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My experiments with cross-sectioning textile fibres

Jenni A. Suomela

Abstract

In this purely technical paper, I share the knowledge and experience I gained from numerous attempts to efficiently perform cross-cuttings of textile fibres. Cross-sectioning is a necessary procedure in analysing the morphological fibre characteristics in transverse direction. The analysis of typical cross-sectional fibre shapes can support textile fibre identification. Moreover, pigment cells can be identified and studied, and cross-cuttings can accurately measure fibre diameter for non-uniform fibre types. These examples highlight possible applications for fibre cross-cutting. Cross-sectioning can be done in numerous ways. Some are more time- or equipment-consuming, while others are more photogenetic for publications. This paper outlines my experimental findings and procedures to produce quality cross-cuttings in a quick, cost-effective manner. These methods include experiments with razor blades and ultramicrotomes, as well as paper glues and epoxies. Small archaeological fibre samples require special methods, in contrast with modern reference fibres which are abundantly available. In this summation, I am sharing my stumbling and success for others to save time and effort when encountering similar challenges.

Keywords: textile fibres, cross-sectioning, cross-cuttings

24.1. Introduction

Textile fibres can be studied with various methods and points of interest. When examining fibres directionally, observations can be done both longitudinally or cross-sectionally. My personal interest is in bast fibres, which are particularly difficult to study due to their natural variation (Suomela et al. 2018, 2020, 2022; Lukesova and Holst 2020; Viljanen et al. 2022). Compared with other fibres, bast materials have typical longitudinal characteristics like dislocation, cross-markings, microfibrillar orientations, and birefringent properties – but none of these as such, enables fibre identification. In protein fibres, comparable qualities include fibre diameter and scale shape. Whether studying bast or protein fibres, observing cross-sectional characteristics provides relevant information about the shape and diameter of the fibre or the lumen/medulla. In protein fibres, for example, the presence of pigment cells is observable in this manner.

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The identification of bast fibres is notoriously difficult, and even with our best efforts and novel natural scientific methods, ground-breaking methods are not to be found, and identification relies on combinations of methods. Depending on the researcher, the combination includes longitudinal characteristics, microfibrillar orientation, possible presence of calcium oxalate crystals in surrounding plant tissues, and cross-sectional observation of fibre shape and lumen. Using cross-sectional observation as an identification tool has been criticized by Lukesova and Holst (2020) by pinpointing differences in individual fibres in cross-cuttings. It is important to note that when studying bast fibres cross sectionally, typical features of each species should be observed holistically and focus on not individual fibres, but the features present in the cross-cutting generally (Suomela et al. 2022). Flax fibres have a polygonal shape, with a small lumen; hemp fibres exhibit a more or less polygonal shape, with a larger lumen; nettle fibres present a kidney shape, with a long and flattened lumen.

In my studies, I have sought practical procedures to conduct cross-sectioning. Some approaches resulted in more time consuming processes, while others produce less photogenic results. In this article I share my experiences and experiments with various cross-cutting methods to provide detailed information on the most suitable methods for different situations and cases.

24.2. Cross-cutting methods with results

I have considered several methods to conduct cross-sectioning; what follows is an overview of the methods that I have previously utilized, or seen potential.

24.2.1. Metal-plate

The metal-plate method is the most common and easiest way to preform cross-sectioning. All that is needed is a metal plate the size of microscopy glass slide with a drilled hole about 0.75 millimetres in diameter and a razor blade. A wisp of fibres is pulled through the hole with the aid of sewing thread and the fibres are cut from both sides parallel to the metal plate (Figure 1) (Greaves and Saville 1995: 39). Careful attention should be paid to the amount of fibres in the wisp; the sample should be large enough that fibres do not fall out of the drilled hole while cutting them with the razor blade, but also few enough to ensure light can go through the sample when examined using a transmitted light microscope (TLM).

