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abstract: This paper discusses the ways that different fabrics, weaving, and structure of a canvas influence its mechanical and hydromechanical behavior. It goes on to consider how this already complex composite is further modified by subsequent layers, whether in a new or degraded state. In particular, it highlights the conditions in which the weave structure—and behavior related to that structure—still influence the overall response of a painting on canvas. The paper also reviews research relevant to conserving canvas in the fields of polymer mechanics, fiber-reinforced composites, and smart materials, looking at research related to both the modeling of canvas and composite properties and at experimental studies. Often, there appears to be a big gap between research carried out in science, engineering, and conservation science and the research that conservators feel will help them solve practical problems and devise effective treatments. This paper suggests directions for future research—pure and applied—that may aid in the structural conservation of painting on canvas.

short\_title: Canvas Complexity

# <A-head> Introduction

The woven structure of canvas, although modified by the subsequent layers of the painting, still influences the mechanical and hydromechanical behavior of this complex composite. To highlight the issues of complexity, this paper brings together and reevaluates collaborative research conducted over twenty-five years that addresses these issues in the context of the structural conservation of canvas paintings. It discusses the methodologies of research related to experimental work, practical conservation implementation, and the modeling of canvas and its composite properties. The key findings, with examples, and the methods used to obtain useful data and practical insights are given, along with the references for the experimental details and results.[[1]](#endnote-1)

Recent research in the fields of polymer mechanics, fiber-reinforced composites, and smart materials that are relevant to conserving canvases of the past (and future) is highlighted, as are directions for future research—pure and applied—that will aid in the structural conservation of paintings on canvas.

# <A-head> Physical Structure

## <B-head> *Types of Canvas*

In the context of artists canvas and lining fabric, most fabrics are made from natural materials. For painted cloth, silk, calico, cotton, and linen have been the most common fabrics both geographically and historically. However, other natural materials—for instance, bark cloth ({{Lennard, Tamura, and Nesbitt 2017}})—are part of rich traditions of painting, and we are only beginning to understand their behavior as painting supports ({{Smith, Holmes-Smith, and Lennard 2019}}).

The choice of canvas by artists is often made for pragmatic reasons, including local production, availability, expense, and size. Important features of these natural materials are their flexibility, texture, and absorbency (see “Moisture Response” below), which make them suitable for the application of paint. For fabric supports, some of these features are a product of the preparation, but most originate from the fiber type, yarn structure, and weave structure (flexibility and texture). It is reasonable to suggest that in all but the most prestigious commissions the artist had little control, or even interest, in these factors, but instead innately, or through treatises and word of mouth, thought of a canvas as either suitable or not suitable for the execution of a particular painting.

The discussion below focuses on cotton and linen but acknowledges the use of silk, both in traditional non-Western and Western art and in contemporary contexts. In a few cases, it has been possible to trace the evidence of artists’ choice through letters, colormen archives, and anecdotes ({{Johnson et al. 2010}}), but rarely has the production of the canvas been under their control. Historically cloth was a commodity for household furnishings, military and naval outfitting, and ecclesiastical and court events. It is with the advent of industrial weaving that different weights of cloth became more accessible through artists suppliers, and the small batch production of artists’ canvas started to occur. However, there is mounting evidence through technical examination and conservation records that, prior to industrialization, artists had access to different types and weaves, and in some cases clearly choose some over others ({{Heydenreich et al. 2008}}; {{Seccarone 2012}}). Sources, including the National Portrait Gallery’s list of British artists suppliers (1650–1950),[[2]](#endnote-2) individual websites, and publications that include research into the trade in artists’ materials ({{Kirby, Nash, and Cannon 2010}}) provide invaluable information from which to build up a better understanding of the context in which artists chose their materials.

Contemporary artists make both conscious and pragmatic choices to use best-quality artists canvas (usually fine plain-weave linen or cheaper cotton duck, which is also available in wider widths), sacking (jute, usually plain weave), bank money bags (cotton and linen, plain or twill weave), and mattress ticking (an old favorite, usually linen with a herringbone twill weave), as well as older, traditional materials used in a contemporary context, such as bark cloth ({{Schneider 2021}}).

