sinnott, 2004). In paper, it is known that hydrolysis and oxidation processes are synergistic, and hydrolysis can increase the rate of oxidation (Fellers et al., 1989, Wilson and Parks, 1979). Given the evidence we see for increased rate of oxidation in alum-treated wood (based on Oxygen consumption experiments), we suggest that such processes may contribute to oxidation in Oseberg wood as well (McQueen, 2019).

2.1 Ammonium alum

While it was previously documented that parts of the Oseberg collection had been treated with potassium alum ($KAl(SO_4)_2{\cdot}12H_2O$), it proved that the alum used was actually a mixture of potassium and ammonium alum ($NH_4Al(SO_4)_2 \cdot 12H_2O$) in varying proportions (McQueen and Braovac, 2019a, McQueen et al., 2019a, McQueen et al., 2019d). Ammonium alum contents varied from 8 to 84% of the alum component in sampled fragments. The two alums have similar properties, and in model studies of their behaviour under the conditions of alum-treatment, they appeared to form similarly acidic solutions. Thus, the different alum mixtures probably did not significantly influence object treatment. Nor have we observed other indications of unusual degradation pathways related specifically to the presence of ammonium alum. Nonetheless, investigations into potential re-treatment of the archaeological objects need to include interactions with both alums, and monitor the volatilisation of ammonia and other reactivity differences.

2.2 Alum stability in wood

The differences we observed between acid- and alum-treated wood artefacts (Łucejko et al., 2019) led to the question of the stability of alum crystals in the wood. Are the differences due to aluminium released during alum treatment, which then interacts with the wood, or is the crystallised alum involved in some way?

In terms of reactions of alum, we have seen the recurring presence of alunite ($KAl_3(SO_4)_2(OH)_6$) and mercallite ($KHSO_4$) in many fragments as by-products of alum treatment (Łucejko et al., 2017b, McQueen et al., 2019c). Alunite was present on the surface of some wood pieces, and inside a crack, presumably having precipitated from solution during treatment of the objects at 90°C. Mercallite is also present in several fragments, and we have suggested that the formation of this acid salt is a result of the extreme acidity of some samples, though we cannot distinguish between whether it was introduced during treatment or forms over time based on our observations. In any case, mercallite is acidic, unstable, and highly hygroscopic and migrates readily within the wood. It is not detectable in all wood samples, which we have attributed to factors such as higher ammonium alum proportions, higher pH and/or reactions of the ions to form compounds with iron. However, we cannot rule out that it is present below limits of detection.

In our studies of temperature and RH responses of alum-treated wood (McQueen et al., 2018, Mortensen et al., 2018), we suggest that migration and reactions of mercallite are probably related to other potassium hydrogen sulphate crystals forming on surfaces of objects exposed to high RH. The presence of mercallite may also destabilise alum crystals, especially at high RH. Pure alum crystals, both potassium and ammonium versions, were stable to short term fluctuations in RH and temperature within normal museum limits. However, it is worth noting here that alum in Oseberg wood cannot be considered "pure", and we cannot rule out instability of alum in the presence of impurities other than mercallite based on these results. Rather, the results indicate that alum could potentially be stable under the right conditions.

Ammonium alum seems to respond similarly to potassium alum in terms of climate responses and acidity in solution, and no significant amount of other ammonium-containing compounds have been found. Therefore we view ammonium alum as similarly, if not less, reactive than potassium alum (McQueen et al., 2019d).

Overall, the conditions currently present in some Oseberg artefacts are not ideal for alum stability. Although evidence of their instability is strongest at high RH, our results allowed for the possibility of reactions under milder conditions. Such reactions could contribute to the observed degradation of alum-treated wood (McQueen, 2019).

2.3 The effect of iron and linseed oil

Oseberg fragments that, in addition to alum, are treated with linseed oil generally less degraded (Lucejko et al., 2018).

There were serious concerns over iron ions contributing to oxidative wood degradation in the Oseberg collection. “We have found that, while it is possible for iron ions to speed up oxidative degradation in alum-treated wood (McQueen et al., 2019f), there is not strong evidence that iron or other metal ions are doing so in Oseberg objects (McQueen et al., 2019c, Łucejko et al., 2017b). We therefore consider this a secondary issue. Original iron parts studied, which were already corroded during burial, appear not to react further with alum or its breakdown products. However, alum-treated Oseberg wood is speeding up degradation of modern iron rods, which are structural elements of objects in many cases” (McQueen, 2019: 3). Any iron-induced degradation is likely to be overshadowed by the hydrolytic reactions due to the alum treatment. Therefore, we will need to monitor the possible activity of iron ions after retreatment.

STUDIES ON THE RATE OF DECAY

2.4 Comparison with alum-treated samples from Lund and Copenhagen

To study the rate of decay of alum-treated wood, we collected samples of wood treated with alum between 1880 and 1940 from museums in Lund and Copenhagen. These were chemically analysed and compared with Oseberg wood and both fresh and archaeological wood aspen and birch treated with potassium alum in 2009 and 2012. Although we can see some relation with time of alum treatment, we cannot infer a rate of decay from the studied objects, since the initial degree of degradation was not sufficiently documented, and the objects in different museums had undergone varying conservation treatments. However, investigating objects from other collections gave us a broader perspective on the problem of alum-treated wooden museum objects (Lucejko et al., 2019b, Łucejko et al., 2021). Also for the WOAM conference in May 2019, there is a poster on the packaging paper samples (Lucejko et al., 2019a).

2.5 Chemical markers of wood degradation

SO-II made a start in identifying compounds (mainly lignin related monomers) which could function as markers of wood degradation using extraction methods, as low-tech alternative for pyrolysis. Wood samples were hydrolysed with acidic and basic aqueous solutions under reflux for 24h, extracted with chloroform, and analysed by FTIR and GC-MS. Additionally, woods samples were extracted with chloroform under reflux and analysed by FTIR and GC-MS as well. The method required no derivatisation. The results pointed out this is a promising approach, showing an interesting trend between state of degradation and the monomers identified. There is also the potential that this method could be used to assess the protective effect on the wood of different treatments against the basic and acidic attack (Murgia, 2019). The study was extended in 2020 with additional samples (Vespignani, 2020) and will lead possibly to a publishable paper in autumn 2021 together with an updated report.

2.6 Oxygen consumption

Alum treatment appears to be related to extensive lignin oxidation (Łucejko et al., 2017b, McQueen et al., 2019b, Braovac et al., 2016). This indicates that the speed of the decay could be at least be partially measured by monitoring oxygen consumption. The results of oxygen consumption experiments using optical meters on alum-treated wood have confirmed that alum treatment increases rate of oxidation (McQueen et al., 2019e, McQueen, 2019:2).

Measurements of O_2 consumption and CO_2 release can be used to monitor the real time chemical degradation of alum-treated wood that either have, or have not, been retreated with the methods investigated in SO-II. The experimental set-ups relevant for the Saving Oseberg project are GC-MS and O_2 optical meters. O_2 optical meters have the advantage of lower costs, flexibility and simple operation, but there is no CO_2 equivalent for this method (Steindal, 2020). Due to its simplicity, the O_2 measurements by using optical meters was preferred for future experiments.