This is a quick and easy way to prepare samples when you have an abundant sample, but becomes impossible when working with small sample sizes, such as those from museum textiles, or especially when working with fragile archaeological samples. While it is possible to surround the sample with a distinctive support fibre, placing the tiny sample in exactly the right spot is quite unfeasible. The images from cuttings made with this method provide only rough information of the cross-sectional shape of the fibres (Figure 2).

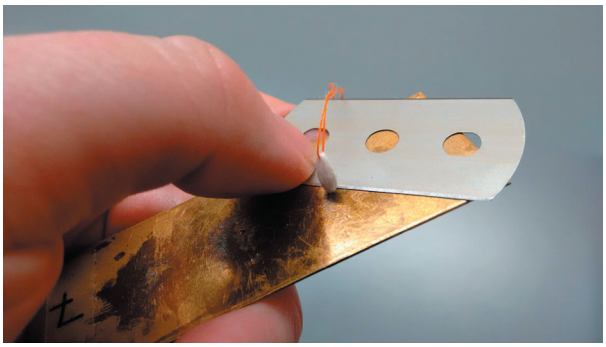

Figure 1. Cutting fibre wisp on the metal plate. (Image: Jenni Suomela)

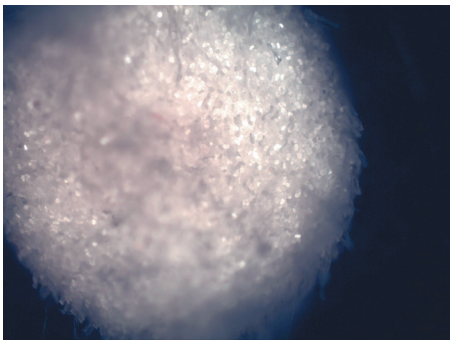

Figure 2. TLM view of cotton fibre through the metal plate taken with 10x objective. (Image: Jenni Suomela)

24.2.2. Hardy microtome

This method has been explained and recommended in older research literature (Greaves and Saville 1995: 40). Fibres are squeezed in the microtome, a little epoxy or glue is added, and after drying the fibres are raised bit by bit by turning a screw and then sliced with a razor blade. This allows 10–20 µm slices to be cut and then studied under the TLM. In general, this appears to be an easy and feasible method; however the problem remains that the required equipment seems to be rare. Unfortunately, none of the laboratories I worked in have had access to a such microtome.

24.2.3. Cork-sheet method

In lieu of the above-mentioned microtome, I created this method for my Master's thesis and presented it in my first article (Suomela 2015; Suomela et al. 2018). The idea is based on Goodway's (1987) article. I used a 2 millimetre thick cork sheet, from which I cut 2 cm by 4 cm pieces. On top of the cork, I mounted a drop of Entellan new and let it dry. Entellan is a permanent mounting media which is generally used for microscopy glass slides. The fibres are placed parallel to each other on the dried Entellan drop and are covered with another Entellan drop. Again, the drop is allowed to dry before cutting. It was difficult to determine when it had sufficiently dried, but was not yet brittle. If it had not dried properly, which took about a week, the Entellan was sticky and bendy. If it dried too much, it turned brittle and glass-like. I then cut three to five slices from every sample using a razor blade under a stereomicroscope. Developing the skills to make proper cross-cuttings by hand took time and practice. The cuttings were placed on a glass slide and, without any mounting, examined them under the TLM. It also took time to learn to properly focus in order to see the fibres in the cutting. At some point I noticed that I was able to cut thinner slices when I removed part of the cork from under the sample (Figure 3).

