“Wearable Metal Origami”?

The Design and Manufacture of Metallised Folding Textiles

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Abstract

"Wearable Metal Origami" is a research leading to a collection of wearable objects, made from metallised folding textile.

The research engages with current concerns in industrialised society, where new materials and innovative products are in demand. The material I have developed is influenced by historical and contemporary jewellery and clothing as well as by deployable structures; folding patterns are based on folding patterns in nature and on the knowledge of origami mathematicians; production processes include traditional printing and jewellery techniques. Bridging all these disciplines, the outcome is a novel material that could be used in various design fields but is particularly relevant to jewellery for its striking visual character, its flexible movement which easily adjusts to the human body, and the possibility to use precious metals.

I based my research in the department of Goldsmithing, Silversmithing, Metalwork and Jewellery because this department had helped me develop the initial material during my MA course, so I knew it could provide me with the necessary equipment and support in designing wearable pieces. My project was finally conducted within a departmental team research project (Deployable Adaptive Structures) in which my colleagues investigated the broader application of metallised or otherwise tessellated folded textile in such fields as interior architecture, sunscreens and water sculptures, and ways of actuating the material either virtually or by mechanical means.

""Wearable Metal Origami"?" is based on MA project work, where I had used one folding pattern and found one production method. I strongly believed that this material would be ideal for the creation of jewellery and larger wearable objects if I could expand the range of flexibly moving patterns, improve the production process of the material and develop appropriate design processes. My research set out to fulfil these requirements and prove the value of the material in the context of metalwork and jewellery and the applied arts.

To expand the range of folding patterns I collected and analysed existing tessellating origami patterns. With this knowledge I created my own variations. All patterns were evaluated on their suitability for "Wearable Metal Origami" and a basic classification was made, based on their folding properties. A small selection of patterns was then tested to

get an understanding of the influence of plate thickness, hinge width and hinge flexibility by making card-textile and plywood-textile models.

I developed and tested new processes for the production of the metallised folding textile. These included preparatory processes (before electroforming), electroforming and various ways of treating the material after electroforming. Each process was evaluated on its practicality.

To develop appropriate design processes for wearable objects of Metallised Folding Textile I ran four case studies, each with its own design brief. I set the briefs in such a way that they addressed different parts of the body and different qualities of the material, such as changing shape and flexibility. For each application an origami pattern was chosen and adjusted through a process of trial and error until it had the correct proportions and movement.

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When no source is listed, work and photography are by Tine De Ruysser

Acknowledgements

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During the period of registered study in which this thesis was prepared the author has not been registered for any other academic award or qualification.

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1. Introduction

Description

Imagine your first encounter with Metal Origami. You look at it sitting on a table. It is static, and looks like a metal object with a complex three-dimensional wall, consisting of geometrical facets with straight edges. These however have a different, non-metallic colour. Then the origami moves, and seems to come alive. Quite literally: it moves like the skin of a small animal breathing, or like a flower trembling in the wind. This seems to contradict the first impression that the object is made of solid metal. So what is metal origami? Is it a textile object? A closer inspection is required. When picked up it feels heavier than originally suspected. Because the structure is so flexible it could be textile, but the weight seems to contradict this. It moves strangely, at first sight almost unpredictably and not is not like anything experienced before. It is a bit wobbly like a balloon filled with water, even though it is empty. The surface is soft and warmer to the touch than to be expected from a metal object. The surface texture is that of a textile but slightly smoothened out. The reflections on the surface are like those found on a metal surface.

