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Textiles on roman mail armour from Dura Europos
(Image: Martijn Wijnhoven)

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Contents

Projects

Ulla Lund Hansen

The road into the textile world: a long journey

Introduction

My current participation in textile studies at Centre for Textile Research (CTR) was not a given and the road to get here has been long, winding and very interesting. I studied prehistoric archaeology at the University of Copenhagen (1962–1968). At the same time, I was student assistant at the National Museum of Denmark, Department of Archaeology (then called the 1st Department and now Prehistory, Middle Ages and Renaissance) – and even though there were several museum curators in this department during that period – such as Margrethe Hald, Hans Christian Broholm and Elizabeth Munksgaard – who were all very interested and engaged in prehistoric costumes and textiles it did not rub off on the teaching of us students nor was there any attempt to engage us in textile studies (Munksgaard 1974; Broholm and Hald 1935; 1940; Hald 1950; 1980). Only a few of the students, including myself, had contact with Munksgaard, while Broholm and Hald had no contact with any of the students. So, there was no inspiration or encouragement to join the field of textile research.

During my time as student, the Institute of Prehistoric Archaeology (now the Saxo Institute) was located on the top floor at the National Museum of Denmark, with a small room for all the students and a large room for the professor, Carl Johan Becker. The institute moved from there in 1976 just round the corner to Vandkunsten (originally an old bicycle factory, now a hostel), and from there to Amager (KUA) in 2005. This move unfortunately resulted in the loss of the close contact between archaeology students, university teachers and the archaeological collections and the staff at the museum. I can only encourage students and researchers to include the archaeological collections in their studies as they contain enormous potential for developing new research projects.

After graduating with a master's degree in 1968, I was employed on a temporary basis at the 1st Department at the National Museum of Denmark and afterwards at the Archaeological Secretariat of the Directorate for Cultural Heritage (1970–1972). As the youngest employee at the National Museum of Denmark, I was often sent out on rescue excavations and other tasks that none of the other museum curators wanted to take on. Sometimes I was exceptionally lucky, for instance with the finding of the Mesolithic grave from Melby in North Zealand and the non-megalithic Neolithic grave field in Vindinge near Roskilde (Lund Hansen 1972; Lund Hansen et al. 1973). As a student, I also had regular contact with the Senior Curator and later Head of the 1st Department, Hans Norling-Christensen, who had specialised in the Roman Iron Age and especially in Roman imports – Roman glass and bronzes – of which we have surprisingly large quantities in Denmark. He had travelled and studied extensively in the Roman provinces and in Italy and had recorded a large amount of comparative material for the Scandinavian Roman finds – carefully documented by drawings and photos. The subject had already caught my interest during my studies, but as it was not part of in the university curriculum, let alone that of my professor, and therefore the subject of Roman imports was not accepted, and I had to write my thesis on the transition from the Late Roman Iron Age to the Early Germanic Iron Age. At that time, the professor rather than the student decided your field of specialisation.

During my employment at the National Museum of Denmark I became a stand-in for Norling-Christensen, and upon his untimely death in 1970 I took care of his material from excavations and research. This included, among other things, the above-mentioned registration of Roman imports, which the museum wanted to discard,

Fig. 1: The office belonging to the head of the 1st Department at the National Museum of Denmark in the beginning of the 1970s. Around the table admiring new finds are the curators (from the left) Kazimierz Salewitz, Elise Thorvildsen, Ulla Lund Hansen and Thorkild Ramskou (Image: photographer unknown)

like so many other records and things that were thrown away in those years, much to the regret of researchers today. Only very recently, this invaluable material has been handed over to the museum again, so it can be included in the study of bronze vessels and glass from the Roman Empire and non-Roman Europe (fig. 1). Among the material left behind by Norling-Christensen was the fully excavated but unpublished finds from the Harpelev burial site in South Zealand dated to the Late Roman Iron Age. I chose this as my first task, which also included an up-to-date chronology for the Danish Late Roman Iron Age (Lund Hansen 1977). In 1972, when I was employed as Assistant Professor at the Department of Archaeology at the University of Copenhagen, I took on my next extensive task: the Late Roman Iron Age grave field from Himlingøje on Zealand had been excavated by several archaeologists since 1828, which here Norling-Christensen had excavated some of the richest graves in 1949–1950 (fig. 2), but the site had never been fully excavated. I thus decided that the excavation of the Himlingøje grave field had to be completed before a publication could be considered, and my excavations together with the National Museum of Denmark took place from 1977 to 1985 (Lund Hansen et al. 1995) (fig. 3). In this way, my interest in Roman artefacts and the unique Himlingøje grave-field material led me to choose Roman imports as the theme of my subsequent doctoral work, which also included a registration of Roman bronze and glass vessels first in all Scandinavian museums and later relevant museums in Germany, the Netherlands, Belgium, Luxembourg, France and Italy in order to achieve the necessary background for the understanding of the Scandinavian material (Lund Hansen 1987). Based on this work, I was promoted to Associate Professor in 1976, and in 1988 docent at the Department of Prehistoric Archaeology. My work on Roman imports in Scandinavia later became an inspiration for the Römisch-Germanische Kommission in Frankfurt am Main to start a similar registration of Roman imports in Germania Libera: "Corpus der römischen Funde im europäischen Barbaricum" (CRFB), a work that is still ongoing. I participated in the initial planning of this major work, and in some archaeological circles I go under the name "Frau Römischer Import". In 2025, I had the pleasure of having been asked to join the project to get it finished and digitised.

Fig. 2: The grave find Himlingøje 1949-2 was excavated by Hans Norling-Christensen in 1949. It is one of the richest women's graves in Denmark dated to the third century CE. The grave was taken up as a block and transported to the National Museum of Denmark where it is now exhibited (Image: Roberto Fortuna and Kira Ursem, National Museum of Denmark)

Fig. 3: The grave Himlingøje 1977-3 was excavated in 1977 by Ulla Lund Hansen. The exclusive equipment was placed in a men`s grave contemporary with grave 1949-2. The purple Roman glass drinking horn is unique and was placed on a silvered bronze plate together with another Roman glass, and a Roman ladle-strainer set and a bone comb. The grave also contained a Roman Hemmoor bucket, a wooden tray, a gold finger ring and a gold snakehead armlet (Image: Lennart Larsen, National Museum of Denmark)

Moving closer to the textiles

Beside my work on Roman Iron Age chronology and Roman imports I have always had an interest in the appearance of prehistoric man, physically (Sellevold et al. 1984) and through jewellery, but it was not before Lise Bender Jørgensen and later Ulla Mannering specialised in textiles and clothing that this subject really caught my attention (Bender Jørgensen 1986; Mannering 2017). An eyeopener took place in 1992 at the Römisch-Germanisches Zentralmuseum Mainz, where I saw the garments and tools from the find of Ötzi (The Iceman), which had just arrived for conservation. It was incredible to see these "primitive" and yet deeply specialised clothing items (Egg and Spindler 2008). A similar great inspiration was the visit to some of the excavations of the Celtic princely burial mounds in Hochdorf, Glauberg and Grafenbühl with their formidable content of textiles (Biel 1985; Fischer 1990; Frey and Herrmann 1997; Banck-Burgess 1999). However, it was not until 2005 when CTR opened close to my own office at the university that a new era started for me. At CTR, many interesting things were happening at that time. New colleagues and fellows joined, exciting lectures were held, and I started coming regularly to CTR and gradually took an increasing part in their many activities. In 2012 when I transferred to emerita status at the Saxo Institute, it was a great pleasure for me that to be given working space at CTR – which I still retain. And here I found a new and much appreciated task: to organise, push forward, contextualise and publish archaeological finds in collaboration with a range of textile specialists and scientists. A first task was in 2010 to write an introduction to the CTR book "Designed for Life and Death" which is still sleeping but hopefully will be published in the near future. Soon I got involved in much larger projects.

Lønne Hede – a multitude of textiles

In 1969 a female burial from the Early Roman Iron Age with exceptionally well-preserved textiles was excavated by Varde Museum at Lønne Hede in Southwest Jutland. In 1995, a new excavation was undertaken, and it became evident that the grave was surrounded by more inhumation burials, of which ten graves contained well-preserved textiles and styled human hair. The best-preserved textiles belong to the 1969 grave which also contained the remains of the deceased's hair set in an elaborate coiffure. In 2009 I became aware of this extraordinary material. Well-preserved pieces of wool textiles dated to the Early Roman Iron Age, and a team of experts were gathered to analyse and publish this important find complex. Altogether the analyses showed that the Lønne Hede women were clad in combinations of tubular garments, skirts and scarfs woven in 2/2 twill or tabby, and that

Fig. 4: Some of the textiles and the silver fibula from the Lønne Hede grave 1969 (Image: Lennard Larsen, National Museum of Denmark)

Fig. 5: The Lønne Hede girl's hair as it is preserved today (Image: Roberto Fortuna, National Museum of Denmark)

the textiles were made of a very fine wool, light and soft to touch, coloured in blue, yellow and red, and patterned with stripes and sometimes checks (Demant et al. 2021) (fig. 4).

Unique to this grave field are, in my opinion, the preserved hairstyles which are both elegant and elaborate, with the Lønne Hede grave-1969 hairstyle as the most exquisite (fig. 5). The coiffure includes bands of three-stranded braids and hair extensions sewn together with wool threads, and this is the first time, that such a complicated hairstyle dated to the Roman Iron Age in the Danish area has been found (Ræder Knudsen 2021) (fig. 6). The Lønne Hede hairstyles and the slightly younger hair finds from Hammerum grave 83 as well as the hairstyles seen on Roman marble busts are invaluable manifestations of the importance of human visual appearance that we sometime tend to forget (Ræder Knudsen and Møbjerg 2019). Similarly, these graves also force us to reconsider the perception of so-called "poor" graves with few or no grave goods. At Lønne Hede, these

Fig. 6: Reconstruction of the Lønne Hede girl's hairstyle as it is on display at the National Museum of Denmark (Image: Ulla Mannering)

seemingly "poor" people were buried in beautifully coloured clothing items made of extremely fine wool with their hair set in elaborate hairstyles, and perhaps we can use these finds to reevaluate how we look at value and wealth in a prehistoric context.

Vorbasse – the next textiles

In 2004 my colleague Steen Hvass offered to take over the processing and the publishing of the burial sites of the Vorbasse village in southern Jutland. In Vorbasse four grave fields were established during the Late Roman Iron Age, attached to a large contemporary settlement. Here the village people were buried for three generations. The diversity of grave goods as well as the very varied sizes of the farmsteads reflect a strongly hierarchical society with great social differences lending an almost dynastic touch to the leading family headed by powerful warriors (Lund Hansen and Ethelberg 2024).

It was my ambition that all textile remains from these burials should be fully utilised and incorporated in the publication, and the employees at the then newly established CTR, Marie-Louise Nosch, Eva Andersson and Ulla Mannering supported this. At CTR, a Vorbasse project was established for the investigation of the textiles and possible clothing preserved in each grave, including analysis of dyes, fibres and wool-preparation processes, weaving experiments and the recreation of a typical Vorbasse textile. The latter is an excellent example of the very fine textile craftsmanship that was found in the graves (Andersson Strand et al. 2024) (fig. 7). Altogether these combined analyses led to a description and reconstruction of the clothing of each individual and the archaeological textile comparisons and perspectives emphasised the importance of knowledge of an archaeological material to be able to evaluate its use, whether for women or men, high-ranking or more simple persons. This distinction is not possible in many other cases, and the Vorbasse graves have provided groundbreaking new information about the three generations inhabiting one of the largest villages dated to the third to the fourth century CE, exemplifying a strongly socially divided society as well as insight into local and more distant and possibly international contacts.

Textile research now and in the future

As can be seen from the brief survey of my career above, I came relatively late to textile research. I would like to finish on some thoughts for the future. For the last two decades textile research has had a strong voice in Denmark and abroad. The interest and expertise in prehistoric textiles and clothing, which existed when I was a student, has been brought back to life – thanks to the establishment of CTR at the University of Copenhagen and its close connection to the National Museum of Denmark. Several Danish local museums have also become active in the field of textile research and thus benefit from the multidisciplinary synergy characterised by modern textile research. No doubt, textile research flourishes again, and this work and approach is an inspiration for students as well as professionals, and the many Marie Curie fellows and visiting researchers who have spent time at CTR since 2005. Many publications in textile archaeology are highly specialised and aimed at a professional readership while reliable, more accessible overviews of our subject remain in short supply. There are many topics which would benefit from being made available to a wider audience, following the style of Mannering 2024. One such topic might be a study of how jewellery and beads were worn, and how other accessories might lead to more holistic studies of individual identity. There are lots of finds in the museums stores as well as recently excavated material that it could be included, and which hopefully can fill some of the gaps in our knowledge in textile research. Another example is male dress in the Iron Age with a focus on the influence that may have come from spending years in the Roman army as auxiliary troops. These soldiers eventually returned home with well-earned Roman denarii. This could well be reflected in the male dress – as it is in the armament of the time. CTR houses researchers who welcome the creation of projects that include several people working collaboratively, and where the knowledge of colleagues is utilised, not

Fig. 7: Wool weaving experiment based on loom weights, yarn and weaving technique as presented in the Vorbasse graves. The textile has about 14.6 warps per cm and 14.6 wefts per cm. Such a fabric, here measuring 150 cm x 150 cm, could have been used for several purposes. Its weight is about 570 g and it would be highly suitable for making clothes (Image: The Vorbasse project)

only in textile research in the narrow sense, but also expanded into a wider field of archaeological vision. It is my great wish that the scholars of CTR and their collaborators elsewhere will be able to maintain their high level of research, and that they will strive to get the many ongoing projects published.

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Editorial

Dear Readers,

Welcome to the 67th issue of *Archaeological Textiles Review* in which we bring exciting news about Viking Age and early medieval textiles, specialist analytical techniques and experimental work. The section on projects is again filled with really interesting initiatives. In this issue, it is the Danish archaeologist and Emerita, Ulla Lund Hansen, who reports about her experiences in textile research. Unfortunately, we also bring the obituaries of two well-known and important textiles researchers, Noémi Speiser and Elisabeth Wincott Heckett. However, reading about their research and scientific impact is enlightening, and this is definitely an important way to honour our late colleagues.

It is now four years since we upgraded our homepage, where past issues can be downloaded free. The editorial group has decided to initiate further changes for ATR. Ever since the publication of ATN was taken over by an editorial team from the Centre for Textile Research (CTR) at the University of Copenhagen in Denmark in 2008 and later transformed into a fully open-source digital publication in 2019, the society of ATN Friends has funded the web hosting and domain, from which the issue is distributed. However, the current complexity of official society rules and the exceptionally high annual banking fees mean that this way of working is not viable in the long term. Therefore, the editorial team has decided that the journal will move to the online publishing platform Tidsskrift.dk hosted by the Royal Danish Library in Copenhagen. We have already signed a contract and in 2026 we will begin the design of the new ATR journal platform and start uploading back issues.

In spring 2026, the editorial team will meet in Copenhagen for an introductory course on the use of the platform editorial system. We will gradually start using the editorial service for the journal and plan to use the system fully in 2027 for the publication of ATR 69.

We hope that the editorial system will help the publishing process and give authors more transparency in the work on their texts. We also hope that readers will appreciate the new platform and the fact that the Royal Library will ensure the survival of all your important work for the future.

Please keep sending articles in good time for our annual deadlines, and please take great care to conform to the *Guidelines for Authors*. The deadline for articles for each issue is the 1 May. We need project reports preferably before the end of June, but we can accept conference reports right after conferences finish, if they are held no later than 30 November. The same deadline applies to all other announcements.

It is still possible to order a printed copy of any of the journals from the web shop at the University of Copenhagen in Denmark (www.webshophum-en.ku.dk/shop/archaeological-textiles-664s1.html).

Please do enjoy ATR 67 and spread the word about it. The ATR editorial team wishes you a colourful and super exciting new academic year 2026.

The Editors

Martijn A. Wijnhoven and Karina Grömer

Threads of warfare: textiles in Roman scale armour

Abstract
Roman scale armour, a type of military equipment, has been part of many studies in scholarly research. Nevertheless, while textile and leather material were known to be used for the base garment, archaeological evidence is relatively rare in the Roman period. This paper presents finds of scale armour with different textile materials attached. The selection of the fabric was deliberate and tailored to the armour's construction demands, with textiles characterised by strength, thickness and durability. The weave choice was also intentional, with certain weaves associated with lighter copper alloy and iron scales, and basket weaves and tabbies found alongside heavier scales. Warp or weft-faced fabrics have only been found in conjunction with heavy, large iron scales. There is also evidence of a double layer of textile in Roman scale armour, which could even be made of two different weave types. This has implications for the interpretations of padded under-armour.

Keywords: Roman army, scale armour (*lorica squamata*), textiles, base garment, padded under-armour, military equipment

Introduction
Archaeological textile studies rarely focus on body armour, while specialists in archaeological military equipment seldom consider textiles (notable exceptions include Bishop 1995; Sumner 2009; Gleba 2012; Nosch 2012). Despite their distinct material emphases – textiles in one field and metals in the other – these materials are intrinsically linked when examining protective military gear of the past. Body armour often relied on a combination of textiles and metal to function effectively, with each material contributing unique properties. Textiles served to connect metal components, form an integral base for the armour, prevent chafing and potentially provide padding. Metal, in turn, offered resistance against sharp implements and distributed the force of impacts over a broader area (Jones 2014; Wijnhoven 2022, 165–181).
This disciplinary disconnect has left significant gaps in the understanding of Roman scale armour – an archetypal example of armour that integrated a textile base with an outer layer of metal scales. While scale armour in the archaeological record is rare, its scarcity should not be overstated. This article compiles evidence from 74 examples of Roman scale armour that preserve both organic and metal elements (tables 1 and 2), offering new insights into the construction and use of a distinctive type of armour.
The Roman army employed scale armour for many centuries with hundreds of finds originating from military installations along the Roman frontier (for example, Bishop 2023; Groh 2023). This armour consisted of scales, typically made of iron or copper alloy, ranging in size from very small (approximately 10 mm in length) to very large (up to 90 mm in length). Roman scales were designed with multiple holes in order to assemble them into functional armour. Each scale featured pairs of holes along the sides, used to link the scales into rows. The scales overlapped their neighbours slightly and were fastened together using short, staple-like pieces of metal wire. At the top of each scale, one or more holes allowed for a 1–3 mm thick cord to be threaded through, securing the scales to a base garment. The rows were sewn in such a way that they partially overlapped vertically, resulting in armour that combined overlapping scales and a textile

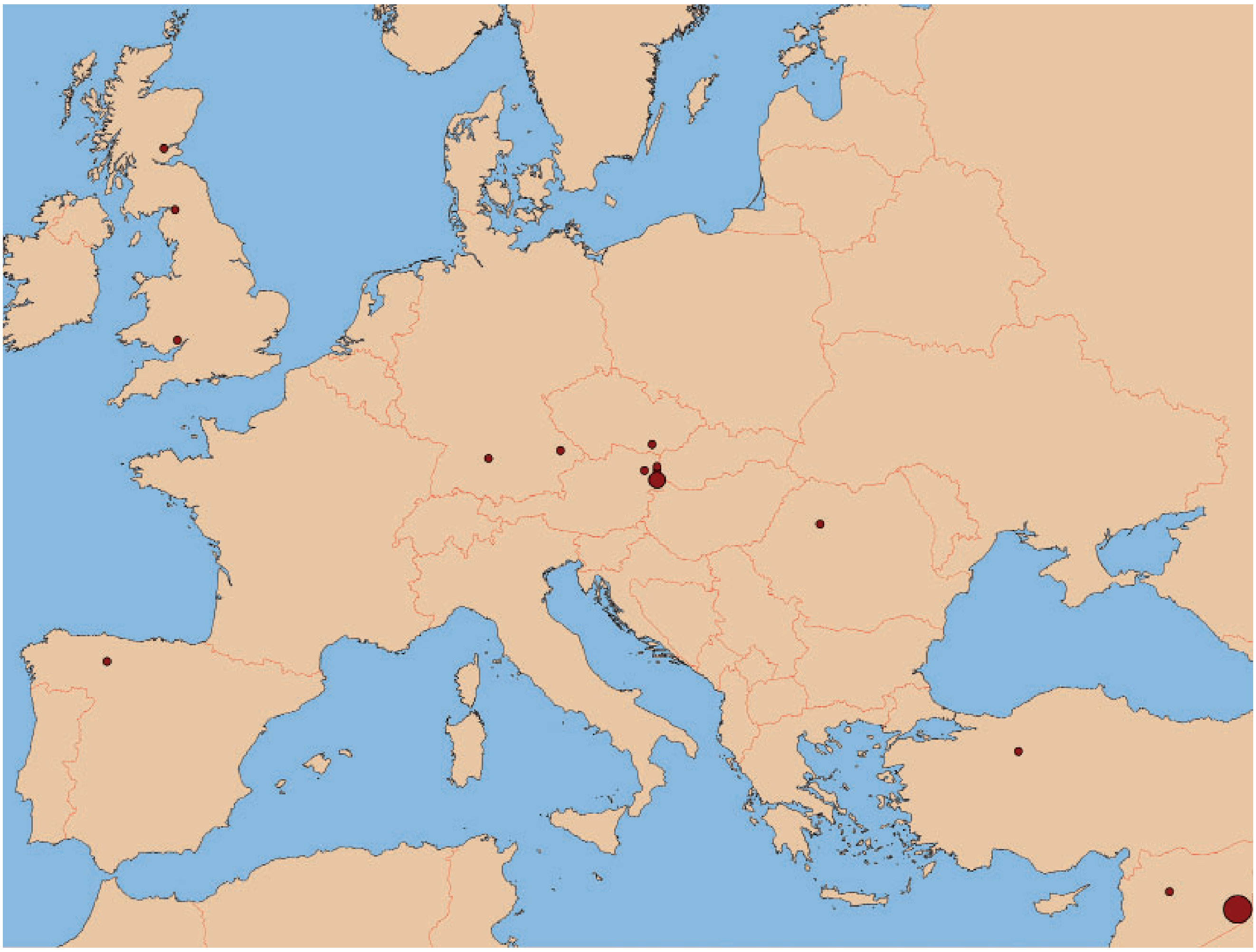

Fig. 1: Distribution of finds of Roman scale armour with associated organic remains (Image: Martijn Wijnhoven)

base to provide both flexibility and protection. This article focuses on the base garment of this armour, looking at its characteristics and how it functioned in relation to the metal scales.

Methodology

A systematic review of Roman scale armour led to the identification of 74 examples with both metal and organic components preserved. The primary source for this review was the direct examination of archaeological collections containing scale armour. Notably, the most significant collections were the finds from Carnuntum in Austria, in the care of Landessammlungen Niederösterreich, Archäologischer Park Carnuntum, and those from Dura-Europos in Syria held by the Yale University Art Gallery. Together, these collections account for nearly 60 examples. This analysis was further enriched by a literature review, which incorporated published data on relevant finds into the database. Additionally, the Yale University Art Gallery's photo archive provided crucial insights into several Dura-Europos finds no longer held in that collection.

Where more than one find of scale armour is

Table 1 (see opposite): Findspots of scale armour with textiles attached, references: Baumgarten an der March 1: Grömer 2014, 169–170; Schramm and Fischer 2015. – Carlisle: Bishop 2009, 689–691; Jones 2009, 1121–1229. – Carnuntum 11: Beutler et al. 2017, 267; Grömer 2014, 165–166; Groh 2023, 96–103; Jobst and Ditmar-Trauth 1992, 294; Von Groller 1901, 93. – Carpow: Coulston 1992, 21–22; Wild 1981. – Dura-Europos: Bishop 2023, 36–38; James 2004, 120–138 and unpublished (Yale University Art Gallery, New Haven). – Gordion: Bennett and Goldman 2009, 40–41. – Isriye: Gogräfe 2016, 203–204. – Mušov-Burgstal: Groh 2023, 264–265. – Potaissa: Bărbulescu 1991, 28–29; Fodorean 2020, 196, 199. – Puente Castro: Aurrecoechea Fernández 2010, 85. – Stillfried an der March: Groh 2023, 227–229. – Straubing: Groh 2023, 302–303. – Usk: Manning et al. 1995, 14–15. – Vienna 10: Groh 2023, 290–292

FIND	COUNTRY	DATE	SIZE	METAL	HOLE ARRANGEMENT
Baumgarten an der March 1	Austria	160-180 CE	medium	copper alloy	large hole at top, pair on each side
Carlisle 1	United Kingdom	140s CE	large	iron and brass	semi-rigid scale
Carlisle 2	United Kingdom	125-140s CE	large	iron and copper alloy	semi-rigid scale
Carnuntum 11	Austria	Roman period	medium	copper alloy	semi-rigid scale
Carnuntum 49	Austria	late 1st - late 2nd century CE	X-large	iron	vertical pair at top, pair on each side
Carnuntum 50	Austria	late 1st - late 2nd century CE	X-large	iron	vertical pair at top, pair on each side
Carnuntum 60	Austria	late 1st - late 2nd century CE	X-large	iron	vertical pair at top, pair on each side
Carnuntum 66	Austria	late 1st - late 2nd century CE	large	iron	vertical pair at top, pair on each side
Carnuntum 70	Austria	late 1st - late 2nd century CE	large	iron	vertical pair at top, pair on each side
Carnuntum 71	Austria	late 1st - late 2nd century CE	large?	iron	vertical pair at top, pair on each side
Carnuntum 72	Austria	late 1st - late 2nd century CE	large	iron	vertical pair at top, pair on each side
Carnuntum 73	Austria	late 1st - late 2nd century CE	large	iron	vertical pair at top, pair on each side
Carnuntum 74	Austria	late 1st - late 2nd century CE	large?	iron	vertical pair at top, pair on each side
Carnuntum 145	Austria	late 1st - late 2nd century CE	large	iron	four holes at top, pair on each side
Carnuntum 181	Austria	late 1st - late 2nd century CE	X-large	iron	vertical pair at top, pair on each side
Carnuntum 188	Austria	120-170/180 CE	large or X-large	iron	unclear
Carnuntum 189	Austria	120-170/180 CE	X-large	iron	unclear
Carnuntum 190	Austria	120-170/180 CE	large?	iron	unclear
Carnuntum 191	Austria	120-170/180 CE		iron	vertical pair at top, pair on each side
Carnuntum 192	Austria	120-170/180 CE	large or X-large	iron	unclear
Carnuntum 193	Austria	120-170/180 CE	large or X-large	iron	unclear
Carnuntum 194	Austria	120-170/180 CE	large	iron	unclear
Carnuntum 195	Austria	120-170/180 CE	large	iron	unclear
Carnuntum 196	Austria	120-170/180 CE	large	iron	vertical pair at top, pair on each side
Carpow	United Kingdom	180-220 CE	small	copper alloy	vertical pair at top, pair on each side
Dura-Europos 3	Syria	mid-3rd century CE	medium	copper alloy	semi-rigid scale
Dura-Europos 13	Syria	possibly Trajanic, 160s-256 CE	medium	copper alloy	semi-rigid scale
Dura-Europos 22	Syria	possibly Trajanic, 160s-256 CE	large	iron	horizontal pair at top, pair on each side
Dura-Europos 25	Syria	possibly Trajanic, 160s-256 CE	large	copper alloy	horizontal pair at top, pair on each side
Dura-Europos 27	Syria	possibly Trajanic, 160s-256 CE	small	copper alloy	three pairs of holes at the top
Dura-Europos 30	Syria	mid-3rd century CE	small	copper alloy	vertical pair at top, pair on each side
Dura-Europos 31	Syria	mid-3rd century CE	small	copper alloy	vertical pair at top, pair on each side
Dura-Europos 32	Syria	mid-3rd century CE	small	copper alloy	vertical pair at top, pair on each side
Dura-Europos 35	Syria	mid-3rd century CE	small	copper alloy	vertical pair at top, pair on each side
Dura-Europos 36	Syria	possibly Trajanic, 160s-256 CE	small	copper alloy	vertical pair at top, pair on each side
Dura-Europos 37	Syria	possibly Trajanic, 160s-256 CE	small	copper alloy	vertical pair at top, pair on each side
Dura-Europos 38	Syria	mid-3rd century CE	medium	copper alloy	vertical pair at top, pair on each side
Dura-Europos 43	Syria	possibly Trajanic, 160s-256 CE	medium	copper alloy	vertical pair at top, pair on each side
Dura-Europos 47 (variant 2)	Syria	255-256 CE	medium	copper alloy	vertical pair at top, pair on each side
Dura-Europos 47 (variant 1)	Syria	255-256 CE	medium	copper alloy	four holes at top, pair on each side
Dura-Europos 48	Syria	possibly Trajanic, 160s-256 CE	medium	copper alloy	vertical pair at top, pair on each side
Dura-Europos 51	Syria	possibly Trajanic, 160s-256 CE	X-large	iron	vertical pair at top, pair on each side
Dura-Europos 62	Syria	mid-3rd century CE	medium	copper alloy	four holes at top, pair on each side
Dura-Europos 63	Syria	mid-3rd century CE	medium	copper alloy	four holes at top, pair on each side
Dura-Europos 64	Syria	mid-3rd century CE	large	iron	four holes at top, pair on each side
Dura-Europos 65	Syria	mid-3rd century CE	X-large		no scales survive
Dura-Europos 66	Syria	possibly Trajanic, 160s-256 CE	X-large	iron	four holes at top, pair on each side
Dura-Europos 67	Syria	mid-3rd century CE	medium	copper alloy	four holes at top, pair on each side
Dura-Europos 73	Syria	possibly Trajanic, 160s-256 CE	X-large	iron	four holes at top, pair on each side
Dura-Europos 75	Syria	possibly Trajanic, 160s-256 CE	large	iron	four holes at top, pair on each side
Dura-Europos 87	Syria	possibly Trajanic, 160s-256 CE	X-large	iron	four holes at top, pair on each side
Dura-Europos 91	Syria	possibly Trajanic, 160s-256 CE	X-large	iron	four holes at top, pair on each side
Dura-Europos 109	Syria	possibly Trajanic, 160s-256 CE	X-large	iron	four holes at top, pair on each side
Dura-Europos 192	Syria	possibly Trajanic, 160s-256 CE	X-large	iron	four holes at top, pair on each side
Dura-Europos 207	Syria	possibly Trajanic, 160s-256 CE	X-large	iron	unclear
Dura-Europos 222	Syria	possibly Trajanic, 160s-256 CE	X-large	iron	unclear
Dura-Europos 231	Syria	possibly Trajanic, 160s-256 CE	X-large	iron	unclear
Dura-Europos 234	Syria	possibly Trajanic, 160s-256 CE	large or X-large	iron	unclear
Dura-Europos 237	Syria	possibly Trajanic, 160s-256 CE	large or X-large	iron	unclear
Dura-Europos 239	Syria	possibly Trajanic, 160s-256 CE		iron	unclear
Dura-Europos 240	Syria	possibly Trajanic, 160s-256 CE	X-large	iron	unclear
Dura-Europos 268	Syria	mid-3rd century CE			no scales survive
Dura-Europos 284	Syria	possibly Trajanic, 160s-256 CE			no scales survive
Dura-Europos 285	Syria	possibly Trajanic, 160s-256 CE			no scales survive
Gordion 3	Turkey	150-220 CE	large	iron	unclear
Isriye 1	Syria	terminus post quem 304/305 CE	medium	copper alloy	unclear
Isriye 7	Syria	early 4th century CE		copper alloy	unclear
Mušov-Burgstal 9	Czechia	170-180 CE	medium	iron	vertical pair at top, pair on each side
Potaissa 2	Romania	168–271 CE	small	copper alloy	vertical pair at top, pair on each side
Puente Castro 1	Spain	150-250 CE	medium	copper alloy	three pairs of holes at the top
Stillfried an der March 1	Austria	late 2nd century CE	medium	copper alloy	semi-rigid scale
Straubing	Germany	150/160-180 CE	medium	copper alloy	large hole at top, pair on each side
Usk 2	United Kingdom	late Neronian – early Flavian		iron	unclear
Vienna 10	Austria	Roman period	large	iron	large hole at top, pair on each side

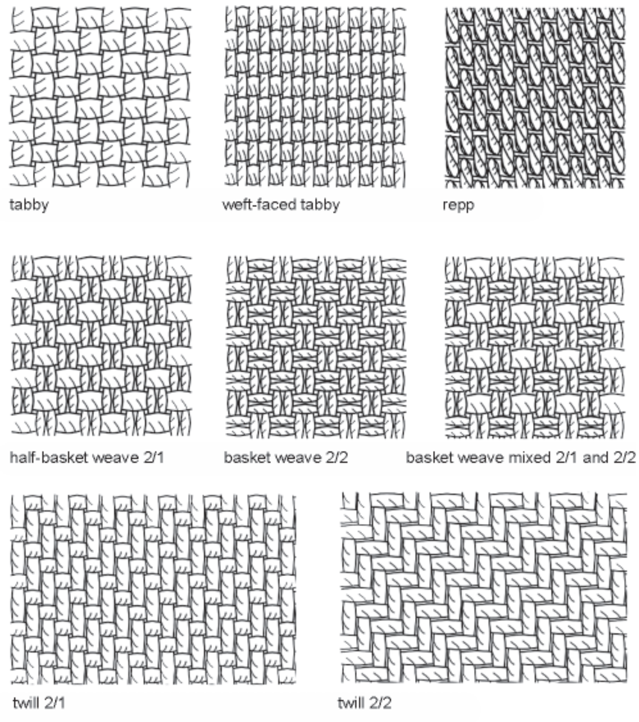

Fig. 2: Weave types that are known in connection to Roman scale armour (Image: Karina Grömer)

represented from the same site, individual examples have been assigned a number following the site's name. These numbers are not always sequential, as they correspond to a more extensive database compiled for a forthcoming monograph on Roman scale armour, scheduled for publication in 2026/2027.
Where possible, the key characteristics of the scale armour were identified and recorded in a database. For the metal scales, the database included details on material, dimensions (length, width) and the number and placement of attachment holes. For the textiles, the recorded features (table 2) encompassed material, weave type, warp and weft identification, yarn plying, twist direction, yarn diameter and the number of threads per centimetre.

Results
The database of Roman scale armour with organic remains comprises 74 finds originating from eight different countries (fig. 1 and table 1): 41 from Syria, 24 from Austria, 4 from United Kingdom, and one each from Czechia, Germany, Romania, Spain and Turkey. The distribution of finds is uneven, heavily influenced by the environmental conditions that favour the preservation of organic remnants. Two sites, Carnuntum and Dura-Europos, provided particularly favourable preservation conditions and account for the majority of the documented finds. At Carnuntum, evidence for the base garments has been preserved together with iron scales through mineralisation (Grömer 2014). The survival of organic components of the armour from Dura-Europos is in large part the result of the arid Syrian climate (Snow 2011, 33–35). These are not only associated with iron scales, as in Carnuntum, but many of them belong to copper alloy scales.
The finds in the database date from the late first century CE to the third century CE, aligning with the period when Roman scale armour appears relatively frequently in the archaeological record. However, the examples from Carnuntum and Dura-Europos represent different periods in time. Most of the Carnuntum finds date from 80–200 CE (Groh 2023, 80–148), while those from Dura-Europos have a *terminus ante quem* of 256 CE (James 2004, 120–124) and mostly originate from the first half to the middle of the third century CE.

Material
Scale armour has a long history, originating in the Late Bronze Age in the Near East (Hulit 2002) and subsequently spreading to various regions, where it is found in a wide range of archaeological cultures. This includes the Roman Empire, where the army adopted scale armour during the Early Imperial period (Feugère 2002, 74; Fischer 2019, 131–132). As far as organic components are preserved, it appears that leather was the common material for the base garment. It was not only employed for an extended period but also seems to have been the standard outside the Roman Empire (for example, Agre 2011, 72; Černenko 2006, 9–25; Symonenko 2015, 128–131).
The database of Roman scale armour clearly shows that the Romans departed from earlier traditions and favoured textile base garments for their scale armour. Of the 74 documented finds, 69 contained textile remains. This does not mean textile was always the only organic material present in these examples; some also contained leather (for example, Carpow, Dura-Europos 62–63, Baumgarten an der March 1, Potaissa 2). In compiling the database, the function of the preserved organic materials, whether textile or leather, was taken as the decisive factor. When multiple organic materials were present, only the material clearly used as the base garment was recorded. Materials that served other purposes, such as edging or fastening, were excluded from the dataset. If only a single organic material was found and could plausibly be interpreted as the base garment, it was registered accordingly.

Detailed examination showed that leather, when present, was typically not part of the base garment but was used as edging along the borders of the scale armour, secured by leather or rawhide thongs. This function is especially clear in the better-preserved examples. In a very small number of cases of Roman period scale armour, leather thongs were used to attach the scales to the base garment.

Leather as the only organic material, and possibly used as a base garment, was identified in just three cases. In two instances, the type of organic material could not be determined. Notably, all examples involving leather correspond to a specific type of Roman scale armour known as "semi-rigid". This differs from standard scale armour in its construction: the scales are not only interlocked in rows but also secured in columns using metal staples (Wijnhoven 2024a; 2024b). Unlike regular scale armour, semi-rigid armour does not rely on a base garment for structural integrity. However, a leather or textile lining would likely have been added to prevent chafing against the wearer's body or clothing. In contrast, all other types of Roman scale armour required a base garment for their structural stability. Without exception, these base garments were made of textile, which must have been a Roman innovation in the development of scale armour.

While textiles could be made from fibres of either animal or plant origin, the vast majority of the finds associated with scale armour are composed of plant fibre. Among the 69 cases with textile remnants, 46 involve bast fibres, 11 involve wool, and 12 remain unidentified. For most of the plant fibre textiles, it was not possible to determine the plant species. However, in three cases, the source was identified: two were flax

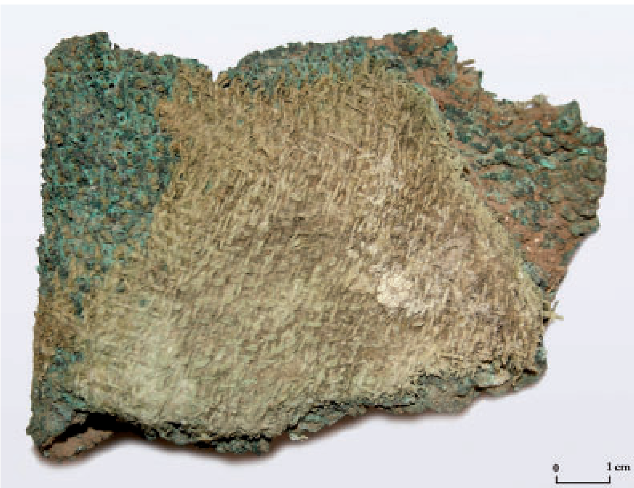

Fig. 3: Twill textiles used for the base garment: Fragment of scale armour from Dura-Europos (27) which has been folded over (Yale University Art Gallery) (Image: Martijn Wijnhoven)

(Carpow, Potaissa 2) and the third was identified as either flax or nettle (Baumgarten an der March 1).

As for wool used in scale armour, all documented examples come from Carnuntum in Austria and are exclusively 2/2 twills. Only one other find reported to involve wool originates from Isriye in Syria. However, while described in the literature as wool (Gogräfe 2016, 203, pl. 46g, 47a), photographic evidence suggests it may actually consist of plant fibres. Unfortunately, the database currently lacks sufficient chrono-geographical variation and datapoints to support definitive conclusions. The use of wool could represent a regional or temporal phenomenon or it may have been more widespread than suggested by the current archaeological record.

Weave types

The type of weave (fig. 2) was identifiable in 53 of the 69 finds of textile remnants. In several cases, the base garment consists of a double layer of textile rather than a single layer (see below). While the double layer was often made from the same textile, in two instances at Dura Europos, the weave of the inner layer, facing the body of the wearer, differed from that of the outer layer, facing the metal scales. This brings the total number of weave identifications to 55.

The most common type of weave observed in the finds is twill (fig. 3), identified in 23 examples. Among these, 18 feature a 2/2 twill weave (11 from Carnuntum, six from Dura-Europos, one from Potaissa), while three exhibit a 2/1 twill weave (two from Dura-Europos, one from Carpow). In two cases (Dura-Europos and Mušov), the specific twill pattern could not be determined. At Carnuntum, only the 2/2 twill variant has been found, and all examples were made of wool. In contrast, at other sites, bast fibres were used in the twills.

The second most common weave is basket weave or half-basket weaves, found in 22 examples of scale armour. Of these, the majority (14) are plain basket weaves (fig. 4). A unique variation of basket weave was identified only at Dura-Europos with eight examples (fig. 5). This variation features consistently woven double weft threads, while the warp alternates between double and single yarns.

Tabby weaves are relatively uncommon, observed in only six examples of scale armour with preserved textiles. In two of these cases (both from Dura-Europos), the identification of the weave is not entirely certain; while it appears to resemble a tabby, it could also represent another type of weave. Of the remaining four examples of tabby weave, one comes from Carnuntum and three from Dura-Europos.

				Warp or thread system 1				Weft or thread system 2			
Find	Double layer	Material	Weave	Twist	Threads	Diameter	Threads/cm	Twist	Threads	Diameter	Threads/cm
Baumgarten an der March 1		flax/nettle	basket weave	zz	paired	0.8	10-12	zz	paired	0.8	10-12
Carlisle 1		leather									
Carlisle 2		leather									
Carnuntum 11		leather									
Carnuntum 49		unidentified	repp-like tabby	s	single	0.8–1.0	5-6	s	single	0.8	16-18
Carnuntum 50		unidentified	basket weave	ss	paired	0.6–0.7	12-14	ss	paired	0.6–0.7	12-14
Carnuntum 60		plant fibres	repp-like tabby	s	single	0.8	8-10	s	single	0.8–1.0	7
Carnuntum 66		unidentified	2/2 twill	z	single	1.2	7	s	single	1.3	6-7
Carnuntum 70		unidentified									
Carnuntum 71	yes	wool	2/2 twill	z	single	1.2–1.5	5	z	single	1.2	5
Carnuntum 72	possibly	wool	2/2 twill	z	single	1.2–1.5	5	z	single	1.2	5
Carnuntum 73		wool	2/2 twill	z	single	1.2–1.5	5	z	single	1.2	5
Carnuntum 74		wool	2/2 twill	z	single	1.2–1.5	5	z	single	1.2	5
Carnuntum 145		unidentified	basket weave	ss	paired	0.6–0.7	14-16	ss	paired	0.6–0.7	10
Carnuntum 181		unidentified	Tabby	s	single	1.1–1.2	6-7	s	single	1.1–1.2	10
Carnuntum 188		plant fibres	repp-like tabby	s	single	0.8	8-10	s	single	0.8–1.0	7
Carnuntum 189		plant fibres	repp-like tabby	s	single	0.8	8-10	s	single	0.8–1.0	7
Carnuntum 190		wool	2/2 twill	z	single	1.2–1.5	5	z	single	1.2	5
Carnuntum 191		wool	2/2 twill	z	single	1.2–1.5	5	z	single	1.2	5
Carnuntum 192		wool	2/2 twill	z	single	1.2–1.5	5	z	single	1.2	5
Carnuntum 193		plant fibres	repp-like tabby	s	single	0.8	8 to 10	s	single	0.8-1.0	7
Carnuntum 194		wool	2/2 twill	z	single	1.2–1.5	5	z	single	1.2	5
Carnuntum 195		wool	2/2 twill	z	single	1.2–1.5	5	z	single	1.2	5
Carnuntum 196		wool	2/2 twill	z	single	1.2–1.5	5	z	single	1.2	5
Carpow		Ffax	2/1 twill	z	single		6 to 7 (warp)	z	single		10-12 (weft)
Dura-Europos 3		unidentified	tabby?								
Dura-Europos 13		unidentified									
Dura-Europos 22		unidentified	tabby?								
Dura-Europos 25		plant fibres									
Dura-Europos 27	yes	plant fibres	2/1 twill	z	single	0.8–1.1	6	Z2s	plied	0.7–1.0	9
Dura-Europos 30		plant fibres		z	single	c. 1		z	single	c. 1	
Dura-Europos 31		plant fibres	2/2 twill	z	single	0.9–1.1	8	z	single	0.8–1.0	8-9
Dura-Europos 32		plant fibres	Twill	z	single	c. 1.2	c. 8	z	single	c. 0.8	c. 10
Dura-Europos 35		plant fibres	2/2 twill	Z	single	1.1–1.3	7	z	single	0.9–1.0	8-9
Dura-Europos 36	yes	plant fibres									
Dura-Europos 37		plant fibres	2/2 twill	Z	single	0.8–1.2 (even 0.5–1.8)	c. 11	z	single	0.9	c. 12
Dura-Europos 38	yes	plant fibres	2/2 twill	Z	single	1.2–1.5	7	z	single	1.1–1.2	6
Dura-Europos 43	yes	plant fibres	2/1 twill	z	single	1.1–1.2	8-9	z	single	1.2–1.4	7
Dura-Europos 47 (variant 1)		plant fibres	tabby	z	single	c. 1	c. 9	z	single	c. 1.2–1.5	c. 6
Dura-Europos 47 (variant 2)		plant fibres									
Dura-Europos 48		plant fibres									

Table 2: Data from textiles found on scale armour

				Warp or thread system 1				Weft or thread system 2			
Find	Double layer	Material	Weave	Twist	Threads	Diameter	Threads/cm	Twist	Threads	Diameter	Threads/cm
Dura-Europos 51		plant fibres	appears 2/2 twill	z	single	0.8–1.0	7-8	z	single	0.8–1.0	7-8
Dura-Europos 62		flax	2/2 twill	z	single		6-7	z	single		6-7
Dura-Europos 63 (layer 1)	yes	plant fibres	basket weave	zz	paired	0.7–1.0 (warp)	12 double = 24	zz	paired	1.0–1.4 (weft)	6 double = 12
Dura-Europos 63 (layer 2)		plant fibres	tabby	ss, s	paired & single	0.8–1.0	8	ss	paired	0.7–1.0	12
Dura-Europos 64	partly	flax	basket weave	z	paired			zz	paired		
Dura-Europos 65	yes	plant fibres	basket weave mixed with half basket	ss, s	paired & single	0.7–0.9 (warp)	5 double = 10	ss	paired	0.7–1.1 (weft)	8 double = 16
Dura-Europos 66	yes	plant fibres	basket weave mixed with half basket	ss, s	paired & single	0.6–0.9 (warp)	5 double = 9 to 10	ss	paired	0.8–1.2 (weft)	6 double = 12
Dura-Europos 67 (layer 1)	yes	plant fibres	basket weave	zz	paired	0.8–1.1	5 double = 10	zz	paired	0.8–1.1	5 double = 9 to 10
Dura-Europos 67 (layer 2)		plant fibres	Tabby	s	single	0.7–1.1	11 to 12	s	single	0.7–0.8	7
Dura-Europos 73		plant fibres									
Dura-Europos 75		plant fibres									
Dura-Europos 87		plant fibres	basket weave with warp-faced border (repp-like)	ss	paired	c. 0.8 (warp)	4-5 double = 10	ss	paired	0.6–0.8 (weft)	10 double = 20
Dura-Europos 91	yes	plant fibres	basket weave	s	single	0.8	6 double = 12	ss	paired	0.8	5 double = 10
Dura-Europos 109		plant fibres	basket weave mixed with half basket	ss, s	paired & single	0.7–1.0 (warp)	c. 6 double = 12	ss	paired	c. 0.8–1.0	c. 8
Dura-Europos 192		plant fibres									
Dura-Europos 207		plant fibres	basket weave mixed with half basket	ss, s	paired & single	0.6–0.9 (warp)	c. 6 double = 12	ss	paired	0.5 (weft)	9 double = 18
Dura-Europos 222	yes	plant fibres	basket weave mixed with half basket	ss, s	paired & single	0.8	6 double = 12	ss	paired	0.6	10 double = 20
Dura-Europos 231		plant fibres									
Dura-Europos 234		plant fibres	basket weave mixed with half basket	ss, s	paired & single	0.8	c. 12	ss	paired	0.8	c. 9
Dura-Europos 237		unidentified									
Dura-Europos 239		plant fibres	basket weave mixed with half basket	ss, s	paired & single	0.9–1.0	c. 9	ss	paired	0.9	c. 8
Dura-Europos 240		plant fibres	basket weave mixed with half basket	ss, s	paired & single	0.8	c. 11	ss	paired	0.8	c. 9
Dura-Europos 268	yes	plant fibres	possibly basket weave								
Dura-Europos 284		plant fibres	basket weave with warp repp-like edge	ss, s	paired & single	0.7–0.8 (warp)	5 double = 10	zz	paired	0.5–2.0 (weft)	4 double = 7-8
Dura-Europos 285		plant fibres	basket weave	zz	paired	0.9	c. 8	zz	paired	0.7–0.8	c. 10
Gordion 3		unidentified									
Isriye 1		wool or flax?	basket weave	z	single			z	single		
Isriye 7		plant fibres	basket weave								
Mušov-Burgstall 9		unidentified	possibly twill								
Potaissa 2		flax	2/2 twill								
Puente Castro 1		unidentified									
Stillfried an der March 1		unidentified									
Straubing		unidentified									
Usk 2		unidentified									
Vienna 10		unidentified									

Table 2 (continued): Data from textiles found on scale armour

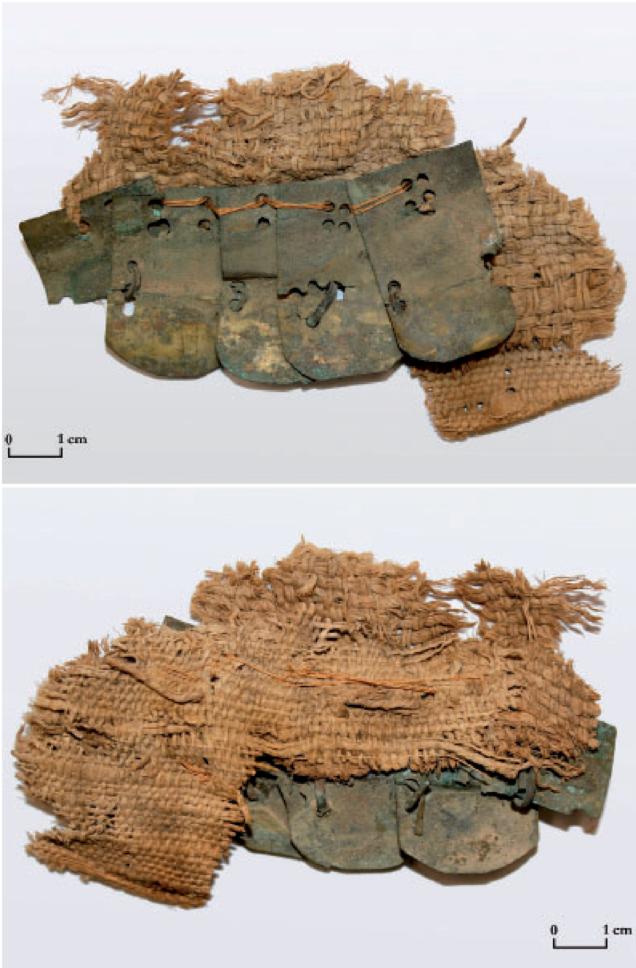

Fig. 4: Scale armour (Yale University Gallery) with double layers of textile (one basket weave and the other tabbby weave), and multiple scales still attached by sewing thread (Dura-Europos 63 and 67): front (top) and back (above) (Images: Martin Wijnhoven)

Fig. 5: Dura-Europos (65) is in a unique basket weave, where the warp consists of alternating double and single threads, while the weft is always a double (Yale University Art Gallery) (Image: Martijn Wijnhoven)

Of these three, two involve double-layered textiles associated with the armour (fig. 4). In these cases, one layer is a basket weave, and the other is a tabby weave. Notably, the tabby weave always faces the wearer, while the basket weave faces the scales.

A warp or weft-faced tabby weave is observed in only five finds, all from Carnuntum (fig. 6). These weaves are characterised by a pronounced repp structure, created by varying the density of either the warp or the weft. This results in one set of threads being visible on the surface, while the other set remains mostly covered.

Warp or weft-faced structures can also be used as borders for a piece of fabric. Two of the finds from Dura-Europos (87 and 284) feature a basket weave with a warp-faced border. This raises the possibility that the finds from Carnuntum either used a whole cloth made of warp-faced fabric or that only the edges survive, similar to those seen at Dura-Europos. In the first case, a unique weave is observed at Carnuntum, while in the second case, a more common phenomenon is present.

Textile qualities (see table 2)

The wool textiles, known only from Carnuntum (Grömer 2014), consist of 2/2 twills woven exclusively with z-spun single yarns (fig. 3b). These textiles are relatively coarse, with yarns measuring 1.2–1.5 mm in diameter and a thread count of five threads per centimetre in the warp and the weft, forming a well-balanced structure.

In contrast, the plant-fibre textiles associated with scale armour display a greater diversity. Although all are made with single yarns, there are both s and z-spun examples, particularly in tabbies, warp-faced tabbies, basket weaves and half-basket weaves. These textiles are finer than the wool samples, with yarns measuring approximately 0.7–0.8 mm in diameter and thread counts ranging from 7 to 12 threads per cm. In rare cases, such as those from Dura-Europos, thread counts reach up to 18 per centimetre. The higher counts are typically found in basket weave textiles and in warp-faced textiles, where one thread system has nearly double the density of the other.

Plant-fibre twills (2/1 and 2/2) from Dura-Europos (James 2004, 114) are primarily woven with z-spun single yarns measuring 0.8–1.3 mm in diameter, with some examples reaching up to 1.5 mm. These textiles exhibit a broader range of quality, with thread counts varying between 6 and 12 threads per centimetre, although a density of 8 threads per centimetre is the most common.

Sewing threads

In Roman scale armour, the individual scales are linked into rows with short, staple-like pieces of wire. The rows are attached to the base garment using binding threads (fig. 4b). This construction method was recognised early on by researchers and described in detail (fig. 7) in the case of Carnuntum:

"The thread used is made of flax, usually two-stranded, more rarely three stranded, and slightly twisted. It was passed through the row of scales in a continuous seam. Depending on the number and position of the seam holes, the stitching varied, but it was always executed using so-called front stitches" (Von Groller 1901, 90–91).

Von Groller's analysis also revealed that the holes through which the threads were pulled were always hammered and filed smooth to prevent the organic material from wearing through. Similar binding threads have been documented in other finds, such as those from Baumgarten an der March 1 (Schramm 2023).

Scale types

The fabric used for the base garment of Roman scale armour was not chosen at random. Instead, there is a clear relationship between the textile weave and the type of scales (fig. 8). Two key scale characteristics influence this choice: size and material. For this study, scale size has been categorised into four groups: small (≤20 mm long), medium (>20 mm and ≤40 mm long), large (>40 mm and ≤60 mm long) and X-large (>60 mm long). The scales are made of either iron or copper alloy. Additionally, though to a lesser extent, the type of textile also correlates with the number and arrangement of holes in the scales – features commonly used to establish typologies of Roman scale armour (for example, Komoróczy 2000, 80; Groh 2023, 22–26, fig. A11–12; Von Groller 1901, 86–95, pl. 15).

Twill fabric is primarily associated with two specific variants of scale armour. The first comprises small copper-alloy scales, which are found exclusively in combination with a twill textile base. In all cases where textile remains are preserved, these scales are attached to twill fabric, with no evidence of alternative weaves. Each scale features three pairs of holes: one pair at the top for stitching the scale to the underlying garment, and two pairs on the sides for linking adjacent scales into rows using small, staple-like metal wires (Groh type IV). A variation of this type has the same number of holes but arranges all three pairs near the top edge, positioning the side holes directly beside the upper pair (Groh type X).

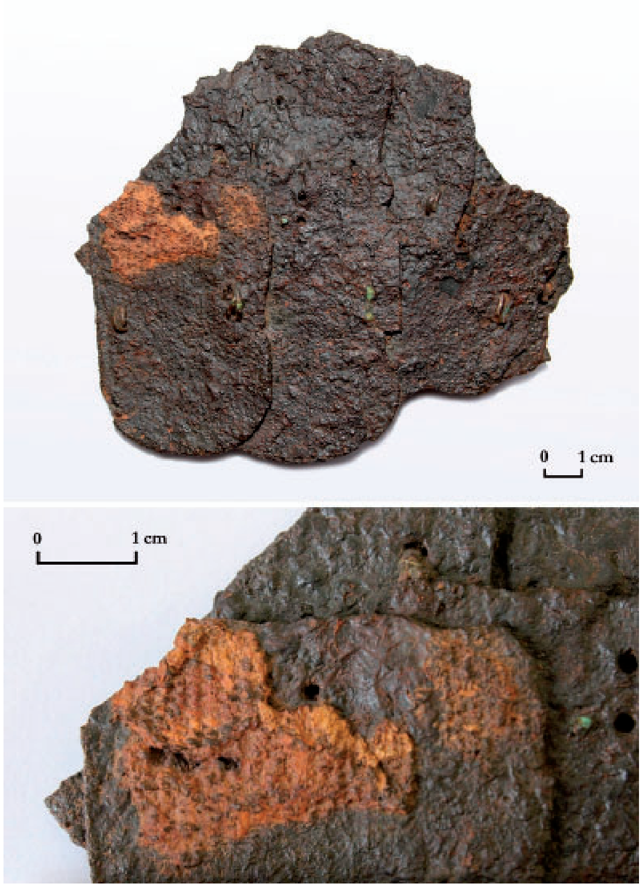

Fig. 6: Armour fragment from Carnuntum (49) consisting of very large iron scales and preserved remnants of a warp or weft-faced tabby weave on the inside of one of them (Landessammlungen Niederösterreich, Archäologischer Park Carnuntum): complete item (top), detail with textile (above) (Image: Martijn Wijnhoven)

The second type of scale associated with twill fabrics consists of large iron scales, which share the same hole arrangement as the small copper-alloy scales described above (Groh type IV). More broadly, Roman scale armour reveals a distinct size pattern based on material. Copper-alloy scales tend to be small, rarely exceeding 40 mm in length, and are almost entirely absent in the large and extra-large size categories. In contrast, iron scales are generally larger and are not represented among the smallest category at all. Although instances of medium-sized iron scales have been recorded, such as those from Mušov-Burgstall, these are rare exceptions among the predominant large and extra-large examples.

Taking this pattern into account, it is significant that twill fabrics are consistently associated with the smaller scale variants of each material. Small copper alloy scales are exclusively found with twill, while

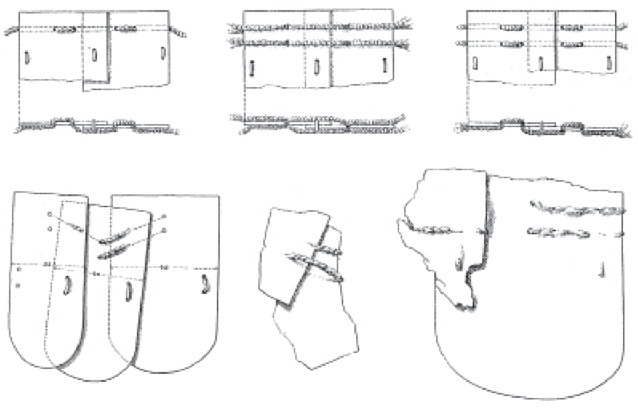

Fig. 7: The use of sewing threads as identified among the scale armour in Carnuntum (Image: After von Groller 1901, table XVI)

among iron scales, only the large types show this association. The extra-large iron scales, by contrast, are never linked to twill fabrics.

In addition to the two main groups of scales associated with twill fabrics, a third variant is occasionally observed. This consists of medium-sized copper-alloy scales that share the same hole arrangement as the smaller copper-alloy types. In one instance (Dura-Europos 62), a different hole configuration is attested, featuring two pairs of holes at the top rather than a single pair (Groh type VIII). There is also a single example of an extra-large iron scale (Dura-Europos 51) for which the identification of the underlying fabric is uncertain, although it may have been twill. This suggests that, on rare occasions, twill could have been used with larger scale types as well.

Base garments woven in a basket weave are associated with a different range of scale types than those found with twill fabrics. Basket weaves correspond to larger – and therefore heavier – scales. As with twills, two main groups can be identified. The first consists of medium-sized copper-alloy scales, which represent the largest examples within their material category. The second comprises iron scales, the vast majority of which fall into the extra-large category, although occasional examples of large iron scales have also been recorded.

The scales associated with basket weaves display greater variation in hole arrangements compared to those linked to twill fabrics. Most commonly, they feature two pairs of holes at the top and a pair on each side (Groh type VIII). However, a single specimen with only one pair of top holes has also been recorded (Groh type IV). In addition, a single find from Baumgarten an der March 1 in Austria consists of copper-alloy scales with a single large hole at the top (Groh type III), rather than the usual paired configuration.

As previously mentioned, tabby weaves are less commonly observed in base garments for scale armour. When present, they are almost exclusively associated with medium-sized copper alloy scales featuring two pairs of holes at the top and one on each side (Groh type VIII). Notably, two examples come from finds where a double layer of fabric was present: the layer facing the inside of the scales was a basket weave, while the layer facing the wearer was a tabby (figs. 3 and 7). There is a single occurrence of a tabby weave from Carnuntum (181) where a different type of scale is observed – in this case an extra-large iron scale. Additionally, there are two single occurrences of other scale types where the associated textile may be a tabby but cannot be determined with certainty.

Taken together, the types of scales linked to tabby weaves are similar to those observed with basket weaves. In both cases, they correspond to the heavier scale variants within their respective material categories. The presence of a double-layered fabric – combining a tabby with a basket weave – may be significant.

Although this combination has only been documented twice among the exceptionally well-preserved material from Dura-Europos, it would not be surprising if this practice was far more widespread. There could be an issue of survival bias. The layer closest to the scales (the basket weave) has a greater chance of preservation, as it is protected on both sides: by the scales on one and an additional textile layer on the other. Moreover, when the scales begin to corrode, the fabric in direct contact with them has a higher likelihood of survival, as it becomes incorporated into the corrosion products. In contrast, the textile facing the wearer (the tabby weave) would have been more vulnerable to decay and may have survived in fewer instances.

Warp-faced fabrics have so far been observed exclusively among the material from Carnuntum. All of these examples concern extra-large iron scales with the same hole arrangement (Groh type IV). Given the weight of these scales, a sturdy warp or weft-faced fabric would be particularly suitable.

Discussion

Textiles for scale armour in the Roman world

It is remarkable that all these textile linings for scale armour consist of different types of fabric (twills and basket weaves of different variants, tabbies, warp-faced tabbies) and that the connection between the scales and the carrier fabric is also different.

The diversity of weave types (including the use of z- and s-spun yarn) is particularly striking, given the presence of distinct textile traditions in different regions of the Roman Empire. This is well illustrated in a case study of Austria during the Roman period (Grömer 2014, figs. 17–19). Coarse fabrics, such as those found on the scale armour, are relatively uncommon; the predominant weave type is tabby, with only a few examples of basket weave or warp-faced variants. In this context, the textiles on the Roman scale armour found in Austria strongly suggest non-local production.

In general, the northern Roman provinces show a clear preference for z-twisted yarns, which are consistently interpreted as indicators of local production (Bender Jørgensen 1992, 58–62). In contrast, s-twisted yarns occur primarily in regions around the Mediterranean, particularly in the eastern provinces of the Empire, including Syria and Egypt. Linen fabrics in s/s twist in particular, are associated with regions around the Mediterranean Sea (Wild 1970, 38, 44–45; Bender Jørgensen 1992, 128).

The variety of textile materials used indicates that there was no standardised "construction scheme" for scale armour. The only consistent feature among these textiles is their relatively coarse and firm quality. There is, however, a clear relationship between the type of scales and the chosen textiles, suggesting deliberate

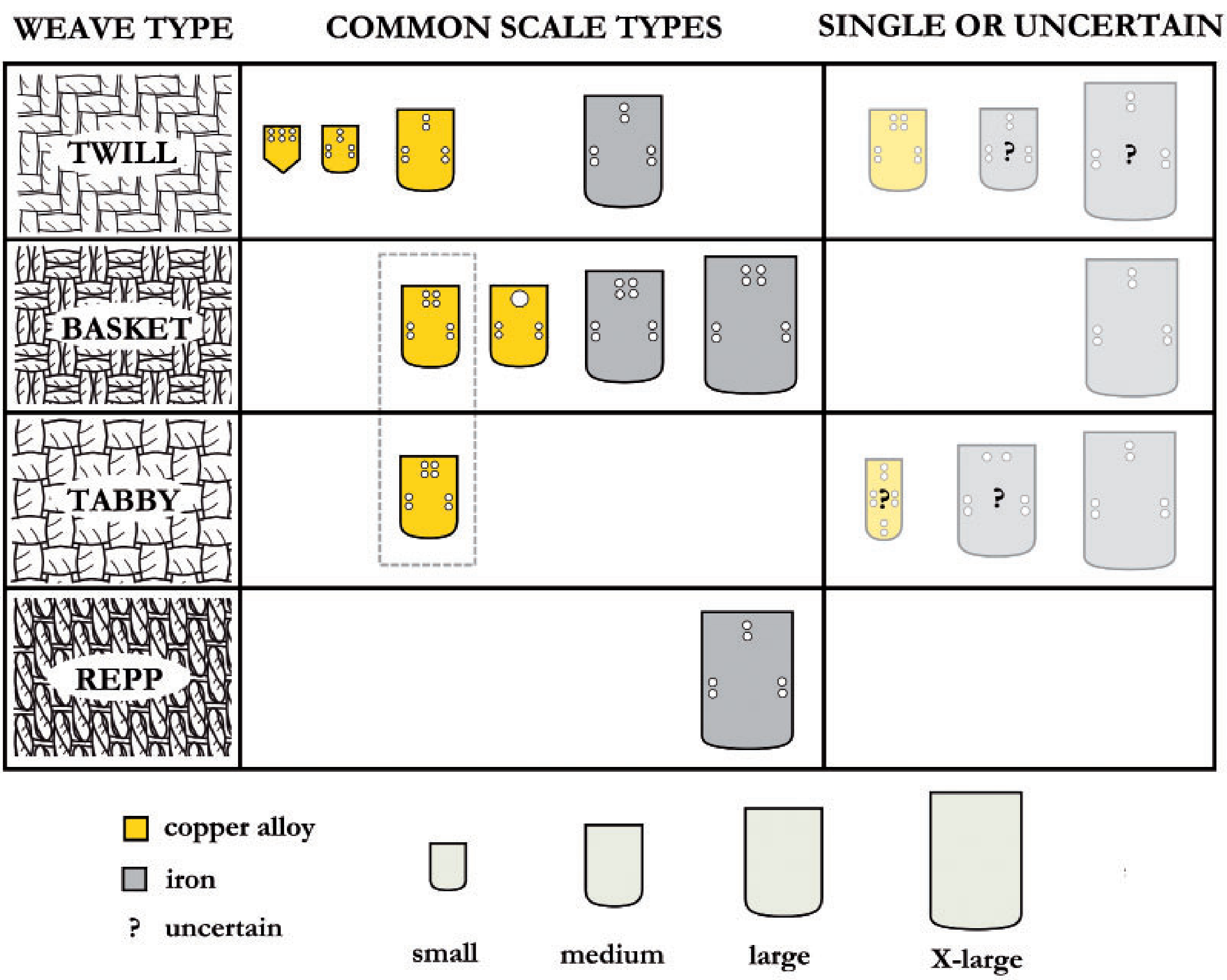

Fig. 8: Weave types and their associated types of scales. Common scales are those of which two or more examples are known. As an exception, two single finds of scale types have been added to the "common types" column. In both cases, there is only one find of that scale type in the entire database, meaning that all available evidence points to one type of fabric. This concerns the small scale with a triangular tip in the top row (Dura-Europos 27) and the medium scale with the larger hole at the top in the second row (Baumgarten an der March 1). All other single associations of weave and scale types are shown in light grey. An additional question mark is added to the single finds where the type of fabric has possibly been determined but remains fairly uncertain (Image: Martijn Wijnhoven)

Fig. 9: Recreation of Roman scale armour: a) full-length view worn by a horse rider; b) close-up of the armour in wear; c) displacement of scale rows during movement; and d) reverse side of the textile lining showing the stitching for the attached scale rows (Image: Ursi Aurei, Leona Kohl and Nina Zajicek)

selection. Unlike leather, these textiles offer elasticity, which improves the pliability and flexibility of this type of armour. It is worth noting that such defensive equipment was also used for horses, as shown by complete examples of horse scale armour from Dura Europos. However, the armour from Baumgarten was clearly intended for a human body, as indicated by the presence of chest plates.

Textile properties in relation to armour construction

Textiles from the Roman period often show evidence of reuse and recycling (for example, Wild 2020). It is not uncommon to find garments that have been patched up or made entirely from re-used pieces of clothing. However, this is not the case with the fabrics used as base garments for scale armour. Among the available evidence, there is no indication that these fabrics were made from recycled materials. This suggests that the fabrics were likely specifically produced with their intended use as armour in mind. This approach may also explain the consistent use of certain scale types and textile weaves.

Unlike most other fabrics used in antiquity, these textiles were not intended to be seen. They were purpose-made to serve as the base garment, with only the metal scales visible when the armour was worn. The textile would have only been observed during the process of donning the armour. Aesthetics likely played a very minor role, if any, with function being the primary concern.

As previously noted, two finds with remnants of base garments exhibit a double layer of textiles woven in different weaves. However, several other finds also indicate the use of a double-layered textile construction. In 11 additional cases, both layers consist of the same type of fabric (fig. 9). Notably, double layers are often observed in more complete or better-preserved finds. While this already represents a substantial proportion of the evidence, their occurrence was likely more frequent than the archaeological record suggests. Some examples may have originally featured a double layer, with the inner fabric – facing the body – now lost due to preservation biases. It is even possible that the majority of scale armour originally incorporated a double-layered base garment and that it was likely a standard practice.

A double layer of fabric would not only have reinforced the base garment, allowing it to better support the weight of the scales and endure the demands of warfare, but it would also have provided essential padding. While metal armour (fig. 9) is highly effective at preventing cuts and penetration from sharp weapons, it offers little protection against blunt force trauma. Without sufficient padding, the impact of a blow could still cause significant injury to the wearer. To function effectively, metal armour therefore needed to be combined with some form of organic padding (Jones 2014, 70; Wijnhoven 2022, 165). Numerous historical examples of such padding exist, either integrated into the armour itself or worn as a separate garment underneath (for example, Blanc 1997; Kelly 2013). Most of these examples date to the Late Middle Ages or later. There is broad consensus that the Romans also used padded under-armour (Bishop 1995; Ubl 2006; Wijnhoven 2022, 165–181). This assumption is primarily based on iconographic and historical sources. Archaeological evidence does exist (for example, Deschler-Erb et al. 2004; James 2004, 116) but remains extremely scarce.

The identification of a double layer of sturdy, thick fabric as the base garment in Roman scale armour could reshape the understanding of Roman padded under-armour. If it also served as padding, then what was once considered an elusive element of Roman military equipment is now be supported by a substantial body of archaeological evidence.

The technical characteristics (table 2) of the base textiles for metal scales suggest a well-considered functional choice. The fabrics are relatively thick and stable, with notably robust yarns and carefully balanced thread counts. Particularly interesting are the wool twills, which, while slightly more open in structure, remain strong. The twill weave offers a degree of flexibility, as it allows for some diagonal stretch. Interestingly, twills were almost always used with the smallest of scales of each material (iron and copper alloy). These properties would have been advantageous for use in armour.

Conclusion

The organic components of Roman scale armour have received relatively little scholarly attention. However, a wealth of information can be gained by examining the collective evidence.

Many studies on Roman military equipment state that the base garment of scale armour was either leather or textile. While leather was widely used for this purpose by other cultures, the archaeological evidence overwhelmingly indicates that the Romans exclusively employed textiles. This distinction represents a Roman innovation and provides a useful criterion for differentiating Roman from non-Roman scale armour. The selection of fabric was not arbitrary or based solely on availability; rather, it was deliberate and tailored to the demands of armour construction. The textiles used were specifically produced for this purpose, characterised by their strength, thickness, and durability. In addition, the choice of weave appears to have been intentional and adapted to the type of scales it supported. Twill weaves are associated with lighter copper alloy and iron scales, whereas basket weaves and tabbies appear alongside heavier copper alloy and iron scales. Warp or weft-faced fabrics have only been found in conjunction with heavy, extra-large iron scales in the examples studied so far.

Finally, the observation that a significant proportion of Roman scale armour preserved a double layer of textile may have implications for the debated existence of padded under-armour. Such a construction would not only have reinforced the base garment but also provided additional padding. This evidence suggests that the presence of padding in Roman armour may be far more archaeologically tangible than previously assumed.

