From Waste to Textiles

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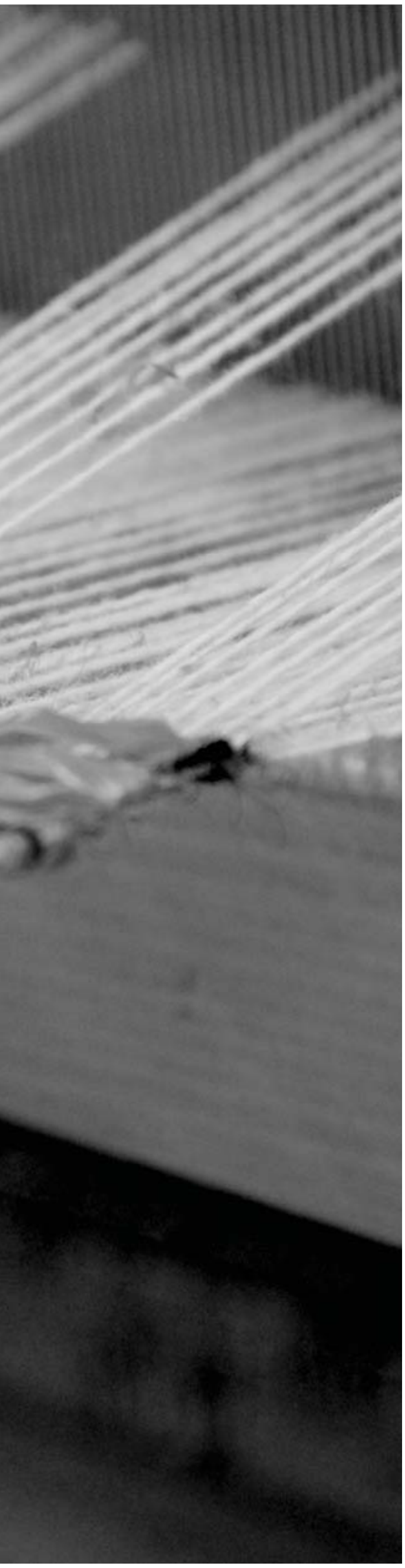
The exploration of the potential application of rice straw waste in the development of eco textile design solutions.

Michelle Macky

2014



Warp

"a set of vertical yarns that are held in tension on a frame or loom."

Weft

"a set of horizontal yarns that fill the weave structure."

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1. Strong wool - characteristic of crossbred sheep producing coarse fibred wool.
2. Retting - process of using moisture to aid in the separation of fibres from the plant e.g. flax and straw.

abstract

With the world's population predicted to grow by another two billion people within the next forty years (United Nations, 2013) the demand for arable land space for agricultural food production will increase rapidly. This in turn will result in an increased volume of waste fibre. The availability of land to produce virgin fibre-only crops is limited. Companies and designers are beginning to use non-traditional innovative approaches to utilise the fibre from agricultural food production or renewable sources. The Formary have placed themselves amongst these companies and have an aim to reduce the need for virgin fibre-only crops, freeing up valuable land space for food production.

The Formary are developing ways to convert fibre waste from agricultural food production into viable and marketable fabrics, "by transforming waste through good design" (The Formary, n.d.).

The Formary developed a relationship with the Chinese Government in 2011, while on the Wellington City Council's Mayoral Delegation to China, approaching them with an idea to use rice straw fibre from the 33% of unused waste.

In 2012, a collaborative partnership between The Formary, Dr. Sandy Heffernan of Massey University's Textile department and Wool Yarns Ltd led to the development of a prototype yarn, using a blend of rice straw waste and New Zealand strong wool[1]. Funding provided by Callaghan Innovation enabled this investigation to further the research into using rice straw waste fibre as a textile material.

The overall research had two key requirements. The first requirement was undertaken by Dr. Gaile Dombroski who researched the technical processing of the rice straw into a viable yarn using different retting[2] processes. This research and design development focuses on the second requirement, investigating design processes that can use rice straw waste as a fundamental material.

The key goal was to use an optimal ratio of rice straw waste to develop innovative, distinctive and viable fabrics.

Fabric experiments were constructed through the reinterpretation and development of traditional textile woven and non-woven techniques. The traditional textile construction process of weave has been comprehensively investigated and experimented with to develop the use of the rice straw and wool yarn within a textile structure. The non-woven textile technique of felting was also incorporated into this research as it offered an opportunity to increase the percentage of rice straw used. It also created a unique way to bind the rice straw and wool fibres together. Both textile processes have added value to the rice straw fibre by highlighting its natural properties, with the intention of producing innovative, high end, marketable fabrics as alternatives to current forms of disposal.

This research depicts the partnership that was formed between The Formary and myself and progresses through my journey to shape the development of using the rice straw waste within textile design.

content

3. Virgin fibre-only crops - agricultural crops grown solely for the fibre e.g. cotton.

scope

From waste to textiles: the exploration of the potential application of rice straw waste in the development of eco textile design solutions.

Issue

Currently the Chinese government claims that figures show 67% of the waste bi-product accumulated from rice harvest is being utilised for the following purposes; organic fertiliser - 15%, feed for animals - 30%, energy production - 18%, fungi production - 2 % and industry/ manufacturing - 2%, (B. Casey, personal communication, July 26, 2013). These figures highlight the issue of the remaining 33% of the waste fibre that remains. China produces up to 35% of the total world production of rice. Asia produces 620 million tons of rice straw annually. It is estimated that China's share of this production is around 200 million tons, equating to 66 million tons of unused rice straw. Thus far there has also been no consideration made to use it within the textile industry. The current practice of infield burning of this waste bi-product is causing aerial pollution in China. It's quite common for the smoke and ash pollution to get so bad that China has to close airports.

The Formary, an entrepreneurial company based in Wellington is interested in the development of converting fibres harvested as a bi-product from agricultural crops already grown for food production into viable and marketable fabrics, rather than growing crops solely for fibre, using arable land. The Formary wants to reduce the need for virgin fibre-only crops[3]. The Formary approached a Chinese rice manufacturer with an idea to use rice straw waste to create unique fabrics, generating alternative uses for this fibre. The Chinese see this as a solution to a problem as much as a manufacturing opportunity.

Research Question

How can textile design processes be applied to rice straw waste fibre, to propose alternative uses for the 33% of the waste bi-product that is still unexploited?

Who am I as a designer?

As a textile designer I value The Formary's approach to incorporate waste bi-products into their design practice. By, "transforming waste through good design" (The Formary, n.d.) The Formary are contributing to sustainable development within the design industry.

This research offered me the opportunity to develop and extend my understanding of sustainable practices within design and allowed me to develop my own advanced textile design processes, initially informed by my existing knowledge and expertise in textile design. My design approach was to push the boundaries of the traditional methods and experiment with the unexpected.

Callaghan Innovation

A technology fellowship provided by Callaghan Innovation enabled this investigation to further the research started by The Formary, Dr. Sandy Heffernan of Massey University's Textile department and Wool Yarns Ltd in 2012. Callaghan Innovation provides businesses with support, knowledge and resources to turn ideas into internationally marketable products. The Formary was granted this technology fellowship to assist in the technical expertise and research and design development required to identify the best application for rice straw waste.

Figure 1 Farmers in the process of buring rice straw, current practice of disposal.

context rice straw

Rice is a major agricultural asset to China. China can account for as much as 35% of the world's rice production (IRRI, n.d.). However the amount of waste bi-product that is accumulating due to rice harvests and the current practice of burning this waste are causing grievous harm to the environment and the population of China.

The common form of disposal is infield-burning which results in widespread aerial pollution. Figures 1 and 2 on pages 14 and 17 illustrate the process of burning the waste and the pollution that is caused during this act of disposal.

In 2008 the International Rice Research Institute claimed that about 620 million tons of rice straw was produced in Asia alone, and this amount is increasing every year. In Henan Province, the central plain of north China, approximately 25% of the straw material is burned to prepare the fields for the next crop. In other areas the problem is worse, such as in Jiangsu Province, where straw burning has increased from 21% in the mid-1990s to 48% in the mid-2000s (Pan, Crowley, & Lehmann, 2011).

Due to its low digestibility, low protein, high lignin and high silica content it is also unable to be recycled back into the soil as it will not completely decompose during the limited time of 20-25 days between each crop (IRRI, n.d.). These particular physical and chemical properties have the ability to function in a textile product or have the ability to enhance textile fabrics, but their value is not recognized within this field.

Rice straw is a cellulose fibre, which makes it viable to be manufactured into a number of products including paper and textiles. The rigid and woody structure of the straw is due to the lignin[4], which can offer strength to a product. The waste fibre also contains a high level of silica, a hard, un-reactive, colourless compound that offered the potential for flame retardant fabrics (IRRI, n.d.). This compound may however cause problems with tools and machinery in regards to industrial manufacturing of the final textile product.

Other key attributes that were vital to the development of viable applications for the rice straw included low thermal conductivity. Rice straw has a thermal conductivity of around 0.036 W/m °C[5], which is comparable to most insulation materials. This allowed the development of non-woven felting techniques to be aimed towards the potential application of interior insulation.

Rice straw has the ability to biodegrade creating a suitable application into Limited Life Geotextiles (LLG). LLG fabric structures provide additional reinforcement to soil until the foundation soil achieves the desired strength over time as new vegetation establishes itself within the structure of the geotextile. The consideration of this particular application for the rice straw was to create geotextiles made from natural fibres that would biodegrade over time, eliminating waste from the environment.

Combining wool fibre with the rice straw waste, enhances its ability to absorb moisture, wool can absorb a third of its own weight in water without feeling wet. Wool also enhanced the potential of the rice straw to be used as acoustic insulation, generating more practical application options for each textile experiment.

4. Lignin - a complex organic polymer deposited in cell walls.

5. W/m °C - measurement of thermal conductivity through a particular thickness.

Figure 2 Aerial polution casued by the smoke.

context sustainability

'Sustainable development' as defined by the Oxford Dictionary is an "economic development that is conducted without depletion of natural resources." However, 'sustainability' or the ability to sustain is popular within design practice and design research; but can be interpreted from many perspectives.

Within the textile industry sustainable development is a major concern and research to achieve this is a crucial objective for this research.

The Formary understand the complexities towards having sustainable practices put in place. They recognize their choices in the design development of a commercial product affect the whole lifecycle, from manufacture to disposal. This is why they believe in using the waste fibres from edible crops like rice, which is a more viable way of increasing land and crop value and freeing up arable land space instead of producing fibre-only crops like cotton.

According to the Organic Trade Association website, cotton covers 2.5% of the world's arable land. Cotton production uses more than 16% of the world's insecticides, more than any other single major crop. The availability of land to produce virgin fibre only crops is limited, therefore companies and designers are beginning to use non-traditional innovative approaches to utilise the fibre from agricultural food production or renewable sources.

Fashion design researcher and sustainable design activist Kate Fletcher (2008) makes a valid statement believing that the challenge towards becoming sustainable is not to go on as before, but to move forward and acknowledge the complexity of the environmental and social impacts of our design choices. She adds that becoming sustainable can seem more real and easily achieved; designers just need to accept waste as an inevitable bi-product and incorporate waste into our design practice. She also believes that sustainable fibres should be chosen for their "appropriateness" to product and user. This is significant to this research, as the waste rice straw fibre has thus far not been considered to be used within the field of textile design.

Fletcher (2008) also addresses the fact that designers should consider the whole lifecycle of fibre to final product. This highlights another significant issue for the design and research development into waste fibre use. The 'cradle-to-cradle' principle outlines the potential to incorporate waste post-production.

Cradle-to-cradle design reflects the whole lifecycle of the designed outcome and models human production processes on the way nature circulates nutrients (Braungart & McDonough, 2009, p. 4). This process aims to eliminate the concept of waste, "to eliminate the concept of waste means designing from the very beginning on the understanding that waste does not exist" (Braungart & McDonough, 2009, p. 104).

Employing the concept of 'cradle-to-cradle' within this research ensures the rice straw will naturally regenerate or biodegrade at the end of its lifecycle and become precious nutrients for the environment.

UK weaving and design company Camira is committed to developing sustainable practices and it shares Fletcher's view in choosing fibre or materials appropriate to the final product.

With the focus on developing a sustainable product, Camira developed a fabric from stinging nettle called STINGplus. Investigation into the use of this natural weed was undertaken due to its inherent properties; the strength of the fibre being stronger than wool and yet finer than hemp illustrating that this fibre was 'appropriate' to create woven interior fabrics with style and substance. The use of this natural weed in manufacturing textile fabrics emphasizes that by using design intervention, value can be placed on sustainable fibres.

STINGplus is manufactured using 25% nettle fibres and 75% wool, in a process using less water and energy than other textile manufacturing processes. Camira is also assessing the whole lifecycle of the fibres and their relative sustainability to achieve the best outcome for its product (Camira: Style and Substance, n.d.).

The Formary appreciate how Camira and Kate Fletcher view the potential in incorporating sustainable fibres within design practice. Camira approachedsustainable practice by utilising a naturally growing plant; stinging nettle, which is often considered as a weed. Creating fabrics that have both style and substance produces a viable way of eliminating this weed.

There is a common distinction between the research Camira is embarking on in regards to this research. The agricultural growth of the stinging nettle is very sustainable, as it requires no pesticides or herbicides and is produced on land that is often unsuitable for other crops (Camira: Style and Substance, n.d.).

The Formary are challenging Camira's approach to sustainable development by using waste bi-products from food sources, which not only reduces waste but also increases value for the farmer and land.

"... sustainable fibres should be chosen for their "appropriateness" to product and user."

The Formary worked collaboratively with Camira to create a new sustainable textile using a unique up-cycling process. By utilising Camira's expertise in bast fibre woven upholstery cloth WoJo was created; a revolutionary fabric made from blending jute from the coffee sack waste stream from Starbucks and New Zealand strong wool.