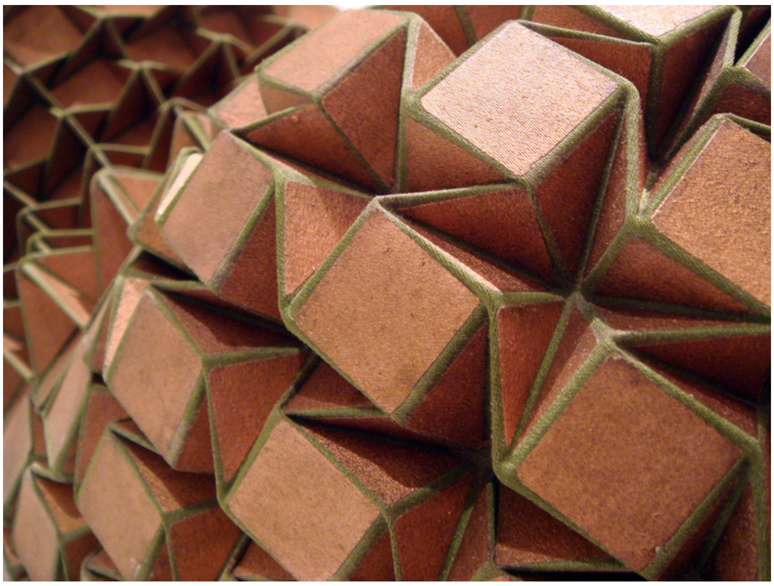


Figure 1.1: Metal Origami, close-up.

At close inspection the coloured edges are evidently made of textile. The platelets in between these flexible textile lines are metal: they are a bit more solid, stiffer and with rounded edges. The textile works as a hinge in between the metal parts. So this is a sort of folded metal-textile composite. But how could it have been made? And what is it used for? It is so flexible and somehow resembles chain mail, so could it be used for body-armour? It folds up to a small packet that could be useful for storage… It is strangely appealing, and feels so nice to hold and play with that it arouses curiosity as to what its applications could be. Every time anyone encounters Metallised Folding Textile (MFT) for the first time a hundred different possible applications flash through their mind. It is these endless possibilities that made me take on this project. I wanted to find my own way of using the qualities of MFT, to make beautiful and interactive pieces.

MFT with its combination of qualities is hard to describe accurately. First there is the ambiguity of its metal appearance and flexibility. Then there is the geometry of the folding patterns, with straight lines reminiscent of origami and Arabic tessellating patterns. Unexpectedly, the way the material moves is more organic, forming gentle curves. It folds up to occupy an often much smaller space than the surface of the sheet material it was made from. It adapts its shape and size to how it is being handled. If it is pulled in one direction it expands not only in that direction, but also in the opposite direction. It is this unanticipated combination of qualities that makes the material so interesting. Each one of the properties on their own is not uncommon, but to have them all together in one material is quite exhilarating.

'Wearable Metal Origami' is innovative because it combines three elements. Firstly there is the strictly controlled selective electroforming; then the non-metallised parts are used to fold the whole like tessellating origami to create a deployable, adaptive material; and finally this material is applied to wearable pieces.

History

The first seed for MFT was planted when I was a jewellery student at the Royal Academy of Fine Arts in Antwerp, and visited Nel Linssen's studio in Nijmegen. Nel Linssen was initially a textile designer. She showed us the piece that started her off on her trademark style paper jewellery. This piece showed a wonderful flexibility when handled. It could also be collapsed in a special way, the visual effect was stunning. Linssen told us she had tried to get one of her flexible designs made by a goldsmith, but this attempt had not been successful. The flexibility of the jewellery could, so it seemed, only be achieved in paper.