Acknowledgments

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Ulla Mannering, Michael Alrø Jensen, Lise Ræder Knudsen, Irene Skals and Ina Vanden Berghe

The Bryndum burial ground in Denmark: news on Viking Age women's clothing

Abstract
In the village of Bryndum on the west coast of Denmark four kilometres north of the modern town of Esbjerg, a Viking Age cemetery dated to first part of the ninth century CE was excavated in 2016. A block lift from grave G12 turned out to contain two oval brooches covered with organic remains and textiles. The subsequent lab-controlled excavation revealed that there were six different textiles preserved in the grave. It is possible that the buried woman was covered by a greyish wool duvet filled with threshed straw which originally may have been filled with down and feathers. The clothing most likely consisted of a blue or purplish wool overwear lined with a whiteish linen fabric. She was probably clad in a blue wool dress with straps made of a tablet-woven wool band, held together with a pair of oval bronze brooches. This is the first time that the tablet weaving technique has been recorded for this specific use. Underneath the dress, remains of a pleated linen inner garment were found. The grave thus contains both well-known and new details relating to Danish Viking Age female clothing. The findings were uncovered during a careful excavation and registration process and are the results of a fruitful collaboration between conservators, archaeologists, and other scientists.
Keywords: Viking Age, female grave, textiles, tablet weave, duvet

Introduction

The village of Bryndum is located four kilometres north of the modern town of Esbjerg on the west coast of Jutland in Denmark. The village was first mentioned in the 13th century as "Brynnum" and "Brunnum", the prefix of which probably refers to a well or spring, while the um-ending (hem) refers to a settlement (Hald 1950, 53). Bryndum Church is among the most distinguished and largest ashlar stone churches in Jutland. It is dendrochronologically dated to the 1240s and was built between two larger burial mounds probably from the Bronze Age. Today, the Danish Wadden Sea extends approximately to Esbjerg, but in the Viking Age it continued further up the west coast of Jutland and provided good sailing connections along the coast and inland via river connections. In the Middle Ages, the parishes throughout the west Jutland coastal zone were able to provide a high tax yield equal to that of the more fertile lands around the fjords of eastern Jutland (Søvsø 2020, 82). In *Ribe Oldermor's* church list from the mid-14th century, the Bryndum church is listed as giving the highest tax to Ribe Diocese, indicating a large resource base and a high degree of wealth in the area.

In 2016, in connection with the construction of a new parish house immediately south of Bryndum church yard, Museum Vest found a burial site consisting of 14 inhumation graves from the Viking Age (fig. 1). Most of the graves were shallow and had already been disturbed by various animal activities. The sandy subsoil in western Jutland tends to provide poor preservation of organic material and metals. Only a few small and very decomposed pieces of skeletal remains were preserved in the Bryndum graves. Traces of decomposed wood indicated that most of the graves once contained coffins or hollowed-out oak trunks of various shapes. Judging by the size of the graves, at least four were burials for children, all the way down to infancy, and one of the children was

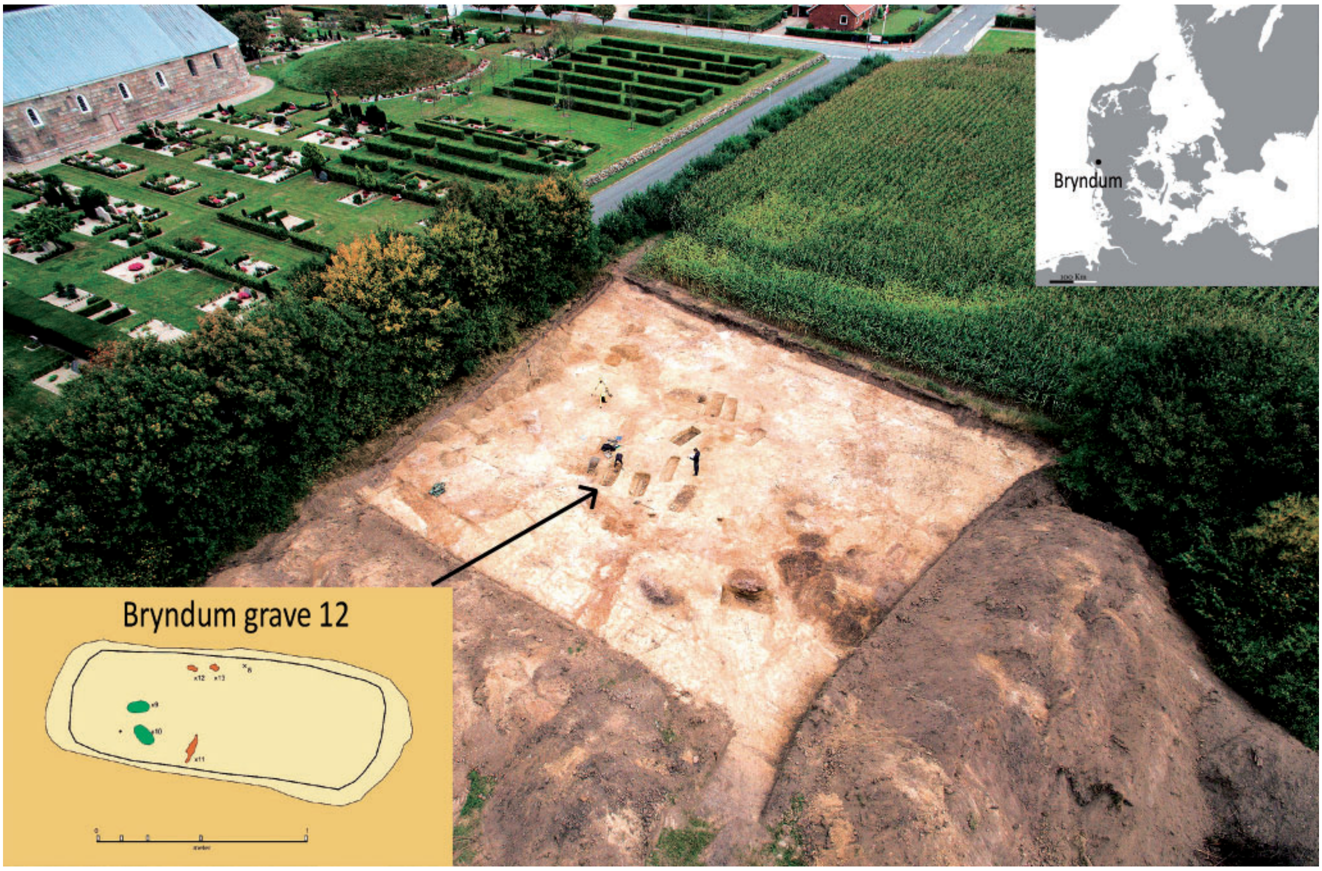


Fig. 1: Overview of the rescue excavation of the Viking Age cemetery next to the church graveyard in the village of Bryndum in Jutland, Denmark, with an outline of Grave 12 (inset left) and where it was found (Images: John Randeris; graphics: Charlotte Rimstad)

evidently buried in a wooden box. All the graves were approximately east-west-oriented, and in four cases it was possible to detect the outline of the body by the colour of the subsoil. In each case the deceased was lying in a supine position with the head in the west. The graves were generally sparsely equipped. In five graves knives had been placed at the hips. One grave, G12, differed from the others in that it contained both jewellery and well-preserved textiles. These are the main focus of this article.

Before the discovery of the Bryndum cemetery, 22 Viking Age graves from more than ten sites were known in the Esbjerg area, several with graves in combination from the Early and Late Iron Age. Three of the sites included both cremation and inhumation burials dating to the end of the eighth or ninth century CE (Stoumann 2009, 253–263). Thus, the burial customs in Bryndum correspond with the general local and overall pattern in western Jutland in the ninth century CE. This includes the pronounced east-west grave orientation and the position of the head to the west (Egebjerg et al. 2009).

The Bryndum woman's grave

Grave G12 appeared to be an oblong cut measuring 173 x 63 cm. Due to its depth of only 35 cm, it was disturbed by bioturbation, but diffuse traces of the coffin were observed along the sides and bottom of the grave. The wooden coffin measured 150 x 55 cm and had rounded sides. It was probably a log coffin. During the excavation, straw was found in the west end of the grave, which at first glance looked like material from a mouse nest. However, it turned out that there were preserved textiles immediately under the straw and a green coloration from two underlying copper alloy objects, which turned out to be a pair of oval brooches. A block-lift was therefore made across the width of the grave, which included the grave goods and the preserved textiles.

Altogether the block-lift turned out to contain one amber bead (ID 200376833) and a turquoise-green glass bead (ID 200376832) placed near the oval brooch, known as find "x10" (ID 200376828) thalay on the right side of the woman's chest. Above the glass bead was a faceted amber ring (ID 200376831) with an inner

diameter of 20 mm. As the amber ring lay over the edge of the brooch it is interpreted as a pendant that was used together with the two beads. The oval brooch, known as find as "x9" (ID200376829) placed on the left side was significantly less well-preserved and deteriorated to a degree that makes the ornamentation almost indistinguishable. However, it can be surmised that they were likely identical. On the right side of the woman, a knife (x11, ID 200330744) was found, and on the left side, several undeterminable iron fragments (ID 200376875, ID 200376876, ID 200376877) (fig. 2).
Although metal detection in recent decades has shown that dress accessories such as oval brooches were more common in this area in the Iron, Viking, and Middle Ages than assumed on basis of the burial finds, the clearest social marker at Bryndum remains the artefacts found in grave G12. On this basis it is likely that the woman in grave G12 at Bryndum belonged to the better-off part of the population. She had the wealth and social class able to acquire jewellery in the markets of nearby Ribe or Hedeby, and she had access to high-quality textiles.

Dating the grave

The beads, and especially the oval brooches of the Berdal type JP 23/24, constitute the primary basis for dating not only grave G12, but the entire cemetery. Berdal brooches are known all over Scandinavia, but occur most often in Norway, Denmark, and Schleswig in northern Germany (Petersen 1928, 19–22; Jansson 1985, 24–25, 31). Berdal brooches are known to have been produced in the nearby emporium of Ribe located just 30 km south of Bryndum, at least since the last two decades of the eighth century and continuing until after the middle of the ninth century CE. At that time, double-shelled oval brooches were introduced (Feveile and Jensen 2006, 155). Until now, no casting-moulds from the production of this specific Bryndum/Berdal type have been found. Characteristic of decorations from the first half of the 9th century, the Berdal and Oseberg/Broa styles are marked by the introduction of the gripping beast with heads shown *en face*. The brooches from Bryndum are voluminous and loosely composed examples, where the profiled body of the gripping beast is placed in a triangle. The dating of this style corresponds roughly to the production period of other Berdal brooches in Ribe, mainly attributed to the first half of the ninth century CE (Jensen and Wilson 1965, 23–57).
As the ring-shaped amber piece and the beads do not contribute to a more precise dating of the grave, it was decided to make two radiocarbon dates of the straw

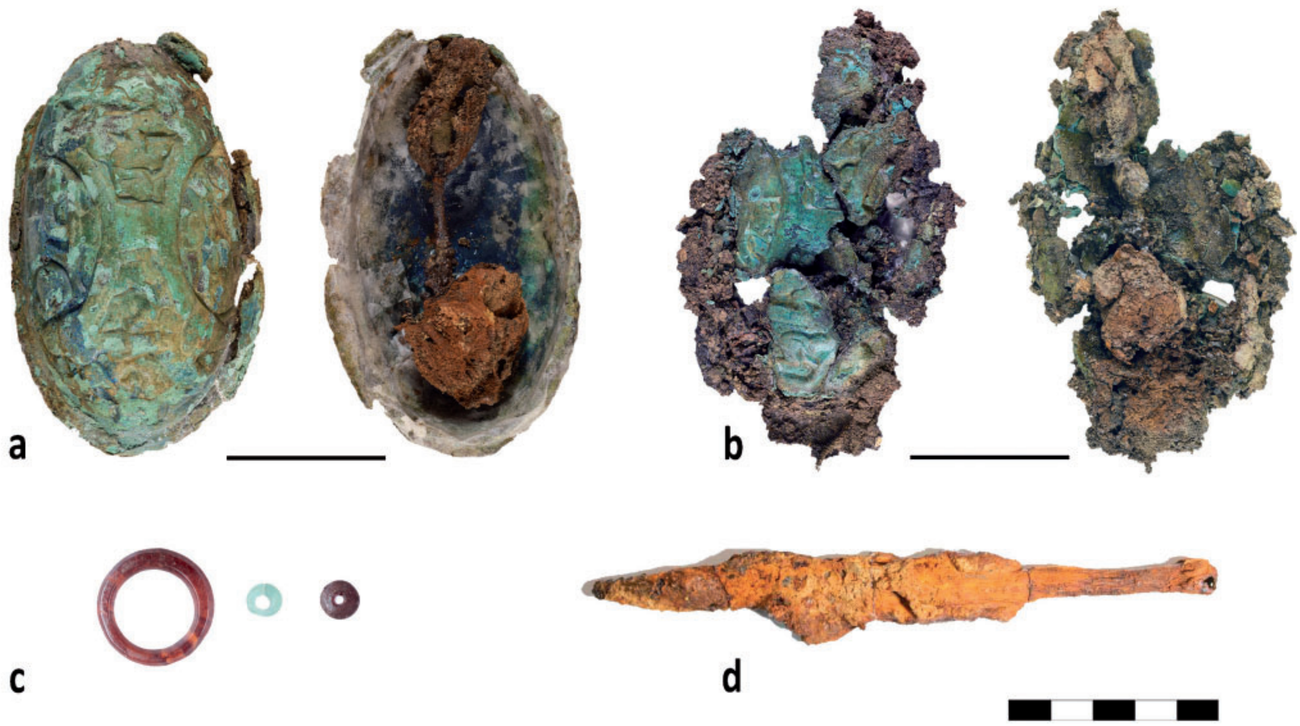
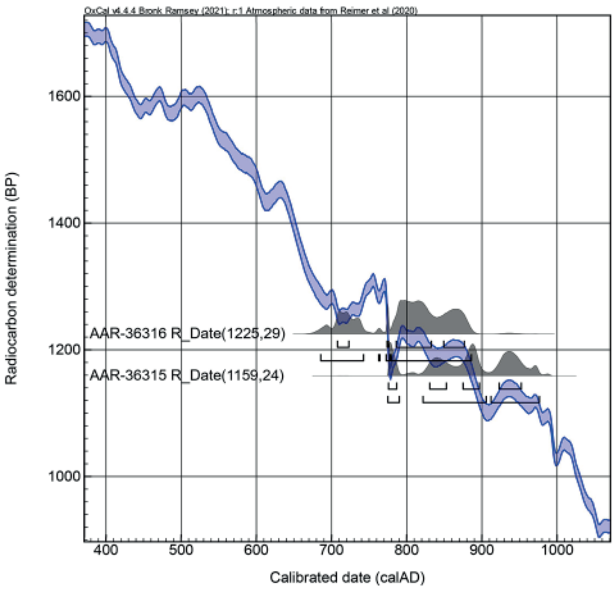


Fig. 2: The front and back of a) the right oval brooch x10; b) the left oval brooch x9; and the other artefacts in Bryndum Grave 12; c) the amber ring, the glass and amber beads; and d) the iron knife x11 (Images: Museum Vest)



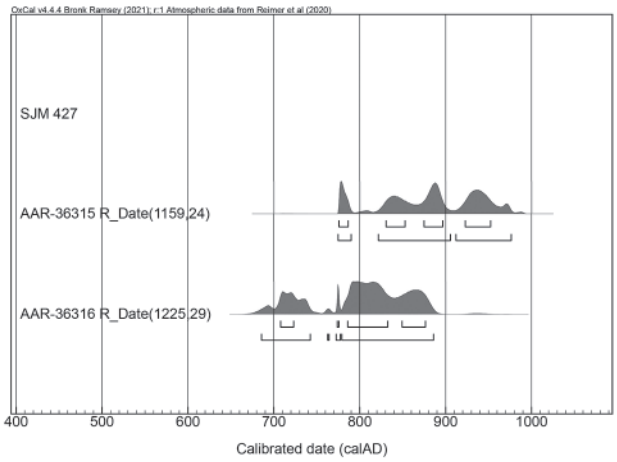


Fig. 3: The radiocarbon dating results of the straw found in Bryndum Grave 12 (Image: Aarhus AMS Centre)

found in the block-lift. The analysis was carried out by Aarhus AMS Centre in Denmark. Results showed that within two standard deviations the samples were dated to the period 775–977 CE (AAR 36315: 14C age 1159 ± 24) and 686–886 CE (AAR 36316: 14C age 1225 ± 29) (fig. 3). Combined with the dating of the Berdal brooches it is most likely that the Bryndum woman was buried sometime during the ninth century CE.

Excavation of the block-lift from G12

The block-lift comprising the oval brooches and the surrounding soil was transferred to the Department of Archaeological Conservation at the Conservation Centre in Vejle. The block-lift was waterlogged upon receipt, and the textiles and other organic remains close to the oval brooches were still well-preserved. The oval brooches were found with the surfaces turned upwards, indicating that the woman was buried lying on her back, and as the body decomposed the oval brooches gradually sank to the bottom of the grave. The distance between the two oval brooches was approximately 7 cm. It is assumed that the poorly-preserved left brooch (x9) originally was positioned more or less as it was found, while the right brooch (x10) had shifted slightly from its original position. Both oval brooches were oriented with the inside pins pointing towards the shoulders.

The top layer above the oval brooches consisted of threshed straw arranged in a random pattern. Samples of the straw were sent for analysis at Moesgaard Museum, but the plant species could not be identified. Underneath the straw, several textile layers were visible. At this stage of analysis, it was decided to conduct a partial separation of the textiles from the oval brooches. This means that the textiles inside the brooches were kept in place, while the textiles from the upper side were separated as one solid layer from each brooch. This made it possible to study the style and decoration of the brooches while the textile layers could be studied from both sides, i.e. the ones that lay above and upon the brooch as well as in cross section. The separation was carried out while the textiles were still waterlogged and had some degree of flexibility. Subsequently, the textiles were freeze-dried without the application of vacuum. This was to prevent the collapse of the fibres. Following this process, the textiles became exceedingly fragile and prone to crumble. From a conservation perspective, it would have been optimal to impregnate the textiles. However, this entails significant drawbacks, as the impregnation agents inevitably create a reflective surface that complicates photo documentation and observation under a stereo microscope. Furthermore, scientific analyses of the fibres (e.g., dye, fibre type, radiocarbon dating, strontium analyses, and future analyses that we cannot yet envisage) would be rendered impossible or considerably more complex.

After visual analysis and photographic documentation of the textiles, they were described, measured, and categorised into various textile types. Some fragments were impregnated with the acrylic copolymer, Paraloid B72, to ensure the future preservation of their appearance. But the majority of the different textile fragments were left untreated. Also, the textile fragments preserved inside the oval brooches were left in situ to maintain their functional context.

Additionally, sample material was extracted for future analysis.
Altogether, the textiles found in close proximity to, and on top of, the bronze brooches are all well-preserved and in an organic state. However, they are extremely fragile. On the other hand, most of the textiles found inside and underneath the oval brooches are hard and brittle. In some cases they are completely mineralised by the iron corrosion coming from the pins placed inside the brooches. Only small parts of these textiles are suitable for analysis. It is evident that the copper salts from the degradation of the bronzes contributed to the preservation of the organic materials, but only those that were in close contact with the brooches.

Methods used
For this study, a wide range of methods were applied. These were implemented primarily on textiles still in their organic state. Fibre diameter measurements were made based on digital photographs captured by transmitted light microscopy using a Primo Star iLED microscope from Zeiss with a 10x objective, equipped

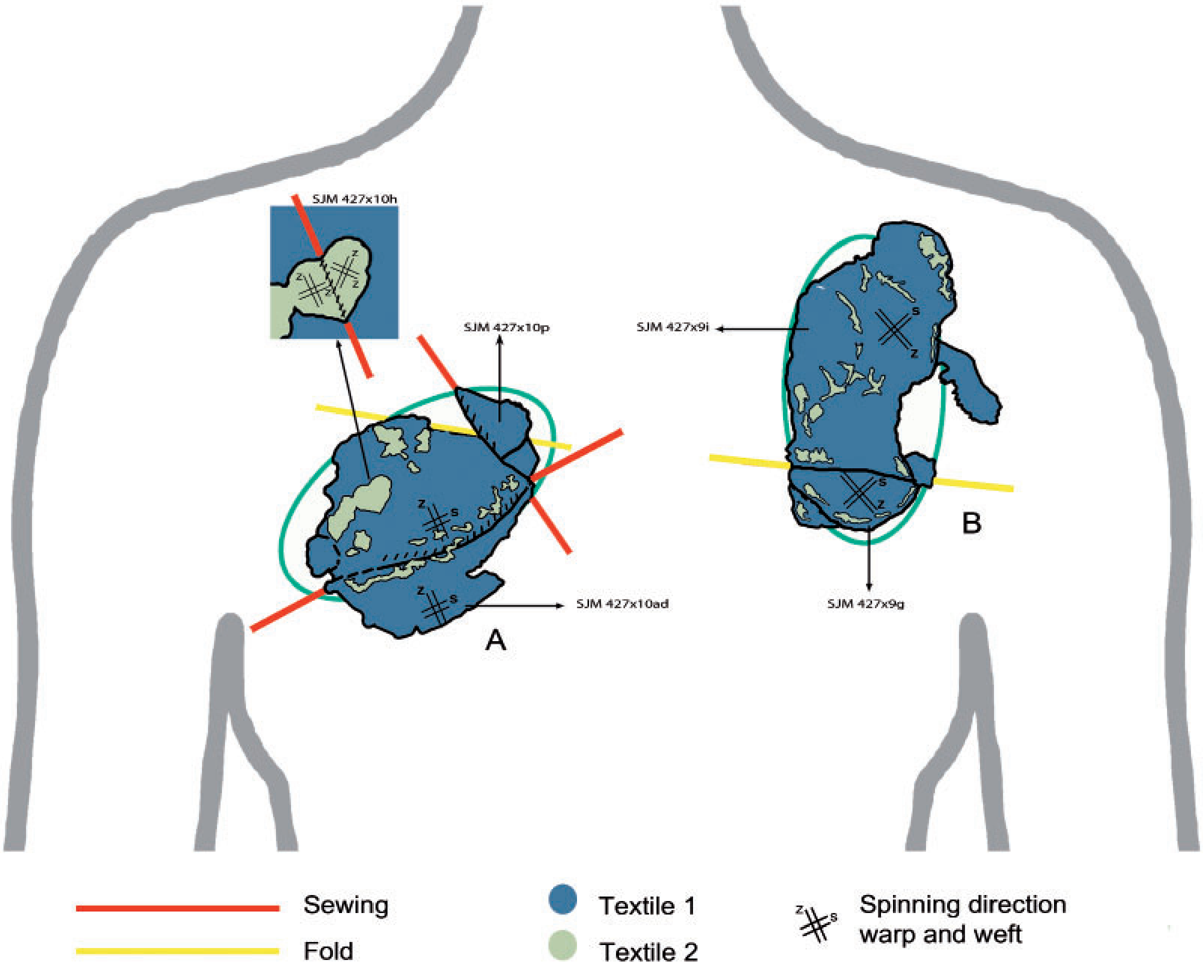


Fig. 4: Visualisation of the layers of Textile 1 (blue twill) and Textile 2 (possibly flax) on top of the brooches. Note that the textiles are drawn on top of a mirrored photo of the inside of the flakes of the textile layers (figs. 6a and 6c) even if they are seen from the outside on this presentation. This makes it possible to see the folds and sewing seen from inside and to compare these between the brooches and relate to the expected orientation of the body. The brooches are placed as they were found in the grave and indicate the possible situation at the burial. Note the direction of the s- and z-twist of the warp and weft of Textile 1 is exactly the same on the fragments of both brooches despite sewing and folds. The fold (yellow line) indicates that the displacement of the proper right brooch happened before the burial or shortly after it, when the brooch slid under the upper garment. Note also the double layered fragment x10p with the stitches facing downward, which may be folded over the neck opening. The lining x10h has different spinning directions on each side of the stitches, indicating it was cut to shape (Image: Lise Ræder Knudsen)

with an AxioCam ERc5s camera and with a minimum of 100 fibre diameters per sample. Statistical data processing was made in Excel. The percentage results were sorted into groups of Fine (less than 25 microns), Medium (25 to 40 microns), and Coarse fibres (more than 40 microns) and cumulative frequency diagrams as well as histograms were created to evaluate and compare the results (Skals 2024; Skals et al. 2024a; 2024b). The results were further classified according to Rast-Eicher's categorisation format (Rast-Eicher 2008; Rast-Eicher and Bender Jørgensen 2013).

Identification of the organic colorants was performed by High Performance Liquid Chromatography and photo diode array detection system (HPLC-DAD) with Arc HPLC equipment (Waters, USA). The analyses were interpreted using the Empower software system from Waters. A detailed description of the analytical protocol has been published by Vanden Berghe et al. (2009). The colourants were recovered from the fibres using extraction with hydrochloric acid and ethylacetate purification.

Fourier transform infrared (FTIR) spectroscopy is a technique that can analyse materials by measuring how they absorb infrared light, resulting in a spectrum that serves as a distinctive molecular fingerprint. FTIR analysis was used to identify the plant fibre textiles, although not to specific species level. Attenuated total reflection – Fourier Transform Infrared Spectroscopy (ATR-FTIR) spectra were recorded on a Nicolet iS5 FTIR spectrometer from ThermoFisher Scientific, fitted with a single bounce ATR (Attenuated Total Reflectance) sampling accessory including a diamond crystal. Spectra of the samples were recorded over the range of 4000–500 cm^{-1} with a resolution of 4 cm^{-1} and 16 accumulations. The spectra were compared with reference spectra in the software OMNIC and OMNIC SPECTRA.

During the preliminary preparation of the textiles on the upper side of the oval brooches, it was challenging to decipher the various layered sequences, as multiple layers were preserved. The textile layers lay with alternating thread directions, and folds and seams were present at different locations. It was therefore not possible to separate all the different layers without causing significant destruction of the material and compromising the integrity of the context. On this basis, a method was developed during the excavation of the block lift, that helped obtaining as much information as possible about the location and relationship between different textiles throughout all levels. This made it possible to document where textile layers, thread directions, seams and folds were located in relation to the oval brooches and the buried woman. All of this information was documented through digital layering in Adobe Photoshop, where images of individual textiles were overlaid onto photographs of the specimen. Images of both the underside and upper side were adjusted, mirrored, or oriented upright, depending on their position, thus enabling a virtual "through-layer" view that was then documented with line drawings for the textiles on the top and inside each of the brooches. This resulted in a total of four drawings. This approach allowed precise visualisation of the placement of seams and folds in relation to the body of the buried individual (fig. 4).

Textile types and layer sequences

Textile 0, straw and down

As mentioned, the top layer above the oval brooches consisted of randomly positioned broken straws that were bent at several points along the stem. This indicates that the straws were not deposited as a parallel cohesive bundle but were most likely straws from threshed grain. Although today the layer is very thin, it may originally have been much thicker. There may also have been additional textile layers above the straw that have not been preserved (fig. 5).

Directly under the straw, remains of a 2/2 twill textile were found (Textile 0, see also fig. 12). It was made of a light grey-brown wool. The yarns used in the weave have combined twist directions: z-spun threads with a twist angle of approximately 56° in one direction, and s-spun threads in the other direction with a twist angle around 45°. All threads in the weave are quite thick. They measure 1.4 to 1.5 mm in diameter, and the weave has a thread density of approximately 6–7 threads per cm (fig. 6 and table 1). The dye analysis revealed that both thread systems contained extracts from clubmoss (*Lycopodium*), which is typically associated with mordanting of the yarn prior to dyeing. Furthermore, both thread systems contained traces of an indigotin-containing plant dye (in this context probably woad), which most likely are the result of leaked dyes from the other blue-dyed textiles found in the grave (table 2). The presence of clubmoss suggests that Textile 0 originally could have been dyed, but that the dye component has completely disintegrated.

The fibre analysis further showed that the z-spun yarn has a predominance of fine fibres, and for the remaining part an equal presence of medium-range and coarse fibres (fig. 7 and table 3). In contrast, the s-spun yarn has a majority of fine and medium fibres with a number of coarse fibres that match the z-spun yarn. The z-spun yarn also contained several kemp fibres, which are short, smooth, and robust hairs with a large medulla (Skals et al. 2024a, 5). Kemp fibres

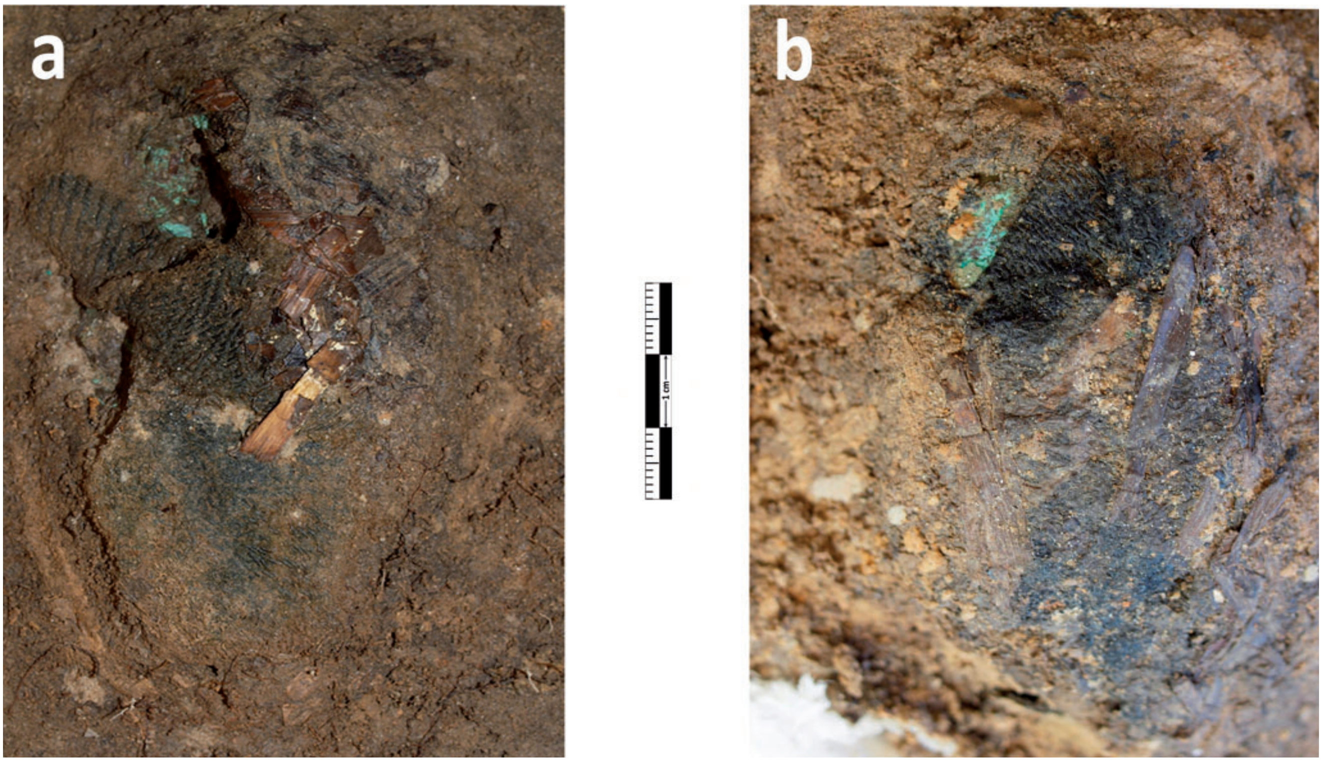


Fig. 5: The upper layers on the two oval brooches revealing straw and the well-preserved Textile 1. Later, when the straw was removed, small and less well-preserved fragments of Textile 0 became visible: a) the right oval brooch x10; and b) the left oval brooch x9 (Images: Conservation Centre Vejle)

are only observed in the most primitive sheep breeds and tend to disappear in the wool composition of the more evolved breeds (Ryder 1983). This combination of fibres is somewhat unusual and indicates that the wool used for the two different yarns may come from the same source but was sorted and eventually spun in different ways. An unexpected side effect of the fibre analysis was that the remains of down were detected among the wool fibres in Textile 0 despite the fact that no traces of feathers or downs were observed on any of the other textile surfaces. It is thus likely that Textile 0 was in close contact with down/feathers during its use or when the yarns for the weave were spun.

Textile 1

Under the wool twill, but still on top of the oval brooches, a fine 2/2 wool twill textile (Textile 1) was found. This weave is more unbalanced, with a thread density of 15–21 threads per cm in the warp and 7–12 threads per cm in the weft. But it still utilises combined twist directions like in Textile 0 (table 1). The warp system is made in a z-spun yarn with a twist angle of 40°, whereas the s-spun yarn in the weft has a twist angle of 26°. The fibre analyses of the warp and weft samples taken from the left oval brooch (x9) show a difference in the wool composition of the two yarns. As such, the warp is characterised by a large content of coarse fibres. The weft has a majority of fine fibres, while the content of medium-range fibres is the same in both yarns. Altogether this fibre combination shows how wool could be sorted in slightly different ways that supported the desire to produce a thin strong warp thread and a softer and more fluffy weft yarn (fig. 7 and table 3). This supports the existing hypothesis that, during the Viking Age, wool was sorted and spun into yarn selected specifically for the intended function of the textile for which it would be used (Skals et al. 2024a).

Textile 1 appeared dark blue to black while it was still waterlogged. Dye analysis confirmed that the warp was dyed with woad (*Isatis tinctoria*). In the weft, woad and an unknown red colour component were detected in the sample taken from the right oval brooch (x10). Only woad and no red colour component was found in the warp and weft samples extracted from the left brooch (x9) (table 2). This feature could imply several things. Either this specific part of Textile 1 has a wide colour band made in a more purplish weft yarn, or the red dye component has leaked from one of the other textiles into the weft yarn. Nevertheless, as none of the other textiles in the grave contain traces of red dye components, this option is the least likely. Based on the overall appearance of this weave, it is likely that all the fragments found on the two brooches come from the same weave – possibly a striped one.

Further, it was noted during excavation that Textile 1 had clear diagonal stripes created by the twill structure in a blue and possibly more purplish colour on one side of the fabric. The reverse side of the twill stripes was less distinct. This optical phenomenon is created by the 2/2 twill structure that on one side has Z-directed diagonal stripes and on one side S-diagonal stripes that line up with the different twist directions in warp and weft. This was further accentuated by the difference in the twist angles (warp with a significantly tighter twist than weft) and the higher thread counts for warp than weft (Hammerlund and Vestergaard Pedersen 2005, 215–216; Oelsner 1915, 20–21).

Another important characteristic of the Textile 1 fragments is the observation of a significant napping. This was particularly obvious on the side that has a less distinct twill structure (the side of the textile with S-twill structure which in most cases are the outside) although the cleaning of the textiles down to visible thread structure during conservation may have removed the napping in some areas. Viewed in the light microscope, the fibres from the napping seem to have a mixture of both strong blue and uncoloured fibres that match the occurrence of dyes in warp and weft.

It is further characteristic that Textile 1 is preserved in several layers on top of the brooches, sometimes in four to six layers on top one another. One of the now loose pieces coming from the lower edge of the right brooch even contains a hem that joins two layers of Textile 1 (x10p, fig. 8). The hem is preserved at a length of 2 cm and measures 4 mm in width. It is most likely two pieces of Textile 1 on top of each other both with the Z-twill direction on the visible side, but the thread direction is slightly twisted so that one side (fig. 8 left) is cut at an angle of about 75° to the warp threads, whereas the other side (fig. 8 right) is cut to an angle of about 90° to the warp. These two pieces are held in place with a decorative line of staggered running

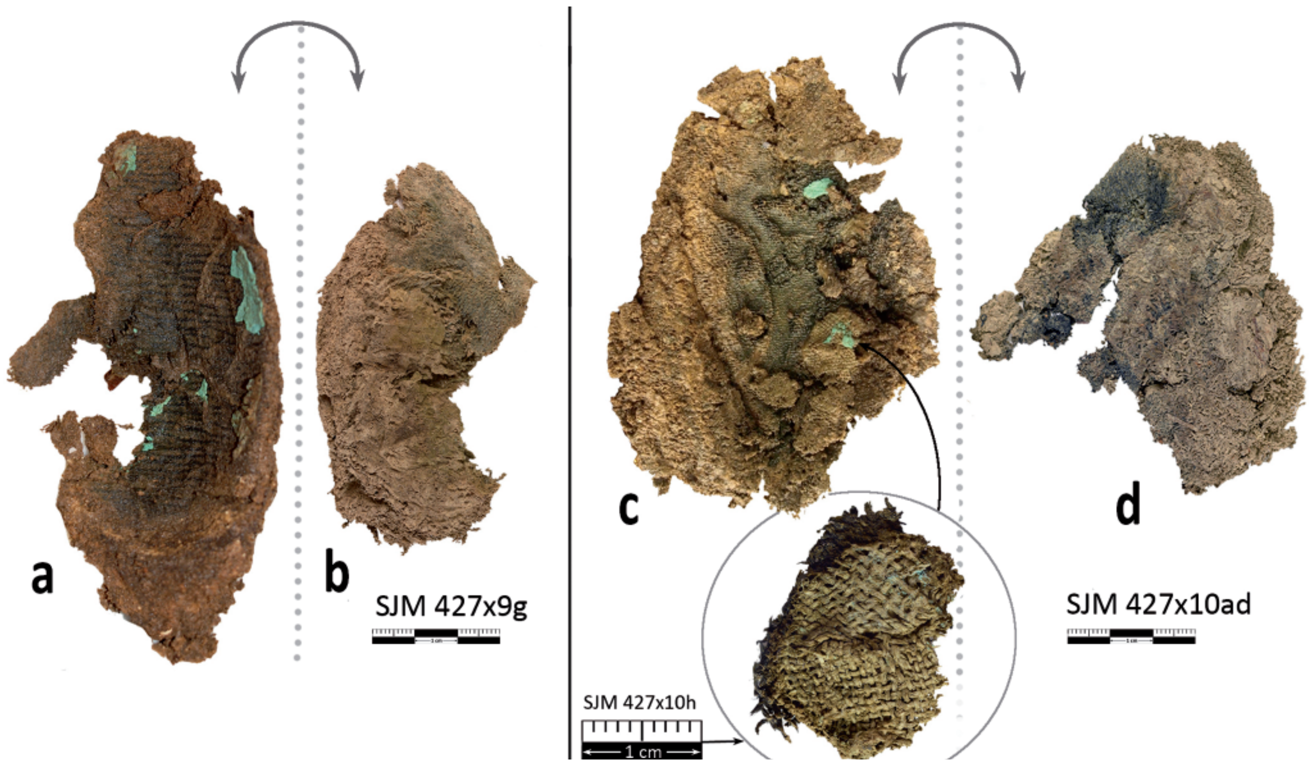


Fig. 6: The waterlogged inner side of: a) the right oval brooch x10 and c) the left oval brooch x9; the freeze-dried upper side of b); the right oval brooch x10; and d) the left oval brooch x9. After freeze-drying, loose fragments were removed, which made the fragments (a and b, c and d) look different. The tiny well-preserved fragment of presumably flax x10h in the middle (magnification below c) has a seam across it and the lower piece has the thread direction running parallel to the stitches, whereas the fragment above c has the thread direction running diagonally to the stitches indicating that this textile could be tailored (Images: Conservation Centre Vejle, graphics: Charlotte Rimstad and Lise Ræder Knudsen)

Textile	Weave/ feature	Twist direction	Twist degree	Thread density per cm	Thread diameter mm	Fiber type	Colour/ dye	Comment
Layers on top of the oval brooches SJM 427x9 (left) and 427x10 (right)								
Textile 0	2/2 twill balanced	z/s	56°/45°	7/6	1.4/1.5	Wool	Light grey	
Textile 1	2/2 twill unbalanced	z/s	40°/26°	15-21/ 7-12	0.4/0.7	Wool	Blue	
Textile 1 hem Sewing thread A	Staggered running stich 8 mm	$S < \frac{z}{z}$	Very light twist		1.5<0.9/0.9	Wool	Blue	Seen on Fragment x10p
Textile 1 seam Sewing thread B	Hem stich 5 mm	$S < \frac{z}{z}$	Very light twist		0.95<0.5/0.6	Wool	Light grey	Seen on Fragment x10ad
Textile 2	Tabby balanced	z/z	13°/12°	14-15/13-20	ca. 0.5/ ca. 0.5 (uneven)	Plant	White	
Textile 2 seam Sewing thread C	Hem stich 3 mm	$S < \frac{z}{z}$	Very light twist		0.27<0.14/0.11	Plant	White	Seen on Fragment x10h
Layers inside and on the lower edges of the oval brooches SJM 427x9 (left) and 427x10 (right)								
Textile 3	Tabby unbalanced	z/z	34°/29°	31/10-15	0.4/0.3	Wool	Blackish	
Textile 3 hem Sewing thread D	Staggered running stich 8 mm	$S < \frac{z}{z}$	Very light twist		1.2<0.8/0.7	Wool	Blue	Seen on Fragment x10q
Straps sewn to Textile 3	Tablet weave 1.4 cm wide Sewn edge to edge to form a tube with a width of 0.6 cm	Warp: $S < \frac{z}{z}$ Weft: s		12 tablets Edge: 2 tablets with 4 threads SZ orientated Pattern: 10 tablets with 2 threads Z orientated	Warp: 0.75 mm Weft: 0.85 mm	Wool	Reddish by rust from the iron needle	Seen on Fragment x10s
Textile 4	Tabby balanced	z/z	34°/33°	14/14	0.5/0.5	Plant	Reddish by rust from the iron needle	

Table 1: The technical data from the Bryndum G12 textiles

stitches placed parallel to the outer hem line. The stitch length is approximately 8 mm while the distance between the staggered rows is around 3 mm (table 1). The decorative stitching is made with a S-plied yarn, S2z, circa 2 mm in diameter. The fragment was found with the hem decoration facing inwards, and as the two layers of fabric have different thread directions it is clear that this clothing item was at least partly tailored. Considering the decorative stitching and the orientation of fragment x10p (see fig. 4), it could be part of a cut-to-shape and folded neckline. When the lump of Textile 1 found on top of the right brooch was turned around so that the side touching the bronze surface was exposed, a seam running from the top to the bottom of the brooch could be observed (x10ad, fig. 4 and fig. 6c). The seam is sewn with regular hem stitches with a spacing of about 5 mm using an S-plied sewing thread approximately 1.0 mm in diameter. In this case, the two textiles joining in the seam have different thread directions, supporting the impression that Textile 1 belonged to a kind of tailored clothing item. The left oval brooch was also covered by Textile

Textile	Weave	Sampled yarn	KIK/IRPA code	Biological source
X9 Textile 0	2/2 wool twill	z-spun thread	14995/69	Clubmoss (trace of Indigo/woad)
X9 Textile 0	2/2 wool twill	s-spun thread	14995/70	Clubmoss (trace of Indigo/woad)
X9 Textile 1	2/2 wool twill	warp	14995/64	Indigo or woad
X9 Textile 1	2/2 wool twill	weft	14995/65	Indigo or woad
X10 Textile 1	2/2 wool twill	warp	14995/66	Indigo or woad
X10 Textile 1	2/2 wool twill	weft	14995/67	Indigo or woad + unknown red
X10 Textile 3	wool tabby	warp & weft	14995/68	Indigo or woad

Table 2: The result of the dye analyses of the textiles from Bryndum G12

1, and together with a larger, now loose, fragment (x9g) it is clear that Textile 1 was mostly positioned with the Z-twill structure stripe direction placed at a right angle to the length axis of the brooches.

Textile 2

Textile 2 is represented by small fragments of a balanced tabby found on the inside of Textile 1 touching the surface of the brooches. This weave is made in a lightly z-twisted yarn with a twist of approximately 12° in both thread directions. Although the average thread diameter lies around 0.5 mm, they vary considerably. As such, the evenness of the threads also varies (table 1). In this case, the FTIR analysis confirmed the suspicion based on the visual appearance that the weave is made of plant fibres. A specific determination between nettle, hemp, or flax could not be made.

A small but well-preserved fragment of Textile 2 (x10h) features a seam sewn together with hem stitches in an S-plied sewing thread, made of slightly thinner z-twisted threads than used in the weave. It is important to note that on one side of the seam, the thread direction of the weave is oriented diagonally to the seam, while on the other side, the thread direction runs parallel to the seam line. This shows that at least some parts of this textile were sewn together from pieces with diagonal cuts (fig. 4 and fig. 6c).

When the complex layers of textiles were removed from the surface of the brooches in the initial wet state, lumps of a vegetal mass and fibres were observed directly on top of the bronzes, which must come from Textile 2. Characteristically, these showed multiple stages of degradation, ranging from well-preserved and largely unaffected by deterioration to a slimy uniform grey-brown mass that would not have been recognised as coming from a textile without the context provided by the more well-preserved parts (see for instance fig. 2a and fig. 6c). Upon drying, this mass formed clay-like deposits around the fibres of the other textiles and on the surface of the bronzes, leaving a clear imprint of the textile that deteriorated after exposure to air. This clay-like deposit was found between different layers of Textile 1, indicating that Textile 1 (wool) was originally separated by layers of Textile 2 (likely flax).

Textile 3

When the bronzes were turned around, two layers of quite differently preserved textiles were discovered. On the inside of the right brooch and arching around the rim (x10), a well-preserved and still organic wool tabby was discovered (Textile 3). The weave is quite unbalanced with 31 threads per cm, a thread thickness of 0.4 mm, and a twist angle of 29° in one direction, and 10–15 threads per cm, a thread thickness of 0.3 mm, and a twist angle of 34° in the other direction (table 1). Although all yarns have the same twist direction (z/z) it is clear that in this case the production of the yarns, starting with the sorting of the wool, was specifically done in order to underline the unbalanced appearance of the weave. In this case warp and weft have an equal number of fine fibres while the content of medium and coarse fibres differs slightly. The warp has more coarse fibres and the weft more medium-range fibres. The difference in the sorting of the fibres for warp and weft yarns is thus not as marked as in the case of Textile

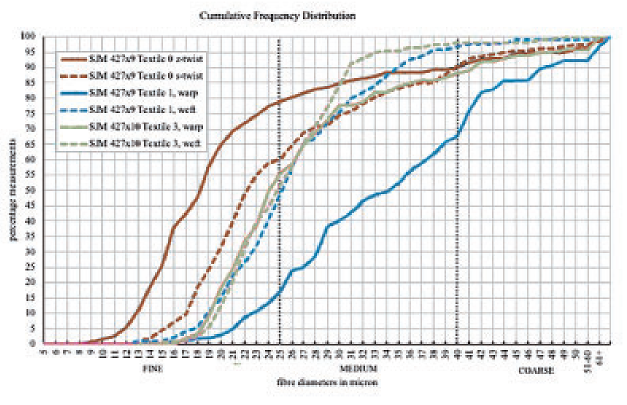


Fig. 7: The cumulative fibre diameter distributions of Textiles 0, 1 and 3 (Graphics: Irene Skals)

1. There can be little doubt that the wool used for Textile 3 came from the same fleece (table 3). Further, it was noted that during excavation Textile 3 appeared entirely black. The dye analysis revealed that both yarn systems were dyed with an indigotin-containing plant dye, most likely woad (table 2). Given that the fibres appeared almost black, it is assumed that the textile was originally a deep dark blue. It is important to note that at the rim of the right brooch a small piece of a hem was found (x10q, fig. 9). This features the

<table>
<tr><td>Bryndum SJM 427 x9 Textile 0</td><td colspan="6">Light with few pigmented fibres. The z-spun yarn has a majority of fine fibres and equal contents of medium and coarse fibres. The s-spun yarn has a majority of fine and medium fibres, and a content of coarse similar to the z-spun. This is an unusual fibre combination</td></tr>
<tr><td colspan="7">Calculations of fibre measurements in microns</td></tr>
<tr><td>Sample</td><td>% Fine</td><td>% Medium</td><td>% Coarse</td><td>Range</td><td>Category</td><td>No. of fibres</td></tr>
<tr><td>z-spun</td><td>79</td><td>11</td><td>11</td><td>9-34, 38, 40-43, 45, 47, 50, 61, 65-66, 70, 82, 104, 124</td><td>D</td><td>199</td></tr>
<tr><td>s-spun</td><td>64</td><td>26</td><td>10</td><td>12-36, 38-44, 46, 48-49, 53, 55, 64-65</td><td>CD</td><td>157</td></tr>
<tr><td>Bryndum SJM 427 x9 Textile 1</td><td colspan="6">Light, unpigmented fibres with traces of blue stains. The weft has a majority of fine fibres and very few coarse fibres while the warp has a majority of medium fibres and a larger content of coarse than of fine. Almost similar contents of medium fibres are recorded in warp and weft</td></tr>
<tr><td colspan="7">Calculations of fibre measurements in microns</td></tr>
<tr><td>Sample</td><td>% Fine</td><td>% Medium</td><td>% Coarse</td><td>Range</td><td>Category</td><td>No. of fibres</td></tr>
<tr><td>Warp</td><td>24</td><td>44</td><td>32</td><td>15, 17, 19-43, 46-48, 54-57, 59, 61-62, 66</td><td>D</td><td>105</td></tr>
<tr><td>Weft</td><td>58</td><td>39</td><td>3</td><td>12, 15-37, 39-40, 44, 70</td><td>B</td><td>95</td></tr>
<tr><td>Bryndum SJM 427 x9 Textile 3</td><td colspan="6">Light, few pigmented fibres with traces of blue stains. Similar contents of fine fibres are recorded in both yarns. The contents of medium and coarse fibres differ slightly in the yarns</td></tr>
<tr><td colspan="7">Calculations of fibre measurements in microns</td></tr>
<tr><td>Sample</td><td>% Fine</td><td>% Medium</td><td>% Coarse</td><td>Range</td><td>Category</td><td>No. of fibres</td></tr>
<tr><td>Warp</td><td>58</td><td>30</td><td>12</td><td>16-32, 34-36, 38-43, 46, 48, 51, 53</td><td>CD</td><td>100</td></tr>
<tr><td>Weft</td><td>58</td><td>40</td><td>2</td><td>14, 17-33, 35, 37, 39, 46, 48</td><td>AB</td><td>114</td></tr>
</table>

Table 3: The results of the analysis of textile fibres from Bryndum G12. The categories listed in the table refer to Rast-Eicher's categorisation (Rast-Eicher 2008)

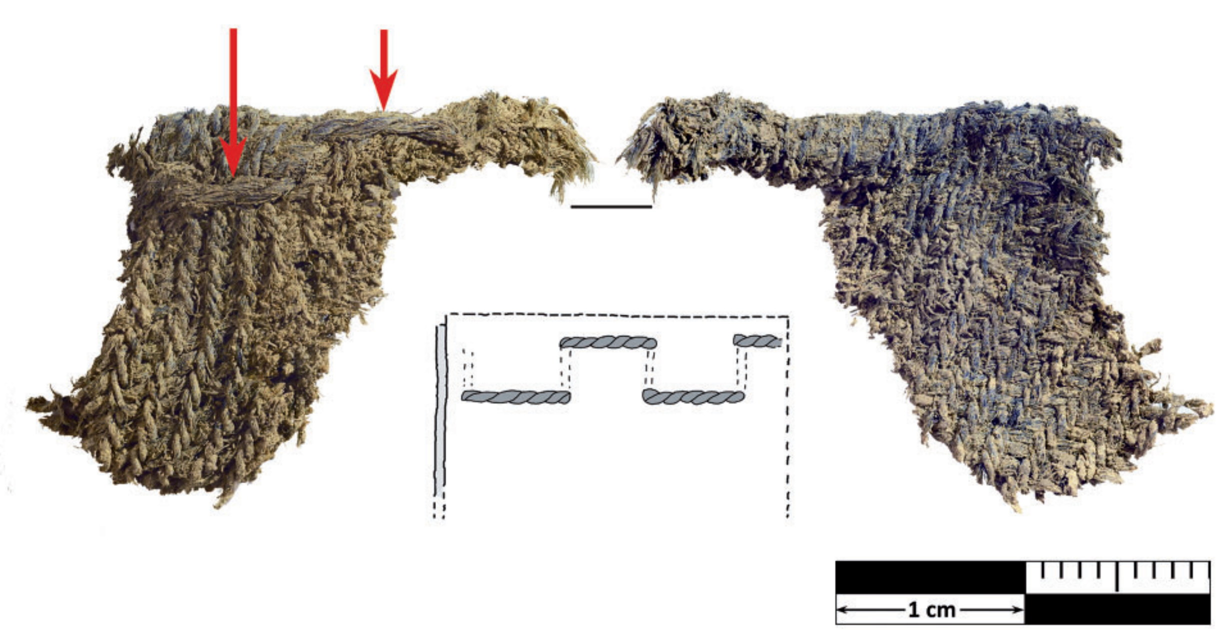


Fig. 8: Fragment x10p seen from both sides. This fragment consists of two layers of Textile 1 both having the Z-twill direction pointing outward, but note that the right image has the warp threads running perpendicular to the upper edge and the left image showing the opposite side has the warp threads running some 70° to the same edge indicating that the edge was not cut on the straight grain. Furthermore, a double sewing thread is seen on the left image forming a hem as seen on the drawing (Image: Lise Ræder Knudsen)

same characteristics and construction – with staggered running stitches – as described for Textile 1.

Further important features recorded inside the right brooch are the textile lumps located approximately at the upper end of the pin. These are heavily mineralised by the iron salts coming from the brooch pin (x10s, figs. 10 a, b and c). Together, they form a strap that was still visibly sewn to the parts of Textile 3 that touch the pin base at the lower edge of the brooch. Fragments of altogether four straps are preserved in situ around the pin catches and pin bases, showing that textile straps were placed around the pins coming from positions above and below the oval brooch. The strap preserved around the pin base of the right brooch is the most well-preserved specimen, and from this it is clear that it consists of a roughly 1.4-cm-wide tablet-woven band. This band was sewn together lengthwise using a S-2z-plied sewing thread, creating a round and sturdy strap (fig. 10). The band is woven using a simple pattern-weaving technique with at least 12 visible tablets, including the two tablets that form one of the band edges. These are threaded with four threads: one in each tablet hole. Unfortunately, due to the stitching, the other edge cannot be seen, but it most likely had an identical construction. The pattern section in the band consists of ten tablets threaded with two threads in the diagonal holes, which gives the surface of the band a more open structure (table 1). By regularly turning the tablets, a diagonal pattern emerged in the middle-part that reveals the weft to a higher degree than in the edges. This gives the band a twill-like appearance. It is further possible to see a reversal of the tablets' turning direction in one of the loose strap fragments (x10s), where the pattern-section tablets are turned in the opposite direction, while the edge tablets continue turning in the same direction (fig. 10). The independent rotation of the pattern tablets thus indicates a desire for disrupting or making variations in the surface pattern, rather than preventing the constant tablet-rotation in one direction unravelling the twists of the warps located on the far side of the tablets (Collingwood 1982, 106–107). The warp in the band is made of the same s-twisted threads approximately 0.75 mm in diameter, while the weft is z-spun with an approximate diameter of 0.85 mm. Altogether there are approximately 20 threads per cm in the warp and nine threads per cm in the weft.

Apart from the stitches joining the band edges, another type of stitch is placed horizontally to the edge of the strap. This Z-plied yarn most likely originates from the joining of the tablet-woven strap to Textile 3 (table 1). The loose strap piece located at :the midpoint of the pin inside the right brooch is in this way connected to the lower edge of a clothing item touching the

Fig. 9: Large piece (x10q) of Textile 3 found on the lower back of the right oval brooch. In the right area, a hem is preserved which has the same construction as in x10p seen in fig. 8 (Image: Lise Ræder Knudsen)

lower part of the brooch. The bent-together strap is approximately 3 cm long measured from the brooch edge to the strap fold. As the straps are heavily mineralised by iron corrosion from the pin of the brooches, it was not possible to take any samples for fibre and dye analysis. On the inside of the left brooch (x9), only a small mineralised part of Textile 3 is preserved at the lower edge. However, remains of the are still preserved in situ around the pin catches and pin bases, which must have been attached to a textile coming from above and below the brooches.

Textile 4

Preserved in the iron corrosion inside the brooches, remains of Textile 4 were discovered. These must have been placed closest to the body. The textile remains, very small and heavily mineralised, are primarily found on the pin bases. Visually determined, Textile 4 is most likely made of a plant fibre such as flax. However, it was not possible to extract any fibres for species determination, nor to take samples for dye analysis. The fabric is a fine balanced tabby with 14/14 threads per cm. The threads are z-twisted. The thread thickness averages around 0.5 mm and has a twist angle of approximately 33° for both thread systems. This is a significantly tighter twist than used in Textile 2 (fig. 11, table 1). All thread counts and measurements were taken on fragment x10r, which was located on the inner side of the right brooch. Additionally, corroded lumps of the tabby textile on the pin fasteners of both brooches have multiple folds. The lumps measure approximately 9 mm in height and have 3–4 folds per cm across the width. The folds are found below the pin bases and were not perforated by the pin but lie parallel to it and perpendicular to the edge of Textile 4. This suggests that Textile 4 was gathered in multiple folds or even pleated. More fragments with folds were found at the top of the left brooch (x9), indicating that the folding of the cloth also continued above the position of the brooches.

Interpretation

Six different textiles (including the tablet-woven band) are preserved in the Bryndum grave. Four were made from wool and two from plant fibres, most likely flax. Altogether the textile analyses show that the textiles found in close proximity to and on top of the bronze brooches are generally well-preserved and in an organic state, although extremely fragile. Most textiles found inside and underneath the brooches are hard and brittle, and in some cases completely mineralised by the iron corrosion coming from the pins inside the brooches. Only few of these textiles could be analysed, and fibre and dye analyses were only performed on the still-organic parts.

Regarding the position of the oval brooches in Grave 12, the excavation revealed that during the decomposition of the body, the right brooch was displaced approximately 30° relative to the left brooch. This probably occurred at the burial or shortly after, as indicated by the skewed position of Textile 3 (fig. 4 and fig. 10). In contrast, the left brooch most likely remained in the position it was in at the time of burial. In the contemporary Birka graves located on Björkö in Lake Mälaren in Sweden, similar information exists about the location of the preserved textile remains that are of great value for understanding the complex processes taking place during the decomposition of a body in a grave. Out of 163 graves with metal brooches, 140 contained preserved textile remains that show how textiles came into contact in various ways with oval brooches, sometimes resulting in a fabric originally placed below the brooches being found on the upper side of the brooch (Hägg 1974, 4–8). Consequently, misinterpretations may arise if it is assumed, without further consideration, that textiles found on top of the bronzes were also positioned in that manner at the time of burial. Based on the careful and detailed excavation documentation, it can be concluded that because the Bryndum textiles appear in the same layer sequences on both brooches, the recorded textile stratigraphy most likely reflects the original sequence at the time of burial (fig. 12).

This also means that three textile types and their connected sewing threads can be seen as items/garments placed above the oval brooches, while the others were placed underneath the brooches. The textiles found above the brooches all have very different constructions and appearances but are interpreted as coming from two different items. The quite thick and relatively coarse 2/2 wool twill, Textile 0, found on top of the Grave G12 brooches, did not contain any traces of dyes. The fibre analysis revealed that the white or light grey wool fibres have a fibre

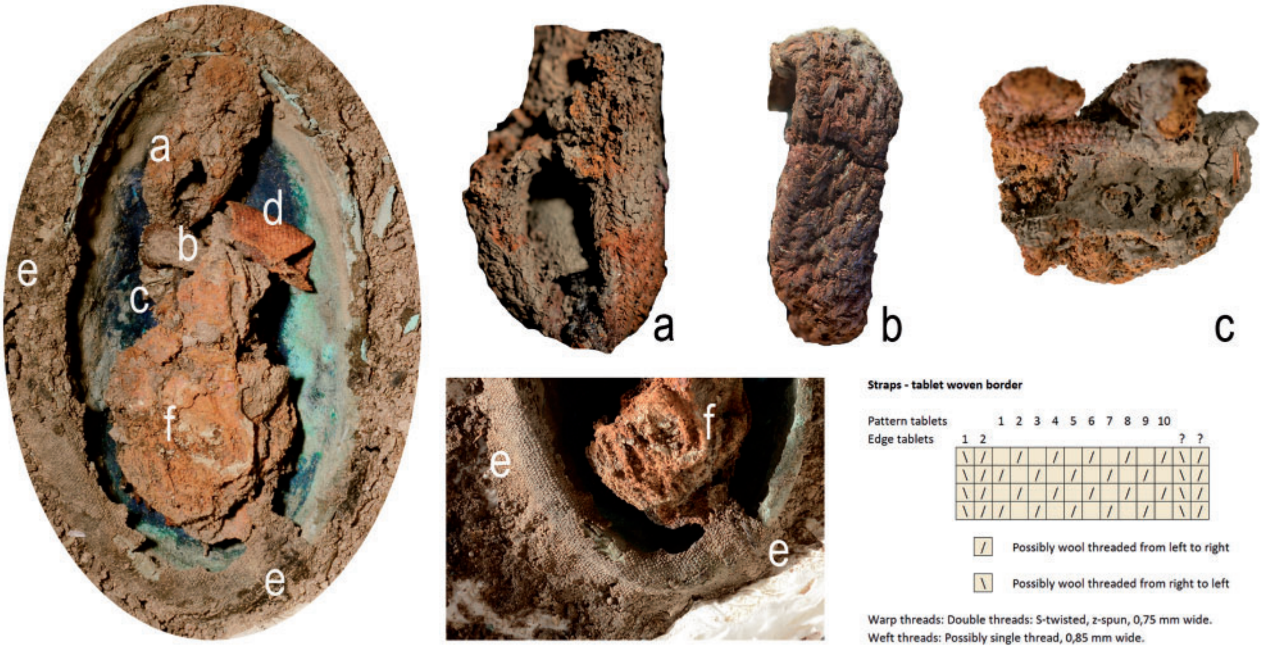


Fig. 10: The inside of the best preserved right oval brooch x10; a) the tablet-woven upper strap. The pin and pin catch can be seen on and below the strap; b) the lower strap. The tablet woven border was pattern woven using two threads in the opposite corners of each tablet by turning the tablets; c) a fragment showing the upper edge of the dress Textile 3, and at the top the remaining two ends of the strap b which were sewn to the folded upper edge of the dress; d) see fig. 11; e) the upper edge of the dress Textile 3 with the folded edge to the right. This textile was probably already twisted in relation to the brooch during the burial ritual. See also fig. 4; f) parallel to the pin on the oval brooch, many folds of textile 4 were seen – presumably remains of vertically folded pleats of the inner layer. Below right is a drawing showing the weaving instruction for the tablet-woven band (Images: Conservation Centre Vejle, graphics and instructions :Lise Ræder Knudsen)

quality that differs from the other textiles found in the Bryndum grave. The closest comparison is found in a twill weave from the female grave from Hvilehøj in northern Jutland, dated to the late tenth century (Mannering and Rimstad 2023, 8, 14; Skals et al. 2024a, 76–77). Just like Textile 0, the Hvilehøj textile has combined twist directions, but this textile was dyed with a blue dye source (Vanden Berghe et al. 2023). As far as it could be determined on the basis of the layer sequences recorded in the Hvilehøj grave, this textile, primarily found underneath fur, and the textile remains that are considered to have come from the deceased woman's clothing, was thus interpreted as a blanket or a cover for a mattress on which the body was placed. The positions of Textile 0 above the body, combined with the different and somewhat coarser fibre qualities, support the interpretation that Textile 0 represents the last remains of a blanket. Another possibility is that Textile 0 represents a duvet that was filled with threshed straw. Although no textile layers were found on top of the straw, traces of down trapped inside the threads in the weave indicate that the cover at some point was in close contact with feathers and down. If Textile 0 was originally a straw-filled duvet, then the top layer of the duvet's fabric would probably not have been preserved, as only textile in close contact with the oval brooches is preserved. It is thus most likely that the duvet – in an earlier life stage – was originally stuffed with feathers and down as is known from several other contemporary Viking Age graves (Rimstad forthcoming). The fact that the downs are only located inside the small fibre samples from Textile 0, and not among any of the other textiles in the block-lift, indicates that the change of the stuffing material, from feathers/down to threshed straw, happened immediately before or during the preparation of the grave.

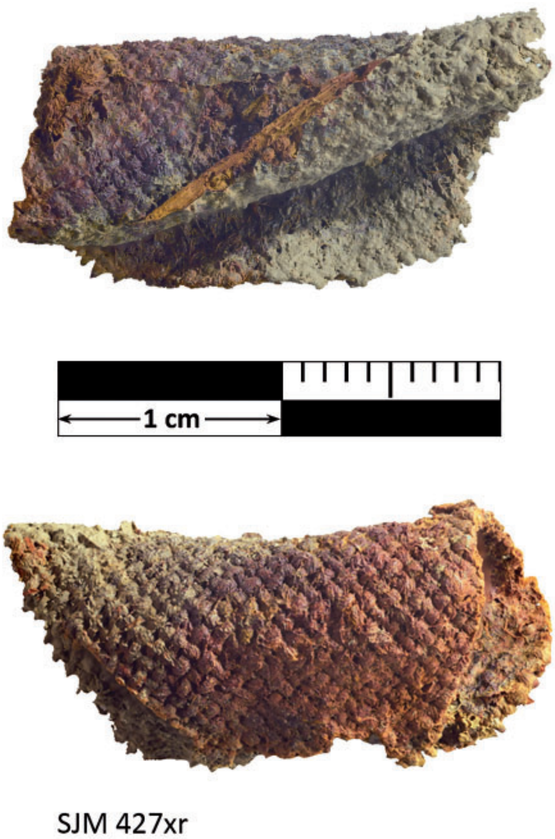


Fig. 11: Textile 4 presumably flax from the inner garment. The fragment is seen in fig. 10 d (Image: Lise Ræder Knudsen).

Textile 1, a 2/2 twill weave, was found in several layers on top of the oval brooches, right underneath Textile 0. In this case, the dye analysis showed that the wool textile, which also has a strong nap on the outer side of the fabric, was dyed in a deep blue colour. Additionally, the dye analysis revealed that in some areas the weft threads also contained traces of a red dye, which may have given the textile occasional or regular stripes in a more purplish/reddish tone. The technical details of Textile 1 combined with its many folds and the recorded hem and seams indicate that it was most likely used as a kind of clothing item. Although the many squeezed-together layers of Textile 1 are difficult to interpret, it is clear that this clothing item was rich in folds. As most of the textile joins do not follow the warp/weft thread directions, the different cuts suggest that the garment was at least partly tailored. Furthermore, Textile 1 was produced in such a manner that there was a significant and discernible difference between the appearance of the two fabric sides, with extensive napping predominantly – though not exclusively – on the side of the textile which has an S-directed twill structure, i.e. the side that appears to have faced outwards.

Although only a few small fragments of Textile 2 are preserved, it is likely that the balanced linen tabby, found on the inside of Textile 1 and thus directly on top of the oval brooches, served as a kind of lining for the garment made of Textile 1. The linen textile was not tested for dyes, but the current light greenish colour indicates that it was undyed. Due to the range of natural colours that plant fibres may achieve during processing, the colour could have ranged from white to greenish or greyish. The colour contrast between Textile 1 and 2, the outer and inner textile layers of this clothing item, would have been striking and even further accentuated by the quite different textures and feel of the fabrics. Textile 2 contributes an important understanding of the look of a highly degraded plant-fibre textile in a wet condition, as the clay-like substance detected around the wool fibres of Textile 1 most likely came from Textile 2. Furthermore, it is important to note that between the several layers of Textile 1, clay-like substances were found, indicating that Textile 2 (possibly flax) may have lined the blue wool Textile 1. The seam that joins pieces of Textile 2 with different thread directions indicates that this textile was tailored and cut-to-shape (see fig. 6c).

It is possible to interpret Textiles 1 and 2 as the outer and inner layers used for a tailored garment in which the blue or blue-reddish outer tweed-like fabric would have given an aesthetically pleasing contrast to the lighter inner lining. As the garment was placed on top of the oval brooches that supported another type of garment, it could have been a kind of linen-lined wool jacket as seen in some contemporary depictions (Bau 1981; Mannering 2017, 156–164). However, it should be noted that the wool twill did not feature a seam in the same position as the seam of the lining, as one would expect if it was a jacket. There are also other possibilities, for instance, that the seam of the lining represents some kind of repair.

Textile 3, which was found underneath the oval brooches, is a fine unbalanced deep blue wool tabby. The presence of a folded edge located in the layer found immediately under the edge of the brooches, as well as the straps connected to the folded edge placed around the pin catches and bases, suggest that this was a kind of dress held in place by the brooches on the chest. All four straps (two inside each brooch) are quite small and delicate, about 0.6 cm wide and with a strap length of ca. 3 cm. Although it is not possible to know if the upper straps were originally much longer, the lower connection to Textile 3 indicates that they were in fact not visible beyond the rim of the oval brooches. In the Viking Age, textile straps seem to be linked to the use of the quite heavy oval brooches – a well-known feature in the above mentioned Birka graves. In these graves, most straps are interpreted as coming from a suspended dress, although just as in the case of Bryndum, they can be made of different types of fabric from the dress and also in different fibre materials (Geijer 1938, 154–155; Hägg 1974; Bau 1981; Glæsel et al. 2010). The diagonal-patterned tablet-woven band from Bryndum that was sewn together lengthwise and cut into four identical parts thus created narrow but strong straps that were integral for carrying the weight of the dress (fig. 10). Interestingly, according to the available evidence from preserved finds, tablet weaving was not a widely

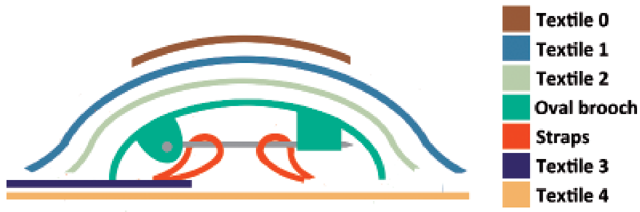


Fig. 12: The sequence of textile layers observed on the oval brooches in Bryndum G12 (Image: Lise Ræder Knudsen)

used technique in the Late Germanic Iron and Viking Ages in Denmark (520/40–1050 CE) (Bender Jørgensen 1986; Ræder Knudsen 2015). While tablet-woven bands were found in approximately 10% of all graves containing preserved textiles dated to the Roman Iron Age (1–400 CE) and around 23% in the Early Germanic Iron Age (400–520/40 CE), there are very few finds from the Late Germanic Iron Age (520/40–800 CE). In the Viking Age (800–1050 CE), the number of tablet-woven bands increases slightly to about 3%, especially due to the occurrence of specialised metal-brocaded silk bands (Ræder Knudsen 2015, 35; Mannering and Rimstad 2023; Mannering and Rimstad forthcoming). Altogether, this is the first time that dress straps made of a tablet-woven wool band have been recorded and are associated with Viking Age female clothing in this specific way.

Finally, Textile 4, a fine balanced linen weave, was found closest to the body. It was preserved within the iron-rust originating from the pins of the oval brooches. In this position, several textile lumps were found parallel to the pins but not pierced by them. The pleating or gathering of the textile into small, fine tucks, approximately 9 mm in width with 3–4 tucks per cm, is a feature well-known in the Viking Age. Especially in the Birka graves, remains of pleated inner dresses were recorded in around 20 of the 140 female graves that contained oval brooches with preserved textiles (Hägg 1974, 4, 26). Of these graves however, the majority are dated to the 900s, and only few such examples to the 800s (Hägg 1974, 36). As the tucks of Textile 4 are also found on the upper edge of the left oval brooch, it is obvious that this garment continued over the shoulders and thus represents an item worn underneath Textile 3. If, hypothetically, the textile had tucks in a front piece measuring 30 cm in the width and with four tucks per cm, each 9 mm deep, it would have required a fabric more than 216 cm wide, which is an impressive quantity of fabric. Garments made of plant fibres are known both in male and female clothing in the Iron Age, but the pleating technique is – in a Danish Viking Age context – unusual and has until now not been recorded in female graves. This adds a new feature to the design of the clothing in Grave G12, and hints at a technical construction and visual appearance that opens for connections to areas beyond the local.

Conclusion

If it were not for the oval brooches preserved in the Bryndum woman's grave, it would have been difficult to date the cemetery more precisely than simply ranging from the ninth to eleventh century. This would make it contemporary with the earliest Christian burials in Denmark found in the cemetery at Ribe cathedral (Søvsø 2020, 185–200). Thanks to the chronology of the jewellery and the 14C-dating we now know that the Bryndum woman lived in the ninth century.

Even if it is difficult to be specific about the exact use of the textiles preserved in Grave G12, it is clear that the grave contains textiles and clothing items that match the general textile production trends of the period (Bender Jørgensen 1986, 317–324), but that also contain unusual details that offer new information. Six different textiles are preserved, four textiles made from wool and two from plant fibres. Three of these textile types and the connected sewing threads are found on top of oval brooches and three textiles are found underneath the brooches. Textile 0 is based on the thick and warm weave interpreted as a furnishing textile made of white or light grey wool such as a blanket or duvet cover perhaps filled with threshed straw at the funeral, but earlier filled with down. Textiles 1 and 2 are interpreted as being part of the same item, possibly a garment, that to some extent was cut to shape and sewn together. The outer layer consists of a blue or blue/reddish/purplish striped tweed-like wool textile with a strong nap on one side. Finally, the fine repp-like and blue-dyed wool tabby that was held together by the straps placed inside the oval brooches is a well-known feature of Viking Age female clothing. The fact that the straps are made in the tablet weaving technique is however unusual. We may imagine that the quite voluminous linen gown gave a beautiful colour contrast to the blue wool dress.