Within the media release The Formary presented in 2010 to announce the development of this new textile fabric, Group Sales & Marketing Director for Camira Andrew Schofield states,

> We have a long history of making environmentally friendly textiles out of natural and renewable raw materials and were excited by the challenge of 'up-cycling' jute by combining it with pure new wool. We manufacture fabrics for everything from offices and universities to buses and trains to now be playing a part in enhancing Starbucks stores by re-using old coffee sacks is fantastic. (p. 2, [Media Release])

Creating a sustainable solution to up-cycle waste fibres like jute had a key challenge to overcome. The challenge was the waste fibres did not have the reliability to stand-alone but needed a carrier to bind them together. Managing Director of The Formary Bernadette Casey developed a solution by blending the fibres with wool,

> It occurred to me that the perfect way to reduce the jute shedding was to blend it with wool. The more I thought about it I was convinced we were onto something. And so we began experimenting with wool and recycled jute in a number of different applications.(p.2, [Media Release])

"... to eliminate the concept of waste means designing from the very beginning on the understanding that waste does not exist."

Figure 3 Wojo Starbucks Chair.

context wool

The key directive for this research was to use an optimal ratio of rice straw within the construction of textile fabrics. Because the rice straw fibre needed a carrier, it meant that this investigation was not only about adding value to rice straw waste but also to New Zealand strong wool. Similar to Camira, The Formary have made wool their primary carrier for blending with waste fibres, “we don’t always work with wool, but when textiles or fibres do not have the integrity to stand alone, wool is a fantastic and forgiving carrier” (TEDxTalk, 2013, [Video file]).

New Zealand wool has provided opportunity for income since the 1840s (Carter & MacGibbon, 2003) and was one of the largest and most valuable exports. The industry has seen a drastic decline over the years and now only represents less than 2% of New Zealand’s export market (Faulkner, 2012).

The use of New Zealand strong wool within this research offers local enterprises with an opportunity to gain more profit, while also promoting design within the wool industry.

Along with the collaboration with Camira to create Wojo, The Formary was also in a partnership with Wools of New Zealand, due to their sustainable-farmed Laneve wool. “Laneve traceable wool is sourced only from accredited farms which meet high standards in regard to animal welfare, land management, farming techniques and environmental practices” (The Formary, 2010, p.2, [Media Release]).

Blending Laneve wool with recycled jute, not only created a sustainable product, but also offered the opportunity to re-brand wool as a luxury fibre.

Brand strategist Brian Richards (2010) created ‘Laneve’ with the main focus on re-positioning wool as a prestigious and luxurious fibre. Consumers today are demanding more than superior quality. They are seeking authentic products, imbedded with natural properties, integrity and sustainability (WoolsNZ, n.d.). Richards however addresses a problem with re-branding wool. He believes knowledge about wools distinguishing attributes exists, just not in one cohesive form. The Wools Benefits System (appendices, page 90) was created to highlight key attributes like beauty, health, integrity and comfort to aid critical decision making when choosing between synthetic and wool products.

The Formary acknowledged the superior attributes wool holds. Blending waste fibres with wool means that the fabrics will benefit from the superior chemical properties and physical characteristics of this unique fibre.

Wool has the ability to repel water. The water-repellent surface makes wool garments naturally shower-proof and also reduces staining. The interior structure creates flexibility, absorbency, elasticity, resilience and wrinkle recovery properties. Wool has naturally high UV protection. Wool fibre has a higher ignition threshold than many other fibres and is flame retardant up to 600º C and produces less toxic fumes in a fire. It is biodegradable, natural wool fibre takes only a few years to decompose, and with high nitrogen content, wool can even act as a fertilizer. Breathable, non-allergenic and naturally insulating; wool can insulate the home providing and retaining warmth, reducing energy costs (Campaign for Wool New Zealand, n.d.).

It was vital to keep these properties in mind and ensure that the relationship between the rice straw and wool was apparent.

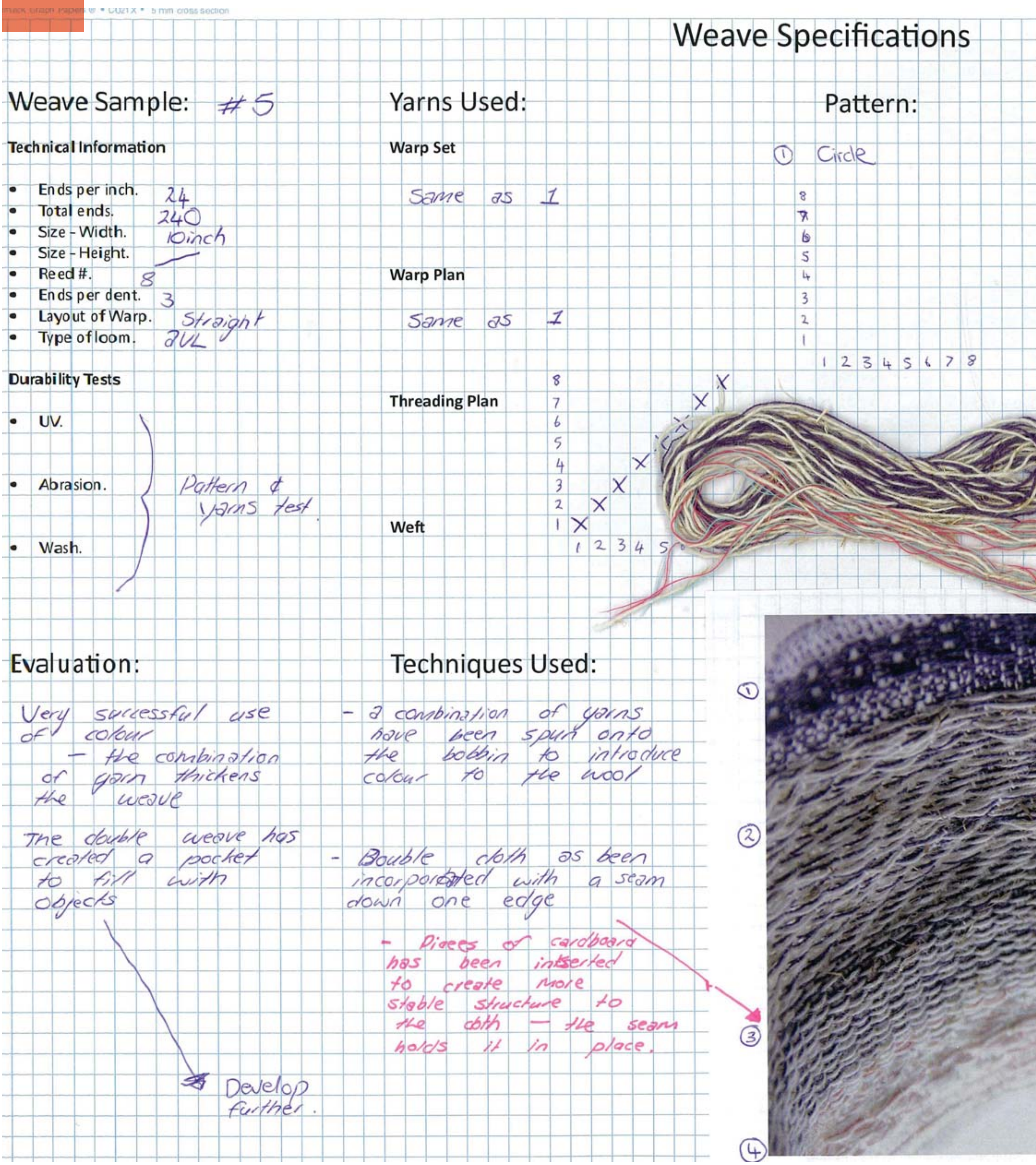
The high silica content of the rice straw fibre within the yarn enhances the existing flame resistant properties of the wool. Rice straw and wool are both highly accessible and are renewable sources increasing the sustainable development of this research.

The relationship between the rice straw fibre and wool is similar to the combination of jute and wool to create a viable fabric. Wojo fabric has been directed towards interior upholstery and was used to enhance the interior environments of Starbucks Coffee houses. Figures 3 and 4 presented on pages 22 and 25 show examples of the Wojo fabric within a final product. The potential to use the rice straw yarn within interior fabrics is reinforced by these examples.

"... we don't always work with wool, but when textiles or fibres do not have the integrity to stand alone, wool is a fantastic and forgiving carrier."

Figure 4 Cloak Chair (2010) Room Two. Wojo and Steel.

Figure 5 Weave specification sheet.



Weave Specifications

Weave Sample: #5

Technical Information

- Ends per inch. 24
- Total ends. 240
- Size - Width. 10inch
- Size - Height. —
- Reed #. 8
- Ends per dent. 3
- Layout of Warp. Straight
- Type of loom. 4VL

Durability Tests

- UV.
- Abrasion.
- Wash.

} Pattern & yarns test

Yarns Used:

Warp Set

Same as 1

Warp Plan

Same as 1

Threading Plan

8 7 6 5 4 3 2 1 / 1 2 3 4 5 … (X marks on diagonal)

Weft

Pattern:

① Circle

8 7 6 5 4 3 2 1 / 1 2 3 4 5 6 7 8

Evaluation:

Very successful use of colour – the combination of yarn thickens the weave

The double weave has created a pocket to fill with objects → Develop further.

Techniques Used:

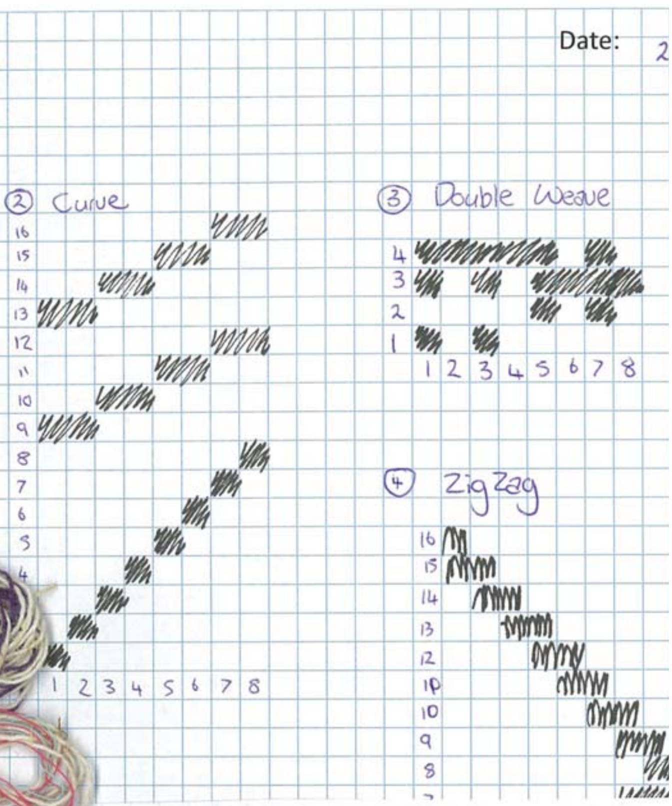
- a combination of yarns have been spun onto the bobbin to introduce colour to the wool

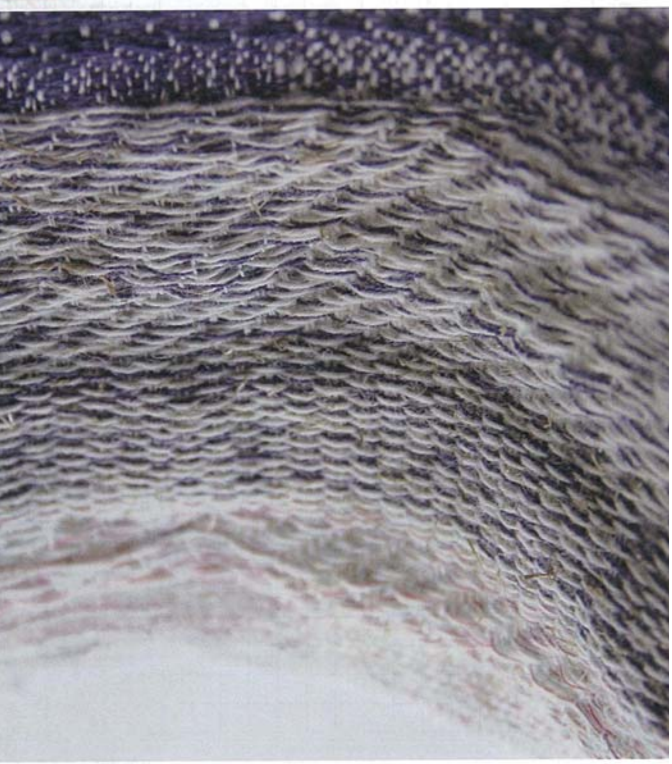
- Double cloth as been incorporated with a seam down one edge

- Pieces of cardboard has been inserted to create more stable structure to the cloth – the seam holds it in place.

① ② ③ ④

method & process





Graphic design researchers Ian Noble and Russell Bestley (2011) believe that design is a cycle and is an 'iterative process' and this process in itself raises further questions through which to develop alternative and innovative outcomes (Noble & Russell, 2011). The overarching methodologies that contributed to the design development in this research were experimentation, design iterations and quantitative sampling. The method explored was to follow an experiment-led process and respond to the material through critical evaluation and analysis.

The method followed six key stages outlined within the proposal presented to Callaghan Innovation (Callaghan Innovation Aim, Objectives and Milestones, 2013). By breaking the research down into the six set intentions, each with defined parameters, each task was made more achievable and the goals of each stage progressed efficiently.

1. Scope/ Literature Review.
2. Experimentation.
3. Initial Material Construction.
4. Changing and Redirecting Existing Processes.
5. Speculative Design, Integrating Technology and Material.
6. Development of Surface and Structural Aesthetics.

The prototype yarn, a New Zealand strong wool and rice straw fibre blend supplied by The Formary developed in earlier research framed the early stages of this exploration. Responding to the physical nature of the yarn being very stiff and scratchy, and adapting to the loose fibres falling off, the technique of weave was selected. This was also due to the warp yarns needing to be strong enough to withstand greater stress and abrasion during weaving. A challenge of using this yarn during the weaving process was having the warp yarns stick together (photo evidence within appendices page 91).

The main focus for the research was to create fabrics with an optimal ratio of rice straw. During the design development of the prototype yarn, the consideration of using the rice straw in its natural form was experimented with. This was to see if the fibre could stand-alone and not need a carrier. Utilising the stalks of the rice straw offered unique colour combinations within the weave structures. Investigating the process of retting the fibre, produced softer and smaller fibres, easily applied as stuffing material. Both options achieved a higher use of the rice straw within each sample.

