Fig. 1 Detail of the fulling process: the soapy mixture is rubbed into the cloth by trampling with bare feet. ■

The process of fulling of wool

Experiments in the Netherlands, 2004

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● The article introduces experiments inspired by archaeological finds of "black pits" which were described as being possibly used as fulling pits. The goal was not only to reproduce the process of fulling but also the identification of factors to be addressed in future experiments.

In the Middle Ages, the area we now know as the Southern Netherlands was well-known for so-called woollen "Laken" ("cloth"). This was a much sought after blue, red and green or black expensive woollen cloth. Its production was not simply a matter of spinning and weaving, which merely gave a piece of cloth, looking quite distasteful.

Instead, wool processing activities were executed by professionals, each of which taking care of certain parts of the process. The spinning of the thread was the only practice done in the countryside. The rest was done in the towns. In the 17th century city Den Bosch (Brabant, NL), the spinning work was well-arranged through guilds (*van den Heuvel 1946*).

The techniques to make the final product included a dozen stages. One stage was the so-called 'fulling'. Fulling is the process by which woollen cloth becomes felt. During this process, rough woven cloth shrinks considerably and well-fulled material develops a dense, tight structure, difficult to stretch or be penetrated by water.

The idea to experiment with fulling in the Historisch OpenluchtMuseum Eindhoven was derived from archaeological finds, dating back to medieval Eindhoven (*Arts 1994*).

Sources

In the books of the Old Testament, clues to the fulling process can be identified. When the troops of the king of Assyria (circa 727 BC) came to Jerusalem where king Ezekiel ruled, *'they stopped at the waterworks of the upper pond, on the way of the fulling field'* (*Kings II, 18-17*). This field was used by the fullers to dry the cloth. In the book of Joshua, prophet of 740-696 BC, a well in the fullers' field is mentioned several times (*Joshua 7-3;36-2*).

In Egyptian hieroglyphs the fuller profession is described and on the walls of the pyramids, one finds "fulling vessels". The Greeks were also familiar with fulling, while the Romans called it "ars fullonica". In Pompeii, swallowed by lava in 79 AD, paintings of a fuller have been found in the house of the Vetii. In those days, the fullers did their work by treading on the wool cloth with their feet (fulling by trampling), one round took 1½ to 2 days. The best fullers' clay (creta fullonia) was found on the island of Cimolus, but other kinds from Umbria, Sardinia, Lemnos and Samos were used frequently as well.

In Western Europe, fulling by trampling occurred throughout the historical period. The Romans introduced it in many areas. In the UK, remains have been found of Roman fulling pits in Chedworth, Kent while in Northern France, similar finds have been recorded among others in Douai, Aire, Hesdin and Arras.

Technique

In Europe, fulling by trampling was introduced by the Romans and persisted up to 1800 AD. However, from the full Middle Ages (10th – 12th century) many Europeans used machines (mills) for fulling.

After producing the rough cloth, the 'fuller' cleans it of fat and dirt, at which point it is ready to start fulling. The goal of fulling is to tighten the cloth into felt, with the scales of the woollen threads hooking into each other.

What exactly happens?

- Becoming more heavy and thick because of the intermediate felting of the fibres
- Loosening the tension and making it shrink, both in length and width
- Making it more heat insulated from rain, fog and winter

- Making it stronger and more wear proof
- Making it less penetrable for water and rain
- Adding a thick hairy layer from the roughening and shaving
- Using this felt to produce other fabrics, such as sheets, velours, frisé, ratiné, et cetera

The process is done in three steps:

1) Degreasing of the fibres, removing glue, making the cloth more pure, more loose and voluminous before the actual fulling.
2) Fulling by applying moist, soap, warmth and vibration by means of feet or hammers.
3) Washing to remove the fulling materials and soap.

Fulling agents

Different fulling agents in use could produce different effects: cleaning, slowing or speeding, sometimes hardening, softening or moistening, in some cases causing damage to the fabric or causing folds.