3 Established and new materials and protocols for consolidation

The overall aim of retreatment is to increase the chemical and mechanical stability of the alum-treated collection. In view of the deleterious effect of the low pH and the possible oxidative effect of the aluminium ions from alum and mercallite, removal of the alum would be the best solution to preserve the Oseberg artefacts. This can be done by desalination in consecutive water baths, which can be followed up by a consolidation step with a water-soluble polymer. However, many of the objects and fragments are too fragile to withstand wetting treatment. For this reason, SO-II investigated both water-based (aqueous) and non-aqueous treatment options, and developed criteria to assign Oseberg objects to either category. We introduce the methods tested here, and report on the results of the tests in sections 4 and 5. Finally, SO-II included a subproject on new consolidants, which have not yet been tested on Oseberg wood. We worked on the development of a lignin-inspired or lignin-based new consolidant, and collaborated with the University of Nottingham on other innovative consolidants (Section 3.4).

3.1 Aqueous treatments tested on Oseberg wood

The aqueous retreatment starts with desalination, removing the alum and other soluble salts and sources of acidity by means of repeated water baths. After that, a consolidating treatment is necessary to avoid shrinkage and deformation of the object upon drying. We have investigated two alternative aqueous consolidation treatments: with polyethylene glycol (PEG) and with Kauramin® resin. Protocols for these steps are included in Braovac et al. (2019), (2021:24-25).

3.2 Deacidification in non-aqueous retreatment tested on Oseberg wood

The deacidification method for non-aqueous retreatment in the SO-II project uses alkaline nanoparticles (NPs) of calcium hydroxide $Ca(OH)_2$ suspended in isopropanol (IPA). These NPs were initially developed to consolidate carbonate-based stones and frescos. In this case, the reaction with CO_2 is the main aim. After application to the stone or fresco substrate, the favourable reaction with calcium hydroxide and CO_2 produces $CaCO_3$, which acts as a cement, thus consolidating the friable substrate (Baglioni et al., 2015).

NPs can also be used for deacidification of acidic materials such as paper, canvas and wood. In this case, the main aim is not to form a consolidating cement, but rather to react with acidic species in the substrate, thus giving a more chemically stable material. In the case of alum-treated wood from the Oseberg collection, the acidic species are mainly the excess sulfates absorbed during treatment, but may also include acidic degradation products from acid hydrolysis and oxidation of wood polymers.

Deacidification of wood using alkaline nanoparticles (NPs) was tested on timbers from both the Vasa ship and the Mary Rose (Giorgi et al., 2005, Schofield et al., 2016, Schofield et al., 2011). Saving Oseberg has also looked into NPs for application to alum-treated wood (Andriulo et al., 2017).

Reactions between NPs and acid involve reactions with the hydroxide part of the calcium hydroxide with hydrogen ions, to form water, and secondly, reactions involving the calcium ion, which readily reacts with the excess sulfates in the wood to form compounds containing both calcium and sulfate. The main expected product is syngenite ($K_2Ca(SO_4)_2{\cdot}H_2O$), which is the reaction product between calcium ions and the acidic salt mercallite ($KHSO_4$). It takes time to stabilize the reaction product to the final form (minimum 30 days). Any unreacted $Ca(OH)_2$ will eventually react with CO_2 from the air to form $CaCO_3$, either as the mineral calcite or vaterite, depending on the RH during the reaction (Andriulo, 2020).

The reactions which take place with alkaline NPs occur in the solid state and proceed from the outer surface of the NPs inwards, the particles growing smaller as the deacidification reactions consume it ('topochemical' reactions). This means that the NPs do not start to react until enough isopropanol has evaporated. This is a very controlled way of adding alkaline compounds, since the pH of the NPs suspension in isopropanol is about 7. If we were to add calcium hydroxide from an aqueous solution (pH 11–12), the high pH may cause damage to the material.

In the presence of excess amounts of NPs, another potential reaction is possible, namely reactions with the potassium and ammonium alum salts themselves (Andriulo, 2020). Given the difficulties of getting enough NPs into the wood, these reactions are less likely, but they should be mentioned.

SO-II thoroughly investigated the stability of the crystal phases that result from NPs treatment. Results obtained indicate that newly formed crystals do not grow > 7 micrometres, and that this treatment does not cause chemical or mechanical damage (Andriulo and De Ferri, in preparation).

3.3 Non-aqueous consolidants tested on Oseberg wood

The SO-II project tested and optimised three consolidation treatments with two commercially available materials, Butvar B98 and Paraloid B72, and three consolidants that involve in-situ polymerisation with a siloxane backbone polymer (Saving Oseberg Team, 2020b). The treatment protocols for each of these are included in the reports on tests with standard archaeological wood samples (Zisi et al., 2021) and Oseberg fragments (Braovac et al., 2021).

The **Sil-FRIA2009** method is a system containing a silanol (PDMS-OH), a cross-linker (MTMOS) and a catalyst (DBTDA) (Kavvouras et al., 2009). During SO-II, experiments were ran in order to adjust the method for application on dry wood. The results and conclusions of these experiments together with an in detail presentation of the method, are given in Zisi (2020) and Zisi et al. (2021:21-25).

Steindal (in preparation) developed the **CS-IV-40C-20** method for conservation of dry archaeological wood during the SO project. The consolidant is a system comprised of a medium range siloxane (PDMS) which copolymerises with methyltriethoxysiloxane (MTES) in the presence of an aluminium-based catalyst. During the curing process, a tridimensional structure forms inside the wooden matrixs.

The third siloxane-based consolidant in the project was developed by Andriulo for use in the **Hybrid System-FA**, and is used in combination with alkaline $Ca(OH)_2$ nanoparticles (NPs).

Except for the Hybrid System, the use of these aforementioned consolidants requires neutralisation of the acidity of the Oseberg wood with $Ca(OH)_2$ NPs.

Finally, treatment with $Ca(OH)_2$ NPs alone, without a consolidant material. The NPs are dispersed in 2-propanol.

Treatment protocols for the non-aqueous consolidants (Butvar, Paraloid and three siloxane-based materials) have been developed and are documented in (Zisi et al., 2021: 21-28) and (Braovac et al., 2021: 28-40). Experiments with Oseberg fragments included both immersion and injection as application method. We injected NPs before the consolidants, except in the case of the Hybrid System-FA, which is a bland of NPs and a consolidant. Treatment with NPs alone is a sixth retreatment option.

3.4 Development of new consolidants

In addition to the consolidants we tested during the project, SO-II invested heavily in the development of entirely new consolidant materials for archaeological wood, with an emphasis on non-aqueous treatments. In terms of project organisation, we distinguish between the research on lignin-based materials, which was carried out first at UiO and thereafter continued largely at Wagening Food and Biobased Research (WFBR), and other polymers that were investigated in the framework of PhD projects at the University of Nottingham. The work on entirely new consolidants was first coordinated by SO-II team member Caitlin McQueen, and subsequently by Fabrizio Andriulo. SO-II hired Prof. Stephen Harding from the University of Nottingham in a five-year 0.2 fte position as Professor II (8/2017–7/2022). His tasks was to promote the research collaboration on consolidant materials and initiate new research projects.

Lignin-based consolidants: This research started with Emily McHale's PhD project (McHale, 2018, McHale et al., 2017). McHale worked on a consolidation method that involved polymerisation of isoeugenol, a lignin-inspired small monomer, inside the treated wood. Some promising results were obtained, but larger scale production of the monomers and further testing proved too demanding for the project's scope.