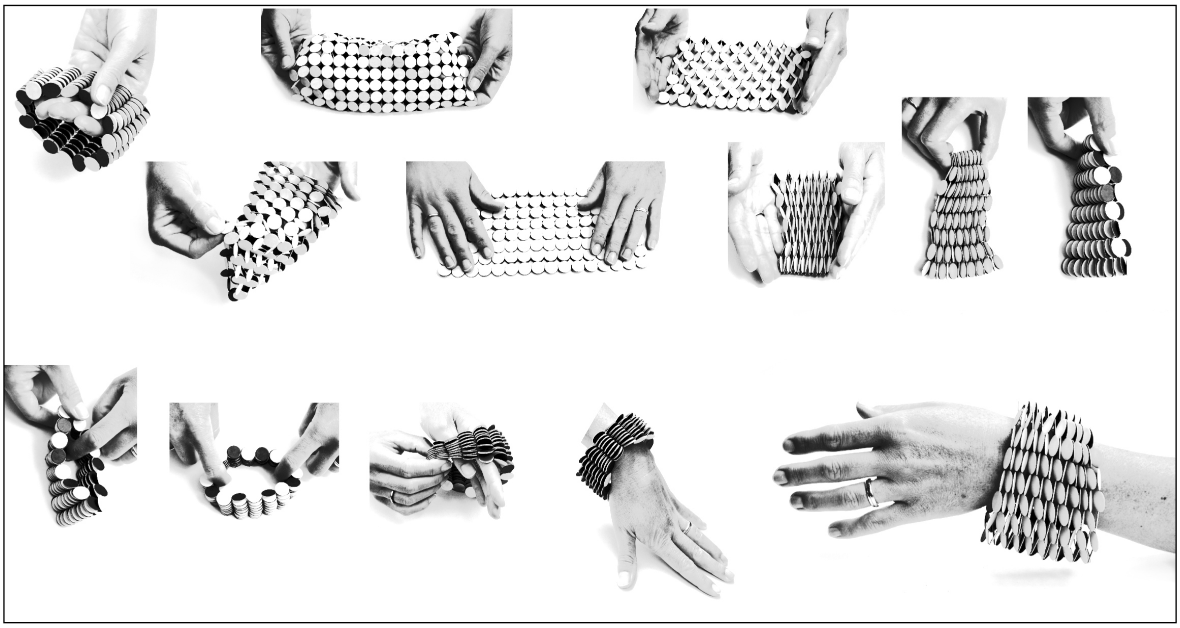


Figure 1.2: Paper bracelet by Nel Linssen. This bracelet folds in the same way as the piece that initiated her move from textile design to jewellery. (Linssen, 2006)

About one year later I started folding paper for an assignment in my drawing classes. I tried to make a honeycomb from a single sheet of paper. I wanted to find a way of folding the paper so that it would take the hexagonal shape of a honeycomb and create a certain depth. The folding structure I came up with did have hexagonal tessellating elements, but in contrast to real honeycombs these did not have a stable structure, instead they were highly flexible. It appeared promising with a broad scope of possible applications. Even though I felt much more could be done with this structure, I could not work out how. I would have to come up with a way of replacing the paper with a more durable material that would fold and unfold in the same way.

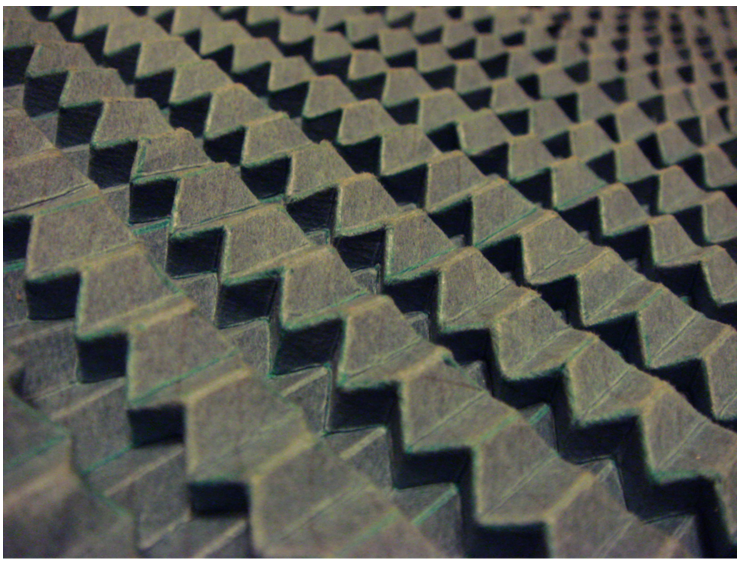


Figure 1.3: Sample of folded paper as made at the Royal Academy of Fine Arts in Antwerp.

A further year passed, and I started my MA course in GSM&J at the Royal College of Art. Through the technical courses offered here, I learned about the techniques of photo etching and electroforming. I had been thinking of making the folding structures on a large scale in plywood, using leather strips instead of hinges. Scaling this principle down, I could replace the leather with textile, and the plywood with metal. Using my newly gained knowledge about electroforming and etching, I deposited a layer of metal to a piece of fabric, and etched away the folding lines to leave textile hinges. I soon found out it would be better to skip the step of etching, and to apply the electroforming in the areas where I needed metal. This would prevent build-up where I did not want any. I spent most of the remaining time of my MA course working out how best to make this early MFT, and made prototypes that demonstrated the qualities of the material.