By working through a series of experiments, developing each different weave structure one by one, numerous experiments were created during each stage of development.

Each sample that was produced was created in an experimental manner, with iterations of an experiment being created from the one that preceded it. After an experiment was finished, it was automatically cut from the loom for critical evaluation to determine the behaviour of the rice straw within the woven structure. Each weave had its own technical information noted down for future reference. Figure 5 on page 26 represents technical information for one particular weave experiment. This was critical to the process as it made it easier to replicate the same weave structure and it communicates the design direction for constructing the woven cloth. The information could then be interpreted during industrial manufacturing.

A technical journal was kept throughout the design process, and was reflected on constantly to aid in the design decision for the next iteration.

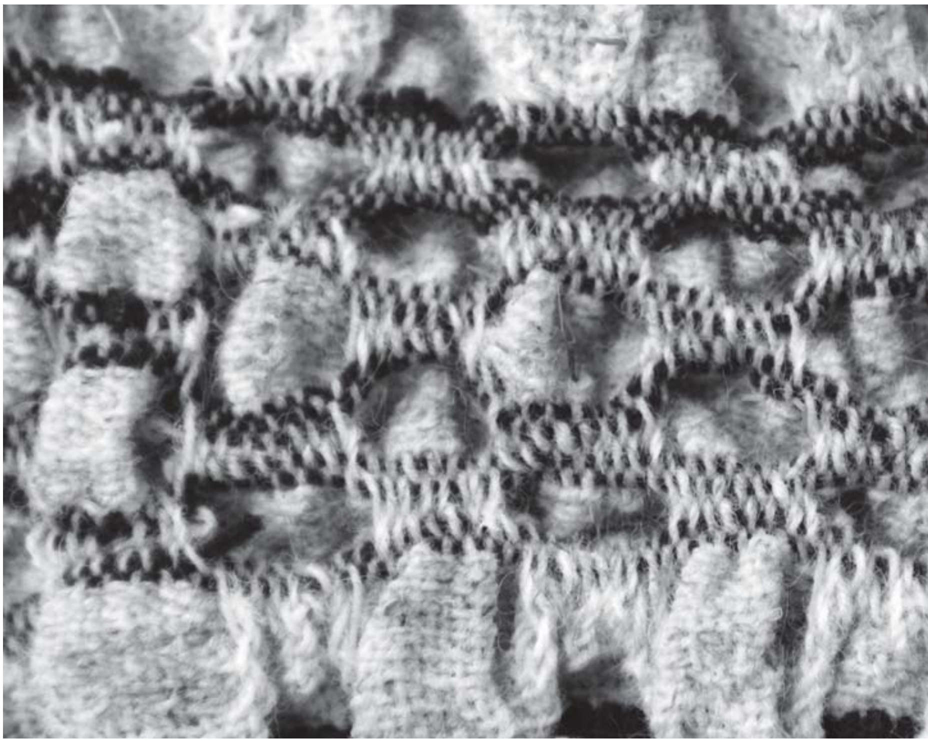
Technical information included:

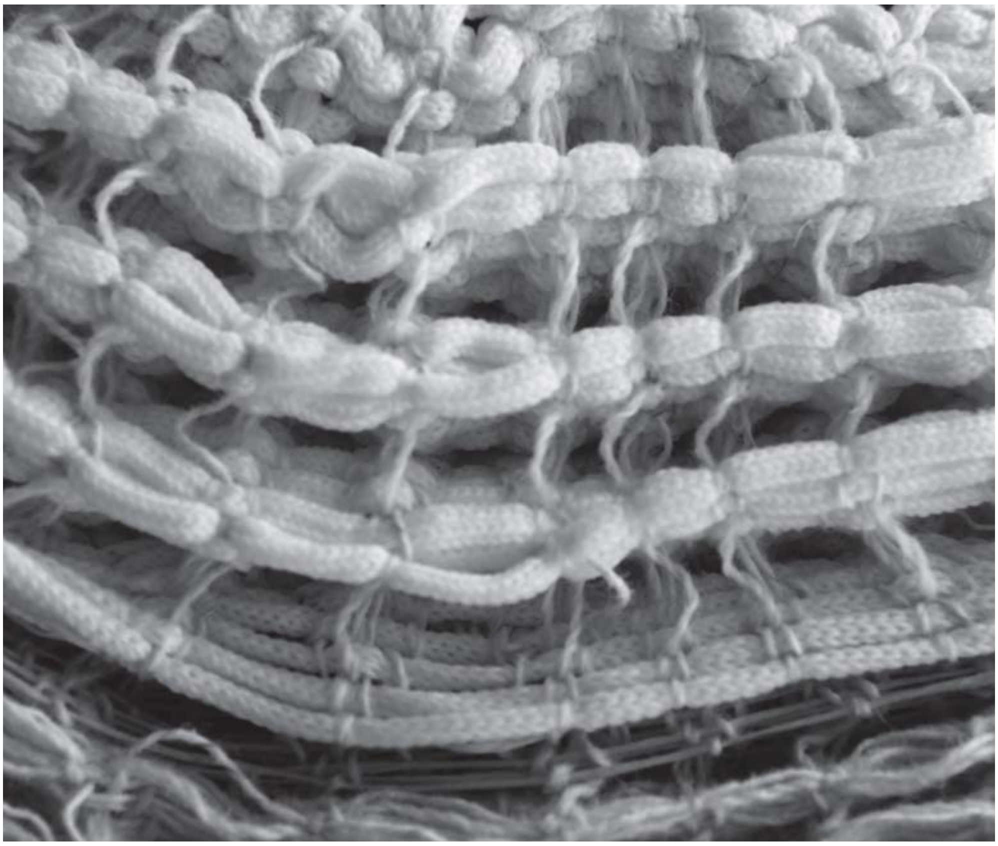
- Size of weave (width) - this is measured in inches.
- Reed size - this determines the tightness of the weave. Most experiments used #16.
- Total number of thread ends.
- Number of threads per inch. 32 threads per inch suited the thickness of the rice straw yarn.
- Number of threads per dent. 2 threads were pulled through each dent; this allowed the rice straw fibres to be pulled through easily.
- Threading plan. Honeycomb, waffle and double.
- Lift plan. Sequence of lifts that created the overall structure of the cloth.
- Warp and weft yarns used.

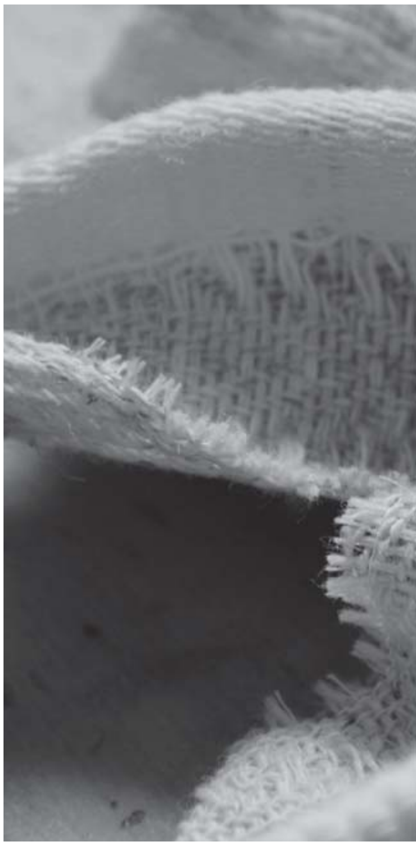
During the development of each weave structure, a mind map was created to illustrate the progression of each sample. This was essential as it portrayed links between each different weave experiment. Examples of the mind map can be viewed within the appendices on pages 92 and 93.

"... design is a cycle and is an 'iterative process' this process in itself raises further questions through which to develop alternative and innovative outcomes."

Initial weave experiments.







weave

Weaving is a very technical process. It is used to construct fabrics for a number of applications and products including apparel, interior upholstery, technical and industrial textiles.

As previously mentioned within Method and Process, the traditional technique of weave was chosen to construct fabrics using the prototype yarn of wool and rice straw. This was to determine the behaviour of the rice straw within a woven structure.

Author Jessica Hemmings (2012) states that long before the cloth exists; the process of weaving begins with individual threads or yarns. This amplifies the essence of this research. The physical properties of the rice straw yarn, which includes the ability to biodegrade, alongside thermal and acoustic absorption, would establish how the woven structure would be created.

Weave enthusiast Ursina Arn-Grischott (1999) states the view of renowned textile designer Anni Albers on how we should portray the use of yarn, which we can incorporate into our weave structures,

> Yarn is a source of endless inspiration. If we as designers cooperate with the yarn, we can solve problems of design and form more objectively. If the design is simple, is adapted to its end use, and the yarn is taken into account, our work will not be short-lived fashion that will one day look out-of-date. It will be ageless. (p.32)

This view that Arn-Grischott (1999) reiterates is valid for this research because the yarn used depicts the overall structure and behaviour of the woven cloth. The final outcome of a woven cloth is the combination of two elements, the character of the fibres, the rice straw and wool and the overall structure of the weave.

Arn-Grischott also states that weaving should be adapted to its end use, and it is believed that form follows function. The overall function or application is a guide to choosing an appropriate yarn for the fabric. Author Ann Richards (2012) believes the yarn and function of a weave is cohesive and highlights this idea by using inspiration from Albers,

> The fastening of its elements of threads to each other is as much a determining factor in its function as is the choice of the raw material. In fact, the interrelation of the two, the subtle play between them, in supporting, impeding, or modifying each others characteristics, is the essence of weaving. (p.7)

This research began with a specific yarn. The application and function was determined after critical evaluation of the yarn's properties. The high silica content of the straw enhances the existing flame resistant properties of the wool, a key attribute for interior fabrics and furnishings. Both fibres have the ability to biodegrade, which created the opportunity to construct woven structures specifically looking at the function and performance as a technical textile.

Fabrics for interior environments are designed to be revealed and have a high degree of aesthetic appeal. The woven structures contributed to this factor as they created design elements within their repeat patterns. Woven fabrics suitable for the interior environment must be able to withstand considerable wear and tear, and when it comes to interior upholstery, money doesn't necessarily buy longevity.

Weaving techniques are such an excellent way to incorporate heritage and beauty into one piece of fabric. Evaluation of upholstery fabric usually begins with consideration of the fibre content. Rice straw fibre has never been used before, however the inclusion of the wool fibre achieved the performance requirements of an interior fabric.

Weaving was, for many years, "the pre-eminent technology employed in the manufacture of industrial textiles" (Horrocks & Anand, 2000, p. 10). Woven technical textiles are designed to meet the requirements for their end use (Horrocks & Anand, 2000). Designers are utilising this simple process of interlacing fibres to create strength, thickness, extensibility, porosity and durability.

Today's textile industry trend is moving towards manufacturing technical, high performance fabrics designed not just to look attractive, but also to offer a significant added value in terms of functionality and performance.

An area of technical textiles considered for this research was geotextiles. Geotextiles are penetrable fabrics which, when used in association with soil or the outside environment, have the ability to separate, filter, reinforce and protect. Geotextiles are a core member of the geo-synthetic family. It has been estimated in a recent market report published by Transparency Market Research (2013) the global market for geotextiles was valued at USD 3.2 billion in 2011 and is expected to reach USD 6.4 billion by 2018. In terms of volume, the demand for geotextiles was 1,904.0 million square meters in 2011 and is expected to reach 3,398.4 million square meters in 2018 (Transparency Market Research, 2013).

Man-made fibres dominate the geotextile industry. Geotextiles are designed according to the desired functional needs, and can be fabricated from both synthetic and natural fibres with different design, size, shape and composition, making geotextiles a dual commodity.

The concept of Limited Life Geotextiles (LLG) has been considered for the final designed outcome incorporating the rice straw and wool yarn. LLG refers to the function of the geotextile in providing additional reinforcement until the foundation soil achieves the desired strength over time, as new vegetation establishes itself within the apertures of the geotextile. This vegetation covers the ground surface and its roots anchor the soil so the geotextile is made redundant biodegrading over time, eliminating waste.

Woven structures can vary almost endlessly due to the two thread systems that are required to construct a cloth, the warp[6] (vertical) and weft[7] (horizontal) threads (Eriksson, Gustavsson, & Lovallius, 2011).

All woven fabrics are derived from three basic structures; plain weave which creates the firmest cloth, twill weave creates a shift in warp and weft threads producing diagonal lines within the weave structure and satin weave is where the warp and weft threads are spread out creating a smooth surface (Eriksson, Gustavsson, & Lovallius, 2011).

The development for this research began with the idea that a woven cloth is a flexible construction. This was amplified through the following development of four advanced weave structures; honeycomb, waffle, rib and double cloth.

6. Warp thread - a set of lengthwise threads that are held in tension on a frame or loom.
7. Weft thread - horizontal threads that fill the weave structure.

Figure 6 Honeycomb cell structure constructed with rice straw/ wool yarn.

Figure 7 Reverse side of the weave structure, curling of the yarn.

honeycomb

The honeycomb weave was identified as a potential weave structure due to the particular aesthetic feature of the deep cells that are created in its structure.

The honeycomb weave derives its name from its resemblance to the hexagonal honeycomb cells of wax in which bees store their honey. The hexagonal hollows that are produced within this structure create a geometric check pattern. The high and low parts of honeycomb woven fabrics are formed by different intersections of the warp and weft. This structure creates a rough texture to the weave, however incorporating wool as a weft material provided softness to the final experiments.

The physical characteristics of the weft threads 'floating' on the reverse side of the woven cloth renders it readily absorbent of moisture. The weaves are, therefore, suitable for towels and bathrobes.

Experimentation with this particular structure was to define the cells of the honeycomb and also to incorporate the use of both sides of the weave, highlighting two aesthetic elements. This took the form of changing the weft yarn used to construct the woven cloth.

By keeping the warp yarn (prototype rice straw/ wool yarn) constant, different experiments were created.

Figures 6 and 7 show how the structure of this weave made the yarn behave in different manners.

The floats caused curling and twisting of the yarn, generating more movement within its structure (Figure 7). The rice straw yarn has a particular roughness due to the loose fibres. The floats that are created in this sample gave it more of a delicate and soft appearance. The use of a different binder weft (plain weave between honeycomb) achieved more depth to the cells, which introduced a new iterative for this structure.