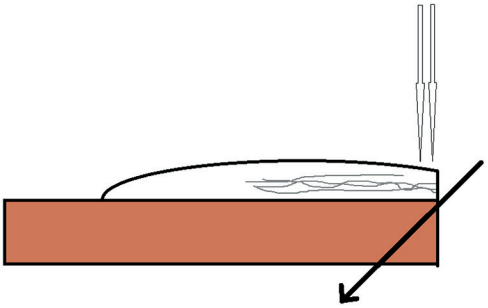

Figure 3. Removing part of the cork sheet to cut thinner slices. (Image: Jenni Suomela)

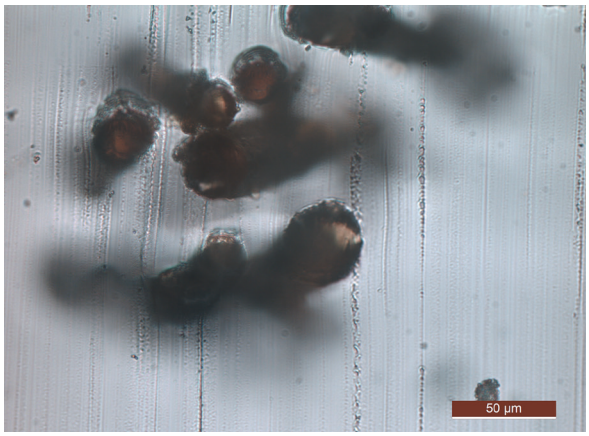

Figure 4. Wool fibres mounted using the cork sheet method. (Image: Jenni Suomela)

This method is both cost-effective and fast, although the drying process requires careful monitoring. The cross-sections are observable once the proper focus point is found, but the outcome is rough and proper imaging is difficult (Figure 4).

24.2.4. Paper glue

For large sample quantities, even faster and less laborious methods than the cork-sheet method mentioned above are needed. For example, in her wonderful book 'Fibers', Rast-Eicher (2016: 70) suggests the use of paper glue for scanning electron microscope (SEM) cross-cuttings. The method is pretty much the same as the cork-sheet method, although fibres are mounted directly to a drop of paper glue, allowed to dry, then sliced with a razor blade. Instead of SEM, I examined the sections using TLM. This is the method I used in my paper about White Karelian textiles, due to the high volume of samples (over a hundred) required (Figure 5) (Suomela et al. 2020).

But can you imagine how many different types of paper glue there are! Some stay permanently soft, while others are too watery; the best paper glue for mounting samples I have come across was sold in a small shop near where my Estonian colleague lives. Despite the wide variety of paper glues available, this method generally worked well, although the cuttings were easily lost without the supportive cork sheet, and it was sometimes difficult to place them sideways because they were so thin (Figure 6). The fibres were more easily found under a microscope than with the cork sheet method, but the images were unfortunately still quite unsatisfactory (Figure 7) (Suomela et al. 2020).

Figure 5. Settings to prepare multiple glue sections. (Image: Jenni Suomela)

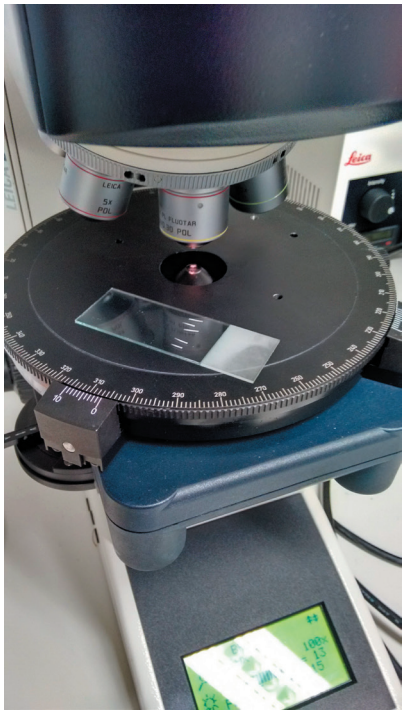

Figure 6. Sections going to the microscope. (Image: Jenni Suomela)