Fulling earth

Actually, this is not a fulling agent but a mechanical washing aid which soaks fat, dirt, stiffing material, soap and colourings loose from the fabric as well as absorbing those. It is a kind of clay which is colloidal (jelly like). It is grey, yellowish or greenish. Reddish or brown fulling earth indicates too much iron, which can be inconvenient to use. The content varies: 11-18% aluminium oxides, 42-44% siliceous oxides, 4-5% chalk or calcium carbonate, 2% magnesium oxides, 6-10% iron oxides, 5% soda and about 23% water.

Locally, fulling earth was dug at Roosendaal and Wouw in Noord-Brabant, NL, near Gent in Flanders, near Eupen (Cologne, Germany), and in Hampshire, UK. After working the material and having it rest for half a year, it was ready to be used. It was mixed with water until a juicy substance and the heavier parts (which could damage the textile) sink to the bottom. Before use, it was sieved once more.

Soap

The kind of soap is determined by the kind of action you have in mind. Washing soap (non-neutral) is actually only used to degrease the cloth. Soap used for fulling must be as neutral as possible (Ph value). There should not be an overdose of alkali in it and it needs to have a low percentage of fatty acids. It is only used on cloth which is already degreased before the actual fulling process.

Soaps are kinds of salt with higher fatty acids, for example, palmitic acid ($C_{16}H_{22}O_2$), stearic acid ($C_{18}H_{36}O_2$) or oil acid. One discerns the hard natrium soaps

and the soft kalium soaps. The soft soaps are better for the fulling process and were usually made from hemp oil, with a well-known green colour. Soft soaps contain 27% water, 10% kalium and 67% fatty acids. It is neutral, but in some cases still contains some alkali and glycerine. In solution, the soap lowers the surface tension of water and intrudes into the capillary space in between the fibres. In this way, it works as an emulsifier and absorbs dirt and fat.

Urine

In the old days, in many places, human urine was used as a fulling agent, preferably old and stale urine. Urine exists for 96% of water. The rest are some different solid agents, of which urea is 2%. Most important difference between fresh and stale urine seems to be the conversion of urea into ammonia and carbon dioxide. This happens relatively quickly (several hours), depending on pH and temperature. This transformation is carried out by the urease enzyme.

$$CO(NH_2)_2 + H_2O \xrightarrow{\text{Urease}} 2NH_3 + CO_2$$

After the conversion, the aqueous ammonia remains in balance with the amonia:

$$NH_3 + H_2O \xrightarrow{\text{pH, T}} NH_4^+ + OH^-$$

This balance is influenced by temperature, the pH and the presence of ammonia in the air (*van Heusden*, personal communication).

Because of the alkalinity, the ammonia forms aluminium salts with certain fatty acids in the mix: oil acid, palmitine acid or stearic acid in the wool fat. These soaps have a cleansing function. The soaps also move the fibres better, encouraging the felting process. As a fulling agent, the urine is not diluted. Urine used as a washing agent is thinned with 1 part of urine against 2 parts of water. Before using it, it is filtered through a linen cloth. Until the 19th century, urine was sold by the bucket (cf. *"kruikenzeikers" – "those who urinate in bottles"* as a nickname for the inhabitants of the textile city of Tilburg, NL).

During the experiment, the urine was replaced by soft green soap (a traditional Dutch brand called "Driehoek").

Water

Water was used extensively in the whole process, with the washing before, the preparation of the fulling earth, when dissolving the soap and finally the washing out of the fulled cloth. The water needed to be clear, free of iron and not hard. Water containing iron causes rust spots while hard water makes the chalk soap deposit on the cloth, making the textiles more grey and tough from the chalk soap depositions and unable to accept paint that well.

