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3D printable recycled textiles : material innovation and a resurrection of the forgotten 'shoddy' industry

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This paper will disseminate an interdisciplinary project, undertaken at Edinburgh Napier University between the Design and Advanced Materials. Several 3D printable materials are commercially available that use recycled material, but none that incorporate textiles. This project was funded by the Textiles Future Forum in collaboration with four Scottish textile companies who provided 'waste' textiles (wool, cashmere and leather), to be used in this way. In the cases of the wool and cashmere, this is predominantly selvedge waste from the looms and knitting machines. The leather was recycled from airplane seats. The paper will outline the historical context of the project, particularly the advent of 'shoddy', how these historical processes have common characteristics with the procedures used in this project, a brief outline of how the 3D printable materials were created and an evaluation of the embodiment of the narrative of Scottish tradition and 'authenticity' in the materials.

Keywords: 3D Printing; Waste; Shoddy; Authenticity; Scottish Heritage

Introduction

Sustainability, biodegradability and circularity are important issues in the textile and fashion industry, with few tangible solutions that have the potential to make an environmental impact. (Fletcher, 2013) The research team's project, which utilises waste from the Scottish textile industry and, in combination with PLA bioplastic, created a 3D printable filament that has the ability to be mass produced in the future. The process of 3D printing, the materials used and the availability of 3D printed objects are increasing and, many believe that digital rapid prototyping has the ability to revolutionise how we manufacture and consume. (Gershenfeld, 2008) In this way, the waste textiles used in this project can be utilised in bulk and are not down-cycled, particularly if the filaments and 3D printed objects are branded and identified with the same luxurious 'craft' narrative as the textile brands that they originated from.

Utilising waste wool, in particular, into a democratically available product is not a new concept. The 'shoddy' industry in Britain and America in the 19th and early twentieth century and then, to this present day, in Prato in Italy, exploited waste wool to create a 'new' textile. In Britain and America, this textile was always known to be inferior and 'inauthentic'. Harris Tweed, as a brand was developed in a particular way that actively shunned the use of shoddy fibres and promoted the authenticity of its Scottish provenance. In Prato in Northern Italy, shoddy was produced and sold quite covertly until recently when it has started to be actively sold as a sustainable material.

The development of 3D printable material utilising specific Scottish textile waste, in many ways, replicates the processes of shoddy production. However, this process and output has the ability, in the current climate, not only to expound its sustainable credentials, impart the story of the authenticity, provenance and heritage of Scottish textiles but also to develop both of these aspects in a way that reflects the revolutionary changes that digital craft and material science offer. In a curious reversal, the processes, materials and perception of shoddy are upturned in this project, where the use of waste and clarity on the provenance of the original sources adds to the brand image, perceived 'luxuriousness' and authenticity of the 3D printed materials and potential products.

While the process of shoddy did not immediately inspire this project, many of the processes and concepts are unexpectedly similar and some of the early machinery involved in its production could have been used, if available. With laboratory conditions, the scrap materials were not dangerous for the Research Assistant to work with, as they had been in the 19th century shoddy industry. 'Waste' materials were mixed with biodegradable 'virgin' PLA, a material known for its sustainable and biodegradable credentials (although potentially this could have worked with recycled PLA).

This paper will give a historical contextualisation of this project, look at the meaning of authenticity, provenance and luxury in this instance and outline the relationship between this information and what happened in the labs and with the industrial partners. The paper will conclude with a discussion on how this 3D printable material related to ideas on the heritage of Scottish textiles and perceptions of it.

What is shoddy?

Shoddy was, and is, a wool textile spun together from the shredded fibres of recycled wool. (Figure 1.) Prior to the industrial revolution, when many of the processes involved in the spinning and weaving of cloth took place in the home, leftover woolen materials would have been kept to hand and then used as garden fertilizer. As the volume of textile waste increased exponentially with the growth of factories and manufacture, its distribution across the landscape shifted. Textile waste built up in urban factory settings. Every key stage in the production process including scouring, carding, spinning and weaving would create some waste potentially available for reuse. In addition to this, an abundance of discarded cloth, at a time of high demand for woolen goods during the period of the Napoleonic Wars, created an environment well suited to the development of the textile recycling industry.