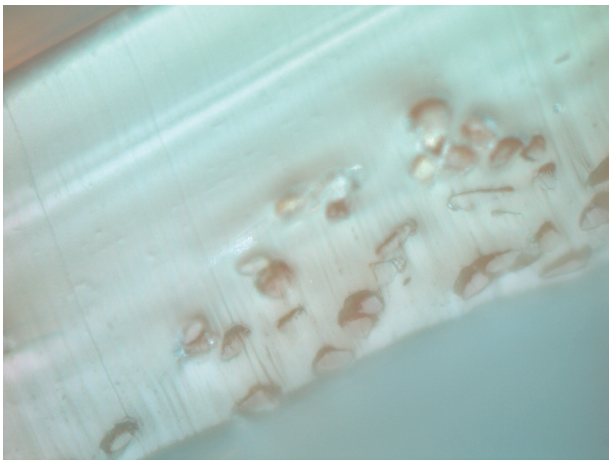

Figure 7. Silk fibres mounted in glue. (Image: Jenni Suomela)

24.2.5. SEM

Scanning electron microscope (SEM) is widely used in scientific publications, although it has appeared generally too laborious for my own research (eg., Rast-Eicher 2016). This is largely due to SEM requiring a great deal of skill, in addition to being costly both in terms of time and money. Cross-sections can be done using loose fibres, but I have not yet to find a practical nor neat way to cut them. Another possibility is to mount the fibres in epoxy, then cut and polish the epoxy block to see the cross-sectional view of the fibres. Experiments with this processes, conducted with Krista Wright, are presented in Figures 8 and 9. The fibres are mounted in Epofix, the surface is not polished, but bright after sectioning ultramicrotome samples for transmitted electron microscope (TEM). The SEM equipment used was a Zeiss Sigma VP, and the epoxy blocks were coated with a 12 nanometre layer of gold-palladium (Au-Pd) to increase their electrical conductivity. Figure 8 was taken with a secondary electron detector, and shows the sample's surface structures, while Figure 9 was taken with a backscattering detector to obtain better contrast between the sample and the epoxy.

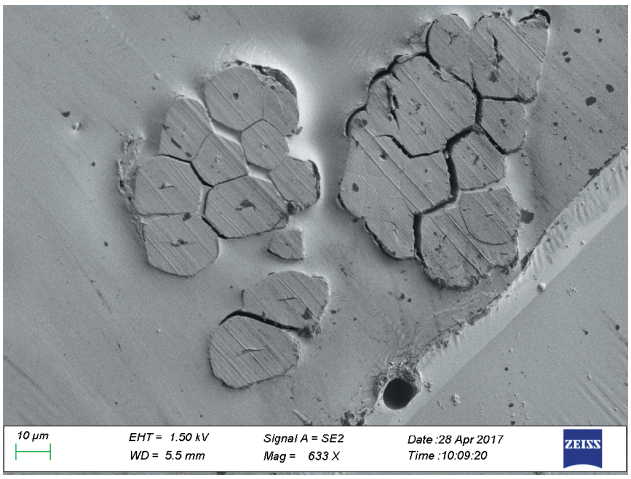

Figure 8. Flax fibres imaged with SEM. (Image: Krista Wright. Image was taken in the Nanomicroscopy centre of Aalto University)

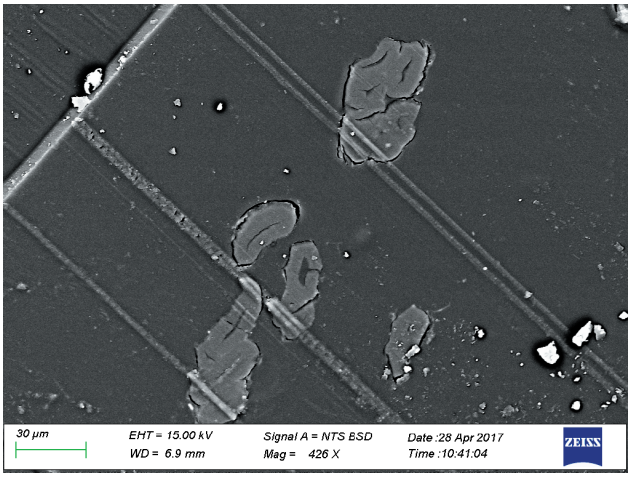

Figure 9. Nettle fibres imaged with SEM. (Image: Krista Wright. Image was taken in the Nanomicroscopy centre of Aalto University)