Although the small preserved textile fragments miraculously preserved in the Bryndum grave cannot be used to reconstruct a complete outfit, the Bryndum woman was undoubtedly buried in well-crafted textiles that fit into the known Viking Age cloth culture. Further the maker of the textiles and the outfit were creative in their design in ways not often preserved. The Bryndum woman was undoubtedly buried in an outfit that had deep roots in an earlier Iron Age clothing tradition (Mannering 2017; 2024), and she was sent to the afterlife in style.

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A blue pile textile dating to the Viking Age from Saaremaa, Estonia

Abstract
A wool textile with a pile surface on one side was found in a bog in Pöide, Saaremaa Island (Estonia), in the 1870s. It was brought to Finland in 1878 and donated to the National Museum collections of Finland soon after. Radiocarbon 14 dates the find to the Viking Age. This fragmentary textile is the oldest significant piece of textile available for study from Estonia and is a remarkable find for the north-eastern Baltic region. The first detailed analysis of the Pöide textile shows that the warp, weft, pile and braid bordering the textile all contain indigoids, suggesting an originally blue *vararfeldur* textile.

Keywords: pile weave, Viking Age, *vararfeldur*, Baltic Sea, dye analysis

Introduction

Archaeologists do not always have to participate in fieldwork to collect new finds. It is sometimes meaningful to carry out "excavations" in institutions dealing with heritage objects, such as museum collections, laboratories, and conservation facilities. Scientific methods and the current base of knowledge give further opportunities for new interpretations and discoveries based on forgotten finds.

The present paper introduces the discovery of an extraordinary textile fragment (KM1931:2) (fig. 1) in the National Museum of Finland storage facilities, based in Helsinki, that, according to the archival records, reached the museum collections almost 150 years ago from neighbouring Estonia. Once radiocarbon 14 dating (14C dating) had confirmed that the fragment was dated to the Viking Age (800–1050 CE in Estonian chronology), it became clear that this is one of the oldest textiles ever unearthed in Estonia. Fewer than ten tiny thread and fabric fragments are known from earlier periods (Peets 1992, appendix 4, table 28). The following paper describes the Pöide textile, gives an overview of the results of detective work carried out in the archives and through analysis, and places this single piece in a broader north European context.

The discovery of the Pöide textile

The Pöide textile was discovered more than once. First, a Finnish student, Oskar Anders Ferdinand Lönnbohm (1856–1927), made a one-year trip to the area of present-day Estonia, which, like Finland in 1877, was part of the Russian Empire. The contact between the two countries has always been close; Finnish and Estonian people are closely related, and both languages belong to the Baltic Finnic languages (Uralic language family). Lönnbohm, genuinely interested in the Estonian language, visited several places in northern and western Estonia and compiled the first Estonian Finnish dictionary (Mustonen 1882). In addition to studying the language, he collected objects to which he attributed heritage value. Among other things, he acquired an archaeological textile while he was on Saaremaa Island. In 1879, he donated this piece, along with a few other Estonian objects, to the Finnish Antiquity Society. The collections of this society were later merged with the National Museum of Finland, where the textile is currently preserved, labelled as "a shawl or a dress fragment" and provided with some incorrect contextual information. After this first discovery, the item was forgotten.

The second documented discovery of the textile find occurred nearly 50 years later. It was mentioned by another Finnish scholar, the archaeologist Aarne Michaël Tallgren (1885–1945), who was the first Professor of Archaeology at the University of Tartu (1920–1923). He highlighted the textile as an extraordinary find in an article introducing Estonian archaeological artefacts in the National Museum of Finland (Tallgren 1925). He also corrected the mistakes in the find context in the museum documentation and collected new folkloric information on the initial discovery on the island of Saaremaa. After this brief attention, the Pöide textile was again left in storage for decades. The artefact was rediscovered at the beginning of the 21st century when study of the textile began and various specialists continued discussing its "life trajectory".

Archaeological context and find location

The earliest preserved notes on the find circumstances are in the National Museum of Finland's documentation, which state that the find location was a bog near an ancient hillfort 1.5 versts north-east of Pöide church on Hiiumaa Island (KM catalogue, no. 1931). The verst is a historical Russian unit of length equal to 1.0668 km. Thus, the distance referred to is approximately 1.6 km. However, the records are wrong in two aspects: first, the direction and second, placing the find on another Estonian island, Hiiumaa. As Tallgren (1925, 38) already proved, the other landmarks (hillfort, bog, Pöide church) in the description leave no doubt that the textile was unearthed on Saaremaa, where the only bog, called Kareda, is located westwards from Pöide church (fig. 2). Like many other well-preserved northern European textiles made of wool, the Pöide item was discovered in the 1870s while cutting peat to a depth of 1.5–2 ells (approximately one metre). Regrettably, the workers' peat shovels tore the original item of clothing apart, and only this fragment is preserved. The estimated find location is relatively easy to locate according to the corrected description, which points to the edge of the Kareda bog. A LiDAR map even shows outlines of some trenches from the time when peat was still cut by hand at the edge of the bog near the hillfort (fig. 3). The putative area of the find location is approximately 2.4 km northwest of Pöide church.

Fig. 1: The Pöide textile, pile side (Image: Krista Wright)

Considering the broader context of the find location, the nearby Pöide Stronghold is worth highlighting. The hillfort is located approximately 0.5–1 km from the assumed find location, near the Kareda bog. The first traces of a settlement on the hillfort are dated to the period around the beginning of the Common Era (Lõugas and Mägi 1994, 29). The first fortification here was built in the seventh to eighth century CE, and the site was also in use during the Viking Age (Mägi et al. 2023, 74; Lõugas and Lõugas-Mägi 1994, 32). Moreover, one of Saaremaa's largest seventh to tenth-century harbour sites, at Tornimäe, is located 6.3 km eastward from Pöide Stronghold. Based on similar find material it has been suggested that the sites were closely related (Mägi 2005, 66). However, the heyday of Pöide Stronghold came later – most of the finds at Pöide belong to the 11th to 13th centuries (Mägi et al. 2023, 87–88). The central location of the Pöide area is stressed by the fact that the church, a

Fig. 2: Location of Saaremaa Island (Estonia) and sites mentioned in the text. The hatched area indicates Kareda bog (Image: Riina Rammo)

parish centre, was built in the 13th century after the Crusades and the Christianisation of Estonia at the beginning of the same century.

Methodology

The structure of the Pöide textile was first examined with a low magnification stereo microscope (Leica S6D with EC6 camera and Las EZ 3.4.0 software). The technical details of the textile were documented, and the following characteristics observed: fibre material, weave, thread count, spin direction of yarns and twist angles, yarn diameter, colour, traces of the finishing process, and notes on other specific characteristics.

Three samples from the warp, weft and braid were taken to examine the wool using optical and scanning electron microscopy (Jeol 7500 FA) coupled with an energy-dispersive spectrometer (SEM-EDS). One hundred fibres from two samples (warp and weft) were placed on the microscopy slide, mounted with Entellan New, and measured according to the procedures of archaeological textile research (Leica 2500 TLM, Leica MC190HD camera, and LAS V4.13.0 software) (for example, Nahlik 1963, 229–242; Ryder 1969; 1974; 2000; Kirjavainen 2005; Rast-Eicher 2008; Gleba 2012; Skals et al. 2024). Fibre diameters, pigmentation, and the presence of medullated hairs were systematically documented. Key statistical parameters, including average diameter, mode, standard deviation, and coefficient of variation, were calculated. The proportion of wool fibres across different diameter ranges, along with their relative distribution within the sample, characterises the specific wool selected for this textile. The natural colour of fibres and the diameter distribution was analysed in more depth to make assumptions on the sheep breed and fibre processing.

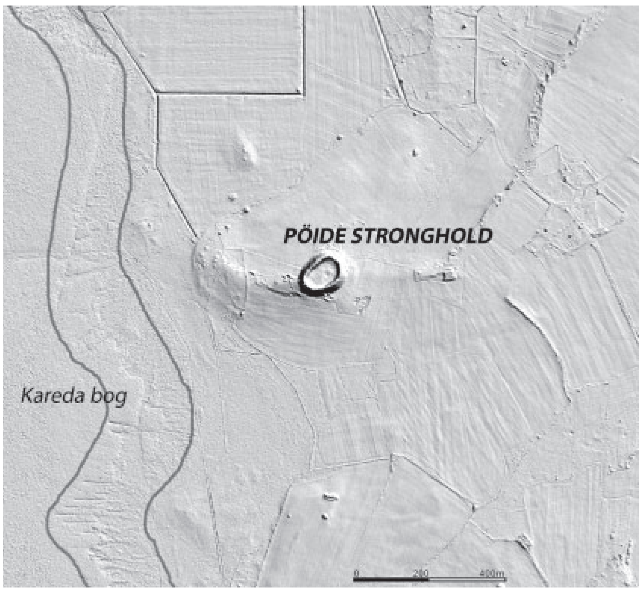


Fig. 3: Relief map of the putative find location. The edge zone of the Kareda bog is marked with grey lines (Image: Estonian basic map 2025, Republic of Estonia Land and Spatial Development Board)

Fig. 4: a) tubular selvage with the braid; b) microphoto of dark plied sewing thread (see arrows) used to attach the braid (Images: Krista Wright)

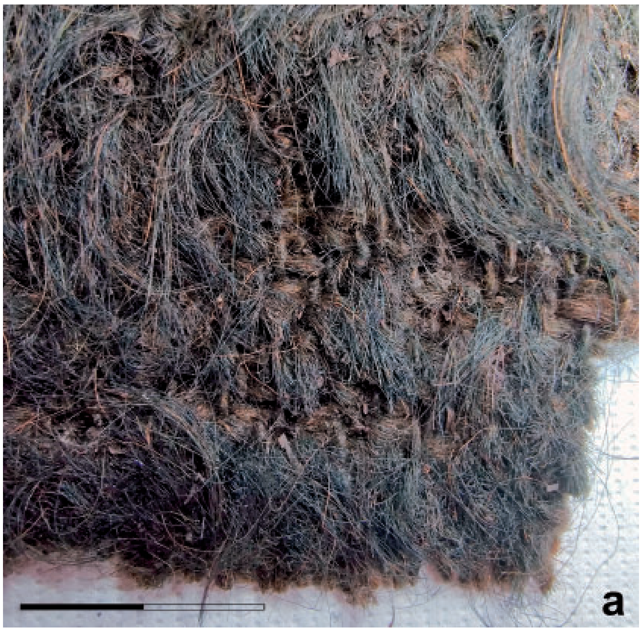
To ensure comparability with previous studies, we classified the fibre distribution of the Pöide samples using established systems developed by Michael L. Ryder (1969; 2000) and Antoinette Rast-Eicher (2008; Rast-Eicher and Bender Jørgensen 2013). Ryder's classification is based on the evolutionary development of six fleece types and corresponding sheep breeds, while Rast-Eicher's system distinguishes 11 wool types, taking into account fibre processing techniques (Gleba 2012, 3656). The most recent and comprehensive overview of these classification methods, including a critical evaluation, has been published by Irene Skals, Ulla Mannering, and Eva Andersson Strand (2024, 30–34).

A sample of the weft yarn was radiocarbon-dated in the Tandem Laboratory at Uppsala University (Sweden) (Ua-74375) and calibrated with IOSACal v0.4.1 (Mucke 2022). Further, four samples (warp, weft, pile, braid) were analysed for dyestuffs in the Royal Institute for Cultural Heritage laboratory (KIK-IRPA) in Brussels (Vanden Berghe and Coudray 2024). The analyses were conducted using high-performance liquid chromatography and a photodiode array detection system (HPLC-DAD) with Acquity Arc HPLC equipment (Waters, US). The analyses were interpreted using the Empower software system from Waters. Separation was achieved using a LiChrosorb RP-18 end-capped column. The dyes were extracted in 250 µL water/methanol/37% HCl (1/1/2, v/v/v) for ten minutes at 105°C, followed by a second extraction with 500 µL of ethyl acetate. After vacuum evaporation of the upper phase, the residue was dissolved in 30/30 µL methanol/water, from which 20 µL was injected into the chromatographic system. A detailed description of the analytical protocol was published by Vanden Berghe et al. (2009).

Findings

The textile is approximately 15 × 27 cm in size (fig. 1), woven in 2/2 twill using z-spun yarns. The fabric is relatively coarse with a density of seven threads in the warp and six in the weft per cm. The warp yarns are notably thinner (1–2 mm in diameter) and more distinct than the thicker and fluffier weft (2–4 mm in diameter), and both thread systems have a twist angle of 45°. The warp and weft threads are clearly distinguishable because of the preserved tubular selvedge approximately one cm wide and woven in tabby (fig. 4). To create a hollow tubular-like selvedge, the weft is woven in tabby fashion as it approaches the edge, but on returning it misses the outer few warp threads (Walton Rogers 2007, 88). An approximately one cm wide simple braid, made presumably of six loosely spun threads (z, twist angle 20°) and looking like a simple but thick plait, is sown onto the selvedge with a dark blue S2z plied thread (2–3 mm in diameter) (fig. 4).

One side of the textile is further covered with a dark pile of wool tufts with a blueish tint that creates a furry surface (fig. 5). The preserved pile is 3–6 cm long but heavily worn and was initially longer. Pile tufts seem to lie in the direction that is roughly parallel to the selvedge. The wool locks, perhaps lightly twisted, were inserted into the shed while weaving and looped around the warp yarns. It is impossible to see a fixed structure and rhythm of inserted wool locks, but it seems that every wool tuft turns over one warp and then runs over four warps in every shed row. Tufting ascends from the left to the right. The system is similar to 11th-century Icelandic and Greenlandic finds (Guðjónsson 1962, fig. 5; Østergård 2004, fig. 50; Hopkin 2021, fig. 4). The pile has been inserted in the



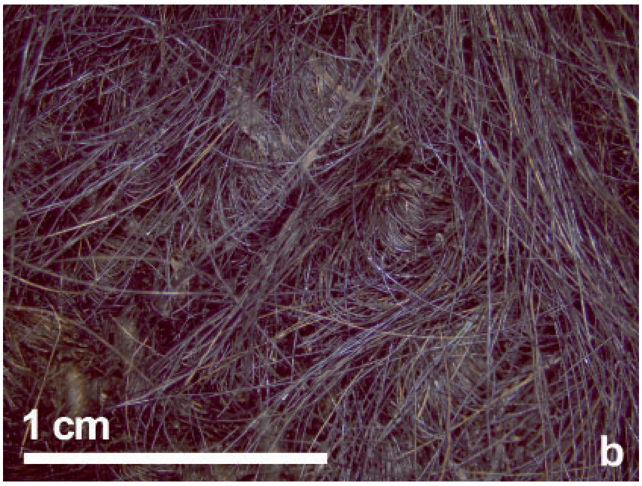


Fig. 5: a) close-up of the pile with some places where wool tufts have been wrapped around the warp yarns, as visible on the left; b) microphoto of a wool tuft wrapping (Images: Krista Wright)

shed so carefully that it is hardly visible on the other side of the textile, which looks like a plain 2/2 twill (fig. 6).

The wool used in the warp, weft, and braid consists of a mixture of fibres in various natural shades, all dyed blue (fig. 7). Visually, the wool in the warp appears slightly lighter than that in the weft, while the pile is more uniformly coloured but darker than the weft. However, fibre analysis does not indicate a sharp distinction between the warp and weft, as the blend of natural fibre colours is relatively similar (fig. 8, table 1). The majority of fibres are white (82% in the warp and 70% in the weft) and brownish (16% and 28%, respectively) in both samples; blackish fibres were rare. Notably, the proportion of medullated fibres is relatively high – approximately 40% in both yarns –, and medullation was also observed in finer fibres.

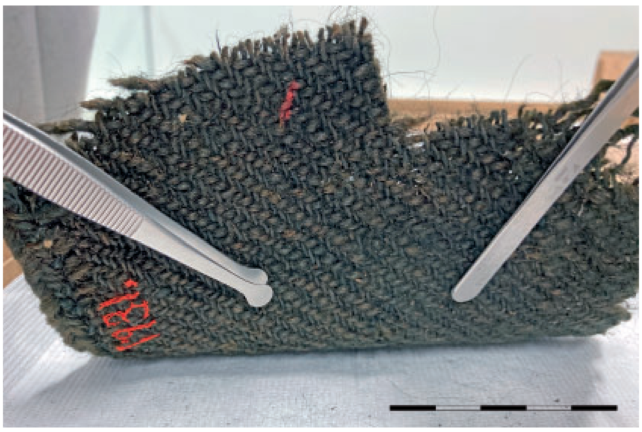


Fig. 6: Pöide textile, non-pile side (Image: Krista Wright)

We attempted to classify the wool samples using the most commonly applied systems based on fibre diameter distribution to make the results comparable with the earlier studies. The warp yarn aligns well with Ryder's Hairy Medium fleece type: fibre diameters range from 9–64 µm, with a mean of 30 µm and a mode of 22 µm, and the distribution is positively skewed (table 1, fig. 7; Ryder 2000, 4). According to Rast-Eicher's classification, the warp wool corresponds most closely to the CD type: 78% of fibres are < 40 µm, 19% > 40.1 µm, and 3% > 60 µm (Rast-Eicher 2008). In contrast, the weft wool does not fit neatly into either Ryder's or Rast-Eicher's categories. It falls between the Hairy and Hairy Medium fleece types, with a relatively high mean diameter (36 µm), a diameter range of 14–64 µm, and a slightly positively skewed distribution. Within Rast-Eicher's framework, the weft wool most closely resembles types D or E: 61% of fibres are < 40 µm, 31% > 40.1 µm, and 3% > 60 µm (Rast-Eicher 2008). The conclusion of both classifications is the same: the wool of the Pöide textile is uneven and lacks uniform distribution around a single modal peak.

Given the heterogeneity and the variety of natural colours, the wool used in the Pöide textile probably originates from the double-coated fleece of native northern short-tailed sheep (e.g., Rammo 2015, 134; for sheep: Tapio 2006, 17–19; Walton Rogers 2004, 86). These sheep are characterised by short tails, horns, and a wide range of fleece colours, and were widespread across northern Europe during

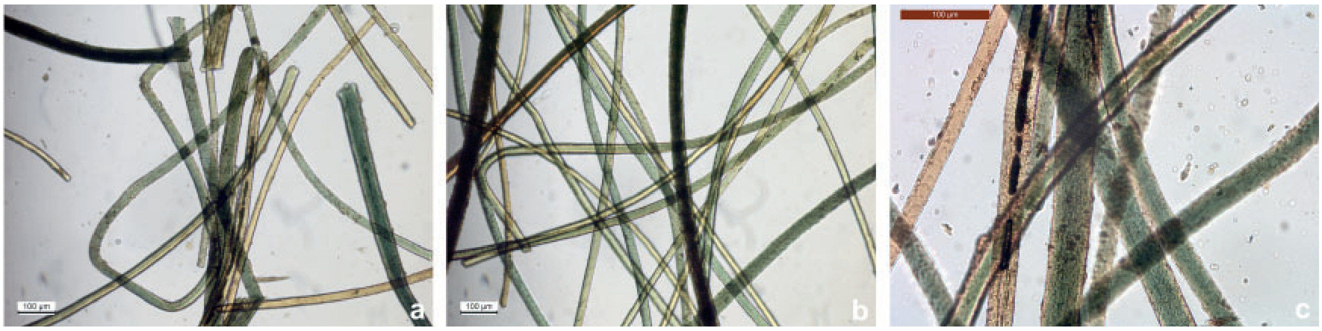


Fig. 7: Microphotos of wool fibres: a) warp; b) braid; c) weft (Images: Krista Wright)

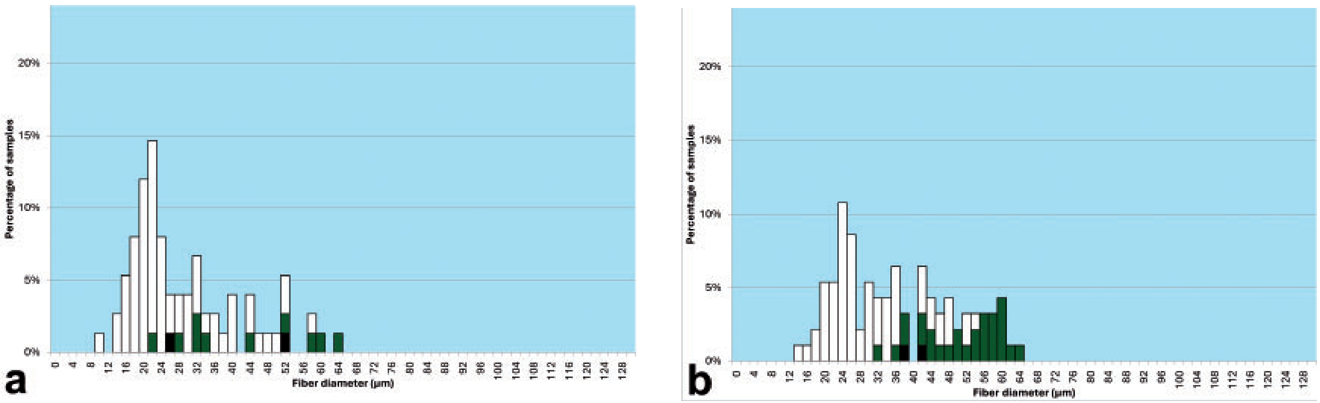


Fig. 8: Results of wool fibre measurements: a) warp; b) weft (Images: Krista Wright)

the Viking Age. Obviously, the wool was sorted and processed prior to spinning, as the proportion of finer fibres is relatively high and fibres thicker than 60 µm are rare (3%). The coarsest fibres were probably removed through combing, a common method in the Nordic region during that period. Slightly different wool types were selected for the warp and weft: the warp contains more fine fibres, while the weft includes a greater proportion of medium and coarse fibres (fig. 8).

Carbon 14 dating shows that the textile was made in the ninth to tenth century. The calibrated age of the fragment falls in the range of 775–977 CE (with 95.4% probability) (fig. 9). This means the Viking Age in the Baltic Sea region.

The HPLC-DAD analysis of warp and weft, and the pile and braid samples revealed the presence of dye molecules of indigotin, indirubin and isatin in all four samples, meaning blue dyeing with an indigoid-containing dye plant such as woad (*Isatis tinctoria*) or tropical indigo (*Indigofera* spp.) (Vanden Berghe and Coudray 2024). Based on the chemical composition detected in the extracts, it is not possible to distinguish between these two plant sources. Considering the historical context of the textile and presuming that the textile was not of Oriental origin, it is probable that woad was the dye source. Trading in tropical indigo pigment only started in this region in the 16th century (Peets 1998, 307; Vajanto 2015, 56–28; Rammo et al. 2022).

	WARP	WEFT
Range	9, 14-55, 58-61, 64 µm	14, 17-38, 41-64 µm
Mean	30 µm	36 µm
Mode	22 µm	24 µm
Median	24 µm	34 µm
SD	12,87	12,98
Coefficient of variation	43%	46%
Medullated	38%	43%
White wool	82%	70%
Brownish wool	16%	28%
Blackish wool	2%	2%

Table 1: Results of wool fibre analysis, counted in a sample 100 fibres (Image: Krista Wright)

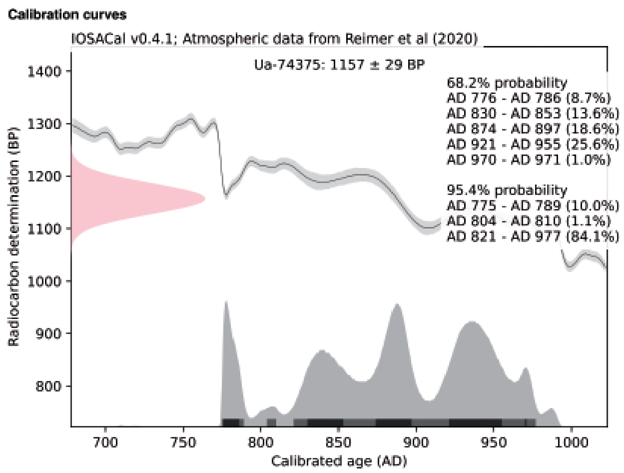


Fig. 9: Calibration curve of the 14C-dating (Image: after Mucke 2022)

Indigotin was found in every sample, although there is a slight difference in the hues in warp, weft, braid and pile, indicating that the wool of the yarns and pile were dyed separately before weaving. The available documentation produced over the years following excavation contains no information regarding the original colours of the textile. Although to date dye analysis has identified only a blue dye derived from woad (or possibly indigo), the absence of other colours does not necessarily indicate their original nonexistence. It remains possible that more delicate organic dyes have degraded or disappeared in the approximately 150 years since the excavation.

Discussion

Pile weaves in Viking Age Europe

The Pöide textile represents a cloth type called shaggy-pile weave. The defining characteristic of pile weave is the additional fibre tufts or threads worked into the fabric when weaving (Guðjónsson 1962, 65; Walton Rogers 2007, 85). There are various ways to achieve the shaggy effect: laying the wool locks in the shed (knotless pile) and winding or tying them around the warp threads (knotted pile) (Guðjónsson 1962, 65). Sometimes the pile is made of spun threads (Hägg 1991, 97; Hayeur Smith 2024, 54). Another possibility is to add the pile by darning in lengths of wool after weaving. Since the exact technique used to create the pile can be difficult to determine when it comes to archaeological textiles (Walton 1989, 335–336) and few technical details are published, this overview does not distinguish between different methods.

In general, piled textiles are widely spread in terms of time and geography (for example, Guðjónsson 1962, 70–71). The most up-to-date overview in a European context is given by Michèle Hayeur Smith (2024, 68–72); what follows mainly focuses on Viking-Age northern Europe. Piled textiles are relatively rare among archaeological finds, forming a heterogeneous group in terms of quality and technical detail. For instance, sixth to seventh century English dyed pile weaves are considered to be luxury textiles, often recorded in high-status male graves. One of the most famous examples comes from the Sutton Hoo ship burials (Walton Rogers 2007, 85). Pile weaves also occur in the eighth-century textiles from the Valsgärde boat graves in Sweden (Arwidsson 1942, fig. 68, 92–93).

Finds of archaeological piled textiles from the Viking Age are even more numerous. At least three bluish-reddish piled fragments have been found in ninth to tenth century Birka graves, also in Sweden (Geijer 1938, 131–132). However, compared to the previous examples, coarser piled fabrics dominate in the 9th to 11th centuries. The geographically closest parallel to the Pöide fragment could be several small coarse reddish pieces with sections of interwoven wool strands, found in a ninth-century deposit at Tīra peatbog, Latvia (Žeiere 2008, 136). Other textile finds are known in Scotland (the Isle of Eigg) and the Isle of Man, England (York), Ireland (Dublin), Germany (Haithabu), Poland (Wolin), Sweden (Lund), Norway (Borgund and Trondheim), Iceland and Greenland (Guðjónsson 1962, 66–68; Lindström 1982, 182; Maik 1988, 176–178; Walton 1989, 336; Hägg 1991, 97–99; Bender Jørgensen 1992, 39; Pritchard 1992; 2017, 120; Østergård 2004, 74; Hayeur Smith 2024). The most extensive collection of 37 piled textile pieces has been documented at Borgund in Norway, dating to the Viking Age and Medieval period (Hayeur Smith 2024, 63).

The most common weave used for piled textiles is plain 2/2 twill woven using yarns with opposite spin-direction (z/s), although other combinations also occur: for example, tabbies and 2/1 twills, or the same spin direction in warp and weft. The pile mainly comprises weakly or unspun wool locks inserted in the fabric during the weaving (Guðjónsson 1962, 66–68; Lindström 1982, 182; Maik 1988, 176; Bender Jørgensen 1992, 39; Pritchard 1992; 2017, 120; Østergård 2004, 73); more rarely, spun threads were inserted into the weave (Maik 1988, 176–178; Hägg 1991, 97–99; Hayeur Smith 2024, 63). In general, the Pöide textile matches well with the abovementioned piled textiles where the typical traits are relatively coarse 2/2 twill weaves and a pile consisting of unspun wool tufts looped around the warp yarns. However, no such fabric combining z-yarns in warp and weft systems has been found.

Regrettably, dye and wool fibre analysis of piled textiles has been conducted rarely. One Greenlandic piece contained a lichen dye and another was dyed with tannin-rich dyestuff (Walton Rogers 2004, 89; Østergård 2004, 74), while in one Dublin fragment an unknown local orange-reddish dyestuff was detected (Pritchard 2017, 120). The Tīra bog tabby fabric was visually reddish (Žeiere 2008, 136). No indigoid dyes have been reported in these coarse twills so far.

All three Greenlandic pile weaves were made of Ryder's Hairy Medium fleece type in both warp and weft (Walton Rogers 2004, 84). This aligns relatively well with the Pöide analysis results. Unfortunately, it remains unclear whether and to what extent the wool fibre composition of the warp and weft yarns differed. Penelope Walton Rogers notes only that, since the fibre distribution results of piled fragments differ markedly from local Greenlandic textiles, the items must have originated elsewhere (Walton Rogers 2004, 84). Specifically, local twill weaves tended to show a coarser fibre blend (Hairy in Ryder's classification) for warp as this thread system needs more strength when weaving. Similar results have been obtained in a study of Viking Age textiles from Denmark (Skals et al. 2024, 42–44). The described fibre distribution pattern also differs from that of the Pöide textile, which features a coarser blend in the weft thread.

Estonian and broader north-eastern Baltic context

Due to the prevalence of cremation burials, textiles are rare in Estonian archaeology before the 11th century, and comparisons for the Pöide textile are thus missing. However, in the 11th to 13th centuries, a relatively well-defined local weaving tradition can be observed based on the preserved textile finds. The Estonian mainland and islands share specific textile technology with south-western Finland in this case, which it can be traced back to at least the beginning of the Viking Age (Bender Jørgensen 1992, 96). This Finnish-Estonian weaving tradition shares several generic features that characterise textile cultures from various periods across Europe, including the Viking Age Nordic region. For example, the Hairy Medium or Hairy Medium/Generalised Medium wool types interpreted as coming from local double-coated fleeces (Peets 1992, 11–34; Vajanto 2013; Rammo 2015, 133–135), the preference for twill weave for wool cloth, and usage of indigoid blue dyestuff, most likely originating from woad (Lehtosalo-Hilander et al. 1982; Riikonen 2003; Vajanto 2015; Rammo et al. 2022), can be cited. Tubular selvedges typical of weaving on the warp-weighted loom are also preserved in Estonian and Finnish textiles (Lehtosalo-Hilander et al. 1982; Riikonen 2003; Rammo and Tamla 2022, 25–26). The structure of some finds is identical to the Pöide textile's tubular selvedge.

A distinct feature of the Finnish-Estonian weaving tradition is the combination of plied warp yarns (S2z) and single weft yarns (z) in 2/2 wool twills (see for example, Bender Jørgensen 1992, 140; Riikonen 2022, 67; Wright and Sahramaa 2023; Wright and Suomela 2025). The Pappilanmäki type (S2z/z, 2/2 twill) named by Lise Bender Jørgensen, is in fact rare in all other Viking Age textile collections in northern Europe (Bender Jørgensen 1992, 96, 100, 140). In neighbouring areas, for example, Scandinavia, Latvia, north-western Russia, and eastern Finland, it is more common to use single yarns in warp and weft. Further, warp yarns are usually z-spun, while the spin direction of the weft varies according to cloth type, specific region and period. In tenth to eleventh-century Scandinavia, z-spun yarn in warp and s-spun in weft in plain 2/2 twills was the most common combination (Bender Jørgensen 2003, 136; Hayeur Smith 2015, 31), which also holds for the 11th-century pile weaves found in Iceland and Greenland. However, the z/z twisted plain 2/2 twills were more popular, for example, in Gotland, Iceland, and Norway (Bender Jørgensen 1992, 138; Hayeur Smith 2015, 27). Regrettably, the spin direction of the Norway shaggy pile weaves is not known; a comparison of this data with that of the Pöide textile would have been of particular interest. Z/z twisted 2/2 wool twills were also produced in Latvia, eastern Finland and occasionally in north-western Russia during the Viking period (for example, Zariņa 1970; 1988; Orfinskaya and Mikhaylov 2020, 44; Vajanto 2021, 60–63), although pile weave does not seem to be a typical textile feature in these regions. Apart from one exceptional find from the Tīra peat bog, no Viking Age shaggy pile weaves have been reported in eastern and east northern Baltic countries (for example, Nahlik 1963; Zariņa 1970; 1988; Lehtosalo-Hilander 1984; Riikonen 2004; Hvoštšinskaya 2004, 110–126; Žeiere 2005; 2017; Orfinskaya and Kotškurkina 2014; Orfinskaya and Mikhaylov 2020).

The provenance of the Pöide textile

Given this Finnish-Estonian weaving tradition with use of a plied warp in wool fabrics, the Pöide textile does not fit into this production scheme, indicating that it could be a non-local textile item that reached Saaremaa Island from abroad. The question about the Pöide textile's provenance is not easy to answer. Coarse pile fabrics in Ireland and Scotland share the same uncertainty about provenance (Bender Jørgensen 1992, 39; Walton Rogers 2007, 85–86; Pritchard 2017, 121). According to archaeologist Irita Žeiere (2008, 136, pers. com. Žeiere 2025), the Tīra bog tabby piled fabric with z-spun yarn in warp and s-spun in weft is atypical for the local weaving tradition and must have been brought from elsewhere.

Although several authors have stressed that piled textiles, for example in the form of cloaks, were produced widely in Iceland from the tenth century and traded along with *wadmal* to Scandinavia, this assumption is primarily based on written sources (Guðjónsson 1962, 68–69; Hayeur Smith 2024, 53–54; Hopkin 2021, 31–32). A recent study on Icelandic and Norwegian archaeological textiles using strontium isotope analysis to determine wool provenance contradicts this popular theory of pile weaves being an Islandic commodity in Viking Age long-distance trade (Hayeur Smith 2024, 73). Hayeur Smith argues that piled textiles were spread throughout north Europe and made locally in various places (Hayeur Smith 2024, 54). It remains unclear at this stage how this outcome corresponds with the observation that the fibre distribution in the piled textiles from Pöide and Greenland deviates from the established Greenlandic and Danish Viking Age pattern (Walton Rogers 2004, 84; Skals et al. 2024, 46–47) as there is not enough comparison material available. Might this result indirectly support the idea that pile weave technique was employed across various locations?

However, the Pöide textile is unique in the eastern Baltic region and does not fit into the local weaving tradition. In addition, the location of Saaremaa on the *Austrvegr*, which means the Viking route from the Varangians to the Greeks, the Pöide Stronghold's relationship with the Viking Age harbour in Tornimäe, and the arrival of this item from Scandinavia, or via Viking mediation, is at present the most likely option. It is, of course, impossible to say whether the Pöide textile was a traded commodity or reached Saaremaa with travellers as a personal item. Future isotope analyses would hopefully clarify the provenance of the Pöide fragment.

The function of the textile item

The archival records documenting the find circumstances indicate that the Pöide textile fragment was part of a larger piece of clothing discovered in the 1870s (KM catalogue, no. 1931). Regrettably, the description is extremely vague: "a shawl or a dress fragment" (ibid.), "a shirt or body covering" and "sleeveless" (Tallgren 1925, 38). The most common opinion is that this cloth type was used mainly for (hooded) cloaks (Østergård 2004, 74; Walton 1989, 336; Walton Rogers 2007, 207; Pritchard 2017, 120; Hopkin 2021, 32–33; Falk 1919, 52; Guðjónsson 1962, 69). The Icelandic sagas, based on the tenth to eleventh century tradition and written down in the 13th century, and other types of written source mention clothing items called *vararfeldur*, *feldir*, and *röggvarfeldir,* which have been interpreted as woven mantles or cloaks with a pile surface, and either circular or rectangular and in various lengths (Falk 1919, 177; Guðjónsson 1962, 68; Hayeur Smith 2024, 53–54). Coloured versions of these garments have been mentioned; among others, blue ones are also known to have existed. Although no other entirely blue examples are currently known among published archaeological finds other than the Pöide textile, this colour is also mentioned in these sources.

The textile from Pöide might originally have functioned as an upper body garment. Due to the absence of buttonholes, fastening bands, or fibulae, it is not possible to determine with certainty how it was worn. The braid sewn along the selvedge might have served either a decorative or reinforcing purpose, or potentially both. Previous research has emphasised the capacity of *vararfeldur* to provide protection in cold and wet conditions (Wincott Hecket 1992, 163–164). If worn with the pile facing inward, the garment would probably have enhanced thermal insulation by creating a warm air layer around the wearer's body. Conversely, if *vararfeldur* were worn with the pile facing outward, they may have functioned as rudimentary rain garments. Archaeological pile weaves have been associated with several medieval European depictions, typically showing men wearing shaggy cloaks, identifiable by their outward-facing pile. In Christian iconography, for instance, the shaggy mantle is a distinctive attribute of John the Baptist (Guðjónsson 1962, 71). Experimental studies have demonstrated that this textile type performs well in wet conditions, offering insulation even when damp and drying relatively quickly (Hopkin 2021, 42). A later analogue to the Viking Age *vararfeldur* can be found in Scandinavian boat rugs, which were used by fishermen to retain warmth in harsh, damp environments. A key feature of these rugs was the presence of lanolin-rich wool staples in the pile (Toikka-Karvonen 1971, 41–41; Kjellmo 1996; Plath 1966, 9). It is unknown though, if the *vararfeldur* contained any lanolin, which would have increased weather performance.

Conclusion

The Pöide textile, which is 14C-dated to the Viking Age, opens an entirely new chapter in Estonian textile history as the oldest textile fragment, bigger than a fingertip, found in Estonia. The textile is a plain 2/2 twill woven of z-spun wool yarns dyed with woad. It belongs to a specific group of piled weaves, where in this case wool tufts were inserted into the shed when weaving, resulting in a shaggy pile on one side of the cloth surface. Based on the technical traits mentioned above, the Pöide textile is a good fit for Nordic Viking Age cloth culture. Because piled weaves are relatively rare among archaeological textile finds, provenance and use are difficult to determine. However, the Pöide textile appears foreign to textile production in Estonia and possibly the entire eastern and north-eastern Baltic region. The closest parallels in terms of technical traits are known from Norway, Greenland and Iceland with pile weaves mentioned in the sagas pointing to a specific Islandic commodity. However, recent isotope analysis and the fibre distribution patterns indicate the possibility that piled fabrics could have been produced in several places, meaning that the question of the Pöide textile's provenance remain unsolved. The find location near the Viking Age Pöide hillfort and its relation to the harbour site supports the interpretation that this textile reached Saaremaa via Scandinavian contacts. Regrettably, the Pöide clothing item was destroyed during its discovery approximately 150 years ago, but it could have been a cloak or other type of loose overgarment.

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ATR-FTIR spectroscopy analysis of mineral-preserved textiles from Viking Age women`s graves in Vinjefjord, Norway

Abstract
Recently excavated, mineral-preserved textile fragments recovered from three largely undisturbed Viking Age inhumation female graves in Vinjefjord, Mid-Norway were analysed by Fourier transform infrared spectroscopy (FTIR) equipped with attenuated total reflection (ATR) to identify fibre type and potential dyes. The textiles were found in intimate contact with copper-alloy garment accessories and originate from a boat burial and a simple oval pit burial at Skeiet in Vinjeøra and a burial chamber at Hestnes in Valsøyfjord. Five textiles were selected for analysis. Three were reliably identified as cellulose-based or hair/wool. The degree of mineral preservation of the remaining two samples was too advanced to establish a conclusive identification. The wool-identified sample tested positive for the plant-based dye indigo. The application of FTIR analysis to archaeological textiles to identify both fibre type and dyestuffs, is not uncommon. However, its application to Viking Age period textile remains recovered from excavations in Norway has not been previously reported.

Keywords: ATR-FTIR, Vinjefjord, Norway, Viking Age, textiles, dye analysis, indigo

Introduction
Mineral-preserved textile fragments recovered from three largely undisturbed Viking Age female inhumation graves in Vinjefjord, Mid-Norway were analysed by Fourier transform infrared spectroscopy (FTIR) equipped with attenuated total reflection (ATR) to identify fibre type and potential dyes. The textiles were found in intimate contact with copper-alloy garment accessories and originate from a boat burial and a simple oval pit burial at Skeiet in Vinjeøra and a burial chamber at Hestnes in Valsøyfjord all of which were excavated as part of the E39 Betna-Stormyra rescue archaeology project.

The site
The European Route E39 is the primary coastal road connecting western and central Norway, running along the southern shore of Vinjefjord to the main Norwegian coastal sea route (the *Norvegr*). Between 2019 and 2020 a large scheme of rescue archaeology excavations commissioned by the Norwegian Public Roads Administration was carried out in selected culturally protected areas of the Vinjefjord region in preparation for the final planned upgrade of the E39 road (fig. 1).
The E39 Betna-Stormyra project is the most extensive archaeological excavation of Late Iron Age cemeteries and settlement features carried out in Mid-Norway (Sauvage 2024, 7). Several settlement sites along the southern shore of the long, narrow fjord were investigated. Archaeological remains from the Iron Age and Middle Ages (500 BCE to 1537 CE) were discovered in three separate locations. These were situated on the farms Skeiet and Fjelnset at Vinjeøra (innermost in the fjord) and Hestnes along Valsøyfjord (a smaller side fjord to the south). The Skeiet site

consisted of two areas: Skeiet 1 and 2. Skeiet 1 contained 11 (possibly 12) flattened burial mounds identified by their circular rings. Excavations revealed 18 graves, and three mortuary houses dated to the Late Iron Age, and the graves were richly furnished with a large collection of artefactual grave goods. Skeiet 2 contained Iron Age and medieval settlement features and remains with at least nine identifiable buildings (Sauvage and Lorentzen 2024, 131–133; Sauvage 2024). The Fjelnset site was characterised by poor preservation, methodical robbing and erosion. The Hetnes site yielded mortuary evidence in the form of a levelled burial ground that contained the remains of a richly furnished, decayed wooden Viking Age chamber burial, including items of jewellery, textile fragments, beads, tools and several fragments of clothing (Sauvage 2024).

During post-excavation conservation of the grave goods recovered from Skeiet 1 and the wooden chamber burial at Hestnes, it was discovered that fragmented remains of the textiles once worn by the buried persons were preserved in close association with metal garment accessories in some graves. A total of 77 textile remains, including some fragments of down feathers, were identified from the three Viking Age female inhumation graves, in particular: Skeiet 1 Graves 2 and 11 and the Hestnes burial chamber (Øien and Heen-Pettersen 2024, 213–216). Skeiet Grave 2 was a simple oval pit burial (circa 900 to 950 CE); Skeiet Grave 11 was a boat burial (circa 800 to 850 CE); and Hestnes was a chamber burial (circa 850 to 950 CE). Øien and Heen-Pettersen (2024) studied and catalogued the technical aspects (for example, fibre, spin direction, thread count) of the textile remains using visual and traditional optical microscopy (OM) techniques. Their further study focused on an evaluation of the funerary clothing and dressing practices related to mortuary rituals during the Viking Age (Øien and Heen-Pettersen 2024).

Textile mineral preservation

A wide range of organic materials, including textiles, are preserved in the archaeological context through the gradual diffusion of metallic cations from nearby

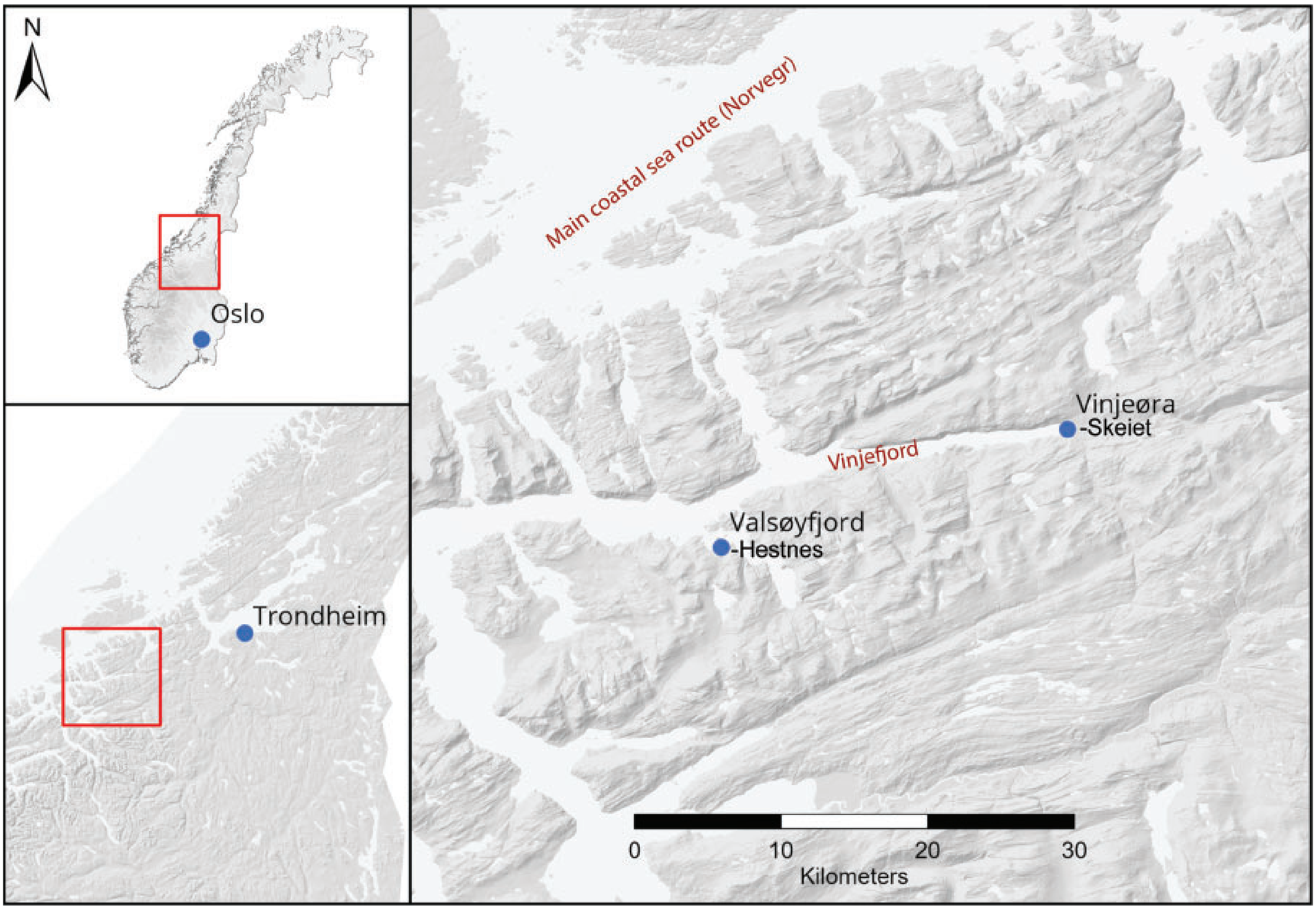

Fig. 1: Location map showing the regional setting in Norway of the E39 Betna-Stormyra project and the Hestnes and Skeiet sites along Vinjefjord (Image: Thea P.B. Christopherson after Kristoffer R. Rantala)

artefacts or, the surrounding environment (Grömer and Grassberger 2018). In fact, it is proposed that finds preserved in this manner can no longer be considered exceptional (Peška et al. 2006, 5). The study of mineral preserved textiles has received more interest in comparison with studies of mineral-preserved leather, for example, in large part because fibre artefacts retain their morphological features and can be more readily visually identified. The permeation process leads to fibres of varying degrees of mineralisation. Preservation ranges from lightly mineralised ("pre-mineralization" (Jia et al. 2024, 10)) retaining close to the original organic and physical properties (for example, a somewhat soft handle) to completely mineralised into a hard or powdery form retaining minor traces of the original organic composition. Attention is now being drawn to previously unidentifiable corrosion features ("ephemeral traces") in metal corrosion products that are traces of – but no longer appear like - textiles (Davis and Harris 2023, 15–18; Angiorama et al. 2020; Peška et al. 2006, 22–26, 28–31, 39–43).

The complex mechanisms of textile mineral-preservation have not been fully ascertained, especially at the nano- to microscale (Reynaud et al. 2020). Several studies have investigated the mineralisation process through experimental degradation in the laboratory (Jakes and Howard 1986; Gillard et al. 1993; Gillard et al. 1994a; Chen et al. 1998). These have provided insights into the preservation process, importantly, that traces of the organic complex can remain in sufficient quantities to allow distinction between protein- and cellulose-based fibres (Gillard et al. 1994a, 138). In fact, Gillard and colleagues concluded that complete mineralisation is probably relatively uncommon (Gillard et al. 1994a, 138).

The near presence of metals such as copper, silver, iron and/or lead (and their alloys) can promote the preservation of organic material, with copper and iron being the most common. Additionally, calcium-rich burial environments contribute to a rarer type of mineral-preservation. Water from the surrounding (burial) environment percolates into and swells the fibres, followed by the transport of soil solutes (for example, calcium) and biocidal metal (for example, copper, silver) cations released during the initial corrosion of closely associated metal artefacts such as garment accessories or tools. If the concentration of metallic cations is high enough, the corrosion products become toxic to many microorganisms and thus inhibit microbial degradation of the fibres slowing down the deterioration process. At the same time, the concentration must be sufficiently low enough to enable the ions to penetrate the fibres. Continued infilling or impregnation of the fibre structure and simultaneous fibre degradation can proceed to the point where the organic composition is either partially or completely replaced, or a hollow cast of the fibre is formed. These are sometimes referred to as "positive" or "negative" casts respectively. Less-studied forms of textile mineral-preservation are found on stone (for example, Schuurman 2023) and ceramics as well as in soils (Unruh 2007).

Study of mineral-preserved textiles

The primary scientific research method of analysis in the study of textile artefacts is visual observation. The presence of textile remains on metal artefacts has been the subject of observation and description since the 18th century (Chave et al. 2024). Scholarly studies of the appearance of fibre morphology and corrosion products of mineral-preserved textiles was based on visual observation with the naked eye. This was later complemented with the development of the simple light microscope. The systematic visual examination and identification using optical microscopy in the form of the compound microscope, was pioneered by Biek (1963, plates 7 and 10) and was complemented by simple microanalytical methods such as microchemical staining (Biek 1963, 118; Anheuser and Roumeliotou 2003) used to identify the broad fibre type. These methods, now including portable USB digital optical microscopy, continue to be the initial and primary tools of study (Peacock 2024). The increasing availability of scanning electron microscopy (SEM) for investigation of artefacts has provided an increasingly essential tool for the systematic examination and identification of mineral-preserved fibres and associated mineralisation processes, especially where transmitted light will not penetrate fibres with a high mineral content (Janaway 1983; 1985; 1989; Rast-Eicher 2016, 16–17, 22, 33–35, figs. 6–7, 14–15, 32–35). Although a surface technique, its excellent depth of field and greater resolution aid identification if the fibre surface is reasonably well replicated. That said, more recent studies have pushed the identification of ephemeral traces of materials in corrosion products that no longer have the appearance of textiles (Davis and Harris 2023, 15–18; Angiorama et al. 2020; Peška et al. 2006, 39–43). When equipped with a backscatter (BSE) detector and energy dispersive X-ray spectrometer (EDS), microanalysis of the surface elemental composition and distribution can be assessed and mapped simultaneously with visual morphological examination of the fragments (Jakes and Sibley 1984; Chen et al. 1996; 1998; Angiorama et al. 2020). As the interest in mineral-preserved textiles has increased over recent decades, SEM has become

the principal examination method, when accessible.
Infrared (IR) spectroscopy, especially Fourier transform infrared (FTIR) spectroscopy, is a widely used vibrational spectroscopic technique that is finding applications to the analysis of the chemical nature of not only historic but also archaeological textiles (Chen et al. 1996; Margariti 2019). The spectrometer measures the absorption wavelengths of an infrared light source that is passed through a material. Specific functional groups and molecular structures absorb specific wavelengths of IR radiation, and the bands of absorbance can be used to identify the composition of the material under study. For textiles this includes fibre group identification, degradation of the organic matrix and presence of dyes. ATR-FTIR is sensitive enough to produce spectra that are distinguishable between fibres from different animal species (McGregor et al. 2018) and plant species (Coletti et al. 2021) when they are modern and in good condition. Gillard and colleagues (Gillard et al. 1993; Gillard et al. 1994a; Gillard and Hardman 1996) investigated the application of FTIR microspectroscopy to modern fibres that had been experimentally mineralised in laboratory-based studies. Their studies showed the presence of measurable amounts of organic component in the mineralised-preserved fibre matrix, and that these traces could remain in sufficient quantities to allow distinction between protein- and cellulose-based fibres. Further, they reported that remnant dye could be detected by FTIR in archaeological textiles; although, mineral-preservation was not specified (Gillard et al. 1994b; Gillard and Hardman 1996). Early in the 1960s, Abrahams and Edelstein (1964) investigated IR spectroscopy for the analysis of solvent-extracted

Fig. 2: An example of a copper-alloy oval brooch (NTNU University Museum T28348:2) recovered from the female inhumation burial chamber at Hestnes and covered with layers of textile. Associated textiles were not selected for ATR-FTIR study (Image: Åge Hojem)

dyes in archaeological wool (circa 135 CE) from the Dead Sea. The FTIR attenuated total reflectance (ATR) mode of FTIR spectroscopy involves the pressing of a sample against a crystal window in an ATR accessory. Penetration depth is few to few tens of µm. Analysis is quick and convenient but might necessitate not only the taking of a sample but also deformation of degraded textiles, such as brittle mineral-preserved. Thus, unlike reflectance mode FTIR, ATR mode cannot necessarily be considered a non-invasive and non-destructive technique in all instances.
Today, a variety of advanced analytical methods are applied to the study of archaeological textiles (for example, Margariti et al. 2024). Contemporary methods of analysing mineral-preserved textiles have expanded to include, for example, peptide mass fingerprinting (PMF) measured by matrix-assisted laser desorption ionisation (MALDI) and time-of-flight (TOF) mass spectrometry (Solazzo et al. 2014), microtomography and synchrotron-based X-ray microtomography (µCT) (Iacconi et al. 2023; Jia et al. 2024), and radiocarbon (14C) dating (Margariti et al. 2023). A comprehensive review has been carried out by Bertrand et al. (2025).
The study reported herein is a pilot investigation of the application of ATR-FTIR to identify fibre types and investigate potential dyes on five selected mineral-preserved textile fragments recently recovered from three Viking Age period female inhumation burials in Norway. The aim of this contribution, in addition to presenting the result, is to address the potential for this method in more detail specific for mineral-preserved textile fibres and the dye indigo than reported in other studies. It describes sampling, sample preparation and methodology while also providing a comprehensive literature review of relevant spectra and infrared band assignments to aid identification. The article introduces the archaeological background of the assemblage but does not include a detailed preliminary technical survey of either the selected textile fragments or other textile remains recovered from the burials (fig. 2). Furthermore, it does not present the ensuing discussion about Viking Age women's burial clothing and mortuary rituals at that time (Øien and Heen-Pettersen 2024).

Methodology

Materials, recovery and post-excavation

The three female burials were apparently largely undisturbed at the time of excavation (Øien and Heen-Petersen 2024, 199). In cases where textile remains were preserved on metal garment accessories, the composite objects were recovered in the field as soil blocks. Investigative excavation was carried out in the conservation laboratory at the NTNU University Museum. Detail records were made of the textiles' layering and how they were positioned on the artefacts before the fragments were separated. Fragments that were integrated with surface metal corrosion products and affixed to the accessories were not removed. A traditional visual technological analysis (for example, fibre, spin direction, thread count) was then undertaken (Øien and Heen-Pettersen 2024). Preservation of partial or possible textile features in metal corrosion products on the surfaces of the accessories associated with the textile fragments examined was not investigated (for example, Davis and Harris 2023; Angiorama et al. 2020; Peška et al. 2006, 22–26, 28–31).

Conservation
Before fragments were selected for analysis, the assemblage received light mechanical surface cleaning of soil and other residues from the archaeological context. No chemicals, including consolidants, were employed, with the exception of an Insular brooch (T28276:3, fig. 3e), which was further mechanically cleaned of surface corrosion. The fragile areas on the reverse surface were strengthened with Japanese tissue affixed with 10% Paraloid B72 (an ethyl methacrylate–methyl acrylate copolymer) (w/v) in ethanol.

Condition assessment
The condition, degree and type (for example, positive cast, negative cast, "complete" mineralisation) of degradation/mineralisation of the textile fragments were assessed using visual observation and optical microscopy. The results of the examination were

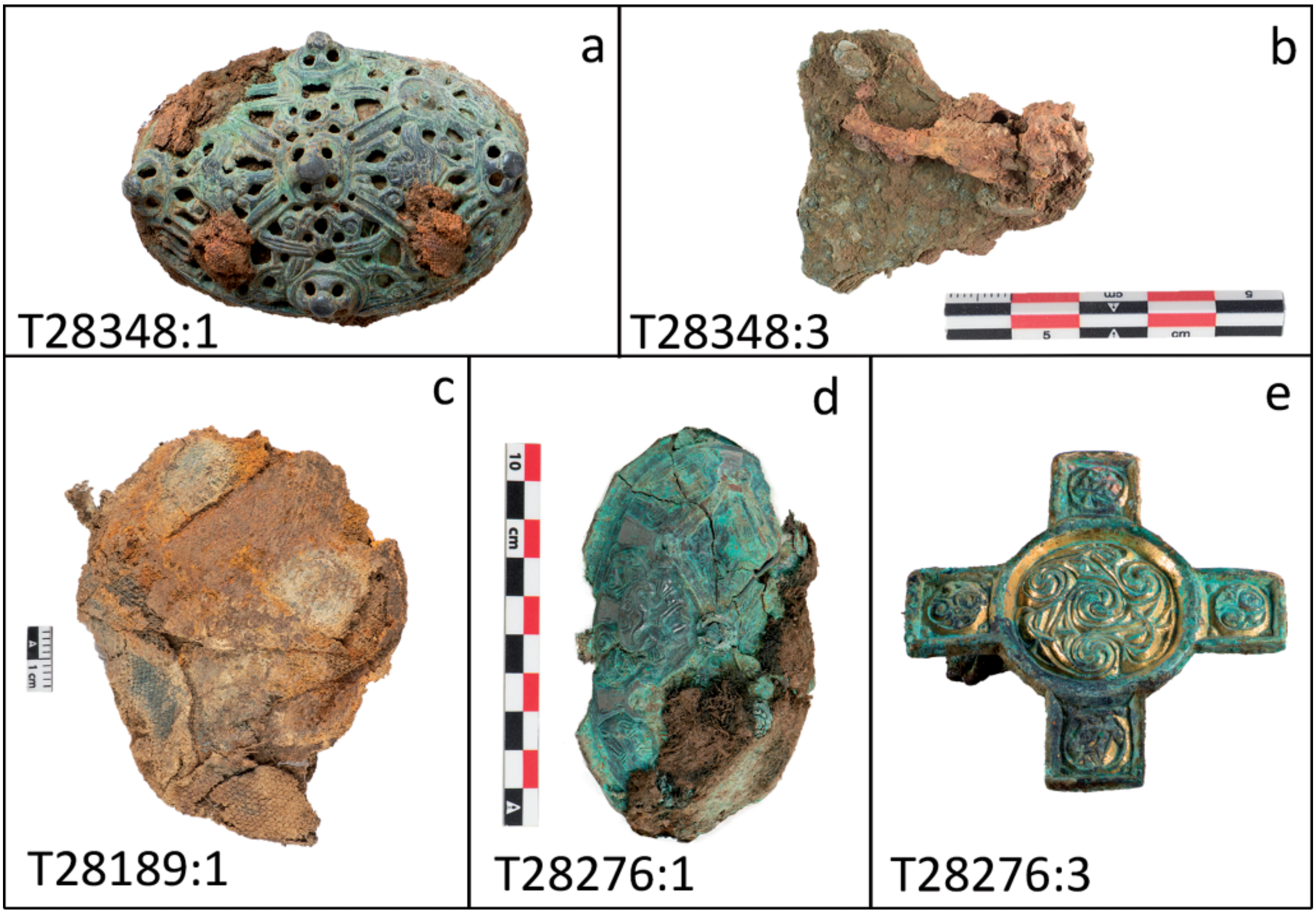

Fig. 3: The five metal artefacts with intimately associated textile fragments that were selected for ATR-FTIR analysis from the NTNU University Museum: a) copper-alloy oval brooch from Hestnes, T28348:1; b) copper-alloy trefoil brooch with iron pin fastener from Hestnes, T28348:3; c) an incomplete, seven-boss, copper-alloy oval brooch from Skeiet 1, Grave 2, T28189:1; d) copper-alloy oval brooch from Skeiet 1, Grave 11, T28276:1; and e) gilded copper-alloy Insular brooch from Skeiet 1, Grave 11, T28276:3 (Image: Thea P. B. Christophersen; a) after Åge Hojem; b) Eystein Østmoe; c) Thea P. B. Christophersen; d) Stian Ingdahl; and e) Åge Hojem)

Site	NTNU Museum number	Find number	Description	Condition	Colour
Hestnes, Female burial chamber	T28348				
		T28348:6	Seven fragments of tabby-woven textile found on the underside of copper-alloy oval brooch T28348:1	Mineral (Fe) preserved	Light orange brown
		T28348:12	Diamond twill-woven textile fragment found on the underside of copper-alloy trefoil brooch with iron pin fastener T28348:3	Partially mineral (Fe, Cu) preserved	Reddish brown, blue
Skeiet 1, Grave 2 Female inhumation grave	T28189				
		T28189:1	Several folded layers of a tabby-woven textile fragment that completely covers the top of an incomplete, seven-boss, copper-alloy oval brooch T28189:1	Hard mineral-like to mineral (Fe, Cu) preserved, powdery iron surface corrosion	Yellow brown, blue green areas
Skeiet 1, Grave 11 Female boat burial	T28276				
		T28276:59	Twill-woven textile fragment found on top of copper-alloy oval brooch T28276:1	Partially mineral (Cu) preserved	Dark brown
		T28276:75	Thread fragments associated with pin fastener on the reverse side of gilded copper-alloy Insular brooch T28276:3	Partially mineral (Cu) preserved	Straw coloured, dark blue green

Table 1: Description of the E39 Betna-Stormyra project textiles and associated copper-alloy garment accessories selected for ATR-FTIR analysis

used to assess the condition of the textiles to choose fragments for FTIR analysis (table 1), and to select an appropriate sampling site.

Selected textile remains

Five of the 77 catalogued textile remains were selected for analysis with Fourier transform infrared spectroscopy (FTIR) with an attenuated total reflectance (ATR) imaging system. As a group, the remains were fragmentary in nature and ranged from loose fibres, individual threads, and narrow fabric loops to woven fragments (of several cm^2). Selection was based on the degree of mineral-preservation, fibre group identification, presence of loose fibres, friability, surface integrity, degree of fusion to corroded metal accessory, suspected presence of dye and research interest. The fragments represented the three female inhumation graves and were found in association with copper-alloy oval (tortoise), trefoil, or Insular brooches (fig. 3). Table 1 presents an overview of the selected fragments (table 1).

Sampling

A sample weighing between 5 and 10 mg was taken from each selected textile fragment (fig. 4). The condition influenced the method of sample taking and analysis preparation. From textile fragments with intact woven structure (binding points), one or two threads were removed. Loose textile fibres (T28276:75, fig. 4e) collected during conservation of the Insular brooch (T28276:3, fig. 3e) were used. For the textile find from Hestnes (T28348:6, fig. 4a) that consisted of seven hard, brittle mineral-preserved fragments, a whole fragment was selected since the textile fabric was too brittle for a thread or fibres to be safely removed.

It was possible to take a sample with visible blue dye from the twill-woven fragment (T28276:59, fig. 4d) from Skeiet 1, Grave 11. For the other textile finds, sampling was limited to areas and fibres without visible colour to minimise disturbance and material loss of textile. Prior to ATR FTIR analysis, each sample was further lightly mechanically cleaned of soil. Textile samples without visible

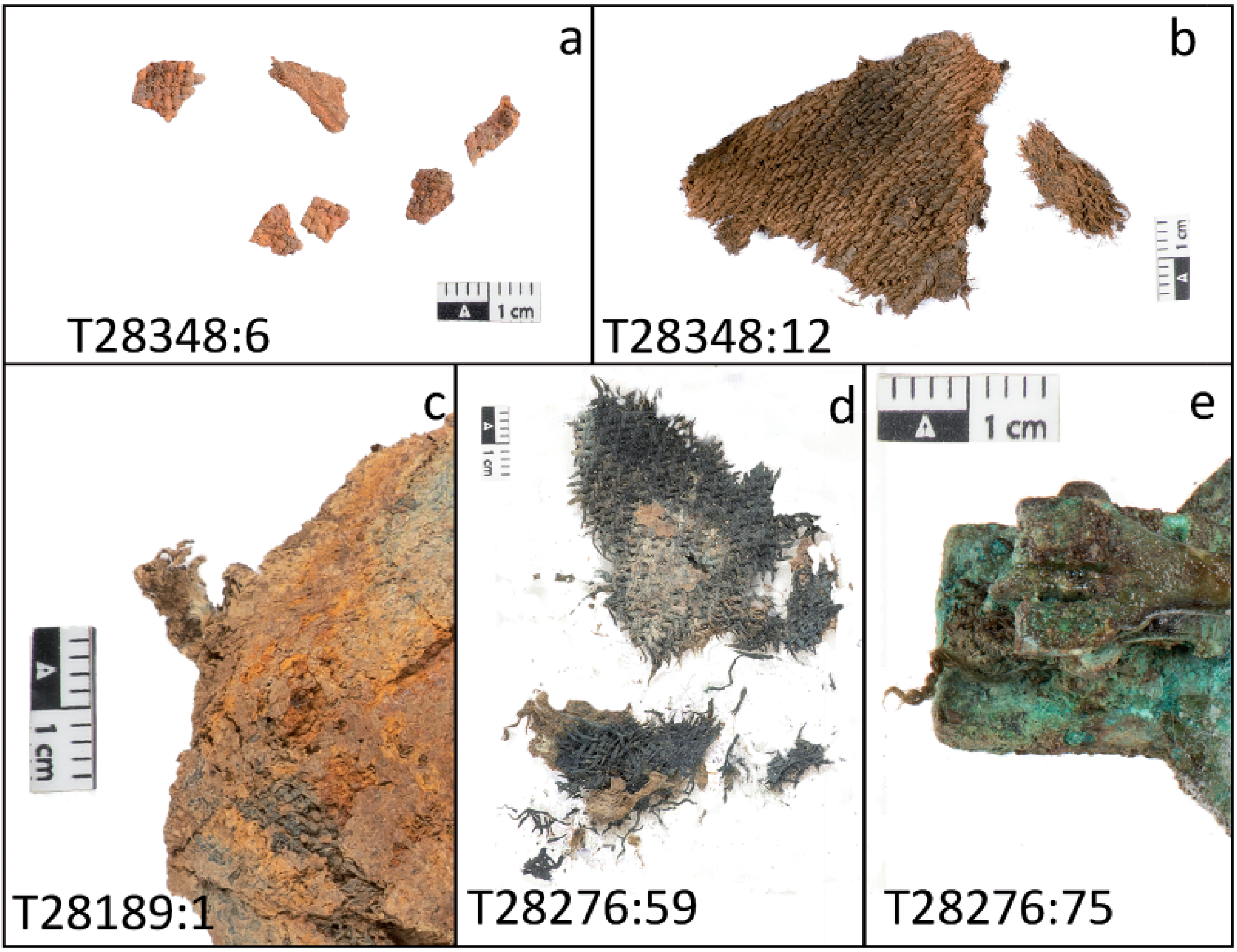

Fig. 4: The textile fragments that were selected for ATR-FTIR analysis from objets of the NTNU University Museum: a) fragment T28348:6 from the underside of copper-alloy oval brooch T28348:1, fig 3a; b) fragment T28348:12 from the reverse side of copper-alloy trefoil brooch T28248:3, fig 3b; c) one thread T28189:1 from the top of copper-alloy oval brooch T28189:1, fig 3c; d) one thread T28276:59 from the top of copper-alloy oval brooch T28276:1, fig 3d; and e) loose fibres T28276:75 from the reverse side of Insular brooch T28276:3, fig. 3e (Image: Thea P. B. Christophersen)

Reference material		Source
Linen yarn	Bockens linen yarn NEL 28/2 ½-BL, 100% linen, semi-bleached flax, undyed	Holma-Helsinglands AB, Sweden
Wool fabric	Unbleached, undyed white vadmel (wadmal)	Røros Tweed A/S, Norway
Blue-dyed wool fabric	Unbleached, undyed white vadmel dyed with indigo fermented in urine	Røros Tweed A/S, Norway
Indigo powder	Genuine indigo, Indigofera tintoria L. CAS-Nr: 84775-63-3	Kremer Pigments GmbH & Co. KG Germany

Table 2: Modern reference fibre and dye materials used in the study. The reference wool fabrics were prepared for and included in numerous experimental burial degradation studies (Peacock 2004, 189–190; Solazzo et al. 2013, 49–50)

colour were additionally brushed with ethanol to eliminate contamination from other residues from the archaeological burial context.

Analyses and measurements

ATR-FTIR infrared microspectroscopy

IR spectroscopy was carried out with a benchtop PerkinElmer Spectrum 400 Fourier transform infrared (FTIR) spectrometer equipped with a Universal attenuated total reflection (ATR) imaging system with a diamond crystal ATR plate. Infrared spectra were taken of both the mineral-preserved samples and modern materials used as references (table 2). Each sample was positioned to cover the ATR analysis window and pressed down with the pressure arm to ensure good contact with the crystal. The instrument was operated with the associated Spectrum software. Infrared spectra were acquired over the frequency range 4000 to 550 cm^{-1}, and 128 scans accumulated with a spectral resolution of 4 cm^{-1}. Between each analysis, the ATR analysis window was cleaned with ethanol and lens paper and a background spectrum was taken to reduce variations in the spectra from background noise due to varying intensity of the laser and surrounding environmental disturbances (for example, humidity and CO_2 level).

Spectra from the archaeological textile samples were compared against those of the reference samples (table 2), as well as with the Conservation Laboratory's reference spectra library, reference spectra in the IRUG Spectral Database (Infrared & Raman Users Group 2025) and those reported in the literature (tables 3–5). Furthermore, the results were compared with the textile technological analysis of the textile finds reported by Øien and Heen-Pettersen (2024, 13–16).

Findings

Visual preliminary survey

In the visual preliminary survey carried out by Øien and Heen-Pettersen (2024, 13–16), four of the five selected fragments were tentatively fibre-type identified as follows: T28189: plant; T28276:59 animal; T2876:75 plant; T28348:6: inconclusive; and T28348:12 animal. In their survey, approximately 38% of the fibres could not be securely identified.

Condition assessment

All the selected textile fragments are mineral-preserved (copper-alloy and/or iron) in various stages (table 1) ranging from organic-preserved fibres/fabric with limited biological decay to remnant textile surfaces with mineral-impregnated fibres and binding points. All fibres are preserved as positive casts.

The twill-woven fabric T28276:59 (fig. 4d) is partially mineralised. The threads and fibres are hard, brittle and break easily. In some areas, the weave is pinched, and the threads are no longer oval-shaped in cross-section. The fabric of the fragments has particles of sand/silt between the threads of the weave, which cause breakage when handled. There is plant material scattered on the surface. The colour of the fabric is a dark green blue indicating possible dye, as well as preservation due to intimate association with copper-alloy. In the centre of the largest of several pieces, is a hole where the fabric may have been attached to the oval brooch (T28276:1, fig. 3d). Surrounding this hole are greenish-white copper salts. In this area, the threads are greener in colour and more mineralised. The raw material of the threads was identified as animal fibre in the visual preliminary survey (Øien and Heen-Pettersen 2024, 215). The fragments of down were identified as seagull (*Larus sp.*) and sea duck (Mergini) (Rosvold [in press as cited in Øien and Heen-Pettersen 2024, 206–207]).

The second selected textile find from Grave 11, Skeiet 1 consists of loose, brittle off-white/transparent and blue green fibres (T28276:75, fig. 4e) from the copper-alloy pin fastener on the reverse side of gilded copper-alloy Insular brooch (T28276:3, fig. 3e). In the preliminary visual examination, these fibres were tentatively identified as vegetable (Øien and Heen-Pettersen 2024, 216). The remainder of the textile fragments left on the reverse of the brooch, consist of loose but compressed fibres – perhaps from fragments of a textile fabric caught around one end of the copper-alloy pin fastener. The condition of these fibres varies from off-white in colour and transparent to dark, mineralised and covered in a dark organic layer. These are stiff and brittle and have been more affected by their association with the permeating copper solution.