Further work on lignin-based was carried out by WFBR in collaboration with UiO-MCH and University of Nottingham (UoN) in 2019–2020, building on an existing collaboration between WFBR and UoN (Alzahrani et al., 2016). This work focused on the ethylacetate-soluble fraction of kraft and soda lignin and investigated the crosslinking with a number of bio-based reactants (terpenes) and film-forming properties of the formulations (Gosselink et al., 2018: 16-17, Saving Oseberg Team, 2020b). After a thorough characterisation procedure undertaken at Nottingham on these materials (Lu et al., submitted), WFBR also carried out small-scale mechanical tests of the consolidation of lab-degraded wood (Braovac et al., 2020) using a three point bending setup. This led to the unexpected preliminary conclusion that the combination of the lignin fraction with other reactants yields results inferior to those of single reactants.

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Polymers worked on in Nottingham: In 2020, Jennifer Wakefield, focusing on natural polymer consolidants submitted her PhD thesis on the application of chitosans and the related aminocelluloses (Wakefield, 2020) and a number of publications have resulted (Wakefield, 2020, Wakefield et al., 2020c, Wakefield et al., submitted, Wakefield et al., 2018, Wakefield et al., 2020b, Wakefield et al., 2020a). Stephen Harding supervised this work, which was funded by the Engineering and Physical Sciences Research Council (EPSRC). Aminocelluloses, which can be tailored and produced to a higher specification than chitosans, emerged from all this as a possible alternative or supplement to PEG for aqueous based consolidation treatments: see also the 2018 annual report (Saving Oseberg Team, 2019) for more details. The EPSRC granted a second PhD project entitled "Saving Oseberg: evaluation of potential polymer consolidants for reinforcing decayed archaeological wood", with a 200 000 kr contribution from the SO-II project. This is the PhD project of Michelle Cutajar, which runs for four years starting 1 October 2018. The focus of Michelle's work has been on the development of new bioinspired consolidants soluble in non-aqueous solvents. First results have been published on terpene polyacrylates (Cutajar et al., 2021a, Cutajar et al., 2021b), and will ultimately help lead to the production of a "polymer" toolbox for application to consolidation strategies for specific situations. Funding is actively being sought for a follow-up project that will also include an investigation on the potential of sporopollenins, nature's most resistant polymer assembly.

4 Testing of non-aqueous retreatment options on standard size archaeological wood samples

4.1 Methods

Two quantitative experiments were carried out using archaeological wood obtained from excavations in Oslo (Zisi et al., 2021). The first experiment used 300 spruce test specimens treated with different consolidants. In the second experiment, we used improved treatment protocols for the consolidants and 96 pine test specimens. The second experiment included the water-soluble PEG instead of Butvar, in order to compare the non-aqueous retreatment methods with the established aqueous PEG conservation.

Parameters evaluated included shrinkage/swelling and deformation, weight uptake, colour change, penetration and distribution, hygroscopicity and mechanical strength. We refer to (Zisi et al., 2021) for the methodology and detailed results. The team SO-II spent much effort on finding and developing methods for testing the mechanical effects of consolidation treatments. The identification and development of these methods belong to the project results.

It proved challenging to evaluate mechanical strength in a quantitative, reliable manner using treated wood, due to the inherent heterogeneity of wood of any type and the even greater heterogeneity of degraded wood. We experimented with testing parameters like stiffness and elasticity in moulded mock-ups using a mixture of sawdust and consolidant, but this proved technically too challenging within the scope of SO-II. We ended up using three methods to evaluate mechanical strength:

Ultrasound: The dynamic modulus of elasticity (MOE_{dyn}) was calculated as the product of the wood's density and the squared ultrasound propagation velocity (Zisi et al., 2021: 44-45), Figure 1. Modulus of elasticity (MOE) and wood density are essential indicators of strength used by the timber industry for grading commercial timber (Ilic, 2003).

Surface **resistance to indentation** ('Hardness'). A commercial handheld fruit hardness tester measured the wood's resistance against indentation (Zisi et al., 2021: 46-47). The acquired instrument is hand-operated, and lowers a 3 mm radius tip down 1 mm into the sample. Engineers at the Department of Chemistry in collaboration with the Department of Physics (UiO) motorised the instrument in order to assure that the force is applied in a controllable and repeatable manner (Figure 2). Testing was performed along the tangential wood axis.

Finally, we evaluated the **surface resistance** against abrasion with the 'shake test' method developed by (Petrou et al., 2009). The electrical device shakes the test samples together with glass marbles held inside a sieve of a specific size screen. The amount of material collected by the mesh after a set period of time and intensity of shaking is weighed as a measure of surface resistance (Figure 3).

Figure 1 *Through transmission ultrasound testing of wood Test Specimen using PUNDIT as pulse generator.*

Figure 2 *Testing hardness of treated wood Test Specimen using an in-house motorised commercial fruit hardness tester (with Calin Steindal).*

Figure 3 *The Retac 3D sieving machine and the 4 mm ø sieve with the 30 glass marbles.*

4.2 Results

Results detailed in Zisi et al. (2021) are summarised below. Differences between the treatments proved to be small in most tests.

Cross-sectional area change Hybrid System-FA, Paraloid B72, Sil-FRIA2009 and CS-IV-40C-20 led to 0–1% shrinkage; PEG to 3.3% swelling. Treatment with Paraloid B72 led to more difference between the tangential and radial shrinkage, so that distortion of surface details may be visual noticeable in this case. Results tell us that all non-aqueous consolidants cause negligible wood shrinkage after application in contrast with the aqueous PEG, which causes wood to swell after treatment. The significance of the amount of swelling and its acceptance is to be defined by the collection carers based on the object to be treated, especially if surface details are present.

Weight increase. The weight uptake was clearly the highest for Sil-FRIA2009 (Tabel 2). This reflects the higher consolidant concentration used in this treatment. Two different molecular weights of PDMS-OH (36,000 $gmol^{-1}$ and 18,000 $gmol^{-1}$) were tested, and showed the same amount of weight uptake (Zisi, 2020). The other consolidants led to a rather similar increase in weight.

Tabel 2. Weight uptake after treatment with five non-aqueous consolidants and PEG.

Treatment (N)	Butvar B98	Paraloid B72	Sil-FRIA2009	CS-IV-40C-20	Hybrid System-FA	PEG 2000
% Weight uptake (avg)	25	42	177	74	39	52
Standard deviation	18	11	39	7	9	14

Colour change. All treatments slightly darkened the test specimens, with only subtle differences between them noted. Note that the archaeological test specimens before treatment were much lighter than the Oseberg wood is. The impression is that all consolidants enhance the visibility of the surface details. Sil-FRIA2009 has a more rubbery feel than the other treatments, in line with its much higher concentration and material gain.

Macroscopic appearance. No significant delamination, cracks or other distortions were observed.

Consolidant penetration and distribution. All consolidants were found in the core as well as on the surface. NPs were found in both the core and on the surface in case of the Hybrid System-FA. Penetration of consolidants was unproblematic for samples of this size (25*25*25 mm).

The siloxane-based consolidants as well as Paraloid B72 tend to fill smaller and sometimes larger cell lumina (‘plugging’). This is most pronounced for Sil-FRIA2009, corresponding with the high concentration used in the treatment protocol. Gap filling is less prominent in Hybrid System-FA and Butvar B98.