24.2.6. TEM sample preparation method with LR White

In the pursuit of the perfect cross-cutting approach, I moved on to more sophisticated methods, such as that used for TEM samples. The procedure is highly time consuming, and includes several steps. First the fibres are mounted to epoxy blocks, as perpendicular as possible (Figure 10). Some scientists first tape the fibres to a strip of paper to enhance the order, but this is not possible with small sample sizes of historical or archaeological fibres. In my experiments, I embedded the fibres in LR White

blocks. LR White is an acrylic resin which sticks around the fibres quite well, which means the fibres do not easily fall out of the cuttings.

Blocks are first rough-cut to a blunt pyramid shape using a trimmer, with great attention paid to the fibres' orientation. Then the upper edge of the pyramid is trimmed using a ultramicrotome and trimmer knife to a trapezoid shape. A histo diamond knife with a water pool is then used to slice the sample into cuttings that float on the water in the pool; from the pool, these ca.70 nm slices are collected with a "perfect loop"-tool on a grid which can be applied to TEM. I have used special grids that have, instead of the actual grid, a large oval opening and thin carbon layer. TEM is usually applied to study nanoscale particles, and compared to those textile fibres are enormous. Due to this, regular gridding would interfere with the analysis. Despite the great deal of effort this process requires, it is nevertheless still difficult to obtain quality images (Figure 11).

Figure 10. Epoxy blocks with razor blade for scale. (Image: Jenni Suomela)

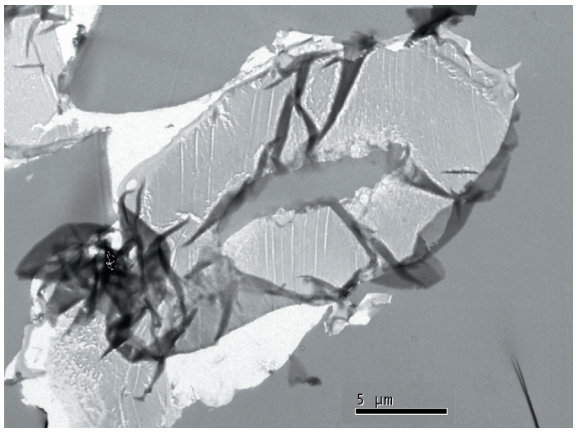

Figure 11. Nettle fibre imaged with TEM. (Image: Jenni Suomela)

24.2.7. Simplified ultramicrotome method

While the TEM equipment is too delicate to study fibres' cross-sectional shape, it is excellent for studying pigment cells in wool fibres, for example. A drawback to this method, however, is that both sample preparation and use of the TEM itself are time-consuming and difficult. To address these concerns, I created a simplified approach to speed up the process and to produce cuttings that can be studied using TLM. These 70 nm thick sections for TEM are too thin to be seen with transmitted light. Straight from the rough trim, it is possible to cut sections, size between 200 and 600 µm by side with a thickness of 2 µm. This thickness allows the cuttings be visible with TLM (Figure 12). Instead of using a grid for TEM observance, the cuttings are collected on a glass slide.