Altering the size of the weft yarn used to create the sections of cells changed the overall structure of the weave; the cells became more defined and had more depth, illustrated in figure 8. The thick felted yarn hides the colour within, however this creates more stretch and movement revealing the colours used, which is shown in figure 9.

The depth of the cells had the potential to hold small objects, leading to the discovery of the next woven structure to be experimented with, waffle weave.

Figure 8 Felt yarn creating depth to the honeycomb cells. Hides colour within.

Figure 9 Stretching the woven structure reveals the colours within the cells.

Figure 10 Waffle weave structure containing grass seeds.

waffle

The structure of a waffle weave is created using a pointed threading plan, creating small hollows that form pyramid like structures. This structure creates a large surface area within the weave allowing air to flow through freely for quick moisture absorption.

It is common to see the waffle weave structure in interior homeware including bath towels due to its quick moisture absorption. It also occurs within the technical textile industry as a solution for soil stabilization.

The inclusion of this structure had the whole lifecycle of the fabric being created in mind. Producing geotextiles made from natural fibres that would biodegrade over time, eliminates waste occurring within our environment.

Experimentation for this particular structure was to extend the idea of being able to hold objects within the structure of the weave. Earlier experimentation saw the use of the honeycomb structure; however the cells were still not deep enough to contain the objects. The waffle weave creates deep hollows, covering a large surface area, suitable to hold small objects like seeds, or be used to stabilize soil. The use as a geotextile is depicted within figure 10.

Figure 11 Experimenting with resin to alter the structural properties.

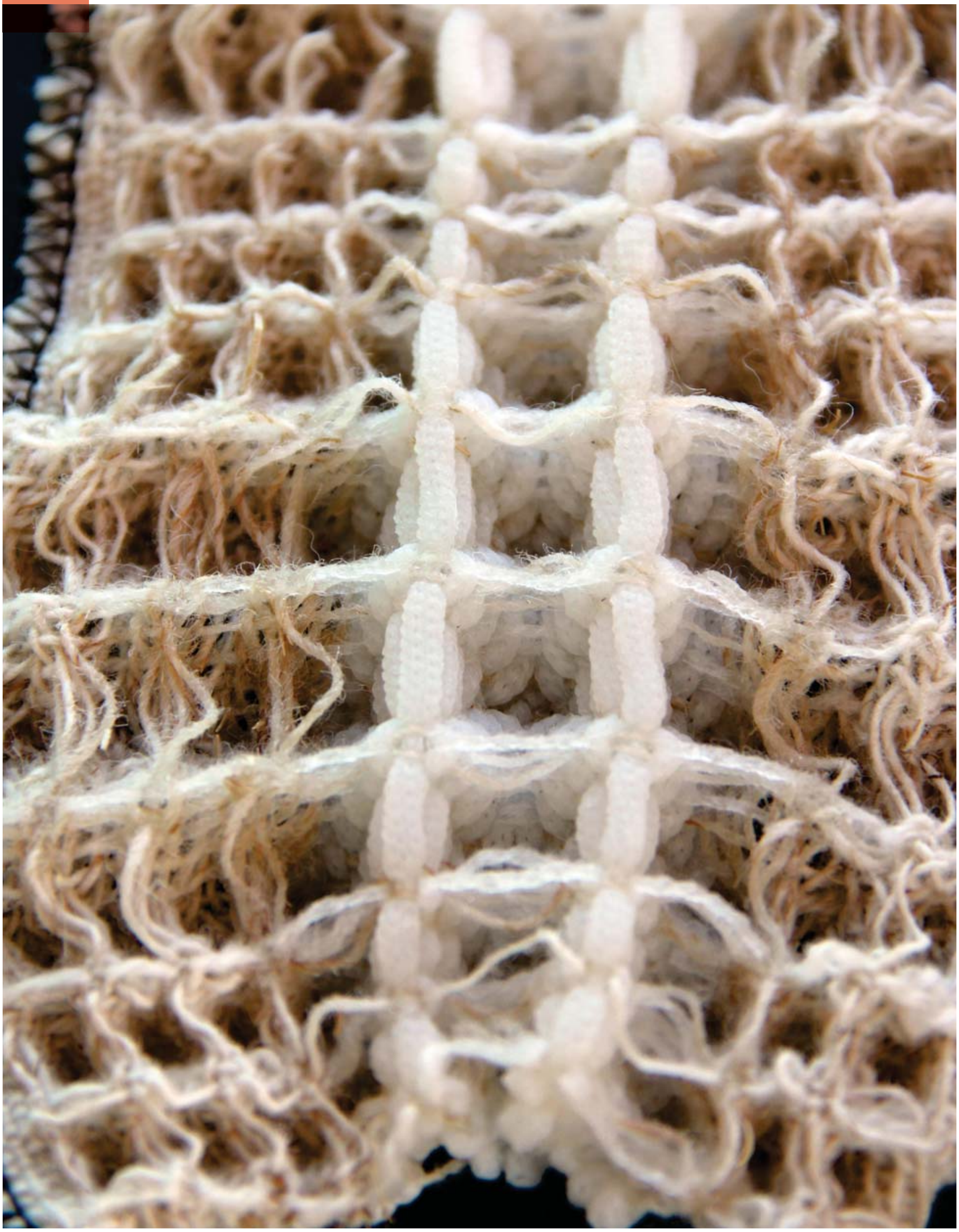
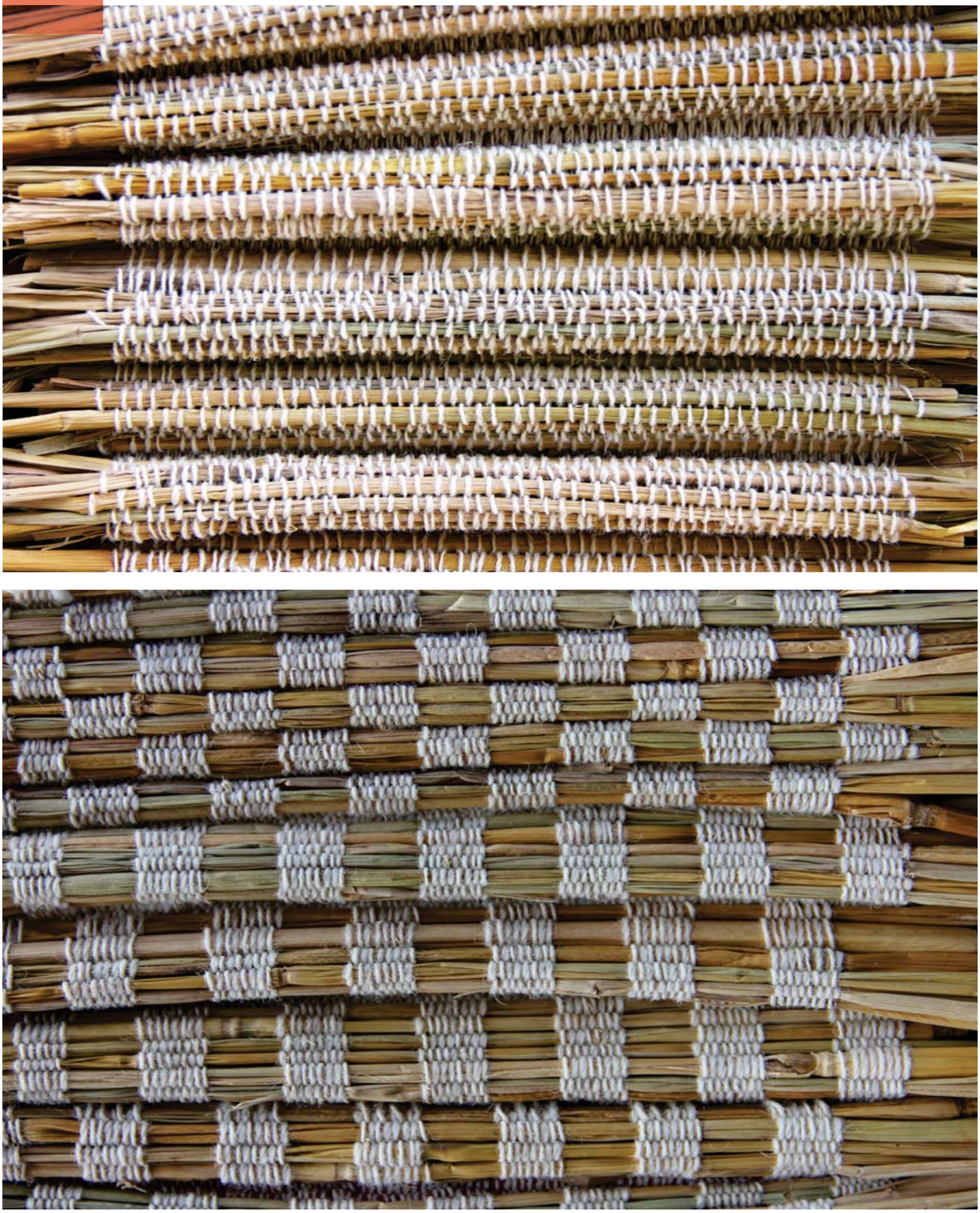


Figure 11 depicts an area of experimentation utilising resin to alter the structure of the weave. This was to replicate the use of bio-resin to construct composite materials. The overall weave became very solid and had no movement; the chemical resin used restricts the natural fibres ability to biodegrade.

"... geotextiles are designed according to the desired functional needs, and can be fabricated from both synthetic and natural fibres with different design, size, shape and composition, making geotextiles a dual commodity."

Figure 12 Rice straw is transformed into a 3D form.



rib

The rib structure was an innovative experiment utilising a twill/ reverse twill pattern. By merging two structures together an unexpected reaction occurred. On the loom the weave was a flat 2D surface, once it was cut, it transforms into a 3D rib structure. This is due to the open warp sections (floats[8]), allowing the weft threads to move. This innovative rib structure gives the weave more movement and flexibility, allowing different materials to be used. Figure 12 illustrates the use of raw rice straw, the stalks were very stiff but were able to transform into a 3D shape due to the movement of the rib

Due to the propensity of the rib to collapse it was very difficult to determine the overall size of the weave. When constructing this structure, weaves were produced at least double the final size to accommodate for the movement of the weft threads and to allow the ribs to form.

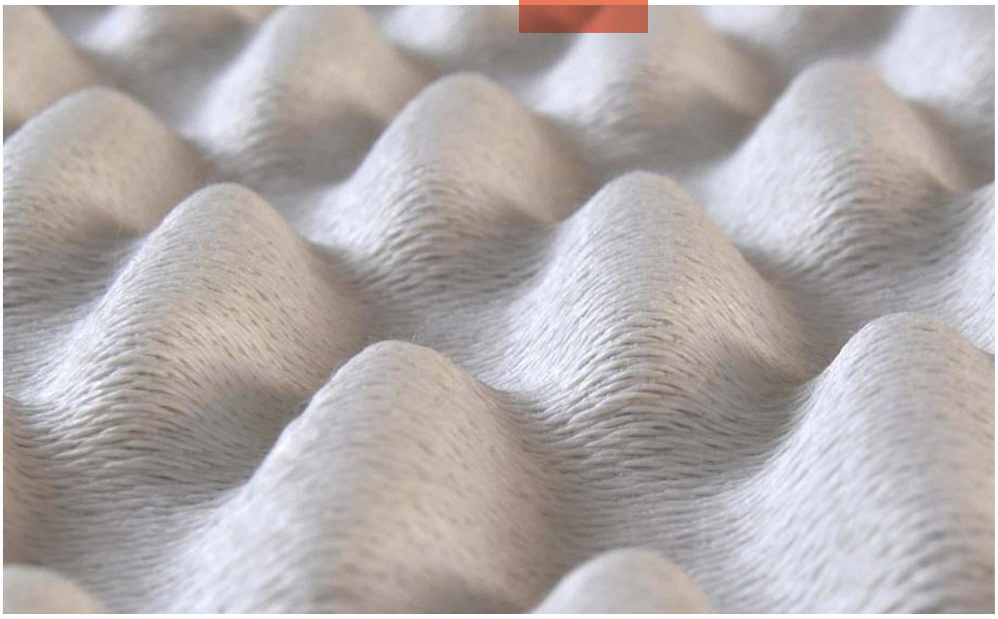
Another unique aspect to this structure was the rib created two sides to the weave, which introduced the consideration of experimenting with double cloth.

The overall size, density and thickness of this particular structure offered the consideration to apply this to interior surfaces as acoustic absorption panels.

Textile designer Aleksandra Gaca is developing the technical possibilities and applications of the woven structure. Gaca creates her 'Architextile' weaves by using different combinations of material and contrasts the use of modern technology with natural materials and traditional processes. This creates extraordinary added value: noise reduction.

Acoustics are often problematic in more minimalistic interior architecture, but thanks to the ribbed textures (figure 13), these Architextile panels absorb sound waves more efficiently than flat textiles and thereby contribute to a more muted environment (Hemmings, 2012), adding a design aesthetic to the surrounding architecture.

Figure 13 Aleksandra Gaca - 'Architextile'.



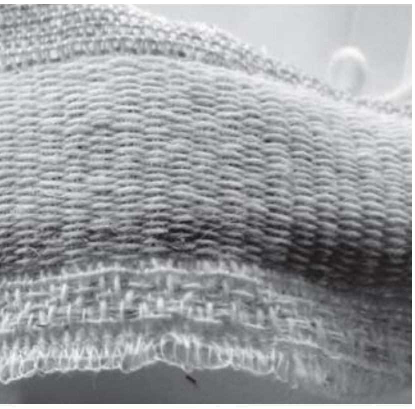
8. Floats - threads that span several other threads without being interwoven.

Early stages of design development. Rib structure utilising prototype yarn.

Early stages of design development. Rib structure transformed with use of two colours.

Figure 14 Forming an opening within the woven structure.

double cloth



The technique of double cloth was experimented with due to the ability to form interesting designs and certain methods of construction.

Double weave can come in many forms, including double cloth, tubular weave, multilayered cloth and double width. To increase the use of rice straw fibre, the development of a unique double cloth structure was trialed.

Pockets were created within the structure of the weave to construct openings allowing the retted straw to be stuffed inside the weave. Figure 14 illustrates an opening within a weave structure. This generated an economical and sustainable solution for interior insulation.