Other

Other fulling agents include butter, pig, cow or sheep droppings, gruel, barley flour, oat flour, bean flour, soda, potassium, ammonia, lard, wine sediment, et cetera. In texts concerning fullers, some materials were forbidden while in other cases they were actually prescribed.

The actual process of "Fat" fulling

The fulling process required skill and sound experience. Different methods of fulling had developed in Europe. For our experiment, we decided to use the method of so-called "fat" fulling in two phases, a process that takes 24 to 30 hours. Originally, old urine was used. Nowadays, we use soap and clay. The oil from spinning and the glue from the preparation from weaving were decided to be able to remain in the cloth.

Stage 1: trampling

When one fulls, the cloth is first folded and put in a pit. This is then drenched with water and stale urine. One starts quietly with trampling for one hour after which the cloth is taken from the pit, spread out, stretched, the folds removed and folded back again. This stretching and folding is repeated every hour until the soaping of the urine with the oil and fat of the cloth is in such a progressed stage that the textile has become more loose and voluminous. This is the sign for a tougher trampling motion to speed up the actual felting (for another 2 to 3 hours). Then the cloth is removed from the pit again, stretched out and some more urine and – if necessary – oil is added to get a heavier soaping if the cloth is too dry. The cloth is again folded and the tougher trampling proceeds for another 2 to 3 hours. The cloth is spread out again, the folds are removed and the width is measured. One checks if the width is the same everywhere. If this is not the case as often happens with handwork, either the two wide edges are twisted and folded, or it is drenched in more urine and the other areas are folded. Then it is trampled for ¼ to ½ of an hour, when the wider locations need more working. When this is done, one can check it again and, if necessary, add some more urine or sieved sheep droppings. Then the cloth is folded differently from before (in rectangles) and this way, the cloth is trampled again for some hours, until the width which was wished for is accomplished. This might total 12 to 14 hours. The cloth has then shrunk with 10 – 15%.

Stage 2: washing

It still has to be cleaned, which takes another 12 to 16 hours. The first hour, the flat folded cloth – in a pit – is hit with a jet of clean water to remove the attached pollutants. During this hour one moves the textile from one corner to the other several times. The next hour, the jet needs to be firmer and one rinses until the water is clear. For 7 to 8 hours, the cloth is allowed to leak out. Then, one sprinkles the cloth with diluted fulling earth and tramples it until the fat has absorbed the

urine completely. In this process, the cloth is frequently unfolded and the earth is divided evenly over the textile. If too much foam emerges, the cloth is sprinkled with urine and trampled for 45 minutes, in the same time sprinkling with water. This latter step is repeated about 4 times. The jet of water should be more powerful every time and the water increasingly more clear. Finally, one takes the cleaned cloth from the pit and rinses it out in a river or stream.

Archaeological traces of fulling

Black pits

Concerning the art of fulling, the municipal archaeologist, Nico Arts, described the find of so-called "black pits" which could possibly be used as fulling pits. These pits were found in 1982 at a large excavation within the old city of Eindhoven at the "Heuvel" area.

".. a still unexplained category of traces is what here are called 'black pits'. The shape and content are always the same, but the size varies. The smaller ones are all situated in the northwest of the 'Heuvel' area, while the larger ones are located in the west. In the northern area (...) two were prospected during earth moving works. The pits are always rectangular with a flat bottom and filled with a black, peat like substance, rich with charcoal. They probably date back to the last part of the period 1225 -1350 as they are often cut through by other traces of this period.." (translation rp, *Arts 1994*).

Identical black pits were excavated as well in the medieval city of the nearby Helmond (*Arts 1998*).

Base of twigs

When looking closer at the archaeological data, the smaller pits are more or less circular and not deep. The bottom was paved with a simple mat of twigs. In some instances, the flat surface of the twig mat was covered with a thin layer of loam. The total number of pits under investigation consisted of three smaller and one larger one. The small basins are each 40 centimetres deep and vary in diameter between 2 and 2,5 metres. The fourth is oval and is much larger and deeper: 3,5 to 4,5 metres in diameter and a maximum depth of 80 centimetres.