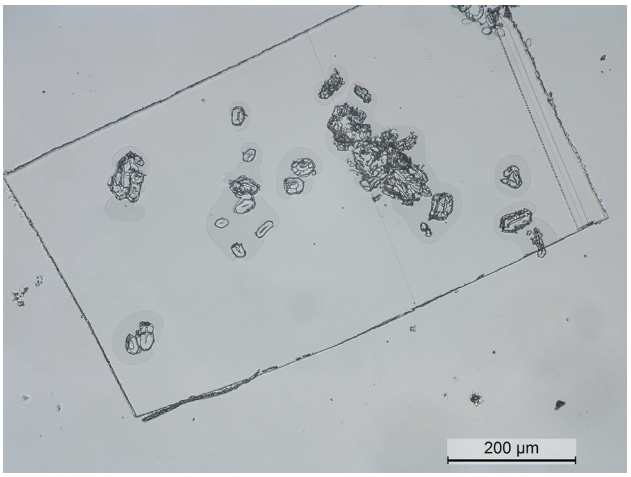

Figure 12. Cross-cutting of nettle fibres where the whole section is visible. (Image: Jenni Suomela)

I have conducted experiments using different mounting medium, including milli-q water, Entellan new, and paraffin oil. In the end, the best image contrast was achieved without any mounting media (Figure 13). In relation to the time required, the results are quite satisfactory. I utilized this method with fragile archaeological samples of Ravattula Ristimäki (Suomela et al. 2022).

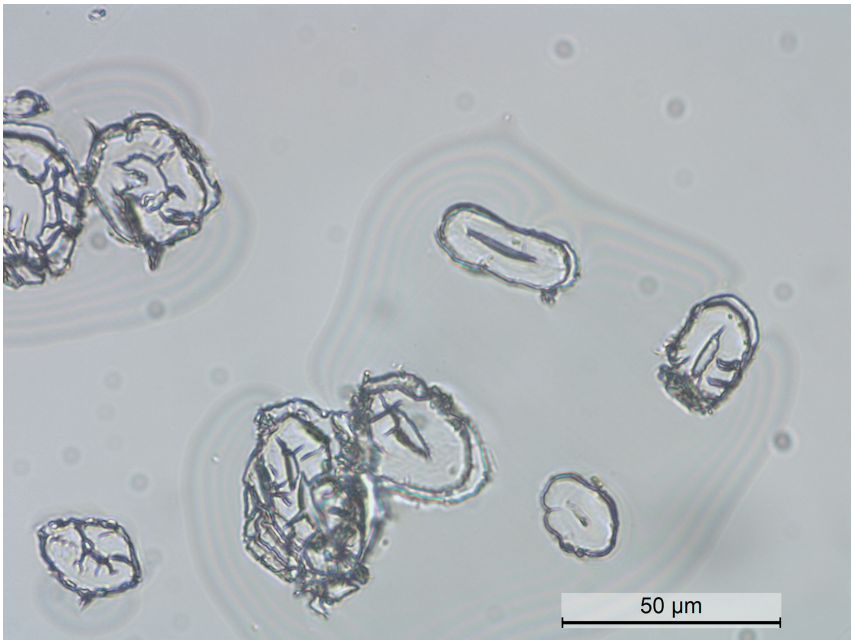

Figure 13. Close-up of the nettle fibres transversally. (Image: Jenni Suomela)

24.2.8. Micro-/Nano-CT

Computed Tomography (CT) is based on frequent cross-sectional X-ray imaging of the sample. By compiling these images, it is possible to produce a 3-dimentional (3D) representation of the sample which can be studied in various manners. Due to the restrictions of the radiographic method, the images are black and white with shade signifying the density of the matter. The imaging accuracy depends on the equipment used; in the context of multidimensional space, the unit is a voxel, a 3-dimensional pixel. In the case of micro-CT, the resolution is to a few micrometres, while nano-CT further refine the resolution to 100 nanometres (Kuan et al. 2020). Micro-CT has been successfully used to study textile structures, yarns, and fibres (Figure 14), but access to nano-CT equipment is still exceedingly limited (Smith et al. 2013; Barburski et al. 2015; Toda et al. 2016, 2017).