Critical evaluation of this particular structure saw that it was a very time consuming construction process, however could be produced faster in industrial manufacturing. The issue of fibre migration also restricted the development of double cloth to be used as interior upholstery.

Once a woven cloth has been formed, it automatically has two obviously different sides to its structure. To construct a true double weave, two separate layers are woven, each with its own warp and weft (Arn-Grischott, 1999). The unique element of revealing two different sides also created an aesthetic appeal to the experiments.

The craftsmanship of fashion designer Jan Taminiau illustrates the use of double weaving within his collections Unfolding (2003) and Follies (A/W 2007-08).

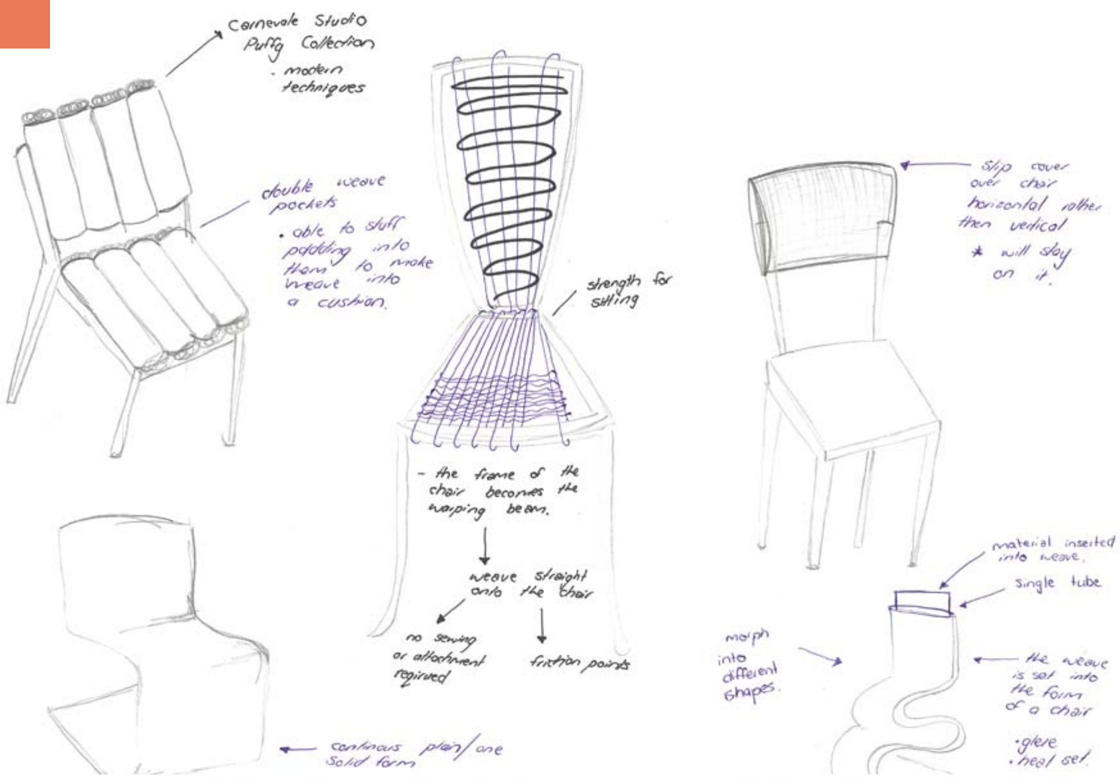
Taminiau transforms flat pieces of fabric into 3D objects. Utilising the technique of double weave allowed him to create multiple layers and openings for the body. The construction of the garment being woven directly into the fabric, no further sewing was required (Jantaminiau, 2013).

Figure 15 showcases Taminiau's use of weave within a fashion application. Due to the feel of the rice straw and the tendency for the fibres to shed off the yarn the areas of application were focused upon interior and technical textiles.

Further research undertaken to formulate a unique retting process to produce softer fibres for the second prototype yarn could influence further consideration into fashion design.

Figure 15 Jan Taminiau - 'Follies'.

Initial design development. Potential application ideas



Early stages of design development.

felt

The felting technique was used to explore a higher percentage use of the rice straw fibre. During the manual process of beating the weft yarn to construct the woven cloth, loose fibres began to shed off the yarn. The loose fibres would accumulate, generating more waste to use. The overall quantity of rice straw within the final woven cloth was unknown. Felting offered a unique way to bind the rice straw and wool fibres together.

Felt has a distinctive history as a textile, used both for craft and industry applications and is currently used as a quick fix to using waste.

Felt has a unique range of possibilities, “thin and translucent, very dense and thick or even hard” (Brown, Dent, Martens, & Matilda, 2009, p. 58). It can be made into sheets or formed into three-dimensional shapes. Due to the range of possibilities, felt can be a heavy dense material concealed within interior walls for insulation. This type of application was considered for the purpose of this research.

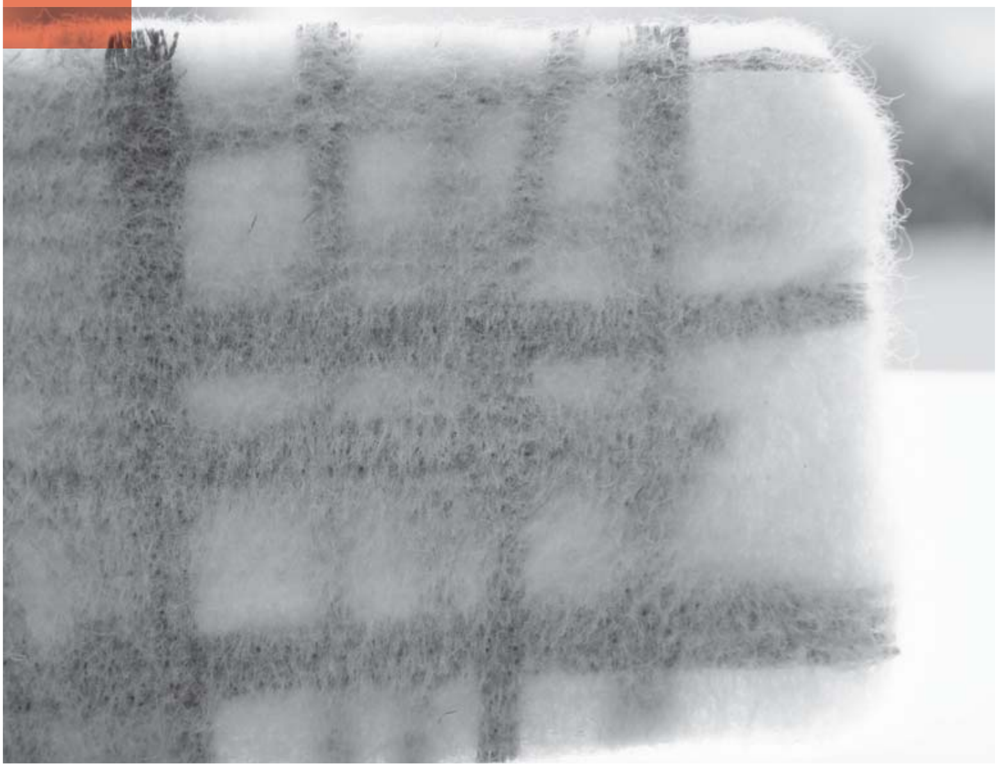
The felting process was explored in numerous ways; including wet felting, which provided both strength and structure to the experiments. Needle punching technology was also included to create dense layers of felt.

Using retted rice straw within layers of felt provided an economical and sustainable alternative to synthetic fibres for use as a stuffing material. The rice straw also added more strength to the felt when layered together. The outcome of the felt was dependent on the number of layers used in each experiment.

Fine and translucent layers allowed the retted rice straw to be visible, depicted in figure 16. Dense and strong restricted the movement of the fabric. Using the stalks of the straw, simple graphic patterns were created within the layers of felt. This altered the appearance of the felt adding value to the fabric. Felt is often hidden. The use of natural light became an important aspect in the development and final outcomes of these experiments. The patterns are revealed between the layers transforming the felt from a simple compact piece of fabric to a textile with higher value with the potential to be viewed with interior environments (figure 17).

Figure 16 Thin layers of felt reveal the rice straw fibre.

Figure 17 Dense layers, rice straw stalks visible in stripe pattern.



nuno felting

The technique of nuno-felting was chosen because it allowed both processes of weave and felt to be integrated creating innovative fabrics, without the need to introduce manufactured synthetic fabric substrates.

Nuno is the Japanese term for cloth, and nuno felting refers to the technique of felting through an existing fabric substrate. In the early 1990s several artists experimented with this technique producing varied results. The desire was to create lightweight felts utilising small amounts of wool and coaxing the fibres through a sheer woven fabric. Artists found that if the weave was sufficiently open the wool fibres would migrate through the woven fabric thus creating a new type of material.

This modernisation of the felting process has had a major impact on the possible uses for felt as it has allowed for the creation of sheer fabrics suitable for window treatments or soft draping fabrics for fashion.

Early experimentation began with using pre existing fabrics with open weave structures, plus pre dyed wool fibre, which can be seen within figure 18. The manufactured fabrics were overshadowing the rice straw and wool. To develop The Formary's requirement to not introduce other fabrics, the exploration into this technique created a new direction for the research - the merging of the weave experiments with felting.

Figure 18 Manufactured fabrics, pre-dyed wool.

Figure 19 Experimenting with large rice straw stalks.

Figure 20 Experimenting with smaller retted fibres.

By merging both construction processes together, a higher ratio use of rice straw fibre was achieved. Experiments took the form of using the thick rice straw stalks, which produced an uneven surface to the weave and felt backing. Figure 19 depicts the uneven surface of the weave; the stalks are too big and have started to fall out. Using the smaller retted fibre within figure 20, an even application between the layers was achieved and less fibre migration occurred.

Experimenting with different materials. Neon green nylon.

design development

To assist in the design development of using the rice straw waste within textile design six key stages were outlined within the proposal presented to Callaghan Innovation (Callaghan Innovation Aim, Objectives and Milestones, 2013).

By breaking the research down into the six set intentions, each with defined parameters, each task was made more achievable and the goals of each stage progressed efficiently.

1. Scope/ Literature Review.
2. Experimentation.
3. Initial Material Construction.
4. Changing and Redirecting Existing Processes.
5. Speculative Design, Integrating Technology and Material.
6. Development of Surface and Structural Aesthetics.

Stage 1 - Scope/ Literature Review

A comprehensive review of relevant literature was undertaken to examine all the salient issues related to fibre development.

Specific topics explored included new fibre and yarn concepts and development, technical processes, technological applications and the latest material development.

Using the research gathered the scope of the research was to determine a range of construction processes to be experimented with. The research question was defined to create a base for the entire design development. This was an essential stage of the research as it opened the doors to numerous possibilities to experiment with.

Figure 21 Experimenting with recyclable materials - newspaper.

Stage 2/3 - Experimentation and Initial Material Construction

The second and third stages of design development began using the prototype blended yarn and experimenting with the traditional textile technique of weave.

Three different types of looms were used (AVL9, Table Loom10 and Rigid Heddle11), to construct initial fabric trials and experiments. Critical steps were outlined for each stage. To begin material construction initial textile equipment was set up. Viable construction techniques were developed to further material samples to enable creative experiments. Evaluation of the physical properties and functional attributes of the fabric samples were documented.

Speculative and unpredictable experimentation allowed the freedom to explore the yarn's full potential within different weave structures. Consideration of utilising different weave patterns, scale, density, colour and aesthetic qualities were trialed to alter the physical properties and functional attributes of each fabric. Exploration into using a range of materials was considered for this stage.

To improve the sustainable practices within the design process, recyclable materials like plastic bags and newspaper (figure 21) were trialed to alter the structure of the weave. The newspaper linked research to the area of geotextiles as it is commonly used as an economical and sustainable weed mat. Synthetic nylon was also experimented with to create a contrast between the natural properties of the rice straw and wool. The nylon provided strength and colour to the weave structures.

Development through stages 2/3 confirmed that the traditional textile process of weave was suitable to develop the prototype yarn into viable textile fabrics. During this early stage of development The Formary confirmed that they did not want the introduction of other materials, as the main directive behind this research was to create textile fabrics with an optimal ratio of rice straw.

The experiments were critically evaluated in regards to how the rice straw behaved and if the rice straw had in fact enhanced the textile fabric. Four advanced weave structures; honeycomb, waffle, rib and double cloth were selected to develop further within the next stages.

9. AVL - Semi computerized loom that inputs the weave pattern. Manual foot press and shuttle.

10. Table Loom - Manual loom.

11. Rigid Heddle - Small compact loom that produces plan weave.

Stage 4 - Changing and Redirecting Existing Processes

The aim of this stage was to advance the use of weaving by changing and re-directing the initial samples.

Critical steps that were put in place involved testing and planning changes to existing construction techniques and processes. A series of trials were produced, utilising an iterative approach. The method used was to create a woven sample, then construct it again with one alteration. This was employed in order to conduct a range of experiments with potentially different physical and performance attributes.

The four key weave structures, honeycomb, waffle, rib and double cloth that were defined within the experimentation and initial material construction were altered through an iterative design approach. This showcased the full potential of each woven structure.

Iterative approaches came in the form of:

- Altering the size of the weft yarn used producing larger weaves. This increased the size of the rib structure.
- Changing the number of threads pulled through each dent on the reed. This either created a tight dense weave or a loose open structure.
- Altering the reed size – how many thread ends per inch. Similar to the above experiment this would determine how tight or loose the overall weave structure would be.
- Increasing the lift sequence to make the rib structure larger.
- Using felted and un-felted strong wool (figure 22).
- Using two structures within one weave.
- Creating double sided fabrics.
- Using rice straw stalks as weft material - generating a sustainable approach, as no processing of the fibre was required, also producing 100% unique weaves.
- Adding colour, this changed the aesthetic nature of the woven cloth.

Progression through this stage allowed each weave structure to be pushed to its full potential. Critical evaluations of the samples led to the development of the final series of concept fabrics.

Figure 22 Felted wool.

Stage 5 - Speculative Design, Integrating Technology and Material

The aim of this stage was to merge techniques to alter the rice straw fibre.