Moisture exclusion. All non-aqueous consolidants waterproof the wood when compared to the untreated controls. There is indication that if the relative humidity (RH) is raised from 50% to 100%, wood treated with the Hybrid System-FA and Paraloid B72 is less resilient to moisture uptake than wood treated with Sil-FRIA2009, and especially CS-IV-40C-20. However, such high RH should normally nor occur in a museum environment.

Elasticity measured with ultrasound. The ultrasound measurement is the only measurement that is completely non-destructive, and was therefore performed before and after treatment. Measurements were done only along the grain (longitudinal wood axis). All tested consolidants, PEG, Paraloid and the three siloxane-based ones, led to an increased specimen density and lower ultrasound velocity. Decrease in ultrasound velocity before and after treatment was statistically significantly different in paired-samples t-tests for all five treatments, and so was the increase in MOE_{dyn}. These changes were expected since the uptake of consolidants increases the density of the samples.

How decrease in velocity affected the mechanical properties of consolidated archaeological wood was of interest to understand as well. Ultrasound velocity measurements are used in the timber industry to assess mechanical properties of fresh wood, using the dynamic modulus of elasticity (MOE_{dyn}). This is possible because the relationships between wood's acoustic properties and physical properties are established. For instance, the dynamic modulus of elasticity (MOE_{dyn}) is calculated by multiplying wood density and the square of the velocity. Wood density is used because it is relatively easy to measure and it is highly correlated to its mechanical properties (i.e. the higher the density, the higher the strength and MOE). Density is also used to assess state of preservation of archaeological wood. Generally the lower the density, the more degraded the wood is mechanically.

However, assessing the effect of *consolidation* on mechanical properties of archaeological wood by measuring ultrasound velocity requires more work. When a consolidant has been applied to archaeological wood, it will increase the density (that is, it has gained weight while maintaining a similar volume). However, this increase in density is solely due to the consolidant. Therefore we cannot assume the same relationships exist between velocity, density and MOE_{dyn}, as for sound wood. This relationship needs further investigation. The application of standard mechanical tests would be a first step in this direction. For instance, using the three point bending tests, such as they were performed at WFBR (Joosten et al., 2021). The SO-team is still working on interpreting ultrasound measurements, to compare the effect of the different consolidation treatments with each other.

Surface resistance to indentation. Preliminary results suggest that treatment with CS-IV-40C-20 and Paraloid B72 increases surface hardness by 7–9% compared to the untreated control group. Increase in surface resistance is clearest for CS-IV-40C-20. The indentation procedure did not leave permanent marks on the wood surface, except in the case of samples treated with aqueous PEG 2000. This treatment appears to soften the surface. Even though Sil-FRIA2009 treated wood gave the same hardness values as wood treated with PEG 2000, it did not get any indentations. This underlines the differences in material properties in treated wood that are not reflected by the values obtained from the measurements.

Surface cohesion. Consolidating the wood with Paraloid B72 did not improve the surface cohesion as the Test Specimens lost the same amount of wood as the untreated controls (13%). Arranging in a descending order of weight loss, first follows PEG 2000 with 11%, then the Hybrid System-FA with 10%, and last, Sil-FRIA2009 with 7%. CS-IV-40C-20 seems to have lost more wood than the controls at 23%.

Our findings suggest that, irrespective of treatment, the samples that absorbed more consolidant were more resilient to surface abrasion during handling. This applies irrespective of the concentration of the consolidant in the treatment solution.

A few test specimens split tangentially due to the shaking treatment. While collection objects will obviously be handled with more care, some might break during retreatment, and the possibilities for reassembling of broken fragments need to be investigated for each consolidant.

Overall conclusion based on the experiments with archaeological test specimens: The tested non-aqueous consolidants and their formulations give similar results under all evaluation criteria tested in this study.

On the non-mechanical parameters, the tested formulations give similar results, except that Sil-FRIA2009 stands out as plugging more of the larger vessels in the wood, making the samples much heavier, and causing a rubbery feel; this can change if a lower PDMS concentration is used instead of the 70% used here. Only a minor—1% or less—shrinkage is expected after using non-aqueous treatments. This is irrelevant of non-aqueous consolidant tested in this study. On the contrary, a 3% swelling is expected in the case of the aqueous PEG treatment. Collection carers should note that these numbers are inherent to the conservation materials. Further shrinkages or swellings are possible, this time related for example to the shapes, construction, re-construction and existing damages of the Oseberg objects that can cause dimensional changes that are difficult to predict. However, these parameters can be considered and dealt with inasmuch as possible during conservation treatment for each object so to minimise their affect.

There is indication that wood treated with PEG is more prone to surface indentations in contrast with wood treated with the non-aqueous treatments. However, all types of consolidants seem to provide fairly robust surfaces that will not rub off during museum handling. Tests must be now run to identify suitable adhesives for each one of them.

It is the first time ultrasound measurements were used to evaluate consolidation treatments. The level of sensitivity of the ultrasound set-up can be improved with new equipment that was acquired during SO-II. Crucially, we need research to understand how the values for ultrasound velocity and dynamic modulus of elasticity may reflect mechanical strength in archaeological wood treated with a consolidant. The initial planning included ultrasound testing combined with three point stress tests on mock-ups in order to understand this relationship. Although initiated during the course of SO-II, we postponed this work due to lack of time.

It is clear from this study that the a*queous* PEG is a different system compared to the *non-aqueous* candidates. Results were not different for the following parameters: weight gain, colour change, macroscopic appearance, hygroscopicity, MOE, surface cohesion. (We did not evaluate consolidant penetration depth and distribution of PEG in this experiment.)

5 Testing of retreatment options on Oseberg fragments

This chapter is a summary of the 190 page report (Braovac et al., 2021).

5.1 Evaluation of aqueous retreatment options

SO-II worked out criteria to identify which objects and fragments are likely to withstand aqueous retreatment, that is desalination and consolidation with a water-soluble consolidant (Braovac et al., 2019, Braovac et al., 2021: 15-16). These criteria were updated with the outcomes of the test described below. Notably, branches with collapsed interior parts were found to be are at high risk of falling apart (Braovac et al., 2021: 167-168).

Aqueous treatments were tested on 31 Oseberg fragments, and results are reported in (Braovac et al., 2021: 41-92, 166-167). We summarise the main findings here: Aqueous methods require that the object is immersed in baths of water. The experiment has shown that highly deteriorated alum-treated wood without linseed oil (pH <2, dark brown, powdery) does not withstand the immersion step required in aqueous retreatment, as it disintegrates in water.

Waterlogging makes the objects heavy and weak. Reconstructed objects were not included in the SO-II test campaign. Based on experiences with single fragments, however, we anticipate that it would be too risky to undertake aqueous retreatments on finds that include many joins (weak points). This limits the use of such methods to smaller fragments which have good structural integrity and which are possible to handle safely. The longest test fragment we have tested was about 50 cm and it was weakened due to propagation of inner cracks. An advantage of aqueous retreatment is that both alum salts (of which we are still unsure of their long-term chemical stability) and acid products are removed during desalination / deacidification. We consider high acidity to be the main factor driving chemical degradation of alum-treated wood. That said, we have observed that waterlogging branches was somewhat problematic, since it caused severe expansion of the collapsed core in some cases. The cores contained little alum salt. Such swelling has led to their fragmentation during the immersion step. Although it may be possible to repair such fragmentation after retreatment, the question is rather whether or not such changes are desirable in the first place. This needs discussion within a wider group of experts.