Shoddy's advent in the early nineteenth century in England as both a textile product and industrial process was made possible by the pre-existing infrastructure of the conventional wool and paper industries and the development of specially purposed machinery for sorting, grinding, scouring and baling of recycled and waste wool. The development of the process of shoddy manufacture is primarily attributed to the mill owner Benjamin Law, in Batley, West Yorkshire, with the first shoddy cloth being dated 1813. Shell's research (2014 : 279) said that 'it occurred to Law that torn woolen rags could be further shred and then re-spun into a kind of 'renaissance' yarn which could be woven into a new type of fabric : a more economical incarnation of wool.' In addition to this, Law's brother in law, Ben Parr, is credited with 'inventing' a shredding machinery for textiles – two cylinders with metal comb like teeth which tear up the rags where the 'swifts' meet.

Three different kinds of wool waste could be turned into this new raw material; scouring refuse, tailors' offcuts and bales of shredded old wool rags. Machines for carding new wool could be slightly adapted to process old soft rags, collected initially from the region and then throughout England, Scotland, Ireland, and Europe. An emergent system of salvage technology could collect rags and sort them into colours.

Shoddy was predominantly used for goods for the 'working classes' including blankets. Few examples of 19th century shoddy garments exist, perhaps reflecting the poor longevity of the clothing, but literature suggests that it was used for simply made male suits and, most often, army uniforms. (Figure 2.) The political demonization of shoddy in the 19th century in America is directly related to poor quality uniforms made for the American Civil War. Confederate soldiers were known as 'ragged rebels' partly based on the inconsistencies and worn through state of their uniforms. War contracts to Jewish tailoring

companies such as Brooks Brothers associated badly made shoddy uniforms with profiteering and, at this time, anti Semitic racism. (Bunker & Appel, 1994)

The demonization of shoddy as a process and material

As with much of the textile industry in Britain during the Industrial Revolution, the conditions involved in the production of shoddy were dreadful. (Foster, 2003) In addition to this, the 'sharp teeth' in the grinding machines and the dust-like quality of the ground, often dirty textiles added to this reputation. The machines became known as 'devils' and ground textiles were 'devil's dust'. (Figure 3.) According to Shell (2014 : 279), this term was thought to have been first publically coined in 1842 by William Ferrand, an MP representing a substantial region of West Yorkshire in the House of Commons. He said, 'the process which is adopted by certain manufacturers, of buying up all the old rags they can obtain, which are torn into pieces by a machine, thus converted into a kind of dust, and are then mixed with wool, which is eventually manufactured into cloth. This dust, from its nauseous nature, and from its engendering numerous diseases, has been christened by the manufacturers and workpeople of Yorkshire the 'Devil's dust'. In 1861, the author of a piece called 'Devil's Dust' published in Chamber's Journal of Popular Literature, Science and Arts, described his impression of the machinery saying 'the principal part of the rag-wool machine is the swift, a frame provided with ten or twelve thousand vicious-looking teeth, and that rotates six or seven hundred times a minute. Not merely torn, it is almost ground.' (Shell 2014 : 380) In the United States, during the American Civil War, shoddy acquired its negative adjective meaning in the popular consciousness based on its association with war profiteering and fear of the possibility of disease being spread through the dirty rags. (Shell, 2014)

In Engel's 'The Condition of the Working Class in England' (1892 : 79 - 80), he talks at length on the inhumanity of the conditions in the textile factories in Yorkshire, but his dislike of shoddy had more to do with its bad quality. He said, 'and if a working man buys himself a woolen coat for Sunday, he must get it from one of the cheap shops where he finds bad, so-called 'Devils-dust' cloth, manufactured for sale and not for use, and liable to tear or grow threadbare in a fortnight.' Towards the end of the 19th Century, the manufacture of shoddy had, therefore, become synonymous with nightmarishly bad working conditions (with Devil's teeth and dust), the spread of disease, dishonest free enterprise and the material itself became symbol of class division.