The thin layer of loam suggests the pits were filled with a liquid when in use. This pit was probably made for craft activities. This could be a kind of fulling basin. In the fulling process, the cloth is emerged in an alakalic liquid and trampled with the feet.

The experiment

The goal of the 2004 experiment was not just to see if we could get the result needed with the activities we had in mind ("does this work"), but also to inventory questions to be addressed in future experiments. We needed to identify the factors which played a role in the process, even if we would not yet be able to control all of them.

Fig. 2 The fulling pit in use. ■ **Fig. 3** The long but not very wide cloth is inspected several times during the whole process. ■

Fig. 4 Probably, most medieval fullers trampled the wool wearing only a loin cloth (Picture: H. van Doormalen). ■

Fig. 5 Digging the experimental "black pit" (Picture: H. van Doormalen). ■

The experiment was executed in the Netherlands, at the Historisch OpenluchtMuseum Eindhoven, September 3 – 5, 2004. To gain more experience, the activity was also performed as a demonstration in the archaeological museum of Biskupin, Poland, during their 10th archaeological festival, three weeks later. During the experiment, all activities were filmed and photographed. Day reports were kept as well.

The chosen material for both occasions can best be described as hand woven sheep woollen cloth. It originated from South America and came through various hands into our possession, waiting a few years to be used.

For the experiment, a pit was dug by two people. It was 150 cm wide and 60 cm deep. As it was more important to have the right pit with the right construction – a pit which would function right instead of a pit made in an exactly authentic manner – we used modern tools to dig the hole. After this, 1 year old willow branches which were harvested a while before were cleaned from their side branches. We tried to cover the bottom and sides of the pit by laying the branches across each other, but this was unworkable. So instead we laid them down, very tight and parallel to one another and cut smaller pieces for the remaining two sides. The willow branches used were not very fresh and had dried out some, but they were still supple enough. Some broke when we tried bending them to the right shape. On future occasions, we should either use fresh willow or soak them for a few days. When trampling, the willow branches generally remained in place, though on occasion they had to be put back into place.

During the second day, a fire place was set up – hot water is a necessity! The fulling earth – bentonite – was mixed with a little water, the cloth was made wet and sprinkled with the bentonite.

When the city archaeologist Arts saw the fulling process in practise, quite a few things became clear to him. He realised why no parasites (common to sheep) were found in the pits: the wool had already undergone many stages of preparation and cleaning. The clay he had found on the branches in the archaeological pit was not to make the pit waterproof. Instead it may have been remains of the fulling earth, left over from the fulling process. The bentonite degreases the wool, making it free of protein, and unwinds the raw material slightly. This means, the woollen fibres get a bit looser, making it easier to felt while fulling. Extra information provided by Arts, on top of the publication and previous interviews, showed that there were actually two kinds of pits. A number were dressed with small branches, while the other few were dressed with moss.

Our pit polluted the cloth with branches, small leaves and at the end even sand.

One of the visitors this day turned out to be a grandson of a textile industrial. He told us some details of the textile industry from over 100 years ago – not of fulling, but we did learn more this way.

The woollen cloth was trampled and cleaned as described above. The working day ended at 17:00 h after four different people – young and old, man and woman, worked the cloth in the pit, with a few others assisting.

The day after, we realised, the liquid in the pit had not sunk away, so we could not make a fresh start. The water contained clay and small pollutants. At the beginning it was found that the trampling was better than yesterday. At regular intervals, the cloth was removed from the pit to measure how it shrinks. It was clearly visible that the weft is not of constant quality. In those cases, we saw some parts shrunk more than others did. That is why we turned and twisted these places which shrunk less and trampled them more. During the process, the textile turned grey, presumably because we laid the willow branches straight on the earth, which in turn seeped through. We are unsure whether the willow itself left any colouring as well.