Artists use canvas in a variety of ways: unstretched, sewn, pierced, or formed into three dimensions. Canvas is also woven from polyester specifically for art and conservation. This is manufactured/supplied by companies such as Federix in the United States, Haywards in the United Kingdom, and Lascaux in Germany.[[3]](#endnote-3) In the performing arts there is more painting on plastic gauzes and projection cloths made from woven and nonwoven synthetics, including polyester, nylon, and Kevlar. The range of fabrics used and available is best appreciated by visiting the website of J. D. McDougall, a company that has supplied fabrics for over a hundred years.[[4]](#endnote-4)

## <B-head> *Types of Weave*

A woven fabric made from a single type of fiber (e.g., flax) is a composite influenced by the way it is grown or synthesized and then processed into yarn ready for weaving. The various levels of hierarchy in the structure influence, in differing degrees, the overall fabric behavior. The yarn type, diameter, flatness, and stiffness affect flexibility and moisture response. The density of fiber yarns and type of weave influence yarn mobility, stiffness, drape, fracture toughness, and permeability ({{Young and Jardine 2012}}). The fabric permeability affects moisture response, consolidation, impregnation, and lining treatments ({{Young and Ackroyd 2001}}).

Additionally, surface or impregnating coatings (e.g., size, paint, and consolidants) affect tensile, shear, bending properties, yarn mobility, and fracture toughness. For traditional Western paintings, we have a good experimental and empirical understanding of the complex composite of woven fabric and coatings. Research into the behavior of double-sided painted cloth such as trade union banners ([**fig. 15.1**](file:///Users/RBarth/Desktop/Finalized%20files-Conserving-Canvas--72122-to%20prep%20for%20TR/15-Young/fig-15-1))({{Smith, [Thompson,](http://eprints.gla.ac.uk/view/author/17095.html) and [Hermens](http://eprints.gla.ac.uk/view/author/4846.html) 2016}}) or the behavior of twill and more complex weaves, however, is in its infancy (see “Reconstructing Weaves” below). Certainly, more research is required to determine the dominant contributing factors in the mechanical and hydromechanical behavior of canvas when new materials and techniques are used in contemporary art or used in mixed media and with new synthetic artists materials such as water-mixable oil paint, inks, or acrylic primed spun polyester canvas (see “Reconstructions for the Contemporary Use of Canvas” below).

Prediction of painted canvas properties from experimental mechanical and chemical data is the first step. Testing on single-constituent yarns, free films, single layers, and/or simple multilayers provides invaluable information that relates to both the present and past and to changes in properties caused by natural aging and conservation treatments. However, these are relatively simple interactions and therefore only partially representative. Conservation treatments themselves are a valuable source of “live” empirical data of the real complex interactions, but they are not easily reproducible. Nevertheless, many years of experience adds up to a powerful knowledge base of possible outcomes.

Analytical or computational studies for fabric/canvas behavior have developed models that can account for one level of hierarchy—fiber level, yarn level, weave pattern level—or with continuous, homogenous layers with simplified superposition of layers. Ideally however, to model fabric permeability, for example, it is necessary to consider both microporosity (fiber spacing) and macroporosity (yarn spacing) ({{Zeng et al. 2014}}). Models based on geomechanical structures (soil and rock) have been suggested as a useful approach to studying consolidation ({{Michalski 2008}}). Certainly, many of the phenomena—such as crack networks, diffusion, and complex interacting layers—are common to both fields. Therefore, applying such models would be beneficial to canvas conservation studies.

Similarly, to predict biaxial behavior of woven fabric, the model of the weave needs to consider friction at the yarn crossover. These more complex multilevel models are yet to be fully developed ({{Aliabadi 2015}}). Past attempts to model the complex structure of canvas paintings and fabrics have used a finite element analysis (FEA) approach ({{Guanzhi et al. 2017}}; {{Mecklenburg, McCormick-Goodhart, and Tumosa 1994}}). By using analytical models developed for tensioned fabric structures, the problems normally encountered with accurately modeling complex curved surfaces are mitigated. Bicubic-spline models developed originally for architectural applications ({{Brew and Lewis 2007}}) are the most representative way to model a woven stretched canvas on a stretcher ({{Young 2013}}; see “Strain Distribution” below). However, the interaction of the uppermost layers can be successfully modelled with FEA, taking into account their viscoelastic properties ({{Tantideeravit et al. 2013}}).