Figure 1.4: “Bowl”, made for my MA course in 2001.

For four years I discontinued developing MFT. During this period I entered competitions and international exhibitions with the material I had developed at the RCA, but was unable to make new material because I lacked access to the necessary equipment.

In 2005 Professor David Watkins won AHRC funding for a three-year research project for the development of MFT, or in his words: Deployable Adaptive Structures (DAS). This meant I was given the chance to further develop MFT as a research student on the project team. I worked alongside 3 part-time members of staff, all thinking about and working on the different possibilities of MFT and related developments. My personal focus was finding out how to design wearable pieces, and how to go about making them. This means I took full responsibility for that part of the research, while being part of the team and working with my colleagues on other related topics.

The aims and objectives

The first prototypes had been made during my MA studies. At this point there were still many problems to solve regarding the efficient production of the material and how to apply it. My research, as described in this thesis, set out to solve these problems and come to the creation of “Wearable Metal Origami”. To achieve this, I had to do three things: I had to be able to create appropriate tessellating folding patterns; I had to improve the processes to make MFT, and I had to find a way of designing wearable objects that would make optimal use of MFT’s properties.

The study of existing tessellating folding patterns and mathematical origami rules enabled me to start creating my own folding patterns. By classifying these patterns I made it easier to select a suitable folding pattern for a particular application. Through the process of model making I could then quickly test the pattern, and better predict how it would behave as MFT. This part of my research is explained in chapter 5, Principles and Practicalities of Folding.

MFT starts with a textile base. Electroforming is used to apply metal platelets to selected areas. This involves making the textile conductive in the places where I want to apply a metal layer, immersing it into a chemical solution and running an electrical current through it. Metal particles dissolved in the solution adhere to the conductive areas of the fabric, and build up a metal layer. At the end of this process, the fabric has metal platelets on one or both sides, separated by non-metallised textile ‘hinges’. The platelets give the material its metal appearance and the hinges allow it to be folded. I investigated the production processes by exploring different ways to prepare the fabric for electroforming, by gaining a better understanding of the electroforming process itself, and by investigating how the material could be finished and which techniques could be used for turning it into objects. This is described in chapter 6, Production of Metallised Folding Textiles.

To use MFT's qualities optimally in a range of wearable objects, I had to find how to design pieces that combine shapes and movements in the best possible way. Since it is a new material I had to find my own way to work with it. MFT does not play by the same rules as plain metal or textile. It has the qualities of both, and can be worked with the techniques applied to either material but it does not behave like the one or the other: it has its own set of rules, which are mine to discover and work with or around. MFT is more demanding than any material I had worked with until now: I cannot simply use a given set of techniques, as from longstanding craft tradition such as metalwork or textiles. Instead, I had to develop up my own set of techniques, borrowing from both. I approached this by setting myself four case studies, each with its own design brief chosen to demonstrate a specific aspect of MFT. Chapter 7 describes each case study in detail.

'Wearable Metal Origami is a product of it's time. In chapter 2, I explain how craft practice and current consumer behaviour have informed my practice. Chapter 3, Precedents and Trends, shows a range of historical and current precedents in metalwork, textiles and innovative materials. A range of folding objects and materials from architecture, science and design has also influenced my way of thinking about and working with MFT. Some of these are only distantly related to MFT, others show remarkable similarities in certain aspects. I will explore them in more detail in my survey of folding behaviour in nature and material culture, chapter 4.

2. Context: 'Wearable Metal Origami' as a Contemporary Craft

Craft and Innovation

My work stems from craft within Bruce Metcalf's definition of craft-as-a-class-of-object[1], in which an object is made substantially by hand, using mostly traditional craft materials and techniques. Within this definition, a certain subject within craft (such as glass, ceramics, jewellery) is chosen because the craftsperson discovers a sensibility for the chosen material.[2] Once this initial connection is made, the maker will develop a bond with the material and learn the physical processes needed to work with it.[3] The struggle with that material teaches the maker the characteristics of the medium, forcing him or her to be inventive and to consider his or her work procedures.[4] I identify with this definition of craft because it reflects my discovery of MFT and approach to the development of 'Wearable Metal Origami'. I instinctively recognised the material as being special and worthwhile of further development. Throughout the research tacit knowledge played an important role in guiding me through the work, and reflection on the chosen processes was necessary to learn which ones give the best outcomes.