Perceptions of authenticity and shoddy

Shoddy was linked to the deceitful nature of the shoddy magnates but also became known as a deceptive, inauthentic material. Shell said, (2014 : 381) 'shoddy seemed to have no respect for boundaries making it hard to tell the pure from the substitute, the derivative from the fraudulent.'

In the second half of the nineteenth century, as 'fashionable' clothing became more available to the lower and working classes, through the advent of synthetic dyes, machine printed calicos and shoddy (Vettese & Christie, 2013), it became harder to differentiate between garments that were expensive and not. This was not only felt to be deceptive, in terms of covering up contaminated cloth and allowing corrupt profiteering, but, from a middle and upper class point of view, made it harder for them to distinguish themselves by way of refinement and taste. The ability of the 'workers' to afford new garments that were similar in visual appearance to those worn by the higher classes, including their employers, began to pervade society. A letter in a women's magazine from 1876 said, 'the cook I have

had for nearly two years, and I have got on very well with her until the last few months. By degrees she has been getting gayer in her dress of late, and last Sunday when she started off for church, she wore a black silk made exactly like the new one I had sent home in the beginning of winter, and a new bonnet which I am certain I saw in Madame Louise's window in Regent Street marked 25s'. (Crane, 2012 : 170). Like Engels, Carlyle was critical of the whole industry of textiles in England but his particular writings on shoddy focus on this inauthentic aspect of it. He said, 'understand, if you will consider it, that no good man did, or ever should, encourage 'cheapness' at the ruinous expense of unfitness, which is always infidelity, and is dishonorable to a man. Universal shoddy and Devil's dust cunningly varnished over; that is what you will find presented to you in all places as ware invitingly cheap, if your experience is like mine.' (Carlyle, 1867 : 12-13)

At the start of the twentieth century, wool growers launched wide-spread anti-shoddy campaigns in both the United States and Britain. The suffusion of uniforms available for shredding after World War One increased panic in the wool industry. From this, the new term 'virgin wool' was introduced to describe 'not-shoddy'. Shell's research said, 'as labeling acts began to require specification of virgin vs shoddy material components, new synonyms for the latter emerged – 'adulterated', 'reworked' and 'renaissance wool' among them. By the last few decades of the twentieth century shoddy-as-noun was a designation almost universally forgotten, except in places like West Yorkshire.'

Positive attributes of shoddy

In the early days of shoddy production, the more alchemic aspects of shoddy production were appreciated. Shells's research (2014 : 383) cited The Westminster Review's essay on Yorkshire, describing Batley as 'the tatter-metropolis' and said 'of moth eaten coats, frowsy jackets, reechy linen, effusive cotton and old worsted stockings – this is the last destination. Reduced to filament and a greasy pulp, by mighty tooth cylinders, the much vexed fabrics re-enter life in the most brilliant forms'. Jubb (1860 : 20) also said, 'to the uninitiated, it must be surprising to see the rags suddenly transformed into fibrous wool; and it is in this process of grinding that the apparent impossibility of making old rags into new cloth vanishes away.' He also went on to say, 'not a single thing belonging to the rag and shoddy system is valueless, or useless, there are no accumulations of mountains of debris to take up room or disfigure the landscape; all – good, bad and indifferent – pass on, and are beneficially appropriated.'

Shell's research (214, 388) describes the 'human kind of job' involved in being a rag sorter saying, 'the goal was to, in as short order as possible, place them into 'grades' by colour, fabric quality, state of disrepair and so on. Touch, smell, actions such as rubbing a cloth against itself by pinching between thumb and forefinger – these were all the kinds of gestures that helped the sorter work efficiently, and the shoddy industry to maximise its potential. The sorter was a kind of material classification specialist. A constant dealing with novelty lent itself to the enactment of a kind of natural history classification built largely out of tacit knowledge.'

The history of shoddy production in Prato

By the end of the nineteenth century the centre of manufacturing for recycled wool had moved to Prato in Italy. According to Hamilton and Fels's research, after the Second World War, several factors contributed to the reestablishment of Prato as the wool regeneration centre - demand for warm

clothing, scarce availability of fuel for home heating, few plentiful sources of virgin wool and the arrival in Italy of bales of donated clothes from America. The piles of used garments were sorted by colour, turned into fibre after being soaked in an oil and chemical mixture to soften the wool and reduce the static electricity. The fibre was then spun, dyed and woven into cloth.