# <A-head> Dealing with Complexity

In what ways is it possible to complement the existing research? One approach is epidemiological studies of collections and promotion of documentation protocols that include canvas weave pattern and count, fiber type, and duty/colorman stamps. This information not only helps in the identification of the date and source of the canvas but is invaluable for understanding the artist’s intent and the provenance of artists’ materials ({{Johnson et al. 2010}}; {{Murillo-Fuentes and Alba 2018}}). It is also important for conservation, as the weave structure still influences the overall response of a painting, whatever its age. Combined with consistent materials characterization, such information may allow further insights to be gained into the mechanical and hydromechanical behavior of real paintings.

While it is not always possible to be historically accurate at every level of the canvas structure, weave, painting, and lining reconstructions allow for repeatability and for endless combinations to be experimentally tested and trends in behavior to be established ({{Daly Hartin et al. 2011}}; also see “Moisture Response of linings” and “Reconstructing Weaves” below). Lined paintings, as well as modern and contemporary use of “canvas”—where if a material exists, an artist will use it, and unconventionally—requires an understanding of geometry, construction, and potentially the properties of many different materials. Reconstructions play a crucial role in understanding these elements.

# <A-head> Strain Distribution

Several factors make the strain distribution within canvas complex: it is a woven rather than a continuous, homogenous layer; the strain response of the yarns is usually different in the weft and warp; and factors including friction, density, and weave pattern influence the strain distribution. Additionally, on a strainer or stretcher, the attachments and the stretcher construction (corners) induce uneven loading. While the stress distribution that this loading creates cannot be directly measured, the strain distribution can be measured by techniques including Electronic Speckle Pattern Interferometry (ESPI), digital image correlation (DIC), and photogrammetry. ESPI can be used to obtain accurate quantitative measurements of strain distributions of primed canvas on a stretcher that replicate a real painting configuration. Biaxial tensile properties of a painting and its constituents can be obtained by mechanical testing. By combining biaxial tensile testing with two-dimensional strain mapping, however, it is possible to gain an understanding of the composite behavior of a stretched canvas and the forces to which it is subjected.

The biaxial restraint of the canvas alters the strain distribution around the tacks or staples, becoming progressively more complex toward the corners. At the macro level, the strain patterns induced by the attachments are similar, with closer spacing resulting in more even strain distribution. If the attachments pass through preprimed canvas there is reduced local cusping, because of the greater resistance of uncracked primed canvas to distortion in the bias direction of the canvas. The restraint imposed by tight corner folds reduces the high load that would be imposed on the attachments near the corners if a loosely folded corner was keyed out. Nevertheless, shrinkage of the canvas or keying out will lead to significant strain concentrations in these areas. The strain irregularities become significantly less if the canvas is attached on the rear face of the stretcher rather than the side. Staples are effective attachments until the canvas between the legs begins to slip; then tears may occur because the staple leg creates very high strain concentrations. Tacks appear to be as effective in restraining the canvas and less likely to cause tears ({{Young and Hibberd 2000}}).

Bicubic spline modelling (validated by ESPI) was the first computational model of a painting to incorporate the stretcher, staples, corner folds, and frictional forces. The inclusion in the model of the measured coefficient of friction of 0.63 for a pine stretcher bar showed that areas of high strain move outward toward the edges of the stretcher. [**Figs. 15.2**](file:///Users/RBarth/Desktop/Finalized%20files-Conserving-Canvas--72122-to%20prep%20for%20TR/15-Young/fig-15-2)and[**15.3**](file:///Users/RBarth/Desktop/Finalized%20files-Conserving-Canvas--72122-to%20prep%20for%20TR/15-Young/fig-15-3)compare the measured strain obtained using ESPI with the modeled strain for the same canvas properties and loading conditions. The close correlation of the two distributions in terms of overall magnitude and specific features is very good. This gives a high level of confidence in using a bicubic spline model to predict modes of failure and improve upon the present methods of tensioning canvas by simulating the strains induced in canvas under different conditions ({{Brew, Lewis, and Young 2016}}).