Two other techniques were experimented with to alter the rice straw; the finishing technique of natural dye and the construction process of French knitting. Critical steps were followed to identify appropriate combinations of textile techniques. A plan was then developed and implemented to merge speculative design, traditional processes and contemporary fabrication techniques to create new innovative samples.

Integrating technology into this research saw the use of the needle felt loom being utilised to create thick layers of felt. The action of the needles and rollers allowed numerous samples to be tested at once, permitting dense layers of both wool and retted rice straw to pass through. The use of this technology created compact fabrics binding the wool and rice straw fibres together, without the need for water. The outcome of the felt was dependent on the number of layers used in each experiment. Fine and translucent allowed the retted rice straw to be visible. Dense and strong restricted the movement of the fabric.

Several trials were conducted to find an optimal ratio of rice straw to be used, these included:

- Different percentage ratios of wool to rice straw (weight) – 50/50, 60/40, 70/30. The weight of each fibre varied. The optimum was that a 70/30 mix was suitable for this experiment, which The Formary were hoping to achieve.
- The number of layers used. One layer of rice straw sandwiched between two layers of wool created an uneven surface. Spreading the retted straw between more layers allowed for a more even and compact sample.

The use of natural dye was introduced to bring a hint of colour into the experiments, and to see how the rice straw would react to this technique.

Red was chosen as the colour to incorporate. This choice was to appeal to the main client of this research, China. The Chinese value the colour red as it is believed to bring good luck and happiness (Nations Online, 1998).

Interpreting the colour for this research, the Rainbow Mountains of the Zhangye Danxia Landform Geological Park in the nation's north-western Gansu province, was used as inspiration (figure 23). The arrangement of sandstone and minerals pressed together for over 24 million years has created a breath taking rainbow mountain range.

Focusing on the range of reds within the mountains, madder was utilised to dye the yarn and rice straw into an array of different shades. Madder was used because of it's ability to produce a variety of reds including orange red, brick red, fiery red and rustic red, showcased in figures 24 and 25, pages 62 and 63. The rustic red was produced to create a natural contrast between the rice straw and wool fibres.

Figure 23 Rainbow Mountains.

A 10% madder extract solution was used, as this is stronger than the usual madder dye that is often used. Varying temperatures were tested with an increase in temperature by about 10-15 °C achieved the desired colour changes. For the yarn and rice straw the temperature was left between 50-60 °C, which accomplished a range of pinks to rust reds.

The standard dye bath is one hour, adding the fibre/fabric when the solution is at the required temperature. As a rule the use of only 10% alum was used, for ease of calculating weight measurements and to be as sustainable as possible, however alum is often used in 20-25% concentrations, which was used within the first formula (figure 24). The percentage of alum was decreased to alter the colour and to become more sustainable.

Natural dye researcher Anne de la Sayette has done a lot of exploration within the field of natural dye and dye commercialization and recommends 8% alum as a more sustainable approach. The 2% different does not affect the results of the colour achieved or the sustainability of the dye bath (ARRDHOR – Horticultural CRITTs, n.d.). A dye solution was used to alter the colour of the yarn. Due to the blend with wool the colour held easily. Retted rice straw fibre was also left to soak in the dye bath allowing the colour to hold without the need of wool to carry the colour.

The Rainbow Mountains' hills, valleys and patterns within the sandstone were also replicated within the structures of the weaves. The rib structure created 3D surfaces similar to the mountains and the horizontal and vertical threads within the weave reflected the patterns within the sandstone.

Figure 24 Experimenting with different fabric samples.

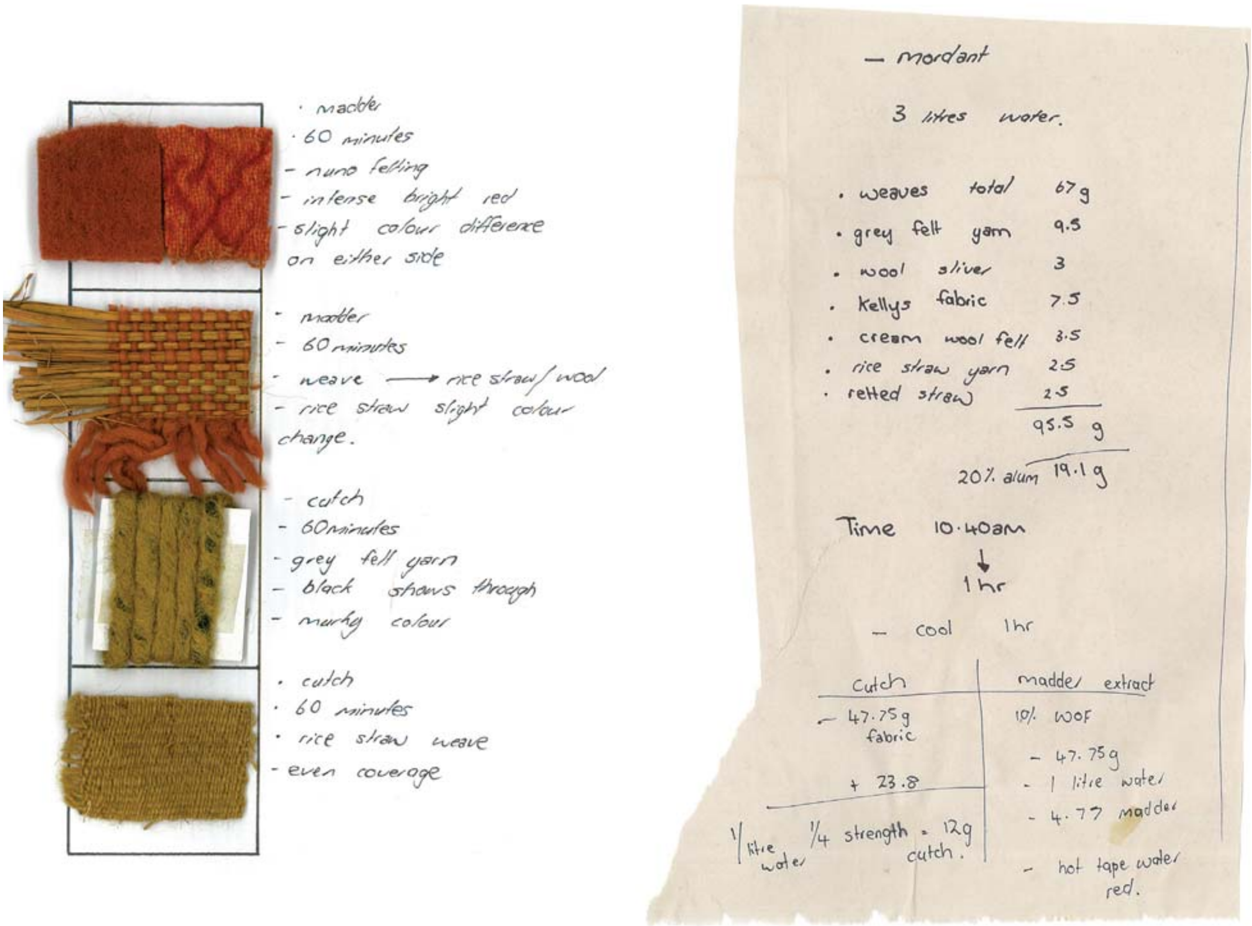
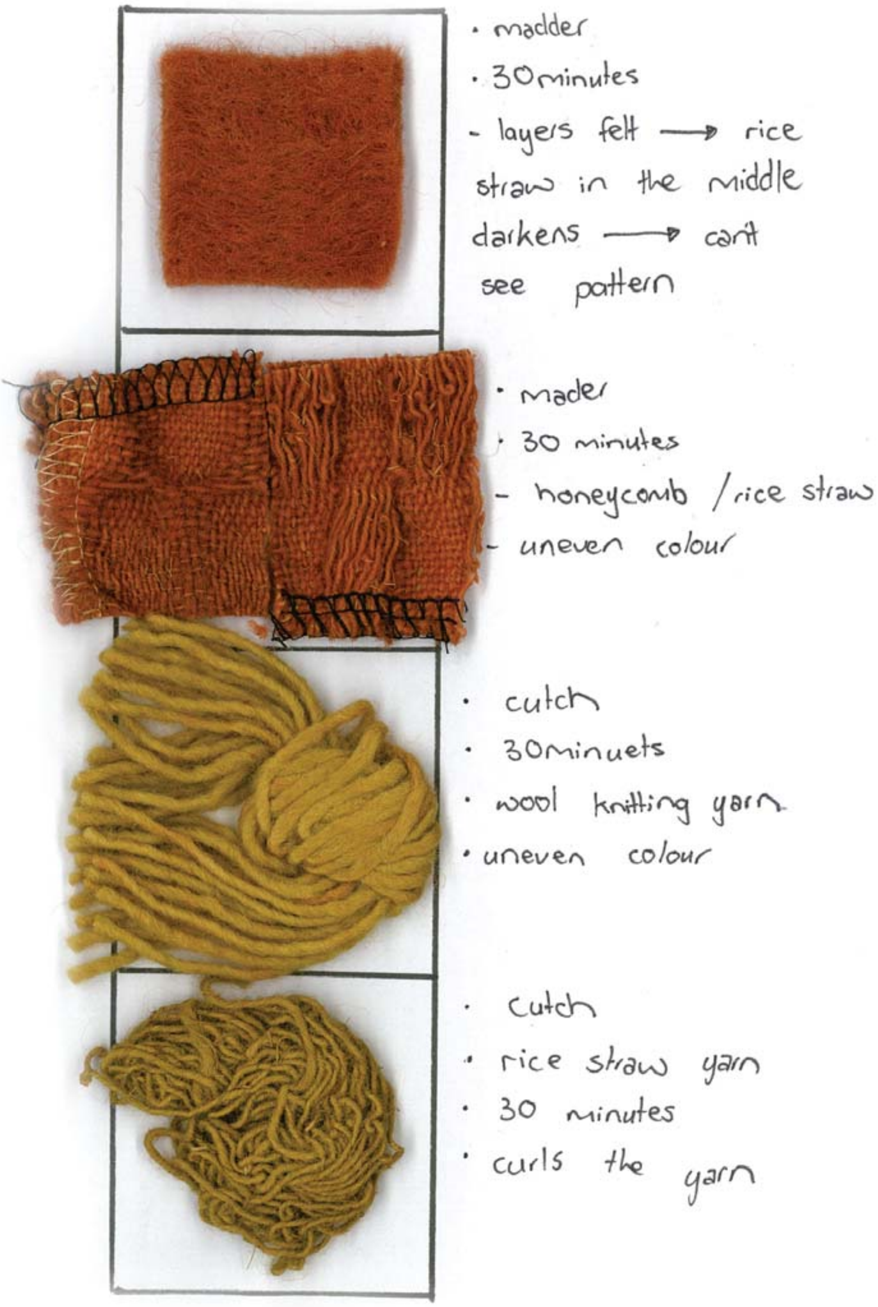


Figure 25 Different shades of colour.



During the weaving process a lot of the warp yarn was left over and was unable to be used. The inclusion of the technique French knitting created the opportunity to re-use this waste yarn to create a larger and thicker cord (figure 26), which could be re-purposed back into another weave experiment (figure 27).

This technique changed the original yarn by producing a very dense cord that had more strength, stretch and movement within its looped structure. The size of the cord allowed the woven cloth to be produced faster as it covered more surface area. The potential for the rice straw yarn within this process allows the opportunity for it to be used on its own. The overall strength of the cord now has the potential to be used as technical textiles.

The size and the loose fibres in the original yarn prevented the use of an automatic coder, as the fibres would catch in the needles. The technique of hand French knitting was tested which was a time consuming approach, but has the potential to be scaled successfully within industrial manufacturing.

Figure 26 Process of French knitting.

Figure 27 Utilising the cord within a woven structure.

Stage 6 - Development of Surface and Structural Aesthetics

The main focus of the last stage was to finalise the samples. Discussing the results of the development stages with The Formary and by documenting valuable connections between the knowledge, skills and insights obtained from the various experiments and construction processes three series were defined. This was to highlight the main attributes of the rice straw fibre and how it was transformed through textile processes and design intervention.

- Aesthetic
- Rice Straw
- Application

Aesthetic

This series focused on utilising the weave structures for their aesthetic properties. Highlighting the geometric shapes apparent in the honeycomb structure added value to the rice straw and enhanced its potential use within interior environments. Applying the finishing technique of natural dye, utilising madder to create a contrast between the natural colours of the rice straw and wool.

This series developed the potential use of rice straw within interior environments, adding cost value to the rice straw. The inclusion of the wool fibre enhanced the physical properties of the rice straw and also made the handle of the rice straw fibre more suitable for interior upholstery.

Rice Straw

This series used only the rice straw waste, showcasing the potential of how it could be used.

Using the yarn within the waffle and rib structures showed that it could adapt to any shape as well as highlighting the key attribute of being biodegradable when used as soil stabilization.

The retted fibre was bound together using natural glue to make a laminate. Utilising the rice straw in its natural form produced unique weave structures. This created a sustainable approach, as no processing of the straw was required.

This series was developed with the aim of having the rice straw revealed within each sample and to show that it does have the integrity to stand alone as a sustainable textile fibre.

Application

Creating the samples for this series focused on developing an application for each weave structure and felted fabric. The chemical and physical properties of the rice straw and wool are heightened through each different application.

- Moisture Absorption - honeycomb and waffle weave structures.
- Biodegradable - geotextiles and waffle weave.
- Insulation – acoustic and warmth - felting and double cloth.

Figure 28 Aesthetic series.

Figure 29 Rice Straw series. 100% unique wallpaper.