The textile remains (T28189:1, fig. 4d) from the female inhumation grave at Skeiet 1 consist of a relatively large, multi-layered folded assemblage of a tabby woven textile fabric sitting on top of a large fragment of a copper-alloy oval brooch with an iron pin fastener (T28189:1, fig. 3d). The fabric is covered in orange powdery iron corrosion products. The condition of the fabric varies from hard mineral-like to mineral preserved, but it is not fully mineralised. Much of the surface morphology is unclear. The fabric is of high quality. There are blue-coloured areas that may indicate the presence of dye. There are also greenish-blue areas suggesting mineralisation by corrosion solutions from the copper alloy. Due

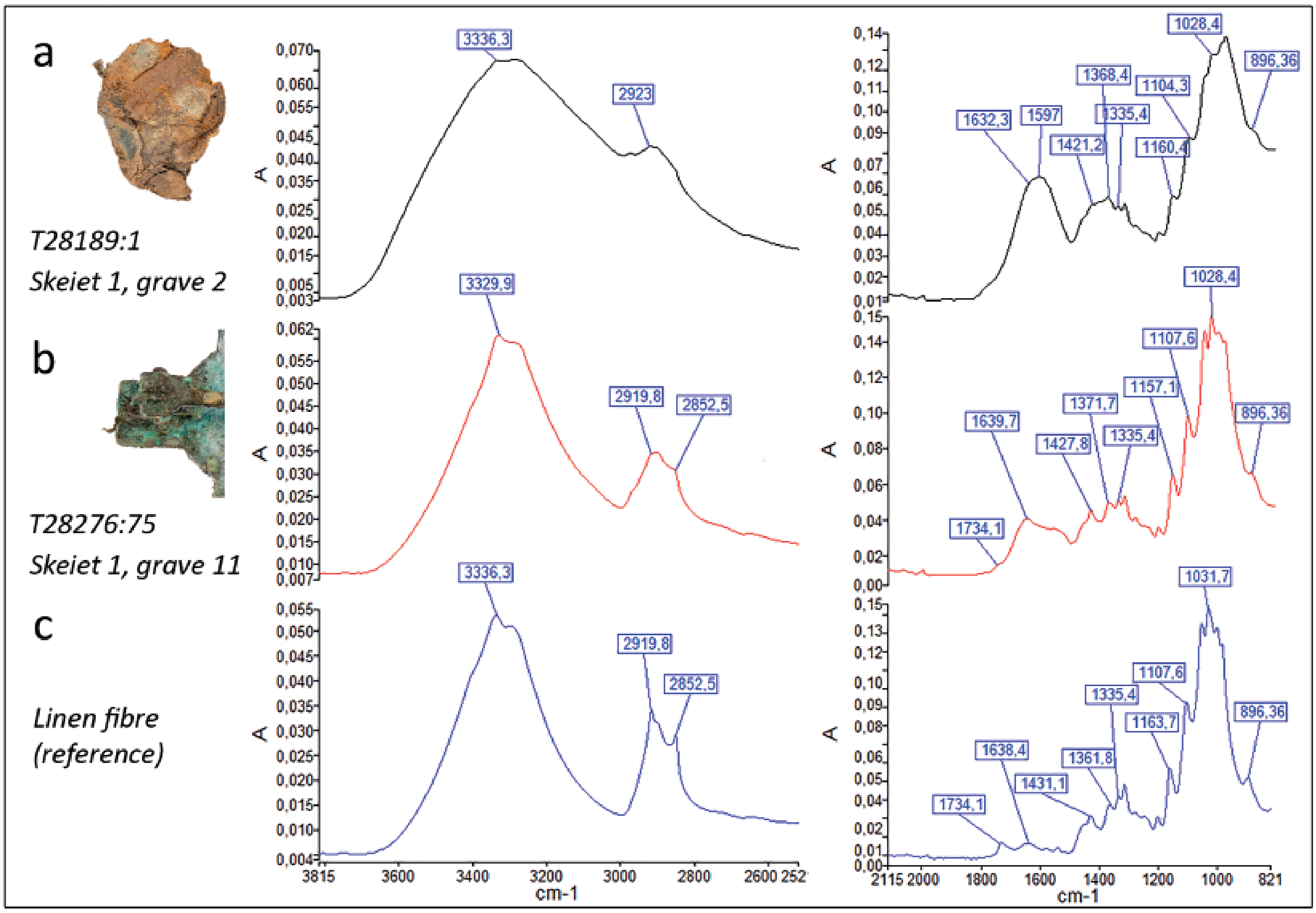

Fig. 5: Infrared spectra for two of the three textile finds from Skeiet 1, kept at the NTNU University Museum: a) textile found on top of copper-alloy oval brooch T28189:1 from Grave 2, see fig. 4c; b) textile fibres T28276:75, see fig. 4e, from the pin fastener on the reverse side of Insular brooch T28276:3, from Grave 11, see fig. 3e; and c) modern linen yarn, reference sample (Image: Thea P. B. Christophersen)

to the poor condition of the surface morphology, the results of the preliminary visual survey for fibre group identification were inconclusive (Øien and Heen-Pettersen 2024, 204–205).

The remaining two selected textiles were recovered from the burial of a woman in a wooden burial chamber at Hestnes. One consists of two larger fragments of a diamond twill woven fabric (T28348:12, fig. 4b) recovered from the underside of a copper-alloy trefoil brooch (T28348:3, fig. 3b). The fabric is predominantly reddish-brown in colour with some undertones of blue, which may indicate the presence of dye. The fabric may be slightly mineralised, but it retains its organic flexible nature. The morphology of the fabric is so well preserved that it was possible to identify it as worsted quality wool in the preliminary visual examination (Øien and Heen-Pettersen 2024, 201, 213). The underside is covered by sand/particles in a thin, dried-out black organic layer that might be human tissue, which was not further investigated.

The final find consists of seven tiny fragments of a mineral-preserved tabby-woven fabric (T28348:6, fig. 4a) that were found on the underside of a copper-alloy oval brooch (T28348:1, fig. 3a). The colour of the fragments is orange-brown, indicating that the textile's preservation is due to close association with corroding iron, probably stemming from the iron pin fastener on the reverse of the oval brooch. The fragments are highly mineralised (that is, solid pieces) but still retain excellent surface details of their fibre, thread and fabric morphology. Such details are less common with iron-preserved fibres. Results from the preliminary visual survey (Øien and Heen-Pettersen 2024, 213), provided an uncertain determination as to whether the fabric consists of animal or vegetable fibres, but leaned more towards animal. There are several areas with a green-coloured under-layer, indicating that the degradation of the textile was initially slowed down due to proximity to the copper-alloy oval brooch before it was permeated by an iron corrosion solution.

Wavenumber (cm^{-1})	Infrared band assignments	Data source
3360-3260	(OH) free	1-2, 5
2900	(C-H) stretching, associated with polysaccharides	1-3, 6-7
2850	(CH_2) symmetrical stretching in cellulose	1-2, 6
1735	(C=O) in ester associated with pectin in hemp and flax, but also carbonyl groups in oxycelluloses in degraded cellulose	2-4
1639-1630	Water absorbed in lignin or cellulose	2-3, 5-6
1605-1591	(C=C) associated with lignin	2-3, 6-7
1428-1420	(C-H) in cellulose	1-2, 4-5
1375-1365	(C-H) in cellulose	1-5
1355-1335	($C-H_2$) in cellulose	1-3
1163-1155	(C-C) ring breathing, associated with polysaccharides in cellulose	1-3
1107-1104	(C-O-C) glycosidic ether band, associated with polysaccharides in cellulose	2-5, 7
1029-1025	(C-OH) in cellulose	2-3, 5
900-895	(C-O-C) stretching in cellulose	2-3, 5

Table 3: FTIR wavelength frequency and band assignments that characterise plant fibres. Data abstracted from: 1 – Garside and Wyeth (2006); 2 – Garside and Wyeth (2003); 3 – Margariti (2019); 4 – Kavkler et al. (2011); 5 – Liu and Kazarian (2022); 6 – Schwanninger et al. (2004); and 7 – Raditoiu et al. (2019)

Wavenumber (cm^{-1})	Infrared band assignments	Data source
3500-3100	Overlap between regions that are characteristic of (O-H) and of amide hydrogen (N-H). A sharp peak at 3285-3275 is especially characteristic of silk fibres. A wide peak at 3300-3260 is characteristic of wool fibres	1-6, 8-9
3070-2850	Saturated and unsaturated (C=H), and (C-H) region	1-2
1680-1610	Carbonyl oxygen, (C=O), in amide I, typical of wool and silk fibres	1-10
1570-1510	(N-H) in amide II, typical of wool and silk fibres	1-10
1390-1385	CH_3 in wool	7
1235-1225	(C-N) in amid III, typical of wool and silk fibres	2-6, 8-10
1200-1000	Sulphur oxygen vibration, S-O, in wool. Peaks in this region at 1175-1160, 1124-1122, 1080-1068 and 1045-1035 are assigned to sulphur oxygen bonds in cysteine in keratin	1, 3, 10
1164-1155	(C-C), (C-OH), typical of silk fibres	4
994-990	CH_3 in silk fibres	4-5
975-970	CH_3 in silk fibres	4-5

Table 4: FTIR wavelength frequency and band assignments that characterise animal fibres, wool and silk. Data abstracted from: 1 – McGregor et al. (2018); 2 – Margariti et al. (2010); 3 – Belukhina et al. (2021); 4 – Garside et al. (2005); 5 – Liu et al. (2011); 6 – Margariti (2019); 7 – Liu and Kazarian (2022); 8 – Peets et al. (2019); 9 – Parker (1971); and 10 – Mabrouk (2020)

Wavenumber (cm-1)	Infrared band assignments	Data source
3436	(N-H) stretching vibration in amide hydrogen bond	3
3270-3260	C=O and hydrogen bonds	3
3060-2850	(C-H) in aromatic ring	3
1628-1623	(C=O) and (N-H)	2-4
1586-1585	(C=C) in aromatic ring	1-4
1484-1481	(C-C) in aromatic ring, and (C-H)	1-4
1462-1459	(C-C) in aromatic ring, and (C-H)	1-4
1394-1389	(N-H), (C-N) and (C-H)	1-4
1318-1315	(C-C) in aromatic ring	1, 3-4
1300-1297	(C-H)	1, 3-4
1199-1196	(C-C) in aromatic ring, and (C-H)	3-4
1175-1172	(C-H), (N-H), and (C-N)	3-4
1129-1123	(C-H), (N-H), and (C-N)	1-4
1070-1065	(C=O) and (C-C) in aromatic ring	1, 3-4
1011-1009	(C-C) in aromatic ring, and (C-H)	3-4
880-877	(C-C), δ(C-N), and (N-H)	3-4
755-751	(C-H)	3-4
714-712	(C-C) and (C-N)	3-4
698-642	(C=O), (C-C) in aromatic ring	3-4

Table 5: FTIR wavelength frequency and band assignment that characterise indigo dye. Data abstracted from: 1 – Lee et al. (2014); 2 – Lee et al. (2013); 3 – Ju et al. (2019); and 4 – Baran et al. (2010)

ATR-FTIR

Infrared spectra of two textile finds from the Skeiet 1 site are presented in figs. 5a and 5b, including the fragment (T28189:1, fig. 4c) from the top of the copper-alloy oval brooch from inhumation Grave 2 (T28189:1, fig. 3c) and the fibres (T28276:75, fig. 4e) from the pin fastener on the reverse of the Insular brooch (T28276:3 fig. 3e) from the boat burial (Grave 11). The spectra strongly conform with plant fibres when compared with a known reference of linen textile fibres (fig. 5c). The infrared band assignments of plant fibres are summarised in table 3.

The infrared spectra of both textile finds have a broad peak in the frequency region for O-H bonding in hydroxyl groups around 3330–3290 cm^{-1}, associated with cellulose. In addition, both have peaks in regions typical of polysaccharides in cellulose, with signal from C-H bonding at 2900 cm^{-1}, signal from C-C bonding in ring 1160/1157 cm^{-1}, and C-O-C bonding at 1104/1107 cm^{-1}. Moreover, both have signals in frequency regions typical of hydrocarbons in cellulose at 1335 cm^{-1}, 1368/1371 cm^{-1}, and 1421/1427 cm^{-1}. Both spectra have signals typical of C-OH bonding at 1028 cm^{-1}, as well as C-O-C bonding in cellulose at 901/899 cm^{-1}. Both spectra also had a peak in the region of water adsorbed in lignin and cellulose at 1639/1632 cm^{-1}. The fibres (fig. 4b) from the Insular brooch (fig. 3b) have a weak shoulder around 1735 cm^{-1} that can be attributed to either ester in lignin or carbonyl in degraded cellulose. The textile fragment (fig. 4a) from the oval brooch (fig. 3a) also shows signs of lignin, with a broad peak at 1597 cm^{-1} assigned to C=C bond in lignin, and a weak shoulder in the region for ester in lignin or carbonyl in cellulose around 1735 cm^{-1}.

The infrared spectrum of the blue-coloured textile fragment from Grave 11 (T28276.59, figure 3d) is presented in fig. 5a. The spectrum is consistent with known references of animal textile fibres, wool and silk (figs. 5b and 5c). The infrared band assignments of proteinaceous animal fibres are summarised in table 4. The blue textile fragment has several signals that are more compatible with wool rather than silk. This is shown by a broad peak in the amide hydrogen bonding frequency region around 3271 cm^{-1}. The spectrum also has characteristic peaks for amide I at 1625 cm^{-1} and amide II at 1533 cm^{-1}, and a small peak at 1227 cm^{-1} assigned to amide III. In addition, the sample has signals from methyl group in wool at 1388 cm^{-1},

and signals assigned to sulphur-oxygen compounds in keratin at 1124 cm^{-1}, 1068 cm^{-1}, and 1039 cm^{-1}.
In addition, the spectrum is also compatible with the known indigo reference, suggesting that the blue colour in the textile is indigo dye (fig. 7c). The infrared band assignments of indigo are summarised in table 5. The blue textile (fig. 7a) has characteristic signals assigned to aromatic rings in indigo with peaks at 1582 cm^{-1}, 1484 cm^{-1}, 1462 cm^{-1}, 1317 cm^{-1}, at 1199 cm^{-1}, as well as 1069 cm^{-1}, a shoulder at 1010 cm^{-1} and a small peak at 698 cm^{-1}. The spectrum also has peaks at 1390 cm^{-1}, 1300 cm^{1}, 1172 cm^{-1}, 1125 cm^{-1} and 880 cm^{-1}, assigned to nitrogen bonds with hydrogen and carbon, as well as carbon and hydrogen bonds in indigo. Peaks at 1299 cm^{-1} and 755 cm^{-1} are also assigned to indigo carbon-hydrogen bonds.
Some typical indigo characteristics are masked due to overlap in frequency regions where there are also signals from wool fibres in the sample. Some signals may also have shifted frequency due to the effects of signal overlapping. This is the case around 3264 cm^{-1}, where a peak appears in indigo that is attributed to carbonyl, C=O, and which is not possible to reliably identify in the sample due to the broad peak in this frequency region from the signal of the N-H bond in wool. This also applies to the peaks between 3068 cm^{-1} and 2877 cm^{-1} that are in the region for hydrocarbons that can be associated with both proteinaceous animal fibre and signals from hydrocarbons in the aromatic ring in indigo. The spectrum has two nearby peaks at 1626 cm^{-1} and 1612 cm^{-1}, which are in the region where there is an overlap of signal frequency for amide I in animal fibres and C=O and N-H bonding in indigo. As both indigo and proteinaceous fibres contain amide hydrogen bonding, the peak at 1390 cm^{-1} (region of bending of N-H bond) in the sample can be attributed to either of these substances. The peak at 1069 cm^{-1} may also possibly overlap with the peak in the frequency region for sulphur compounds in keratin, at 1080–1070 cm^{-1}.
The infrared spectrum of the textile from the chamber tomb at Hestnes that consists of large fragments of

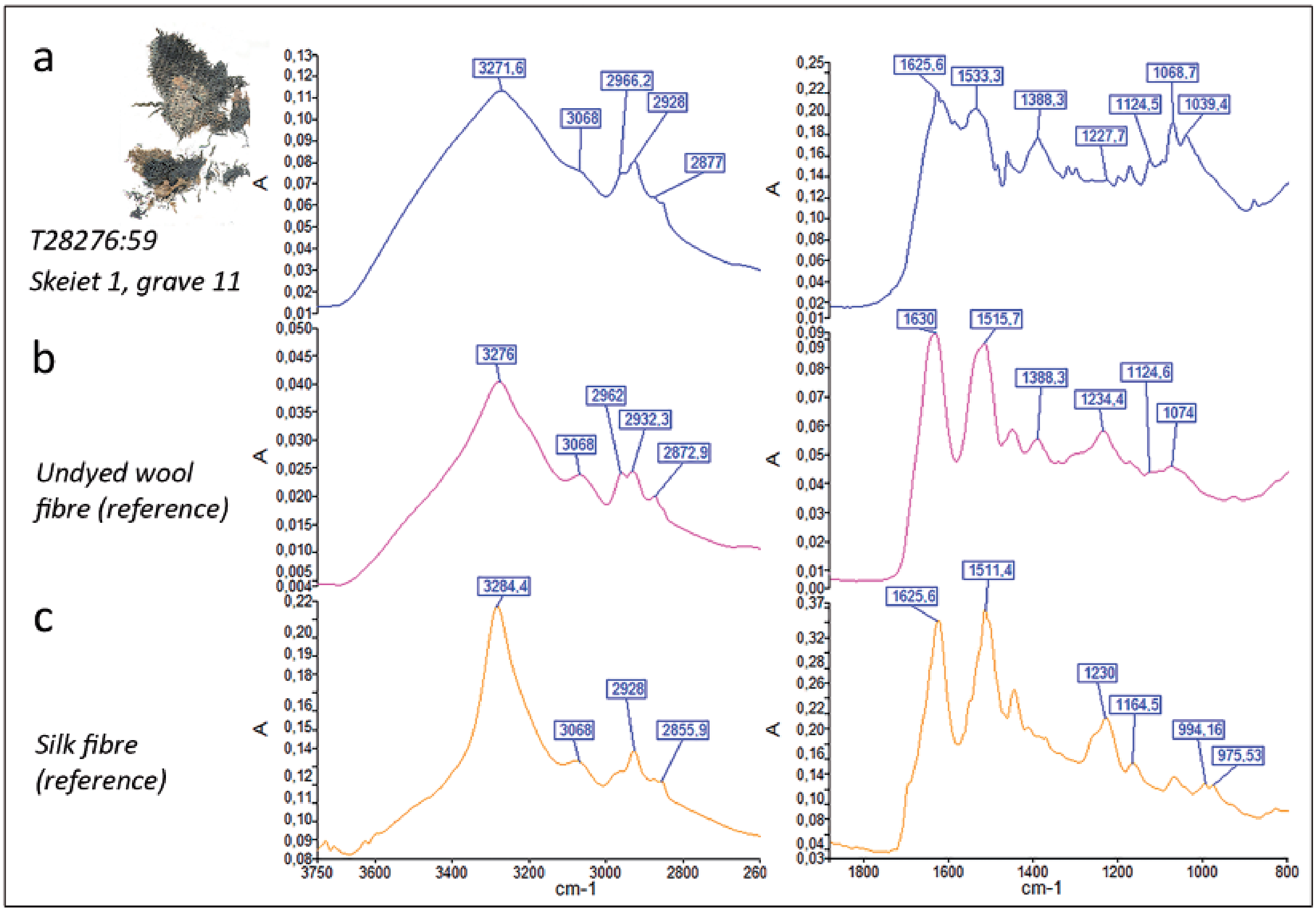

Fig. 6: Infrared spectra for the blue-coloured textile fragment compared to reference spectra for protein-containing textile fibres: a) blue-coloured textile fragment from Skeiet 1, Grave 11, NTNU University Museum T28276:59, see fig. 4d; b) modern undyed wool yarn, reference sample; and c) silk, reference from NTNU IAK Conservation Laboratory's reference library (Image: Thea P. B. Christophersen)

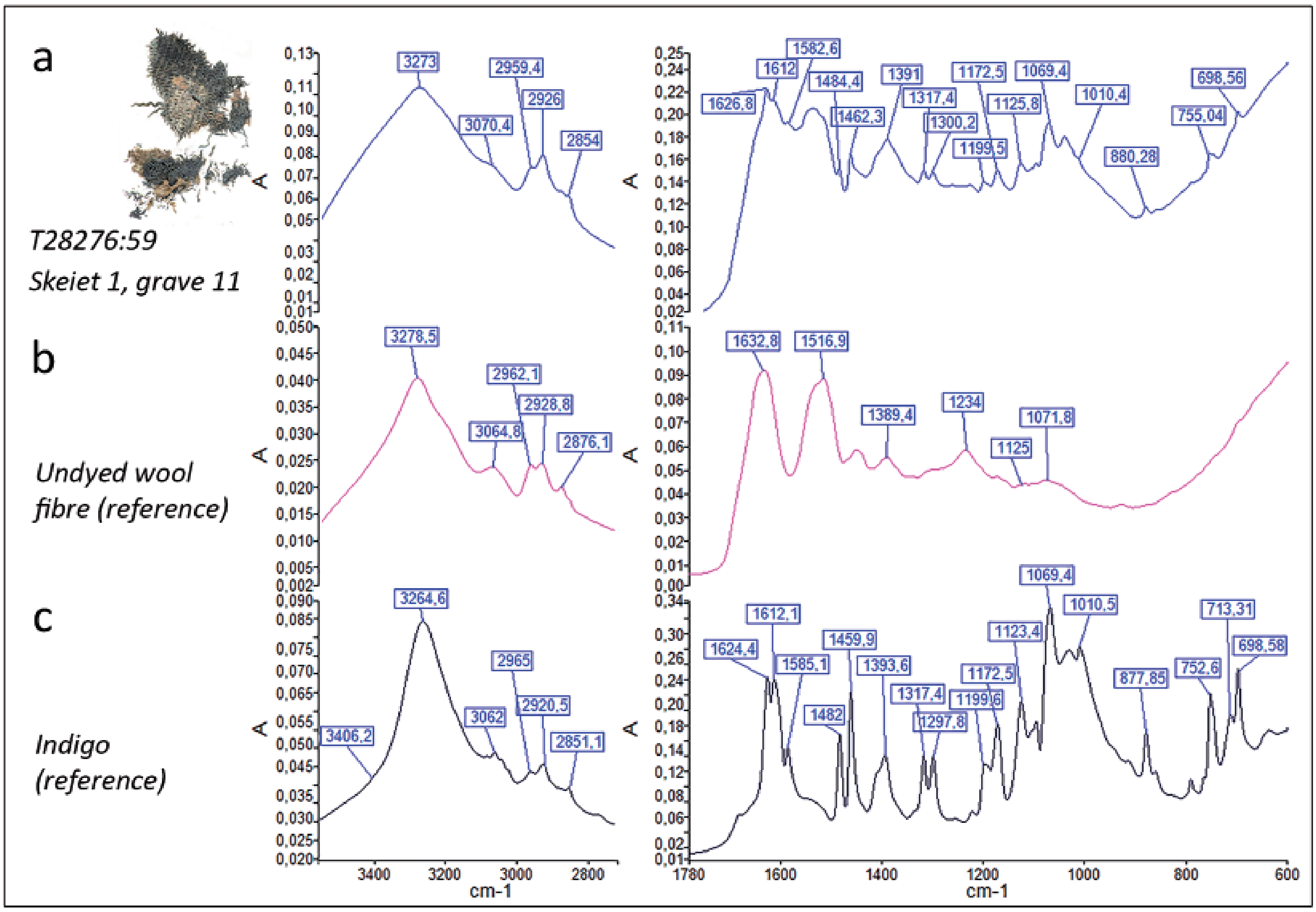

Fig. 7: Infrared spectra for the blue-colored textile fragment compared to reference spectra for modern wool and indigo: a) blue-coloured textile fragment from Skeiet 1, Grave 11, NTNU University Museum T28276:59, see fig. 4d; b) modern undyed wool yarn, reference sample; and c) modern indigo, reference sample (Image: Thea P. B. Christophersen)

woven fabric (T28348:12, fig. 4b), lacks recognisable, clear characteristic signals from typical substances in organic textile fibres (fig. 7b). This makes it challenging to reliably assign the textile to a textile fibre group. The spectrum shows some distinct characteristics that can be attributed to proteinaceous fibre when compared to the wool reference spectrum (fig. 8a). This includes a broad shoulder at ~3264 cm^{-1}, two peaks around 2930 cm^{-1} and ~2852 cm^{-1}. The sample shows one broad shoulder in the region ~1597 cm^{-1} where in well-preserved proteinaceous animal fibre, one would otherwise see two characteristic peaks (around 1625–1615 cm^{-1} and 1530 cm^{-1}, as in the blue textile from Grave 11, fig. 6). The peak at 1386 cm^{-1} can be attributed to C-N in amide III. A broad peak around ~1035 cm^{-1} can be associated with sulphur-oxygen compounds in keratin. In combination with the preliminary visual examination, it is possible to assign a tentative identification of the textile's raw material as hair/wool.

The other textile from Hestnes, the seven small textile fragments (T28348:6, fig. 4a) has few characteristic signals that can be attributed to a specific fibre group (fig. 9).

Discussion

The results of the visual and macroscopic condition analysis show that the textile fibres have different progressive stages of mineralisation of the original organic fibre structure. This is because the contact area between the metal object and the textile fibres produced a microsystem in which the process of fibre degradation in the textiles and metal corrosion interacted both physically and chemically. Often the fibre has retained an organic character in the core in the form of intact fibres (Peacock 1994; Marian and Niculescu 2016) but has metallic salts on the surface that have played a major role in its preservation. Furthermore, the occurrence of both copper mineralisation and iron mineralisation together in

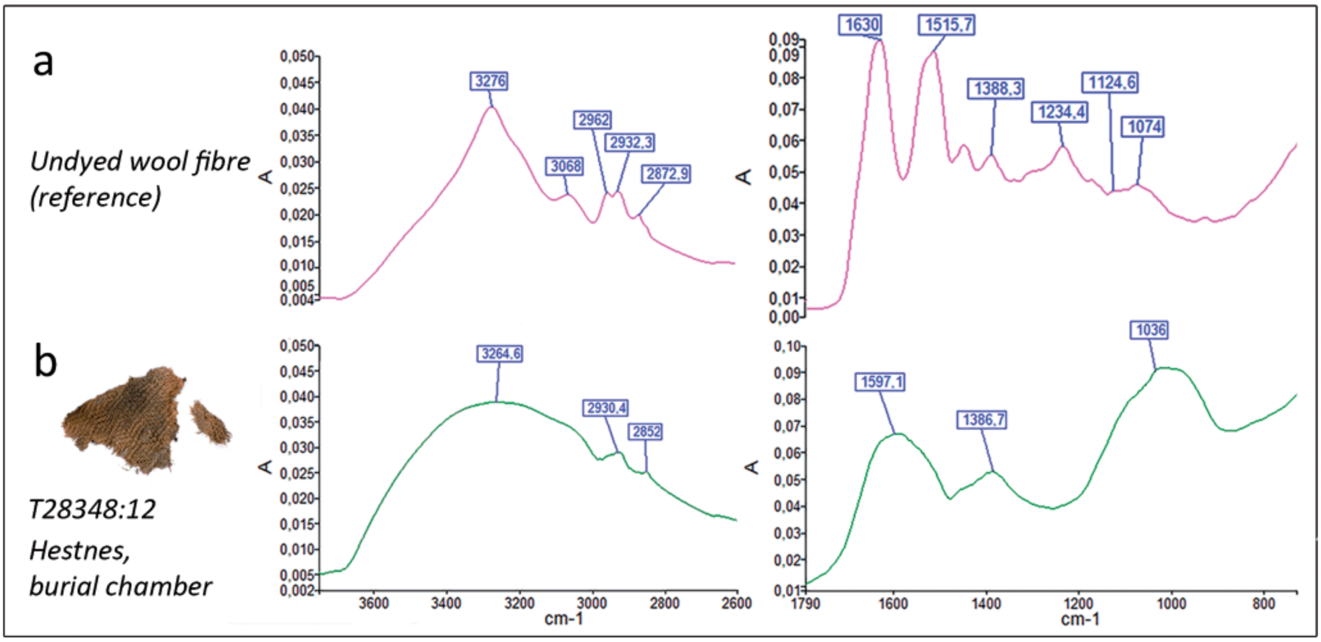

Fig. 8: Infrared spectra for textile fragment from the Hestnes burial chamber compared with a reference of modern wool yarn: a) undyed modern wool yarn, reference sample; and b) textile fragment (NTNU University Museum T28348:12, fig .4b) found on top of trefoil brooch (NTNU University Museum T28348:3, fig. 3b) (Image: Thea P. B. Christophersen)

several of the textiles (fig. 4a and fig. 4d) illustrates that this is more common than often assumed (Mannering and Peacock 1998, 13).

The results from FTIR analysis show that the identified plant fibres in the two textile finds from Skeiet 1 (fig. 4c and fig. 4e) have clear, well-preserved cellulose/lignin signatures despite visually appearing highly mineralised. This suggests that mineralisation has not led to advanced or total replacement of the organic component of the textiles, which has also been observed in studies of other plant fibre mineralised archaeological textiles (Chen et al. 1996; Margariti et al. 2010; Reynaud et al. 2020).

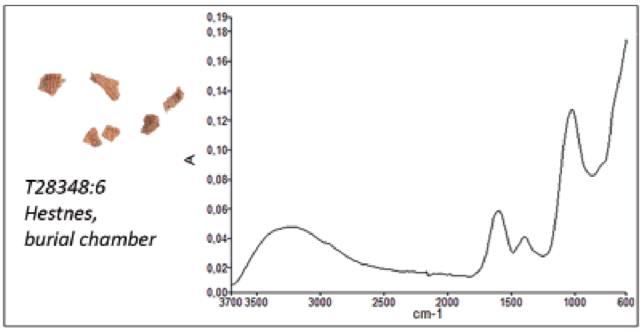

Fig. 9: Infrared spectrum for one of the seven small textile fragments (NTNU University Museum T28348:6, fig. 4a) found on the underside of an oval brooch (NTNU University Museum T28348:1, fig. 3a) from the Hestnes burial chamber (Image: Thea P. B. Christophersen)

The fact that it was possible to identify both wool/hair and indigo in the bluish-coloured textile fragment from Skeiet 1 (fig. 4d) demonstrates the additional potential of ATR-FTIR for the characterisation of dyestuffs in mineral-preserved archaeological textiles. Although both wool and silk are protein fibres, the distinctions in the spectra characteristics are significant enough to enable fibres to be identified as either wool/hair or silk (fig. 6). The results from the analysis of the two textile finds from Hestnes illustrate some of the limitations of ATR-FTIR. The unclear signals in the infrared spectra can be caused by a range of factors. The stage and nature of preservation of the textiles, their thickness, the way they have been preserved in the archaeological context, the use of dyeing mordants/assists can all affect clarity of results obtainable with FTIR analysis (Margariti et al. 2010; Margariti 2023). Additionally, although not the case with the recently excavated E39 fragments, post-excavation storage and conservation treatment (e.g., consolidation) can interfere. The lack of clarity in the spectrum from the large textile fragment with well-preserved organic, flexible part (fig. 4b) that was identified as worsted wool in the preliminary survey, may be due to overlapping signals from other organic materials that have infiltrated the textile. Davis and Harris (2023, 16) note that mineral-preservation of textiles and the corrosion of the metals in proximity can be independent in forming the remains that survive due to the interaction between different materials, both organic and inorganic, during degradation of the assemblage. The lack of distinct signals from the second, highly mineralised textile fragment (fig. 4a) can be due to its thickness and/or much reduced organic matrix in the fragment, for example. The specific degradation or mineralisation products that may appear in the spectra from the archaeological samples was not investigated. SEM-EDS analysis of the samples might provide some clarity and insight into what degree these affect the spectra, if at all.

FTIR spectroscopy is becoming more accessible to conservators either in laboratory acquisition or interlaboratory cooperation, especially with the introduction of compact, portable handheld spectrometers. FTIR can operate in transmission, reflectance or attenuated reflectance (ATR) modes. Peets et al. (2019) and Margariti (2019) have evaluated their application to modern and mineralised textiles, respectively. Both investigated FTIR spectroscopy in reflectance and ATR modes and concluded that FTIR applied in the contactless reflectance mode was less damaging. The pressure of the ATR arm and its potential to deform or crush a sample with the potential consequence of reducing the spectrum quality, is a drawback of consideration for ATR-FTIR.

The analytical study of archaeological textiles is challenging. Multi-analytical and combined techniques are recommended. Advanced analytical techniques require specific expertise and often are invasive and/or destructive, both of which are to be avoided if possible. Bertrand et al. (2025, 124–125) review necessary considerations when evaluating non-invasive versus invasive analysis and non-destructive versus destructive analysis of archaeological textiles. The necessary handling during post-excavation study or conservation treatment unavoidably disassociates small samples from artefacts. In the present study, these were collected and stored for future analysis, which was the case for the Insular brooch (T28276:3, fig. 3e) and thread fragments (T28276:75, fig. 4e). In this study, small fibre samples (in the form of thread) were taken from three intact fragments, loose shedding fibres from the reverse of one brooch, and in the case of the fifth, a whole hard, brittle fragment was used. The first three were invasive, whereas the remaining two were non-invasive in that no sample was taken. None of the samples required preparation such as mounting for analysis, and all could be used in future chemical analysis. The analysis itself was quick to carry out but requires reference spectra (libraries) to aid interpretation.

It was possible to identify indigo in one of the textile samples. The concentrations of dyestuffs such as indigo in textiles is low, due to indigo's high tinting strength (Kramell et al. 2015, 1039). More conclusive identification of indigo dye in ancient and historic textiles requires instrumental analysis of high sensitivity. There is a wide selection of methods to choose from with the most sensitive and widely used Gas Chromatography (GC) or GC coupled with pyrolysis (Py-GC-MS), or High-Performance Liquid Chromatography (HPLC). These, however, completely consume the sample through derivatisation or thermal decomposition to identify dye compounds (Kramell et al. 2015, 1039; Shahid et al. 2019, 63).

Conversely, spectroscopic techniques, including Raman, fluorescence and IR spectroscopy, can be employed as either partially or completely non-destructive surface techniques, making them preferable in assessment of dyestuffs in heritage textiles of limited availability (Kramell et al. 2015, 1039; Shahid et al. 2019, 63–64, 66). Fiber Optics Reflectance Spectroscopy (FORS) is another non-invasive technique, which has been investigated by Gulmini et al. (2013) and Shahid et al. (2019, 64). As for ATR-FTIR, the common disadvantage of these less-invasive techniques is that they require interpretation and comparison with known reference materials (Shahid et al. 2019, 63). The spectra may be challenging to interpret due to signal overlap from molecular bonds with similar absorbance bands from different components in the sample. Dyestuff identification is further complicated by the minute concentration of dye relative to the fiber matrix (Kramell et al. 2015, 1040). As outlined above, archaeological samples will also contain impurities from use and burial context, as well as products from mineralisation and chemical degradation of the organic textile (Bertrand et al. 2025, 128–129; Kramell et al. 2015, 1040). It is therefore necessary to base spectral interpretation on the known absorbance bands that are characteristic of the chemical compounds under study. In the study reported herein, this colour assessment challenge was overcome by employing literary references (summarised in table 5) as well as samples of known references of modern indigo dye (table 2, fig. 7).

Conclusion

The E39 Betna-Stormyra project is the most extensive archaeological excavation of Late Iron Age cemeteries and settlement features conducted in Mid-Norway. Investigations carried out in the Vinjefjord area have provided insights into past lives and societies that thrived in the region in the Iron Age and medieval period. The detailed preliminary technical survey carried out by Øien and Heen-Pettersen (2024, 200–206, table 1) formed the basis for an evaluation of dressing practices related to mortuary rituals during the Viking Age. The investigation reported herein shows that ATR-FTIR can be successfully applied in the identification of raw materials in mineral-preserved archaeological textile fibres. The organic matrix in three of the five selected mineral-preserved textile fragments was well enough preserved in the archaeological context for the fibre type to be identified. The infrared spectra showed characteristic features that gave clear indications that the textile finds from Skeiet 1 found in association with the copper-alloy oval brooch recovered from Grave 2 (fig. 3c) and the light-coloured fibres from the copper-alloy Insular brooch in Grave 11 (fig 3e) undoubtedly consist of cellulose-containing plant fibres.

Spectra from the visually bluish-coloured textile from Skeiet 1 Grave 11 (fig. 4d) show that the textile was produced with a protein-containing animal fibre, probably wool/hair and dyed with indigo. For the two textile finds from Hestnes, it was not possible to inconclusively determine the appropriate fibre group with ATR-FTIR. Although, the spectrum of the sample from the larger, woven fragment (fig. 4b) can be tentatively classified as belonging to a proteinaceous animal fibre group.

The study demonstrated the potential of ATR-FTIR for identifying fibre type and dyestuff in mineral-preserved archaeological textile fragments – a distinct category of archaeological textile. It is a quick, minimally to non-invasive, micro to non-destructive and low-cost analytical technique that requires minimal sample preparation. Although it may be considered only partially informative, it is useful to guide selection and sampling for further analysis that may be destructive in nature (Bertrand et al. 2025, 128). The dye results reported herein complement other studies of the textile remains from the three female inhumation burials including traditional visual technological analysis of fragments and down feather remains to conclude that the woman in Skeiet Grave 11 (T28276) was partially covered by a blue-dyed, down-filled wool quilt. To Øien and Heen-Pettersen's (2024, 209) knowledge, this is the only example of blue-dyed bedding known from Viking Age Scandinavia.

The application of FTIR analysis, to archaeological textiles to identify both fibre type and dyestuffs, is not uncommon. However, its application to Viking Age period textile remains recovered from excavations in Norway has not been previously reported. Lukešová (2015; 2017) reactivated the University Museum of Bergen's (Norway) archive of textile fragments from the Viking Age that were excavated at the end of the 19th century or in the first half of the 20th century and is one of the oldest archaeological textile collections in Norway. Most fragments were recovered in association with metal artefacts and many are mineral-preserved. Recent studies focused on optical and scanning electron microscopy and staining techniques (Lukešová et al. 2017, 282–283), the latter excluded mineral-preserved and carbonised fragments from investigation. ATR-FTIR spectroscopy analysis of mineral-preserved fragments in this collection could form the basis for a combined approach to complement fibre type and dyestuff identification by other analytical methods.

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Beyond the *ṭirāz*: ninth to 13th centuries domestic textile production in al-Andalus

Abstract
This article explores domestic textile production in al-Andalus between the ninth and 13th centuries, with a focus on spinning tools and their archaeological contexts. While previous scholarship has prioritised elite textiles and state-sponsored workshops (*ṭirāz* (s.), *ṭurūz* (pl.)), this study highlights the material remains of non-elite, household-scale production. Drawing on data from over seventy sites, it documents technical changes in spinning tools – including ceramic and bone spindle whorls and metal spindle tips – and argues for a process of increasing standardisation and specialisation. These developments reflect broader economic transformations linked to the internal market, fiscal policy, and labour organisation under the Islamic state. By analysing these everyday artefacts, the study reconstructs patterns of production, exchange, and social reproduction, demonstrating the centrality of textiles to Andalusi material life. Textile production emerges as an important sector for approaching economic dynamics and social structures in the medieval western Islamic world.

Keywords: Archaeology, textiles, spinning, al-Andalus, economy, tools

Introduction

Historiography on textiles in al-Andalus has tended to coalesce around two major axes of investigation. On the one hand, scholarly attention has privileged the study of textiles in their commercial, economic, and political dimensions, with particular emphasis on their central role in Mediterranean exchange networks and in the fiscal structures of the Islamic state. The significance of this activity has led to characterisations of the medieval Islamic period as a veritable "textile civilisation" (Lombard 1978), a view supported by an extensive corpus of references found in chronicles, administrative records, and mercantile inventories that attest to the circulation of textiles among the major urban centres of the Islamic Mediterranean (Remie Constable 1997).

This approach has been closely linked to analyses of the state-sponsored textile workshops – the *ṭurūz* – and their role in the formation and consolidation of political authority, initially under the Umayyad emirate (756–929 CE) and subsequently during the caliphate (929–1031 CE). In this study, the term *ṭirāz* is used not only to refer to inscribed textile bands, but also in its institutional sense, as state-owned and state-controlled textile production centres intended for the political elite, high-ranking administration, and diplomatic purposes, functioning as symbols of authority and political legitimacy. These manufacturing centres, inherited from Byzantine and Sasanian models, functioned not only as large-scale economic structures but also as key ideological instruments in the representation of sovereign power, particularly in urban hubs such as Córdoba or Almería (López Martínez 2023, 23–35). The production of luxury textiles intended for ceremonial use, clientelist distribution, or diplomatic gifting has received particular attention in the historiography, owing to the richness and abundance of documentary references relating to these practices.

In the same vein, the study of preserved textiles held in royal or ecclesiastical collections has provided a complementary material perspective – for example,

Fig. 1: From cloth to thread. Left: Textile from Las Águilas (Almería, 12th century). Right: Spinner from al-Ḥarīrī (Les Maqāmāt de al-Ḥarīrī, 13th century manuscript, fol. 138v). A) Distaff component; B) Spindle whorl; C) Spindle rod (Images: left: reproduced with the permission of M. Ramos 2022, 535; right: digital version released into public domain by https://gallica.bnf.fr/ark:/12148/btv1b8422965p/f36.item.r=maqamat%20al%20hariri#)

the *Tejido de las Águilas* of Saint Bernard of Calvo or the *Tejido de los Grifos* from the reliquary of Santa Librada (Saladrigas 2017, 64–65). Through technical and stylistic analyses of these pieces – often produced in silk, including samite, taqueté, or lampas – it has been possible to reconstruct aspects of the technological complexity of Andalusi textile production and to propose the existence of specialised production centres, such as that documented in twelfth-century Almería (Barrigón 2022, 50–69) (fig. 1, left). Nevertheless, the Medieval period has received relatively limited attention from a systematic perspective focused on textile production as a whole, beyond its elite manifestations.

Textile production should be understood as a phenomenon whose study requires a holistic approach to the *chaîne opératoire*: from the cultivation or gathering of plant fibres, metallic threads, and the breeding of fibre-producing animals, through the successive phases of spinning (fig. 1, right), weaving, dyeing, finishing, and distribution. This perspective – informed by textile-archaeological methodologies in other medieval contexts (Andersson Strand 2021; Andersson Strand et al. 2010, 151) – breaks the process down into stages and actors, contributing to the reconstruction of past ways of life, social relations, and economic structures.

The archaeology of textile production in al-Andalus

The historical issue at stake here lies in understanding how, why, and by what means thread and cloth were produced in al-Andalus. From an archaeological perspective, the available material evidence – despite the breadth of activities comprising the textile *chaîne opératoire* – is concentrated chiefly in the tools associated with spinning and weaving, recovered from archaeological contexts, most notably from the ninth century onwards. From this period, significant changes become evident, such as the appearance of new types of looms and spindle whorls, the use of new raw materials, and, above all, the availability of a larger archaeological record that allows these evidences to be more clearly traced.

The study of textiles in al-Andalus has traditionally held a secondary position compared to sectors such as ceramics or metallurgy, owing both to the limited archaeological visibility of textile materials and to a historiographical tendency to privilege other forms of production. However, since the 1990s, medieval urban excavations have uncovered new evidence that highlights the significance of textile production. It is within this framework that the first textile tools from al-Andalus began to be documented, appearing in monographs on key sites such as Mértola (Luzia et al. 1984, 49–51), Ciudad de Vascos (Izquierdo 1999, 126, 166, 171), and Castillo del Río (Azuar 1994, 172, 239). At the same time, more focused studies were published addressing specific categories of implements, such as horizontal looms (Retuerce 1987) or bone spindle-whorl components (Torres 1986). Progress in this line of research during the 1980s was uneven. Most publications of the time focused on the technical or typological description of objects, without addressing their articulation with the economic and social systems underpinning textile production.

This limitation, however, is now beginning to be overcome. In recent years, there has been a marked increase in studies that have explored the organisational complexity of state-controlled textile production in al-Andalus, drawing on historical sources (López Martínez 2023). At the same time, growing attention is being paid to approaches that integrate less visible or traditionally underestimated productive sectors, beyond the well-documented sphere of silk manufacture. Noteworthy in this regard are recent contributions that assess the scale and quality of staple textile production (Fábregas 2022, 130–133) and highlight its significance in the broader dynamics of medieval economic development.

The historiography of Andalusi textiles

The study of textiles and their inherent complexity require holistic approaches that integrate, in a coordinated manner, textual sources, archaeological evidence – including both the material remnants of decayed fabrics (fibres, dyes, weave or knit structures) and the spatial contexts in which textile tools are found, such as houses, neighbourhoods, villages, castles, or citadels – together with insights from experimental research. This approach, developed in works such as those by Margarita Gleba and Susanna Harris (2019) and Eva Andersson Strand et al. (2010), not only enables the reconstruction of specific technical materialities, but also supports broader interpretations concerning political structures, forms of social organisation, and economic dynamics. In the case of al-Andalus, textile production was embedded within a particularly complex framework, marked by the coexistence of multiple economic scales. The diversity of social classes – each with its corresponding levels of consumption and differential access to textile goods – was compounded by a plurality of organisational forms of production, including both domestic arrangements and extramural workshops. These operated within networks shaped by social, fiscal, political, and geographical factors (Grömer 2016, 241; Moreno-Narganes 2024, 98–100).

Recent studies have re-evaluated traditional interpretative models. In *The Donkey and the Boat* (Wickham 2023), the author proposes a re-reading of textile production and circulation in the early Middle Ages, challenging the longstanding historiographical bias that privileged textiles mentioned in written sources – frequently associated with aristocratic elites or state apparatuses – over more local or regionally produced textiles, which are more difficult to trace yet quantitatively predominant. Wickham's proposal, in line with recent studies (Moreno-Narganes 2020, 241–252; 2023), calls for renewed attention to internal trade and exchange networks between countryside and city, or among rural settlements, to explain the central role of textile production in medieval economies. It highlights the predominance of non-elite textile labour and allows for a reinterpretation of archaeological evidence related to spinning and weaving as key to understanding the economic functioning of al-Andalus. Far from being secondary remains, these artefacts stand as direct indicators of everyday productive dynamics and the social structures sustaining them.

Textile production centres

In this context, a recent study examined the richness and complexity of domestic textile production in al-Andalus (Moreno-Narganes 2024). Based on the systematic analysis of more than seventy archaeological sites (fig. 2) across the southern and southeastern half of the Iberian Peninsula, it has become possible to begin delineating the general features of this type of production. Given the diversity and inherent difficulty of encompassing the entirety of textile production over such a broad chronological span, the research focused on domestic production between the ninth and 13th centuries.

The study concentrated on tools associated with two fundamental phases of the production process: on the one hand, those linked to thread manufacture – such as spindle whorls, spindle rods, and distaff components – and on the other, implements associated with vertical and horizontal looms, including weaving picks and *templenes*. Templenes, or "temple claws," were devices used to preserve the working width of the fabric during weaving on horizontal ground or treadle looms, by maintaining tension and preventing lateral shrinkage.

In order to understand how this production was structured within the framework of a developed and territorially interconnected political economy, a range of sites was selected – including rural settlements (sg. *qarya* pl. *qurā)* fortified centres, and urban nuclei – with the aim of identifying patterns, contrasts, and regularities in modes of production and consumption. Through this lens, it becomes possible to trace regional and social diversity in these practices, and to examine how they were shaped by, and in turn contributed to, the territorial structure of the state. The study of working tools in domestic contexts provides access to a social segment that is generally underrepresented in historical sources: a relatively homogeneous group in terms of household structure and socio-economic position, composed of both urban and rural labourers whose work underpinned a substantial part of the productive base of the Andalusi state (Chalmeta 2021).

The breadth of the archaeological record, as demonstrated by territorial-scale studies focused on the Mediterranean littoral and the Garb al-Andalus, particularly in the southern Alentejo region (Moreno-Narganes 2024, 765–771) – reveals a strong regionalisation of thread and textile production centres. This territorial fragmentation suggests the existence of productive units primarily oriented towards the supply of nearby markets, with dynamics comparable to those observed in the case of Islamic ceramics, for the Guadiana valley (Gómez 2014, 34–36) and the Vinalopó Valley (Azuar 2020, 213–214).The hypothesis of a regionalised market, long argued in ceramic studies, may likewise be applied to textile production: the majority of cloth consumed in al-Andalus was likely produced in local centres, integrated into well-organised market networks operating from at least the tenth century onwards.

Although al-Andalus has been extensively studied as the westernmost terminus of the great commercial routes of the Mediterranean – connected to the Silk Road and to the reception of goods from the Near East, including textiles inspired by models originating in present-day Iraq and Iran (Idrīsī 1999, 281–282) – this focus on long-distance exchange should not obscure the structural significance of internal and short-range networks, largely overland in nature, which operated continuously and often independently of shifting political frontiers within al-Andalus. The consolidation of these networks was closely linked to the development of the Andalusi state apparatus (López Martínez 2020) and contributed to a certain standardisation of production and consumption patterns, a phenomenon observable in ceramics (Amorós-Ruíz 2022, 66-67; García Porras 2020, 162–169) and, as this study proposes, also increasingly evident in textiles – a sector that this research seeks to place at the centre of economic reconstructions for the period.

This account of a territory which, from the eighth century onwards, entered into a transformative dynamic that reshaped its material foundations, reflects both the internal complexity of each region and the accumulation of inherited traditions. From the ninth century, long-established production practices – such as the use of flax and wool, present since prehistoric times – converged with the expansion of new raw materials, such as cotton and silk, whose production and consumption increased significantly during this period (Dozy 1961), though their true scale has yet to be fully measured through the archaeological record. These fibres were cultivated and produced for the first time in the Iberian Peninsula during this period, marking a significant shift in the region's agrarian and artisanal landscape.

Spinning technologies

The spatial and typological breadth of the present study makes it possible to document systematically the technical transformations in spinning and weaving tools from the eighth century onwards, providing a robust empirical basis for analysing these changes in relation to the evolving social and economic structures of the period. Spinning, in particular, constitutes a key stage in the textile *chaîne opératoire*, not only from a technical perspective but also in terms of its structural economic significance. Its study enables critical questions to be addressed regarding the gendered and social division of labour, the dynamics of domestic and specialised production circuits, and the role of textiles in the mechanisms of economic redistribution driven by the Andalusi state. In this respect, the analysis of spinning tools – spindle whorls, spindles, and distaff components – offers privileged access to the modes of production employed by the urban and rural working classes, whose activities, though scarcely recorded in written sources, were essential to the maintenance of the state economy.

Nonetheless, current understanding of spinning practices prior to 711 CE remains extremely limited. Despite the considerable number of archaeological excavations conducted in Visigothic and Late Antique contexts, publications documenting materials associated with spinning are exceedingly rare, making it difficult to identify technological continuities or ruptures between Late Antiquity and the Islamic period. This methodological and evidentiary gap underscores the need to reassess the study of spinning

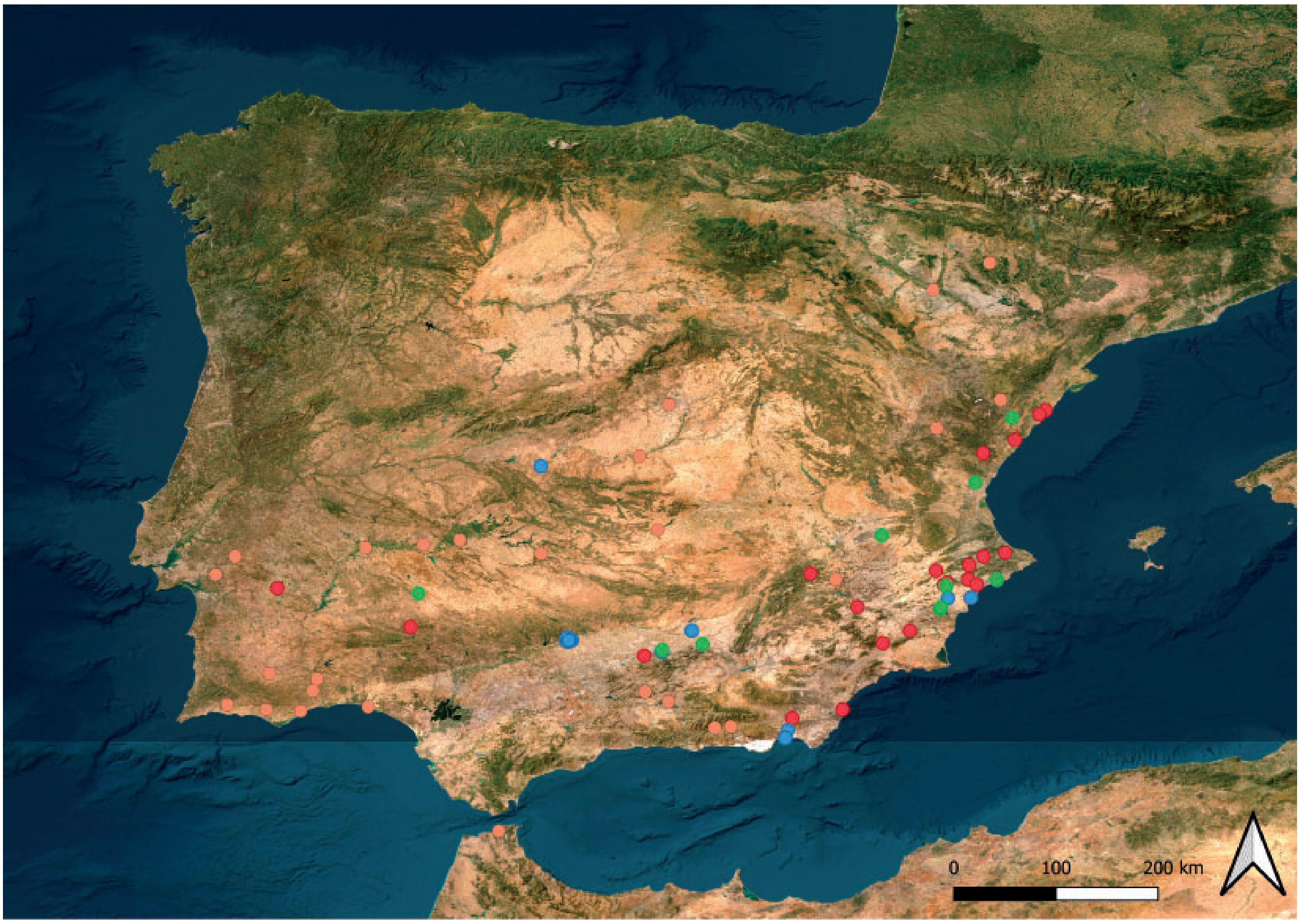

Fig. 2: Distribution of sites with evidence of textile production (9th–13th centuries). Blue: urban centres; red: fortified settlements; green: rural settlements; orange: cases identified exclusively through secondary literature (Map: José María Moreno-Narganes)

as a long-term historical phenomenon – one that is crucial not only for understanding technical change, but also for interrogating the political and social logics that underpinned the economic development of al-Andalus.

Spindle whorls

Spinning, though a fundamental stage in the textile *chaîne opératoire* determining thread quality and type, has received limited scholarly attention. More than a preparatory task, it represents a key phase of technical design shaping the final outcome. The earliest references for the medieval period are found in written sources such as Isidore of Seville's *Etymologies* (seventh century) (2004, 1311), which mention instruments related to spinning but fail to provide sufficient technical descriptions to establish clear material correlates within the archaeological record. This documentary gap continues well into the eighth and even the ninth century. Nevertheless, recent re-evaluations of assemblages from sites such as Tossal de la Vila (Serra d'en Garcerán, Castellón) and Tolmo de Minateda (Hellín, Albacete) have begun to yield significant evidence concerning spinning practices during this period. In these cases, spindle whorls exhibit notable morphological and technical variability: artefacts include pieces fashioned from sawn animal femur heads, reused fragments of protohistoric ceramics employed as flywheels, and even Iberian-period spindle whorls redeployed within Umayyad contexts (Moreno-Narganes 2024, 131–143). This assemblage reflects a marked absence of standardisation, consistent with a loosely structured economic landscape and a technology still undergoing consolidation. The use of animal femur heads as counterweights for spinning – also attested in early medieval contexts such as the caves of Las Peñas (Cantabria, seventh to eighth centuries) (Gutiérrez and Hierro 2010, 262–267) – highlights the persistence of archaic craft practices during the early centuries of the

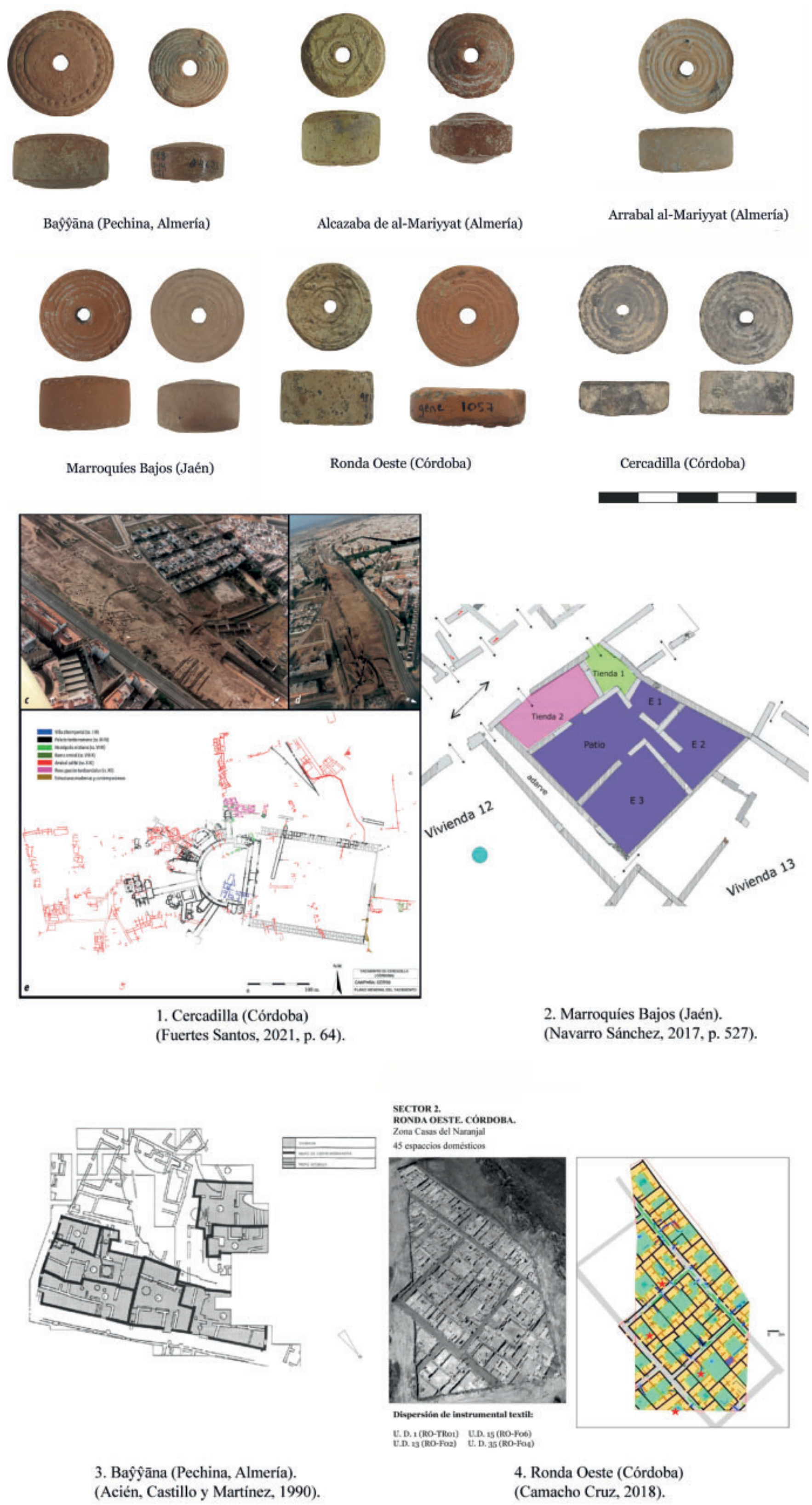

Fig. 3: Selected case studies from the 10th to 11th centuries. Right: urban archaeological sites. Top: recovered spindle whorls (Image: José María Moreno-Narganes)

Islamic period. This suggests a degree of continuity in domestic production practices, particularly in rural or peripheral areas. However, from the ninth century onwards – coinciding with the economic, social, and political developments accompanying the expansion of the Andalusi state and the process known as the "agrarian" or "green revolution" – a significant transformation in spinning technologies can be observed (Moreno-Narganes 2023). This shift is evident in both the increased abundance of material indicators and the formal homogenisation of tools at a territorial scale.

Excavations in numerous urban neighbourhoods dating to the tenth and 11th centuries – in cities such as Zaragoza, Madrid, Jaén, Córdoba, and Almería – (Moreno-Narganes 2023, 64, fig. 1) have yielded spindle whorls displaying recurrent typological characteristics, indicating the presence of interconnected production and distribution circuits (fig. 3). These mould-made spindle whorls are typically rectangular in section with rounded edges, and exhibit stamped decoration on their upper and lower faces. The decorative motifs range from circular bands to symbolic figures such as the six-pointed star or Seal of Solomon. Within Islamic material culture, these designs were not mere embellishments but part of a shared symbolic language linking art and architecture to notions of divine unity and order. Geometric patterns based on circular grids expressed faith and sacred power through abstraction, while symbols like the star held protective and apotropaic meanings. Their presence on everyday objects such as spindle whorls reveals the transmission of these religious and cosmological connotations into domestic contexts, where the act of spinning itself was integrated into a wider symbolic universe (Abdullahi and Bin Embi 2013, 245–248).

The study of spinning goes beyond technical aspects, offering insight into labour organization and social dynamics in al-Andalus. Spinning tools, imbued with economic and political meaning, reflect the structural transformations of the ninth to eleventh centuries, as evidenced by the clear formal standardisation of spindle whorls during this period. The specimens analysed display a consistent diameter – predominantly between 2.5 and 3.5 cm – albeit with a range of weights varying from 10 to 30 g (fig. 4, in red). This correlation between weight and size suggests a formal standardization, possibly aimed at optimizing the work process through the repetition of specific characteristics. Rather than indicating complete homogenization, the variation in weight – which remains between 10 and 30 g – points to a technical horizon oriented toward the production of well-defined types of yarn. This, in turn, reflects differentiated consumption needs and, consequently, a deliberate planning in the design of these tools.

The application of experimental models developed in other European contexts (Andersson Strand et al.

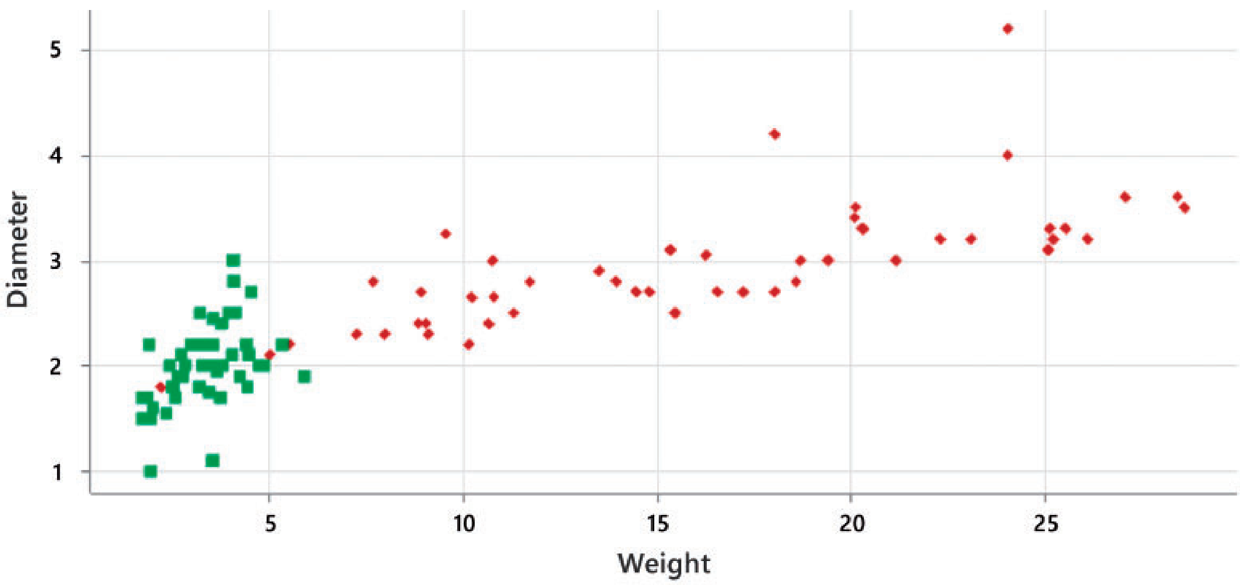

Fig. 4: Scatter plot (diameter vs weight). Red: Ceramic spindle whorls (10th–11th centuries). Green: Bone spindle whorls (12th–13th centuries). For the graph, cases have been selected from the 10th–11th centuries: Zona Arqueológica de Marroquíes Bajos, Bayyāna, Cercadilla, Ronda Oeste, and Vascos. For the 12th–13th centuries: Torre Bofilla, Lonja de los Caballeros, Sotanillo II, Torre Grossa, Torre de Haches, San Esteban, Alcazaba de Almería, Mesón Gitano, Mojácar, Baza, and Torre d'en Galmés (Image: José María Moreno-Narganes)

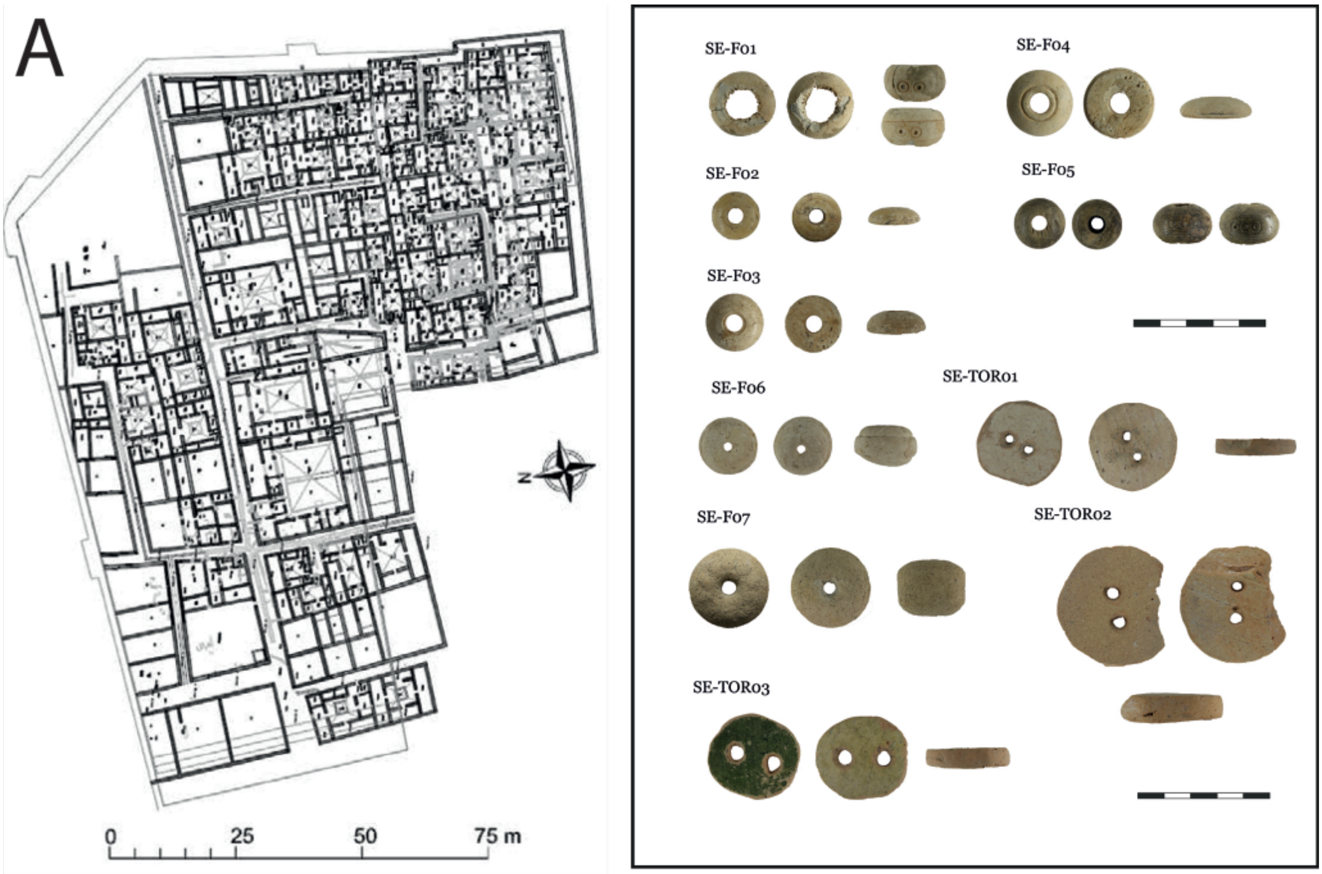

Fig. 5: San Esteban Quarter (northern sector of the city of Murcia, 12th–13th centuries). Left: Excavated urban neighbourhood. Image: reproduced with permission of P. Jiménez Castillo. Right: Bone spindle whorls (F01–05), ceramic spindle whorls (F06–07), and twisting implements (TOR 01–03) recovered during the excavation (Image: José María Moreno-Narganes)

2010; Mårtensson et al. 2006) ought to be extended to the medieval contexts of al-Andalus in order to assess whether this dimensional variability was linked to producing threads of varying thicknesses and optimising raw material processing. Although it is not currently possible to establish a direct correlation between the type or quality of thread produced and the weight of the spindle whorl, the regularity observed suggests tighter technical control over the spinning process. This hypothesis is further supported by the discovery of spindle whorls with these characteristics in pottery production contexts – such as those in Córdoba and Toledo – where they have been found among the refuse of ceramic workshops (Aguado 1999, 174), pointing to their manufacture by specialised potters within organised production circuits.

In parallel, from the ninth century onwards, various documentary sources – particularly the *ḥisba* treatises (urban economic regulation manuals) – explicitly mention the activity of female spinners, as well as the products derived from spinning (wool, flax, cotton). These include measures aimed at ensuring consistent quality and preventing market fraud: "*Cotton and linen threads must not be sold in skeins, because it invites fraud, as women are accustomed to hiding foreign objects in the skeins to increase their weight*" (Seville, twelfth century, Ibn ʿAbdūn 1992, 169). This normative oversight indicates the strategic importance of spinning in the Andalusi urban economy, as a foundational activity for other essential manufactures – from garment-making to domestic furnishings and naval applications.