ESPI has also been a useful tool for evaluating structural conservation treatments, for instance, tear mending. A painting will have high strains near the tear and strain concentrations at the ends of the tear, which are sites for potential propagation of the tear. If a tear is close to a corner or a tack/staple, this situation will be exacerbated because of the nonuniform loading. Implicit in restoring the mechanical integrity of a painting is the requirement to reestablish a uniform strain field across the painting—or at least one whose average strain is commensurate ({{Young 2003}}). This can be seen for the Heiber (thread-by-thread) tear mend strain map shown in [**fig. 15.4**](file:///Users/RBarth/Desktop/Finalized%20files-Conserving-Canvas--72122-to%20prep%20for%20TR/15-Young/fig-15-4)for an acrylic primed canvas under 50 N biaxial tension. Redistribution, reduction, or eradication of strain concentrations (one color in the map) implies a uniform strain field. Both the patch ([**fig. 15.5**](file:///Users/RBarth/Desktop/Finalized%20files-Conserving-Canvas--72122-to%20prep%20for%20TR/15-Young/fig-15-5)) and the Heiber mend demonstrate that this can be achieved to some degree.

In both cases residual strain concentrations are present. For the Heiber—or any equivalent tear mend—reducing these concentrations below these levels is very hard to achieve by visual inspection alone. A “perfect” mend would eliminate strain concentrations around the original fracture site, preventing potential propagation of the tear. Similarly, any patch should have high fracture toughness and minimal stiffness. The patch strain map (see [**fig. 15.5**](file:///Users/RBarth/Desktop/Finalized%20files-Conserving-Canvas--72122-to%20prep%20for%20TR/15-Young/fig-15-5)) shows that the level of strain concentrations has been reduced, but small discontinuities in strain occur at the edges of the patch.

Patches, which impart additional flexural stiffness with the aim of keeping the tear flat, are likely to result in an area of lower strain across the patch, but also larger discontinuities. The adhesive and type of adhesive interface will be the major factors in determining whether a tear mend is strong enough to withstand “normal” stress distributions within the canvas. The onset of failure will be evident as an increase in strain concentrations while loading.

Apart from assessing which techniques are mechanically most successful, future research needs to look at how the materials used in the subsequent layers of fill and retouching alter the balance of forces in and around the tear. This includes looking at interfacial tensions built up by the drying of fills and coatings ({{Daly Hartin et al. 2011}}), as well as the ability of the filled mend to withstand fatigue caused by cycling of temperature and relative humidity ({{Young 2013}}).

Strip-lining is another structural treatment perceived as minimally invasive that aims to reinstate, as far as possible, the structural integrity of the painting. Evaluation of the various configurations and methods to prevent a sharp change in stiffness at the edge of a strip in the picture plane have been evaluated by ESPI. For example, strip-lining with Beva 371 and polyester sailcloth (00169, manufactured solely to order by Richard Hayward & Co., UK)—with pinked edges to prevent a hard transition—actually results in strain concentrations within the picture plane at the point of the pinked triangle of polyester ({{Brew, Lewis, and Young 2016}}). As expected, under the same loading conditions a feathered edge transition results in lower strain concentrations. However, if too much adhesive is used, the stiffness of the adhesive (even Beva 371) dominates, and a strain concentration along the edge of the feathering occurs.

ESPI is a very sensitive technique and does not always work well for real paintings, especially those with glossy varnishes or that are in situ where exterior vibrations occur. For the application of strip-linings and other structural conservation treatments, DIC with a relatively inexpensive, fast-frame rate, high-resolution camera can produce good results. Such systems are standard in engineering and offer a complementary technique for nondestructive evaluation of structural conservation treatments.

# <A-head> Moisture Response

The literature on the moisture response of canvas paintings and the key findings are covered in *On Canvas* ({{Hackney 2020}}). For emphasis, some specific points from some of the published literature follow.

## <B-head> *Moisture Response of Original Supports*

Most of the data in the literature on moisture response relates to uniaxial testing. The results, however, can be misleading, as uniaxially the canvas is unconstrained in one direction, and this is not representative of the stresses that build up under biaxial constraint on a stretcher. Nonetheless, careful experimental design and interpretation can mitigate this difference. One of the most valuable resources for measuring moisture response has come from deaccessioned paintings and from nineteenth-century primed loose-linings. [**Fig. 15.6**](file:///Users/RBarth/Desktop/Finalized%20files-Conserving-Canvas--72122-to%20prep%20for%20TR/15-Young/fig-15-6) shows the typical load response in the weft and warp direction for a primed loose-lining produced by Roberson colormen ({{Carlyle, [Young,](http://eprints.gla.ac.uk/view/author/37894.html) and Jardine 2008}}). The tension in the two directions drops until an inversion occurs at 70% RH, where the tension starts to rise as relative humidity increases.