Main results of the aqueous retreatments experiments:

- Applicable for single fragments which are robust: medium to low risk condition.
- Final pH ca. 5.
- PEG and Kauramin are well distributed and do not fill pores.
- Kauramin gives lighter coloured wood. This can be amended by application of surface coatings to give a more ‘wood’ look.
- PEG caused either little colour change or darkened the wood.
- Mould growth may have discoloured fragments in some cases (may be permanent).
- Most retreated pieces fitted well with alum-treated references. (Good idea to have these as comparisons). But there are some volumetric changes.
- Risks: Branches may swell causing mechanical weakening. We observed elongation of cracks in some cases. Swelling may lead branch to fall apart or warp/deform in water. Branches saturated with linseed oil will likely result in warping, rather than breaking into fragments.
- For test fragments that broke, we must consider how well the broken pieces fit after retreatment and whether we can repair them satisfactorily.

Factors affecting desalination rate:

- The initial weight of the sample. Larger fragments require longer desalination times.
- The amount of alum present: In some cases, there was very little alum; These were desalinated first.
- Whether linseed oil or varnish was present: Desalination went faster for fragments only containing alum.
- The extent of saturation with linseed oil (based on visual assessment): Highly saturated test fragments took longer to desalinate. Test fragments with linseed oil and/or varnish allowed for alum removal at room temperature, even though it was slower than for those without linseed oil.
- Fragments with broken end grain surfaces after treatment with alum and linseed oil tended to desalinate faster than those that had an intact linseed oil coating.
- Extent of mould growth on linseed oil coated fragments: layers of slime mould may also have contributed to slower desalination rates.
- Recommend room temperatures to desalinate, due to increased risk of damage at higher temperatures, and risk of extending the desalination period at lower temperatures. Recommend frequent changes (1x per week) as long as the increased handling of fragments does not cause damage. Recommend using K_{adj} to compare different baths.

5.2 Evaluation of non-aqueous retreatment options

Non-aqueous treatments were tested on 44 Oseberg fragments. Procedures and results are reported in (Braovac et al., 2021: 93-155, 168-170); the main findings are reproduced here:

Deacidification was undertaken by injection of calcium hydroxide NPs in isopropanol. Some test fragments broke or were weakened during NPs injection, indicating that isopropanol penetrated enough to weaken the wood. X-ray images after NPs application show that in some cases new cracks were formed or existing ones elongated/widened.

Even distribution of NPs was difficult to achieve. NPs mainly settled in open pores and in cracks and voids. Both 10g/L and 5g/L concentrations were tested. It appears that the 10g/L was more effective in increasing pH, and there was no difference in extent of penetration. Final pH was on average 3.3.

Consolidants were both injected and immersed. Immersed test fragments had better distribution of consolidant than injected fragments. However, immersion in solvents increased weight and extent of swelling, especially in test fragments with collapsed wood (which is found mainly in branches). Although immersion in Sil-FRIA2009 increased the weight of the fragment, the turpentine likely caused least swelling. Weight gain due to solvent saturation was on a similar scale for solvents as it was for water. However, aqueous immersion made saturated fragments much weaker. In some cases, the combination of weakening and swelling, even during injection of NPs, likely resulted in fragmentation during the immersion step. One test fragment broke into several pieces after curing, likely due to new stresses imposed during the retreatment process. In most cases, broken pieces fit well together, and are reparable with an appropriate adhesive. We need to test which adhesives are best to repair silane-treated fragments.

Highly deteriorated alum-treated wood without linseed oil (pH <2, dark brown, powdery) withstood injection of both NPs and consolidant (immersion was not tested) with only minor loss in detail, or change in maximum dimensions, which were below ±6% for width or height. This class of fragments is very porous (unless filled with alum salts), which allows uptake of both NPs and consolidant. The retreated fragments in this study became significantly darker. The pH of these woods was raised from 1.5 to 3.3.

Main results of non-aqueous retreatments:

- Considering all parameters, we believe that in most cases, better retreatment results were obtained with injection, rather than immersion. The greatest downside with immersion is that it appears to cause greater weight gain and swelling than injection, especially for B98 and B72. Although injection can give uneven consolidant distribution – again, especially for B98 and B72 – one has more mechanical control than with immersion. That said, injection does involve more physical handling, which may lead to damage. Thus, we can still consider immersing small fragments in Sil-FRIA2009, if in the low risk group, especially if they have been weakened during NPs injection. We do not recommend immersion for B72 and B98, CS-IV-40C-20 and Hybrid system-FA.
- Final pH ca 3.3: lower than we would have liked. Can we improve NPs penetration?
- NPs treatment resulted in little overall weight change in treated fragments, and the NPs distribution is uneven. However, during NPs treatment, the weight gain due to isopropanol absorption in the wood may be great enough to weaken it, causing existing cracks to widen, or new ones to form.
- Overall, we found that the extent of penetration of both NPs and consolidant is highly dependent on a fragment's porosity. Generally, there is better consolidant distribution in wood without collapse, excessive amounts of alum salts and/or linseed oil, all of which reduce porosity for most consolidants.
- That said, penetration of 70% Sil-FRIA2009 in collapsed wood appears to be improved if pre-treated with NPs. This may also be true for the other consolidants. A hypothesis to explain this may be that the slight swelling effected by NPs treatment 'opens up' the wood, even in collapsed zones.
- Injection concentrations of 5% for B72, B98 and Sil-FRIA2009 were adequate to provide 'enough' strength (i.e. in terms of handling). Furthermore, for 5% concentrations of Sil-FRIA2009, alum salts were not a hindrance. For CS-IV-40C-20 and Hybrid system-FA the same concentration was used for both injection and immersion, both giving 'enough' strength.

- Drying conditions for CS-IV-40C-20 may be too harsh (40˚C 30 days). Curing at high temperatures for shorter periods should be investigated. A practical alternative would be either a higher temperature (initially the curing was conducted at 60˚C) for a shorter period, or a lower temperature for a longer period; this needs to be investigated.
- Average total colour change was similar for all non-aqueous test fragments, ΔE*ranging from 7-11.
- Most retreated pieces fitted well with alum-treated references. (Good idea to have these as comparisons). But there are some volumetric changes.

Risks

- Swelling in immersion can lead to warping, breakage in fragments with large amounts of collapsed wood.
- For test fragments that broke, we must evaluate how well the broken pieces fit after retreatment and whether we can repair them satisfactorily.
- With uneven deacidification in the wood, its chemical degradation can continue in acidic regions. Consolidant degradation may also be possible if the wood is too acidic.
- With uneven distribution of consolidant, mechanical tension can arise in the wood.
- Uncertainties: What happens long-term to consolidant if wood is not deacidified well? Should we consider NPs-only without consolidation at first, while investigating long-term stability of consolidants? Are there ways to improve distribution of NPs by injection?