This shift in tools cannot be dissociated from the broader processes of political and fiscal transformation driven by the Andalusi state, especially from the ninth century onwards. The consolidation of state apparatus brought about the systematic taxation of artisanal production as part of an economy grounded in fiscal extraction (Manzano 1998), which may explain the progressive standardisation and specialisation observed in spinning tools. From the 11th century onwards, a significant innovation in the materials used for spinning tools is observable, marked by the

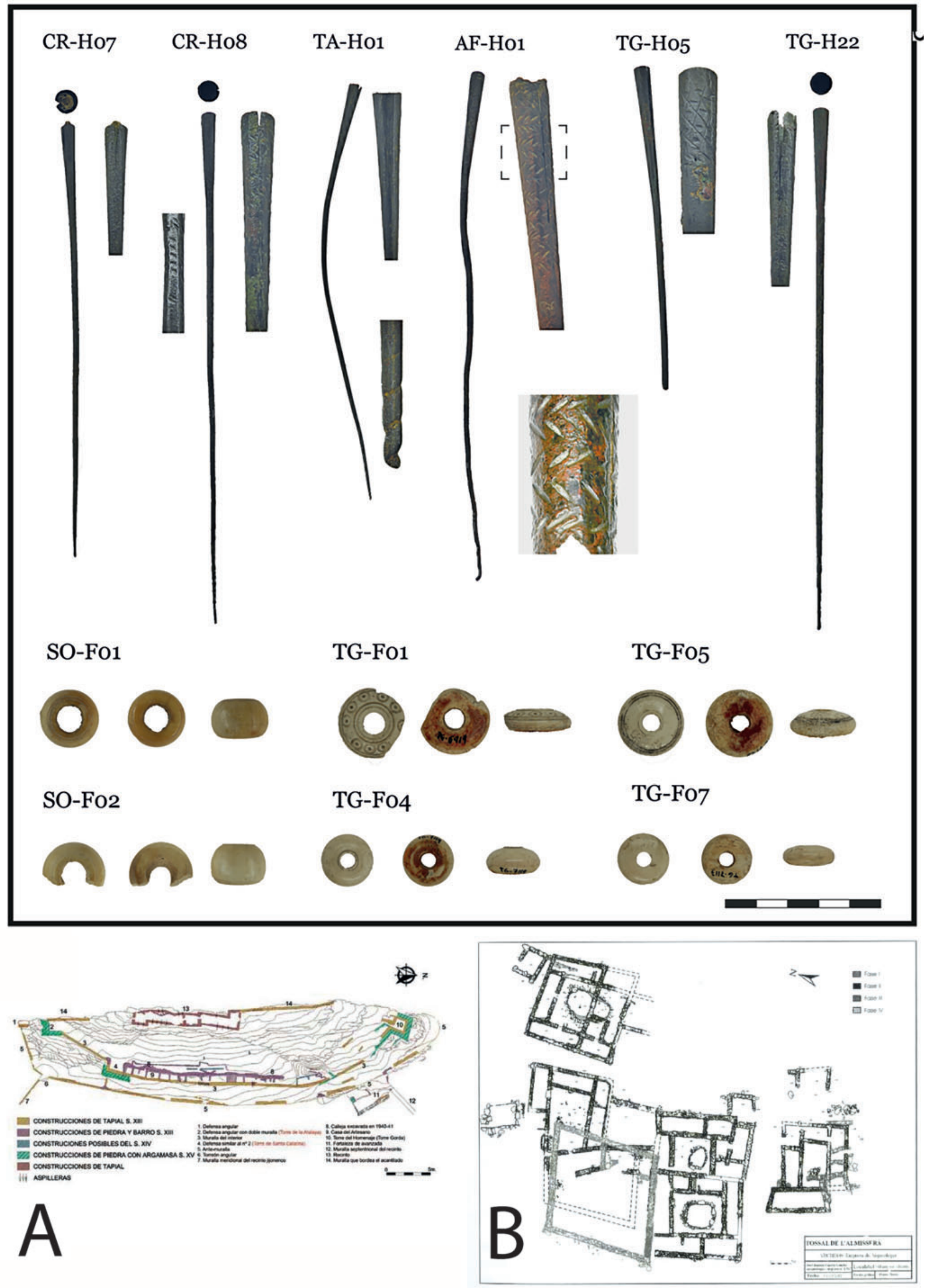

Fig. 6: Examples of textile production from the 12th–13th centuries in rural and fortified settlements. Top: Examples of spindle rods and spindle whorls from various rural settlements; bottom: A) Castle of Torre Grossa (Alicante, Spain); B) Village of Almiserà (Alicante, Spain). Image: reproduced with permission of R. Azuar (A) and J. R. García (B)); (Image: José María Moreno-Narganes)

Fig. 7: Examples of metal spindle rods: 1: Ronda Oeste, Córdoba; 2: Vascos, Toledo (10th–11th centuries); 3–6: Cercadilla, Córdoba (12th–13th centuries). The tips preserve a threading hook used in the spinning process (Image: José María Moreno-Narganes)

emergence – and subsequent standardisation – of spindle whorls made of bone (Moreno-Narganes 2024, 694–701). Although during the Caliphate (tenth to 11th centuries) this type remained a minority compared to ceramic whorls, from the 12th century onwards, a widespread expansion of bone spindle whorls is documented across a broad territorial spectrum, from al-Gharb al-Andalus (present-day Portugal) to Sharq al-Andalus (the Spanish Mediterranean coast). These bone whorls are characterised by more regular shapes, typically lenticular in section, and by finely incised decoration: circular bands, concentric dots with marked centres, and geometric lines, which recall

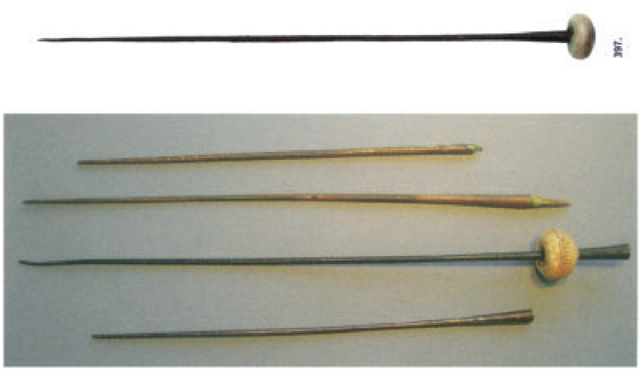

Fig. 8: Examples of spindle rods with bone spindle whorls in situ. Top: Tavira. Bottom: Mértola (Images: reproduced with permission of S. Gómez Martínez 2008, 59)

earlier ceramic decorative repertoires reinterpreted through incision.

From a technical perspective, they exhibit smaller diameters and a significant reduction in weight (fig. 4, in green), which – following experimental models of efficiency (for example Andersson Strand 2008, 75; and Grömer 2005, 111, fig. 6) – may be interpreted as a deliberate search for finer threads and greater efficiency in raw material processing. The discovery of spindle whorls weighing less than 4 g – well below the average recorded for earlier periods – suggests a high level of technical refinement in spinning. Although no definitive explanation exists for this shift, experimental studies on wool spinning indicate improvements in thread quality and fineness resulting from the reduced weight of spinning tools. However, the very low weight of many spindle whorls is difficult to associate with wool or flax, suggesting their use with finer fibres such as cotton or silk. This may relate to the adoption of cotton in al-Andalus from the ninth century onwards, particularly in urban contexts—a fibre that also required lighter spinning implements than those used for wool or linen (Kossoeska-Janik 2016, 109, fig. 2). The correlation between raw material, tool type, and technical outcome reinforces the notion of increasingly specialised production adapted to emerging market demands.

The expansion of bone spindle whorls did not, however, entail the disappearance of ceramic ones, suggesting functional diversification rather than complete technological replacement – a phenomenon possibly derived from consumer preferences, material availability, or other procurement strategies. Despite the general shift from ceramic to bone spindle whorls, from the twelfth century onwards, in some cases, both types appear within the same context, indicating the coexistence of multiple spinning techniques aimed at producing threads of varying thickness, strength, or intended use. A paradigmatic example is the suburb of San Esteban (Murcia, 12th–13th centuries) (fig. 5), a newly founded settlement to the north of the Umayyad city, where excavations have revealed ceramic and bone spindle whorls of differing weights and dimensions dispersed across domestic dwellings. Other twelfth-century examples include Albalat (Cáceres, Spain), which exemplifies the diversity of tools found within the same urban quarters (Moreno-Narganes 2021), or the *qarya* (pl. *qurā* – village or rural settlement) of Almiserà (Alicante, Spain), where similar implements have been recovered (fig. 6).

Taken as a whole, this survey demonstrates that from the tenth century onwards, spinning practices in al-Andalus underwent significant transformations, characterised by reduced tool weight, increased material specialisation, and typological standardisation across broad areas of the territory. The combined analysis of both urban and rural contexts reveals that these transformations were not isolated developments, but rather part of a deeper process linked to the expansion of internal markets and the growing homogenisation of textile production and consumption. This phenomenon, reflecting an economy in expansion, demonstrates that spinning was not a marginal activity, but a structural component of the economic and political development of medieval al-Andalus.

The technological development of the spindle

Due to its frequency in the archaeological record and generally good state of preservation, the spindle whorl is one of the most reliable indicators for understanding spinning practices in al-Andalus. Nevertheless, it is not the only material evidence. Alongside the improvement and standardisation of spindle whorls – with variations in typology and raw materials – there is evidence, from the ninth century onwards, of a progressive increase in the use of spindle tips made from copper alloys, a phenomenon that intensifies in subsequent centuries. These artefacts may trace their origins to similar forms known from Late Antiquity, possibly small metallic hooks used as spindle terminations (Gutiérrez and Hierro 2010, 266, fig. 5). From the tenth century, they exhibit specific technical features in urban contexts such as Córdoba and Jaén, and from the twelfth century, they are widely attested throughout the Andalusi territory (Moreno-Narganes 2023, fig. 4; Moreno-Narganes 2024, 362–369).

From a technical standpoint, these are slender metal rods (predominantly brass, according to compositional analyses conducted on several specimens: Bottaini et al. 2022, 5–6), produced by cold-rolling sheets – approximately 0.1 cm thick – around a mould to create a cylindrical form. The lower end of the piece is hollow, allowing for the insertion of a slender wooden shaft (approximately 0.5 cm in diameter), while the upper end gradually narrows and becomes solid, terminating in a point. In some cases, this point is simply rounded; in others, it features a fine helical groove that appears to have functioned as a guiding track, helping to keep the thread in place and ensuring its continuous twist during rotation – as observed in at least one of the studied examples (fig. 7).

The dimensions of these items vary in both length and weight, yet a clear correlation between the two parameters can be observed, which may reflect either a technical rationale in their design or basic physical constraints adapted to the type of thread produced. This correlation between weight and size has often been interpreted as a sign of functional standardisation, possibly intended to optimise spinning processes for threads of specific characteristics. However, experimental research has shown that there is "*no reliable connection between weight or MI of spindles and the resulting thread length, yardage, or thickness*" (Kania 2013, 15), since the variation in yarn properties largely overlapped across all spindle types. The decisive factor proved to be the spinner, not the tool. Thus, rather than a strict technical determinism, these patterns should be understood as part of a broader horizon of practices, where morphological regularities in whorls may reflect tendencies towards recurrent solutions, while still allowing for a wide spectrum of functional possibilities.

In three well-documented cases – including that of Saltés, where a complete spindle assembly was recovered with a spindle whorl made from a lightweight fish vertebra (Bazzana and Bedia 2005, 342, fig. 258) – spindle tip and whorl were found associated in situ (fig. 8). These finds have made it possible to confirm their use as spinning implements and to dismiss alternative hypotheses that had suggested other functions (Moreno-Narganes 2024, 251). These findings demonstrate increasing technical sophistication within the textile sector, extending from ceramic to metalworking crafts. The introduction of copper reflects greater investment in tools and possibly enhanced productivity, though it may also result from its growing availability and lower cost. Overall, its adoption should be understood within a broader framework of technological choices adapted to changing material conditions.

Arabic textual sources confirm this process: several twelfth-century authors mention the "spindle-maker" in cities across the western and eastern Islamic Mediterranean, indicating the existence of specialised workshops and a sustained market demand for such implements (al-Idrīsī 1999, 143). Moreover, the recurring presence of these items in large assemblages – such as those recorded at Mértola or Silves (Moreno-Narganes 2024, 748) – suggests that their function was not limited to direct use as spindles. It is plausible that they also served as storage bobbins, adapted for varying thread qualities and intended to organise and preserve spun threads, classified according to type or thickness.

This hypothesis is reinforced by references in technical treatises such as that of al-Saqaṭī: "*linen thread differs from silk… because the latter is of a single type, whereas linen thread comes in many varieties*" (Málaga, 13th century, al-Saqaṭī 2014, no. 138), or the earlier reference in Ibn ʿAbdūn (1992, 169), which describes how women spinners inserted weights into skeins – likely as part of a process of preparation for sale, in which the thread was transferred from a spinning device to a storage implement. This detail reinforces the notion of organized production: the skein served as a storage medium, and the addition of weights indicates an intention to standardize and classify the thread for market circulation. The study of metal spindle tips thus reveals a technological innovation embedded within a complex artisanal network—potters, metalworkers, and spinners—linked to a structured demand and to the broader economic and political development of al-Andalus between the 10th and 13th centuries.

Discussion: fibres, techniques, and thread markets

The morphometric analysis of spindle whorls, with the aim of interpreting their specific functionality – that is, their relationship to the production of threads of differing thicknesses and qualities – presents significant methodological limitations. Although experimental studies have helped identify certain general trends, such as the gradual decrease in the average weight of spindle whorls over time, numerous unresolved questions remain, which cannot be answered through the archaeological record alone.

In addition to the type and quality of the fibre and the technical skill of the spinner – all of which are decisive factors in the outcome of spinning (Médard 2005) – the total weight of the operative ensemble depends not only on the whorl itself, but also on the spindle's wooden and metal components, whose mass and morphology are rarely preserved.

These challenges underscore the need to continue collecting both archaeological and experimental data through a comparative and quantitative approach, to advance functional interpretations of these tools. Even within such constraints, the systematic study of spindle whorls offers scholars a privileged window into long-term technical and economic processes. From the tenth century onwards, for instance, there is clear evidence of technical improvement in the tools, with greater control over weight, shape, and regularity – suggesting a deliberate effort to produce more homogeneous threads, suited to increasing demand both in volume and in the diversity of their applications. This expansion and standardisation of textile production chains should not be viewed as an isolated phenomenon, but rather as part of a broader transformation in the material world of al-Andalus, also evident in the increasing sophistication of ceramics, glass, and architectural forms. Textiles, as a basic necessity, emerge as a key indicator for analysing the socio-economic dynamics of the period, serving as a thread through which to understand the interconnections between technology, economy, and society.

A clear and definitive correlation between specific tool types and thread characteristics has yet to be established. The archaeological record offers only indirect information: for instance, the presence of flax seeds in archaeobotanical assemblages, the identification of subadult to adult sheep slaughtering patterns in faunal contexts, and written references to wool, flax, and cotton from the ninth century onwards together provide a general picture of the textile raw materials in use in al-Andalus. However, we still lack precise knowledge about how these fibres corresponded to particular types of spindle whorls. To date, only two fragments of linen textiles (*Linum usitatissimum*) have been documented in medieval Islamic archaeological contexts on the Iberian Peninsula: a mineralised fragment from Albalat (Extremadura, Spain), dated to the early 12th century, and a burial shroud recovered from a *maqbara* (cemetery) in Crevillente (Alicante, Spain), dated to the 14th century. Both specimens indicate the use of relatively fine linen. In the case of Albalat, the thread diameter does not exceed half a millimetre, ranging between 0.32 mm and 0.22 mm, with a fabric density of 22 × 22 threads per cm (Gilotte and Cáceres 2017, 171). The analysis of the Crevillente textile reveals a plain weave tabby (1/1), a high-quality and balanced construction, with a density of 15 (warp) × 19 (weft) threads per cm, and thread thicknesses of 385.28 microns in the warp and 392.61 microns in the weft. In both cases, the yarns exhibit a Z-twist torsion (Trelis et al. 2009, 189).

Although few in number, the linen fragments from Albalat and Crevillente are valuable due to their diverse origins—domestic and funerary—and their locations at the western and eastern edges of al-Andalus. They offer insight into the use of linen across different social contexts, even if their scarcity prevents broader conclusions about its overall prevalence. The fineness of the threads suggests the use of lightweight spindle whorls, around 4 grams, as documented in several Andalusi archaeological contexts. However, current experimental research suggests that some fibres, such as wool, are difficult to spin efficiently using spindle whorls lighter than 8 g (Mårtensson et al. 2006, 11; Andersson Strand 2008, 76; 2010, 13). This apparent contradiction indicates that lighter tools may have been employed for shorter or finer fibres (such as flax or cotton), or that a broader variability of spinning practices and raw materials needs to be considered when interpreting the archaeological record.

Fig. 9: A) Intra-muros quarter of Mértola; B) Intra-muros quarter of Albalat; Red: Spindle whorls; orange: metal spindle rods; purple: distaff components; blue: *templenes* (horizontal loom) (Images: A) reproduced with permission of Campo Arqueologico de Mertola; B) reproduced with permission of Albalat project)

This suggests that the numerous Andalusi specimens weighing below this threshold – frequently attested from the 12th century onwards – may have been associated with the spinning of other fibres, such as cotton or shorter-staple varieties, whose torsion requires less inertia. Spindle whorls weighing less than 3 g, which are unlikely to be suitable for spinning coarse wool or flax, could plausibly be linked to cotton – a raw material widely cited in agronomic treatises from the late medieval period, such as those of Ibn Baṣṣāl (1050–1100 CE) and Ibn al-ʿAwwām (circa 1100–1170 CE), particularly in the urban centres of the Guadalquivir Valley (Camarero 2008, 128).

Although direct archaeological evidence for cotton cultivation in al-Andalus is still lacking – in contrast to Mazara (Sicily), where it has been documented (Fiorentino et al. 2021, 560) – the hypothesis that cotton was a technical factor underpinning the use of ultra-light spindle whorls remains valid and may provide a basis for future research. This body of evidence, still preliminary, points to a possible progressive specialisation in the spinning of flax and cotton from the tenth century onwards, in line with the growing presence of these fibres in textual sources and their association with warm climates and highly productive irrigated agricultural zones (Jiménez and Camarero 2021, 27).

This interpretation must also be contextualised within broader critiques of the idea of "self-sufficient" domestic production disconnected from the market – a notion that has dominated many traditional interpretations, which have often overlooked textile production as a significant sector warranting thorough analysis. Both the material analysis – which reveals increasing technical investment in tools – and the numerous Arabic sources that refer to dedicated markets for female spinners and embroiderers, together with references to quality control and anti-fraud regulations, point to a form of production oriented towards commercial exchange. In this regard, in *Risāla* No. 87 by Ibn ʿAbd al-Raʾūf (11th century), it is mentioned that, in Emirate Córdoba, women "*were the ones who spun flax, rubbing it with water to improve its appearance and increase its weight. For its sale, it was advisable that they employ only pious and virtuous elderly men. This is because these intermediaries interact with women, conversing with them during the delivery or payment (of their spun thread). It was recommended that they have a designated gathering place to sell their thread and that they not be allowed to establish themselves in shops*" (al-Raʾūf 2019, 73 [trans.] – 36 [Arabic]). Similarly, Ibn ʿAbdūn (d. 1134 CE) warns: "*Only trustworthy and honourable men, whose integrity and reliability are well known to all, should engage in commercial transactions with women, and this responsibility should fall to the guild members. Women should be prohibited from entering the marketplace of embroiderers, for they are all prostitutes*" (Ibn ʿAbdūn 1992, 146 [trans.] – 143 [Arabic]). In another reference

Fig. 10: A) Traditional foot-treadle loom from the textile cooperative of Mértola (Alentejo, Portugal). B) Modern *templén* of a horizontal loom; C) *Templenes* from Albalat (left) and Mértola (right) (Image: José María Moreno-Narganes)

(*Risāla* No. 199), the same author denounces: "*Women often insert foreign bodies into cotton and flax skeins to increase their weight*".

The importance of spinning is also evident in political chronicles, which record that Caliph al-Nāṣir reproached his late grandfather, Emir ʿAbd Allāh (d. 912), for "*having involved himself in overseeing a woman's spinning, when such matters were the responsibility of the ʿalamīn of the thread market*" (Ibn Saʿīd 1997, 180). These activities were subject to control mechanisms governing measures and weights, intended to preserve order and functionality – a perspective that underscores the textile sector's importance, on a par with agriculture and livestock production. Moreover, from a volumetric perspective, it can be concluded that over 40% of the professions listed in *ḥisba* documents from the ninth to 13th centuries (including Ibn ʿAbd al-Raʾūf (2019) – Córdoba, mid-tenth century; Ibn ʿAbdūn (1992) – Seville, 12th century; and al-Saqaṭī (2014) – Málaga, 13th century) relate to some aspect of the textile *chaîne opératoire*. This highlights the essential importance of these crafts for the daily functioning of urban life in al-Andalus.

Chronicles also document examples that challenge the notion of household self-sufficiency. One account notes that al-Manṣūr Ibn Abī ʿĀmir, the *ḥājib* Almanzor (tenth–11th centuries), sold threads spun by his mother in the marketplace during his youth (Marín 2000, 268). Similarly, a juridical ruling (*fatwa)* records the case of a poor woman who spun at home, whose bequeathed possessions were subject to formal valuation (Lagardère 1995, *fatwā* 49). These episodes – drawn from both chronicles and legal sources – alongside the costs of production, tool maintenance, and the accumulated technical knowledge required, invite a reconceptualisation of the household not merely as a unit of consumption, but as a productive node embedded in local or regional commercial networks for the manufacture of thread and cloth. The study of textile materiality and the cited historical references allow us to interpret that, moreover, such work could provide single women with economic independence, enabling them to support their families or accumulate capital over time.

Recent studies on specific neighbourhoods such as Mértola (Alentejo, Portugal) and Albalat (Cáceres, Spain) (Moreno-Narganes 2021, 38–39) offer crucial new insights into the historical and economic significance of textile labour within these communities. Both large-scale analyses encompassing wide areas of al-Andalus and more regionally focused case studies – such as those concerning the garb – have demonstrated the central importance of local textile production centres, whose output was primarily intended to meet local or regional demand. These economic dynamics, often undervalued or insufficiently explored until recently, have gained new interpretative significance thanks to recent research. This scholarship moves beyond outdated economic paradigms by placing market-based supply and demand – specifically within local markets – at the core of processes of transformation and economic development (Wickham 2023, 664).

Excavations in the intramural quarters of Mértola and Albalat (fig. 9) provide a deeper understanding of how families interacted socially and economically through textile production (Moreno-Narganes 2021, 431–432). These connections, articulated around the *chaînes opératoires* of spinning and weaving, reflect the complexity of the socio-economic networks sustaining everyday textile demand and reveal a degree of productive specialisation distributed among households and family units. In both urban sites, the archaeological evidence reveals a marked presence of tools associated with spinning – primarily spindle whorls and spindles – indicating that the vast majority of households were actively engaged in these tasks. In Albalat, spinning tools were documented in 12 of the 20 analysed domestic units (eight spindle whorls, five spindle tips), while in Mértola, 27 spindle tips and 50 spindle whorls were recovered from 12 of the 16 excavated dwellings (Moreno-Narganes 2021, 37–38). The archaeological evidence indicates that spinning was a common domestic activity and that significant economic interaction existed among families within each community. The inconsistent correlation between spindle whorls and spindle tips may reflect the use of perishable wooden components or, as in Mértola, the storage of these tools as bobbins or for specific thread types.

Regarding textile production using looms, the identification of *temple claws* (Retuerce 1987) – metal implements associated with horizontal treadle looms, although in principle such tools could also be employed with warp-weighted or two-beam looms, as attested in northern Europe. However, in the Iberian Peninsula, no evidence currently links vertical looms to the use of temple claws, making their association with horizontal treadle looms the most plausible interpretation in this context. These tools therefore remain the most reliable archaeological indicators of weaving activity (Moreno-Narganes 2019) (fig. 10). Such finds have been documented in two specimens at Albalat and two at Mértola, suggesting a comparable presence of this activity in both sites, revealing a notable disparity amounting to a ratio of roughly 6:1. This disparity may be attributed to the considerable amount of thread required to operate the looms, and although the archaeological record remains limited, the available evidence confirms the economic significance of the textile sector within these urban quarters.

These indicators clearly demonstrate that textile activity not only structured the domestic economy but also fostered economic connectivity and interdependence among many households, creating a robust network of production oriented towards the regional market. Archaeological evidence reveals how certain sectors of the urban fabric formed a productive web of interdependence, with some households engaged in animal husbandry or flax cultivation, others in spinning, and others in weaving – all participating in constant flows of exchange and commerce (Fábregas 2022, 129). This model of neighbourhood-based (Costin 2020), territorialised economy places domestic production at the centre of analysis as the quantitatively dominant form of economic activity, restoring its central role in the dynamics of everyday life (Wickham 2023, 664).

Conclusion

In recent years, historiography has begun to reconsider the structural impact of the so-called “Green Revolution” in al-Andalus – a phenomenon that not only transformed the agricultural landscape of the Iberian Peninsula but also profoundly reshaped the political, economic, and social life of medieval Europe (García-Contreras et al. 2025). However, the role of the textile sector in this process of transformation has, until now, received relatively little attention, despite being an activity inseparable from the development of human societies since prehistoric times.

Through the study of spinning and weaving implements – particularly spindle whorls, spindle tips, and other tools preserved in archaeological contexts – this work has proposed a material reading of the structural changes that al-Andalus underwent from the ninth century onwards, a period in which processes of technical specialisation and typological standardisation intensified. The lack of solid data for earlier centuries – with a few exceptions – still prevents us from tracing a clear line of evolution from the Visigothic or Late Antique periods. Nevertheless, from the ninth and tenth centuries, signs of a reorganisation of textile production begin to emerge, in which the introduction of new raw materials, such as cotton, coincides with the intensification and diversification of traditional fibres like flax and wool.

Comparative analysis with other Mediterranean contexts has made it possible to situate the Andalusi phenomenon within a broader horizon of change, without losing sight of its regional specificities. Within this framework, the extremely lightweight spindle whorls documented from the twelfth century onwards may be linked to the expansion of cotton – mentioned in agronomic treatises such as those by Ibn al-ʿAwwām (2003) – although direct archaeobotanical evidence is still lacking. This line of interpretation remains open, but it is reinforced by the consistent similarities in shape and function observed in the tools, as well as by the repeated finding of lightweight spindle whorls across both urban and rural contexts.

Despite these advances, there remains a wide field of study to explore, particularly regarding rural contexts and well-stratified assemblages from the ninth and tenth centuries, during the Umayyad emirate and caliphate. It is precisely in these centuries that a territorially articulated model of textile production appears to consolidate, already showing signs of technological standardisation – as has also been documented for the horizontal loom in various *qura* (villages or rural settlements) from the ninth century onwards, and more clearly from the 11th century (Moreno-Narganes 2024, 377–384). From a critical analysis, it is essential to emphasise that the hypotheses proposed in this study – particularly those concerning the technical improvement of spinning, evidenced by the progressive lightening of spindle whorls, and the diffusion of horizontal looms as tools of productive rationalisation – should be tested in future research through the systematic analysis of preserved textiles from well-dated archaeological contexts. Although scarce, the extant textile fragments from al-Andalus provide valuable insights into thread fineness, twist direction, and fabric density, which would allow scholars to establish empirical correlations between specific tool typologies and the technical qualities of the final product. This dialogue between tool and thread, between production and finished cloth, represents a crucial line of inquiry for advancing a comparative technological history of medieval textile production that integrates archaeological, analytical, and experimental data within a rigorous interpretive framework. The future documentation of textiles from stratigraphically secure contexts – particularly in *maqābir*, domestic spaces, and workshop areas – will make it possible to assess the extent to which tool standardisation was driven by emerging demands for quality, specialisation, and volume within regional production circuits.

These transformations must be read in direct connection with the economic development of al-Andalus, which is amply attested in fiscal records from the ninth century onwards (Chalmeta 2021, 577). The taxation system, organised by administrative districts (*kūra*) and centrally controlled from Córdoba, included levies on textile goods, particularly concerning caliphal silk (Dozy 1961, 90, 132). This institutional framework facilitated the consolidation of internal commercial networks, articulated through local and regional markets – documented through the figure of the *sāḥib al-sūq* ("market inspector") (Chalmeta 2010) – which animated the circulation of goods across all territorial scales. Economic growth, therefore, relied not only on long-distance Mediterranean trade circuits but also – and fundamentally – on a dense network of internal exchanges between countryside and city. Within this interpretation, the expansion and increasing sophistication of spinning tools should be understood as a direct consequence of the rise in textile production centres, both urban and rural, in response to the growing demand of an expanding population. Urban growth, agricultural intensification, and the foundation of new villages from the tenth century onwards – a process that can be interpreted as a form of internal colonisation (Jiménez-Castillo et al. 2023) – created a setting in which textiles assumed a central role.

In sum, the available evidence demonstrates that spinning – far from being a minor activity relegated to the domestic sphere – formed a structural component of the Andalusi productive system. Material analysis enables the reconstruction of the techniques and knowledge of those who produced thread, while also providing access to the fiscal, specialised, commercial, and social processes that shaped the economic landscape of al-Andalus between the ninth and 13th centuries. In this sense, textiles are not an isolated sector but offer a privileged lens through which to understand the overall functioning of a highly connected, complex, and continuously evolving western Islamic society.

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Medieval latrine textiles from Rådhusgaten in Tønsberg, Norway

Abstract
This paper examines medieval textiles from the 2022/2023 excavations at Rådhusgaten, Tønsberg, shedding light on textile consumption in a Norwegian urban medieval setting. 52 textiles, predominantly wool twill, were analysed for their technical characteristics and functional significance. Many were found in a latrine deposit, suggesting secondary use as sanitary materials, offering insights into medieval hygiene practices. The finds highlight the multifunctionality of textiles in domestic life and in a harbour context. This study questions the end use of the latrine textiles and integrates textile analysis with stratigraphic data to explore textile consumption and disposal practices in the 12th to 13th centuries.

Keywords: Urban medieval textiles, latrine deposits, harbour, stripes, colours, caulking

Introduction
This paper discusses a significant assemblage of textiles unearthed in 2022/2023, during a large-scale municipal renovation project in Rådhusgaten, in the medieval town centre of Tønsberg (Norway). Rådhusgaten is one of the streets extending from the waterfront, mirroring their medieval counterparts (fig. 1). Excavations conducted by the Norwegian Institute for Cultural Heritage Research (NIKU) have yielded exceptional textile finds due to favourable preservation conditions (Bergland et al. 2025; Haugesten 2020; Halvorsen 2023; Bergland in prep.).
In total, 52 catalogued textile fragments, representing at least 57 distinct pieces, were documented, accounting for about 7% of the town's medieval textile finds (Lindh 1992; Brendalsmo 1986a; Brendalsmo 1986b; Brendalsmo 1989; Vedeler 2000; Vedeler 2007; Nordman and Tjeldvoll 1988; Nordman et al. 1986; Tjeldvoll 1990; Jordahl 2013; Ekstrøm 2008; Ekstrøm 2010). These textiles provide valuable information about both technical and social aspects of textile consumption in the central harbour area in medieval Tønsberg. Most of the textiles were recovered from a latrine deposit, suggesting secondary use as sanitary materials and offering insights on hygiene practices and potentially gendered use of space. The fragments indicate the diverse roles textiles played beyond clothing, the use and reuse of textiles, and their importance in domestic and maritime contexts.
This paper addresses two key research questions: the technical characteristics of the textiles and their contextual significance. The textiles were analysed for structural variations, weaving techniques, and distribution patterns to identify potential functional categories. The excavation context SL6693 serves as a case study for textile reuse in a medieval latrine. By integrating textile analysis with information from the archaeological context, this study enhances the understanding of the role of textiles in everyday activities, contributing to broader discussions on medieval urban life.

Methodology
The objective is to classify the textiles by observable structural characteristics and assess their significance within the archaeological context. We ask: (1) What technical characteristics (fibre, weave, counts, yarn, colours/patterns/finish) are present? and (2) How do

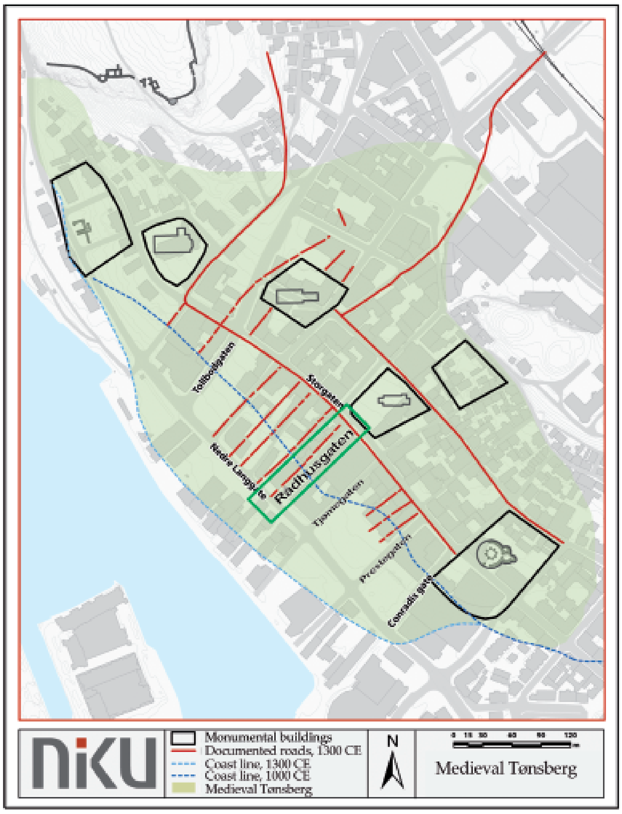

Fig. 1: Map of medieval Tønsberg and modern day Tønsberg (Image: NIKU, licence CC BY-SA 4.0)

these relate to context, reuse and function?

Textiles were grouped based on weaving technique, yarn properties, fabric qualities, and evidence of use, and/or indications of finishing treatments. The contextual section examines how the textiles correspond to the broader findings from the excavations. Most textiles (45 of 52) were recovered from SL6693, a latrine deposit rich in organic waste. This concentration was examined as a case study, with a focus on spatial distribution, fabric types, functions and textile reuse patterns. This study examines medieval textile consumption by combining technical textile analysis with archaeological context.

Technical terms

The terms woollen will be used for yarn or cloth made from wool, whereas "loft" refers to the thickness of the fabric. A lofty yarn has a low density and contains a lot of air. When discussing wool textiles, it is also relevant to define the process of "felting" versus the process of "fulling" (Walton and Eastwood 1988, 3; Emery 1994, 22–24). A "felt" refers to fibres that are not interworked but have been adhered and matted together into a fabric. When the finish process of a fabric involves matting, shrinking and thickening like a felt, it is termed "fulling", and the textile is described as "fulled" (Emery 1994, 20–24).

In this paper, "braid" is defined as oblique interlacing (Emery 1994, 62–69). "Whipcord braiding" corresponds to the Norwegian term "*slyngning*". "Cords" are usually plied and cabled from multiple elements (Walton and Eastwood 1988, 12, 23). "Ribbon" refer to a narrow, flat-woven fabric, with its own warp, weft and selvedges. Textile strips that have been cut from a woven fabric, folded with the raw edges turned in, and sewn, will be referred to as "tubes".

Yarn measurements are taken from within the fabric. Loose spun yarn refers to twist angle up to 10°, medium refers to a twist angle of 10° to 25°, and tightly spun yarn have a twist angle between 25 to 45° (Emery 1994, 11–12; Walton and Eastwood 1988, 11).

Context: latrine deposits and household waste

The textiles all come from layers dated to the 1100–1200s CE (Bergland et al. 2025). Layer SL6693, a latrine deposit inside building SA3864 (at least 4.2 × 2.4 m), containing most of the textiles, moss, faecal matter and insect remains. The presence of large concentrations of insect eggs suggests that the layer remained undisturbed *in situ*. The deposit extended beyond the excavated area. The latrines are unusually large for Norwegian medieval towns. It might have served as a public latrine, potentially associated with the harbour, belonging to an inn, or to multiple households (Bergland et al. 2025, 90–92).

A radiocarbon date places the deposit around 1221–1282 CE. Other finds from the layer include everyday objects, some of which may contribute comparative dates, such as a comb (1200–1400 CE), pottery sherds (1150–1350 CE), shoes (1225–1350 CE), fragments of baking stones, sausage skewers, and wooden objects. The variety of artefacts suggests that this area may have also served as a general waste disposal site. The presence of large amounts of faecal matter raises the possibility that waste from other latrines in the vicinity was also emptied here (Bergland et al. 2025; Ulriksen 2002; Molaug 2024).

One suggested interpretation for textiles in a latrine context is that some of them might be from sanitary pads, while the moss may have functioned as toilet tissue. Textiles may also have been used for wiping and could be disposed of for other reasons as well. Textile finds were concentrated in the northeastern section of the latrine, suggesting a spatial pattern, perhaps linked to use or gender. However, there were no visual division preserved to prove that the

Name	Thread count (warp/weft)	Thread	Twill weave	Context	Colour
F401891	12/6	z/s	2/1	SL6693	Red
F402534	12/10	z/z	2/1	SL6541	Yellow/green
F402530	13/7	z/s	2/1	SL6541	
F402528	13/11	z/s	2/2	SL6541	Black
F402027	6-8/?		2/1	SL11301	Black
F401909A	12/10	z/z	2/1	SL6693	Brown
F401909B	12/10	z/z	2/1	SL6693	Red
F401909C	20/16	z/s	2/1	SL6693	Golden/Yellow
F402301	10/10	z/z	2/1	SL6693	
F401897	10/8	z/s	2/2	SL6693	
F401929	10/8	z/z	2/1	SL6693	Green
F402299A	6/3	z/s	2/2	SL9051	
F404098	12/8	z/s	2/1	SL6693	Striped; Brown, black, light brown
F401937A	14/6	z/s	2/2	SL6693	Green
F401937B	12/9	z/s	2/2	SL6693	Green
F404096	12/12	z/s	2/1	SL6693	Dark brown
F404116	4-6/?	z/z	2/1	SL6693	
F404123	12/8	z/z	2/1	SL6693	
F404126		z/z	2/2	SL6693	
F404120	8-9/5-6	z/z	2/2	SL6693	
F404122	10/8	z/z	2/1	SL6693	
F401913	10-12/?	z/z	2/1	SL6693	Green/Yellow
F401931	10-11/?	z/z	2/2	SL6693	Green
F401901	10-12/?	z/z	2/2	SL6693	Red
F401915	10-12/8	z/s?	2/2	SL6693	Yellow
F401917	12/8	z/s?	2/2	SL6693	Green, brown
F401893	14/12	z/z	2/1	SL6693	Brown, black
F404097		z/?	2/1	SL6693	
F401923	12/12	z/z	2/1	SL6693	Black
F401903	6-8 /4-5(6-8)	z/s?(z/z)	2/2	SL6693	Striped; yellow, brown, black
F401935	9-10/?	z/s	2/1	SL6693	Green / Red
F401927	10-12/?	z/z	2/2	SL6693	Green / Yellow
F401921	10/8	z/s?	2/2	SL6693	Green
F401911	12-14/?	z/s	2/2	SL6693	Green
F401933A	12/10	z/s	2/2	SL6693	Striped; green, brown, black
F401933B	8/6	z/s	2/2	SL6693	
F401933C	12-14/?	z/z		SL6693	
F401895	12/8	z/s	2/2	SL6693	Black
F401919	12/8	z/s	2/2	SL6693	Green
F404150	5/6	z/s	2/1	SL6693	

F404152A	14/8	z/s	2/1	SL6693	Striped; Light brown, dark brown
F404152B	6-8/6	z/s	2/2	SL6693	Dark brown
F404108		z/s	2/2	SL6693	
F404099		z/z	2/2	SL6693	
F404124	13/7	z/z	2/1	SL6693	Light brown
F404101		z/s	2/2	SL6693	
F404105		z/s	2/2	SL6693	
F404154	12/10	z/s	2/1	SL6693	Brown
F404156	6/9	z/s?	2/2	SL6693	Brown
F404127	6-8/?		2/1	SL5188	Black
F404120	8-9/5-6	z/z	2/2	SL6693	

Table 1: Twills from Rådhusgaten in Tønsberg, Norway

spatial distribution may reflect a physical or social division of space (Bergland et al. 2025, 90–92) and no documentary or pictorial evidence has yet been identified which suggests that this was a convention of the Medieval era.

Five textile samples from the latrine context were submitted to the laboratory for analysis of blood residue, hormones and insect eggs. Initial laboratory testing of these textiles suggests there may be traces of blood on them. So far, the laboratory has only reported on the insect sampling from one of the textiles, F401923 (fig. 2). The stomach contents of flies and fly larvae (Diptera) found on one of the textile fragments (PT401923) were extracted. Through isotope analysis, it was concluded that the insects had likely fed on human blood (Bergland et al. 2025, appendix 12.6).

Beyond the 45 textiles from SL6693, five other contexts produced textiles: SL11301, SL9051, SL5188, and SL3369 each contained a single find, while three textiles came from SL6541. SL1130, dated to before 1164–1266 CE, contained latrine waste, wood shavings and caulking material (FI402027). SL9051, SL3369 and SL6541 were levelling layers, with construction and household waste and urban fill material such as wood shavings, faecal matter, leather, and ceramics and animal bones. Two coarse textile fragments (F402299), both woven into a fabric with a net-like structure, were found in SL9051. SL3369 contained the braided fragments of F404158. SL6541 gave the find F402530, a fragment sewn into a tube, and F402529 and F402034 which both contain medium-density textiles that could be fragments of clothing. F402528 is a smooth and well balanced black-brown 2/2 twill with a 41 cm long hem. The hem is folded double on the longest and best-preserved fragment, but there are only raw edge on the other fragments, probably because the fabric was torn at the folded edge. Thread density is 13/11 threads per cm, z-spun in one direction and s-spun in the other direction. F402034 consists of a slightly hairy, possibly napped, 2/1 twill with thread density of 12/10 threads per cm. The yarn is z-spun in both directions. The fabric was yellow-green when excavated.

SL5188 was an activity layer above the wooden decking of the medieval main street, beneath Storgaten. It contained caulking material, F404127, though this is a bit removed from the harbour. Textile caulking material could come from buildings as well. F404127 consisted of several fragments of a very lofty and wrinkled black-brown, 2/1 twill low-density fabric sewn into tubes with widths varying between 1.5 and 4 cm (Bergland et al. 2025).

Findings

All the textiles contain animal fibres, primarily wool, though some possibly incorporate animal hair. The preservation of textiles in archaeological contexts is closely tied to the environmental conditions of the deposited layers (Wild 1988; Peacock 2014). The excavated deposits consisted of heavily saturated, acidic, and compact urban layers, which are typical of medieval towns (Rytter and Schonhowd 2015; Halvorsen et al. 2022). Under these conditions, protein fibres tend to survive better than cellulose fibres (Gleba and Mannering 2012, 2; Gillis and Nosch 2007).

Most of the textile finds are woven fragments, with a total of 52 woven fabrics identified (Bergland et al. 2025). These textiles fall within the common parameters of textiles found in Norwegian medieval urban contexts (Hammarlund et al. 2008; Øien 2007; Schjølberg 1998; Vedeler 2007; Kjellberg and Hoffmann

Fig. 2: F401923; showing a balanced 2/1 twill, with thread count 12/12 threads per cm, and z-spun yarn in both warp and weft (Image: Gorm Seljeseth, NIKU, licence CC BY-SA 4.0)

1991; Thomassen 2024; Øye 1988). All identifiable woven textiles, except from one tabby weave, are variations of twill: 25 are woven in 2/1 twill, and 25 in 2/2 twill (table 1).

Two groups of weaves could be distinguished among the textiles: Those with a somewhat balanced ratio of warp to weft threads and those with a significant imbalance. This imbalance is primarily due to differences in the quality of yarn used for the warp and weft, though weaving techniques, technological aspects, and traditional craft practices may also be considered (figs. 2–3).

When examining a simple woven fabric, it is generally only possible to determine the warp and weft directions if a selvedge is present. However, in many of the textiles analysed, the distinct characteristics of the yarn provided strong indications of which threads were used for the warp and which for the weft. Warp yarn must withstand greater tension and weight than weft yarn. The weaving technique and warp tension also contribute to a generally higher thread count in the warp. A warp-weighted loom would likely require an even stronger warp yarn compared to warps used on a horizontal loom. The type of loom and the intended textile would determine key parameters of the warp yarn, such as its strength and elasticity (Hammarlund 2004; Mårtensson et al. 2006). Factors such as fibre type, thickness, spin direction, twist, and elasticity all play a role in how a textile is designed (Hammarlund et al. 2008; Bender Jørgensen 1986). This is reflected in the unbalanced textiles, where the warp threads have a higher thread count than the weft threads.

Fig. 3: F401937; an example of an unbalanced 2/2 twill, with smooth z-spun warp and thick, loosely s-spun weft, 14/6 threads per cm (Image: Gorm Seljeseth, NIKU, licence CC BY-SA 4.0)

All the woven textiles analysed contain single-thread yarns. Almost without exception, the warp yarn is hard, smooth, and shiny, with a consistent z-spin, designed to endure heavy tension. The weft yarns are either s-spun or z-spun, with some textiles featuring a combination of z-spun warp and s-spun weft, while others have both warp and weft in z-spun yarn. In most fragments, warp yarn thickness ranges from 0.5 to 1.5 mm.

Greater variation is observed in the weft yarn. In the 19 cases where the weft is also z-spun, its thickness is comparable to that of the warp, resulting in relatively balanced fabrics, rarely showing more than a two-thread imbalance per centimetre. The material suggests a slight predominance of 2/1 twill (11 instances) woven with z/z-spun yarn, while only six 2/2 twill fabrics share this characteristic. Although the sample size is small, this variation may indicate a preference for certain weaving qualities in different textile types and applications.

For comparison, only six fabrics woven in 2/1 twill feature a thicker, loosely s-spun weft, whereas 20 textiles overall contain thick, loosely spun s-spun weft yarn. When the weft is s-spun, it often has a low spin angle, has a loftier texture, and is more likely to create an unbalanced thread count between warp and weft. Only four fabrics with an s-spun weft have a relatively balanced structure, with weft yarns similar in thickness to the warp. Additionally, six fabrics contained weft yarns that were too loosely spun to determine whether they were z- or s-spun. However, these six textiles share visual characteristics with the other s-spun weft fabrics. They also display a significant imbalance in thread count between warp and weft, reinforcing a common structural feature among them. The weft yarn thickness varies considerably but generally falls between 1.5 and 4 mm.

Fabric qualities

Thread count refers to the number of threads per centimetre and serves as an indicator of fabric density, flexibility, and fineness (Bender Jørgensen 1986; Hammarlund et al. 2008). It can provide insight into potential uses, as higher thread counts might correspond to finer, more labour-intensive textiles, while lower thread counts with coarser threads may suggest more utilitarian fabrics (Øien 2007; Vedeler 2004; Vedeler 2007). Additionally, significant imbalances in thread count may indicate distinct fabric groups with specific functions.

Thread thickness and density are crucial factors in determining fabric quality (Hammarlund et al. 2008). The coarsest textiles generally have the lowest thread counts. Four textiles in the collection have thread counts ranging from three to six threads per centimetre. These relatively open, net-like fabrics likely served utilitarian purposes, possibly related to packaging and transport. F402299B is the only plain-weave fabric, measuring 12 × 2 cm, with a net-like structure, only 3–4 threads per centimetre, and a yarn thickness of 2–3 mm. The fabric is sewn together into a tube using a S2z twisted thread. Another open, net-like fabric is F402299A. This is a 2/2 twill with 3/6 threads per cm and a weft thickness of up to 4 mm. F404150 is a loosely woven fabric featuring a lofty weft of varying thickness (1–4 mm) and a thread count of approximately 5/6 threads per cm. F404116 is an open-weave fabric, with 1 mm thick yarn, and a thread count of 4–6 threads per cm.

Seven textiles were grouped as low-density textiles, with thread counts ranging from 6–9 threads per centimetre, though exhibiting greater variation in density and structure. A common characteristic of these fabrics are thick, lofty wefts, with warmth, softness, and flexibility, which suggests they may have served as utility textiles as blankets, insulation or padding. F402027 and F404127 are both fulled fabrics, which are hemmed and folded, and sewn into tubes. F402027 was probably used for caulking or sealing. Both fabrics are woven in 2/1 twill, while the remaining five in this group are 2/2 twill. F404156, F404152B and F401933B have unbalanced fabrics, with 8-9/6 threads per cm, featuring a thick, loosely spun weft. F401903 is a more complex, striped fabric, combining two distinct qualities. The warp thread count is 6–8 threads per centimetre, with the darker stripes woven maintaining this density, using the warp yarn quality. The lighter stripes are made from a thicker, more loosely spun yarn, reducing the density to 4–5 threads per centimetre. This fabric has been interpreted as a thicker utility textile, possibly for interior use, such as a blanket. F404120 features a variation in thread count, with 8–9/5–6 threads per cm. The weft yarn is approximately 3 mm thick, while the warp is only 1 mm. This textile could have functioned as a utility fabric or belonged to a thicker garment.

The group for medium-density fabrics includes 33 textiles with thread counts ranging from 10 to 14 threads per cm, a common density in the Norwegian Middle Ages (Vedeler 2007; Kjellberg and Hoffmann 1991). Some of these fabrics exhibit a significant imbalance in thread count. The likelihood that a fabric originates from clothing increases with thread count. Several of these textiles are likely remnants of clothing, particularly those showing signs of dyeing, surface treatments such as napping or fulling, and seams. Relative balance in thread count, along with the use of hard-spun and durable weft yarns, can also indicate textiles originally used for clothing. The possible clothing fragments are F402034, F402528, F401909, F402301, F401929, F404123, F404122, F401913, F401931, F401901, F401893, F401923, and F404154. Some of the medium-density fabrics are equally likely to originate from utility textiles as from clothing. These include textiles with high warp thread counts but lower, loosely spun weft thread counts, some of those showing signs of seams or dyes: F401897, F401937, F404096, F401915, F401917, F401935, F401921, F401933A, F401895, F404152A, and F404124. Within the group for medium-density textiles, there are also textiles that have been folded and sewn into tubes, including F404098, F402530, F401911 and F401919. Additionally, some fragments appear to have been woven as ribbons rather than repurposed, such as F401891, and potentially F401933C. This will be investigated further later on.

Only one fabric in the collection might be categorised as a high-density fabric. F401909C, with 20/16 threads per cm, has a high likelihood of being a clothing fabric. This interpretation is further supported by the textile's golden colour, suggesting it may have been a high-status garment or a decorative piece.

Fig. 4: F401905 is a 16 cm long braid from SL6693 (Image: Gorm Seljeseth, NIKU, licence CC BY-SA 4.0)

Fig. 5: F401891 is a woven, red ribbon, 1 cm wide and 19 cm long, tied in a slipknot and finished with a tassel or elaborate bow (Image: Gorm Seljeseth, NIKU, licence CC BY-SA 4.0)

Braids, cords, ribbons, textile strips and tubes

Among the textiles examined, two braids have been identified. F404158 looks to be made by whipcord braiding with multiple groups of threads. There are several fragments, likely from the same object. The colour is light-medium brown. The braid appears to be made up of 4–6 intertwined bundles of 1–2 mm thick, single s-spun threads. F401905 is a much better-preserved braid (fig. 4). Although not stratigraphically related, the two finds share comparable textile qualities, and both might be whipcord braiding. F401905 is a 16 cm long and 1 cm wide circular braid, with a knot at the top. The braid consists of five groups; each composed of four to six threads. F401907 consisting of 12 fragments of very loose s-spun wool threads, might also originate from a braid. The colour was green during excavation but now appears black.

F401891 is a woven red ribbon from SL6693, made up of two fragments, approximately 1 cm wide and 19 cm long combined (fig. 5). The ribbon is tied in a slip knot, with remnants of a tassel at the end. It has 12 warp threads and 6 weft threads per cm. The z-spun warp yarn is about 1 mm thick, while the weft yarn is loosely s-spun and 2–3 mm thick. The weave structure is 2/1 twill with a warp-rib effect, and in some areas, the ribbon is heavily fulled. This ribbon might have been woven on a rigid-heddle loom.

There are several tubes and textile strips, varying in structure, weaving techniques, and potential function. Some tubes are folded and hemmed woven fabrics. One such example is F402530 from SL6541, which is blackish brown in colour and loosely woven in a soft 2/1 twill. The fragment was folded into a tube, measuring about 1 cm in width, though no visible evidence of seams remains. The thread density is 13/7 threads per cm, with s-spun weft.

Similarly, F404127 from SL5188 includes several fragments of blackish brown, fulled 2/1 fabric with visible evidence of seams. Three of these fragments were hemmed and sewn together to form tubes measuring 1.5 cm, 2 cm, and 4 cm in width. The largest fragment features a single hem along one long side. The fabric appears very coarse and fulled, though a thread density of approximately 6–8 threads per cm can still be observed. It is interpreted as remnants of a utilitarian textile, possibly boat caulking or another practical application.

The woven tubes and textile strips seem to have served both functional and decorative purposes, though their exact function remains unknown. One such example is F401927, a 35 cm long textile strip woven in 2/2 twill. When excavated, it was green, though it has since faded to light yellowish-brown. One surface appears fulled, and the textile is cut lengthwise, with a possible single hem along one side. At one end, the textile splits into two separate 15 cm-long textile strips, each measuring approximately 1 cm wide. The fabric is evenly and densely woven, with 10–12 z-spun threads per cm.

F401911 consists of a 21 cm long tube sewn from a 2/2 twill fabric. It was initially recorded as green, but it now appears medium brown. The fabric is folded, with the raw edges tucked inside, and is sewn with coarse overcast stitching (Emery 1994, 236). The thread density is 12–14 threads per cm, with a loosely s-spun weft. The sewing thread is two-ply, S2z approximately 2 mm in diameter. In addition, four smaller fragments with evidence of seams (2–4 cm long) have been preserved.

F401919 consist of a corner combining two perpendicular textiles, 21.5 cm long and 1.5 cm wide, and 7 cm long and 2 cm wide. The fragment might be from a utility textile and is heavily fulled in some areas. The raw edges are hemmed at the back, possibly folded twice. The fabric has 11–12 warp threads per cm, 1 mm or less thick, and the weft is 8 threads per cm, 2 mm or more thick, and loosely spun. Two different sewing threads were used: a 2 mm thick, S-plied thread in the longer textile, matching the fabric colour, and a 1 mm thick, black, single-strand z-spun thread in the shorter textile. This textile was green when excavated but now appears light-medium brown.

Caulking material
A few textile fragments have been identified as *drev* (norwegian), a type of caulking material traditionally used to seal boats (Rodum 2013). However, they might also be sealing from between wood beams in buildings. One example is F402027 from SL11301, which consists of two lightly twisted and felted strings of animal hair and wool, each approximately 20 cm long. Another textile interpreted as caulking is F404127 from SL5188, which consists of several fragments of blackish brown, fulled 2/1 fabric with evidence of seams. Some of these fragments appear to have been hemmed and sewn together into tubes of various widths (1.5 cm, 2 cm, and 4 cm). The heavily fulled texture suggests that this fabric may also have been used for caulking.
Fragments of loosely s-spun wool threads, varying in diameter from 0.3–0.8 cm, were found in F401907, possibly originating from a cord. The fragments had a greenish hue, but they now appear dark brown. The threads vary in diameter from 0.3–0.8 cm. F401925, consists of a folded bundle made from animal hair. A twisted strand of the same hair was found wrapped around or near the rest of the hair. This cord measures 9 cm in length, is 1.5 mm thick, and is loosely S-plied of z-spun threads. The construction of this cord resembles that of F401899, which was found in the same layer.

Seams
Evidence of seams may indicate that textiles are the fragments of clothing (Vedeler 2007; Vedeler 2004). However, very few of the textiles in this material display evidence of seams indicative of advanced sewing techniques. In total, 13 fabrics show evidence of seams, but all of these originate from from hemming of raw edges, folded tubes, or fabrics sewn together (possibly as repairs). These could just as easily belong to utility textiles as to clothing items (Pritchard 2003). Except for a few small wedge-shaped fabric pieces, there are no textiles that exhibit clear cutting patterns that could be linked to a specific garment shape. The deposit contexts should be considered here, as most of these textiles were likely secondarily used and cut up, before being discarded.
F402528, from SL6541, is possibly a fragment of clothing. It consists of cohesive fragments that appear to form a hem approximately 41 cm long on a black-brown fabric. The fabric is woven in a smooth and balanced 2/2 twill. The longest and best-preserved fragment has a double fold, while the other fragments display a single indented raw edge—likely due to tearing along the folded edge. The thread density is approximately 13/11 threads per cm. The yarn is single-stranded, about 0.1 mm thick, z-spun in one direction, and s-spun in the other. The raw hemline is approximately 0.4 cm wide. The outer hem edge, where the raw edge is folded in, is about 1.2 cm broad. There is an impression left by stitching, with intervals of approximately 0.5 cm, although no sewing thread has been visibly preserved.
Another sample interpreted as potential clothing, or other fine decorative textile is F401909 from SL6693. This sample consists of three small fragments. Fragment A has a potential selvedge preserved on one side, measuring approximately 4 cm in length. Fragment B forms a corner, between a selvedge and a sewn edge. F404098 consists of eight cohesive fragments of 2/1 twill fabric that have been folded and sewn together. At least one fragment appears to have been sewn into a tube, and the others may either be tubes or remnants torn from a folded edge. The raw edge is sewn down on the back using coarse overcasting stitches, spaced approximately 0.5 cm apart, and visible on both sides of the fabric. The sewing thread is approximately 2 mm thick, and s-spun and Z-plied (Z2s). The fabric is dark black-brown, with one fragment preserving a 2 cm wide strip of lighter brown yarn. The thread density of the fabric is 12/8 threads per cm, with a 1 mm thick, z-spun warp yarn, and approximately 1.5 mm thick, s-spun weft.
A light brown fragment, F401893, woven in 2/1 twill, with a seam in black brown, very loosely spun wool, has traces of possible repair stitching, or what may be decorative stitching (fig. 6). It has a narrow-hemmed edge along one long side, but no visible stitches. The surface is smooth and dense. There are approximately 14 × 12 threads per cm, both directions z-spun. The sewing thread is 1–4 mm thick. Impressions and stitch marks from black yarn are visible on the surface and along the edge of a torn short side.

Fig. 6: F401893 is a 2/1 twill, with repair stitching or maybe decorative stitching in a hairy black-brown sewing thread (Image: Gorm Seljeseth, NIKU, licence CC BY-SA 4.0)

F404152 consists of two connected fragments. The larger fragment is an open-weave 2/2 twill fabric with a coarse, lofty texture. The warp is a hard, z-spun approximately 1 mm thick, in a 2/1 twill with a thread density of 6–8 threads per cm. The weft is loosely s-spun, measuring 2–4 mm in thickness, with a thread density of around six threads per cm. The fabric is dark brown in colour. The smaller fragment features warps and wefts in different colours. The warp is light brown, z-spun, with a thread density of 14 threads per cm. The weft is a variety of dark browns, s-spun, with a thread density of approximately 8 threads per cm. On one short side of the fragment, there is a 2 cm wide section where both the weft and warp are dark brown. This may indicate a woven stripe. The fabrics were originally joined by a thread, twisted from both light and dark fibres, suggesting that they were sewn together (fig. 7).

An L-shaped fragment, F401935, woven in 2/1 twill, with approximately 9–10 threads per cm, features a single folded, hemmed edge. All other edges are torn. The fabric was yellow-green when excavated but is now a dark reddish brown. The warp yarn is hard z-spun, approximately 1 mm thick, but the weft is somewhat looser and s-spun.

Fig. 7: The fabrics in F404152 are woven in 2/2 twill and 2/1 twill and sewn together with a thread twisted from both dark and light yarn. One fabric has a dark brown colour, and a coarse, lofty texture. The other fragment has a smoother surface, and more colour effects, with a light warp yarn, and weft in alternating light and dark stripes (Image: Gorm Seljeseth, NIKU, licence CC BY-SA 4.0)

F401895 consists of two interlocking fragments of brown-black woven 2/2 twill with indentations where there may have been a seam. Parts of an edge are sewn down in a simple hem with rough hemstitches. The sewing thread is loosely z-spun and sewn with two parallel threads, 2 mm thick. The hem is 1.2 cm wide. The warp yarn is hard and shiny, z-spun, 1 mm thick, and there are approximately 12 threads per cm. The weft yarn is lofty, loosely s-spun, with a thickness of approximately 1.5–2 mm and a thread density of 8 threads per cm.

Colours

Colours may provide a great deal of information about both the textiles and the people who owned them (Fett 1991; Andersson 2006; Jahnke 2015; Heller 2021). Which colours could be achieved would have depended on availability of dyestuffs, technical expertise and specialisation, craft traditions and social traditions, trade networks and economics (Pedersen 2009; Barber 2007; Cardon 2007; Munro 2003). The fairly well-preserved textiles reflect a relatively rich colour spectrum. The field archaeologists wrote a short note on the colours they observed during excavation. Some colours have since oxidised. Only a few textiles, mainly those with coloured stripes, were photographed during the excavation. Several textiles still display visible colours and patterns.

Red is observed in three textiles: the woven ribbon F401891, in addition to F401909 and F401901. Three textiles appear yellow green: F402034, F401913 and F401935. Seven fabrics are described as green: F401937, F401931, F401927, F401921, F401911, F401919, and F401907. Yellow and golden colours are observed in F401909C and F401915. Blackish brown tones are seen in five textiles: F402528 I, FI402027, F401923, F404127, and F401895. There are also four fabrics with a striped effect: F404098 (dark and light brown), F401903 (yellow, brown, green), F401933A (green, now light and dark brown) and F404152A (brown stripe). Three fabrics appear to have different colours in the warp and weft: F401929 (green), F401917 (yellow-green, light and dark brown), and F404152A (light and dark brown). Several textiles that now appear brown may originally have been dyed in more vibrant colours.

F401903 comprises four likely connected fragments of a thicker, striped 2/2-twill. Described as striped with yellow, brown, and green when collected, it now looks

Fig. 8: F401903 consists of fragments of a 2/2 twill decorated with what was probably yellow, brown, and green stripes (Image: Gorm Seljeseth, NIKU, licence CC BY-SA 4.0)

light medium brown and dark black-brown (fig. 8). The fabric has an unbalanced structure, with a hard z-spun warp, 1.5 mm thick, with a density of 6–8 threads per cm. The wefts consist of two types of yarn: there are light stripes of loosely spun, lofty yarn, approximately 2–4 mm thick, with 4–5 threads per cm. There are also dark stripes of z-spun yarn, approximately 1.5–2 mm thick, with 6–8 threads per cm. The warp and dark weft may be from the same yarn, but the weft appears more loosely spun. The wider light stripes appear darker in colour than the narrower ones. This fabric was likely part of a thicker utility textile. The largest fragment has the following stripe pattern:

- Wide, light brown stripe: 1.4 cm
- Dark stripe: 0.5 cm
- Light stripe: 0.5 cm
- Dark stripe: 0.5 cm
- Light stripe: 2 cm
- Dark stripe: 1 cm
- Light stripe: 0.4 cm
- Dark stripe: 0.5 cm
- Interrupted light stripe: 0.3 cm

Five fragments of woven textile, F401933, are likely from two or three different fabrics. The largest fragment is decorated with four stripes (fig. 9). The pattern alternates between black-brown and light brown stripes. The fabric is woven in 2/2 twill. The warp is dark brown, hard z-spun with approximately 12 threads per cm, and a thread diameter of 1 mm. The weft is slightly looser s-spun, with a diameter of 1–2 mm, and thread density approximately 10 per cm. The textiles were originally described as green but now appear to be various shades of brown.

Processing

For most of the fabrics, it is hard to say if the surface has been processed after weaving. Fulling can be the natural result of wear in wool textiles; this may indicate use patterns on textiles. Most of these textiles displays wear and tear, which, together with the deposit context, may indicate that they were used and reused several times over. A few fabrics have a texture that may indicate processing after weaving. One possible interpretation of the loose, lofty s-spun weft yarn is that these were napped or fulled.

F402034 may show evidence of having been napped. This is a 2/1 twill with a slightly hairy surface. It is possible that the fabric was originally napped or had a more refined finish than what has been preserved. The thread density is approximately 12/10 threads per cm. The yarn is z-spun in both directions. The fabric appears light-medium brown but was initially observed as yellow green. F404150 consists of 11 smaller fragments of an open-weave lofty fabric, likely to have been woven in 2/1 twill. The thread density is approximately 6/5 threads per cm, although the thread thickness varies significantly, ranging from 1–2 mm in the warp to 1–4 mm in the weft. The warp is tightly z-spun yarn, and the weft is a loosely spun yarn. Several fragments are heavily tangled with what appears to be unspun wool. This could indicate that the fabric was either napped to create a raised surface

Fig. 9: F401933A is a 2/2 twill featuring four dark black-brown and light brown stripes. The fabric appeared green when it was excavated (Image: Gorm Seljeseth, NIKU, licence CC BY-SA 4.0)

Fig. 10: F402301 is an example of a wedge-shaped rag (Image: Gorm Seljeseth, NIKU, licence CC BY-SA 4.0)

or woven using minimally spun wool, possibly to produce a warm blanket or a thick utility textile.

F404154 is a triangular, medium brown textile fragment woven in 2/1 twill. The fabric is evenly and tightly woven, with lofty yarn, possibly indicating that the surface was napped. The thread density is approximately 12/10 threads per cm. The yarn is about 1 mm thick, z-spun in one direction and s-spun in the other.

A fragment cut into a trapezoidal shape, F402301, is possibly a remnant of a wedge (fig. 10). The widest side measures 6 cm at what appears to be a selvedge. The fabric is a tightly woven 2/1 twill with a thread density of approximately 10/10 threads per cm. The yarn is z-spun and 1–2 mm thick. The surface is lightly fulled.

Another fragment of woven fabric, F401929, with a sewn down edge, may have fulled during use. The fabric is woven in 2/1 twill, approximately 10/8 threads per cm. The yarn is z-spun, approximately 2 mm thick. A 4 cm long edge is preserved and folded down with a S-plied, z-spun sewing thread, secured using 0.5 cm long running stitches. The fabric was green when excavated and has one thread direction appearing darker than the other. F404123 is a fragment of fulled, woven fabric. The exact weaving technique cannot be determined, but a twill variant is probable.

A triangular woven fragment in 2/2 twill, F401931, has a somewhat lofty surface. Initially recorded as green, it is now uniformly dark brown. All the edges are cut off. The thread count is 10–11 z-spun threads per cm.

A folded triangular fragment, F401901, in 2/2 twill features a slightly curved, simple hem, with no visible evidence of seams. The hem may have been part of an opening in clothing or a utility textile. The fabric has a smooth surface, while the inside of the hem appears slightly loftier. Its colour was initially reddish-brown, but it now appears dark reddish-brown. The thread count is 10–12 threads per cm, of 1 mm thick, z-spun yarn. F401915 is an elongated, square fragment woven in 2/2 twill. Initially described as yellow, it is now medium brown. The fabric is unbalanced, with 10–12 z-spun, 1–1.5 mm thick, glossy warp threads per cm, while the weft has eight threads per cm. The weft is lofty, 2–3 mm thick, with a low spin angle. Some areas of the fabric surface appear lofty.

F401917 consists of two fragments of fabric woven in 2/2 twill. All the edges are torn. The surface is smooth but shows the remains of a possibly napped texture. The warp is dark brown, smooth, z-spun, with 12 threads per cm. The weft is light brown, loftier, loosely spun, at approximately eight threads per cm. Initially the colour was yellow-green, now it is a light medium brown. The difference in colour may be due to variations in the warp and weft fibres.

Discussion

The textiles' technical distribution and grouping patterns might be useful for a better understanding of life in the central harbour of medieval Tønsberg.

The predominance of wool fabrics, particularly twills, aligns with broader textile traditions observed in medieval Norway (Kjellberg and Hoffmann 1991). The presence of low-density, lofty fabrics suggests their use as padding, insulation, or blankets, supporting interpretations of textiles serving practical household or personal comfort purposes, as well as for trade and handicraft (Schjølberg 1984). In contrast, the medium to high-density textiles, often with balanced thread counts and finer structures, indicate potential use as clothing. Several fragments have traces of dyes and finishing techniques, hinting at variations in social status and access to specialised textile production.

One of the most compelling aspects of the Rådhusgaten assemblage is the concentration of textile fragments in the latrine deposit. The presence of torn, hemmed, and folded textile strips and tubes may suggest their secondary use as sanitary products or toilet tissue. This potential interpretation may provide some insight into medieval hygiene practices and the social aspect of the latrine, with the clustering of textiles in one section of the deposit potentially indicating spatial division based on gender, though other social or practical distinctions may also apply. The preliminary laboratory analyses show traces of blood in the tested fibres, and that insects in at least one textile have fed on human blood. This may strengthen the theory that some of these textiles were used as menstruation rags, though other explanations for blood on the textiles, such as wound dressings, are possible. It must be noted that we do not know if these insects fed on blood from the textiles, or blood directly from human hosts.

Many questions remain unaddressed in this case, as the use of sanitary products has not previously been developed in any depth in archaeological settings.
A comparable find is the 95 woven textiles excavated in Baglergaten in Tønsberg, mainly from a latrine area (Brendalsmo 1989). The excavation focused mostly on describing the structural layout of the medieval town, and the latrine textiles were not thoroughly addressed. The oval pit interpreted as a latrine, "construction 530", had human waste and small pieces of wool textiles in the top layers (Brendalsmo 1989, 18). 90% of the textiles from Baglergaten 2–4 "were found in such a context that they must be interpreted as menstruation pads or toilet tissue disposed of in latrine areas" (Brendalsmo 1989, 31). In the proceedings from the Baglergate 2–4 excavations, there is a paper thoroughly discussing the different kinds of moss in the samples from latrines (Griffin and Foldøy 1986, 3). Here as well are the mention of the textiles in the latrine as possible female sanitary products, though the question is not further addressed. The test samples from the latrine were investigated to identify several different species of moss and pollen.
Another site in Tønsberg where textiles have been found in waste layers or latrine layers is the excavation at Storgaten 24/26 (Lindh 1984, 57). These textiles are briefly mentioned as "rags, often in the form of strips torn from larger fragments. These were most likely used as toilet paper in latrines or as menstruation pads" (Lindh 1984, 57). The largest part of the textiles from Storgaten 24/26 were found in layer L248, noted as a "typical waste layer, where waste from households (…) were deposited. The concentration of textile finds might indicate that the waste is from latrines. Whether the textiles have been used as toilet paper or as menstruation pads, and what this may imply about gender distribution in the urban population, have been discussed. However, this discussion will not be addressed in this paper" (Lindh 1984, 97). The idea here is that a concentration of textiles in a waste layer might indicate that the waste is from a latrine – thus there is a sort of circular argument when it comes to discussing latrine textiles.
Textiles have been found in latrine contexts in Oslo as well. Kjellberg and Hoffman (1991, 49) mentions a context from Oslo, where several cut-off selvedges were found in a latrine or dung heap. They mention that these could have been used for toilet paper or "other things". In 2015, two latrine areas with very well-preserved textiles were excavated in Oslo (Nordlie et al. 2020). Molaug (2024, 103) briefly touches on the possibility that such latrine textiles might have been used as sanitary pads, as it is an established truth that it was the peat moss Sphagnum that were commonly used for toilet paper (Molaug 2024).
The established truth that it was moss that were used for toilet tissue, rather than textiles, is a bit surprising. While the moss in question has excellent absorption qualities, it has a weak structure that might not be the best for wiping. Wool textiles might be a structurally better choice for wiping, though they may have lower absorption powers. The cost of textiles in the medieval economy, even as worn rags, might be the reason to choose moss for toilet tissue. From the perspective of a menstruating woman, the moss with the excellent absorption powers and the bonus of antiseptic and antibacterial qualities, would be the better choice. Sphagnum is otherwise known as "blood moss", which might both refer to the use for dressing wounds and for menstruation absorption.
A combination of textiles and moss might be a logical solution (Gilbert 2025; Zankl 2021). But both textiles and the moss would need to be kept in place, if they were to function as menstruation rags. Menstruation rags may have been pinned in place, fastened to the underwear, but the use of underwear is uncertain. The preserved Lengberg underpants are identified as male, largely because historical writings indicate that female underpants were considered improper (Case et al. 2017; Nutz and Stadler 2015). Nutz and Stadler (2015) gives a brief overview of mentions of female underwear from the Middle Ages through the 1500s and 1600s. However, just because men who wrote about women's underwear ridiculed it, did not mean that women would never wear underwear. Rules about what someone should or should not wear may indicate that the opposite is true. As Nutz and Stadler (2015) point out, the question of underwear was a question of social power and cultural taboos. Female underwear might have been perceived as shameful, maybe due to its connection to the stigma of menstruation (Ott 2018; Green 2005).
Before the modern use of adhesive sanitary pads, sanitary belts or girdles were the common way of fastening the re-usable sanitary pads (King 2023). A solution like the menstruation girdle might explain why so many of the latrine textiles are long strips, tubes, braids or cut of selvedges – some of these textiles may have been used for the fastening of menstruation rags, though there are of course several other potential uses for these fragments. Some medieval medical written sources indicate that herbal remedies must be inserted vaginally, for example to cure the lack of menstruation. This kind of remedy would also need to be kept in place, for example by strings and textile strips (Kruse 1999, 246–250).

A find from the Herjolfsnes burial site might be of relevance. A woman (grave Ikigait I), aged 30–40 years old, suffering from scoliosis, was found with little pieces of sealskin fastened with twisted wool cords over the pubic bones. Plant fibres, small hairs of sheep wool and a little bit of moss were found beneath the sealskin. This was interpreted as a bandage for the absorption of secretions, such as incontinence (Nørlund 1924, 322–332; Netherton 2006).

"Being on the rag" alludes to the rags women would wear as menstruation pads. The first known mention of such "menstruation rags" indicates that such rags were used in antiquity (Booth 2017, 128; King 2023). Two of the earliest preserved manuscripts of the Book of Isaia (Septuaginta 300–100 BCE, Codex Leningradensis 1008 CE) refer to menstruation rags, or menstruation clothing (Barstad 2025; Eidsvåg 2025). There are a few medieval mentions of menstruation rags as well, for example from the physician Bernard de Gordon, who said that menstrual cloth should be inspected by the physician to diagnose sickness (McClive 2004). A record from the 1300s mentions menstruation rags as part of a magical potion (Ladurie 1980). Menstruation rags or cloths are mentioned more often as the number of written sources increases from the 1500s onwards (Reed 2008).