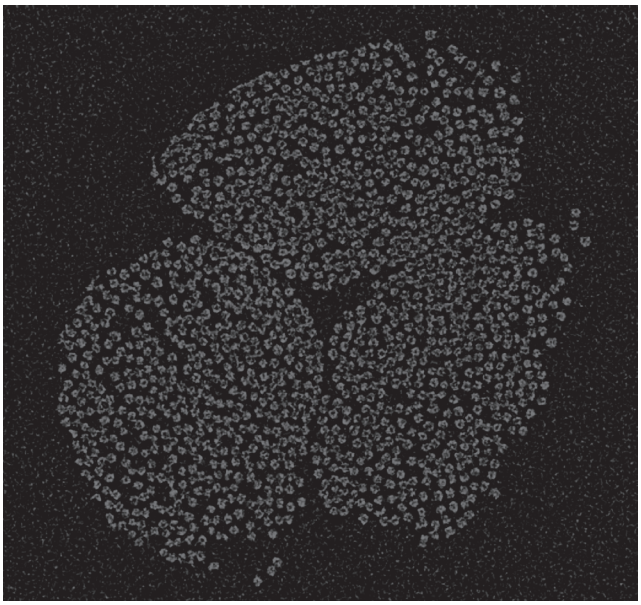

Figure 14. Cross-section of a 3-ply polypropene cord. (Image: Jenni Suomela)

24.2.9. Confocal Microscopy

There is always room for advancement, especially in the field of non-invasive methods; the less we permanently destroy samples, the more there is left to explore using new and developing methods in the future. I have not yet tried the method proposed here, which is included for its potential to address new and developing textile research.

Confocal microscopy is a fluoresce-based microscopy method which can produce both longitudinal and cross-section views from the same sample regularly mounted on a glass slide. This enables study of even smaller sample sizes, particularly as it is unnecessary to divide the sample for different analysis. This method has already been applied to textile fibre studies, with clear demonstrations of its cross-sectional viewing possibilities (Tedesco and Browne 2021; Kirkbride and Tridico 2010; Umer et al. 2011).

24.3. Discussion

Selecting a cross-section method should be based on the intended purpose, and demands of an individual sample. The metal plate method is useful if time is rationed and there is no shortage of sample material. General observations of the fibres' characteristic appearance can be made, but only in a rough manner. For archaeological and museum textiles the method is useless. Glue and cork-sheet methods are beneficial in cases with large sample quantities. They require some skill on the part of the preparer to correctly adjust the microscope to observe the fibres. The fibre characteristics are just as visible as with more sophisticated methods, but it is quite difficult to produce publishable images. SEM requires costly equipment, skill, and time to prepare the sample by either embedding the sample in epoxy and polishing the surface, or by cutting the fibres in some other manner. Despite these difficulties, clear images with full depth can be made utilising this method. Due to the complicated procedure, TEM preparation should only be considered when research interests focus on fibre nanostructures, for example in pigment cell or fibrillar layers. Then again, the simplified ultramicrotome method produces excellent images with TLM with less effort, but still requires rarer equipment. Micro-CT is valuable in situations where the sample cannot be destroyed, while confocal microscopy is a practical solution when the sample consists of very little material.

It cannot be stressed enough that the success of most of these methods depend on the direction of the fibres, as they must be cut exactly transversally. As such, the skill of the preparer is crucial, regardless of the equipment selected for analysis. Poorly prepared samples can result in misdiagnosis, as diagonally cut flax fibre appears easily as oval with long lumen (nettle) instead of polygonal with small lumen as it should be.

24.4. Conclusions

Methodological possibilities for conducting cross-sections are abundant as seen in prior examples. It is important to choose the most practical one for the situation, depending on the resources of time, equipment, sample quantity, and skill, as well as the significance of the sample. Most importantly for future analysis, the methodology selected must meet the needs of both the sample and the research questions under consideration, with each method having advantages and disadvantages.

Jenni Suomela (MA, Education) is finalizing her dissertation at the University of Helsinki, Finland, in the field of Craft Science. She has a broad understanding of textiles from the fibre level to cultural meanings. Her field of interest particularly includes ethnographic textiles, from archaeological finds to the historical era.

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