The final trampling should be done with water and bentonite only, to clean the wool. However, we could not clean the pit to the point that we could expect this result: the pit was too soaked with soap. In total, the test piece of cloth was trampled for 9 hours.

When cleaning the cloth with water, we realised how much it was contaminated with sand et cetera during these two days. Pollution with sand should be refrained since it damages the wool fibre making the cloth look somewhat rough. The problems we had and could not overcome with the pits becoming polluted with sand and soap make us believe that different pits were used in the same process: one for processing the cloth with the fulling earth (bentonite) and one for use with water and soap (the actual fulling). Why pits, covered with moss? Possibly, this prevented the cloth from being contaminated with sand, but without branches, one cannot effectively do the fulling. The branches caused a lot of rubbing movement, like with an old fashioned washing board. Trampling itself caused no feet to hurt, even the branches felt comfortable.

Fig. 6 Fulling. After a stained glass window in the cathedral of Semur-en-Auxois, 15th century. M. Pavon 1972, quoted in Sorber 1998. ■

The best way we could think of cleaning the cloth was using a washing machine with a cold wool wash programme. When ready, we could clearly see that one section had shrunk less in width as did the others and over all, it did turn very white again.

We stretched the cloth with nails to the wall in order to let it dry. When it was dry, the cloth measured 6,05 metres by 50 centimetres. It had shrunk 11,7% in length and 16,7% in width. The cloth shrunk 7 (warp) * 9 (weft) threads per centimetre. The original seizes at the start were 6,85 metres by 60 centimetres and 7 – 8 (warp) * 6 - 7 (weft) threads per centimetre.

Different observations made during the experiment were directly discussed with the excavator of the original black pits. The conclusion at this moment is that the collected information further supports the hypothesis, that the pits were used in the fulling process. However, the chance that they were used for some other activity still cannot be ruled out.

In order to be better able to compare the experimental pit with the archaeological examples, it was decided to let the experimental pit 'rest' in the ground for at least 12 months and have it then excavated by the archaeologists who excavated the original pits as well. At the moment of writing, this has not yet been done.

The demonstration in Poland made clear that such an activity can be executed as a demonstration, without the experimental aspects suffering that much. One person needs to be responsible for the documentation, i.e. actually in charge of the experiment. Just like brewing beer, fulling consists of several monotonous activities which leave plenty of time for explanation. Since, however, people only see a very small part of the lengthy process – and no results – the explanation of the process needs to be clarified with images, text, explanation and maybe even film.

Positive side effect

Explaining to the public that textiles in the past were not just an easy-to-throw-away-article is an eye-opener. Textiles stood at the brink of the Industrial Revolution, which was so important for the creation of today's world. In other words, discussing textiles nowadays is relevant.

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Anneke Boonstra and Nico Arts. During their conversations, the idea of experimenting with the "black pits" from Eindhoven first came up. Municipal archaeologist Drs Nico Arts enthusiastic support is the maximum, our team could have wished for. We received first hand information, access to the sources and answers to all of our questions, though we left him, with some new insight and questions as well.

The experiment was thoroughly prepared and coordinated by Ing Toon Reurink, whose literature search, years of experience and practical insight prevented the team from making beginners' mistakes and not only that.

The textile group of the Historisch OpenluchtMuseum in general, counting 15 members, has executed the experiment as well as the follow up in Biskupin, Poland. Those volunteers and employees are highly valued.

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Summary

Der Prozess des Wollfilzens – Experimente in den Niederlanden im Jahr 2004

Die Idee, Experimente zum Filzen von Wolle im Historischen Freilichtmuseum Eindhoven durchzuführen, hat seine Grundlage in den archäologischen Befunden sogenannter schwarzer Gruben, die in das Mittelalter datiert werden. Diese Gruben, die möglicherweise als Filzgruben benutzt worden sein können, wurden 1982 bei umfangreichen Ausgrabungen im Altstadtbereich von Eindhoven entdeckt.