Medieval women's ability to menstruate were probably affected by fasting periods, malnutrition, pregnancies and nursing. Medieval women generally experienced more pregnancies than modern women, and as nursing also might delay periods after pregnancies, they would have had fewer menstruations. Considering how each pregnancy is followed by lochia, up to six weeks of heavy bleeding post-partum, there would still be lots of blood to dispose of (Harris and Caskey-Sigety 2014, 36–47; Delaney et al. 1988). Menstruating women with a heavy flow, or those experiencing the lochia, must have had solutions in place. It is difficult to consolidate the image of free-bleeding women (Reed 2008) with the medieval stigma of menstruation and of the high value of clothing.

Medieval nuns might have been menstruating almost as often as modern women. Monastic clothing was strictly regulated in theory, though some of the written sources indicate that privately owned lay clothing prevailed within some monasteries. The reform statutes of 1453 by Nicholas of Cusa for the Sonnenberg nunnery (Germany) give a detailed list of which clothing the nuns should have, including "if they suffer women's infirmity, they may use linen shirts and linen cloths for as long as the infirmity lasts" (Torggler 2016, 41–55).

The shapes of the textile finds are diverse. While most of the fragments are small, torn rags, 12 of them have square or rectangular shapes that could function as pads from a modern perspective. Some of the textile strips, tubes, cords, braids and ribbons might also be fastening for menstruation rags, or combinations of rags and moss.

The body of textiles are too diverse to be explained as solely remnants of menstruation rags and girdles, or toilet tissue. As the latrine layer also includes other household waste, some of the textiles could have been part of general waste disposal. The variety of the textiles point to a diverse and dynamic use, and re-use of textiles beyond clothing. The rather colourful ensemble of textiles with reds, yellows, greens, black and browns hint at the value these textiles would have had, before they were at the end of their usefulness and were cut down to rather small fragments and disposed in the latrine.

From a broader archaeological perspective, the Rådhusgaten textiles show how textiles were integrated into daily life and personal hygiene. However, the textiles from Rådhusgaten are too few to base wider conclusions concerning further distribution patterns within the social town structure on. Previous excavations and research into the harbour area have unfortunately skipped a deeper technical analysis of textiles. For example, a larger excavation in Nedre Langgate in 1976 revealed 179 textiles. Half of these were not analysed, the rest was rope, thread and caulking cords (McLees 1999, 91–65; Ulriksen 2002).

Conclusion

The excavation at Rådhusgaten, Tønsberg, has revealed a small corpus of medieval textiles, offering insights into textile technology, daily life, and hygiene practices. The predominance of wool twills, varying in density and processing, reflects the versatility of textile production and usage. The presence of textiles in urban fill layers, as well as within latrine deposits, hints at the diverse re-utilisation of textiles in medieval daily life. It is interesting to note the diversity in colours and patterns in textiles, as this raises questions on the availability and social distribution of dyed textiles in the medieval town.

This study has discussed how textile fragments found within a latrine deposit potentially may have been used as menstruation rags and girdles. Little archaeological research has previously been done on medieval menstrual hygiene practices, the secondary use of textiles in latrine settings and the potential gendered organisation of latrine spaces.

The presence of caulking materials, ribbons, cords and tubes, packaging and evidence of sewing further demonstrates the multifunctionality of textiles within both domestic and harbour settings.

For future research, it would be very interesting to take a closer look at the combination of the textiles found in other latrine deposits, such as those from Baglergaten 2–4, Storgaten 24–26 and those found in Oslo. A comparative study of the qualities of the textiles in these contexts might give indications on possible uses of these textiles. Further testing focusing on hormones, DNA, traces of blood and pubic lice would be very interesting and should be considered whenever textiles are found in latrine contexts in the future.

These findings emphasise the importance of textile studies in medieval archaeology, demonstrating how fabric remains can reveal details about daily habits that are often absent in historical records, as well as observations related to trade, economy and technology. Future research, including laboratory analyses and hopefully dye identification, might further refine our understanding of these textiles and their broader implications for medieval Scandinavian society.

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Twill on the warp-weighted loom: reconsidering double-notched supports

Abstract
In the 1970s, five wooden artifacts were extracted from the medieval layers in Trondheim (Norway). These implements, 30–34 cm in length with a notch at one end and in the middle, were interpreted as attachments for the warp-weighted loom, a factor of keen interest to textile historians. Even before these implements were documented, a theory developed for how "double-notched heddle-rod supports" could be used for weaving 2/2 twill. Other methods for weaving twill on this loom have been proposed over time, with and without reference to the Icelandic method drawn from 18th to 19th century records, but no other interpretation for how double-notched supports may have been used has been presented. In this research, the role of these supports is reimagined, and an alternative method is proposed for how 2/2 twill may have been woven. It is as effective, and more straightforward and intuitive than the previously proposed method.
Keywords: Warp-weighted loom, twill, heddle-rod supports, loom technology, medieval weaving

Introduction

The warp-weighted loom was a major element of European weaving technology for thousands of years. The primary products of this loom were plain weave and the slightly more complex twill. Thanks to Marta Hoffmann's ground-breaking study, which documented the few remaining warp-weighted loom practitioners in Norway and Finland, the method by which plain weave was woven on this loom in northern Europe is well understood (Hoffmann 1964) (fig. 1). The loom was no longer used to produce twill by the 20th century, and therefore the exact method by which this other major structure was woven is less clear. Evidence survived from Iceland in the form of late 18th century drawings depicting twill in progress on the loom (fig. 2), and in late 19th century letters from two elderly women who remembered weaving twill on the warp-weighted loom in their youth. While

Fig. 1: The warp-weighted loom set up for plain weave in Hordaland (Norway), as documented by Marta Hoffmann in 1956. Evident in the developing weave are several traditional hand-selection techniques that were commonly woven in a plain-weave setup (Image: Per Gærder, Norsk Folkemuseum)

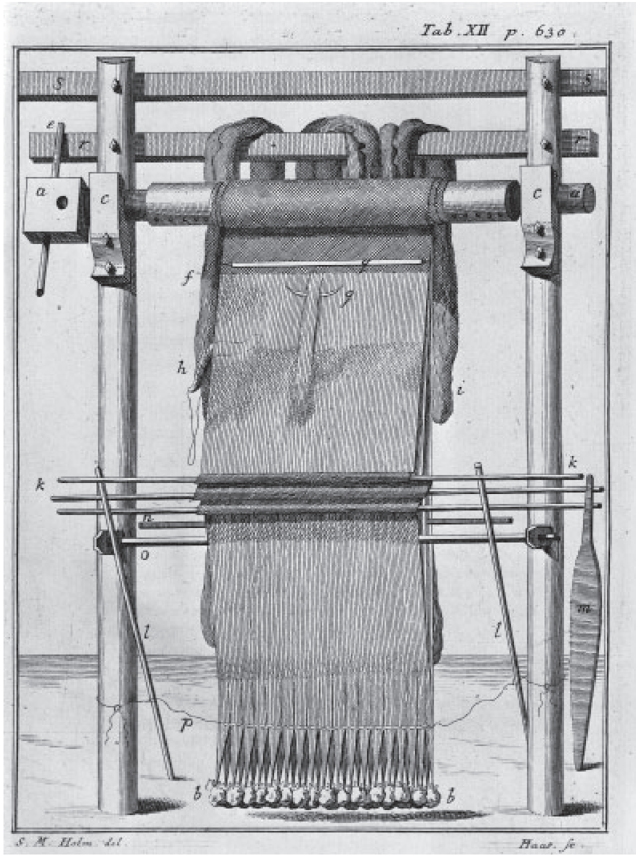

Fig. 2: Twill weaving on the Icelandic loom, as published in a 1780 volume by Olaus Olavius, now in the collection of the Royal Danish Library (Image: Norsk Folkemuseum)

not as detailed as Hoffmann's documentation of a living tradition, the latter information, first published in the yearbook of the Icelandic Archaeological Society (Þórðarson 1914), was summarised in Hoffmann's treatment of the warp-weighted loom (Hoffmann 1964, 114–140).

Among the details recorded by Icelandic sources were several important elements for weaving 2/2 twill. Similar to the method documented for plain weave, the loom was set up with a "natural shed", composed of two consecutive warp threads in front of the fixed shed rod (the forward layer), followed by two consecutive warps behind the shed rod (the back layer), thus creating one of 2/2 twill's four sheds. The remaining three sheds were each controlled by one of three heddle rods, with each heddle pulling forward two neighbouring warp threads. The setup of the Icelandic loom further differed from those Hoffmann had observed in Norway in the type of slanted brackets (*meiðmar*) that held the heddle rods in the open position to form a shed. Whether all of these elements were unique to Iceland or had once been common elsewhere in Europe is not known.

Over the years several methods other than that reported in Icelandic sources have been proposed for how 2/2 twill may have been woven on the warp-weighted loom. These methods fall into two basic categories: those that break completely with the Icelandic method by dispensing with the shed rod and the natural shed it creates, enclosing a single warp thread in each heddle, and dividing the warp into four layers that are separately weighted (Schlabow 1952; 1976; Schierer 2005; Grömer 2016) (fig. 3a); and those that follow part of the Icelandic method by utilising the natural shed formed by the shed rod and enclosing two warp threads in each heddle, but employing heddle-rod supports

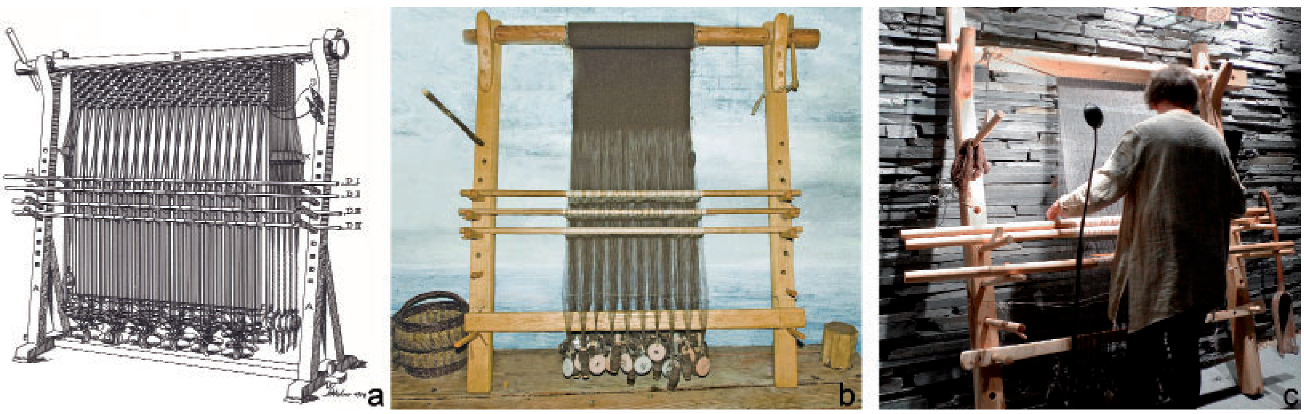

Fig. 3: Methods for weaving 2/2 twill using one or two warps per heddle and a varying number of single-notched support pairs: a) proposed method for weaving the Thorsberg mantle: one warp per heddle, four support pairs, four heddle rods (after Schlabow 1952); b) weaving sailcloth at the Viking Ship Museum: two warps per heddle, three support pairs, three heddle rods (Image: Werner Karrasch, © Viking Ship Museum, Roskilde); and c) weaving diamond twill at the Lendbreen tunic exhibit, Norsk Fjellmuseum: two warps per heddle, two support pairs, three heddle rods (Image: Randi Andersen, Osterøy Museum)

with single notches similar to those that survived in Norway and Finland, using variously one, two or three pairs of supports (Hoffmann 1964; Hansen 1978; Nørgård and Østergård 1994; Walton Rogers 2007; Hákonardóttir et al. 2016) (fig. 3b and fig. 3c).

In the 1970s, the discovery of five small wooden artefacts in the medieval layers of Trondheim (Norway) made a further contribution to the question of how twill was woven. These implements, 30–34 cm in length with a notch at both the midpoint and one end, were interpreted as attachments for the warp-weighted loom (Nordeide 1994, 230) (fig. 4). Such implements, for which a use was theorised even before their discovery (Haynes 1975), formed the basis for a third twill-weaving method that combined elements from both of the above-mentioned schools of thought. After further refinements (Batzer and Dokkedal 1992), this method, often identified as the four-weight-row method, has been included in numerous studies describing how twill was woven on the warp-weighted loom (Stærmose Nielsen 1999; Andersson Strand 2010; 2015; Olofsson and Nosch 2015; Ulanowska 2017; Andersson Strand and Demant 2023).

The current research reconsiders this third method for weaving twill, specifically its use of double-notched heddle-rod supports, and suggests an alternative interpretation for how these implements may have been used. It is based on the Icelandic method of enclosing two warps per heddle but utilises heddle-rod supports as attested in the Norwegian tradition rather than the slanted supports reported from Iceland. In the proposed method, double-notched supports solve a problem concomitant with enclosing two warp threads per heddle, namely occasional heddle jamming when opening a shed, and result in a weaving procedure that is both effective and more straightforward for 2/2 twill than that proposed. A comparison of these very different uses of double-notched supports follows.

Fig. 4: Four double-notched heddle-rod supports (museum numbers N31160, N37223, N33146, N33433) discovered in medieval layers in Trondheim (Norway), now in the collection of NTNU University Museum, Trondheim (Image: Katherine Larson)

It should be noted that the incorrect understanding of double-notched supports as an innovation that allowed the weaving of 2/1 twill on the warp-weighted loom (Crowfoot et al. 1992, 21; Nordeide 1994, 230; Øye 2016, 37) appears to have resulted from a conflation of experimental results presented in the seminal article on the four-weight-row method (Batzer and Dokkedal 1992). Both 2/2 and 2/1 twill methods are mentioned in that article, but as described there, 2/2 twill utilised double-notched supports, while 2/1 twill required only single-notched supports.

The four-weight-row method and double-notched supports

A review of how the four-weight-row method developed is instructive. The impetus for devising this new approach to twill was the observation of uneven warp tension when using the Icelandic two-weight-row system (Haynes 1975, 156). Haynes proposed a different system with changes to several main elements:

- Where the Icelandic method divided the warp evenly over the fixed shed rod, thereby creating one of 2/2 twill's four weaving sheds (the natural shed), Haynes divided the warp into four layers, with one placed in front of the shed rod and three behind.
- Where the Icelandic method included two warp threads in each heddle, Haynes suggested single warps per heddle, requiring the coordination of two warp groups to form each shed.
- Where the Icelandic method formed all but the natural shed in front of the forward-layer warp threads, Haynes proposed forming two sheds in front and two sheds behind the forward layer warp threads.
- Where Hoffmann's description of the Icelandic method indicated a row of weights tensioning

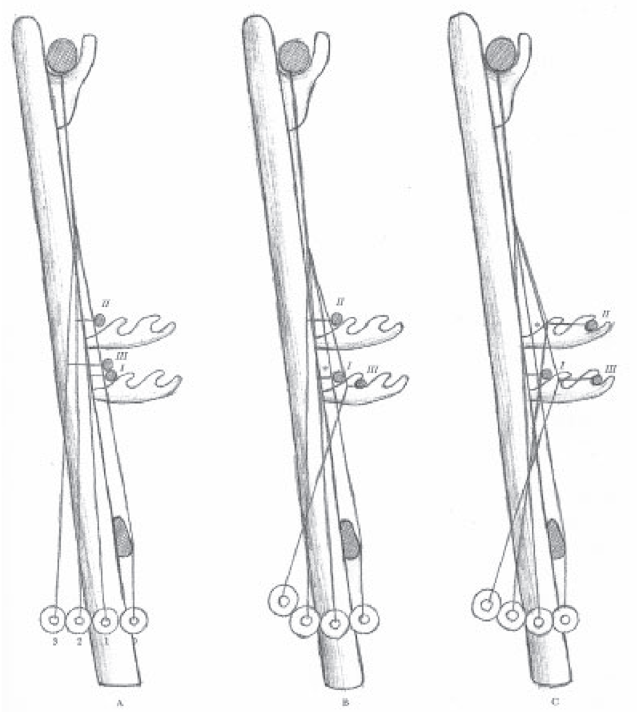

Fig. 5: Weaving twill with the four-weight-row method requires two pairs of double-notched supports, with sheds formed by combinations of two heddle rods or one heddle rod plus the fixed shed rod: a) heddle rods at rest; b) shed 2 formed with heddle rod III in inner notch; and c) shed 3 formed with heddle rods II and III in outer notches (Image: Anne Batzer, after Stærmose Nielsen, 1999)

each of these two layers, Haynes proposed four separate weight rows that would provide equal tension to all warp layers.

Thus, Haynes combined elements from the two divergent approaches to twill weaving described above by dividing the warp into four separately weighted layers yet using the shed rod to hold forward only one of those layers. Haynes also added a further element to this proposed method. In forming two of the four sheds in this revised system, specifically those combining one of the back-layer warps with the single layer in front of the shed rod, Haynes noted that the back-layer warps only needed to be brought into alignment with the forward layer to open a shed at the back of the loom, and for this purpose a heddle-rod support fitted with a notch at midpoint would suffice. In addition, these midway notches reduced the tendency for back-layer weight rows, when pulled forward, to diminish shed sizes by pushing forward on neighbouring weight rows. Double-notched supports, with a notch at one end and in the middle, were thus envisioned as a way to address these two issues in the proposed new method.

Further experimentation with Haynes' proposed method by the Historical-Archaeological Research Centre in Lejre (Denmark) resulted in a slightly modified version of Haynes' method, with several refinements that are now considered standard (Batzer and Dokkedal 1992) (fig. 5):

- Where Haynes had used three pairs of heddle-rod supports (two with double notches), it was realised that only two pairs were required (both with double notches).
- Where Haynes had suggested a revision of the top-to-bottom order in which heddle rods were arranged (I, III, II rather than the more intuitive I, II, III), the revised order called for the upper pair of supports to hold heddle rod II and the lower pair to hold heddle rods I and III.
- Where Haynes made no mention of heddle size, varying heddle sizes were suggested to improve shed formation: heddle rod I – 5.5 cm; II – 8 cm; III – 7 cm.
- In a later description of this method, a further refinement was noted: the importance of sloping the height of weight rows in the back three layers to keep them from riding up on each other as they were pulled forward (Olofsson and Nosch 2015, 124).

Reimagining the purpose of double-notched supports

In comparing a twill method that proposed dispensing with the shed rod (Schlabow 1952), with that recorded for weaving twill in Iceland, Marta Hoffmann noted: "…the Icelandic method is both simpler and much more ingenious. It bears the mark of long use, and shows that this had reached a point of technical perfection that could hardly be improved upon" (Hoffmann 1964, 139). This statement must be taken to include all aspects of the Icelandic method, with the most obvious elements being the long warp and the unique method for supporting the heddle rods with slanted sticks. Yet despite these noticeable aspects, those features would seem to represent practical solutions when weaving twill. The less visually obvious, but possibly more important feature of the Icelandic twill method may be the practice of including two warp threads per heddle. The current research is based on the idea that enclosing two warp threads per heddle is an important element for weaving 2/2 twill, and in fact one uniquely suited to the warp-weighted loom's divided warp. The archaeological find of double-notched heddle-rod supports, interpreted as implements for the warp-weighted loom, implies that weave structures more complicated than plain weave were being woven, with twill a likely candidate. From this it would follow that, at least in Trondheim, weavers may have controlled their twill shedding differently than in Iceland, using heddle rod supports with double notches rather than the Icelandic slanted supports. Accordingly, experiments in the current research were designed to determine how double-notched supports have been used to facilitate the weaving of 2/2 twill.

Experimental methods

Study design

The central problem addressed by this research was heddle jamming noted in specific circumstances when weaving twill with two threads per heddle. Heddles on the warp-weighted loom are only secured at the forward end, where they are attached to the heddle rod. The other end of the heddle is held more or less taut by tension on the weighted warp threads, but that tension changes as various heddle rods are pulled forward. In the current research, which utilised heddles tied in an open loop, heddle jamming was especially notable in the case of the middle heddle rod that controls all back-layer warp threads. When this heddle rod was pulled forward, heddles on the upper and lower heddle rods, each of which also contained one back-layer warp, no longer had warp tension holding them back and therefore became slack. Pulling forward heddle rod II past these now slack heddles led to heddle jamming as the back-layer warps attempted to pass through the forward layer, and sometimes to tangles between heddles and neighbouring warp threads when releasing the heddle rod. While these problems could be resolved by plucking apart tangles and tugging on the heddle rods to relieve jamming, this constant effort took time and could cause wear on the heddles and warp threads involved.

The current research therefore concentrated on the problem of heddle function as it might relate to double-notched heddle-rod supports. It should be noted that aspects of the warp itself, such as the use of sizing to improve heddle passage or the potential for achieving a suitable fabric density through fulling a less dense web, were not considered. Instead, a method for avoiding slack heddles was envisioned by using double-notched heddle-rod supports to provide a midway return point for the upper heddle rod after it opened a shed. The intended purpose was to hold these warps and their heddles taut to facilitate the passage of the middle heddle-rod warps. However, a preliminary assessment indicated that similar problems arose during the transition between the middle and lower heddle rods. Therefore double-notched supports were chosen for both the upper and middle heddle rods to test whether keeping each group of heddles taut after opening their respective sheds would improve the passage of subsequent groups of warp threads.

Fig. 6: Test loom with three pairs of heddle-rod supports: two upper pairs had experimental double notches, lower pair had single notches; holes for moveable pegs in the experimental heddle-rod supports allowed flexibility in finding a suitable distance from the uprights for both inner and outer notches (Image: Monika Ravnanger, Osterøy Museum)

Materials

Experiments were carried out using Hoelfeldt Lund single-ply wool yarn from the Nordic short-tailed sheep (*spælsau*). Two warps with different properties were tested at different warp densities. The first warp was z-spun, 4,500 m/kg, a mixture of underwool and outer wool (hair), with a higher percentage of underwool; it was woven at a density of 8 threads/cm and a weaving width of 60 cm. The second warp was s-spun, 5,250 m/kg, also a mixture of underwool and outer wool, with a higher percentage of outer wool. It was woven at a density of 12 threads/cm and a weaving width of 66 cm. Both warps were weighted on the loom at approximately 50 g/thread to provide sufficient tension.

Loom setup and warping procedures

Experiments were conducted at Osterøy Museum

(Norway) and at a weaving studio in the Seattle area (United States). The looms were set up as follows:

- The warp was arranged in two evenly divided rows, with alternately two warp threads in front of the shed rod and two behind.
- Experimental "double-notched" support pairs were created with holes at 2 cm intervals to receive small pegs, thus permitting heddle rod placement to be calibrated to heddle length and shed size.
- Three pairs of heddle-rod supports were used, ordered I, II, III from top to bottom; the two upper pairs (heddle rods I and II) utilised the experimental double-notches, the lower pair (heddle rod III) required only single notches (fig. 6).
- Both forward and back warp rows were divided into bundles and weights were attached to each row, providing a tension of 50 g/thread.
- Heddles were tied to create the 2/2 twill structure, with two neighbouring warp threads enclosed in each heddle: heddle rods I and III were tied concurrently, each containing one forward- and one back-layer warp thread; heddle rod II was then tied between I and III, enclosing pairs of back-layer warps.
- All heddles were of equal length.
- After heddle tying, warp threads in the back weight row were divided into two rows based on the warp division established by the heddles; the newly divided bundles in these rows were then tied with halved weight amounts to maintain the tension of 50 g/thread (this and the following point are elements of the Icelandic method described in the discussion section below).
- The two back weight rows were joined together with a spacing chain that included four warp threads per loop, two from each row of weights.
- All weight rows were tied at approximately the same height.
- The front weight row was also divided into two rows, each with halved weight amounts, and warps were chained together in the same manner as the back row.

In determining appropriate notch distances on the experimental supports, the placement of heddle rod I was adjusted so that when held by the inner notches, the affected warp threads were slightly in front of the forward warp layer. This ensured that these heddles were taut for the passage of heddle rod II. For heddle

Fig. 7: Placement of the heddle rods to form the four 2/2 twill sheds, using double-notched supports for the upper two support pairs: a) shed 0 is open, all heddle rods at rest against the uprights; b) shed 1 is open, heddle rod I in outer notches; c) shed 2 is open, heddle rod I in inner notches and heddle rod II in outer notches; and d) shed 3 is open, heddle rods I and II in inner notches and heddle rod III in single notches (Images: Katherine Larson)

rod II, an inner notch distance that held affected warp threads approximately even with the forward warp layer was found to be sufficient (fig. 7). The distance to the outer notches of both pairs was determined by the desired shed size of approximately 6 cm. Thus, the upright-to-notch distances for the two pairs of supports were not the same, with heddle rod I notches being somewhat closer to the uprights than those of heddle rod II.

Weaving procedures and findings
Weaving followed a regular pattern: a shed was opened to insert the weft, the shed was changed, the weft was beaten in, and the following weft inserted. Weaving order progressed from shed 0, the natural shed, through sheds 1, 2 and 3 by accessing heddle rods I, II and III. All heddle rods were pulled forward to the outer notches of a support pair to open their respective weaving sheds, but after use, heddle rods I and II were returned to the inner notches of their supports before the next shed was opened. In contrast, after the weft was inserted in shed 3, heddle rod III was returned to rest against the uprights, followed by heddle rods II and I, thus again forming shed 0 with all three heddle rods at rest against the uprights (fig. 8).
Results were consistent when weaving at both 8 threads/cm and 12 threads/cm: the steps in weaving were straightforward, heddle jamming was not a factor, and sheds were clear, with the exception of several sticky warp threads evident in every shed, which required minimal clearing. There were no problems with uneven tension since both front and back layers were divided, thereby adequately tensioning the warp threads controlled by heddle rods I and III, and the spacing chain held the divided back weight rows together so that they travelled as one, causing no interference with each other.
Weaving twill in reverse order was also straightforward if slightly less intuitive. Accessing

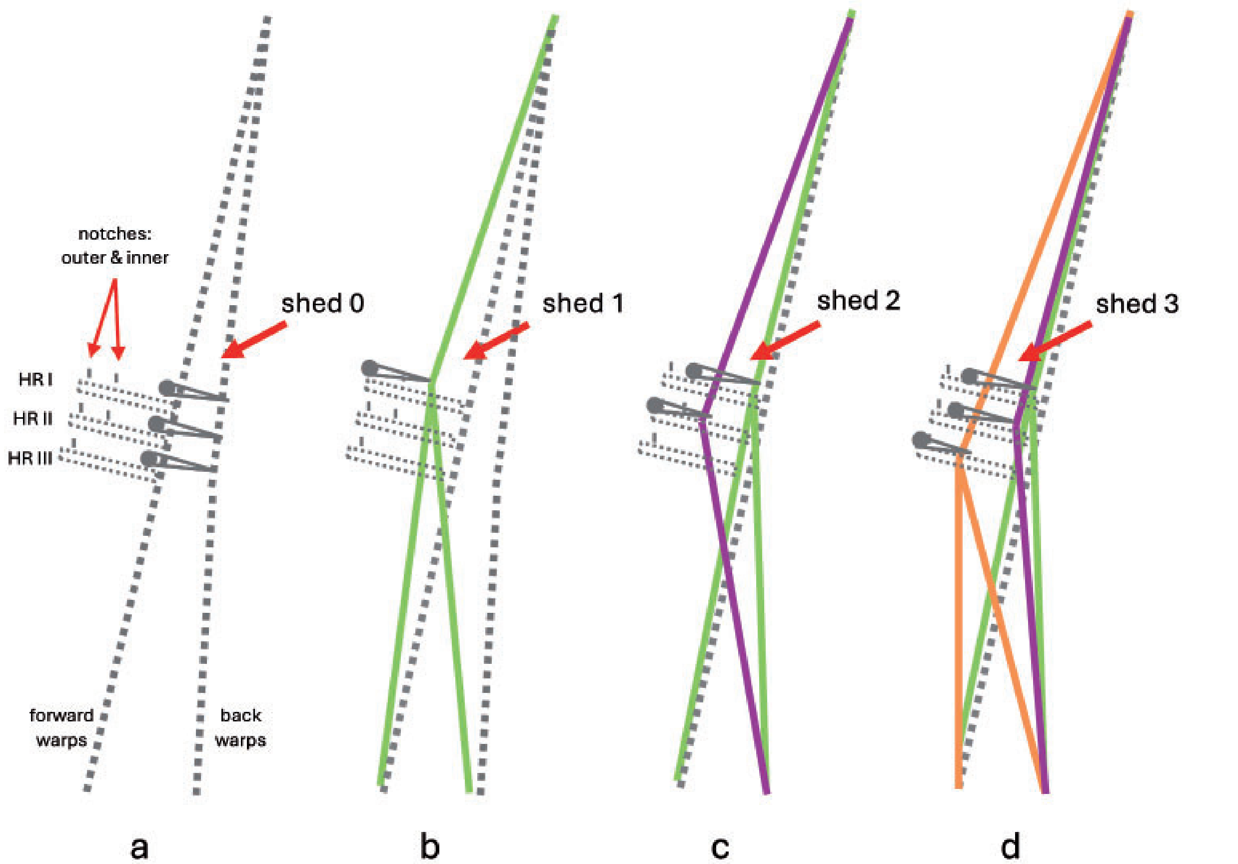

Fig. 8: Simplified view showing movement of the warp layers as heddle rods are manipulated to form sheds: a) all heddle rods at rest against the uprights for shed 0; b) heddle rod I placed in outer notches for shed 1; c) heddle rod I placed in inner notches, heddle rod II placed in outer notches for shed 2; and d) heddle rod II placed in inner notches and heddle rod III placed in single notches for shed 3 (Image: Katherine Larson)

sheds in the order 0, 3, 2, 1 required placing heddle rods I and II in their inner notches following the 0 shed, from which point these two heddle rods operated normally, that is they were pulled to their outer notches to open their respective weaving sheds.

Comparison of single-notched support options with double-notched supports

The use of single-notched supports for weaving twill likely represented a departure point from which the use of double-notched supports evolved. As noted above, the use of one, two and three single-notched support pairs had been suggested by past research, and therefore support-pair conformations were altered on the test warps to compare these combinations to each other and to the use of double-notched supports as proposed in the current research. Four options using single-notched supports were tested:

- Three pairs of single-notched supports, each pair holding a single heddle rod.
- Two support pairs holding two rods on the upper supports and one rod on the lower supports.
- Two support pairs holding one rod on the upper supports and two rods on the lower supports.
- One support pair holding the middle heddle rod and two pairs of pegs (above and below) holding the upper and lower heddle rods. All three heddle rods utilised the middle support pair's notches to open a shed.

It should be noted that the use of one pair of supports was the basis for Marta Hoffmann's twill experiment, referred to but not fully described in her book (Hoffmann 1964, 131–136). However, this method was clearly documented in her unpublished research notebook and therefore was included in these tests (Hoffmann 1952–1953) (fig. 9).

Problems were found across all four options upon opening and closing shed 2, in other words when bringing forward and releasing heddle rod II, which controlled pairs of back-layer warp threads. As noted above, when heddle rod II was pulled forward, heddles on rod I became slack and jammed when back-layer warp threads encountered the forward-layer warp, thereby blocking shed formation. After heddle rod II was placed in its notches, tugging on heddle rod I usually cleared these jams, and a shed, albeit obscured by many residual sticky warp threads, began to form. Shed 2 could then be fully cleared by pulling on heddle rod II again, or "overpulling" it from its already open position, to separate the sticky warps that remained. Although the slack heddles attached to heddle rod III, located below heddle rod II, did bunch slightly in front of the forward warp layer, they usually did not jam or require tugging on that heddle rod to facilitate the clearing of shed 2. Upon closing shed 2 similar problems were experienced, with heddles attached to heddle rod I again becoming jammed or sometimes tangled with neighbouring warps, blocking the warp threads from assuming their at-rest positions. Tugging on heddle rod I cleared most of these jams, but occasional tangles between heddles and neighbouring warp threads had to be plucked apart by hand.

In contrast to the significant problems experienced with shed 2, in all four single-notched support-pair setups the opening and closing of sheds 1 and 3 was relatively trouble free. However minor heddle jams, especially in the transition between sheds 2 and 3, occasionally required tugging the heddle rods, and all sheds required clearing of sticky warp threads through a combination of overpulling the open heddle rods, strumming the warp threads and/or hand clearing individual sticky warps.

In comparison to all options using only single-notched supports, the use of double-notched supports for heddle rods I and II resulted in a weaving cycle with no heddle jamming or tangling with neighbouring warps. However, similar to all single-notched options, weaving with double-notched supports still required the clearing of a limited number of sticky warp threads in all sheds.

Discussion

Questions regarding the four-weight-row method

The perceived uneven tension in the Icelandic method, which was the instigating factor in Haynes' original proposal for using double-notched supports, was unfortunately based on incorrect information reported by Hoffmann. Her twill experiments, which were partially based on the Icelandic method, were performed several years before a discrepancy was noted in the original Icelandic source documents. In 1979, a careful rereading of the original Icelandic sources by weaver Sigríður Halldórsdóttir revealed that two details in the loom's setup had been overlooked: a division of the back weights into two rows that were then chained together, and the use of an additional floating rod to assist in separating the sheds (Guðjónsson 1985, 121). These elements resolved the tension problems noted by Haynes. Without knowledge of these refinements to the Icelandic method, Haynes' revisions represented effective, logical choices.

However, it should be noted that the newly designed system addressed a difficulty in the Icelandic method that did not actually exist, and envisioned double-notched supports as a means to facilitate the functioning of this new system. Moreover, in solving the perceived tension problem and devising a new implement as part of that system, no consideration was given to the accompanying major changes from a known method, primarily dispensing with both the natural shed and the practice of enclosing two warp threads per heddle. Regarding possible methods for weaving twill on the warp-weighted loom, Marta Hoffmann remarked: "everyone concerned with the technical aspects of textile production is well aware… that the same result can be achieved by various methods" (Hoffmann 1964, 139). It would seem that the system proposed by Haynes and the method that evolved from it underscores this statement.

An important element in the positive reception of the four-weight-row method has been the greater flexibility it affords in weaving a variety of different

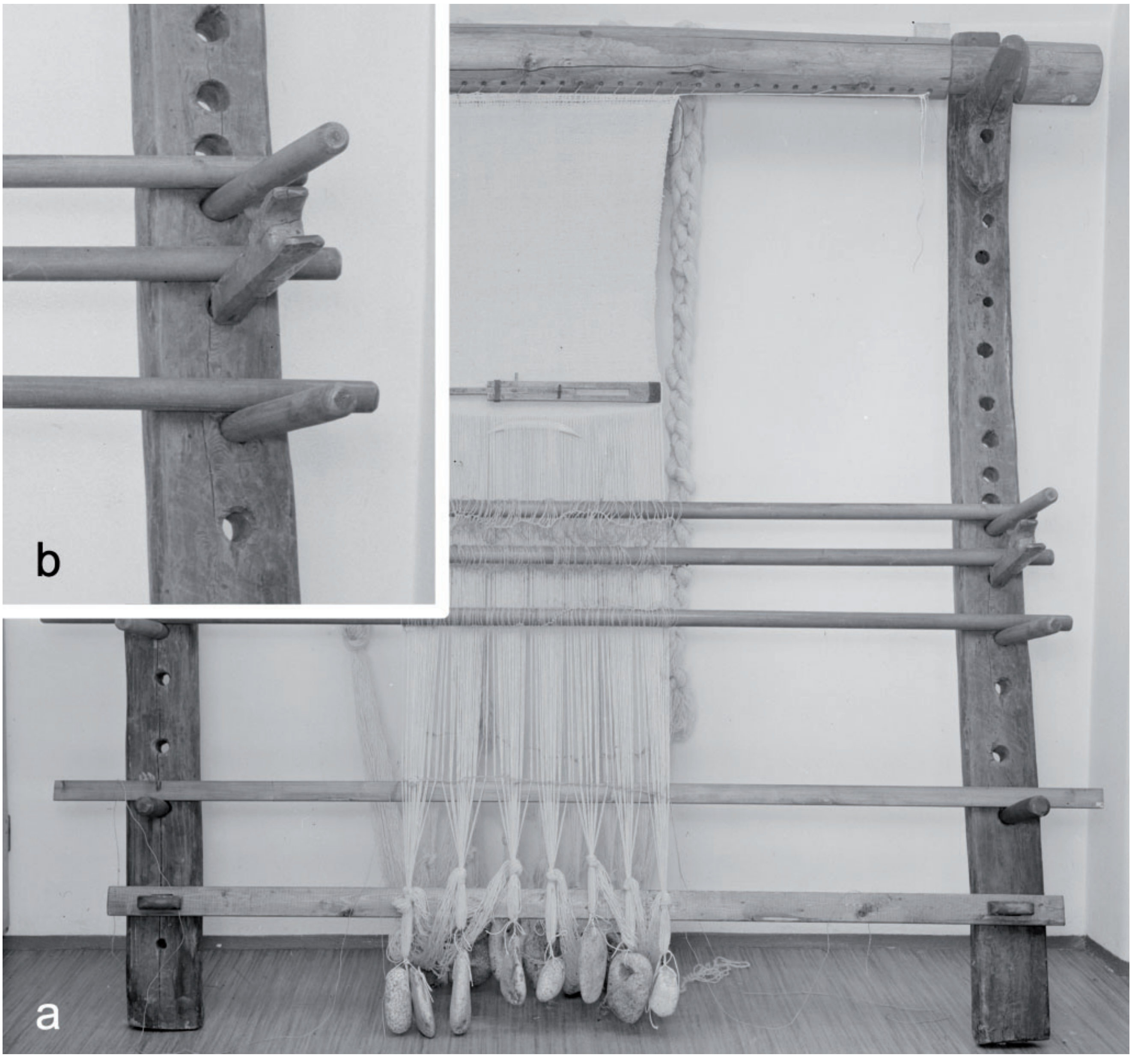

Fig. 9: Twill experiment on the warp-weighted loom conducted by Marta Hoffmann in 1952–1953: a) three heddle rods were held separately; and b) (detail) one pair of single-notched supports held the central heddle rod, upper and lower heddle rods rested on pegs, and all three heddle rods used the central pair of single-notched supports to open a shed (Image: Norsk Folkemuseum)

fabric structures, including "tabby, basket-weave, 2/2 and 3/1 twill and different floating lacings and pattern effects" (Batzer and Dokkedal 1992, 234). Such an expanded flexibility introduces the intriguing possibility that textiles once interpreted as coming from a more sophisticated production setting may have in fact been woven on the warp-weighted loom (Stærmose Nielsen 1999, 96). Clearly the advantages derived from the four-weight-row method do increase the warp-weighted loom's capability, especially when viewed with an inherent understanding of modern loom technology. As noted by Haynes, "Using the principles propounded in this article, with four warp systems and three heddle rods, all the weave plans which are possible on a modern four-shaft loom are technically feasible" (Haynes 1975, 164). In essence, this new system mirrors the flexibility of the modern treadle loom transferred into a system that utilises a divided warp.

The factor of warp separation may have a bearing on a further perceived advantage of the four-weight-row method: the capacity for weaving dense twills (Batzer and Dokkedal 1991, 151; Olofsson and Nosch 2015, 122). The separate layers of the four-weight-row method are theorised to confer this advantage, especially when the warp-weighted loom is compared to other early looms such as the two-beamed vertical or ground loom, both of which function with the warp in a single plane (Andersson Strand 2015, 54). However, concerning the issue of warp separation at the centre of this argument, the four-weight-row method is often distinguished from the Icelandic "two-weight-row" method (Olofsson and Nosch 2015, 120; Andersson Strand 2015, 54). On face value this appears to be an accurate distinction: the divided back weight rows of the Icelandic method are joined together by a spacing chain, visually forming a single back row of weights. But the chained-together weight rows nonetheless transmit their divided effect up the warp threads, providing tension results similar to completely separate rows. It is possible, then, that the four separate layers of the four-weight-row method are not necessary to achieve this density advantage. With elements of the Icelandic twill-weaving method as a basis, the loom's characteristic two layers, divided but chained together, may confer a similar benefit from separation when weaving a denser twill warp, especially if that weaving is facilitated by the use of double-notched supports as proposed in the current research.

Despite the perceived advantages of the four-weight-row method, it is significant to note that problems with both heddles and shedding have been noted in a recent comprehensive study employing this method (Andersson Strand and Demant 2023). For example, after attempts to stiffen the heddle material with wax, heddles still had a tendency to "curl against the layers of warp which they have to pass through when the shed was changed" (Andersson Strand and Demant 2023, 41). It was also noted that although weaving went "relatively smoothly," finding a proper shed required "practice and attention… [since] each shed had to be worked differently". This resulted from the need to coordinate two heddle systems to create each shed. It was further noted that shed openings, two of which were formed in front of the forward warp layer and two behind, appeared variously below, between and above the rows of heddles, and once identified, in some cases had to be pressed open and up into the weaving area (Andersson Strand and Demant 2023, 41–42). Aside from the "practice and attention" required to use this system, the four-weight-row method appears to suffer from the same problem as that addressed in this research, namely the impact on shedding by heddles held securely at only one end within the inherently mobile warp layers of the warp-weighted loom.

Advantages of the proposed use of double-notched supports

The use of double-notched supports proposed by the current research holds several advantages over the use of those implements in the four-weight-row method. First, the loom setup adheres to the only known practice for weaving twill, enclosing two warp threads per heddle, a system that ensures uniform alignment of warp threads for shed openings. It also uses three pairs of heddle-rod supports rather than two, a practice possibly supported by evidence of wear in three closely set holes on a surviving warp-weighted loom (Hoffmann 1964, 134). Furthermore, the simplicity of the proposed system contrasts markedly with the complexity of the four-weight-row method. In the proposed system, heddle rods are ordered and employed in a logical progression; heddles do not need to be of different lengths to form effective sheds since each shed is controlled by one heddle rod; there is no need to tie weight rows in a sloping orientation to avoid riding up on one other; and all sheds except the natural shed, which is clearly formed behind the shed rod, are unambiguously formed above the heddles at the front of the loom.

A recognised limitation of the current study regards the accuracy of materials, which can be a significant factor in attempting to replicate processes and products that were once woven on the warp-weighted loom. This suggests that further experimentation is needed, similar to the study mentioned above, which was designed to meticulously replicate selected archaeological textiles (Andersson Strand and Demant 2023). With notable attention devoted to appropriate fibre selection, yarn spin and weight-row conformation, the 2/2 twill textile produced in that study closely resembled the original artefact. However, the weaving process that utilised the four-weight-row method seems to have been less successful. It is possible that revising the weaving method to the one suggested by the current research would facilitate similar future investigations, advancing the understanding of how twill may have been woven on the warp-weighted loom.

In assessing the two possible uses of double-notched supports under consideration, the more complicated four-weight-row method seems unlikely to have had very wide use. Supporting this suggestion is a comparison between two forms of diamond twills present in the archaeological record: those with symmetrically formed diamonds, often referred to as goose-eye twill, which may be taken to represent the greater flexibility in weave structures that the four-weight-row method makes possible, and those that are asymmetrical, typically referred to as broken diamond twill, in which the points of reversal are staggered (Emery 1966, 98). The broken diamond structure flows naturally from a warp that is divided into two equal parts, which is the basis for the two threads per heddle of the Icelandic method. This heddle-tying order can easily be altered to produce a broken diamond twill by tying two single-warp heddles at the points of reversal without disrupting the system in which single heddle rods open a shed, but it is not suited to tying heddles that enclose three neighbouring warps as required for a symmetrical diamond twill.

After evaluating perceived problems with the Icelandic method for weaving 2/2 twill, and describing how the newly envisioned four-weight-row method was capable of weaving a symmetrical, or regular diamond twill, Haynes remarks on this very issue, seemingly missing the point: "During the very long period over which diamond-patterned cloths were produced, the 'broken' form appears to have been of considerable importance; but evidence of the 'regular' version is extremely rare. The very length of time seems to discount fashion as the reason for this apparently overwhelming preference; although almost certainly related to the technology of the loom employed, the explanation remains obscure."

If the single-warp-per-heddle system of the Haynes method had been widespread, would broken diamond twill have remained the norm for such a "very long period"?

A lack of uniformity in weaving practices?

A Faroese expression, "*Nu er ikki beint a midskaftid*" (now it's not right with the middle shaft), likens problems with the middle heddle rod to disagreements arising between people (Broholm and Hald 1935, 305). This saying has been taken to mean that, "the most difficult shed to get right was the one controlled by the middle rod" (Hoffmann 1964, 150). The jamming and tangling noted in the current research when weaving solely with single-notched supports bears out this analogy. This expression, then, may be taken to indicate two things: first, that twill was warped with two threads per heddle, a practice entirely in keeping with the extensive presence of broken diamond twill in archaeological textiles; and second, that use of solely single-notched supports, with their concomitant heddle problems, was a common practice.

Marta Hoffmann documented different practices among warp-weighted loom weavers in various cultural settings: use of a woven starting border among the Sami in north Norway, use of a weaving sword to beat in the weft in southwest Norway, and weaving from the back of the loom among the Sami in northern Finland, to name a few. Given this lack of uniformity, it is possible that when weaving twill, the solution to slack heddles proposed in this research may have been limited to medieval Trondheim. Or instead, it may indicate that innovations in weaving techniques were slow to spread and/or did not spread evenly. Medieval Trondheim offers one small window into past twill weaving practices, as does the saying from the Faroe Islands. The purpose of this research has been to interpret the possible use of double-notched supports found in Trondheim. How widespread such usage may have been is an open question.

Conclusion

Enclosing two warp threads per heddle is an intriguing aspect of the Icelandic method, allowing each of 2/2 twill's four sheds to be formed easily and evenly, with one heddle rod or the fixed shed rod controlling each. However and whenever this idea arose, it is uniquely suited to weaving this important type of cloth on the warp-weighted loom, and it represents a significant departure from the one thread per heddle method employed in plain weave. This research, based on the premise that such a warp treatment may have been foundational to the 2/2 twill weave structure, focused on what appeared to be an obvious problem when using the heddle-rod supports as they survived in Norway, namely heddle jamming. The resulting method presents a solution that includes several attested aspects of the warp-weighted loom tradition: the use of two threads per heddle for weaving twill, as reported from Iceland; the use of double-notched supports as documented from medieval finds in Trondheim; and the use of single-notched heddle-rod supports based on those in surviving Norwegian weaving traditions. The blending of these factors to devise a method for weaving twill stands in contrast to the basis for the four-weight-row method: a new device envisioned to facilitate a novel approach.

It seems likely that over time a variety of methods were employed to weave twill on the warp-weighted loom, perhaps including all of those described in this article. This was, after all, an important fabric and weavers are endlessly inventive. Those using a loom similar to the one that survived in Norway may well have worked with an imperfect system, clearing heddle jams and occasional tangles while using one, two or three pairs of supports, until a solution such as the double-notched supports presented itself. It is possible that some weavers experimented with loom refinements that allowed more flexibility in what fabrics could be woven, and if so, they may have come upon the idea of using double-notched supports in a four-weight-row system, just as Haynes did. But given the problems inherent with that system, such a method was probably never widespread.

Without a living tradition to provide evidence, the manner in which twill was woven on the warp-weighted loom remains open to conjecture. However, if double-notched supports were a part of that method, the use suggested by the current research seems the most likely.

Acknowledgements

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Chiara Spinazzi-Lucchesi and Elsa Yvanez

The *Pharaonic Textiles* database: a new tool for recording archaeological textiles from Egypt

Introduction

The study of Pharaonic Egypt has long been distinguished by the exceptional preservation of organic remains, especially well represented in burial archaeology. Textiles are particularly plentiful in the context of mummification, which saw the use of numerous fabrics for wrapping dead bodies. From the beginning of scholarly explorations in Egypt, textiles have therefore been the constant companions of archaeologists, conservators, and art collectors. Despite the quantity of material available, which is in some cases preserved to an astonishing degree, this treasure trove of information has long remained inaccessible in global textile research. However, recent efforts have seen the growth of research projects and field studies which are producing increasing quantities of data on ancient Egyptian textile production. However, these different bodies of data remain fragmented according to sites, time periods, and/or researchers.

Inspired by the recent systemisation of textile analysis methods, the project reported here intended to create an easy-to-use tool for the recording of Pharaonic textiles, which would be open to any interested party working on this type of material. The objective was to unify the data entry system under a common workflow and terminology so that systematic data with opportunities for comparisons and collaborations could be offered. The *Pharaonic Textiles* database was conceived to be as holistic and exhaustive as possible by documenting technical characteristics (such as the manufacture of the fabric) as well as different aspects relating to the original function and reuse. In addition, the project planned to produce a tool that could be easily adapted by the users and could function in different settings – from a single-object study in a museum to vast quantities of items to be registered in the field.

The relational database was developed at the Centre for Textile Research (University of Copenhagen) from 2021, as part the *EgYarn* project (MSCA grant agreement 890144, Spinazzi-Lucchesi 2021), which investigated textile production and consumption in Egypt during the New Kingdom. The structure was built by Chiara Spinazzi-Lucchesi and Elsa Yvanez, and designed by Obaida Hanteer of the University of Copenhagen's DataLab, using the Base software of LibreOffice. This software was selected for its flexibility, its resemblance to many other well-known database systems, and its compatibility with open access standards. It was tested in subsequent years in both field and museum contexts by recording Egyptian textiles dated to the Middle Kingdom, New Kingdom, and first half of the first millennium BCE (2000–500 BCE), during eight field seasons and one museum project. Depending on access to electricity and other logistical issues, the textiles were recorded directly in the database or on a paper recording form and later entered in the database during the post-excavation phase.

Installing and using the database

The database files are available for download at the following URL: 10.5281/zenodo.17542485. Download and save the entire folder on a computer. Moving or renaming individual files may break the internal links between tables, so it is important to move the entire folder as a unit if relocation is necessary. Once downloaded, the database is opened directly in LibreOffice©, freely available to download online (see www.libreoffice.org).

Some users may experience difficulties with macros

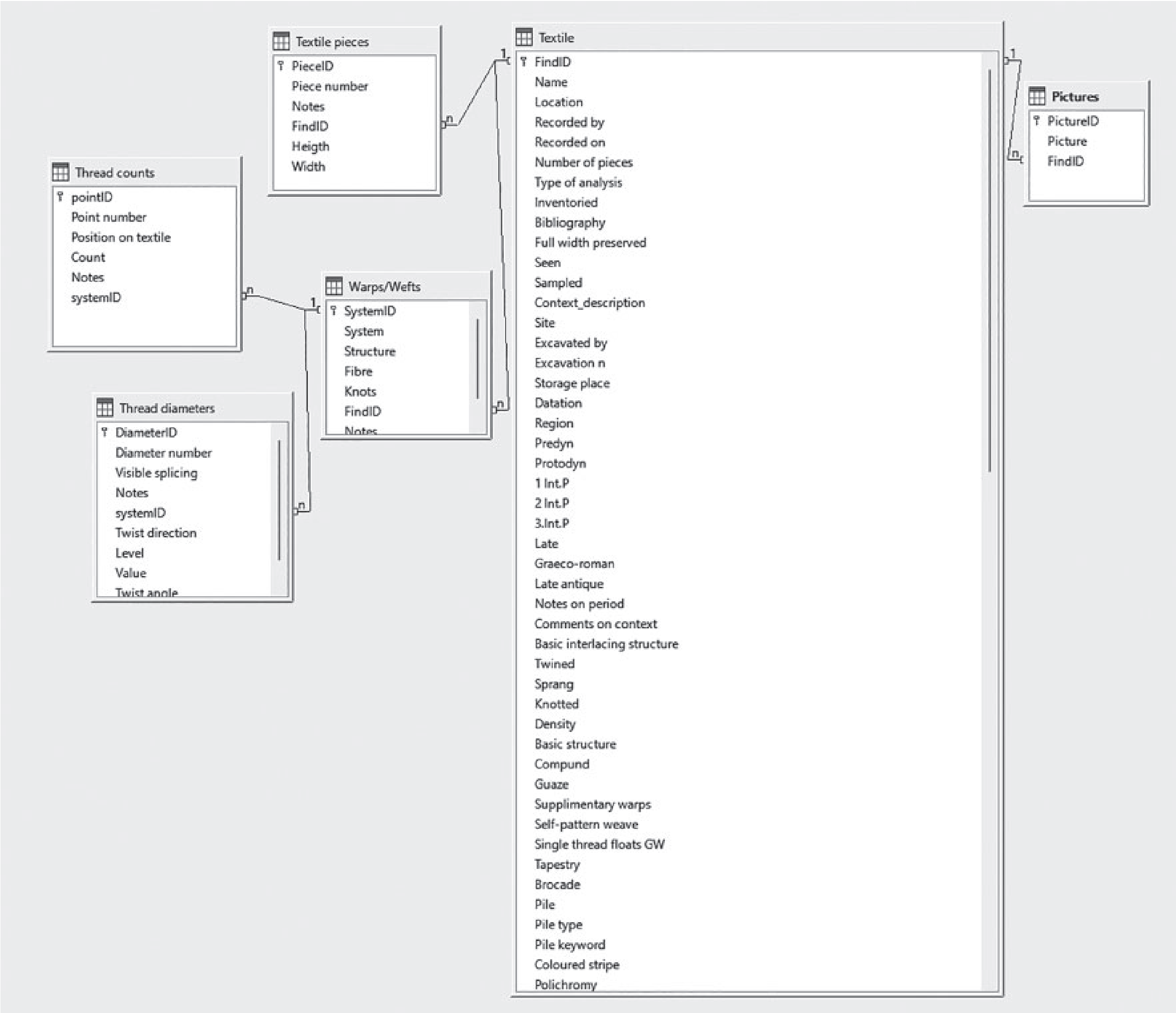

Fig. 1: Entity relationship diagram (ERD) of the *Pharaonic Textiles* database showing how the different entities are structured and related to each other (Image: Chiara Spinazzi-Lucchesi)

when first opening the database, depending on their local security settings or software version. Since the database uses a small number of macros to automate navigation and data-entry functions, it is important to enable macros on opening it. If the programme blocks them by default, users should follow the software's security prompts to allow trusted content, or adjust the settings to permit macros from reliable sources.

Structure of the database
The database rests on six distinct but related tables, linked through the object unique identifying number (fig. 1). For ease of use, the information from these different tables is assembled into a form (fig. 2) which is divided into three main areas: one dedicated to the basic information about the textile artefact (number, provenance, measurements, description); one to its woven or non-woven structure and decoration; and one to recording the warp and weft features.

Basic information and context of the textile
This section constitutes the core of the database, where each textile or textile-related object is first entered. It includes fields for the object name or identifier, as well as metadata concerning authorship and date of data entry, allowing users to trace who created or last modified each record. Additional tick boxes enable users to indicate which types of study have been carried out on the textile:

- Bibliographic study – whether the object has been published or discussed in secondary literature;
- Direct examination – whether the textile has been

personally inspected or analysed by a researcher;

- Sampling – whether physical samples have been taken for fibre, dye, or other forms of laboratory analysis.

These indicators provide a quick overview of the available documentation and the research status of each object, helping users to identify which materials have been examined in detail and which remain to be studied further.

Textile pieces

This section contains detailed information about the individual textile fragments or, when applicable, sets of related fragments that form part of a single object record. Each entry includes measurements (such as length, width, and thickness), as well as a descriptive field for recording observable characteristics such as weave structure, thread count, colour, and condition of preservation. A bibliographic field links each textile piece to relevant publications, excavation reports or catalogues in which it has been previously described or illustrated. This ensures that every record can be traced back to its documented sources, facilitating cross-referencing and scholarly verification.

Weave

The weave section (fig. 3) records the fundamental structural characteristics of each textile. A drop-down menu allows users to select the basic interlacing structure, distinguishing between woven and non-woven techniques such as sprang or knotted fabrics. Within the woven category, a further drop-down menu specifies the basic weave type, including tabby and its known variations, which are especially relevant for Pharaonic textiles. As mentioned in the introduction, the database has been designed with flexibility in mind and can be easily adapted to other cultural or chronological contexts. Additional tick boxes provide information on more specific structural features such as twining, single thread floating, and pile weave (with a dedicated section for detailed description). Together, these options allow users to capture both the standard

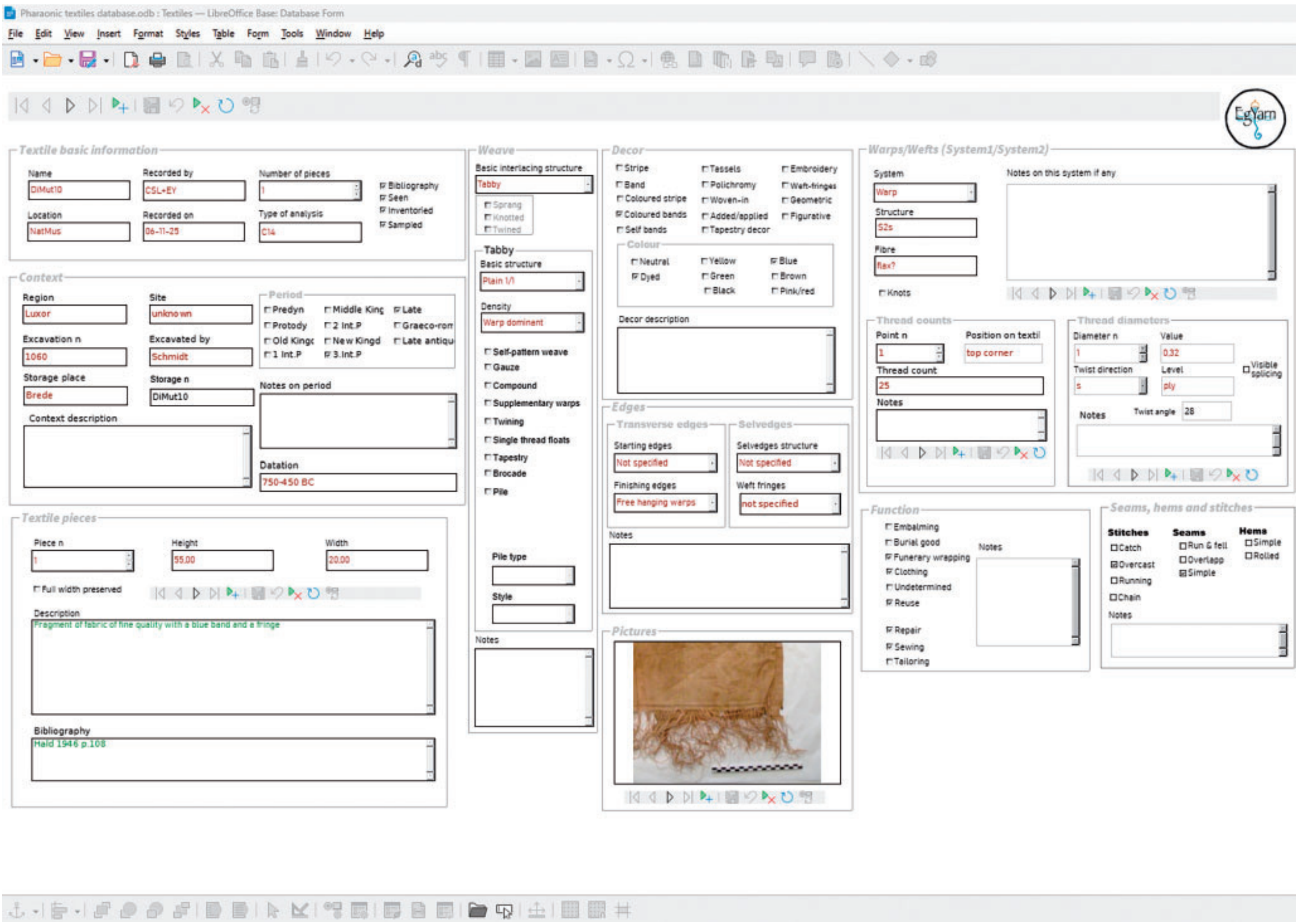

Fig. 2: View of the database in the "form" mode, offering an easy overview of each record (Image: Chiara Spinazzi-Lucchesi)

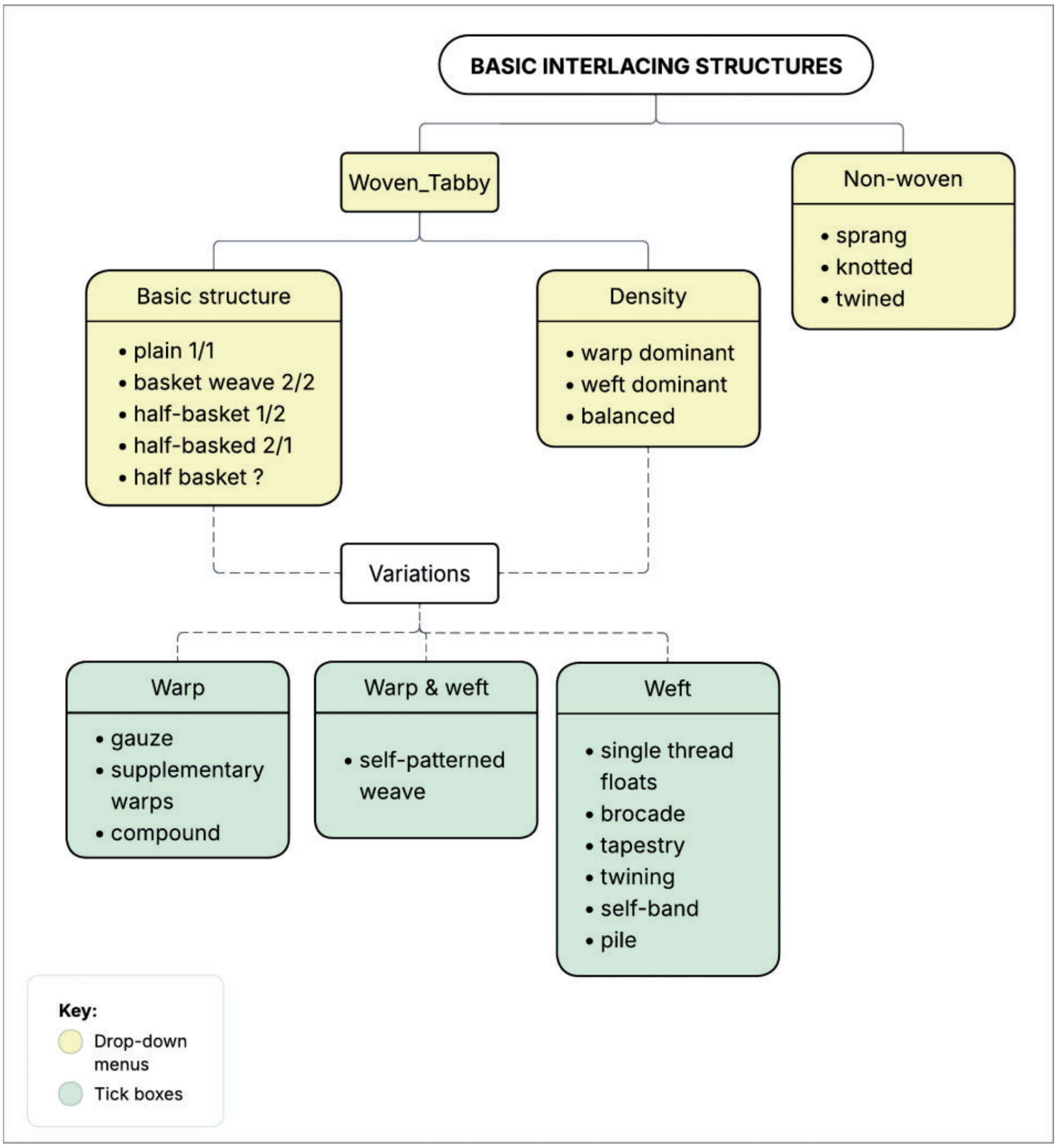

Fig. 3: The categories and terminology used in the weave section (Image: Elsa Yvanez)

and exceptional aspects of textile construction in a systematic and comparable way.

Decor

The decor section records the decorative features of each textile, whether woven or non-woven. A series of tick boxes allows users to indicate the type of decoration present, for example, patterning achieved through colour variation, weave structure, embroidery, applied elements, or other techniques. An accompanying open description field provides space for a more detailed account of the decorative motifs, their placement, and any notable stylistic or technical aspects.

Edges

The edges section (fig. 4) documents the different types of finishing elements present along the borders of a textile. Two main categories are distinguished: the transverse edges (starting and finishing borders) and the selvedges, with or without weft fringes. Each category is accompanied by a drop-down menu offering a set of subtypes, allowing users to record the specific form of edge treatment observed. The terminology follows that used by Gillian Vogelsang-Eastwood as presented in her publications on Amarna textiles (Kemp and Vogelsang-Eastwood 2001) and that developed by Ingrid Bergman in her study of Late Antique Nubian textiles (Bergman 1975). This

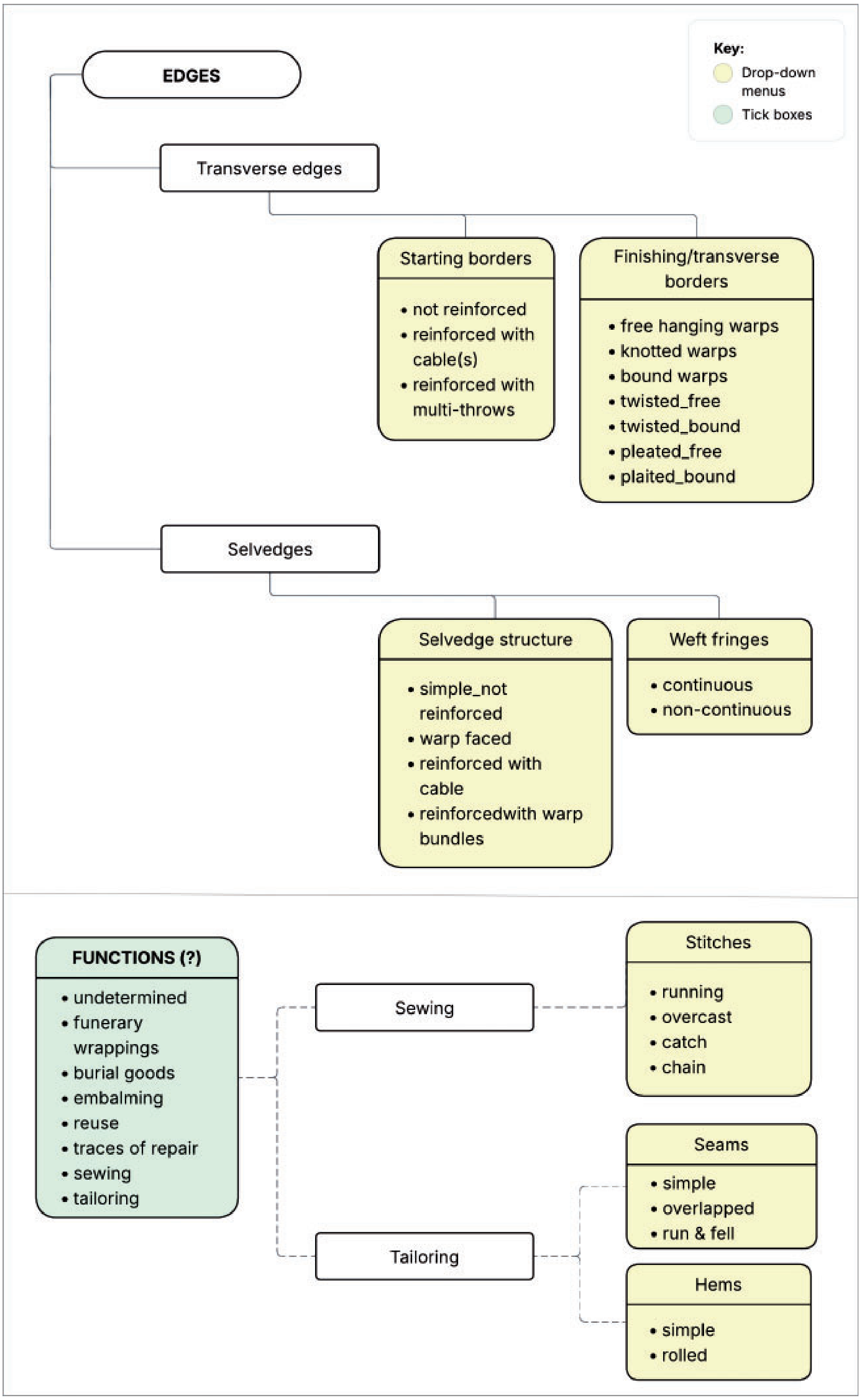

Fig. 4: The categories and terminology used in the edges and function, repairs, and sewing sections (Image: Elsa Yvanez)

vocabulary reflects the specific archaeological and cultural contexts in which the original research was conducted. Currently, the database terminology has been kept minimal and pragmatic, acknowledging both the need for consistency and the limitations imposed by the available material. In particular, the classification of weft fringes remains provisional: a more detailed and structured typology will need to be developed in future work, ideally in dialogue with more experts to include a broader comparative corpus of Egyptian textiles.

Pictures

The pictures section contains photographic documentation of the textiles and related objects. Images are stored directly in the database, ensuring that each visual record remains linked to its corresponding entry. To ensure the database remains lightweight and functional across different systems, low-resolution images are recommended. These photographs are intended primarily for reference and visual identification, allowing users to confirm object attributes, weave structures, or decorative details at a glance.

Warps and wefts

The warps and wefts section is more complex than the other parts of the database, as it was originally developed for a project focusing primarily on spinning and thread technology. Its structure allows the recording of a large variety of detailed quantitative data, enabling statistical analysis of yarn and fabric characteristics.

When recording this information, the first step is to select whether the record refers to a warp, a weft, or an unknown system (system 1 or system 2). Once this is defined, users can proceed to enter information about the fibre type (if known) and the general yarn structure, such as whether it consists of a single thread, a plied, or a cabled yarn.

Subsequent fields are dedicated to numerical data, beginning with thread counts per centimetre. The database can store up to one hundred measurements per record, each with fields for the position on the textile, the number counted, and any relevant notes.

A similar structure applies to the recording of yarn diameters: for each measurement point, users can enter the sample number, the exact value, the direction of twist, the yarn level (indicating whether it concerns a single or plied thread), and the twist angle. Additional note fields allow for the inclusion of contextual observations.

When switching from warp to weft measurements (or vice versa), it is essential to create a new record (or tab) within the upper panel and to select the corresponding system again. This ensures that the values are correctly stored and associated with the proper dataset. This structure reflects the logic of a relational database, in which each system—warp and weft—is treated as a distinct but interconnected entity.

Function, repairs, and sewing elements

The final area of the form concerns the function(s) and use of the textile. A series of tick boxes allows users to indicate whether the textile was intended for embalming, burial goods, clothing, reused, or if its function remains undetermined. Closely related to this are additional tick boxes for recording evidence of repair, sewing or tailoring. These simple indicators make it possible to identify modifications, reuse, or maintenance practices affecting the life cycle of a textile.

A separate area, again employing tick boxes, is dedicated to the documentation of stitches, seams, and hems, accompanied by a notes field for further description. Together, these elements provide a concise yet flexible framework for recording the technical and functional aspects of textile construction and reuse.

Relational structure

The relational structure of the database is intentionally simple and intuitive. Most information is connected directly to the main table, “Textile”, which serves as the central node of the system. Separate tables are used in cases where multiple entries may correspond to a single textile record, allowing for more flexible and accurate data management.

These include:

- The “Textile pieces” table, which accommodates cases with multiple fragments;
- The “Pictures table”, which links one or more images to each object; and
- The “Warps and wefts” table, which is further connected to its own sub-tables for “Thread count” and “Thread diameter”.

This relational structure ensures both data consistency and scalability, enabling complex datasets to be queried without redundancy.

Information can be retrieved through the query functions built into the database software. Users can perform searches using any field, such as site, context, material, weave type, or function or combine several criteria to refine their results. For more advanced analysis, data can be exported as spreadsheets or CSV files, allowing integration with external statistical or visualisation tools. Results from different tables can be joined based on their shared identifiers (for example, linking textile fragments, images, and thread measurements to a single object record).

In summary, the database permits detailed recording of all archaeological information about each textile and all technical and decorative characteristics of the fabric, including basic structure, yarn manufacture, fibres, colours, patterns, seams, etc. Queries can be generated at each information level and immediate sorting and data extraction is possible thereby producing quantitative analyses of any element of interest, such as the thread count per centimetre.

Conclusion

The *Pharaonic Textiles* database was developed for archaeological textiles from the Nile valley. It demonstrates the project team's commitment to transparent, reproducible, and cumulative research. While its structure reflects the specific requirements of textile studies in ancient Egypt, its underlying logic and relational design can be readily adapted to other archaeological or material culture datasets. The database is conceived as an evolving platform, which will continue to grow as new data, typologies, and analytical approaches are introduced. By making it openly accessible and modifiable, the development team aims to foster collaboration and dialogue within the scholarly community, encourage users to build, refine, and expand it to address new research questions and comparative perspectives.