6 Documentation protocols and decision models

6.1 Documentation of treatments

An important part of the retreatment effort is the documentation of the objects before, after and in some cases also during the retreatment, e.g., after desalination but before treatment with NPs and/or a consolidant. SO-II worked out and described the procedures of imaging, and measurement of pH, colour, weight change, dimensional changes, polymer distribution and chemical characterisation (Braovac et al., 2021: 16-24).

The project attributed particular effort to develop a methodology for 3D documentation. If and object is documented in 3D before and after the retreatment, any volume change or deformation can be traced in detail. Much experience was gained with both structured light scanning (Kimball et al., 2020) and photogrammetry (Kimball et al., 2019). Both techniques can be used with advantage, but require considerable expert assistance to render the images and to compare before and after images. A third option is to document object size and shape with the help of a CT scanner. An advantage of this method is that it can also provide information on the composition of the object under the surface, notably the presence of alum salts and reaction products of injected NPs. SO-II did some first tests with the CT scanner at the Natural History Museum in Økern.

SO-II formulated criteria that assign objects and fragments to a risk category (low, medium, high) which indicate whether the object is likely to withstand the removal of alum with water (desalination), see section 5.1.

6.2 Decision models

The SO-II Steering Group asked Jan Bill (KHM-AS), Kristiane Strætkværn (SO-II Reference Group), Ingrid Louise Flatval (project owner at KHM-SF) and Louis Boumans (project leader) to draft a model for how to decide on the best treatment option for individual collection objects. This resulted in a categorisation of the collection objects in terms of their value for research and public exhibition (Bill, 2020), a description of the outline of the decision model (Boumans, 2020c) and two proposals for decision trees (Strætkværn, 2020, Boumans, 2020a). The discussion on decision models took place early 2020. The decision process and criteria need to be reviewed in the SO Interim period, taking into account the experience gained in the tests with archaeological wood and Oseberg fragments in the course of 2020 (sections 4 and 5).

7 Project management

General remarks: Work at the Viking Ship Museum on preventive conservation was initially administered under the Saving Oseberg II project, but with a separate budget and project number (000286); these tasks were in 2018–2019 transferred to David Hauer's PhD project, and the museums project to prepare for the construction of the new Viking Age Museum.

SO-II was originally planned to last three years (2017–2019). A number of circumstances caused delay and associated underspending: Delayed hiring of some staff members, conservation scientist Nora Piva leaving after one year, and moving the laboratory from Bygdøy to Økern in autumn 2019. The project owner decided to extend the project until the end of 2020.

7.1 Project staff, Steering and Reference Group

Louis Boumans was project manager from 16/1/2016 to 20/11/2020; Susan Braovac took over this role thereafter until the end of the project. Caitlin McQueen coordinated the chemical analysis work and the work on new materials until the end of her contact December 2019, when Fabrizio Andriulo took over this role. Susan Braovac coordinated the conservation science part of the project.

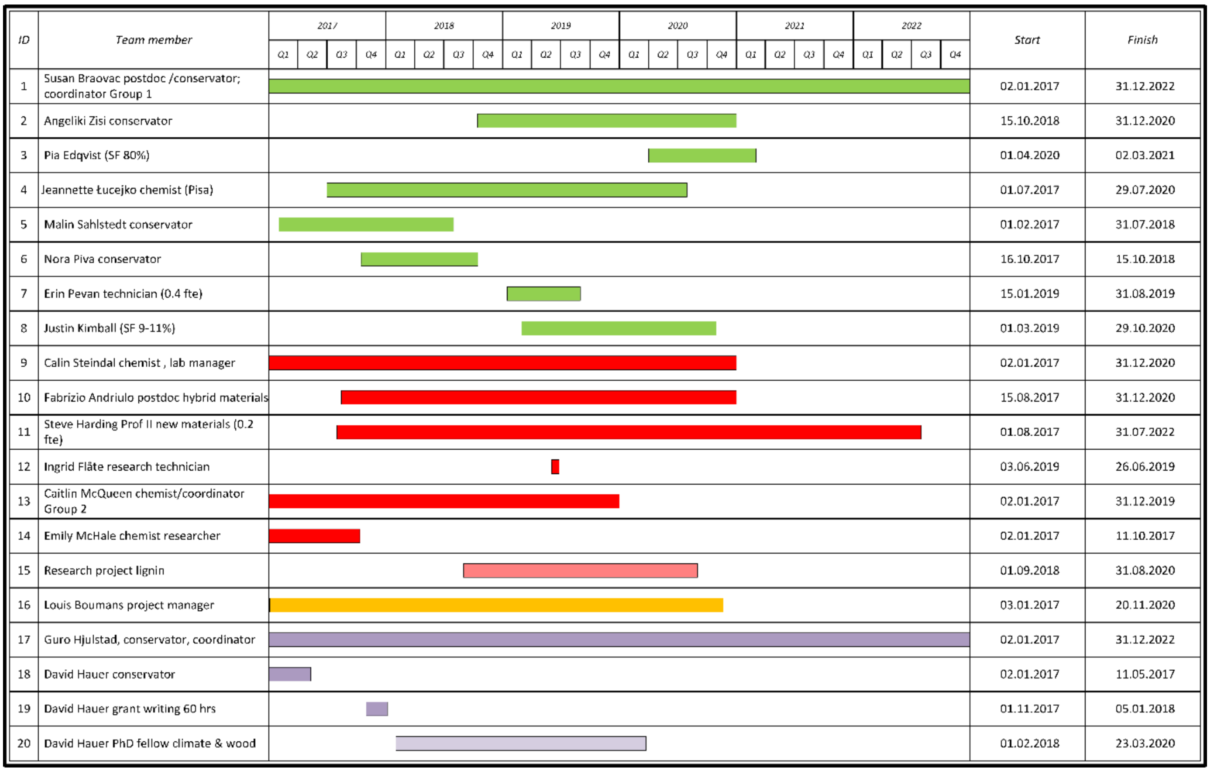
Project management included hiring of temporary staff and arrangements for involving internal staff at MCH (frikjøp) as shown in Figure 4, and personnel responsibilities for the project team. The project manager also contributed to other hiring processes at MCH. The University of Pisa hired Jeannette Łucejko for three years to work in the SO-II, funded by UiO. Łucejko et al. (2021) collected all the characterisations done at the University of Pisa using gas chromatography and mass spectrometry (Py-GC/MS) are in a separate large report; chapters of this report are or will be included in several publications. Łucejko was registered as a guest researcher at MCH in order for her to have access to the project's data files and IT services of UiO. Likewise, chemists Caitlin McQueen and Emily McHale had a guest researcher status following their engagement as an employee in order to facilitate the final work on some publications. In addition, Jennifer Wakefield, at the time PhD student in Nottingham, was a guest researcher at the project during her visit and experimental work in Oslo in 2018.

Three Erasmus+ exchange students participated in SO-II: Simone Murgia and Laura Vespignani from Italy and Anne Frizon de Lamotte de Règes from France (documents in ePhorte 2019/7166), cf. (Saving Oseberg Team, 2020b:32).