Die Böden der Gruben wurden mit einfachen Matten aus Zweigen ausgelegt. In einigen Fällen wurde die flache Zweigmatte mit einer dünnen Schicht aus Lehm überdeckt.

Während des Filzens schrumpft grob gewebte Kleidung und entwickelt eine dichte, feste Struktur, die schwer auseinander zu ziehen und fast wasserdicht ist. Der Prozess findet in drei Schritten statt: Reinigen des groben Gewebes von Fett, Filzen unter Einsatz von Feuchtigkeit, Seife, Wärme und Vibration sowie schließlich das Waschen, um die zum Filzen benötigten Stoffe zu entfernen.

In Europa wurden unterschiedliche Filzmethoden entwickelt. Beim Experiment in Eindhoven wurde sich dafür entschieden, die Methode des so genannten Fettfilzens in zwei Phasen anzuwenden. Beim ersten Schritt wird die Kleidung gefaltet, in eine Grube gelegt, mit Wasser und abgestandenem Urin durchnässt und mit Füssen gestampft. In Abständen wurde die Kleidung herausgenommen, wieder gefaltet und nochmals gestampft. Dieser Prozess dauert zwischen 12 und 14 Stunden.

Danach muss die Kleidung weiter gereinigt werden, was weitere 12 bis 16 Stunden dauert. Unterschiedliche Beobachtungen beim Experiment wurden direkt vor Ort mit dem Ausgräber der originalen schwarzen Gruben diskutiert.

Eines der Ziele des Experiments war es, die Faktoren zu bestimmen, die beim Prozess von Bedeutung sind, um Fragen für zukünftige Experimente festzulegen. Um genauer die experimentellen Gruben mit den archäologischen Befunden vergleichen zu können, wurde entschieden, die Gruben des Experiments für eine Zeit „ruhen" zu lassen, um sie später ausgraben zu können.

Fabriquer le feutre

L'idée de l'expérimentation consacrée à la fabrication du feutre est sortie, à l'Historische Openluch Museum Eindhoven, des vestiges archéologiques dites „fosses noires" qui datent du moyen-âge. On a découvert ces fosses susceptibles d'être employées à la fabrication du feutre en 1982, au cours des recherches archéologiques réalisées dans la Vieille Ville d'Eindhoven. Une couche de branchettes tapissait leurs fonds. Dans quelques cas, celle-ci a été recouverte d'une couche mince de sédiments.

Au cours de la réalisation, on fait rétrécir une toile grossière pour obtenir une texture dense et ferme. Une telle étoffe n'est pas souple et elle est imperméable à l'eau. Le procédé est articulé en trois phases: dégraissage, feutrage par l'eau, le savon, la chaleur et la vibration et enfin lavage pour enlever des agents facilitant le feutrage.

En Europe, on a développé de différentes méthodes de feutrage. A l'HOME, on a adopté celle de „feutrage gras" qui se déroule en deux étapes. Dans la première, une étoffe pliée est introduite dans la fosse, arrosée d'eau et d'urine éventée, foulée aux pieds et laissée reposer. Après un certain temps, on sort le tissu, le replie, le foule de nouveau et ainsi de suite, à plusieurs reprises. La première étape peut prendre 12-14 heures. Puis, le tissu est épuré ce qui prend 12-16 heures de plus. Les observations faites pendant cette expérimentation ont été discutées avec l'archéologue qui avait découvert les fosses originales.

Identifier les déterminants qui jouent un rôle dans la fabrication du feutre et alors, formuler les questions dont partiront d'autres expérimentations, c'était l'un des objectifs de ce projet. Afin de pouvoir mieux comparer les fosses expérimentales avec les vestiges archéologiques, on a décidé de laisser „reposer" celles-ci avant de les fouiller.