I believe in Peter Dormer's view that to learn a craft, the maker has to go through several stages before he or she becomes an expert. Dormer refers to Dreyfus[5] when listing the different stages as: Novice, Advanced beginner, Competence, Proficiency, and Expertise. He claims that as a novice, one has to learn the rules of the craft, and through the different stages those rules become so engrained that once one is an expert, they have become available through 'intuition'. However, to reach this stage the maker has to keep the rules in mind and analyse his or her working method. I feel that this research project has been helpful in taking the journey to become an expert in MFT and 'Wearable Metal Origami'. I do not think I have reached the stage of expert quite yet, since I can still see many ways of improving my work. But the application of different research methods at the different stages of developing the 'Wearable Metal Origami' has enabled me to set the rules and to start integrating them.

Just as my work is soundly craft-based, it is exceptional in a craft context because I did not choose a traditional or commonly available material as my subject, but developed my own raw material instead. Craftspeople can, and often will, choose to use innovative materials, but they do not normally create their own material. When I invented the textile-metal laminate MFT, I wanted to recreate the flexibility of paper folded according to tessellating origami patterns. I did this with the intention of making jewellery and used a craft approach to make the material. But when making MFT I am not making jewellery, only the material that can then be transformed into jewellery or other wearables. And it is not limited to wearables: the material can be used for a broad range of applications. In the DAS project, we tested applications such as sunblinds, room dividers, fountains and mechanically activated devices. So the material I make through a craft process, can now be applied to a range of craftfully made objects. I have split my craft in two parts: making the raw material, and making objects with the raw material. The disadvantage of working with a new raw material is that there is no expert to learn from, although I have gathered information about different materials and processes from a variety of sources. On the other hand, there is a significant advantage of working this way: I can adapt the material to fit the design of the objects. I can choose the type of movement I want for a specific application, and adjust the folding pattern accordingly. I can choose to use different colours or textures of fabric, and adjust hinge width and platelet thickness as desired. I can think through the design process in two directions: either designing the material to fit the object, or designing the object to fit the material. I can even go through the loop of adjusting one to the other several times before the final design is executed.

The making of MFT and 'Wearable Metal Origami' involves a combination of traditional and contemporary processes. I have them all under my control, from the hand sewing to the vinyl and laser cutting and the electroforming. I make the computer drawings myself, and operate the machines. This gives me the opportunity to get the quality of each step exactly as I want it. As Peter Dormer states: *'To claim that one possesses a craft is to claim that one has autonomy in a field of knowledge: craft is something one can do for oneself. It does not mean that tools or other labour-saving and -enhancing devices are forbidden, on the contrary. But it does mean that the craft person remains the master or mistress of the craft.'* [6]

Contemporary Society

Even though I see myself as a craftsperson, my work crosses the boundaries between art, craft and fashion. This is only possible because those boundaries are not clearly defined[7]. In fact, 'Wearable Metal Origami' is made in a multi-faceted context. Our current society is complicated, and this is reflected in the objects with which we surround us. As Paul Greenhalgh stated in his paper for the conference 'Exploring Contemporary Craft' in 1999: *'The next phase of modernity will be characterised by four things: interdisciplinarity, globality, pan-technicality and eclecticism. … We swim in a sea of stuff that we have made. This stuff responds to thousands of codes, contexts and consciousnesses and fires* *in a million directions.'* [8] Greenhalgh was right. Material databases[9] have come into existence to advertise both traditional materials and newly launched innovative materials to designers and objects for everyday use become increasingly customisable. This variety in products and materials is a reflection of our society: people desire to have some influence on their environment and to demonstrate their individuality. At the conference of 'The Body Politic' Sorrel Herschberg and Gareth Williams talk about this: they say that the new spirit tends towards increased personalisation of culture, interaction and the customisation of art, architecture and design[10]. Products that invite interaction and customisation by the user are popular because they accentuate the individuality of their owner. 'Wearable Metal origami' fits in well with this diverse context and desire for interaction. The work crosses the boundaries of several disciplines. It is a new material, made with a combination of traditional and computer-aided processes. It is designed so that the consumer can shape the object to his or her own body or even change the function as desired. MFT bears enough resemblance to historic and contemporary precedents to allow people to connect with it, yet is novel enough to appeal to the desire for personal influence and change.