The head of the Department of Collection Management represented the project owner. This was Torunn Klokkernes during the first two years and Ingrid Louise Flatval after that. The Steering Group had the following members:

Torunn Klokkernes / Ingrid Louise Flatval	UiO-MCH Department of Collection Management
Helmer Fjellvåg	Professor at Department of Chemistry, University of Oslo
Charlotte Gjelstrup Björdal	Professor at Department of Marine Sciences, University of Göteborgs

Jan Bill	UiO-MCH Department of Archaeology
Marting Hager Saltnes	UiO-MCH Department of Exhibitions, Education and Public Services



ID	Team member	Start	Finish
1	Susan Braovac postdoc /conservator; coordinator Group 1	02.01.2017	31.12.2022
2	Angeliki Zisi conservator	15.10.2018	31.12.2020
3	Pia Edqvist (SF 80%)	01.04.2020	02.03.2021
4	Jeannette Łucejko chemist (Pisa)	01.07.2017	29.07.2020
5	Malin Sahlstedt conservator	01.02.2017	31.07.2018
6	Nora Piva conservator	16.10.2017	15.10.2018
7	Erin Pevan technician (0.4 fte)	15.01.2019	31.08.2019
8	Justin Kimball (SF 9-11%)	01.03.2019	29.10.2020
9	Calin Steindal chemist , lab manager	02.01.2017	31.12.2020
10	Fabrizio Andriulo postdoc hybrid materials	15.08.2017	31.12.2020
11	Steve Harding Prof II new materials (0.2 fte)	01.08.2017	31.07.2022
12	Ingrid Flåte research technician	03.06.2019	26.06.2019
13	Caitlin McQueen chemist/coordinator Group 2	02.01.2017	31.12.2019
14	Emily McHale chemist researcher	02.01.2017	11.10.2017
15	Research project lignin	01.09.2018	31.08.2020
16	Louis Boumans project manager	03.01.2017	20.11.2020
17	Guro Hjulstad, conservator, coordinator	02.01.2017	31.12.2022
18	David Hauer conservator	02.01.2017	11.05.2017
19	David Hauer grant writing 60 hrs	01.11.2017	05.01.2018
20	David Hauer PhD fellow climate & wood	01.02.2018	23.03.2020

Figure 4. Staff contracts in Saving Oseberg Phase II. In addition, the subproject on lignin-based consolidants in collaboration with Wageningen Food and Biobased Research and the University of Nottingham is shown as item 15. Colour codes: Green = alum project 00208 conservation scientists, red = idem, chemists, purple = preventive conservation in project 000286, orange = project management for projects.

The Reference Group (RG) was composed of five members; Stephen Harding left the RG after he became a project team member in his position of Professor II at the MCH.

Roger Rowell	Retired Senior Technical Pioneering Scientist at the USDA, Forest Products Laboratory
Tom Sandström	Conservation scientist at the Swedish National Heritage Board
Kristiane Strætkvern	Conservator at the National Museum of Denmark
Steve Weiner	The Kimmel Center for Archaeological Sciences, The Weizmann Institute, Rehovot, Israel
Steve Harding	The School of Biosciences, University of Nottingham

7.2 External collaborations

SO-II had a close collaboration with the University of Pisa, where Jeannette Łucejko was hired fulltime for three years to work on SO-II. The collaboration with the University of Nottingham resulted in hiring Stephen Harding as a Professor II (0.2 fte) for five years (Figure 4) to develop the research in new consolidating materials. SO-II collaborated intensively with Harding's team in Nottingham, including the PhD students Wakefield and Cutajar. SO-II project enabled the acquisition of funding for Cutajar's project by contributing 200 KNOK. UiO-MCH and Harding's lab in Nottingham participated in the project on lignin-based consolindants with WFBR (section 3.4).

In addition to these external team members, we collaborated with NMBU and the University of Florence for various analyses.

7.3 Work planning and project meetings

In the course of the first year, the SO-II team finished the report ion the previous Phase I project (2013–2016) (Saving Oseberg Team, 2017a, Klokkernes and Boumans, 2017) and worked out a Project Plan document (Saving Oseberg Team, 2017c) with an Annex 1 listing the tasks and deliverables in more detail (Saving Oseberg Team, 2017b). Both documents were updated regularly as needed, reflecting progress and input from the SO Steering group. In the previous annual reports (Saving Oseberg Team, 2018, Saving Oseberg Team, 2019, Saving Oseberg Team, 2020b), tasks and achievements were presented in the same order as in the Project Plan, Annex 1 version 8 (Saving Oseberg Team, 2020a). The Project Plan identifies individual tasks and planned reports (deliverables). The previous technical reports delivered are listed in the annual reports and in this final report. All reports are archived in ePhorte (2017/6982).

Team meetings were held almost every week, usually with participation of the team members in Pisa and Nottingham through video link. The colleagues in Wageningen joined in meetings where we discussed new consolidant materials. The SO-II project manager had weekly meetings with the head of the department of Collection management, representing the project owner.

The Saving Oseberg Steering Group (SG) met four times a year, fifteen times in total. The meeting in November 2019 was held subsequent to the Reference Group meeting. The meeting documents are archived (ePhorte 2017/5406). The SO Reference Group (RG) met with members from the SO-team and SG over two days in Mai 2018 and once more in November 2019. In the first RG meeting, there was much focus on methods for measuring mechanical consolidation. The main recommendations from the second meeting was to focus on treatment and evaluation on treatments in the remaining project year, with the use of uniform testing protocols and reducing the number of consolidant systems to be tested. In 2019, the RG deemed chemical stability of the wood more important than mechanical strength. Detailed recommendations are archived in the RG report and Sahlstedt's report in ePhorte (2017/6982-21) and in the meeting documents of the SG meeting of November 2019.

7.4 Grant applications and the SciCult laboratory

The project team submitted a number of applications to the Horizon2020 program and Joint Program Initiative (JPI), either as coordinator or as participant. Details are given in the previous annual reports. Most applications were not granted, but two of them were: Participation in H2020-INFRAIA RIA "Integrating Platforms for the European Research Infrastructure ON Heritage Science (IPERION-HS)", and in JPI-CH "Development of Storage and Assessment methods suited for organic Archaeological artefacts" (StAr)". These two projects are currently ongoing.

Project leader Boumans together with Kaja Kollandsrud, Lavinia De Ferri and Espen Uleberg (both MCH department SF) coordinated the preparation of a large NFR infrastructure application SciCult, submitted in November 2020. This grant application includes the major players in the cultural heritage sector in Norway, and may be the first step towards a national coordination of these institutes. The aim is to create a distributed national research infrastructure for heritage science, which may eventually join the European infrastructure E-RIHS.

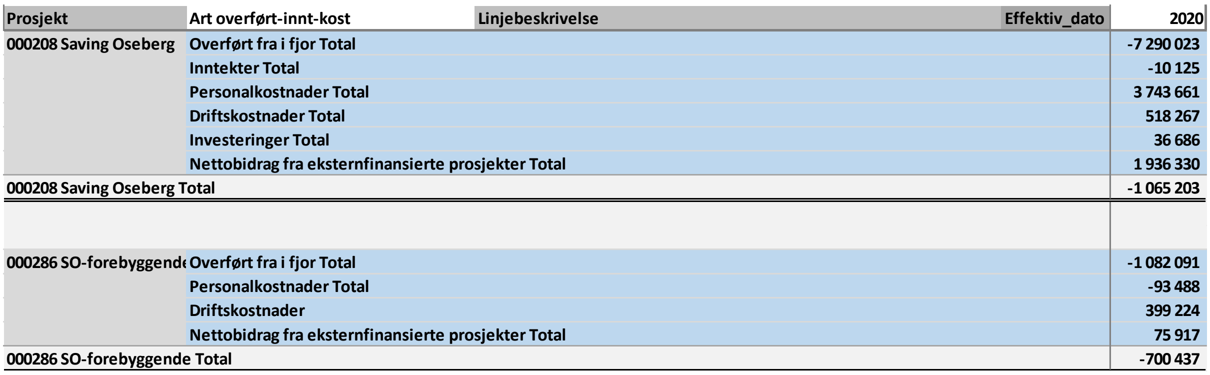
At the same time, the SO-II team did preparatory work for a broader use of the laboratory set up for the Saving Oseberg after the project. This consisted in various small collaboration projects with researchers from MCH and other Norwegian institutions like NIKU.