These tasks required labour, but none was readily available in this region apart from the 'peasants in the countryside' who 'migrated' to Prato. It is thought that this type of workforce and the 'orrù' familial system of industrial organisation allowed Prato to thrive producing, to the present day, shoddy fabric using many of the same techniques as was used in Batley in the 19th century, with better working conditions. According to Russell & Ireland, (2016) 'Italian fabric makers are turning a dirty secret into marketing weapon. Wool producers in the city of Prato have long used scraps to produce fabric more cheaply. Once taboo, the practice may now attract an eco-friendly clientele, saving the industry from tough Chinese competition. Prato has dug the skeleton out of its closet and turned it into a powerful marketing weapon.'

Prato has produced a particular product that builds on the 'hidden' shoddy industry that has developed there. The Cardato Recycled brand, which involves many of the factories and businesses within Prato, sell its product on 'being produced in the Prato district; being made with at least 65% recycled material (clothing or textile scraps) and having measured the environmental impact of its entire production cycle taking into account three aspects: water, energy and CO₂ consumption levels. (Figure 4.) To carry the label, products must be produced in Prato, produced with at least 70% of recycled material (recycled clothing or textile off-cuts) be made by mills that have accounted for their CO₂ emissions and have purchased emission credits from the Prato Chamber of Commerce. The credits purchased must correspond to production volume. Certificates are issued to individual lots of products, in order to allow businesses to eliminate only the emissions of the textiles that they eventually sell. Twenty-two thousand tons of 'rags' that have been produced with the Cardato technique are recycled in Prato every year. Cardato production is characterised by the use of short and heterogeneous pieces of yarn that are mixed together to create various textile combinations'. (Cardato, 2017)

Shoddy in Scotland

Scotland's textile industry, on the other hand, has developed its distinctive 'Made in Scotland' and 'Harris Tweed' branding strategy as a direct result of the potential of shoddy to disrupt its developing industry. Harris Tweed is old on its provenance and handmade nature, which was in direct contradiction to the industrialized shoddy industry. Although, at one point, recycled wool could have become integrated into Harris Tweed production methods and 'hidden', as in Prato, this did not happen and a more expensive, localized method was used and maintained. Moisley (1961 : 353) said, 'this quality [Harris Tweed] has been achieved, and is maintained by the use of selected raw materials and by the maintenance of high standards of design and craftsmanship. In particular, the Scottish industry depends on virgin wool and shoddy and other remanufactured wools, used extensively in West Yorkshire, are scarcely recognised.'

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The history of the development of Harris Tweed and the way that it has been branded has developed over the years. In Moisley's research, he said that interest in the 'authenticity' of the product started in the early twentieth century and that there was a growing recognition of the particular value of tweed 'for country' use and an increasing fashion for handicraft products – a reaction against the uniformity of machine-made goods. (Moisley, 1961 : 355) 'Great play was still made in advertising, of cottage craftsmanship and the Hebridean environment'. (Moisley , 1961 : 361)

By 1934, the definition of 'Harris Tweed' was eased to permit the stamping of any cloth 'made in pure virgin wool, produced in Scotland, spun, dyed and finished in the Outer Hebrides and hand woven by the Islanders at their own homes in the Islands of Lewis, Harris, Uist, Barra and their several purtenances and all known as the Outer Hebrides. It was further added that 'Woven in Harris', 'Woven in Lewis' etc could be added and also 'Hand-spun' in the case of tweeds made entirely from hand-spun yarns. The renewed Harris Tweed Association embarked on a world-wide advertising campaign and a period of rapid expansion and great prosperity ensued, particularly for Lewis mill-spun tweed. (Moisley , 1961 : 361-362)