The Body

I have noticed that when people touch 'Wearable Metal Origami', rather than just looking at it, they become more enthusiastic and more engaged. The interaction with the material is physical rather than mental. Our brain cannot explain the behaviour of MFT because it is too different from what we are used to, but somehow it feels right. For one moment, it stops us analysing our environment rationally and puts us in touch with our senses. This tactility might explain the appeal MFT has: it allows us to "*process and come to terms with being in a world of materials"* [11]. It also implies that craft is still a valid approach to making objects in our current society. As Pamela Johnson states in her paper for the 'The Body Politic' conference: *"I would suggest that the crafts are not out of touch… …But they are made out of a sense of touch, and invite a tactile response."* [12]

I chose to apply MFT to 'Wearable Metal Origami' because bringing it into close contact with the body is the best way of exploring its tangible character. By making MFT wearable, it becomes impossible not to touch it. This sense of touch, the close relationship to and interaction with the body are more important to me than classifying my work under a label such as jewellery or fashion. That is why I chose to use the word 'wearables': it stands slightly apart from either discipline, yet clearly refers to objects closely related to the body.

The folding patterns of MFT resemble the minute folds of skin. This is another good reason to use it for the creation of wearable pieces: I can make use of the natural shape and movement of the body to test and demonstrate the qualities of the material, creating a second skin. I have only recently become aware of the implications this might have on how the work is perceived. It makes ‘Wearable Metal Origami’ tie in much stronger with fashion because clothing has been seen as a second skin for much longer. But fashion implies more than the functionality and decorative aspect of what is being worn: it is about projecting an image of oneself. For this research project, I concentrated on the functionality and decoration, and have not investigated in detail what sort of image one would project when wearing ‘Wearable Metal Origami’. I know there are the visual references to skin and armour, and to pleated clothing, but I now realise that further research will be necessary to discover the implications of these connections. I will follow this up in the future.

Conclusion

The views of the people referred to in this chapter reflect my philosophical approach to ‘Wearable Metal Origami’: I see it as a contemporary craft practice, based within contemporary society and give it a place on the body. Bruce Metcalf describes the crucial initial and continued connection with the material in which I recognise my bond with MFT. Peter Dormer explains the self-reflective learning-process I used to develop the new skills necessary to work with MFT. The current demand for innovative and interactive materials and objects, as identified by Paul Greenhalgh, Sorrel Herschberg and Gareth Williams, is the context within which I work. Because of the characteristics of MFT, it invites the physical engagement, defined by Pamela Johnson, that allows the wearer to get in touch with their senses. This makes it extremely suitable to be worn on or close to the body as ‘Wearable Metal Origami’. Within the context described in this chapter there is still a lot of scope to further develop MFT and ‘Wearable Metal Origami’. I will continue to work on this in the future.

3. Precedents and Trends

Of course a novel material does not appear out of thin air. It can only be created within a context of existing materials, designs and mindsets. I have explained how the mindset within which I work is that of craft in multi-faceted consumer society. But I am also building on tradition. Wearable materials and objects made throughout the centuries up to the present have inspired me in the creation of ‘Wearable Metal Origami’.

Wearable Metal structures

Chain-Mail and Body Armour

Chain-mail and body armour are closely related to MFT. The similarities are that they are flexible, made to be worn on the body and constructed of small metal parts held together in a variety of ways. They have been in use over centuries and in many different forms throughout the world. Their function was to protect in battle or to show off the wealth and power of the wearer. Different techniques were applied, producing a variety of attributes and appearances. The best-known variation of chain mail is made up of jump rings, linked together in intricate patterns. In other examples metal platelets were sown or riveted onto a leather carrier or in between textile or layers of leather. Japanese armour was made from lacquered wood or bamboo, strung together with silk. Chain-mail is still produced. There are handmade replicas worn by enthusiasts of the Middle Ages, but it is also professionally used as protection for people handling sharp tools, such as butchers, and for shark diving. For these contemporary protective applications, the production process of chain-mail is now partly industrialised. Body armour consists of larger metal pieces, shaped to fit around different parts of the body and linked together to allow the wearer a certain degree of movement. The parts are linked with leather straps, hinges and rivets. Hooks-and-eyes and buckles make sure the elements stay in place once they are fitted around the body.