7.5 Financial report

Report on 2020 (Table 1): The expenses in the alum/project 000208 were 364 KNOK lower than expected in the last annual report. This is explained by the transition of Boumans to another position in November and fewer costs for external services and travel due to the covid/19 epidemic.

In the preventive conservation project 00286 there was no activity in 2020, except that load cells for weighing the Gokstad ship were paid from this project. The financial report shows only negative staff costs because of a correction on the booking of the previous year, and because contribution for the work of Boumans on the IPERION project was booked (as frikjøp) on 000286 instead of 000208 due to administrative reasons.

Table 1. Financial report over project year 2020.



Prosjekt	Art overført-innt-kost	Linjebeskrivelse	Effektiv_dato	2020
000208 Saving Oseberg	**Overført fra i fjor Total**			**-7 290 023**
	Inntekter Total			**-10 125**
	Personalkostnader Total			**3 743 661**
	Driftskostnader Total			**518 267**
	Investeringer Total			**36 686**
	Nettobidrag fra eksternfinansierte prosjekter Total			**1 936 330**
000208 Saving Oseberg Total				**-1 065 203**
000286 SO-forebyggende	**Overført fra i fjor Total**			**-1 082 091**
	Personalkostnader Total			**-93 488**
	Driftskostnader			**399 224**
	Nettobidrag fra eksternfinansierte prosjekter Total			**75 917**
000286 SO-forebyggende Total				**-700 437**

Table 2. Financial report over project period 2017–2020.

Summer av Regnskap					
Prosjekt	**Art overført-innt-kost**	**2017**	**2018**	**2019**	**2020**
000208 Saving Oseberg	Overført fra i fjor	-6 164 042	-11 473 166	-6 873 965	-7 290 023
	Inntekter	-11 333 257	-10 012 958	-10 005 030	-10 125
	Personalkostnader	3 487 249	4 734 001	4 891 436	3 743 661
	Driftskostnader	1 635 950	3 147 215	2 650 610	518 267
	Investeringer	-87 118	0	936 104	36 686
	Nettobidrag fra eksternfinansierte prosjekter	988 053	2 199 088	1 152 665	1 936 330
000208 Saving Oseberg Total		**-11 473 166**	**-11 405 820**	**-7 248 180**	**-1 065 203**
000286 SO-forebyggende	Overført fra i fjor		1 223 199	-2 136 983	-1 082 091
	Personalkostnader	851 674	598 707	637 179	-93 488
	Driftskostnader	-7 020	368 895	262 907	399 224
	Nettobidrag fra eksternfinansierte prosjekter	378 545	334 732	154 806	75 917
000286 SO-forebyggende Total		**1 223 199**	**2 525 533**	**-1 082 091**	**-700 437**
Grand Total		**-10 249 967**	**-8 880 287**	**-8 330 270**	**-1 765 641**

Table 2 summarises revenues and expenses in the project period 2017–2020. Some booking errors occurred between projects 000208 and 000286. Note that in 000208, from the positive result of -11 405 KNOK at the end of 2018, only -6 873 KNOK was transferred to 2019. The difference of 4 531 KNOK corresponds roughly to the budget of project 000286: 2 525 + 2 136 = 4 662.

Major investments in lab instrumentation: Dynamic Vapour Sorption (VPS) instrument 585 KNOK, handheld XRF 350 KNOK, both amounts including VAT.

8 The road ahead

The retreatment methods are described in the test reports (Braovac et al., 2021, Zisi et al., 2021) and will be presented in the Retreatment Protocol. Data from both aqueous and non-aqueous experiments undertaken on single fragments of alum-treated Oseberg wood not only show the final result of each method on different states of wood preservation within the collection, but also inform of each method's risks. This information will likewise feed into the final Retreatment Protocol. This Protocol will act as a guide in potential future retreatment campaigns – aimed at experienced archaeological conservators – which links the most appropriate reconservation method to condition of alum-treated wood from Oseberg. The Protocol will contain the most promising retreatment methods for the different conditions of wood in the collection. The 'most promising methods' will be chosen by applying a Decision Model, also being developed in Saving Oseberg. Additionally, the Protocol will include the most relevant parameters to measure, based on the results presented in the two experimental reports.

For 2021 and 2022, an 19-month Interim-SO project is established, funded by the ca. 1700 KNOK remainder from the 000208 and 000286 projects (Boumans, 2020b). The aim of Interim-SO is to prepare groundwork in order to create a realistic plan and budget for SO-III, which will focus on reconservation of parts of the collection and research on aspects not touched by SO-I and SO-II. During the Interim-SO, we will also reflect on what all the data generated during this project means.

The first part of 2021 (March) we plan a workshop to gain outsider input on retreatment methods used. This will give us a wider perspective, and possibly identify knowledge holes we have missed.

Work from both SO-II and the workshop will allow us to design a collection survey. We plan to carry out the survey in April, and analyse results for 3–4 weeks afterwards. The survey information will feed into plans and budget for SO-III.

During the Interim-SO, we plan to do oxygen consumption on selected samples of retreated material, which will give us a start on long-term monitoring of chemical stability. Additional ways of long-term monitoring must also be thought about and planned during Interim-SO. Other Interim-SO activities include entries of retreatment reports into the MUSIT database, organizing information to update the Analysis module of MUSIT and ensure all data from SO are placed into our server folder. All test material and sample material must be organized, packed and stored properly.

In Braovac et al. (2021: 185-186) we list uncertainties about the risks of retreatment that require research in the coming years, either prior to or concurrent with the retreatment project SO-III. The main uncertainty involves reconstructed objects containing metal parts and putty. SO-II has not done any testing on such objects.

As for the new materials, lignin-like consolidants produced at the University of Wageningen will be investigated on test specimens of archaeological wood during Interim-SO and supported by an EC Cost program involving Wageningen, Oslo, Nottingham and Pisa ("Lignocost" – Gosselink / Slaghek / Harding / Phillips-Jones).

Work on the aminocelluloses is continuing and the application of these and chitosan for wood consolidation is being extended to the preservation of the Oseberg textile artefacts as part of the recently NFR funded "TexRec" project (H. Kutzke, M. Vedeler, J-Y. Hardeberg, S. George, S.E. Harding & A. Herrmann 2021-2024). The Engineering and Physical Sciences Research Council (EPSRC) continues funding the work on the terpene acrylates, supporting Michelle Cutajar's PhD. Further funding is now being sought together with the Mary Rose Trust to extend this work and to the study of sporopollenins. This will ultimately help lead to the eventual production of a “polymer” toolbox for application to consolidation strategies for specific situations.

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