Waste textiles in contemporary Britain

In the author's discussions with the Scottish industrial partners for this project, who were all interested in the recycling of their 'waste' textiles (in this case primarily selvedge waste from looms and knitting machines), none of them had heard of the shoddy industry or were aware of developments in Prato. They were all interested in the production of new textiles from their waste, and, in one case, the partner sought to find (and subsequently bought) a machine that would shred materials in the exactly the same way that shoddy was produced. One partner specifically asked if a new yarn could be made using recycled wool. Several of the partners in this project pay to have their selvedge waste taken away and one looked into using it as burnable fuel. In addition to this, several small companies, primarily involved with 'handicrafts', sell Scottish selvedge waste as a knitting material along with specially made, large needles. (Figure 5.) Harris Tweed are known to have issues with their waste being retrieved and represented in inferior 'craft goods' without their license, discussed in a Textiles Future Forum presentation.

Contemporary West Yorkshire's recycling industry has outlived the production of shoddy cloth. The same machinery is used to shred the recycled textiles but it is now used for 'carpets, mattresses, speaker systems and automotive padding'. (Shell, 2014)

A brief outline of the processes involved in the creation of 3D printable textiles

For the purposes of this piece, elementary timelines and processes that happened in the Advanced Material Labs at Edinburgh Napier University will be summarised and depicted rather than a detailed quantitative dissemination of the results. The project came about through a series of short presentations by academics and representatives from the Scottish textile industry, in events put together by the Textiles Future Forum. This funding body '[invited] proposals for projects from the textiles industry that will provide innovative and commercial benefit to the Scottish Economy and beyond'. The partners who decided to be involved in the project saw the authors present their work on 3D printing and the previous project utilising powdered cellulose from Lenzing. Further meetings were

taken with managing directors of the companies. The Textiles Future Forum match funded the in kind support from the textile companies which consisted of their time and offcuts of their textiles.

The research team were given 'bags' of textile 'waste' from four Scottish textile companies – mixed fibre selvedge from Calzeat, pure wool selvedge and scraps from Bute, cashmere scraps from Begg and Co and shredded recycled leather from the Scottish Leather Group.

The initial plan had been to 'powder' all these materials before the process would begin and the team searched, with very little success, for equipment that was, in essence, a 'devil'. The team had previously used powdered material before and we sought to replicate its successes. Through a fortuitous, casual conversation with another academic, an old 'pulveriser' from the 1970s was discovered tucked away behind another piece of equipment in the labs. This could produce around one kilogram of powder an hour. In the end, the process did not require 'devils' dust' rather, it was found by the Research Assistant that whole pieces of textile and yarn could be used. (Figure 6.) Using a process that the Research Assistant had explored before (creating a 3D printable material using powdered cellulose and flexible PLA), the wool, cashmere and leather pieces were laminated between sheets of PLA, turned into pellets then extruded into a filament. PLA was chosen for its sustainable credentials and that it is known as a versatile, successful material for 3D printing. Two types of filament were produced; one using a flexible PLA and another 'regular'. The second produced a filament that gave a better print. However, it was found that a very interesting material was produced with the flexible PLA that, when it did not have to be 3D printed, made a ribbon shape that could then be laser cut. (Figure 7.) Experiments were undertaken with the temperature that the filament could be printed at. Some of the early prints burned and smelled unpleasant. (Figure 8.) At this time, using budget from the funded project, the jeweller Kathy Vones is creating a range of 3D printed jewellery utilising the regular filament. Sarah Taylor is experimenting with these, towards a woven piece incorporating fibre optics. (Figure 9.) Several projects, with the industrial partners are developing including using 'waste from the waste' textiles with a selvedge yarn company, 3D printable 'soft' textiles, 3D printed textile Scottish 'souvenirs' and sheet material using the formula from this project. The research team are also in the process of patenting the material.

The embodiment of authenticity and heritage in a 3D printable material ?

The 3D printable material created in this project shares many of the same attributes as shoddy but, as with Cardato, with contemporary attitudes to recycling and sustainability, what was concealed in the processes and material components can now be a branding strategy.