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Francisco B. Gomes, Catarina Costeira, Ricardo Basso Rial, Nelson Almeida, Cleia Detry, Linda Melo, Eduardo Porfírio, Sérgio Gomes and Carina Nunes

The *TransTexTec Project*: exploring transitions in textile technologies and economies in southern Portugal (2200–700 BCE)

Introduction

Research on early textile production in southern Portugal remains underdeveloped; recent work has nonetheless demonstrated that, despite the scarcity of textile finds (Soares et al. 2018), it is possible to explore the dynamics of textile production in this region, as well as its technological and logistic features, and its socioeconomic and symbolic significance. This, however, requires an integrated, interdisciplinary, and creative approach to multiple strands of evidence, covering different stages of the textile *chaîne opératoire*. Work along these lines has led to notable progress in the study of textile production in the southern Portuguese Chalcolithic (Costeira 2024a; 2024b) and Iron Age (Gomes and Dias 2024). The same cannot be said for the Bronze Age (BA), a period which, in this regard, remains severely underexplored. This knowledge gap raises significant concerns, for three interconnected reasons:

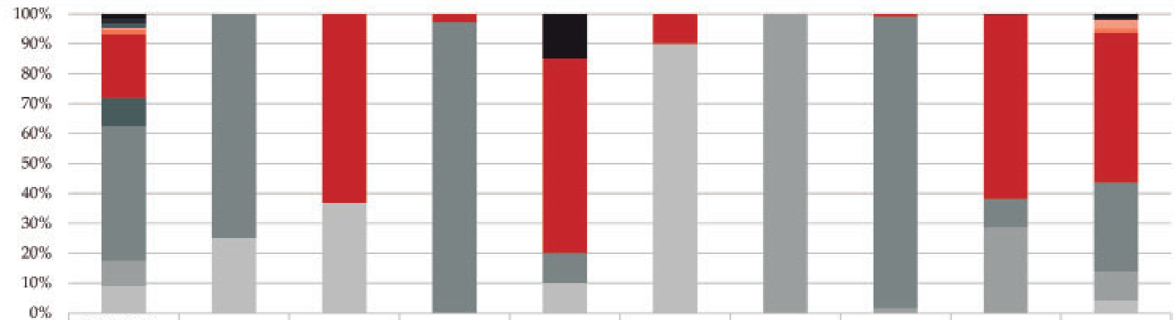
1) It limits the understanding of the diachronic development of textile crafts, as there are notable discontinuities between the pre- and protohistoric periods which cannot be understood without characterising the developments of the BA.

2) It hinders the assessment of the full reach and ramifications of the "textile revolution" which took place during the second millennium BCE in other areas, including neighbouring Spain (Basso Rial et al. 2021; 2022; 2023).

3) It may be obscuring a major economic feature of the development of regional BA societies and a potential factor of sociopolitical change during this period.

Lately, however, there has been an increase in research concerning the regional BA. Recent data has shed new light on the settlement patterns and funerary practices of this period (Mataloto 2013; Soares 2013; Soares et al. 2021), but also on some of the economic underpinnings of the sociopolitical models attested throughout this period. This being said, the role of craft activities (except for metallurgy) in the development of regional BA communities remains underexplored. Textile production, which has been recognised as a key economic activity at this time elsewhere in Iberia (Basso Rial et al. 2021; 2022; 2023) and beyond (Sabatini and Bergerbrant 2019), is a case

Fig. 1: Logo of the TransTexTec exploratory project (Image: Francisco B. Gomes)



	Perdigões - Ditch 7, Phase 3	Outeiro Alto 2	Montinhos 6	Alto de Brinches 3	Torre Velha 12	Torre Velha 3	Belmeque	Horta do Jacinto	Castro dos Ratinhos	Outeiro do Circo
	EBA	MBA							LBA	
Canis sp.	3	0	0	0	3	0	0	0	1	5
Equus sp.	3	0	0	0	0	0	0	0	0	2
Equus cf. Caballus	3	0	0	0	0	0	0	0	0	0
cf. Capra hircus	1	0	0	0	0	0	0	0	0	10
Ovis aries	3	0	0	0	0	0	0	0	0	5
Ovis/ Capra	40	0	24	3	13	1	0	1	601	171
Sus domesticus	18	0	0	0	0	0	0	0	0	0
Sus sp.	85	6	0	106	2	0	0	115	91	102
Bos taurus	16	0	0	0	0	0	2	2	279	33
Bos sp.	17	2	14	0	2	9	0	0	0	14

Fig. 2: Percentage of different mammal species in southern Portuguese BA faunal assemblages, with caprines highlighted (for data sources see references in the text)

in point, as data regarding this craft during the BA remains elusive.

While some scarce textile remains have been reported for the Middle Bronze Age (Soares et al. 2018), discussions regarding the textile tools of this period have only recently begun (Basso Rial and Costeira in press). Preliminary data on loom weights in particular suggest a replacement of regional Chalcolithic types by new, cylindrical weights (Basso Rial and Costeira 2025). A similar process is well documented in southeastern Iberia (Basso Rial et al. 2022; 2023) and has been related to a broader technological and economic transition spurred by the introduction of wool (Basso Rial et al. 2023). This is consistent with a body of evidence from Europe and the Mediterranean, which outlines a veritable BA "textile revolution" related to the generalisation of wool textiles, with all its socioeconomic ramifications (Breniquet and Michel 2014; Sabatini and Bergerbrant 2019; Sabatini et al. 2019; Schier and Pollock 2020).

Zooarchaeological studies, which may shed further light on the role of wool production during the regional EBA and MBA, are scarce and mostly limited to small assemblages accompanying funerary contexts, suggesting a growing significance of caprines (Costa et al. 2019; 2023), while non-funerary samples are generally sparse (Costa and Cabaço 2012; Costa and Baptista 2014; Delicado et al. 2017; Senra et al. 2019; Costa et al. 2019; 2023; Costa 2013; 2021), with some exceptions (Almeida and Valera 2021). Nevertheless, existing data suggests a significant increase in the importance of sheep/goats, at least in some faunal assemblages (Costa 2013; 2021). New work is required to understand what role the demand for wool plays in this process, and in the development of sheep herding throughout the BA.

Further insights into textile crafts can be glimpsed from bioanthropological data. Dental marks interpreted as the result of the use of teeth as a "third hand" in textile processes have been documented in MBA funerary contexts (Fidalgo et al. 2019; Willman et al. 2021), opening a window into the identity and status of textile craftspeople.

For the Late Bronze Age, the available evidence is even scarcer, as only a few textile tools, namely loom weights, have been published so far (Mataloto 2013). Zooarchaeological studies remain very limited in number too, even if the continuity of a shift towards a prevalence of caprines persists in the LBA at Castro dos Ratinhos and Outeiro do Circo (Liesau and García 2010; Almeida et al. 2023). Other indicators, however, suggest an important socioeconomic role for textiles and an increased investment in dress as an identity and status marker. The appearance of

Fig. 3: 3D Scan of a Middle Bronze Age cylindrical loom weight from Montinhos 6 (Serpa) (Model: Carina Nunes)

the earliest bronze fibulae (Gomes in press) and the presence of pottery decorated with geometric motifs possibly reproducing textile patterns (Cáceres 1997) suggest that textiles became an important social and ideological commodity at this time.
It seemed therefore that there were enough indications of a significant shift in textile production during the BA to warrant a more in-depth exploration, mobilising as much information as possible to understand the development of the textile craft in southern Portugal during this period and assess its impact on local communities. To do so, an 18-month exploratory project was set up, with the title *TransTexTec, Exploring transitions in textile technologies and economies in the long second millennium BCE (2200 – 700 BCE): the southern Portuguese territory as a case study* (fig. 1). This project is funded by the Portuguese Foundation for Science and Technology and hosted by UNIARQ, the Centre for Archaeology of the University of Lisbon, and the School of Arts and Humanities of the University of Lisbon.

The *TransTexTec* exploratory project: goals, methods, and tasks

To fill in the current gap in knowledge, the *TransTexTec* project will deploy an interdisciplinary, multi-proxy approach to assess the role and significance of textile production in the political economies of the southern Portuguese BA. Its core goals are to shed light on the second millennium BCE as a critical watershed in the development of textile technologies and economies, to foster a better understanding of the socioeconomic structures of the regional BA communities, and to incorporate Portuguese data into pan-European discussions on the nature and scope of the BA "textile revolution".
In order to pursue these goals, the *TransTexTec* project will systematise and expand the existing datasets related to regional textile technologies and economies. Considering the available evidence and taking the textile *chaîne opératoire* as a framework, the project will comprise three major tasks, focusing respectively on textile resources, textile production, and the sociopolitical and symbolic significance of textiles.
The first task will explore potential shifts in patterns of textile fibre procurement. A major research question is whether the production of wool became a significant economic factor in the region during the second millennium. As faunal remains are a vital source to address this question, this task will systematise and expand existing zooarchaeological datasets on sheep herding (fig. 2) and deploy new analytical methods to assess the role of wool production in strategies of herd management.
Existing studies on BA faunal assemblages (see above) suggest an increase in the significance of caprines during this time, especially during the MBA and LBA. However, this data still needs to be finetuned to discuss the potential significance of the production of wool. In particular, a better understanding of the ratio of sheep to goats among caprines is necessary.
For this purpose, and alongside the implementation of morphological and linear biometric analyses, the project will promote a pilot study using Zooarchaeology by Mass Spectrometry (ZooMS) on selected assemblages from different time points within the BA to assess the representativeness of sheep. The results will be cross-referenced with data on the sex composition and culling patterns of herds to gauge the significance of wool as a factor in herd management, and its change over time. Attention will also be paid to potential changes in sheep types as indicated by morphometric data, as these may relate to an intensification in wool production.
A second task, dealing with textile production from a technological and logistical perspective, will focus on the study of textile tools (fig. 3). Currently, textile tool assemblages are reported for 17 regional BA sites (Basso Rial and Costeira 2025). These, however, still need to be further characterised. The project will undertake a systematisation of this data and in-depth studies of selected assemblages from different time points within the BA to establish their typological, metrological, and functional parameters.
Of particular concern will be the understanding of the rhythm and sociocultural context of change in textile

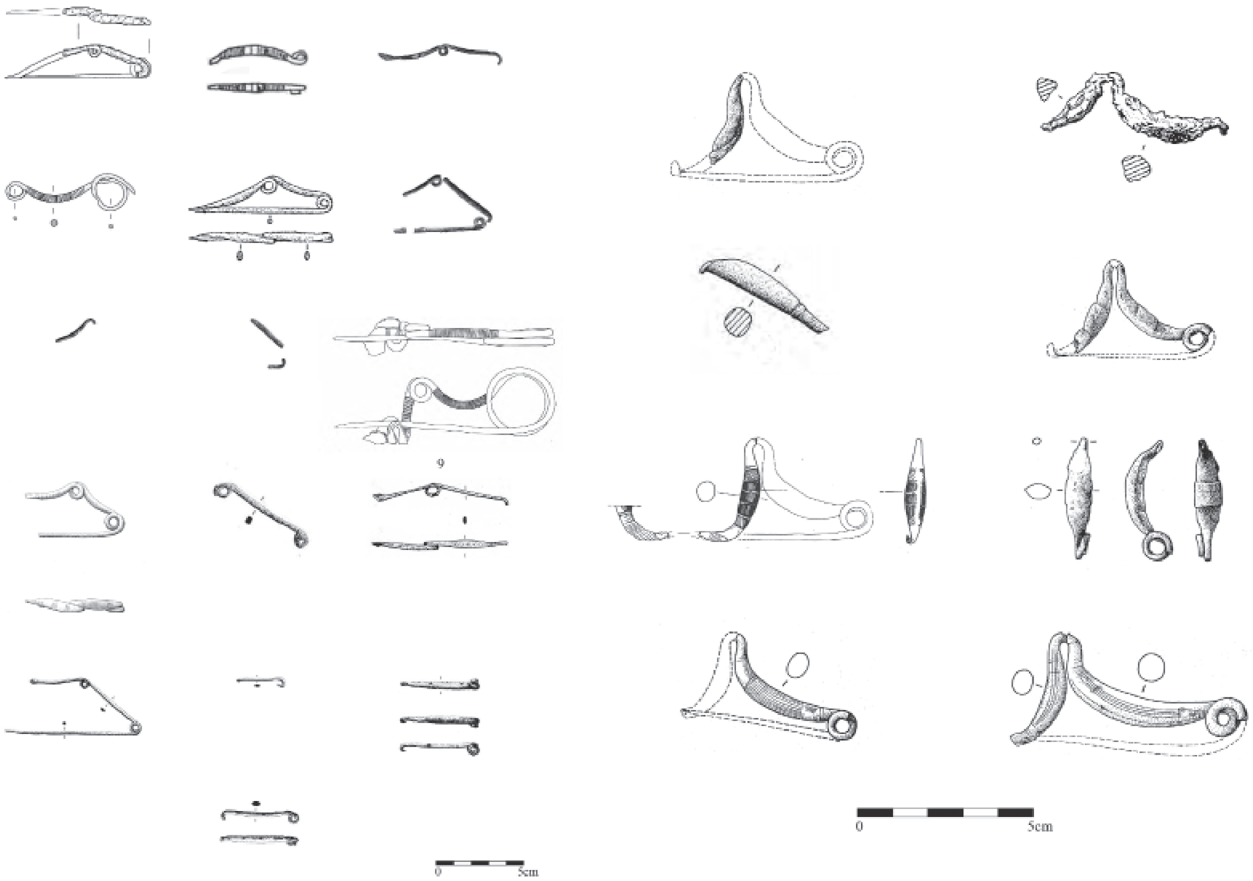


Fig. 4: Main types of Late Bronze Age fibulae from the Portuguese territory (*apud* Gomes in press, with bibliography)

tools, namely through systematic comparisons with better known areas (Basso Rial et al. 2022). Finally, the functional parameters of documented tools will be analysed and experimentally tested following existing guidelines (Andersson Strand and Nosch 2014).

This task will also look into the craftspeople and the social context of textile production. In this regard, data from funerary sites is particularly relevant. The project will integrate bioanthropological data, namely dental marks relating to textile activities (Fidalgo et al. 2019; Willman et al. 2021), with other contextual information to discuss the identity and status of textile producers.

Finally, the third task will focus on secondary sources related to the nature and use of textiles in the southern Portuguese BA. These include dress complements in non-perishable materials, especially fibulae (Gomes in press) (fig. 4). Their introduction is indicative of shifts in dress patterns and practices during the BA, but the project will deploy innovative approaches, including morphometric, statistical, use-wear, and experimental studies to assess their functional parameters and their usability with different textiles/ garments.

On the other hand, this task will also explore the link between the patterns of LBA decorated pottery, namely burnished pottery (Osório 2016), and those of high-end, perhaps imported textiles. Such a link has been hypothesised (Cáceres 1997) but not yet proven. Here it will be experimentally tested by attempting to reproduce the patterns of these decorations using the available textile technology of the period.

Echoes of the "textile revolution": final remarks

By the end of this project, the produced body of data will be fully integrated to create a coherent reconstruction of the technical, economic, and social features of the regional BA textile production, which can then be placed in its diachronic setting.

In addition, it seems crucial to compare the Portuguese data with those available for the BA in other areas, with particular emphasis on southeastern Iberia (Basso Rial et al. 2021; 2022; 2023), an area which offers parallels with southern Portugal (Basso Rial and

Costeira 2025). Ultimately, however, the project aims to highlight changes in regional textile technologies and economies and their links with the broader BA "textile revolution" documented across Europe and the Mediterranean, and to place Portuguese data on the map of international scientific debates and research.

Finally, it is worth highlighting that this project offers a unique opportunity to raise the profile of textile archaeology in Portugal, where it remains underexplored. It also opens the doors to new collaborations and synergies with different stakeholders, such as craftspeople and creatives. The project will also seek to deploy creative storytelling techniques about textile heritage to engage a broader public, raising awareness of the importance of this crucial and highly relatable aspect of cultural heritage.

Acknowledgements

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Antoinette Rast-Eicher

Iron Age asbestos strings found in eastern Switzerland

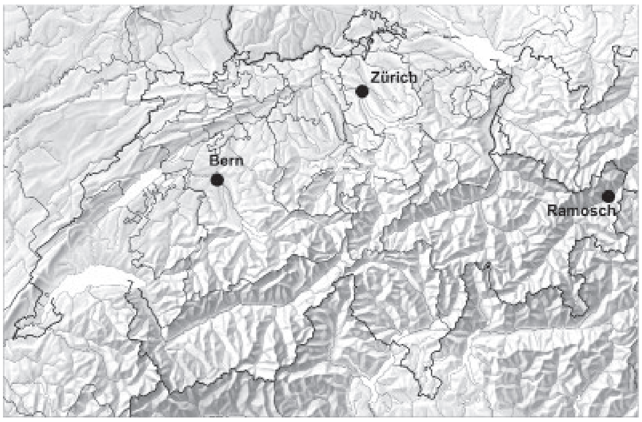

Fig. 1: Map of Switzerland (Image: Antoinette Rast-Eicher)

The first excavations of the site of Ramosch-Mottata in the Lower Engadin in eastern Switzerland were undertaken 70 years ago. In 2024 the site was published in its entirety. It is an important site in the valley, containing five phases dated to the Bronze- and Iron Age (16th century BCE to the fourth century BCE; fig. 1).

Strings were documented on five ceramic fragments. The ceramics are dated to the Early Iron Age and belong to the Laugen-Melaun culture, which is found in the Alps, in Tirol (Austria), Trentino (Italy) and in the Engadin (Switzerland) from around 1350 BCE to the sixth century BCE. These strings were analysed in 2023 (fig. 2).

The strings are all S-plied and have a diameter of 2–3 millimetres and were fixed in holes in the rims of cooking pots. Two samples were taken to the SEM, and the result was quite astonishing: the fibres showed a smooth surface, and very fine fibrous parts were peeling off this surface (fig. 3). It looked like asbestos. But as the result was quite special, and sinew not 100% excluded, and as such organic remains seemed quite improbable in this site, we decided to check the result with FTIR (Fourier Transform Infrared Spectroscopy). This analysis was carried out by Erwin Hildbrand of the Swiss National Museum. The FTIR spectroscopy showed the same curve for the samples of Ramosch-Mottata as a sample of chrysotile asbestos.

The village of Ramosch is situated close to an asbestos source in the Val S-charl, the so-called “window of the Engadin“, meaning that very low geological layers appear on the surface in this zone. Asbestos is linked to the green stone serpentinite. Contrary to the short needle-like grunerite and riebeckite asbestos, chrysotile asbestos builds fine and long fibres of 1–15 cm and is therefore spinnable. This fibre has

Fig. 2: Fragments of ceramic with strings (Image: Archäologischer Dienst Graubünden)

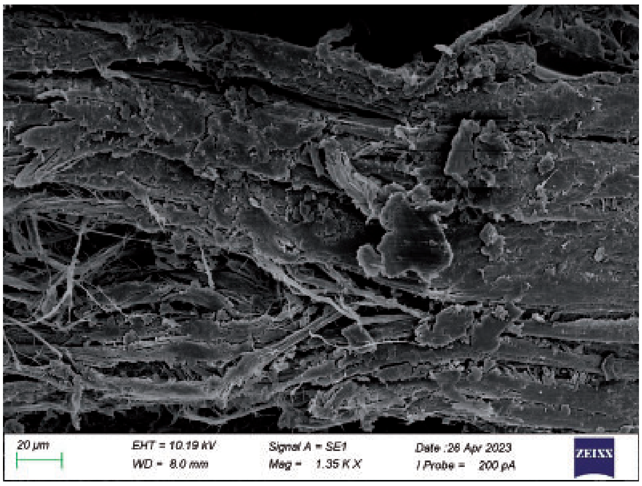

Fig. 3: SEM picture of a sample of Ramosch-Mottata (Image: Antoinette Rast-Eicher)

been known by many people around the world who have used it for several purposes since prehistoric times (Cameron 2000). According to the Greek writer Plutarch, the Greeks used asbestos for towels, nets, and women's head-coverings (Plutarch, *De defectu oraculorum*, 43). The Roman author Pliny the Elder records the use of this fibre for woven shrouds as "they don't burn and become white" (Pliny, *Natural History* XIX, 4). In Neolithic and Bronze Age Scandinavia, unspun asbestos fibres were added to ceramics to stabilise the paste/clay (Gerasimov et al. 2019; Kulkova et al. 2022; Børslid Hop 2016).

The strings found in Ramosch are the first proved processed asbestos fibres found in prehistoric central and western Europe. The strings were ideal for cooking pots, as these handles did not burn.

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Julia Katarina Fileš Kramberger, Margarita Gleba, Karina Grömer and Hrvoje Potrebica

Textile research in the Croatian Science Foundation's project *Creating European Identities*

Introduction
As part of the project "Creating European Identities – Food, Textiles, and Metals in the Iron Age between the Alps, Pannonia, and the Balkans" (2020–2024) the topic of textiles was addressed through investigation of textile remains and tools from sites in the territories of Slovenia, Croatia, Bosnia and Herzegovina, and Serbia (fig. 1). The project (CSF IP-2020-02-2371, IronFoodTexMet) was led by Hrvoje Potrebica from the University of Zagreb, Faculty of Humanities and

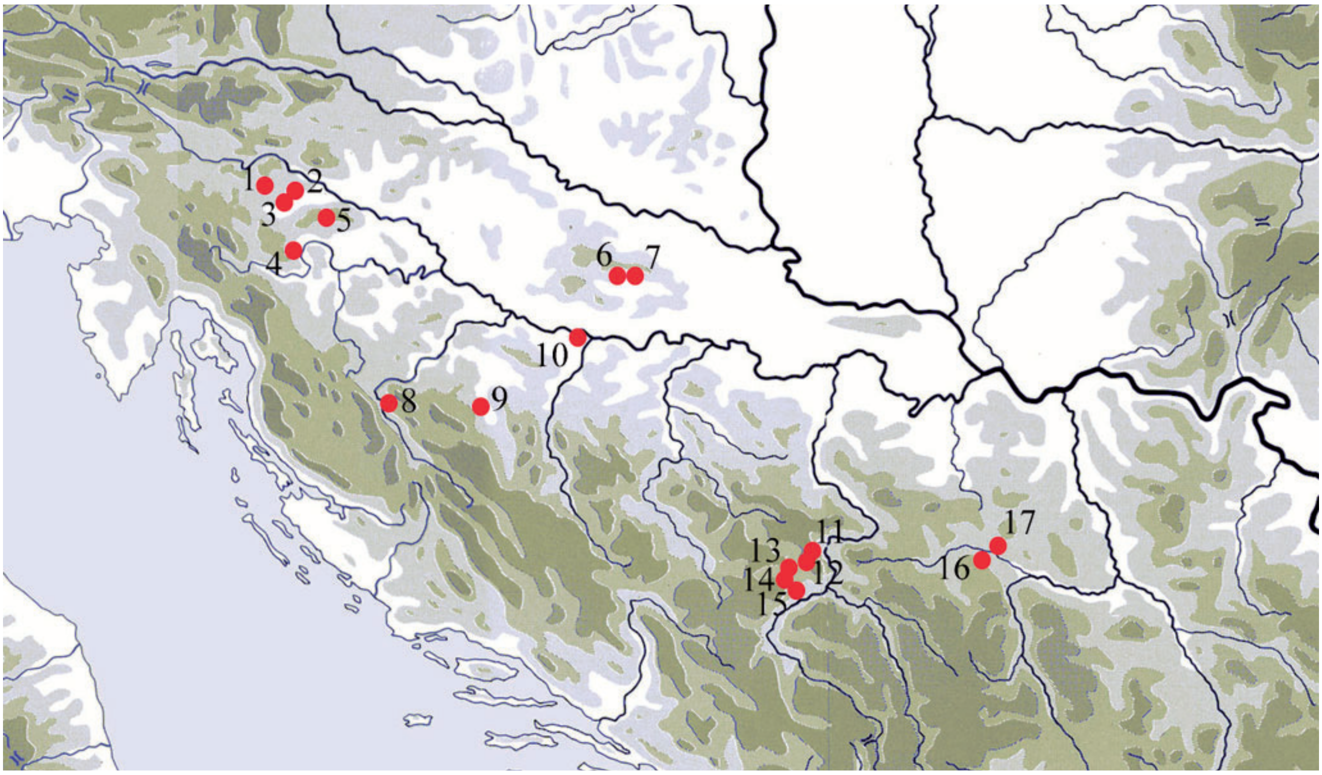

Fig. 1: Map showing the sites from which textile production tools and samples of mineralised textiles analysed in the IronFoodTexMet project originate: 1) Medvedjek, SLO; 2) Ivanec, SLO; 3) Novo Mesto, SLO; 4) Podzemelj, SLO; 5) Budinjak, CRO; 6) Kaptol, CRO; 7) Vetovo, CRO; 8) Ripač, BiH; 9) Sanski Most, BiH; 10) Donja Dolina, BiH; 11) Sjeversko, BiH; 12) Osovo, BiH; 13) Rusanovići, BiH; 14) Kovačev Do, BiH);15) Ilijak, BiH; 16) Atenica, SRB; 17) Mojsinje, SRB (Image: Julia Fileš Kramberger)

Social Sciences, and was funded by the Croatian Science Foundation. The aims of the research were to identify the impact of textiles and textile production on societies and their cultural networks in the first millennium BCE through studies focused on techniques of yarn and fabric production.

Material

Textile production tools

The *chaîne opératoire* of textile production involves a series of steps from the procurement of raw materials to the creation of finished textile products (Andersson Strand 2012; Grömer 2016). Textiles are the result not only of the technical procedures of spinning and weaving but also of social needs that shape the use of resources and the development of technology (Andersson Strand et al. 2010). Production requires specific knowledge, skills, tools, and appropriate spaces to effectively carry out the individual steps. In total, over 3,300 textile-related implements were analysed. Table 1 summarises the number of recorded items from each site.

From Tumulus X at the Kapiteljska njiva site in Novo Mesto, Slovenia, 28 items were examined. From the settlement and necropolis of Kaptol-Gradci, as well as from Tumulus 1 at Vetovo-Kagovac, Croatia, 205 finds were analysed. Most of the corpus comes from Bosnia and Herzegovina, including 2,887 items from Donja Dolina, 91 items from Sanski Most, and 116 items from Ripač.

The most numerous category of finds consists of spindle whorls, followed by loom weights, spools, and smoothers. In Donja Dolina, most of the finds originate from the settlement areas of Gradina and the pile dwellings, with only 5% of the analysed material found in burial contexts at the Greda site. The finds from Ripač come from the settlement area, while those from Sanski Most originate from unknown locations along the Sana River and outside of grave structures.

A

Site	Spindle Whorls	Loom Weights	Spools	Smoothers
Sanski Most	26	35	30	0
Donja Dolina	1,995	569	290	33
Ripač	13	81	22	0
Kaptol	79	121	1	0
Kagovac	4	0	0	0
Novo Mesto	25	3	0	0
Total	**2,142**	**809**	**343**	**33**

B

Site	Location	Grave	Find no.	Object	SEM analysis
Brezje/Glasinac	Tumulus III	Grave 5	13512	iron ring	yes
Gosinja Planina	Tumulus XXXVII	Grave 2	11284	fibula	no
Ilijak	Tumulus TXIII	Grave 2	5676	fibula	yes
Ilijak	Tumulus TXIII	Grave 2	5683	spearhead	yes
Ilijak	Tumulus TXIII	Grave 2	5684	spearhead	yes
Kovačev Do	Tumulus I		3012	fibula	yes
Kovačev Do	Tumulus III	Grave 1	3010	fibula	yes
Kovačev Do	Tumulus III	Grave 1	3010	fibula	yes
Osovo II			11514	fibula	yes
Podilijak	Tumulus B	Grave 1	41667	knife	yes
Podilijak	Tumulus B	Grave 11	41723	knife	yes
Podilijak	Tumulus B	Grave 7	41707	iron fragments	yes
Rusanovići	Tumulus X	Grave 1	11900-11904	whetstone with bronze handle	yes
Rusanovići	Tumulus X	Grave 1	21742	fibula	yes
Rusanovići	Tumulus XXXXIX		7240	fibula	yes
Sanski Most		111/69	12525?	bronze belt	yes
Sanski Most		122	12595	fibula	yes

Table 1: Number of analysed finds related to textile production through the IronFoodTexMet project: A) textile tools; B) mineralised textile remains from sites in Bosnia and Herzegovina

Textiles

Most textiles analysed during the project have been preserved in a mineralised state, primarily in contact with iron, and in some cases with bronze, while only three examples of organic textile remains survived.

A total of 81 finds of mineralised textile fragments were analysed, all originating from burial contexts. In Slovenia, 30 textile finds were analysed from the sites of Novo Mesto, Medvedjek, Ivanec, and Podzemelj. In Croatia, 28 finds of mineralised fabric were analysed from Budinjak, Kaptol, and Vetovo-Kagovac. In Bosnia and Herzegovina, 18 finds were analysed, specifically from the sites of Brezje, Gosina Planina, Kovačev Do, Osovo, Ilijak, Podilijak, Sjeversko, Rusanovići, and Sanski Most. In Serbia, 5 finds were analysed, from the sites of Atenica and Mojsinje. From these finds, a total of 68 samples were taken for fibre analysis using Scanning Electron Microscopy (SEM).

Methodology

The morphological analysis of textile production tools aids in understanding archaeological contexts, as their dimensions, mass, and ratios are key factors in yarn and fabric creation. Finds were catalogued in an Excel table, adapted from the Centre for Textile Research Textile Tools Database (Andersson Strand and Nosch 2015; University of Copenhagen; http://ctr.hum.

Fig. 2: Textile tool finds from the settlement of Donja Dolina (BiH). A and D) textile tools (spindle whorls and spools) from several unknown locations of the pile-dwelling settlement; B and C) textile tool assemblages found in Houses 4 and 1, respectively, at the pile-dwelling settlement (Image: Julia Fileš Kramberger)

ku.dk/). Measurements of relevant morphological parameters were taken with digital calipers or rulers. Additionally, weight, surface treatments, use-wear, and damage were documented.

Textiles underwent technological and fibre characterisation analysis to determine culturally and chronologically relevant fabric characteristics. Technological analysis involved examining weave type, thread count, twist, diameter, angle, and features like edges and patterns, using visual observation and digital microscopy at various magnifications. Fibre analysis aimed to identify the raw material, aiding in understanding processing and thread structure (spinning or splicing). Microscopic (1–10 mm) samples were taken for fibre characterisation, which was carried out using SEM at the McDonald Institute for Archaeological Research at the University of Cambridge and the University of Padua.

Preliminary results and outlook

Over 2900 textile tools From Donja Dolina (BiH) (fig. 2), were analysed as part of a PhD research and included spindle whorls, loom weights, spools, and smoothers—revealing significant variation in form, function, and manufacture (Fileš Kramberger 2024). Clay spindle whorls (2.9–4.9 cm diameter; 1.4–2.8 cm height) are mostly biconical or lenticular, often decorated, and grouped by weight—lighter ones for fine yarn, heavier possibly for thick yarn or as loom weights. Loom weights (3.5–20+ cm; 24–2200+ g) are usually pyramidal or trapezoidal. Clay spools (avg. 6.1 × 4.6 cm, 157 g) may have served as bobbins, yarn holders, or weights (depending on weight). Smoothers (averaging 7 cm, 122 g) with flat bases and handles were likely used for pleating, pressing, or pigment application, although their function remains hypothetical, pending experimental confirmation.

The precise dating of the tools from Donja Dolina is quite challenging due to limited contextual data, though most likely they originate from the period between the seventh and early third century BCE, when Donja Dolina's Gradina hillfort was occupied. The tools from other analysed sites researched within the project show similar characteristics with certain variations, depending on context (settlement or funeral). Further research into these assemblages as well as their inter-site comparison might show certain local stylistic preferences in tool shaping, as well as possible nuances in textile production techniques.

The diversity in the shaping of spindle whorls and loom weights in Croatia and BiH indicates a variety in yarn and fabric production – from very fine wool yarns and dense fabrics to thicker flax threads, plied yarns, and coarser weaves. Spindle whorls in Slovenia are generally conical, while biconical and lenticular shapes prevail in eastern Croatia and Bosnia. Perforations of the spindle whorls are significantly larger in Donja Dolina than at other nearby sites indicating the use of thicker spindles at this site. The use of very large loom weights weighing over 5 kg in Donja Dolina suggests a possible special weaving technique that may have preceded the introduction of a two-beam loom. It is furthermore worth emphasising that, judging by the high density of textile tools across settlements, textile production in the Early Iron Age was not the prerogative of specialised workshops, but rather was carried out in almost every household.

The presence of varied and, in several cases, numerous spindle whorls within graves in Slovenia, Croatia, and Bosnia and Herzegovina (Fiala 1896; Truhelka 1901; Teržan 1990; Dular 2003; Križ 2019; Potrebica

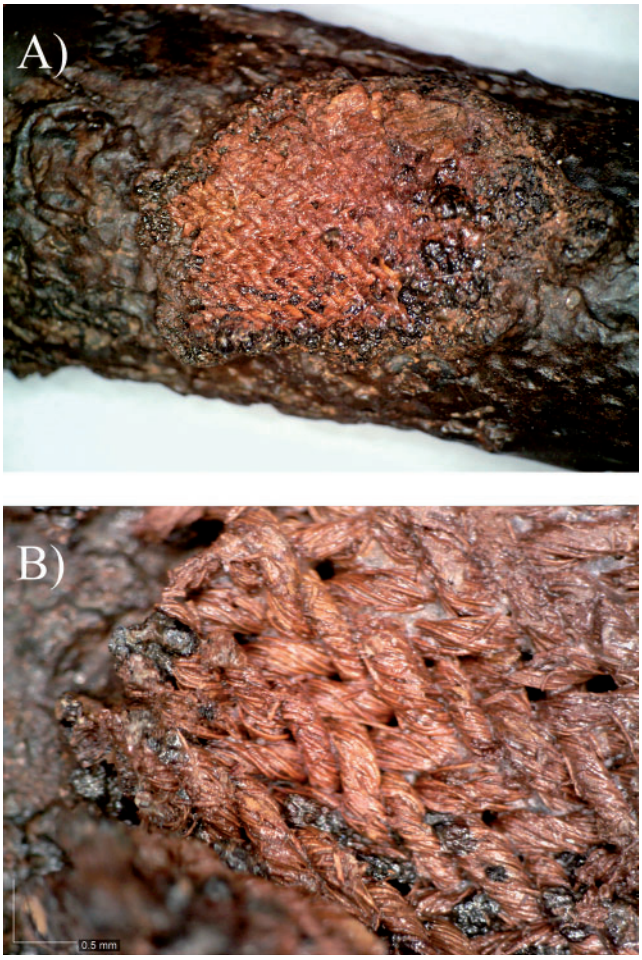

Fig. 3: Mineralised textile remains found on an iron piece of horse-gear from the princely Tumulus 6 at Kaptol, Croatia: A) preserved twill fragment; B) Dino-Lite image at x20 magnification (Images: Julia Fileš Kramberger)

and Fileš Kramberger 2020; Fileš Kramberger 2024) points to a symbolic connection of textile production tools with women in whose graves they are most often found. Possibly, spindle whorls symbolise the deceased woman's gender, but also potentially her occupation, and even her role and status in society (Gleba 2008; Potrebica and Fileš Kramberger 2020; Fileš Kramberger 2024). At Bosnian sites, the quantity of spindle whorls in graves appears to be somewhat more limited, although, in the somewhat later Early Iron Age cemetery in Sanski Most, spools are also found in graves, while they are rare in Donja Dolina.

When it comes to textiles, twill weaves are typical for the Italic and central European textile culture during the Iron Age (Lau 2021; Gleba 2017; Grömer 2016; Grömer et al. 2013). The results of textile analysis carried out through the IronFoodTexMet project confirm this trend for Slovenia and Croatia (fig. 3)

Fig. 4: Hallstatt days festival: A) speakers of the *Iron age textiles: stories from European Crossroads* scientific conference (back left to right: Peter Grömer-Mrazek, Hrvoje Potrebica, Matija Črešnar, Borut Križ; front left to right: K. Rupert, Julia Fileš Kramberger, Karina Grömer, Kayleigh Saunderson, Ronja Lau, Bela Dimova, Margarita Gleba); B) Roman togatus at the *Catwalk to the past* fashion show at Kaptol main square; C) detail from the handweaving workshop (Images: A: Kristina Rupert, B and C: TZ Zlatni Papuk/StiglicPhoto)

(Fileš Kramberger 2022a; Gleba et al. 2024; Gleba in press). Weft-faced tabbies, on the other hand, are typical for the Aegean region and western Asia in the first half of the first millennium BCE, where twills or tablet-woven textiles have not been identified so far (Gleba 2017). The weft-faced tabbies from Atenica and Mojsinje point to connections between the area of present-day Serbia and the south, specifically Greece. The Bosnian region seems to be at the crossroads of these two textile cultures, with the presence of both twills and weft-faced tabbies, although the latter are on average of coarser quality than the fabrics from Italy/central Europe and Greece.

A peculiarity of all recorded wool textiles in Bosnia is the use of plied spun yarn in both systems. So far, the use of plied yarn in both systems, especially in twill, has only been documented in western Europe, and is specifically associated with the western Hallstatt area (southwestern Germany, France, and even further, Spain). In wool weft-faced tabbies, the use of plied yarn is known only in the Aegean region and western Asia. In Bosnia, however, the use of plied yarn appears to be a local tradition not recorded so far in other parts of the region and connected to the quality of raw material. The uniformity of wool fibre quality suggests that all these textiles were made from wool of similar quality, probably of local origin, possibly characterised by a short staple. In the future, additional data should be collected, especially from regions south and west of the investigated zone, to clarify the geographical and chronological extent of this tradition.

Science communication has also been an important part of the research project. In June 2024 (June 13th–16th) the festival "Hallstatt Days" was held in the municipality of Kaptol, Croatia, on the theme "Textiles of the Iron Age". The event was organised by the Kaptol Municipality, Tourist Board Zlatni Papuk, Archaeological Museum of Zagreb, Iron Age Danube Route, Centre for Prehistoric Research and University of Zagreb, Faculty of Humanities and Social Sciences. The three-day festival had a diverse programme including a scientific conference titled "Iron Age Textiles: Stories from European Crossroads" (fig. 4, A), organised as part of the IronFoodTexMet project as well as a public engagement event. The latter included an exhibition by Karina Grömer and Kayleigh Saunderson, titled "Dressing the Past – Hallstatt Period Costume from Austria", accompanied by a public talk on textiles in prehistoric archaeology by Julia Fileš Kramberger. The festival also involved various workshops for the public, among them one on hand-weaving (fig. 4, C), as well as a fashion show organised by Karina Grömer, Julia Fileš Kramberger, and Kayleigh Saunderson at Kaptol's main square. In the fashion show, titled "Catwalk to the past" members of the local community as well as researchers were dressed in costume reconstructions based on textile research from the Neolithic to the Roman period (fig. 4, B).

The IronFoodTexMet project has, for the first time, carried out a systematic collection of archaeological evidence related to the Iron Age textile production in the northern and central Balkans (Gleba et al., forthcoming). The quantity and the quality of the data collected to date allow us to begin filling the lacuna that until recently characterised Iron Age archaeology in the region, which was an important crossroads between the Italic-central European and Greece-Near Eastern textile cultures. Future research will hopefully allow expanding the area of investigation by adding new sites and a focus on the regional and chronological specificities.

Conclusion

The Croatian Science Foundation's project "Creating European Identities – Food, Textiles, and Metals in the Iron Age between the Alps, Pannonia, and the Balkans" concluded in 2024. The aim of the project was to identify formative elements of the identities of Iron Age communities (among them textiles) which occupied a region that played a key role in linking three large European cultural areas: central Europe, Eastern Europe and the Mediterranean. This project gathered the first systematic collection of archaeological evidence related to Iron Age textile production in the northern and central Balkans.

Acknowledgements

The project *Creation of European Identities – Food, Textiles and Metals in the Iron Age Between Alps, Pannonia and Balkans (IronFoodTexMet)* was funded by the Croatian Research Fund CSF (project IP-2020-02-2371). Project lead: Hrvoje Potrebica, University of Zagreb, Faculty of Humanities and Social Sciences, Department of Archaeology. Project partners: Luka Drahotusky-Bruketa (University of Zagreb, Faculty of Humanities and Social Sciences), Julia Katarina Fileš Kramberger (University of Zagreb, Faculty of Humanities and Social Sciences), Renata Šoštarić (University of Zagreb, Faculty of Science), Laura Šejić (University of Zagreb, Faculty of Humanities and Social Sciences), Damir Doračić (Archaeological Museum in Zagreb), Mathias Mehofer (University of Vienna), Karina Grömer (Natural History Museum, Vienna), Margarita Gleba (University of Padua), Borut Križ (Dolenjska Museum in Novo Mesto), Petra Stipančić (Dolenjska Museum in

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Francesca Coletti

The A3TEX research centre: archaeology and archaeometry of ancient textiles at the Sapienza University of Rome

Introduction

From prehistoric basketry to Roman imperial garments, textiles reflect technological advancements, economic systems, social hierarchies, gender, identity, and religious and spiritual values. Their exceptional mobility, fragility, and technical complexity make them both challenging and extraordinarily revealing for researchers. Recognising this remarkable complexity, the *Sapienza Research Centre A3TEX – Archaeology & Archaeometry of Ancient Textile* was officially established in 2023 as an interdepartmental research hub dedicated to the study, conservation, and enhancement of textile heritage.

The origins of A3TEX date back to 2016, when a network of scholars from different research fields began collaborating to address the unique challenges posed by ancient and historic textiles. The official establishment of the centre marked a new phase in this collaboration, bringing together six key departments of Sapienza University – Antiquities, Biology, Chemistry, Physics, Modern Literatures and Cultures, and SARAS (History, Anthropology, Religions, Art, Performing Arts) – in a shared effort to build a comprehensive platform for textile research. The centre is administratively based at the Department of Antiquities and operates as a multi-institutional infrastructure that reflects Sapienza's growing leadership in cultural heritage science.

A3TEX brings together archaeology, anthropology, materials science, conservation science, and digital technology to investigate the multifaceted role of textiles in ancient societies.

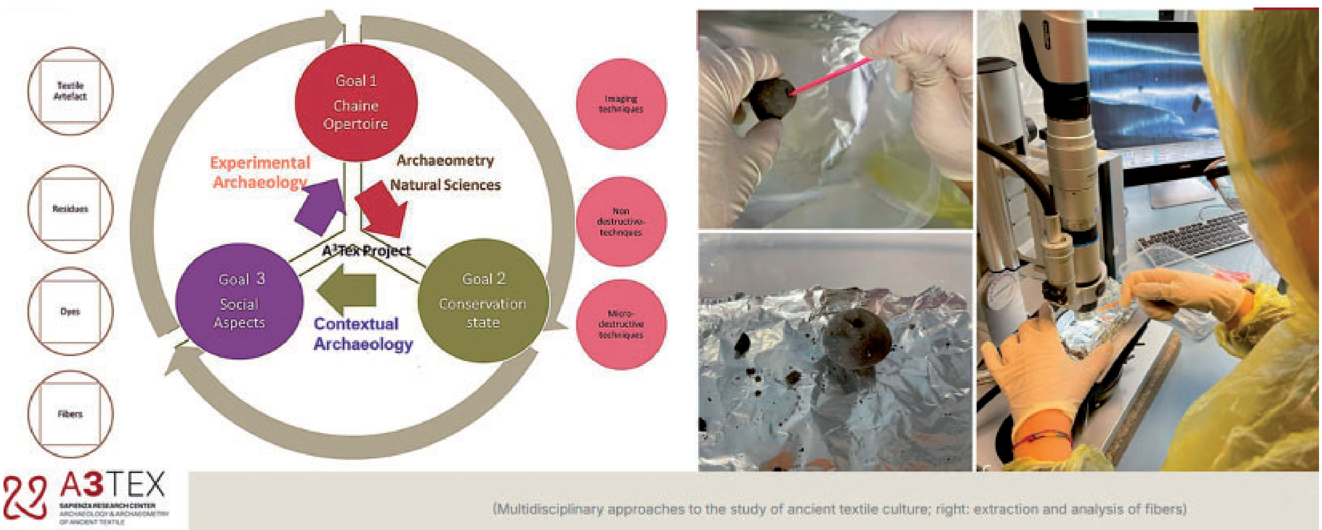

Fig. 1: Activities of the A3TEX research centre (Image: Francesca Coletti)

Fig. 2: Digitisation of carbonised textiles (Image: Francesca Coletti)

Agenda of the A3TEXresearch centre

A3TEX explores a wide range of aspects related to ancient textiles, including their material composition, production techniques, socio-economic context, and conservation strategies. A central focus lies in the study of ancient textile manufacturing, with particular attention to the entire *chaîne opératoire*—from raw materials and textile tools to finished products and their subsequent reuse over time.

At the core of the centre's mission lies an interdisciplinary vision that approaches textiles not merely as functional or decorative objects, but as sophisticated expressions of human knowledge, labour, and cultural meaning. Each fabric, fibre, or thread is treated as a bearer of narrative potential—one that reveals not only the techniques of its manufacture, but also the identities of its makers, the provenance of its raw materials, the transmission of artisanal knowledge across generations, and the cultural and symbolic value attributed to the finished object within its historical context. To reconstruct these layered narratives, A3TEX integrates archaeological research with advanced scientific methodologies and experimental reconstruction (fig. 1).

The centre relies on a wide range of advanced diagnostics – including spectroscopy (XRF, FORS, FTIR in ATR, reflectance and transmission modes, FT-RAMAN, RAMAN, RAMAN-SERS), mass spectrometry (HPLC-HRMS), optical (OM and PLM) and confocal microscopy and scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy (SEM-EDX), Mass Spectrometry-Based Proteomics, and 3D imaging – to analyse and investigate textiles, fibres, dyes and degradations using a multi-analytical strategy that ranges from non-invasive to invasive techniques. Equally central is the experimental component: ancient textile tools are studied through trace analysis and replicated through controlled experimentation, allowing researchers to reconstruct techniques, gestures, rhythms, and procedures throughout history. This integrated approach enables A3TEX to navigate across multiple scales – from the microscopic structure of fibres to the macrostructures of production networks and cultural exchange.

A3TEX also serves as an incubator for innovative conservation strategies. The centre is actively developing new green nanomaterials and micro-invasive extraction techniques using microgels to investigate and preserve highly vulnerable textile remains. Its Mobile Laboratory (Mob Lab) brings these technologies directly into the field, enabling in-situ diagnostics, first aid and long-term conservation interventions.

The centre's digital agenda includes a fruitful collaboration with the University of Padua on the Open Access *Roman Textile Database.* This platform is designed to host and disseminate spatial, analytical, and chronological data for scholars worldwide, facilitating collaborative analysis and digital preservation of textile-related data.

A3Tex is committed to fostering collaboration with both academic institutions and external partners, including museums, research centres, and private enterprises. By offering its expertise and advanced analytical capabilities, the centre supports a wide range of projects aimed at documenting, studying, conserving, and understanding ancient textiles. Among these, the European project *TEXTaiLES,* funded under the Horizon programme, seeks to create a comprehensive technological ecosystem for textile digitisation, utilising a combination of various acquisition techniques (photogrammetry, 3D scanning, micro-CT scanning, RTI, and multispectral imaging), artificial intelligence, and robotics to deliver tools, strategy and digital replicas for creating and populating the new European Cloud for Cultural Heritage (ECCCH) (fig. 2).

The *ArchTex* project, supported through the Marie Skłodowska-Curie Seal of Excellence and Sapienza SAPI-Excellence programme, focuses on the textile remains excavated at Herculaneum and the wider Vesuvian area. At the national level, A3TEX leads the PRIN-funded *ADigTex* project, which aims to integrate to integrate archaeology, archaeometry, and digital humanities in Roman textile research. Together, these and other research projects position the centre as a scientific hub with tangible impact on cultural heritage policies, museum practices, and international collaboration.

Beyond research and conservation, A3Tex is deeply committed to fostering the growth of the textile research field by offering training and educational opportunities. The centre provides hands-on training in its laboratories, supports thesis and doctoral research, and contributes to university curricula in Archaeology, Conservation Science, and Fashion Studies. Since 2017, Sapienza students have been able to explore textile archaeology through dedicated courses, such as *Archaeology and Archaeometry of Textiles and History, Production, and Conservation of Heritage Textiles*. Summer schools, workshops, internships, and second-level master's programmes broaden the centre's educational outreach, engaging both professionals and early-career researchers. In parallel, A3TEX actively promote collaborative training through joint research initiatives with academic institutions and research organisations, fostering knowledge exchange and the development of a dynamic network of expertise. Internship and fellowship opportunities support the professional growth of emerging scholars, offering them the chance to engage in interdisciplinary projects and advance innovative methodologies in textile archaeology.

In July 2025, the centre organised its first summer school, titled *Archaeometry, Conservation, and Digitisation of Archaeological Textiles* (fig. 3), which combined archaeology, materials science, and cutting-edge diagnostic techniques. Through a series of lectures, laboratory exercises, and direct analysis of diverse textile artefacts, the 15 participants acquired theoretical and practical knowledge in documenting, analysing and conserving archaeological textile remains, providing critical insights into analytical procedures based on different material types and conservation status. Thanks to the participation of TEXTaiLES partners, the A3TEX Summer School introduced participants to cutting-edge digital methods and strategies for digitising, communicating and musealising textile heritage. To further enrich the training experience, participants visited the Museum of Roman Ships in Nemi, where they attended seminars and engaged in hands-on activities related to experimental and digital archaeology.

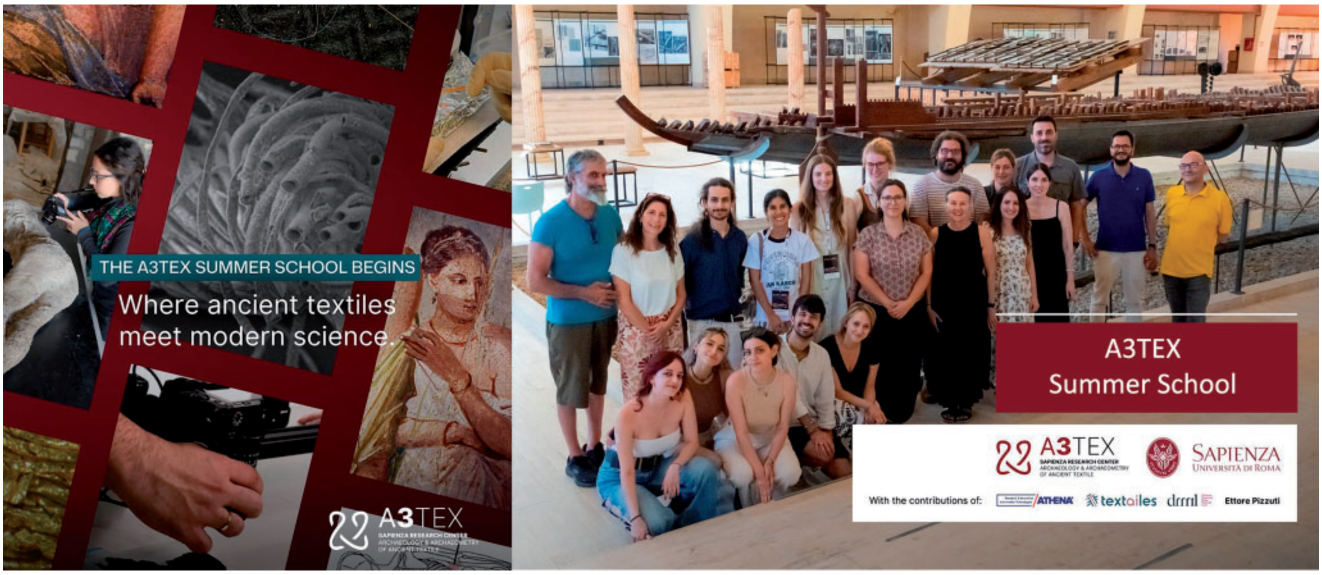

Fig. 3: A3TEX Summer School, https://www.a3tex.com/summer-school/ (Image: Francesca Coletti)

A3Tex is also committed to expanding its collaborations with both the public and private sectors. The centre actively seeks partnerships that foster joint research initiatives, where its expertise in textile analysis and conservation can contribute to advancing the field.
Whether through collaborative research with other universities or heritage preservation projects with public institutions, A3Tex aims to serve as a catalyst for scientific innovation and knowledge exchange in the field of ancient textile studies. In this sense, A3TEX is not only a centre of research, but also a space of intellectual hospitality. By weaving together disciplines, technologies, and people, the centre aspires to become an open and dynamic hub for knowledge sharing, fostering research and collaboration among scholars and institutions dedicated to textile heritage.

The A3TEX team

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The TEXTaiLES project brings together 10 partners from 8 countries, each contributing specialised expertise in archaeology, conservation, artificial intelligence, robotic engineering, 3D modelling, and cultural heritage digitisation. For more information, see https://research-and-innovation.ec.europa.eu/research-area/social-sciences-and-humanities/cultural-heritage-and-cultural-and-creative-industries-ccis/cultural-heritage-cloud_en.

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Georgia Gould

The development of motif and technique in early medieval north European tablet weaving

Introduction

The doctoral thesis reported here is being undertaken at the Department of Scandinavian Studies at University College London. Owing to the interdisciplinary nature of the research, the supervisory team is based across two institutions. The author's principal supervisor is Haki Antonsson, based at University College London, a prolific scholar in the fields of Old Norse literature and hagiography. In addition, he convenes modules on Viking Age material culture in Scandinavia, during which the author has contributed by teaching on Viking Age textiles. The author's second supervisor is Jane Hawkes of the University of York. Hawkes specialises in Anglo-Saxon art, language, culture, and history. Her academic interests include textiles and textile iconography, and she regularly supervises postgraduate students working on textile-focused research.

During their master's degree at University College London, the author specialised in early medieval, Anglo-Saxon, and Viking Age studies. An enduring interest in the literary and material cultures of these periods ultimately inspired a deeper engagement with early medieval scholarship. It was also during this time that the author became involved in historical reenactment, focusing on the period 400 to 1000 CE. A key aspect of this activity was the study of textiles and clothing from the era, a topic that soon became the central focus of the author's academic interests.

Since then, the author has acquired practical experience in textile craft, practised tablet weaving since 2019 and has experimented with various techniques associated with narrow wares. Living history remains a particular passion, and the author has participated in practical demonstrations at museums across England, Scandinavia, and Germany. In addition, they are part of the EXARC management team - an organisation that promotes the role of practical craft in archaeological research – encouraging contributions from both academic and non-academic practitioners engaged in experimental work. Throughout this project, the author has maintained a strong awareness of the practical dimensions that underpin textile production and craft.

Tablet weaving has been addressed in scholarly literature for more than a century. However, in comparison to the study of metalwork, woodwork, weaponry, bone artefacts, and other personal items, textile archaeology remains a relatively recent subfield within archaeology (for example, Øye 2022, 1). As such, it offers significant potential for further scholarly exploration, welcoming both fresh academic perspectives and experimental approaches.

Textiles may be analysed through a range of methodologies, some of which are more robust than others. These include approaches grounded in material culture studies (Lund and Semple 2021, 1–5), the examination of established trade routes, literary analysis, and comparative studies between textiles and other artefact types, such as metalwork, furniture, bone items, and manuscript art (fig. 1). The integration of these methods offers a richer, more nuanced understanding of the archaeological record.

Methodology

Throughout the 20th century, the question of the origin of objects became central to the study of archaeological finds, historic cultures, and past peoples. This trend can be partly attributed to the National Romantic movements that swept across Europe in the late 19th century, during which many countries turned to their historical pasts in order to construct national identities amidst the transformations of the industrial revolution (for example, Leerssen 2013, 9–25). A desire to categorise cultural identities through objects, motifs, buildings, monuments, and artefacts gained considerable prominence. This project interrogates the constructed dichotomies between Germanic/Scandinavian/pagan and central European/eastern/Christian identities.

The classification of Germanic and Scandinavian identities has long been contested, not least because of notable similarities in artistic styles. During the fifth and sixth centuries CE, various forms of metalwork, artwork, clothing, and textiles circulated and were shared across northern Germany, England, and Scandinavia. The prevailing consensus within the scholarly literature is that many such artefacts were produced locally or regionally. Several studies, for instance, assert that sixth-century Scandinavian textiles were woven in the Scandinavian region—such as the tablet-woven bands from Snartemo and Högom (for example, Hougen 1935; Nockert 1991). This project revisits this assumption by considering the existence of broader international and interregional networks of trade and migration.

Current academic publications often present a stark contrast between the Late Roman Central European world and the Scandinavian regions. The former is depicted as a thriving centre of textile trade, characterised by the export and import of silks, linens, tapestries, and fine garments across the Roman Empire (for example, Gleba and Pásztókai-Szeőke 2013). The latter is typically represented as comprising small-scale, localised production units that occasionally produced high-quality textiles. This binary construction reinforces the notion of early medieval Scandinavia as underdeveloped or culturally stagnant, trapped within the so-called "Dark Ages". This project challenges such reductive interpretations, arguing instead that the tablet-woven bands of fifth-century Scandinavia offer evidence of dynamic cross- and trans-cultural exchange.

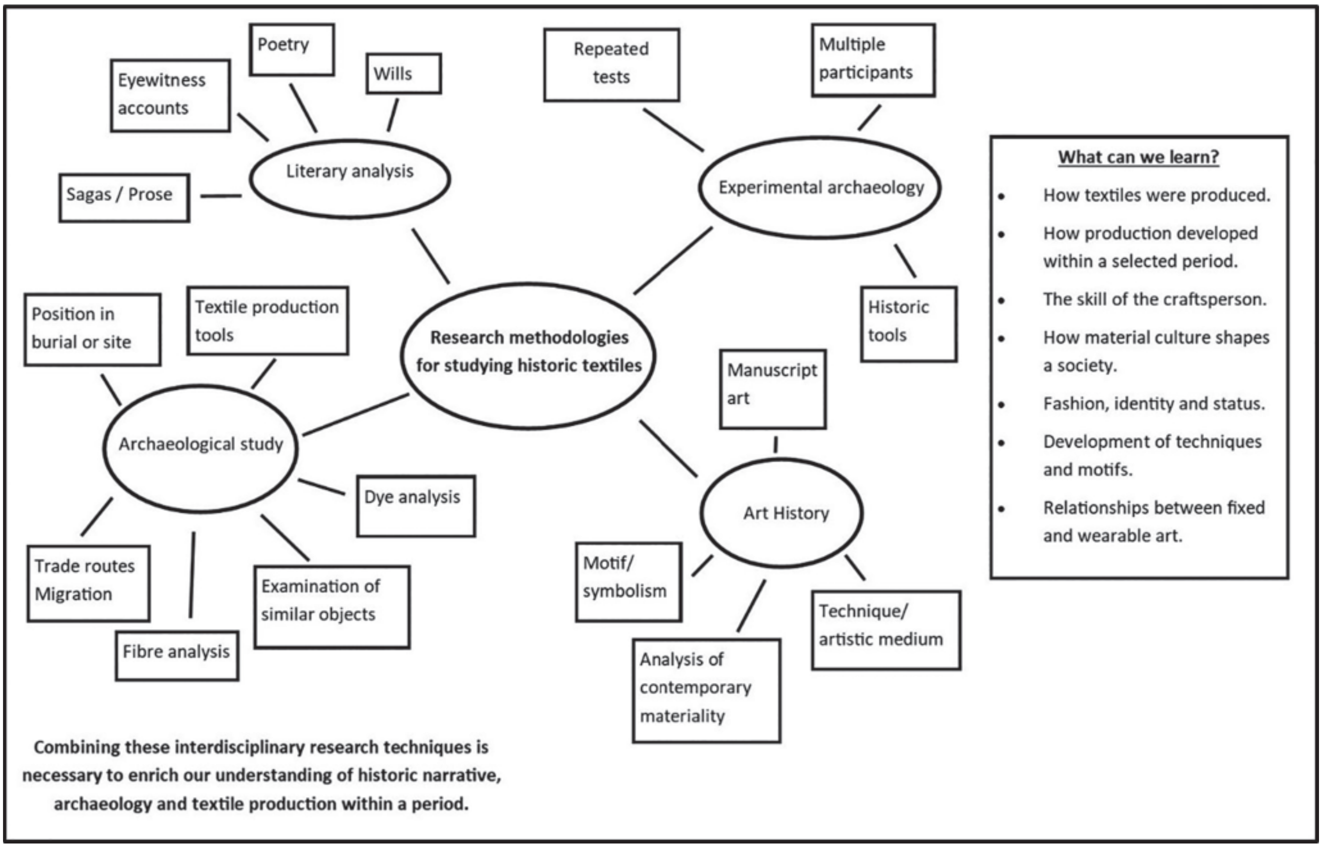

Fig. 1: Examples of the principal textile research methodologies (Image: Georgia Gould)

Tablet-woven textiles are products of manufacture; their creation is determined by specific craft technologies. Taking wool as an example: the process begins with the rearing of sheep, followed by the shearing of their wool, which must then be treated, washed, and combed using specialised tools. Only after this preparation can spinning commence. Using a spindle and distaff, the craftsperson invests many hours transforming raw fleece into fine, workable yarn. At this stage, the yarn may be dyed—either before or after spinning, depending on the desired vibrancy of colour. Once spun and dyed, the yarn must be wound, and a warp prepared. Depending on the intended size of the textile, this stage alone may take several days. A weft yarn must also be prepared before the labour-intensive weaving process can begin. Textile production is, therefore, a protracted and skilled endeavour, often involving the work of multiple individuals (Walton Rogers 2007, 4–91).

Actor-Network Theory (ANT), which evolved from post-processual archaeology, emphasises the role of human agency in the creation of artefacts, artworks, and objects. However, it has been criticised for overlooking the agency of the artefacts and materials themselves. For example, when viewing a painting by a renowned artist such as Leonardo da Vinci, viewers may experience emotions such as awe or inspiration. These responses are elicited not solely by the artist's skill but by the material object—the painted canvas—which acts upon the observer. The painting is the result of a complex interplay of backing material, pigments, brushwork, and time. Agency, therefore, does not reside solely with the artist or the makers of the canvas and paint, but also with the object itself, which shapes its reception. This concept of object agency can be extended to archaeology and artefact studies, prompting scholars to acknowledge that even the smallest textile fragment carries with it a rich history of production, use, and interaction. This perspective reshapes the ways in which archaeologists and art historians engage with material culture.

In addition, it is possible to appreciate the interrelationship between textile artefacts and other objects involved in their creation. In the case of wool textile production, the relationship between the human and the raw material is far from linear. The tools employed in textile production—such as wool combs, typically made of wood and iron—are themselves the products of skilled craftspeople, including woodworkers and metalworkers. These tools are subsequently traded or passed on to others involved in textile preparation. Even the shears used in the initial shearing process were forged by metalworkers. Each tool is itself the result of a prior object and process, forming a complex network of relationships: human–object–object–product–object–human. Recognising this intricate web of interactions allows for the identification of local and regional trade networks.

Fig. 2: Detail of tablet-woven band from Oseberg, Historical Museum, Oslo, , Norway, inventory number: 12L1B2 (Image: Georgia Gould)

Through the examination of selected tablet-woven bands, this project considers the agency of all constituent parts, tracing their lifecycle from production to their eventual inclusion in grave assemblages. This approach aligns with the principles of object biography, is an archaeo-anthropological method which builds on the theory of *chaîne opératoire*. It establishes a "life cycle" of an artefact, charting its course from "birth" to "death" (Joy 2009, 543). Object biography is a tentative analysis of how an artefact came to be, from its conception in the minds of its creator/s to its function and potential burial or destruction. Whilst this methodology has its flaws as both purely theoretical and in also appreciating that one object can have more than one "life", there is a benefit to viewing an artefact as more than just an old object. By examining its object biography, it is possible to bring a "silent" object and "back to life" – a tool which is useful in the curation of artefacts in museum and heritage contexts.

Joy uses the example of the bronze Portesham mirror, an Anglo-Celtic artefact dated to the first century CE. Using the technical processes of manufacturing the mirror, she suggests how the mirror was "born", describing the extensive metalworking which

Fig. 3: Textile tools from Oseberg, Viking Ship Museum, Oslo, Norway (Image: Georgia Gould)

contributed to its creation, as well as the number of craftsmen who were involved. Furthermore, Joy examines the wear-and-tear on the mirror, suggesting the possible function of the mirror, how it was used and by whom. She studies the position in the burial, what this might signify both in its life and in its "death", as well as providing a consideration of its agency on the owner and on those who discovered it. Joy postulates how it would have appeared in its heyday, whilst still in use (ibid., 546). This life cycle brings an anthropological element into the theory; it establishes further networks of trade and craftsmen. In addition, providing information in this context allows both academics and laymen to engage with the history of an object beyond a solely archaeological study of an artefact.

This can be demonstrated by analysing the object biography of the silk and linen bands from Oseberg, such as the narrow band on the fragment 12L1B2 (fig. 2). Even within this one narrow band, just 6 mm at the widest, the "birth" of the linen and silk yarn of the band will have been very different. The silkworms were reared in the near or far east, the silk threads then manufactured and reeled using a myriad of tools of various materials. Then, it would be transported across continents, possibly traded, dyed, worked and reworked. The linen's journey may have been shorter, beginning its life as raw flax, before being harvested, dried, worked and transformed into spun thread. Eventually, these two yarn bundles met – either on the Oseberg farm or elsewhere – and were once again worked with tablets and tools to become a fine textile border (fig. 3). Even as one of the smallest tablet-woven bands in the collection, its creation was a long process, with networks of actors which travelled across the world.

Building upon the notion of "bringing objects to life", it is necessary to incorporate the concept of sensory engagement into the analysis of textiles. Human beings navigate their environment through a complex interplay of sensory experiences—textures, sounds, sights, tastes, and scents—many of which are processed unconsciously. These sensory inputs profoundly shape our perception of the world, our interactions with others, and the ways in which we engage with our surroundings. Even in contemporary analyses of artefacts, the senses remain central. For example, fibre structures are frequently examined visually and categorised using descriptors such as "hairy", "medium hairy", or "fine"—terms which implicitly reference the tactile qualities of the textiles (Harris 2019, 210). However, textile artefacts are often poorly preserved, having undergone significant distortion, degradation, and discolouration during their long interment. As a result, conventional archaeological methods can offer only a partial reconstruction of their original form and function. Therefore, object biography and sensory archaeology can be employed together to animate these objects. It must be acknowledged that any sensory interpretation is inevitably shaped by modern contexts and contemporary frameworks of meaning. However, examining how these artefacts interacted with their original sensory environments can enhance our understanding of both the objects themselves and the lived experiences of historical periods. This approach is particularly valuable in the case of fragmentary or poorly preserved textiles, whose material histories risk being lost without such interpretative frameworks.

The second branch of this anthropological study of the artefacts and their agency considers the "bewilderment principle" and *varietas.* These theoretical frameworks are new in the study of artefacts, but relevant literature has been published by Mary Carruthers (2013) and recently Matthias Friedrich (2023). To reiterate the analogy of studying a painting by Leonardo da Vinci in an art museum and the agencies involved, the painting acts upon the viewer in various ways, although this may vary from person to person. An Italian scholar of the renaissance might recognise some of the finer nuances of the piece, perhaps the brilliant mind of the artist, or the background of the time in which he lived. A layperson may appreciate how the Mona Lisa's gaze follows them. Perhaps the viewer is not interested in art at all, passing by the piece with only a cursory glance. The same object, art piece, or artefact can influence different people/recipients in different ways. This further applies to textiles, particularly tablet-woven bands, especially those that incorporate motifs or functional elements; for example, a fifth-century animal motif (fig. 4) may initially appear "Germanic" to an archaeologist, especially when compared with contemporaneous material. However, zoomorphic motifs were also prevalent in Roman dress, and thus a Roman viewer might interpret such imagery as indicative of Roman artistic influence. Similarly, a Sasanian observer might discern stylistic parallels with silk bestiary motifs from their own cultural repertoire. The weaver, meanwhile, may have been working with a particular vision – either one communicated by the commissioner or owner of the textile, or one shaped by their own cultural background and lived experience.

Findings

Although the project is ongoing, there are some preliminary findings from the study of luxury tablet-woven bands. A secondary framework, which will be outlined fully in the thesis, has been developed

Fig. 4: The wide band from Snartemo grave II, Historical Museum, Oslo, Norway (Image: Georgia Gould)

Fig. 5: Reconstructed garments based on the Bjerringhøj and Hvilehøj finds on display at the National Museum of Denmark (Image: Georgia Gould)

to evaluate whether a textile may be classified as luxurious within an early medieval context. This framework is linked to the main framework for textile analysis. Application of these frameworks support the hypothesis that the weaving techniques employed in the production of luxury tablet-woven bands evolved alongside the increased use of certain materials such as silk and metal. One notable development is the growing prevalence of brocading techniques between late 500 and 1100 CE, marked by the introduction of metal-brocaded tablet-woven bands into northern Europe, such as those found in late sixth-century Kent (Crowfoot and Chadwick Hawkes 1967, 50). This observation must be qualified by the recognition that metal-brocaded bands possess a higher likelihood of partial preservation compared to those composed solely of organic materials.

Some motifs remain ubiquitous in tablet-woven textiles from the fifth to the 11th centuries. For example, the swastika motif is present in the wide tablet-woven bands from sixth-century Snartemo V and Helgeland, Norway, as well as in the tablet-woven cuffs from tenth-century Bjerringhøj, Denmark (Hougen 1935; Mannering and Rimstad 2023). The cultural significance of this motif is further corroborated by its recurrence in contemporary jewellery and furnishings. However, a discernible shift in animal motifs is evident between the Migration Period and the Viking Age. The ambiguous yet full-body depiction of animal figures woven in 3/1 broken twill structure and soumak during the fifth and sixth centuries appears to develop into similarly ambiguous yet partially formed faces and geometric designs by the tenth century, as exemplified by finds from Dublin and Birka. Complete animal motifs are present in Viking Age textiles, but there is a noticeable stylistic trend that may be attributed to changing weaving techniques.

Discussion

While it is possible to examine the potential reasons behind the selection of specific motifs, it is equally valuable to consider the agency of both the weaver and the viewer or owner of the textile. These textiles existed as lived objects – worn garments, wall hangings, furnishings, and other accessories – that actively engaged with people and their environments. They functioned as sensory artefacts, mediating visual, tactile, and even auditory experiences, thereby shaping the world in which they circulated.

This perspective offers a richer understanding of these artefacts and deepens the narrative surrounding their production, use, and trade throughout the period. By drawing these threads together, experimental archaeology can assist in reconstructing the archaeo-anthropological processes, networks of production, and sensory dimensions of textile use and function in the past. A pertinent example is the recently completed *Fashioning the Viking Age* project (fig. 5), which this project will draw upon in its own reconstructions of relevant tablet-woven bands (Mannering and Rimstad 2023; Strand and Demant 2023).

Conclusion

This project introduces a new multidisciplinary methodology for the analysis of early medieval textiles, with a particular focus on tablet-woven bands. It offers a renewed and integrative approach that synthesises methodologies from archaeology, art history, and anthropology to examine both the motifs and techniques employed in these textiles. By doing so, the project seeks to illuminate the broader cultural significance of tablet-woven bands, exploring their roles in trade, migration, and the expression of social status within early medieval material culture.

This methodological framework is designed to have wide-ranging applications. It may be employed not only in academic research but also in curatorial practice, offering museum and heritage professionals a richer interpretative lens through which to present textile artefacts to the public. By foregrounding the social, technical, and symbolic dimensions of textile production and use, the approach facilitates more nuanced and engaging displays, contributing to both scholarly discourse and public understanding. The project is scheduled for completion between late 2025 and early 2026, with the intention of disseminating its findings through academic publications, conference presentations, and potential collaborations with heritage institutions.

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Irene Waggener

Updating knitting history: a connection between Egypt and Armenia?

Introduction

Knitting history has received little scholarly attention despite knitting's popularity as a living craft practiced around the world (Strawn 2012). The majority of knitting books are designed for knitters and focus on providing patterns that can be replicated. While some of these books offer a chapter on the history of knitting, a lack of academic research and organised cataloguing of artefacts limits what can be referenced in these books for the general public. While research on early European knitting has gained ground in recent years (Malcolm-Davies and Mearns 2018; Gilbert 2018; Ringgard 2018; O'Connell Edwards 2018; Odstrčilová 2018; Lundin 2018; Willemsen 2018), more work on early knitting in north Africa, the location of knitting's earliest finds, is needed.