Figure 3.1: Detail of Japanese chain-mail, reinforced with plates. Date unknown, The Royal Armouries, Leeds. Photograph by Tine De Ruysser, 2008

Figure 3.2: Detail of a garde-de-rein, or loin-guard, composed of overlapping plates riveted onto leather. Probably Italian, about 1600. The Wallace Collection, London. Photograph by Tine De Ruysser, 2006

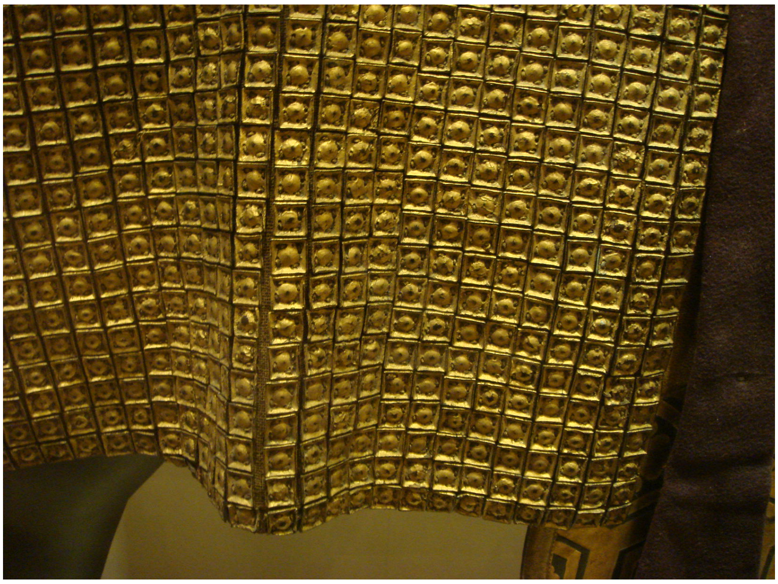


Figure 3.3: Japanese horse armour, Ise, 1863. Made from metal platelets sown between a layer of fabric and small leather squares. The Royal Armouries, Leeds. Photograph by Tine De Ruysser, 2008

Figure 3.4: Field armour, English, Greenwich, about 1630, The Tower of London.
Photograph by Tine De Ruysser, 2006
One can see how the gauntlet is constructed. Rivets are used to attach the small plates covering the fingers to a leather strap. The larger platelets, covering the back of the hand are riveted together at either end, allowing for movement of the hand.

I have looked with great interest at the armour on display at the Tower of London and the Royal Armoury in Leeds. Especially the glove at the Tower of London, provided so that visitors could touch and see it move, drew my attention. Like 'Wearable Metal Origami', these objects are very tactile. When actuated, they seem to come alive. All this protective metalwork is cleverly designed to allow as much freedom of movement as possible while warding off blows from sharp objects. But this is where the comparison between MFT and armour must end: MFT is not suitable as protection against sharp objects. It is made from a single folding sheet of material, rather than from many little parts, and the folds create ridges that might very well guide a sharp object towards the body rather than let it slide off. The hinges are made of a thin material, and would be easily penetrated by a sharp object, especially when it reaches the inside folds. So the importance of chain-mail and armour for the project of 'Wearable Metal Origami' has not been their function. It is their visual and tactile aspect, their life-like movement that provided inspiration for shapes and possible construction methods.