The provenance and narrative behind the Scottish waste textiles can potentially become part of their identification. 'The narrative behind a product, its authenticity and provenance, are key drivers in luxury textile brands with the perception of quality of utmost importance. Long standing companies have interwoven provenance with their spiritual birthplaces, people and environments which can be leveraged in product introductions and branding.' (Collins and Weiss, 2015 : 1030) Provenance refers to the source of origin or birthplace of a product. It delineates history of ownership, providing contextual evidence as to its authenticity. In *The Luxury Strategy*, Kapferer (2012) noted at the luxury level that consumers are purchasing a 'product steeped in a culture or in a country'. Geographic origins and provenance of items are historically entangled establishing connections to a place. (Pike, 2009) These local roots anchor a brand to its history, culture, geography and ancestors, increasing perceived value

and are integral to brand identity.’(Collins and Weiss, 2015 : 1031) Products may contain natural ingredients or time honoured traditions in materiality or production methods that are intrinsic to the place.(Collins and Weiss, 2015 : 1033) There may be links to historic styles as well as subjective elements created by local culture, employees or consumers. Marketeers continue to cultivate myths about local products. ‘They develop sincere stories, which consist of a creative blend of public avowal of hand crafted techniques, relationship to place and uniqueness’. (Iverson and Hem, 2008) The workforce of selected companies includes artisans and craftspeople, as well as generations of family within the companies studied. Kapferer (2012) noted that artisanal manufacturing is ‘an integral part of the dream; someone who knows the product well, who belongs to the same cultural universe’.

Authenticity of products also has a different contemporary meaning than when ‘inauthentic’ shoddy hid its origins and true identity from the buyers. Boorstin (1961) and MacCannel (1973) suggest that object authenticity can be determined by testing or assessing it according to certain standards. Products and processes are usually described as authentic or inauthentic depending on whether they are made or performed by locals according to their traditions.

In contrast to the historic perceptions of shoddy and despite being made from waste, the 3D printable material can still be described as ‘luxurious’ using particular definitions. Kapferer and Bastien (2009) specified that ‘luxury is the expression of a taste, of a creative identity, of the intrinsic passion of the creator’. Traditional luxury relies on authenticity focused on craftsmanship, heritage, materials and rarity. (Collins and Weiss, 2015 : 1033) In Kettley’s research, the positive definition of ‘craft’, often applied to the luxury textile market, also applies in this context. She said ‘craft is no longer being defined simplistically as hand made goods, nor are assumptions being made about the cultural status of the C-word in relation to Design or to art. (Kettley, 2017) The contemporary form of Craft offers a promising model for the development of tangible computational products that seek to be metaphorically meaningful as well as useful, and as one of the earliest interactive art forms, offers us a unique opportunity to shape our new technologies. It allows us to rethink the nature of material itself and to explore the values we wish to embed in our emerging communities of practice. (Kettley, 2017)

Conclusion

Shoddy was a process and material invented during the industrial revolution. The environments in many of the industries at that time were notorious for their appalling working conditions and for the unscrupulousness of the entrepreneurs in their pursuit of profit. The shoddy industry has been recorded no differently along with the additional spectacle of the ‘devil’ and the ‘devil’s dust’. This was further added to with the widely held idea that shoddy hid filth, diseases and that someone’s old clothing, who was either foreign, destitute or criminal, had found its way into the cloth, in some way. Although the idea of branding products did not fully develop until much later, the ‘aura’ (Benjamin, 1935) surrounding shoddy, at this time, did not bode well for its status and popularity. Engels went as far as to say shoddy represented class repression.

In Prato, a different reputation and system surrounded the development of shoddy. One simple difference is that the adjective meaning of shoddy was lost in translation and did not carry the same connotations. Italy responded to the challenges they faced after the Second World War with inventiveness and humility by taking on a process that was difficult, messy and required hard work to make the business thrive, albeit with somewhat better working conditions than the 19th century English

and American shoddy mills. However, 'recycling' was not a process particularly linked to the Italian fashion industry, despite many of the well known fashion houses buying from Prato (Bijaoui, 2015). More recently, this has changed with Prato imparting its sustainable credentials.