This pattern occurs for many oil-primed canvases (loose-linings), as was demonstrated by Hedley under uniaxial tension ({{Hedley 1998}}). The initial drop in tension is attributed to the size layer becoming softer as it absorbs moisture, until it reaches a gelatinous state. Simultaneously, the fibers in the canvas are absorbing moisture. At some point, the swollen fibers cause the canvas to contract, and because it is tacked in place the tension rises. Typically, the tension in the weft direction increases significantly more than the warp because it has less crimp. The major influences on where this inversion occurs are weave density and the glue size application. Inversions have been measured from between 65% to 85% RH for nineteenth-century English commercially glue-sized oil-primed canvases and glue-sized new canvas. [**Fig. 15.7**](file:///Users/RBarth/Desktop/Finalized%20files-Conserving-Canvas--72122-to%20prep%20for%20TR/15-Young/fig-15-7) shows the response of another Roberson primed loose-lining with the inversion at 65% RH ({{Carlyle, [Young,](http://eprints.gla.ac.uk/view/author/37894.html) and Jardine 2008}}; {{Carr et al. 2003}}).

## <B-head> *Moisture Response of Linings*

A database of moisture response for archival canvas, reconstructions, and new types of canvas is useful in deciding on a moisture treatment (how long and at how much moisture), especially when the complexity of two canvases is involved, as is the case with lined paintings. As a first approximation, one can think of the problem as a superposition of two canvases, and hence two moisture responses that induce expansion and contraction, leading to stresses within the canvases and induced stress distributions in all the layers. This can be modeled with appropriate boundary conditions using FEA and/or analytical models—if the properties of each layer are known. However, there is often added complexity because the lining adhesive (especially traditional glue-paste and wax) has impregnated the original canvas, cracks, and interfaces of the painting. Nevertheless, it is possible to see trends in behavior when there is sufficient archival material to characterize degradation and mechanical properties ({{Young and Ackroyd 2001}}).

## <B-head> *Moisture Response of Modern Materials*

The use of synthetic/modern materials in painted textiles can be traced to the patents for textile coatings of the nineteenth century ({{Young 2012}}). Research into their properties began to have a direct influence of practice with the work of Hedley and Hackney in the 1980s ({{Hackney 2020}}). Artists’ use of new materials, plus the conservator’s desire to find a suitable lining canvas, means we need to continue to characterize a wide selection of natural and synthetic fabrics. It is insufficient to characterize only the type of canvas (linen or polyester), because even for synthetic fabrics the yarn processing, fabric weave density and coatings (for example, fire retardants) influence moisture response ({{Young and Jardine 2012}}). More disconcerting for those choosing materials for treatments is the generic naming of canvases; for example, “12 oz Belgian linen,” is a name, not a description—it does not even mean it comes from Belgium. This is confusing and misleading if one assumes certain properties are dependent on the material’s source country. Similarly, cotton duck data produced over twenty years ago ({{Young 1996}}) will generally be valid today, but changes to the source—and therefore the twist of the yarn, sizing, tension during weaving, and subsequent regulatory coatings and processes—can change the hydromechanical response.

Of course, this has always been the case. For instance, in the eighteenth century, weavers in the east of Scotland branded their linen fabrics “Osnaburg” (or Osnabrigg) an imitation of Osnaburgh (also known as Osnabrück) ({{Young 2012}}). Similarly, Lascaux P360 polyester (a linen look-alike) has changed properties since it was introduced ({{Young and Jardine 2012}}). Ideally one should characterize (or at least empirically test) each new batch if one cannot guarantee its response.

# <A-head> Reconstructing Weaves

Reconstructions of painted textiles in general—starting at the yarn level and proceeding through weaving, stretching, preparation layers, and subsequent artists materials/techniques relevant to the work—are invaluable for understanding how the manufacturing process, subsequent preparations, and materials influence the aesthetic, kinesthetic, and physiochemical behavior of the painting. Fraught with uncertainty as to how authentic or historically accurate they may be, reconstructions still allow one to explore which properties have the biggest influence on behavior through trying different variations and through repeated testing.

Reconstruction of canvas weaves is a relatively new approach. It has come about in part from a greater awareness of and interest in the weave’s significance in the provenance, interpretation, and conservation of a painting. For example, during the conservation treatment at the Cleveland Museum of Art of *The Crucifixion of Saint Andrew* (1606–7) by Caravaggio, it was possible to retrieve some information about the original canvas from the x-radiograph, even though it had been lined with a plain-weave canvas.[[5]](#endnote-5) This painting may have been cut down, which would mean less cusping would be visible. Inferences drawn from the cusping had been extrapolated from simple plain-weave canvases, rather than the complex weave of Caravaggio's original canvas.