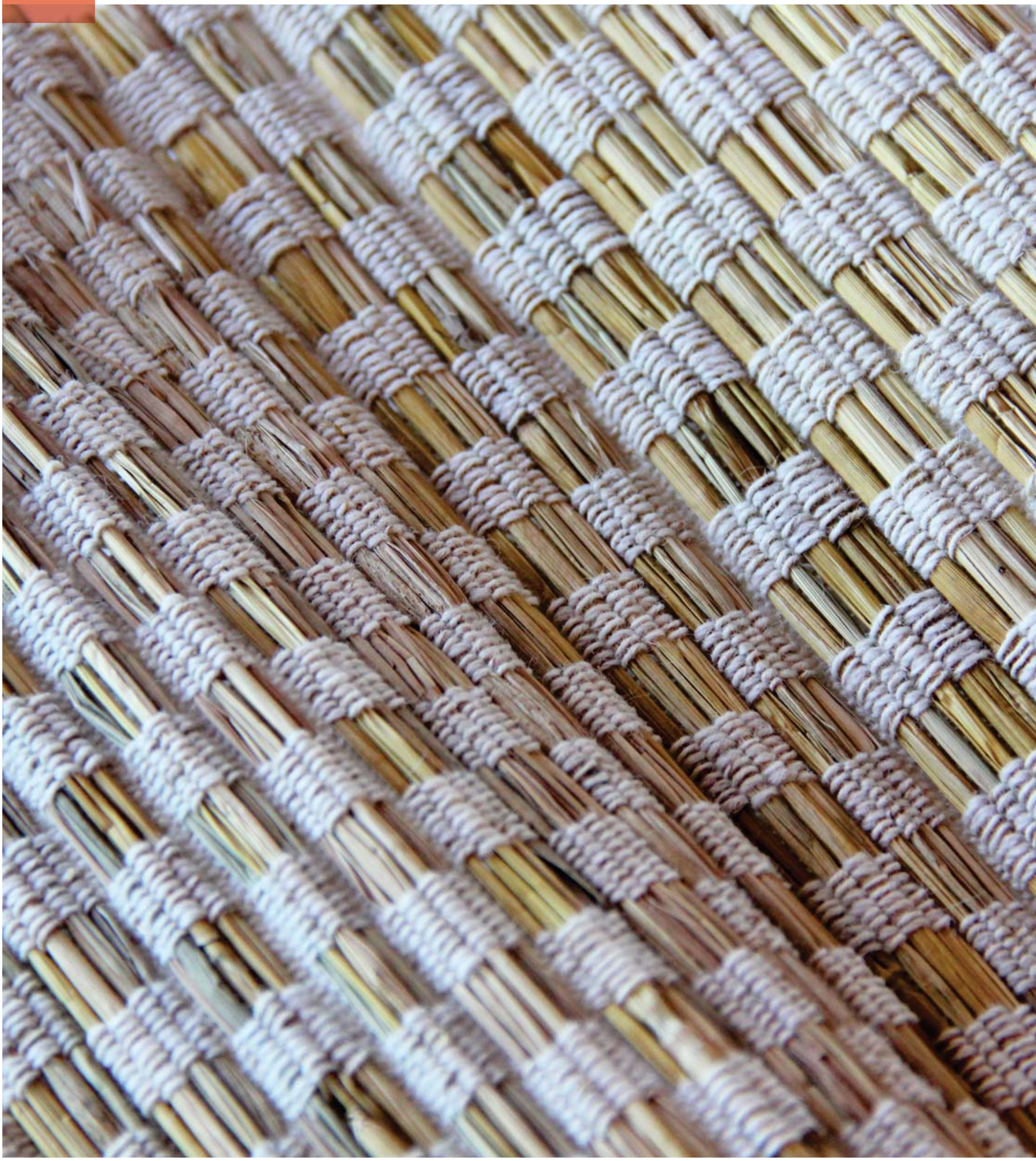


Figure 30 Application series. Insulation.

“... a process of experimentation, trial and error, invention and design development.”

conclusion

From waste to textiles explores the potential application of rice straw waste in the development of eco textile fabrics. This research follows the experimentation and development of utilising rice straw waste within textile construction processes to create unique and viable fabrics. It creates alternative uses for this waste bi-product eliminating the need to employ the current practice of infield burning to dispose of the unused waste.

The prototype yarn, a New Zealand strong wool and rice straw fibre blend supplied by The Formary developed in earlier research framed the early stages of this exploration. Responding to the yarn's physical characteristics and chemical attributes was a crucial stage in the design process. These characteristics and attributes were to have a significant influence of the final outcomes of my research.

The key elements of the rice straw fibre; biodegradability, flame retardant properties, thermal and acoustic insulation were isolated. Vital to the development of this research was to develop a high ratio of rice straw use within the textiles created.

The initial direction was the creation of textile fabrics suitable for interior and fashion applications. Critical reflection and challenges of working with the yarn concluded fashion was not a relevant line of enquiry. The feel of the fibres within the yarn would feel unpleasant against the skin and had the tendency to shed off the yarn.

Acknowledging the shedding propensity of the yarn, the traditional textile construction process of weave was selected, formulating initial concept fabrics. This was to determine the behaviour of the prototype yarn within a woven structure as it was unknown how this yarn would react because it has not been used before.

An experiment-led iterative, material responsive design methodology was implemented to direct the research through a process of experimentation, trial and error, invention and design development. Critical evaluations of the experiments identified four advanced weave structures; ***honeycomb, rib, double cloth*** and ***waffle*** would be further investigated, each highlighting key attributes of the rice straw fibre. The ***waffle weave*** structure will be discussed further on in this section.

Honeycomb weave provided an element of design and aesthetic appeal, thus adding value to the rice straw within the woven structure. Focusing on the visual aspects of the ***honeycomb***, the intention of applying the rice straw yarn within interior environments was achieved.

The *Rib* structure was an innovative development merging two structures together. This developed very dense, thick and compact weaves with the potential use as technical acoustic absorption fabrics.

Double cloth, a weave that can have numerous variations; tubular and double layers. *Double cloth* was trialed as a way to construct pockets within the woven structure. The openings permitted the rice straw fibre to be used as an alternative to synthetic stuffing materials used for interior insulation.

The development of these woven structures led the research into the experimentation with the non-woven technique of felting. Felting created a new direction for this research, a unique way to bind the rice straw fibre and wool together, plus generating the opportunity to use a higher percentage of the rice straw waste.

By documenting the connections between the knowledge obtained from the various experiments and construction processes, three series of concept fabrics were created; *Aesthetic, Rice Straw* and *Application*.

Aesthetic incorporated the use of the prototype yarn and wool in the construction of fabrics with a high-end value suitable for interior environments. The inclusion of extra wool was essential to this series as the benefits of wools superior stain resistance, insulating and water repellence properties enhanced the performance as an interior fabric. *Aesthetic* utilised the woven structures of honeycomb, waffle and rib to create fabrics with an element of design, however this resulted in a low usage of rice straw fibre.

This led to the development of the series *Rice Straw*. As the name suggests, rice straw yarn, retted fibre and rice straw stalks were the only elements within the final concept fabrics. This series confirms rice straw is a viable fibre to construct textile fabrics and also that it has the integrity to stand-alone as a fibre, not requiring a carrier.

The initial direction for this research was to create fabrics suitable for interior or fashion uses. As mentioned fashion was not relevant to this research, however the third series *Application* generated new avenues of research for the rice straw waste. More value was placed on the physical characteristics and chemical properties of the fibres as the concept fabrics were constructed with performance and function in mind rather than their aesthetic appeal.

An area The Formary had not considered for the development of the rice straw was technical textiles, specific to this research - geotextiles. Geotextiles are used in association with the exterior environment providing support, filtration and separation within the earth. Limited Life Geotextiles was considered as they are constructed using natural fibres that would biodegrade eliminating waste occurring within the environment.

During the development stages I established that the ***waffle weave*** structure best suited this application and the prototype yarn. The physical construction of the structure forming pyramid like hollows enforced the idea of using the ***waffle weave*** for soil stabilization. Highlighting the key attribute of both fibres ability to biodegrade, I was able to consider the whole lifecycle of the final fabric.

A key aim of this research was to place value on an unexploited waste fibre. Value is not only present within the concept fabrics that have been constructed, value can also be found within my documentation of the technical specifications of each woven structure. The method of detailing all the technical information was critical to the design process as it made it possible to replicate each weave and communicate the design direction for constructing the woven cloth.

This vital information proved my expertise knowledge as a weaver to reproduce small test experiments and upscale them into viable concept fabrics. This information can now be passed onto industry manufacturers for further development.

The Callaghan Innovation proposal suggested six key stages of design development to assist with my research. Breaking the research down into the six set intentions, each with defined parameters made each task more achievable and the goals of each stage progressed efficiently.

Sticking to this time frame was vital for the construction process of weave as it is a very concise and long process to create a woven structure. My design approach was to push the boundaries of traditional processes and experiment with the unexpected which I was able to incorporate into this structured method of working.

Reflecting on these stages I was able to keep to a schedule and was able to inform The Formary on my current stage of development. The Formary were supportive of my design directions and let me shape the development of the use of rice straw waste in my own way.

The Formary's ethos of sustainable practices within design directly affected my design process. Employing the cradle-to-cradle approach within the design development, a process that aims to eliminate the concept of waste, ensured the rice straw and wool would naturally regenerate or biodegrade at the end of its natural lifecycle and become precious nutrients for the environment.

Material choices were restricted to natural fibres. Repurposing the ends of the warp threads into the construction process of French knitting limited the amount of waste material. The sustainable finishing technique of natural dye provided the opportunity to introduce colour within the concept fabrics.

This research confirms that rice straw waste is a viable fibre to be used within the construction of textile fabrics. Using the waste bi-product from an agricultural food source to create unique and viable fabrics is a feasible way of introducing sustainable practices into the design industry. We do not need to rely on producing fibre-only crops like cotton. Incorporating food bi-products not only frees up arable land space, more value is gained for the farmer and land.

conclusion

With a strong understanding of textile techniques and with the application of proper methods and processes, the potential for further development can occur.

Investigating the retting process of the rice straw fibre to produce a softer fibre, combined with the construction of a yarn that binds the fibres securely will lead research into the development of fabrics for the fashion industry.

The experiments and final fabrics have proved that the structures of the weaves were vital in developing an end use for the rice straw. The combination of wool and rice straw within the yarn and in the woven structures is a viable relationship in the construction of interior fabrics.

These final concept fabrics mark the end to this stage of development, but opens the door to further research into using waste bi-products as a key material within design practices.

Retted rice straw laminate. Natural glue.

glossary

Acoustic Absorption: to absorb sound within an environment.

Arable Land: land that is available/ suitable to grow agricultural crops. Includes meadows, home gardens and lawns.

AVL: semi automatic loom. Inputs weave lift sequence via computer, manual weft placement.

Biodegrade: be decomposed by bacteria or other living organisms, which avoids pollution.

Bi-product: materials created through the manufacturing and/ or processing of something else.

Campaign for Wool: a global endeavor to promote the benefits of using wool.

Commercial Waste: commercial waste consists of waste from premises used wholly or mainly for the purposes of a trade or business.

Design Intervention: change or improve a situation/ problem or product using design.

Double Cloth: two separate layers are woven, each with its own warp and weft. Double weave can come in many forms, including double cloth, tubular weave, multilayered cloth and double width.

Ends per Dent (epd): how many thread ends are placed through each dent. Either creates a loose or tight weave. For example a size 16 reed has 2 epd, this would make a total of 32 ends per inch.

Ends per Inch (epi): amount of threads that can fit within an inch of the reed. For example a size 8 reed would have 8 dents per inch.

Felt: created in mass using wool fibres, transformed through the use of soap, water and friction where the fibres entangle with one another.

Fibre: a thread or filament from which a vegetable tissue, mineral substance, or textile is formed.

Floats: loose warp threads within a weave structure.

French Knitting: using a spool to knitt a length of cord.

Geotextiles: are penetrable fabrics which, when used in association with soil or the outside environment, have the ability to separate, filter, reinforce and protect.

Glycerin (Glycerol): a colourless, sweet, viscous liquid formed as a by-product in soap manufacture.

Honeycomb: the honeycomb weave structure derives its name from its resemblance to the hexagonal honeycomb cells of wax in which bees store their honey. The high and low parts of honeycomb weaved fabrics are formed by different intersections of the warp and weft.

Iterative Design: working through a process of changing one design aspect to alter the final outcome.

Jute: a long, soft, shiny vegetable fiber.

Laminate: overlay (a flat surface) with a layer of plastic or some other protective material.

Limited Life Geotextiles (LLG): refers to the function of the geotextile in providing additional reinforcement until the foundation soil achieves the desired shear strength over time.

Madder: natural dye colourant from the plant Rubia tinctorum.

Ministry of Business, Innovation and Employment (MBIE): aid in assisting with the economic development of New Zealand.

Natural Dye: dyes or colorants derived from plants, minerals or insects.

Nuno Felting: nuno is the Japanese term for cloth, and nuno felting refers to the technique of felting through an existing fabric substrate.

Plain Weave: simple structure that follows a sequence of 1, 3, 5, 7, & 2, 4, 6, 8. Creates the firmest cloth.

Reed: steel comb with teeth that space the warp at an even density for the desired width. Reeds are sized by length and by the number of spaces—called dents—per inch (i.e., 4, 5, 6, 8, 10, 12, 15, 18, etc.). The reed is placed in the beater and acts to press the weft into the cloth as well as space the warp.

Research and Development (R & D): research into the development of new innovative products.

Resin: a solid or liquid synthetic organic polymer used as the basis of plastics, adhesives, varnishes, or other products.

Retting: use of moisture to aid in the separation of fibres.

Rib: this structure utilises the warp threading from both the honeycomb and waffle weaves. It was created using a stripe formation, alternating between twill and reverse twill. The desired outcome of the weft threads filling the floats.

Rice Straw: bi-product from rice harvests.

Rigid Heddle: small hand held loom; set to create plain weave only.

Satin Weave: consists of floated warp threads, passing over all but one of the weft threads, in order to produce a smooth surfaced fabric (for light reflection/ sheen).

Shuttle: flat pieces of wood that are usually notched at each end so that the weft yarn can be wrapped from end to end around the shuttle and be placed within the warp with ease.

Strong Wool: characteristic of crossbred sheep, coarse fibred wool.

Sustainable Development: economic development that is conducted without depletion of natural resources.

Table Loom: the frame that holds the warp threads aligned and under tension so that weaving can take place. Manual.

Technical Textiles: high performance fabrics designed not just to look attractive, but also to offer a significant added value in terms of functionality and performance.

TedTALKs: inspiring talks by remarkable people from around the world.

Twill Weave: creates a shift in warp and weft threads producing diagonal lines within the weave structure.