The gap in scholarly writing about early knitted and other non-woven objects is attributed to minimal material evidence, inconsistent data collection, and limited acceptance of knitting as an academic subject (Malcolm-Davies 2018, 3; Strawn 2012, 1). This project aims to demonstrate the research potential of knitting by taking a granular look at two objects – one from the Egyptian site of Quasr Ibrim at the British Museum in London and another from Armenia in the collection of the History Museum of Armenia in Yerevan (fig. 1). An in-depth analysis of these knitted objects will illustrate the cross-disciplinary and cross-cultural study potential of knitted artefacts and knitting traditions. As a case study, this project will contribute to the foundation of a larger inventory of knitted object analysis and research that will collectively shine a brighter light on the earliest chapters of knitting history.

Fig. 1: Knitted socks from Armenia (dated 20th century CE), History Museum of Armenia, inventory number 1203 (Image: Irene Waggener)

Research landscape

The available source material for the study of knitting is extremely uneven. Researchers have a handful of early evidence for knitting on the one hand and the living craft of the present on the other; however, it is unclear how they connect. Further complicating this task is a poorly catalogued corpus of knitted artefacts as well as the active loss of "traditional" knitting knowledge. Unlike researchers working with woven textiles, the knitting researcher must make do with a small, scattered, poorly documented collection of knitted objects; little to no identified evidence for tools; and limited information about older knitting practices. However, it would be remiss to dismiss knitting research outright because of the paucity of available evidence. Knitting researchers must carefully document and analyse available objects and living traditions to organise and develop a corpus of material that is better able to inform and shape future research.

To date, the earliest archaeological evidence for knitting comes from Egypt's medieval period when the Fatimids and Mamluks were in power. The highly skilled nature of this evidence suggests that knitting likely replaced nalbinding in Egypt sometime between 500 and 1200 CE and was mostly used for producing footwear (Rutt 1987, 39). This hypothesis is based on a handful of publications largely from the first half of the 20th century that focused on individual artefacts of technical complexity (Lamm 1937; Thomas 1938; Bellinger 1954; Norbury 1973; Turnau 1991). From this limited dataset, a history of knitting that connects it to the spread of Islam across north Africa and into the Iberian peninsula has been shared with a global audience via knitting books marketed for the general public (Rutt 1987; Bush 1994; Nargi 2011; Pomar 2013). In general, very little detail is provided about the social, historical, economic, cultural, and environmental contexts in which knitting developed and spread.

Separate from these medieval Egyptian artefacts are a handful of ethnographic collections and publications that reveal knitting practices in the western half of north Africa (Bel and Ricard 1913; Euloge 1956; Ferchiou 1971; Besancenot 2000; Rabaté and Sorber 2007; Huet and Lamazou 2012; Waggener 2020). Although knitted artefacts rivalling the antiquity of those from Egypt are not yet known from the lands west of the Nile, the ethnographic and historical evidence suggests that knitting traditions in Morocco, Algeria, and Tunisia may have deep roots as well as a connection to the practice of knitting in Egypt (Waggener 2020, 99–118). However, these traditions have attracted even less attention from scholars and knitters than Egypt's knitted artefacts.

Fig. 2: Knitter from Morocco's High Atlas Mountains, 2019 (Image: Irene Waggener)

The book, *Keepers of the Sheep: Knitting in Morocco's High Atlas and Beyond* (Waggener 2020), is currently the only publication that addresses in detail the practice and history of knitting in north Africa with a specific focus on knitting in Morocco. This book combines ethnographic work with knitters in the High Atlas and a review of the available historical, material, artistic, and linguistic evidence for the history of knitting across north Africa (fig. 2). By piecing together these sources along a continuum from the present to the past, an attempt is made to stitch together the broken story of north African knitting. The result is a more nuanced hypothesis for the development and diffusion of knitting across north Africa.

Interestingly, this book notes the possibility for a connection between north African and west Asian knitting. Sources cited remark on similarities between Algerian knitting and Turkish knitting as well as a reference to the growth of Tunisia's *chéchia* cap knitting industry when the country was part of the Ottoman Empire. Furthermore, the book notes that (some) Arabic (dialects), Turkish, and Farsi share terminology for knitted items, which suggests that there could be a connection between knitting in north Africa and west Asia (Waggener 2020, 106–110). Although largely anecdotal, these observations about a possible relationship between north African and west Asian knitting are worth exploring. Beyond what is noted in this book, there have been no formal studies comparing knitting from north Africa and west Asia despite the long history of exchange between the two regions (fig. 3).

Most of the information about west Asian knitting is relatively modern and written for the general public (Özbel 1981; Avagyan 1983; Harrell 1981; Rutt 1987; Zilboorg 1994; Gibson-Roberts 1995; Nargi 2011). Many of these works document "traditional" knitting patterns and techniques of unknown antiquity that have been passed down from one generation to the next. Currently, the oldest known piece of knitting from west Asia is a sock fragment that was found in a cave near the border between modern Georgia and Armenia (Bakhtadze 2013, 14). While the toe of the sock is visible, its heel has been destroyed. However, a brief look at the sock shows that its toe is strikingly

Fig. 3: a) Qasr Ibrim; b) Armenia, Azerbaijan, northern Iran, and southern Georgia (Image: Google Maps)

Fig. 4: Knitter from Armenia, 2024 (Image: Eugene Ho)

similar to the toes made by knitters in both Georgia and Armenia today (fig. 4). The fragment's suggested date is the 12th–14th centuries CE, which places it within the date range for many medieval Egyptian socks and knitted fragments from the late Fatimid and Mamluk periods. Significantly, people from west Asia, such as the Armenians, were present in Fatimid Egypt and actively contributed to the politics, culture, and economy there (Jiwa 2023; Dadoyan 1997; Brett 2017; McKenney 2011).

The historical, material, and ethnographic evidence for knitting in north Africa and west Asia coupled with these regions' intertwined histories suggests that their knitting traditions should not be studied in a vacuum. Rather, they should be considered in tandem. Since the medieval Egyptian artefacts first came to light in the 20th century, new findings in a variety of fields have updated understandings of the cultural, historical, environmental, economic, and political contexts in which those fragments existed. Moreover, advances in chemical analysis provide further opportunities to more securely date these artefacts and identify geological signatures that could more definitively identify raw material origins. The time is ripe to revisit the knitted artefacts from Egypt that were published in the 20th century. They, along with the many undocumented knitted fragments held in museum collections around the world, should be (re)documented, analysed, and considered against the backdrop of a broader range of multidisciplinary evidence available today.

Research problem

A knitted fragment at the British Museum illustrates how knitted objects from north Africa and west Asia are intertwined. This fragment's geometric bird motif, in which birds are placed back-to-back and inverted one from the other so that one's head is above and the other's below, can also be found on knitted socks and pile carpets from Armenia, Azerbaijan, and Iran (fig. 5). In fact, there is a knitted sock in the Armenian National History Museum's collection bearing the same motif (fig. 1). However, these examples from west Asia are considerably newer than the Qasr Ibrim fragment. While a date ranging from the 11th-12th centuries CE is suggested for the Qasr Ibrim fragment, the example from Armenia dates to the 20th century. This considerable difference in age poses a challenge in identifying a direct relationship between the two objects. Nevertheless, the presence of this particular bird motif on knitted textiles from Egypt and Armenia is noteworthy and immediately raises several questions. Why does this bird motif appear on the knitted fragment from Qasr Ibrim and the socks from Armenia? Are the knitting traditions related?

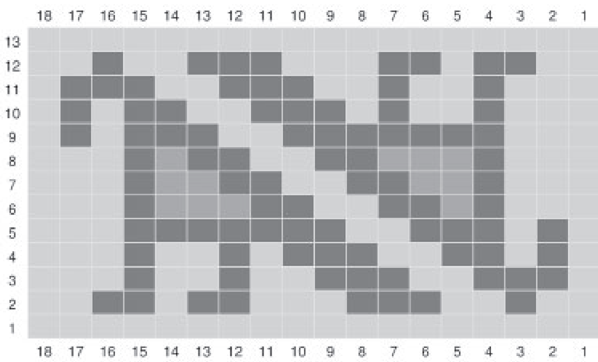

Fig. 5: Example schema of bird motif found on knitted and woven textiles from medieval Egypt and modern Armenia, Azerbaijan and Iran: light grey represents the main colour; dark grey the contrast colour 1; and mid-dark grey the optional contrast colour 2 (Image: Irene Waggener)

What might connect the Armenian people, and people from west Asia in general, to Egypt, especially in the Fatimid period? Does this geometric bird motif exist in other forms, and can it help researchers trace lines of connection via trade and/or migration?

Proposed methodology

As in the book, Keepers of the Sheep: Knitting in Morocco's High Atlas and Beyond, this project will take a multidisciplinary approach to investigate these questions. Ethnographic, historical, material, artistic, and linguistic evidence will be used to piece together a hypothesis for a connection between medieval Egyptian and 20th century Armenian knitting. At the heart of this case study will be an analysis of the objects from Qasr Ibrim and Armenia utilising the protocol for knitted objects proposed by Jane Malcolm-Davies, Ruth Gilbert, and Susanne Lervad (Malcolm-Davies et al. 2018, 10–24). This will be accompanied by a thorough review of the history, politics, events, culture, and economy of Egypt in the 11th–12th centuries to provide background information and illuminate the relationship between north Africa and west Asia in this time period. Special attention will be given to the role of Armenians in Egypt since the comparative material in this case study comes from Armenia. While strontium isotope analysis and carbon-14 dating is likely not possible for the scope of this project, a review of other archaeological and historical evidence from Qasr Ibrim dating to around the time period proposed for the knitted fragment will be considered. This information taken in conjunction with historical accounts of trade networks, like that of the Armenians which spanned from east Asia to India to north Africa and Europe, might provide further insight on the object.

Expected results and future plans

It is expected that this project will establish a relationship between medieval Egyptian knitting and west Asian knitting traditions, with a special focus on Armenian knitting. The project will build a case for this hypothesis by:

1) Documenting and analysing the Qasr Ibrim fragment and Armenian knitted socks, which will result in:

- a description of the objects' materials;
- the identification of techniques used in their production;
- a comparison of the objects based on the collected data;
- a hypothesis for how the Qasr Ibrim fragment may have been used based on the comparison of that data; and
- an argument for the transmission of knitting knowledge in the medieval period between north Africa and west Asia and the sustained use of that knowledge in west Asia based on the use of similar techniques and design motifs in the creation of both objects.

2) Surveying historical records and events as well as archaeological findings, which will provide:

- a description of the political, economic, and cultural context of north Africa and west Asia at the time of the Qasr Ibrim fragment;
- a description of the diverse peoples who resided in Egypt and participated in Fatimid Egyptian life;
- a description of Armenian communities in Fatimid Egypt and their contributions to the political, artistic, economic, and religious spheres of the Fatimid empire; and
- information about the nature of trade and cotton production at the time of the Qasr Ibrim fragment.

3) Referencing linguistics, related crafts, artefacts, and artistic depictions of clothing from west Asia and north Africa, which will:

- provide further evidence for the circulation of products and craft skills between the two regions; and
- shed light on the possible direction of influence - whether in a single direction or successive waves going back and forth.

The insights gained through this case study will inform the development of a larger project on the history and practice of knitting in north Africa and west Asia. This project will be centred around the creation of a database of knitted objects from these regions. The detailed analysis of the objects in this database, as in this case study, will result in a larger corpus of material for knitting researchers to draw from and extract the broader themes and patterns needed to further unravel the history of knitting.

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Textiles make the world go round: the international winter training school on textile archaeology

20 to 24 January 2025, Padova, Italy

The Department of Cultural Heritage (DBC) of the Università degli Studi di Padova (UniPD, Italy), organised, for the first time, a five-day international training school for researchers, conservators and curators on textiles under the heading: *Textiles make the world go round*. The academic training had a multidisciplinary approach, including theoretical/practical courses, a public communication event and an excursion. The programme included the expertise of more than 20 renowned instructors and 20 trainees. The participants came from 12 different countries (Canada, USA and all over Europe) and diverse professional backgrounds (archaeologists, conservators, curators and artists). The initiative was funded and supported by the University of Padua's *Shaping a World-Class* University programme and the DBC.

The first day comprised introductory presentations at the *Museo di Scienze Archeologiche e d'Arte*. Margarita Gleba and Maria Stella Busana (UniPD, Italy) started with a welcoming introduction of the course contents and participants. Josephine Andrews (*Haptic & Hue*), followed with a talk on the impact of textiles and clothes. Finally, Eva Andersson Strand (University of Copenhagen, Denmark) explained the *châine opératoire* methodology and the benefits of its application in textile research. The afternoon culminated with a guided tour of the venue.

The second day was held at *Ponte di Brenta*, the archaeological laboratory of the DBC, and it had

Fig. 1: Activities at the training school: seminars, structural analysis, experimental archaeology (Images: DBC and UniPD training school)


Fig. 2: The participants at Museo di Scienze Archeologiche e d'Arte in Padova (Image: Yaqi Yan)

a more analytical approach. Hana Lukesova (University Museum of Bergen, Norway) began with an introduction to the basics of conservation and retrieval of archaeological textiles. Margarita Gleba offered a presentation on the fundamentals of structural analysis. Bela Dimova (UniPD, Italy) gave a theoretical lecture on digital microscopy and, to end the morning, there was a practical session on textile documentation/analysis led by Margarita Gleba and Bela Dimova. After lunch, the training focussed on textile tool analysis. A theoretical and practical framework by Bela Dimova, then, the case study of the Roman Veneto by Maria Stella Busana. To conclude the day at the lab, a practical session on tool analysis/ documentation was supervised by Bela Dimova and Vanessa Bratella (UniPD, Italy).

The third day delved into fibre identification and archaeological science. The first half of the day was held at the Centre of Analytical Services, and the focal point was fibre identification. Margarita Gleba commenced with a lecture on animal fibres. Secondly, Hana Lukesova complemented the session with her introduction to plant fibres and live TLM analysis. After lunch, the school moved to the Museum of Nature and Humankind for a session on scientific perspectives of textile archaeology. Christina Margariti (Hellenic Ministry of Culture, Greece) offered an overview of non-invasive approaches (FTIR, FORS) to archaeological textiles; Luise Ørsted Brandt (The GLOBE Institute, University of Copenhagen, Denmark), provided a fascinating vision of textile proteomic and DNA analyses, while Mathieu Boudin (KIK/IRPA, Belgium) explained textile radiocarbon dating. The lectures ended with Joanne Dyer's presentation (British Museum, UK) on the textile collections of the British Museum and how they undergo their complex interdisciplinary study.

Day 4 offered methodological case studies and an introduction to experimental textile archaeology. The morning started with Susanna Harris's (University of Glasgow, UK) thought-provoking talk on public engagement and textile archaeology. Francesca Coletti (University of Rome Sapienza, Italy) brought the case study of the Vesuvian area and the current stage of the research of both carbonised textiles and fabric imprints on the casts of the victims. Sanna Lipkin (University of Oulu, Finland) put the emphasis on the ethical aspects of working with archaeological burial textiles. Karolina Pallin (University of Uppsala, Sweden) demonstrated opportunities with digital textile reconstructions. The session ended with the expertise of Agata Ulanowska (University of Warsaw, Poland) on textile imprints. The afternoon was focused on experimental archaeology. Kayleigh Saunderson (University of Vienna, Austria) and Ronja Lau (University of Bochum, Germany) offered a framework on experimental archaeology in research. In the following practical training, the trainees got to experience different textile techniques (splicing, spinning and tablet weaving) under the close supervision of craftspeople: Marie Wallenberg

(Sweden), Katrin Kania (Pallia, Germany), Kayleigh Saunderson and Ronja Lau.
The last day included a trip to Venice for a guided visit to *Tessitura Bevilacqua,* the oldest functioning artisanal weaving workshop in Venice. The programme finished with an archaeological fashion show, *Catwalk to the Past*, and a keynote lecture "Thousands of years of European identity through dress" by Karina Grömer (Natural History Museum Vienna, Austria) at *Sala dei Giganti* (Palazzo Liviano). The livestream of the event is available here: https://www.youtube.com/watch?v=PKcKDwYwk9g.
The training school was immensely stimulating and the programme offered insights into basic, but also important holistic and multidisciplinary approaches. There are only a few possibilities in Europe to participate in this type of structured academic programme affordable for trainees and early career researchers. It was very intensive, but fantastic to acquire the basis of a rigorous textile methodology, expand personal networks and talk with experienced specialists. The fact that the participants came from different academic backgrounds and carreer stages was profoundly beneficial. The possibility of discussing ideas with archaeologists, conservators, craftspeople, curators or conservation scientists was eye-opening. At a personal level, it was a fantastic experience too. We all made new friendships, wonderful memories and were truly inspired. In the future, I hope this initiative continues, although more in-depth shorter length training should be taken into consideration.

By Leyre Morgado-Roncal

FARO workshop: ancient textiles – fresh perspectives

20 June 2025, Athens, Greece

The Hellenic National Archaeological Museum (NAM) in Athens hosted the workshop organised as part of the ongoing research programme **FAROS** (*The Fabric of Kings: Funerary Textile Remains from Mycenae and the Early Mycenaean Textile Production*). The project involves collaboration between the University of the Peloponnese (host institution), the Directorate of Conservation of the Hellenic Ministry of Culture, the Hellenic National Archaeological Museum (NAM), the Hellenic Centre for Research and Conservation of Archaeological Textiles (ARTEX) and the Sorbonne University Abu Dhabi. It is headed by Stella Spantidaki.
Bringing together a distinguished group of scholars, conservators, and students, the workshop focused on early Mycenaean textile research, including textile production, conservation and iconography, and underscored the extraordinary potential of interdisciplinary collaboration in archaeological and material culture studies. Additionally, it highlighted the significance of public engagement and the dissemination of archaeological research within museum contexts. The event attracted more than 100 participants, including university students, archaeologists, conservators, and members of the wider public.
Stella Spantidaki opened the workshop with a comprehensive overview of the FAROS project, detailing its research aims, institutional collaborations, and ongoing activities. Highlighting the exceptional rarity of funerary textile remains from Mycenae, she presented the project's integrated methodological framework, which combines textile archaeology, conservation science, archaeometry, iconographic analysis, and philological studies. This comprehensive approach aims to reconstruct Mycenaean textile production systems and their socio-cultural contexts.
The workshop's opening presentations laid the historical and archaeological foundations for the subject. Konstantinos Nikolentzos (NAM) delivered an insightful presentation on Late Bronze Age weaving traditions across the Aegean, situating the Mycenaean textile remains within the broader framework of Mediterranean prehistoric textile production. Drawing on iconographic, archaeological, and ethnographic parallels, Nikolentzos traced the technical and symbolic dimensions of textile work in Mycenaean society, particularly its association with elite craft and ritual functions.
Next, Vassiliki Pliatsika (Department of Prehistoric Antiquities, NAM) provided a detailed contextual analysis of the Mycenaean textile finds. Reviewing the stratigraphic, spatial, and burial contexts in which the textiles were found, she highlighted the rare preservation conditions that allowed organic material


Fig. 3: The participants in the lecture hall (Image: Christina Margariti)

to survive and advocated for a holistic understanding of funerary assemblages – integrating textiles and other grave goods, and human remains as interconnected social systems.

A workshop highlight was the joint presentation by Stella Spantidaki and Christina Margariti (Applied Research Department at the Directorate of Conservation). Together, they shared preliminary analytical results derived from macroscopic, microscopic and dye analysis, as well as fibre identification of the textile fragments, offering rich insights into both the technical and aesthetic characteristics of the fabrics. Their findings revealed a remarkable diversity of textiles, from plain-woven fabrics to elaborately decorated pieces with tapestry designs. Particularly noteworthy was the discovery of dyed textiles employing advanced weaving techniques. The analyses also confirmed the presence of both plant and animal fibres, suggesting a sophisticated textile economy that integrated varied resources and complex techniques.

Kalliope Sarri contributed with an insightful presentation on textile tools from Mycenae, such as spindle whorls, loom weights, and related artefacts. Through the comparative study of similar implements from contemporary Aegean and Anatolian contexts, she reconstructed plausible weaving techniques and discussed the possible use of different types of looms—a central debate in Bronze Age textile research. Sarri's analysis emphasised the regional variation and shared technological traditions in the textile production of the eastern Mediterranean and established that early Mycenaean weaving was already a skilled craft. The study of textile tools demonstrated in particular that early Mycenaean textile technology retained certain traditions from earlier periods but developed with new types of tools and techniques, indicating an increasing diversity of textile production and social demand for new textile products one step before the Mycenaean palatial period.

Turning to the visual and symbolic dimensions of textiles, Nikolaos Harokopos (National and Kapodistrian University of Athens) presented an engaging study of Minoan and Mycenaean artistic representations, focusing on depictions of textiles in frescoes and seal imagery. Harokopos paired the results of the analysis of the Grave Circles textile fragments with the broad artistic evidence deriving from a composite cultural horizon. In doing so, he highlighted connections in Aegean visual culture that include elements such as tassels, fringes, and dyed garments, with a particular focus on murex purple – the prestigious and costly dye associated with status and sanctity. Furthermore, he has convincingly argued that this approach underlines the central role of the textiles not only in ritual and funerary contexts, but also in the articulation of social hierarchy and power.

From the technical perspective of conservation, Georgianna Moraitou (Conservation and Archaeometry Department) and Panagiotis Lazaris (NAM) shared their recent efforts to improve the storage and preservation of the excavated textiles. They presented novel materials and methodologies developed to support fragile textile fragments to accommodate their specific needs. Their work reflects a forward-thinking philosophy that prioritises long-term stability while allowing for accessibility and further research. The use of customised mounts, acid-free materials, and controlled environments demonstrates a sophisticated understanding of the technological challenges in preserving archaeological textiles.

In two particularly compelling presentations, Vasileios Petrakis (National and Kapodistrian University of Athens) and Katerina Voutsa (Department of Prehistoric Antiquities, NAM) delved into the cultural and administrative aspects of Mycenaean textile practices. Dr Petrakis examined burial customs in Mycenae, linking the presence of textiles to ritual practices, status display, and possibly mourning or commemorative rites. He emphasised the challenges posed by the perishable nature of textiles, noting that their rare preservation offers profound insights into mortuary ideologies. Voutsa analysed weaving references in Linear B tablets, illuminating administrative records relating to cloth production, personnel (such as weavers), and textile types. Her study highlighted the bureaucratic significance of textiles within Mycenaean palatial economies and their role in redistribution networks, shedding light on standardisation processes, production scales, and gendered labour organisation in the textile industry.

The workshop finished with a summary Aimilia

Fig. 4 A miniature warp-weighted loom demonstrated during the workshop (Image: Christina Margariti)

Banou (University of the Peloponnese) that eloquently reiterated the importance of interdisciplinary collaboration in reconstructing ancient practices and expressed optimism about future research pathways.

A practical highlight was a live demonstration of ancient textile production techniques conducted by Sarri featuring hand spinning (by textile artist and weaver Faye Chatzi) and weaving on a warp-weighted loom. Participants actively engaged with reconstructed tools, gaining invaluable insight into Bronze Age textile production. This hands-on component was especially well received by students and younger attendees, enriching the research discussions with experiential learning.

The FAROS workshop exemplified the best practices in contemporary archaeological research: collaborative, cross-disciplinary, and commitment to the ethical stewardship of cultural heritage. It demonstrated how funerary textiles – often considered as marginal or fragmentary – can yield rich insights about production, ritual, and identity in the ancient world when approached through integrated methodologies.

Equally important was the workshop's success in effective knowledge transfer, engaging diverse audiences, encouraging student participation, and fostering academic collaboration. Early-career researchers and students expressed significant enthusiasm, indicating promising future developments. As archaeological science and conservation technologies continue to advance, the potential for new discoveries from these Mycenaean textile remains is significant. The workshop also foregrounded critical questions for future research: How were Mycenaean textiles exchanged or traded? What roles did women play in textile production beyond palatial economies? Can colour palettes, weaving techniques, or workshop organisation be reconstructed with greater precision? By addressing these questions, the FAROS project is poised to make a lasting, transformative contribution not only to Mycenaean studies but to the broader discipline of textile archaeology and ancient material culture.

Acknowledgments:

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By Christina Margariti

Mining archaeology, restoration and museum practice: Textilien im bergbaulichen Alltag

3 to 4 July 2025, Goslar, Germany

The conference *Tagung für Montanarchäologie, Restaurierung und museale Praxis/Textiles in everyday mining life – research, preservation and presentation* was organised from the Lower Saxony State Office for the Preservation of Historical Monuments and the Rammelsberg World Cultural Heritage Site. The conference took place on the world heritage site Rammelsberg where archaeologists, restorers and conservators presented their current research on archaeological textiles. The focus was on textiles from mines as workwear, their secondary use and context. The interdisciplinary approach of the conference

aimed at answering questions such as: How can textile finds in mining regions be archaeologically preserved? What role do work clothing collections play in mining collections? What insights can be gained from research into miners' workwear? How can work textiles from mining contexts be best preserved and prepared for presentation in exhibitions? How can clothing or clothing fragments be exhibited in a didactically comprehensible way when both their wearers and the working environments no longer exist?
In total, 12 presentations were given by researchers from Germany and Austria, showing finds from the Iron Age to modern times. The conference started with the presentation of the archaeological textiles from Rammelsberg. Georg Drechsler and Ronja Mücke presented the exceptionally well-preserved finds from the mine and illustrated the documentation process, followed by the detailed report of the conservation of the textiles by Dorte Schaarschmidt. The presentation by Katrin Struckmeyer on wool fibre analysis showed results dealing with the medieval textiles from the Rammelsberg.

Fig. 5: The conference announcement (Image: Ronja Lau)

Fig. 6: Karina Grömer giving her lecture (Image: Ronja Lau)

The second part, focusing on excavated textiles from the mining context consisted of two presentations. Ronja Lau (Ruhr-University Bochum) gave a impressive presentation of her interdisciplinary research on Iron Age textiles from the Dürrnberg (Austria) salt mine, focussing on traces of use wear and possible secondary use of the textiles. Beatrix Nutz (Innsbruck) then presented well-preserved textiles and garments from Carinthia, Salzburg and East Tyrol. Each part was followed by a discussion rounding off the topics. The evening programme included a lecture by Karina Grömer (Natural History Museum, Vienna) on clothing from the salt mine in Cherabad, Iran.

The second day, the general topic of researching and preserving miners' work clothes included a presentation by Karina Grömer about the clothing, bags, and recycled goods from the Hallstatt salt mine; new investigations of the textiles from Altenberg by Susanne Bretzel-Scheel (Museum für Kunst und Kultur, Münster) and an insight into the more modern mining clothing from Ibbenbüren by Thomas Schürmann (Cultural Anthropology Institute Oldenburger Münsterland Cloppenburg, Germany). The aspects of handling textiles was given more attention in the second part which was about receiving and exhibiting miners' work clothes. Zofia Durda (Rammelsberg World Heritage Site) and Lea Dirks (World Heritage Foundation, Harz Mountains) shared their considerations regarding the presentation of workwear in the future permanent exhibition at the Rammelsberg World Heritage Site. From the German Mining Museum in Bochum, the audience gained insights of the collection of workwear by Stefan Siemer. Diving into the economics of mining in modern times, Axel Heimsoth gave an overview of the miners' clothing in the Ruhr region.

The conference ended with a final discussion and a tour through the site of Alten Lager at the Rammelsberg. The proceedings of the conference will be published.

By Ronja Lau

Stitched together: needlework making and research

21 to 22 August 2025, Royal School of Needlework, Hampton Court Palace, UK

The Royal School of Needlework (RSN) has been located at Hampton Court Palace for most of the 20th century and is still making its presence felt there today. Despite its long and well-respected history, this was the first conference to be hosted by the school. The theme was needlework in its broadest sense, which the organisers classified as "all art and craft involving a needle, hook, or shuttle". This included embroidery, plain sewing, lace making, knitting, crocheting, and weaving. The programme featured four keynote speakers and six panels, visits to the textile conservation and RSN studios, with a roundtable discussion at the end of the second day.

Isabella Rosner and Rhian Harris opened the event

Fig. 7: This 20th century mola depicting a kingfisher and fish is in the Royal School of Needlework's collection (Image: Isabella Rosner)

and welcomed 45 in-person delegates and many online participants to the two-day programme. The first panel featured linked papers from researchers at Uppsala University who discussed "material literacy" from three different perspectives: the study of practical approaches in embroidery (Cecilia Candréus), as a research tool for reading historical tailoring in context (Cecilia Aneer), and a protocol for recording early evidence for knitting (Jane Malcolm- Davies). Hannah Sutherland gave the first keynote paper which was an excellent follow-up to the material literacy papers. She talked about her experience of conservation as craft and the role of embodied knowledge in work with textiles.

The second panel explored "Innovation through collaboration". It featured Kris Cnossen on Ann Plato's needlework and the challenge of conserving it. Liz Rose and Catherine Harris presented new storage solutions and conservation work on embroidered book bindings. Valerie Wilson and Roisin Aiston discussed collaborative work on "Drawn threads and running stitches".

Keynote speaker Raisa Kabir presented the concept of new cartographies in "plotting the woven world". Three speakers then looked at various sources available for textile study. Sarah-Joy Ford discussed 19th century quilting. Justyna Galińska explained embroidery in rare 18th century Polish portraiture. Beth Saunders focused on historical lace in 19th century photographs.

The second day of the conference opened with the fourth panel for which the theme was "Cross-cultural exchange". Ya Liu illustrated collaboration in the study of Chinese and western embroidery. Chinese needlework in the making of early 18th century British beds was the subject of Shilei Zeng's paper. Georgia Gould presented the textile from Llangorse

Fig. 8: The question-and-answer session after the material literacy panel (Image: Isabella Rosner)

Crannog as an exotic early medieval Welsh textile.
Lynn Hulse provided a keynote paper with an account of the founding of the Royal School of Needlework and Lady Victoria Welby's role in it. This was followed by a panel on "Reflecting on making, together and apart". This began with Brock Whitman Dishart's lessons on care and resistance in a queer embroidery circle. Toni Buckby presented her project based on "an unstitched coif", which used contemporary needlework, collective making and art practice as museum interpretation. Pragya Sharma discussed 19th century hand-knitted Indian socks and gloves in American museum collections.
The final keynote speaker was Rose Sinclair who talked about the role of "Dorcas narratives" in her research. The theme for the final panel was "Needlework now". David Torres del Alcázar explained how women in Lorca, Spain, are guardians of their embroidery traditions. Anum Rauf provided a vivid insight into Sindhi embroidery in contemporary Pakistani fashion. Geneviève Moisan explained her work in reclaiming historical knowledge via digital embroidery.
The conference offered a rich tapestry of subjects and ideas. The programme distributed in advance and at the event lacked detail about all the speakers' affiliations. A booklet or online link to this information and all of the abstracts would be a welcome outcome. All attendees had access to recorded versions of the presentations for several weeks after the event, which was a useful facility for following-up on the conference.

By Jane Malcolm-Davies

31st European Association of Archaeologists (EAA) annual meeting 2025

2 to 6 September 2025, Belgrade, Serbia (online)

The theme of this year's EAA Conference was *Intertwined Pasts*, which evokes the importance of textiles and textile-related technologies in the narratives of past societies. The conference, hosted by the Belgrade Organising Committee, was held online as a consequence of the ongoing political situation in Serbia. There was a significant presence of textile research presentations in the programme, including two focused textile research sessions and a significant portion of interdisciplinary sessions, which featured textile and fabric-related papers and posters. The latter sessions allowed for conversations between experts across the field of archaeology, spreading the word on how intertwined textile and related technologies relate to our conception of past peoples. The following is a brief overview of the textile-related sessions at the conference.
Two sessions were organised around textile tools and fibre research:
EAA Session 170 – "Flax and linen in antiquity: a multidisciplinary approach" was organised by Chiara Serena Spinazzi-Lucchesi (University of Copenhagen), Susanna Harris (University of Glasgow) and Cristina Ambrosioni (University of Padua). The session aimed at a multidisciplinary investigation of this important fibre crop and its role in ancient economies, societies and ecologies. The papers focused on the cultivation of flax, processing and materiality of the fibres, and language and representation of flax and linen in past societies.
EAA Session 197 – "Textile tools made of hard organic material: new perspectives on textile production in European protohistory and Roman period" was organised by Vanessa Baratella (University of Padua, University of Ljubljana), Ricardo Basso Rial (University of Granada) and Margarita Gleba (University of Padua). The session contained papers on a diverse range of textile tools made from hard organic materials. Moving beyond clay, these papers expanded our knowledge about textile tool materials, highlighting tools made from wood, bone, horn, antler, and amber, and specialised storage.
Textile-related presentations were given in multiple interdisciplinary sessions that allowed for conversations outside of textile archaeology:
EAA Session 21 – "The social life of crafts(people): exploring the interplay between crafts and social structures and norms in first millennium BCE Europe" was organised by Karina Grömer (Natural History Museum Vienna, HEAS Human Evolution and

Archaeological Science), Matija Črešnar (University of Ljubljana), Manuel Fernández-Götz (University of Oxford) and Francisco Gomes (UNIARQ, University of Lisbon). This session investigated multiple craft activities within the context of socio-spatial relationships in the first millennium BCE in Europe. Five papers and one poster addressed this relationship within the workspaces of textile-related craftspeople.

EAA Session 59 – "Crafting identity: a multidisciplinary approach to the relationship between material culture and gender in the Mediterranean from prehistory to us" was organised by Carmen Ramírez Cañas (University of Seville), Nina Ferrante (Sapienza University of Rome), Violeta Moreno Megías (University of Seville), Patricia Rosell Garrido (INAPH, University of Alicante) and Francisco Gomes (UNIARQ, University of Lisbon). The session examined the interplay between craft practice, object materiality, and the construction of gender identities. Two papers and a poster investigated how gender identities have evolved around textile production within a prehistoric Mediterranean context.

EAA Session 79 – "Worlds of sensation: the human body, the senses and neuroscience" was organised by Susanna Harris (University of Glasgow), Karina Grömer (Natural History Museum Vienna) and Sonia Machause López (University of Valencia). This session brought together five papers that explored the multisensory world of cloth, alongside sensory archaeological research. The papers explored fabric patterns, sensory relationships with other materials, and present-day heritage experiences.

EAA Session 135 – "Shaping techno-traditions at the emergence of the Neolithic between SW Asia and Central Europe" was organised by Bogdana Milic (Spanish National Research Council, IMF-CSIC), Michael Brandl and Sonja Kačar (Austrian Archaeological Institute, Austrian Academy of Sciences), Clare Burke (University of York) and Emma Baysal (Bilkent University). This session allowed for important conversations between textile tool researchers and field archaeology experts within a specific regional and temporal context. Three papers investigated the role of textile tools in northern Italy, north-western Greece and Macedonia, and underlined the importance of sharing textile tool analysis methods and involving relevant researchers within excavations in this region.

EAA Session 142 – "Plant power: interdisciplinary approaches to the study of non-food plant resources" was organised by Cristina Ambrosioni (University of Padua) and Anita Radini (University College Dublin). It was a session that spoke to the diversity of plant materials and their role in daily life and community practices beyond nutritional value, within Europe and ancient Egypt.

Related papers and posters addressed the identification, technology and use of plants in textiles and adjacent crafts, and in fabric dyes.

EAA Session 182 – "Invisible economies: food, fibres, textiles, timber, leather, people and more" was organised by Bela Dimova (University of Padua) and Mila Andonova-Katsarski (Institute of Biodiversity and Ecosystem Research, Bulgarian Academy of Sciences). This session aimed to shed new light on the economic roles of often understudied materials in human history.

Fig. 9: The announcement of the EAA Session 21, The social life of crafts(people): exploring the interplay between crafts and social structures and norms in first millennium BCE Europe (Image: Karina Grömer, Maria Elena Bertoli & Nysa Loudo)

Two papers focused on how textile remains and plant fibre usage fit into that narrative from a wide temporal period in Europe across to east Asia.
One workshop was held the final morning of the conference:
Workshop: EAA Session 144 – "Open science in textile archaeology education: Bridging research, outreach, and engagement" was organised by Margarita Gleba (University of Padua) and Hana Lukesova (University Museum of Bergen). This workshop was proposed by the EAA Community for Textile Archaeology and Conservation (ComTex) to share good practice in archaeology science communication and develop open science resources. The following speakers contributed to the discussion: Tereza Štolcová, Karina Grömer, Francisco Gomes, Ronja Lau, Islam Shaheen, Yaqi Yan and Orsolya Zay.
The textile-related sessions, papers and posters from this year's EAA conference detailed some exciting work being conducted across the discipline, which expands the horizons of textile research. Although the online format presented difficulties, the many textile-related presentations in the interdisciplinary sessions opened up important cross-disciplinary discussions that provide archaeologists across Europe with a new lens for interpreting these materials.

By Maria Elena Bertoli & Nysa Loudon

The Ninth International *Purpureae Vestes* Symposium

22 to 24 October 2025, School of Arts and Humanities, University of Lisbon, Portugal

In October 2025 Lisbon welcomed the Ninth International *Purpureae Vestes* Symposia with the topic *Weaving Together Traditional and New Approaches to Textile Production and Consumption in the Ancient Mediterranean and Beyond*. Since its inception in 2002, under the initiative of Carmen Alfaro Giner, this series of symposia have become one of the major forums for textile archaeology and textile heritage of the ancient world in the Mediterranean area and its hinterland. This was the first time the event was held in Portugal, after eight successful editions in Spain (2002, 2010, 2014 and 2019), Greece (2005 and 2022) and Italy (2008 and 2016).
The event was co-organised by UNIARQ, the Centre for Archaeology of the University of Lisbon, the School of Arts and Humanities of the University of Lisbon, LAQV – Laboratory for Green Chemistry/ Requimte – Network for Chemistry and Technology, and the Department of Conservation and Restoration of the NOVA School of Science and Technology. This year's theme aimed to mix traditional and innovative interdisciplinary approaches, which is reflected in the synergy between institutions in the Humanities and Natural Sciences collaborating to advance knowledge on Textile Heritage.
During the three days of the symposium, a total of 135 authors and co-authors from 20 different countries across Europe and beyond presented their research. The 40 papers and 25 posters showcased some of the new and innovative research projects currently exploring textile technologies, economies and cultures across the ancient Mediterranean, blending significant empirical data with new and exciting theoretical and methodological approaches.
The participants were formally welcomed by the Directors of LAQV and UNIARQ, followed by the presentation of the proceedings of the eighth edition of the symposium in Athens by the editors Christina Margariti, Stella Spantidaki and Alina Iancu.
The scientific programme then began with an opening lecture by the organising committee, which explained why Portugal has historically lagged behind in textile archaeology and textile heritage research, and how this situation has changed in the recent years thanks to the COST Action EuroWeb.
The sessions that followed over the three day event included themes about: Ancient textiles in Egypt and Sudan, Ancient textiles from Egypt to western Asia, Neolithic and Bronze Age textiles in the eastern Mediterranean and the Aegean, Bronze Age textiles in the western Mediterranean and in Europe, textiles in Greece and Cyprus from the Bronze Age

to the Hellenistic Period, Iron Age Textiles in the Mediterranean and beyond, Textiles in the Roman Mediterranean and beyond, and beyond Antiquity: Textiles in the Middle Ages.

A poster session included methodological topics to contributions on Bronze and Iron Age textiles and dress, and all the way to studies dealing with Roman and Late Antiquity. These gave the presenters the opportunity to share and discuss their work with the other attendees.

The scientific programme finished with the team of the Horizon Europe project TEXTaiLES, represented by Christina Margariti, presenting their groundbreaking research on the digitisation of textile heritage. This pioneering work opened a window into the future of a research field that will certainly be discussed in the next symposium.

The scientific programme was complemented with a visit to the Museum of Lisbon – Pimenta Palace, and postsymposium visits to the Museum of Lisbon – Roman Theatre, and MUDE – The Design Museum. The Archaeological Museum of Carmo and the Portuguese Museum of Decorative Arts also supported the symposium by offering free entrance to participants during the event.

The intense scientific programme was also complemented by a Symposium dinner, sponsored by the TransTexTec Exploratory Project (2023.13050. PEX), which provided a welcome occasion for socialisation and networking among the participants in the *Purpureae Vestes* community.

Overall, the symposium showed the vitality and dynamism of the field of textile heritage research, in general, and textile archaeology, in particular, and the many new projects and studies, as well as the strong participation of early career researchers and colleagues from countries which do not yet have a strong tradition of textile archaeology. It suggests that this area of research has now gained tremendous momentum, and that it will continue to expand and grow in new and exciting ways in the future.

Finally, the importance of this event for textile heritage in Portugal cannot be overstated. The success of the conference thus mirrors the intense work of setting up Portugal as an active and reliable part of the international network in textile heritage research and is a great boost to the fledgling lines of research that have started to develop htere. With this event, it is clear that Portuguese researchers are fully integrated in the international, interdisciplinary and inter-sectorial collaborations and connections offered by this symposium.

By Francisco B. Gomes,
Paula Nabais and Catarina Costeira

Fig. 10: Participants of the Ninth International *Purpureae Vestes* Symposium at the School of Arts and Humanities of the University of Lisbon in Portugal (Image: Francisco B. Gomes, Paula Nabais and Catarina Costeira)

Textiles from the Nile Valley XIII: *Pile Textiles from Egypt and Neighbouring Countries*

14 to 16 November 2025, Antwerp, Belgium

The *Textiles from the Nile Valley* conference is held every two years with the aim of encouraging discussion about archaeological textiles from Egypt and neighbours, with a focus on textiles from the first Millennium CE. This 13th edition also marks the 20th year that the conference has been graciously hosted by the Phoebus Foundation at HeadquARTers in Antwerp.

On Saturday morning the large international audience was welcomed by the organisers Cäcilia Fluck, Petra Linscheid and Antoine De Moor, who introduced the participants to the topic of this year's conference: pile weave. Although textiles with woven pile are frequently found in museum collections, many questions remain about the chronological and regional variations in style and technique, and how they were used for clothing and furnishing textiles.

Kristin South (Brigham Young University) opened the first session by providing an overview of pile textiles in the context of the Graeco-Roman/Early Byzantine cemetery of Fag el-Gamus in Egypt. While they accounted for just 0.1% of all textiles found at the site, they were clearly highly valued and positioned either on the outside or inside of burials. Working at the same site, Giovanni Tata (Brigham Young University) showed two especially rich burials containing textiles featuring polychrome decoration in a wool pile weave. Fleur Letellier-Willemin (Sorbonne) continued with news from the excavations, presenting textiles with cut and uncut pile from El-Deir (Kharga Oasis) also in Egypt that were woven with recurring motifs. Next, Alexandra Plesa took us to Berenike on the Red Sea coast, where several different types of linen, cotton and wool pile textiles were found in contexts dating between the third and sixth centuries CE. To conclude the morning session, Viola Costanza and Nicole Reifarth (Technische Hochschule Köln) discussed two extremely rare finds of *scutulatus* damask silk with a pile weave, one found in a saintly tomb in Trier in Germany, the other from the Vatican in Rome. Their research revealed that the silk pile was worn on the inside of a sleeve.

Fig. 11: Textiles from the Nile Valley logo (Image: Cäcilia Fluck and Petra Linscheid)

After a short lunch break, Veerle van Kersen (KU Leuven) shifted the focus to the Pharaonic era, highlighting the differences between the pile weaves of the Middle and New Kingdoms using new evidence from Qubbet el-Hawa in Egypt. The possible Nubian connection of these finds was further supported in the next presentation by Elsa Yvanez (Centre for Textile Research/University of Copenhagen) and Théophile Burnat (University of Neuchatel), who are working on a Nubian cemetery in Kerma in Sudan from around the same period. Through four finds in different techniques, they showed that pile weave could be used in conjunction with leather as both clothing and sleeping mats. Moving on to the first millennium CE, Maria Mossakowska-Gaubert (CNRS, Paris) discussed the pile fabrics in the National Museum of Denmark, explaining how they were crafted by specialist weavers. The second part of her talk focused on the terminology used in Greek papyri to describe these weavers and the various types of *tapês* they produced. Next, Cäcilia Fluck and Kathrin Mälck (Staatliche Museen zu Berlin) presented a selection of pile fabrics from the Museum für Byzantinische Kunst in Berlin, detailing the various combinations of techniques and fibres that could be employed. A short excursion to Iraq was provided by Annete Paetz gen. Schiek (Deutsches Textilmuseum Krefeld), who analysed a number of tiny calcinated textile fragments from Assur, dated to the second century CE. As John Peter Wild commented afterwards, there is a significant gap in our knowledge of textiles from this region and time period, which could be addressed by raising awareness among archaeologists of the potential presence of textiles.

The final session of the day took us into the Islamic period. Gisela Helmecke (Museum für Islamische Kunst Berlin) examined an inscribed fragment dating around 800 CE, which included not only the name of the caliph, but also that of the weaver. In the next paper, Petra Linscheid (University of Bonn) presented

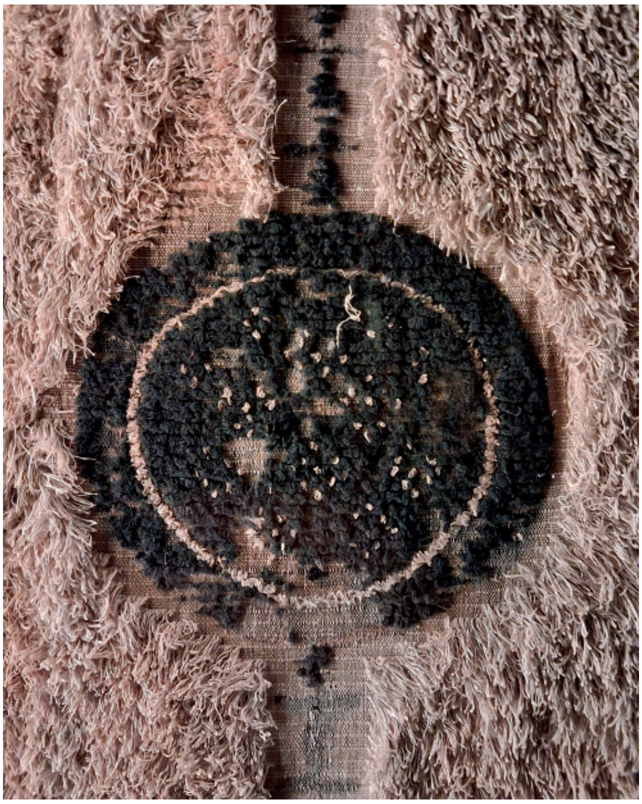

Fig. 12: Detail from a large furnishing textile decorated with linen and wool pile weave in the collection of the Phoebus Foundation, dated to the 3rd-5th century CE (Image: Veerle van Kersen)

a small fragment of multicoloured pile from Abbasid Egypt which is kept in the Phoebus Foundation's collection. This fragment is important because it bridges the gap between Byzantine and later medieval carpets in terms of technique. Following this, Katarzyna Lubos (University of Bonn) shared several newly 14C-dated textiles which were added to the *Textile Dates Database*, which has been an essential resource for scholars for many years. She warmly invited all researchers who have carbon-dated textiles to share them through this tool (https://www.iak.uni-bonn.de/christliche-archaeologie/de/forschung/textilforschung/textile-dates/datenbank-fuer-datierte-textilien-1, accessed 01/12/2025). Stephanie Caruso (Chicago Museum of Art) then finished the day showing the many Egyptian textiles in Chicago Museum of Art and how they relate to other pieces in European collections.

On the second day, participants were given the opportunity to take a step back and consider the wider theme of textiles from Egypt and beyond. Textile conservators Thalia Bajon-Bouzid, Laure Cadot and Patricia Dal Pra reported on the study and conservation of the mummified body of Myrithis, which was discovered by Gayet in Antinoë and is now housed in the Musée de l'Homme in Paris. This was followed by Magdalena Wozniak (Universities of Warsaw and Copenhagen) who discussed the variety of textiles found in burials at Saqqara in Egypt, which date from both the Old Kingdom and the Greco-Roman periods. Returning to the topic of pile textiles, Anne Kwaspen (University of Cambridge) surprised by providing an overview of all the pile-woven tunics she had studied over the past ten years, exploring the chronological evolution of styles and techniques. Subsequently, Giulia Pallotini (Museo Egizio) reported on the conservation work carried out by her and her colleagues Valentina Turina and Federico Taverni on the textile collections of the Egyptian Museum in Turin in Italy. The museum houses almost 7,000 textile objects, most of which date back to the Pharaonic period, for which they have implemented an innovative open storage strategy that allows these fragile materials to be presented to the public. Reflecting on the last topic, Hero Granger-Taylor (Early Textiles Study Group) presented her research on Chinese silks and how they were transported to Europe in Roman times, generating interesting discussions.

After a short break, the final two contributions were presented, bridging the gap to European textiles. Regina Hofmann-de Keijzer, Ines Bogensperger, Beatrix Petznek, Ivan Radman-Livaja and Andreas Heiss have researched the inscriptions found on lead tags, or *tesserae,* from a fuller's workshop in Carnuntum in Austria. The authors found that that several types of clothing and fabric treatment were indicated, including fulling, mending, fumigating, perfuming, and dyeing in various colours. Chiara Stombellini (Ca' Foscari University, Venice) gave the final presentation, in which she highlighted the interconnections of texts, textiles and other art forms in Early Medieval Europe and beyond through her study of Early Medieval embroidery.

Following the organisers' concluding remarks, participants were given the opportunity to visit the impressive textile collection at HeadquARTers. The next conference is planned to take place at the same location in November 2027. To stay in the loop about future *Textiles from the Nile Valley* conferences, please contact Cäcilia Fluck (c.fluck@smb.spk-berlin.de) or Petra Linscheid (linschei@uni-bonn.de).

By Veerle van Kersen

Noémi Speiser
1926–2025

Noémi Speiser (11 August 1926 – 18 September 2025) was a textile artist and a pioneer in the field of off-loom techniques such as braiding, ply-splitting and sprang. Without her interest and work, especially in the field of loop braiding, these techniques would have remained obscure. All further research in that field is based on her methods and analyses.

Although she was born in the UK, she lived most of her life in Switzerland. She began her textile career by studying handweaving, textile design and embroidery. She taught at the Art School in Basel from 1967 to her retirement in 1986. She also taught braiding courses at the Basel Museum of Culture. Her connection to this museum opened doors to the world of braids, where she took on the challenge of classifying textiles stored at the museum. Later, the museum director, Professor Bülhler, facilitated her travel to Japan. She took copious notes, and when she returned to Switzerland, she reproduced what she had seen, pioneering techniques then unknown in Europe.

Noémi Speiser (Image: Ferdinando Godenzi)

Noémi's work at the Museum of Culture launched what she herself called "obstinate research on obsolete off-loom fabric-making techniques which were, at that time, regarded as inferior or negligible". She found braids as "the only textile for which you control every single thread". Fuelled by her desire to create order, her independent thinking led her to a solid understanding of the techniques of braiding which she shared with the world. She was a friend of the late Peter Collingwood and they corresponded for many years, discussing terminology and definitions in connection with aspects of braiding, sprang and ply-split braiding. Peter Collingwood included photos of many of Noémi's artworks in his book *The Techniques of Sprang*.

Noémi published *The Manual of Braiding* in 1983 with a foreword by Peter Collingwood. It was the result of many years of braiding investigations, containing a thorough analysis and description of techniques from all over the world, including Tibet, South America, Japan, and Europe among others. Techniques such as ply-split braiding and loop braiding were presented and explained in detail for the first time outside of ethnographical research. The manual was republished by Haupt Verlag in 2018.

Noémi's work is particularly valuable for its contribution to the understanding of loop braiding. By examining manuscripts from the 15th to 17th centuries and historical samples of braids, she interpreted the enigmatic directions from handwritten texts, translating them into clear instructions for today's braiders. She made this information available to all through the publication of her books *European Loop Braiding, Part I, II, III,* and *IV* co-authored with Joy Boutrup, and edited by Jennie Parry, between 2009 and 2012. A further contribution to the topic is her book on *Old English Pattern Books for Loop Braiding* published in 2000.

Haupt Verlag published her last book, *An Annotated Classification of Textile Techniques*, in 2024. In it, she laid out myriad textile structures in an orderly fashion. She wrote "The same structure can be executed in many different ways. In a final structure, the process is lost ... Nonetheless, it is always extremely important to emphasise the essential and to disclose it clearly and accurately".

Noémi Speiser was a brilliant researcher and instructor. The challenges she posed are to delve ever deeper into techniques and structures, and then to communicate these in a clear, concise manner. Textile researchers are grateful for her contribution to the understanding of textile structures, and braided structures in particular. As a German speaker, she felt that she could have presented her work more clearly

in German. However, she could converse with English speakers such as Peter Collingwood with whom she discussed her insights into braids.
Perhaps her greatest contribution to the braiders of the world transcends language; for example, her explanatory drawing of eight girls doing a maypole dance. Her concept of track plans, illustrated with many drawings, provided a critical tool for braiding analysts. Track plans offer a way in which to examine and decode braided structures. They make it possible to reproduce braids whose construction methods would otherwise have been buried in history. In her own words, Noémi explained "a track plan illuminates the internal construction of even the most complex braids in a flash". It is her track plans that are perhaps her most valuable legacy. Peter Collingwood said it best - in a letter to Noémi on the publication of *The Manual of Braiding* - he wrote: "You have both explored a strange country and provided a foolproof way for those who want to follow".

Acknowledgements
Joy Boutrup, Hazel Clarke, conversations with braiders who took classes with Noémi, and her own writing contributed to this obituary. It is also published in *The Braid Society Newsletter* (2025).

By Carol James

Elizabeth Wincott Heckett
1934–2025

Textiles were a means of self-expression, an intellectual passion and a source of joy for Elizabeth Wincott Heckett throughout her life.

She was born Elizabeth Loveday Wincott, the second child of the financial journalist Harold Wincott and his wife, Joyce White Wincott, who came from a family of keen dressmakers. To her colleagues, family and friends, she would always be "Libby". As with most children of her generation, World War II had a profound influence on Libby's childhood. Whisked out of London for fear of the Blitz, she grew up in the English countryside. When she was not in school, Libby's mother taught her to sew and to knit, not only out of necessity due to wartime rationing but also as a source of entertainment. When the war ended, Libby and her sister Rosemary, then aged 11 and 13, remade some old clothes into new outfits. On VE Day, they wore their recycled finery, swishing up and down Brighton Pier and "feeling very fine indeed".


Elizabeth Wincott Heckett on her graduation day in 1986 (Image: The Heckett family)

In young adulthood, Libby held a number of administrative jobs in England and the United States, one of which involved the publicity stunt of frying an egg on the bonnet of a car during a heat wave. In 1961, she married Eric Heckett, an American who had come to the US from Germany as a child in 1939. An accomplished seamstress by this time, Libby insisted on making her wedding dress. The couple lived for a while in Greece, where Libby played the roles of muse and helpmate while Eric, a poet, tried to write "the great American novel". That did not pan out, so he became a businessman. They settled in Ireland and had four children. Libby mothered, gardened and managed their property. She found creative release in the Tick Tock Room (so called because of its noisy clock) where she sewed outfits for herself and her children.

When those children were nearly grown, her marriage ended. Aged 48, Libby enrolled in the Archaeology Department at University College Cork. A pioneer "mature student," she was older than all of her classmates and most of her professors. Her cut-glass British accent was not an asset in the Ireland of the 1980s. Despite these challenges, Libby thrived. The archaeologist Elizabeth Shee Twohig took Libby under her wing and urged her specialise in textiles.

Seeking a project for her master`s thesis, Libby went to Dublin to meet with Frances Pritchard, who was in charge of more than 2,000 textiles recovered from the excavations of a Hiberno-Norse site at Wood Quay. Pritchard suggested that she analyse a group of mysteriously similar silk and wool textiles.

Libby's research into the Viking Age head covering that became known as "the Dublin cap" won international acclaim. She presented her findings at the NESAT conference in 1987 (Wincott Heckett 1990a), and later published them in full (Wincott Heckett 2003).

Rising from the ashes of a divorce, she had reinvented herself. For the rest of her life, Libby's favourite picture would be the one taken in her graduation gown. According to her daughter, Jo Heckett, she would point to it and say: "That is *me.*"

Research became her passion. As well as analysing many textiles for several Irish archaeologists, Libby wrote about ancient Irish textiles held in museum collections. Among these were two held by the National Museum of Ireland: the Bronze Age horsehair ornament from Armoy, County Antrim (Wincott Heckett 1998), and the wool mantle and leather cloak dating from the second to fourth centuries CE, from County Kildare (Wincott Heckett 2001). She also wrote about a shaggy textile, dating from the tenth century CE, discovered in County Meath, in the collection of the British Museum (Wincott Heckett 2004).

In time, Libby became the "go to" person for Irish textiles. Her reports appeared in two of the most important books on Irish archaeology published in recent years. She wrote about the linen and wool textile fragments, as well as Ireland's earliest known leather weaving tablet, discovered at the site of a raised ringfort in County Antrim (Wincott Heckett 2011). Her report on the impressions of cloth on the broken weapons found in an early Viking Age burial in Waterford was published in 2014 (Wincott Heckett 2014).

In Cork, Libby catalogued and analysed the liturgical textiles created in the early 20th century for the Honan Chapel by the Dun Emer Guild and the women who worked for William Egan & Sons, a Cork-based manufacturer of items for churches (Teehan and Wincott Heckett 2004).

An entertaining speaker and storyteller, Libby made presentations at nearly every NESAT conference held between 1987 and 2017. Among these were "The apparel oft proclaims the man: Late 16th and early 17th century textiles from Bridge Street Upper, Dublin" (Wincott Heckett 2005), and "Late Bronze Age textiles, hair and fibre remains, and spindle whorls from Killymoon, Co. Tyrone, Northern Ireland" (Wincott Heckett 2007). At the final conference she attended, NESAT recognised her for lifetime achievement (Wincott Heckett 2017). She also addressed the European Association of Archaeologists, the Textile Society of America and The 15th Viking Congress in Cork and spoke at many other meetings. For 14 years, beginning in 1993, she served as a member of the editorial board of the *Archaeological Textiles Newsletter*, the predecessor to this publication, and became a member of its Scientific Committee.

As a part-time faculty member in the Archaeology Department at UCC, Libby was known for her enthusiasm for her topic and her generosity towards students and colleagues.

In 2014, I sent a tentative and fearful letter to the renowned Elizabeth Wincott Heckett. I didn't want to bother her. I knew she was busy! But I was doing research for an historical novel set in Early Medieval Ireland, and if it were not *too* much trouble, was there any chance she would speak to me about the textiles associated with the seventh century "Lady of Cloonshannagh Bog" (Wincott Heckett 2013)? An invitation to Cobh followed. Libby met me at her door with a hug.

We became friends. Over the next few years, whenever I would drop into Cobh for a visit to her extensive library, Libby would regale me with stories about the textiles she had studied. The 17th century gold lace from castles sacked by Oliver Cromwell's forces (Wincott Heckett 2015). The out-of-date clothing depicted on the funeral effigy of the mighty Margaret Fitzgerald, who died in 1542 (Wincott Heckett 2002). The shockingly bright orange textile, which might have been worn beneath armour, excavated from the 13th century Cork city wall (Wincott Heckett 1990b).

Clearly, she had amassed a substantial body of work and there had not been a book on Irish textiles since Mairéad Dunlevy published *Dress in Ireland* (1989). I couldn't help but ask: had she thought of doing a book? She had, she said, but she did not think she was able to do it now. I said: let me try. A few years earlier, I had edited a large book for the archaeologist Caimin O'Brien. So with Libby's permission, the encouragement of her family, and the fabulous support of Frances Pritchard (by this time Honorary Research Fellow of the University of Manchester) and Raghnall Ó Floinn, former director of the National Museum of Ireland, I got to work.

On 17 December 2024 in the Aula Maxima of University College Cork the book was finally launched (Wincott Heckett and Williams 2024). By this time, although she was still physically strong, Libby had lost her power of speech. Her daughters Jo and Louisa arranged for her to have a special viewing of the book before the launch began. When she saw the pyramid of blue volumes on the table, Libby's eyes lit up. Raising her hands to her head, she began to mime a head covering, with a peak at the crown, and ties that could be knotted beneath the chin: the Dublin cap. I opened the book and showed her that chapter, with its wonderful illustration by Kelvin Wilson. She beamed. Then she gave me a hug – for the last time.

Five months later, surrounded by her children, Libby passed away peacefully in the house where she had lived since 1964. Her work on Irish textiles will be a resource and an inspiration for years to come.

Beannachtaï Dé ar do hAnam hip dhílis, a Libby.

(Libby, may the blessings of God be on your gentle soul)

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By Mary Ann Williams

Recent publications

***Bog Fashion – Recreating Bronze and Iron Age Clothes* by Nicole DeRushie (2025). ChronoCopia Publishing AB**

For thousands of years, prehistoric people made beautiful, practical garments designed to keep the elements at bay, taking full advantage of the natural properties of plant and animal fibres. Join historian and fibre artist Nicole DeRushie as she studies the textile finds from bogs and other sources in order to explore Bronze and Iron Age fashion from northern and western Europe.

In *Bog Fashion* you will discover the impressive skills behind these garments and find an appreciation for the many ways these clothes still speak to us today. This book provides the history behind some of the most prominent finds as well as patterns and instructions for 13 ancient garments and accessories you can make at home.

ISBN: 9789198105698

Price: € 48.95

https://chronocopia.se/books/bog-fashion/

***Funerary Textiles in Situ: Towards a Better Method for the Study of Textile-Related Burial Practices* by Elsa Yvanez and Magdalena M. Wozniak (2025). Springer Nature**

This open access book explores the role of textiles in death to investigate questions into how the body was prepared before the funeral, how the body was seen and perceived by its relatives and community, and the role of textiles in its metamorphosis into a deceased. The volume's geographic coverage is broad, encompassing areas where textile and skeletal conservation is optimal (the ancient Nile Valley) and areas where only minute fragments could be preserved adhering to metal objects. The case studies cover Egypt, Sudan, Greece, the Iberian Peninsula, Scandinavia, and central Europe, ranging from the 12th century BCE to the end of the 19th century CE. Going beyond this geohistorical framework, the book presents new methods for the study, retrieval and conservation of funerary textiles *in situ* during excavations. It offers useful tools for future research in both textile archaeology and bioarcheology and promotes interdisciplinary collaborations between the two fields for a better understanding of burial practices. Contributors to this volume include experts from the fields of bioanthropology, archaeology, textile research and conservation.

ISBN: 3031694619

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***Medieval Clothing and Textiles 19* by Melanie Schuessler Bond and Cordelia Warr (2025). Boydell & Brewer**

The best new research on medieval clothing and textiles, drawing from a range of disciplines. The essays collected here continue to showcase the Journal's wide-ranging and eclectic tradition. The topics addressed are the sensory perceptions of textiles in Early Medieval Britain; evidence of the global textile trade as reflected in church facades in Lucca, Italy; the ways in which spinning and weaving in late medieval Cologne influenced the presentation of the cult of the Eleven Thousand Virgins within the city; sumptuary legislation in 13th century Montauban, in the Occitan region of southern France; visual representations of male underwear in northern European art; and the late 16th and 17th century trade in knitted jersey stockings in Norwich and Yarmouth.

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***Outward Appearance vs Inward Significance: Addressing Identities through Attire in the Ancient World* by Aleksandra Hallmann (2025). Institute for the Study of Ancient Cultures of the University of Chicago**

Clothes are often considered mundane, yet they play a crucial role in people's lives beyond mere bodily protection. The meaning of a piece of clothing changes

the moment it is worn, as it becomes associated with its wearer. Because attire can demonstrate affiliation with a particular religious, ethnic, or political group, it serves as an important means of constructing self-identity and plays a vital role in social acculturation and assimilation. To understand what clothing reveals about the ethnicity, beliefs, social rank, profession, gender, or age of the wearer, one must examine its sociocultural context and the nonverbal language it conveys. This volume takes a multidisciplinary and comparative approach to dress studies in the ancient world. Spanning a wide geographic spectrum, from the Near East and north Africa to the Mediterranean world and the Americas, it explores the cultural, social, and political significance of attire and engages the reader in a debate about the cross-culturally developed role of dress in construing and projecting various identities. Essays by experts from a range of disciplines, including art history, anthropology, archaeology, classics, Near Eastern studies, and conservation, approach the subject from different perspectives, apply varying methodologies, and draw on a diverse array of primary sources, including artefacts, iconography, and texts, to offer a nuanced understanding of the clothed self in ancient societies. This book will be of interest not only to experts in dress studies but to everyone interested in the cultural anthropology of dress and fashion.
ISBN: 9781614911272
Price: $ 44.95
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***Reading the Thread: Cloth and Communication* by Lesley Millar and Alice Kettle (2025). Bloomsbury Publishing**
Reading the Thread brings together artists, theorists and designers to explore the nature and use of cloth as a means of record and communication. Cloth is constructed from threads and, in acknowledging its qualities of recording or communicating a story, we are reading the threads – the read thread. There is also, however, an east Asian myth that when you are born you are linked by an invisible red thread to your soul mate; no matter what you do, this red thread connects you to your fate and, although the thread may become tangled or infinitely long, it will never break. Exploring histories of making and cultural practices, a multidisciplinary team of international scholars use the metaphorical thread to link the experiences of cloth production, lineage practices, contemporary challenges and sustainable futures, and to explore, through imagery and ideas, the agency of cloth to shape and communicate the sensations and emotions connected with human experience. Divided into four sections on reading cloth, challenging the stories it tells, following the thread of its narrative and finally anticipating its future, *The Read Thread* allows a variety of viewpoints and a diversity of voices, without favouring theory or specific cultural approaches, to interrogate cloth as a record of experience within its social, historical, psychological and cultural context; the authors explore our encounters with cloth and its role in the exploration of identity and biography, representative of passage, exchange, life and death. Provocative and timely, and beautifully illustrated with over 50 colour images, it is vital reading for students and scholars of textiles, fashion, material culture, art and anthropology.
ISBN: 9781350320482
Price: £ 24.99
https://www.bloomsbury.com/uk/reading-the-thread-9781350320482/

***Textiles and Textile Imagery in Early Medieval English Literature: Traditions and Contexts* by Maren Clegg Hyer (2025). Boydell & Brewer**
This book identifies and analyses a wide range of textile metaphors and imagery from peace-weaving in *Beowulf* to word-crafting in *Elene*. Textile metaphors, or metaphors involving the process and product of cloth making, occur widely in literary traditions around the world. The same phenomenon holds true among the peoples of early medieval England.As close observers of a long and culturally significant textile tradition, pre-conquest English writers drew upon their close familiarity with spinning and weaving to create a wide range of metaphorical textile images in both Old English and Anglo-Latin literature. This book examines early medieval English textile imagery in close detail, situating it within its cultural and material contexts and addressing the ways in which lived experience informed these metaphors, whether inherited, invented, or both. It explores imagery linked to themes of creation, peace, death, magic, and fate in a comprehensive variety of texts, including *Beowulf* and *Elene*, Anglo-Latin letters and riddles, the Exeter Book riddles, prognostics, penitentials, hagiographic and homiletic texts, medical collections, and glossaries. Overall, it demonstrates how an understanding of this important body of textile metaphors alters and shapes the ways in which we read the literature of this period.
ISBN: 9781843847441
Price: £ 85.00

https://boydellandbrewer.com/9781843847441/textiles-and-textile-imagery-in-early-medieval-english-literature/

***Textiles and War in Europe and the Mediterranean from Prehistory to Late Antiquity: Proceedings of the International Conference held at the Institute for Advanced Studies in Levant Culture and Civilisation in Bucharest, Romania, 17-19 May 2023* by Luviu Mihail Iancu and Francesco Meo (2025). Archaeopress**

This volume explores the role of textiles and leather in warfare from prehistory to late antiquity, examining production, acquisition, symbolism, and practical use. Studies draw on archaeological, iconographic, and written evidence from Iberia to Mesopotamia, with a focus on Greece, Rome, and the Italian peninsula.

This volume primarily consists of a collection of papers presented at the conference *Textiles and War in Europe and the Mediterranean from Prehistory to Late Antiquity*, held in Bucharest in May 2023. Its main goal is to explore the opportunity to establish a new and well-defined direction for academic investigation: the autonomously conceived research of the textile items used or manipulated by prehistoric and ancient armed groups.

The book revolves around two central issues. The first outlines the main sources and methodologies with the potential to provide noteworthy results, starting by sketching a map of the current state of the research in the field. The second is topical and deals with highlights a few relevant themes that could be tackled, such as particular studies on specific textile items used in the military field, the systems of production and acquisition of garments and other textile materials for the armies, the expression of military rank and status through textile items, the economic and cultural effects of military campaigns in the field of textiles acquisition and consumption.

The 13 papers operate with a wide array of archaeological, iconographic and written sources to examine various aspects of the use of textiles and leather by armed individuals and armies in diverse regions of the prehistoric and ancient world, from western Iberia to northern Mesopotamia and from the bogs of northwestern Europe and the rugged mountains of the Balkan peninsula to the Arabian desert, preserving however as focal points Greece, Rome and the Italian peninsula.

ISBN: 9781805830801

Price: £ 55.00

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***Textiles in context: An analysis of archaeological textile finds from early 16th-century Groningen* by Hanna Zimmerman, translated by Dorothée Wortelboer, edited by Jane Malcolm-Davies (2025). Fat Goose Press**

The discarded 16th century textiles excavated in Groningen in the Netherlands in 1976-1977, 1984, 1995-1996 and 2000 included parts of doublets and bodices, stockings and hose, gloves and mittens, caps and hats, plus examples of trimmings and other embellishments. These finds shed light on historical clothing and the people who wore, made and mended them more than 400 years ago. Key discoveries among the finds are an unprecedented number of hose fragments and knitted items from the 16th century which provide a wealth of detail about their materials and construction. They are also an unlikely treasure trove of information about the fabrics and sewing techniques used for ordinary people's clothing in the past. It is thanks to Hanna Zimmerman's similarly unlikely doctorate (at the age of 75) that these details of dress are available at all. Hanna was a (very) mature student with a successful career as an educational psychologist behind her when she took up the challenge of documenting the Groningen material. Since 2007, a mere 500 copies of her thesis, written in Dutch, have provided the only access to details of these numerous archaeological finds. This translation into English offers a new window on the waste from the city's old moat. It benefits from more photographs of the than the original book. It also features other publications Hanna wrote about the finds for academic journals and conference proceedings. A clear message from Hanna's research is the convention of repair, reuse, and remaking of clothing from which there is much to learn today. She also demonstrated that people can reinvent themselves and achieve great success at any age.

ISBN: 978-0-9562674-5-0

£50, available at https://tinyurl.com/mryusmtj

***Threads of Contact: Tracing the Relationship between Egypt and the Southern Levant through Textile Tools* by Chiara Spinazzi-Lucchesi (2025). Oxbow Books**

This book is part of the Ancient Textiles Series. It investigates spinning and weaving tools from the southern Levant and Egypt, exploring their evolution, regional differences, and cross-cultural influences from the Neolithic to the Persian period. Textile tools offer a fascinating and yet intimate approach to ancient people. Textile production has been one of the core activities for millennia, spanning domestic production to royal needs. Textiles were light goods, easy to transport and often exchanged over long distances. Technology and know-how, however, might not have always travelled so easily. This work examines spinning and weaving tools from the southern Levant (inland and coastal) and Egypt. The chronology of the study is broad, ranging from the Neolithic to the beginning of the Persian period (600 BCE). The objects are investigated from both a diachronic and synchronic perspective to understand their evolution and continuity of use, as well as regional differences and textile production methods. The two areas present an only apparent discontinuity, as political boundaries gave way at various historical moments and the two areas had very close contacts, such as during the Second Intermediate Period of Egypt or the Egyptian domination of the Late Bronze Age. This seems to be reflected in textile documentation, which shows the appearance of Egyptian tools in the Levant, such as spinning bowls, and Levantine tools in Egypt, such as loom weights. However, the result is not so predictable.

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Guidelines to Authors

The *Archaeological Textiles Review* aims to provide a source of information relating to all aspects of archaeological textiles. Material from both prehistoric and historic periods and from all parts of the world are covered in the ATR's range of interests.

1. Contributions are accepted in English.

2. Contributions may include articles or project reports as finished works or accounts of research in progress. These may cover any research or activities related to archaeological textiles from recent excavations or in museums and galleries. Projects may encompass technology and analysis, experimental archaeology, documentation, exhibition, conservation and storage.

3. News contributions may include announcements and reviews of exhibitions, seminars, conferences, special courses and lectures, or queries concerning the study of archaeological textiles. Bibliographical information on new books, announcements about awards, and completed PhDs are also welcome.

4. The authors' guidelines can be found at www.atnfriends.com. Please check the current guidelines as they are updated regularly.

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6. Illustrations should be electronic (digital images or scanned copies at 600 dpi resolution or higher). Preferred format is TIFF (maximum size is 17.4 x 21.6 cm). Illustrations should be sent as separate files and not embedded in text. Colour images are welcome. Only illustrations with cleared copyrights, permission for internet publication, and full credit information as required by copyright holders can be used.

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