The processes undertaken in this project emulate Prato shoddy in many ways. Although this project could have taken place anywhere, the inclusion of Scottish waste textiles, and the reputation that 'Made in Scotland' has, will be a starting point for further investigations into whether a new material (and relatively new digital craft process) can carry this provenance. It will look into whether characteristics that were previously demonised, such as the inclusion of unusable 'floor sweepings' within the 3D printable material, can be a selling point. With digital craft, in particular 3D printing, ideas around what makes an object 'authentic' are repositioned. Because of the experiential nature of the 3D printing process and the little glitches that occur in each print, a 3D printed object can be unique and mass produced, hand crafted and digitally created and incorporate the impression of the unique passion of the creator. It is anticipated that the addition of the material created in this project will not only innovate in the products that are created, but also challenge perceptions of what Scottish traditional craft and textiles are.



Figure 1. Shoddy fabric
Source: TDRG - Source

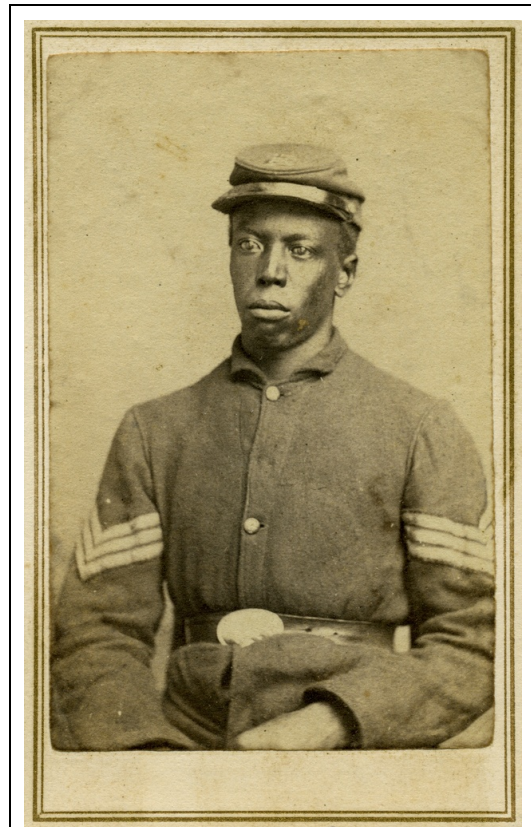


Figure 2. Example of shoddy Confederate uniform
Source: TDRG - Source

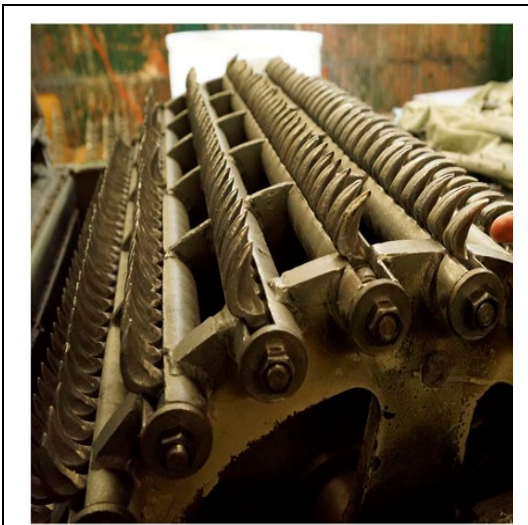


Figure 3. Devil's teeth
Source: TDRG - Source



Figure 4. Cardato recycled wool
Source: TDRG - Source



Figure 5. TDRG – Selvedge sold for knitting
Source: TDRG - Source



Figure 6. wool yarn laminated with PLA
Source: TDRG - Source



Figure 7. Laser cut ribbon made with recycled wool and PLA
Source: TDRG - Source



Figure 8. Early experiment with 3D printed wool
Source: TDRG - Source

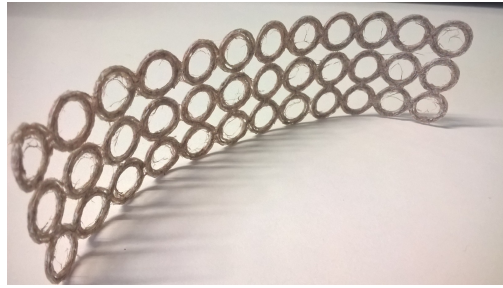


Figure 9. 3D printed wool by Sarah Taylor
Source: TDRG - Source

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