Virgin fibre-only crops: agricultural crops grown solely for the fibre e.g. cotton.

Waffle: the structure of a waffle weave is created with small hollows that form pyramid like structures that allow air to flow through for quick moisture absorption.

Warp: all of the threads that are aligned vertically on a loom before weaving begins.

Warp-faced: warp ends hide the weft completely on the surface.

Waste: anything that is discarded and not used.

Weave: form (fabric or a fabric item) by interlacing long threads passing in one direction with others at a right angle to them.

Weave structure: is the order in which warp and weft threads go over and under each other.

Weft: all of the horizontal threads that interlace with the vertically aligned warp.

Weft-faced: wefts completely hide the warp.

W/m °C: measurement of thermal conductivity through a particular unit thickness.

Wojo: a revolutionary up-cycled fabric that was developed from blending jute from the coffee sack waste stream with New Zealand strong wool.

Wool: fibre produced from sheep.

Yarn: a continuous strand that is formed by a group of fibres.

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appendix

Application for Embargo

Appendix D

MASSEY UNIVERSITY
Application for Approval of Request to Embargo a Thesis
(Pursuant to AC98/168 (Revised 2), Approved by Academic Board 17/02/99)

Name of Candidate: Michelle Macky ID Number: 04200209

Degree: Masters of Design Dept/Institute/School: Massey Wellington

Thesis title: REmaterial - from waste to textiles: an exploration into textile processes using rice straw waste.

Name of Chief Supervisor: Sandy Heffernan - Massey Telephone Ext: 63225

As author of the above named thesis, I request that my thesis be embargoed from public access until (date) ~~MARCH 20th~~ 1 DEC 2015 RDW for the following reasons:

- [x] Thesis contains commercially sensitive information.
- [ ] Thesis contains information which is personal or private and/or which was given on the basis that it not be disclosed.
- [ ] Immediate disclosure of thesis contents would not allow the author a reasonable opportunity to publish all or part of the thesis.
- [ ] Other (specify):

Please explain here why you think this request is justified:

This is a Callaghan Innovation project in collaboration with The Formary. The Formary have requested an embargo to protect the patent application process.

Signed (Candidate): [signature] Date: 30/09/13

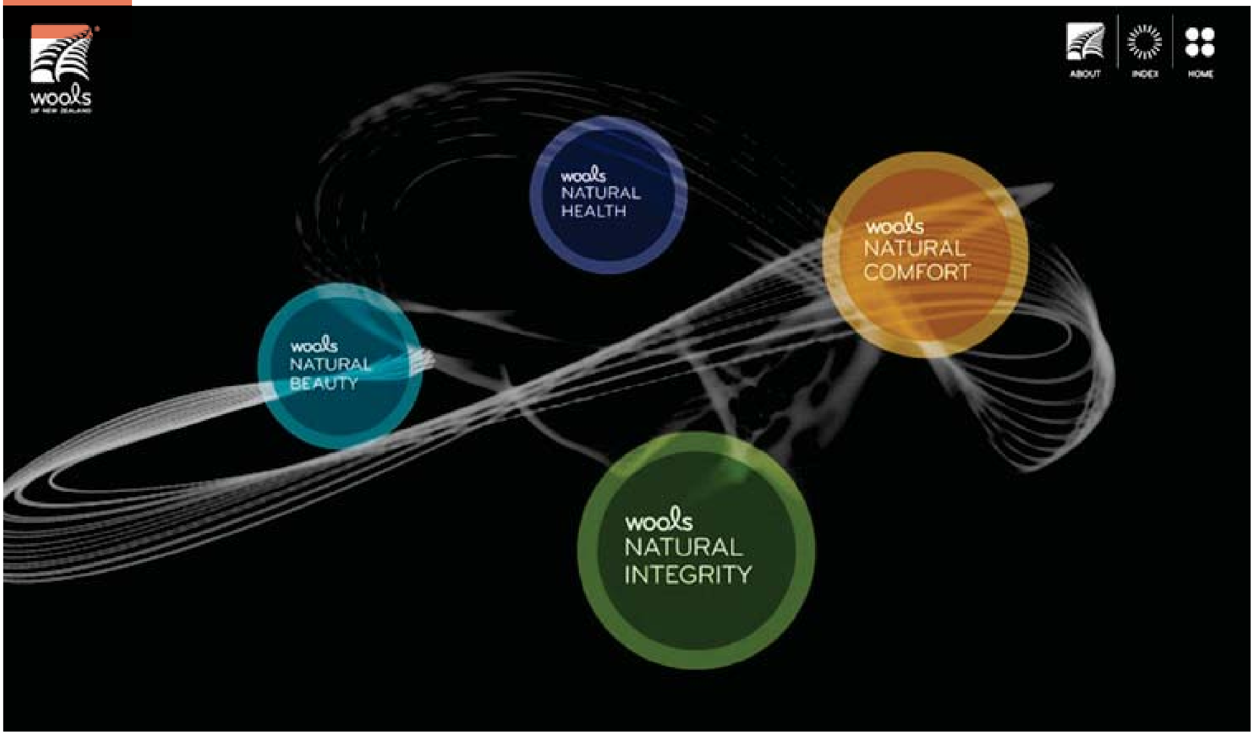
Endorsed (Chief Supervisor): [signature] Date: 10/11/13

Approved/Not Approved (Representative of VC) [signature] Date: 2/12/2013

Note: Copies of this form, once approved by the representative of the Vice-Chancellor, must be bound into every copy of the thesis.

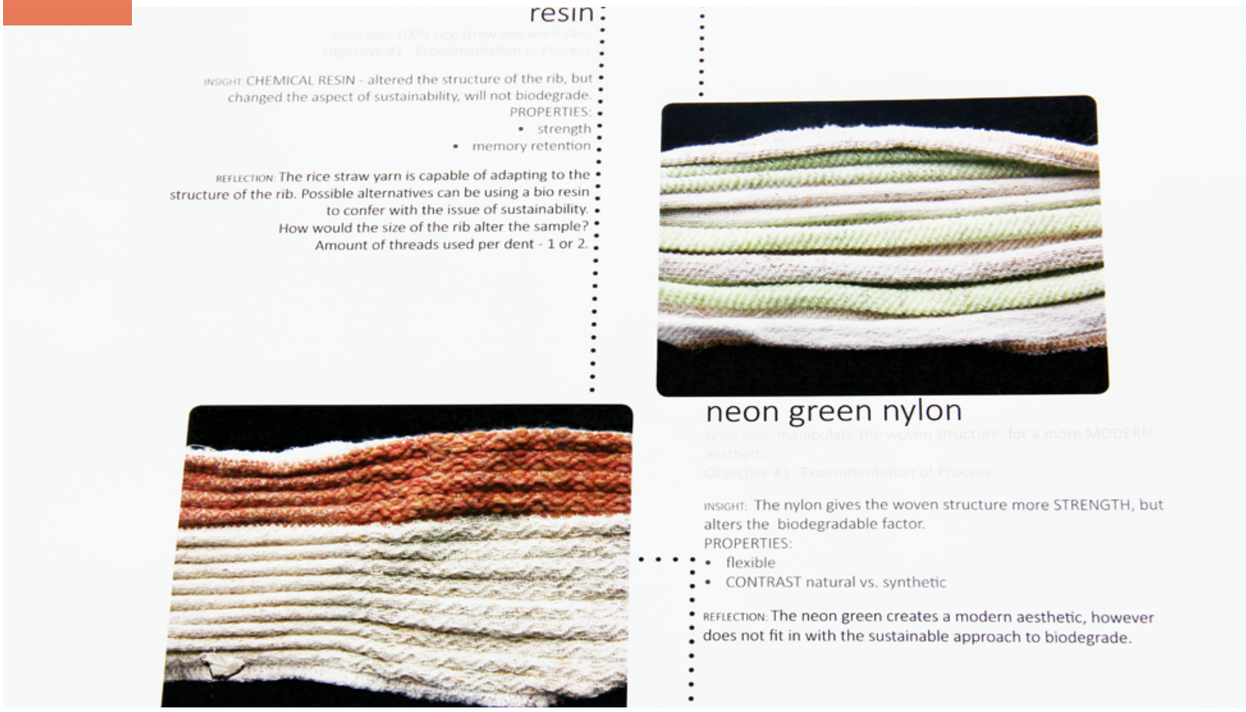
1

Wools Benefit System.



Fibres that had shed of yarn during weaving process.

Mind Map.


resin

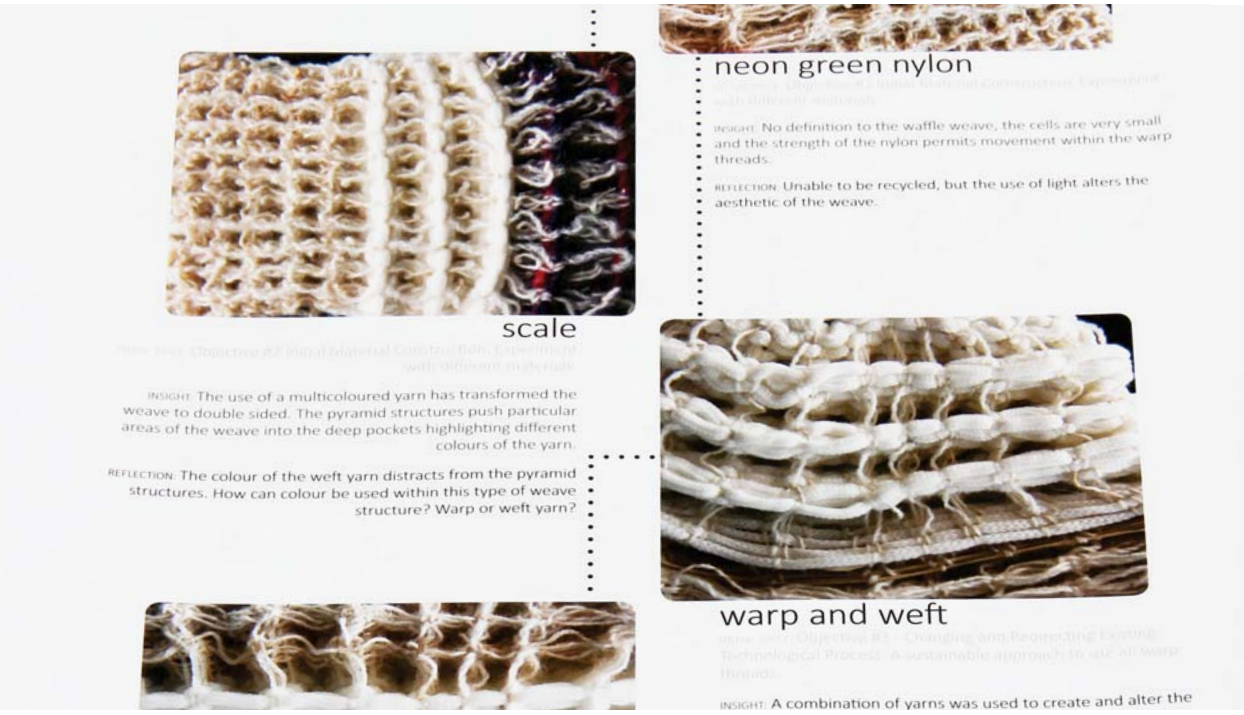
INSIGHT: CHEMICAL RESIN - altered the structure of the rib, but changed the aspect of sustainability, will not biodegrade.
PROPERTIES:
- strength
- memory retention

REFLECTION: The rice straw yarn is capable of adapting to the structure of the rib. Possible alternatives can be using a bio resin to confer with the issue of sustainability.
How would the size of the rib alter the sample?
Amount of threads used per dent - 1 or 2.

neon green nylon

INSIGHT: The nylon gives the woven structure more STRENGTH, but alters the biodegradable factor.
PROPERTIES:
- flexible
- CONTRAST natural vs. synthetic

REFLECTION: The neon green creates a modern aesthetic, however does not fit in with the sustainable approach to biodegrade.


neon green nylon

INSIGHT: No definition to the waffle weave, the cells are very small and the strength of the nylon permits movement within the warp threads.

REFLECTION: Unable to be recycled, but the use of light alters the aesthetic of the weave.

scale

INSIGHT: The use of a multicoloured yarn has transformed the weave to double sided. The pyramid structures push particular areas of the weave into the deep pockets highlighting different colours of the yarn.

REFLECTION: The colour of the weft yarn distracts from the pyramid structures. How can colour be used within this type of weave structure? Warp or weft yarn?

warp and weft

INSIGHT: A combination of yarns was used to create and alter the


rice straw
The floats that are produced on the back of the weave allowed the weft threads to move and CURL when washed, contrasting to the tight sections of plain weave
The overall structure PERMITS movement to the weave. How can this be adjusted?
Using thicker yarns, spacing between each section?
neon green nylon
INSIGHT: Introducing the nylon gave STRENGTH to the structure of the weave, however compromises the ability to biodegrade. The application use can change, this weave could be incorporated into interior surfaces utilising the effect from light shining through the cells of the honeycomb.
PROPERTIES:
• strength
REFLECTION: Experimenting with the nylon gave insight to how the weave structure could be changed by using a STURDY material. The NEON GREEN colour and the TRANSPARENCY of the nylon changes the TRADITIONAL perspective of a weave .
plastic bag
INSIGHT: The plastic altered the BEHAVIOUR of the honeycomb structure by constricting the movement within the floats, which creates the cells. Experimentation into BURNING the plastic was trialled to disrupt the weave structure.
REFLECTION: The overall TEXTURE and STRUCTURE of this weave has changed due the NATURE of the plastic. An opportunity to recycle a common object found in every house hold, BUT this experiment has started to OVERSHADOW the rice straw and wool.
newspaper
Research into geo-textiles influenced the use of newspaper as a weft material. Newspaper is often used as a CHEAP and ECONOMICAL weed mat.
PROPERTIES:
• biodegradeable
The colour contrast between the black and white print and the hints of colour makes an attractive AESTHETIC appeal.
the rice straw.
How can geo-textiles be incorporated more?

exhibition

Initial stages of development.

Rice Straw, Aesthetic, Application.

Aesthetic: Waffle weave/ Madder.

Rice Straw.

Application - Geotextiles.

Application - Double cloth insulation.

Application - Rib