While the clarity of the original weave was hard to discern, a trained eye (in this case, Dr. Dan Coughlan, curator and master weaver at Paisley Museum, Scotland) identified the weave as a huckaback, which is a plain weave with a floating warp. Hence, he was able to set up the weaving pattern for a traditional four-frame hand loom. Linen and jute yarn samples were sourced from Jos Vanneste, a Belgian linen company. The closest match to a yarn fragment from the painting was a linen yarn, which was then woven into a canvas by a local Scottish weaver. Empirical testing found that the canvas was more stable on the bias than an equivalent plain weave without a floating warp, and it developed less cusping when tacked onto a stretcher.

The canvas was also prepared with a traditional double ground layer, and, interestingly, drying cracks within these layers were of a very similar size and pattern ({{Brunton 2018}}). A more systematic and controlled set of tests are now being performed on these samples using the biaxial tensile tester in the Conservation Research Laboratory at the Hunterian, Glasgow University. Such reconstructions are useful not only for understanding the complexity of canvas but also for possible use as fabrics for structural treatments. Having control over the weaving process allows for a bespoke pattern (see [Loermans’s poster](file:///Users/RBarth/Desktop/Finalized%20files-Conserving-Canvas--72122-to%20prep%20for%20TR/15-Young/paper-47) in these proceedings) and, combined with testing, the ability to tune its properties.

# <A-head> Reconstructions for the Contemporary Use of Canvas

The value of reconstructions for conservation/preventive issues related to contemporary works as well as older works cannot be underestimated. Either by working directly with the artists, gallery, artist’s studio, fabricators, or documented interviews, much can be gleaned, if not always volunteered, that enable the use of the same materials and technique in the reconstruction. This approach has been used in cleaning ({{Barker and Ormsby 2015}}; {{Krueger 2017}}; {{Diamond et. al. 2019}}), very effectively for tear mending ({{Piotrowska and Amann 2009}}), and assessment of structural stability and preventive treatments ({{Griffin, Young, and Hale 2014}}).

One is example is a series of for acrylic preprimed linen and polyester canvases on which acrylic paint and screen print ink had been applied either directly or through a screen. These works were unstretched on arrival for a display of the artist’s work at a gallery in London. Several features were considered undesirable: a general buckling of the canvas with sharp cupping in certain areas, cracking in the upper paint layers, and some buckling remaining in the works, once stretched, with an overall lack of tension. By matching the canvases as closely as possible and using the inks used by the artist, it was possible to conduct a series of tests on the biaxial tensile tester to recreate the phenomenon and to understand its cause.[[6]](#endnote-6) This allowed recommendation of an appropriate treatment and possible ways to mitigate the effects in future. It was found that the liquid phase of inks caused local shrinkage of linen. In the synthetic canvases, the liquid phase interacted with the acrylic priming, softening it, unlocking the woven polyester yarns, and allowing distortions to occur.

Possibly more challenging to the conservators of the future is the embedding of materials within canvas ({{Nahum, McGuirk, and Watson 2019}}) and haptics ({{Bianchi 2016}}).[[7]](#endnote-7) The testing of contemporary materials that an artist might use as a “canvas” or in a sculpture/installation or that might be a suitable alternative to traditional lining materials should be an ongoing, proactive area of research within conservation. While attempts have been made to work with manufacturers to produce materials to our specifications, commercial production of bespoke lining fabric is not viable. A proactive approach is required to understand textiles manufactured for other industries and to specify/design fabrics, as well as an investment in our profession if we are to drive research and production.

Future directions for the conservation of canvas could include:

* Designing, fabricating, and assessing canvas for artists and conservators.
* Collecting more data on material properties and making it available through master classes and online resources, including how to interpret the data.
* Devising better simple, studio-based evaluation tests before and during treatment or when using new materials.

# <A-head> Future Options: Complex Canvas Complexity—Good Candidates for Artists’ Canvas and Lining Fabrics

The largest drivers of the development of new materials comes from the aerospace, military, and apparel industries. The fact that woven fabrics are part of contemporary composite engineering materials attests to their success in increasing the fracture toughness of structures. Fracture toughness prevents cracks (tears) from propagating: in degraded canvas, it is the brittleness of the yarns due to chain scission and increased crystallinity of the cellulose (for flax and linen) that substantially reduces the fracture toughness. Cotton duck has a much lower fracture toughness even when new because of its short staple length. Interestingly, natural materials, including linen, are still part of active research into improving the service life of structural composites, as they have properties yet to be fully replicated by other methods ({{Pandian and Jailani 2019}}).

Nonwoven fabrics have been used both by artists and conservators, typically as part of collage pieces or, in conservation applications, as interleaves in linings. Such fabrics can be made to be homogenous and heterogeneous, so it would seem their relative lack of use is due to the lack of texture, drape (ability to bend and form shapes, e.g., around a stretcher bar corner) and “responsiveness” when painting. However, the low absorbency of many synthetic materials may be considered a good property for linings.

State-of-the-art fabric structures use surface modifications to give the desired properties, such as hydrophobicity using vapor deposition on fabric ({{Xu et al. 2019}}). Filled yarns have been developed to increase stiffness and fracture toughness ({{Gilchrist, Svensson, and Shishoo 1998}}). Triaxial weaves, which have two sets of warps at 60 degrees to the weft, give increased stability and stiffness on the bias and better fracture toughness ({{Wang et al. 2018}}).

Embedded sensors in fabrics have been experimented with for over twenty years and offer the possibility of in situ monitoring of canvas properties: moisture content via electrical resistance and induced strain via fiber optics ({{Zawadzki et al. 2012}}). The problem from a conservation/preventive point of view is that embedded optical devices considerably stiffen the fabric. However, with the present development of haptics and wearable sensors in the military, sports, and gaming industries ({{Muhammad Sayem et al. 2020}}), it is likely that the technology will evolve to enable development of embedded sensors for structural conservation and the monitoring of canvas complexity. Shape memory sensors may also offer an additional option. For example, self-regulating structures that respond to environmental conditions could be woven into fabric ({{Ibrahim et al. 2010}})—and at the least they are bound to be part of future artworks.

Driven by the need to reduce our carbon footprint, energy-harvesting fabrics are being developed that convert ambient energy into electrical energy. These include dye-sensitized solar cells fabricated into functionalized yarns and made into films that can be spray-coated onto textiles ({{Torah et al. 2018}}), as well as screen-printable polymer film and polymer fibers that can harvest mechanical energy from textiles. Maybe the canvas paintings of the future could provide their own “active” microclimate.

# <A-head> Acknowledgments

I would like to thank Tim Green, retired Paintings Conservator, Tate; Dean Yoder, senior conservator, Cleveland Museum and Art Gallery; Dr. Dan Coughlan, curator and master weaver at Paisley Museum; Jean Mabon, for her expertise and for weaving the Cleveland canvas reconstructions; Jennifer Brunton, technical art history student, Glasgow University; Janey Zagreb (London); and my colleagues at the Hunterian, University of Glasgow.

# <A-head> Notes

1. For an up-to-date, comprehensive review of the published research in the conservation field, see Stephen Hackney’s *On Canvas: Preserving the Structure of Paintings* ({Hackney 2020}). [↑](#endnote-ref-1)
2. See <https://www.npg.org.uk/research/programmes/directory-of-suppliers/>.

   [↑](#endnote-ref-2)
3. Fredrix: <https://fredrixartistcanvas.com/product-category/canvas-rolls/polyflax-poly-cotton-rolls-acrylic-primed>; Haywards (now part of Heathcote): <https://www.heathcoat.co.uk/contact>; Lascaux: <https://lascaux.ch/fabrics/polyester-fabric-p110>. [↑](#endnote-ref-3)
4. McDougall website: <https://mcdougall.co.uk/fabric/fabrics/>. The company’s longevity is described in Ian McDougall’s biographical statement at <https://powertotransform.gla.ac.uk/interviewees/>. [↑](#endnote-ref-4)
5. Private communication with Dean Yoder, senior conservator, Cleveland Museum and Art Gallery, 2018. [↑](#endnote-ref-5)
6. Testing performed in the Conservation and Technology Department at the Courtauld Institute of Art. [↑](#endnote-ref-6)
7. Haptics is any type of technology that provides a tactile response. The technology can be embedded in fabrics or directly fabricated as a woven structure. [↑](#endnote-ref-7)