Jewellery inspired by Chain-Mail and Armour

As chain-mail was designed to be flexible for comfortable wearability it is no wonder that, prior to my interest, other jewellers in the 20th and 21st Century have been inspired by its construction techniques to create magnificent jewellery. In recent years Tone Vigeland (b. 1938) from Norway and Salima Thakker (b.1975) from Belgium have applied the chain-mail technique in their designs. Tone Vigeland made her first pieces assembled from individual links in 1967, and fully developed this range in the late Seventies through to the early Nineties Salima Thakker has developed her own variation on this theme since 1999, linking metal tubes to create bracelets and neckpieces. When worn, the play of light on the metal plates and tubes combined with their flexibility makes the pieces come alive.

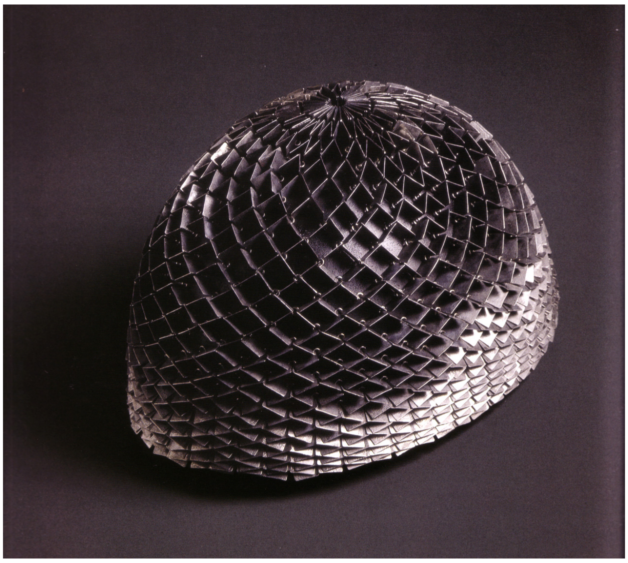


Figure 3.5: Tone Vigeland, Cap, 1992 Silver, 15x21 cm Private Collection
(Brundtland, 2003, p.112)

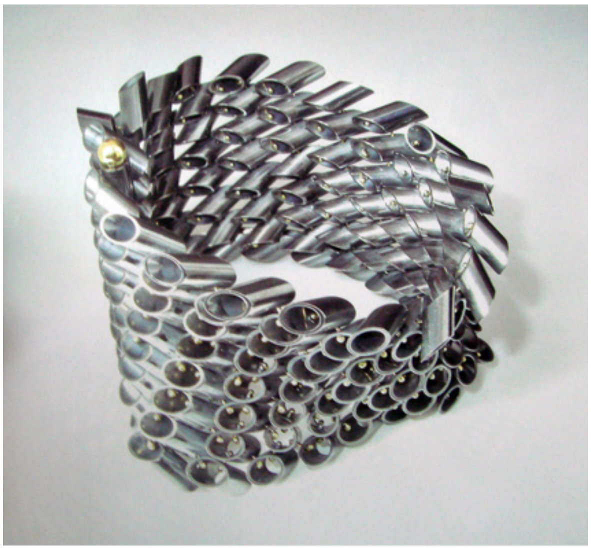


Figure 3.6: Bracelet, Salima Thakker, silver, gold (Dougherty, 2008)

Other jewellers have sought to find other methods to achieve similar effects. Since the 1960s, Arline Fisch has created jewellery by applying textile techniques such as knitting and weaving with metal wire. The pieces bear similarities to chain-mail in the way they wrap around the body. They are light in weight and have fluid shapes, but are less flexible and seem less alive when worn.

Figure 3.7: Shoulder Wrap by Arline Fisch, shoulder ornament, 1986, fine and sterling silver, 203x356x279mm (McFadden, 2000)

I have always been attracted to these types of jewellery that interact with the body and add an extra liveliness. Even though their construction method is different, they often sit on the border between jewellery and clothing, just like ‘Wearable Metal Origami’. Their success has stimulated me to follow through with the idea to turn MFT into wearables.

Fashion inspired by Chain-Mail and Armour

Fashion designers have also taken inspiration from armour and chain-mail to create out-of-the-ordinary clothing. In the 1960’s Paco Rabanne constructed dresses with metal, plastic and leather plates, joined together with jump rings. His designs with unconventional materials and shapes were revolutionary, when he started and they continue to appear in new collections. The techniques are similar to the ones used for chain-mail, the shapes have followed fashion throughout the years.

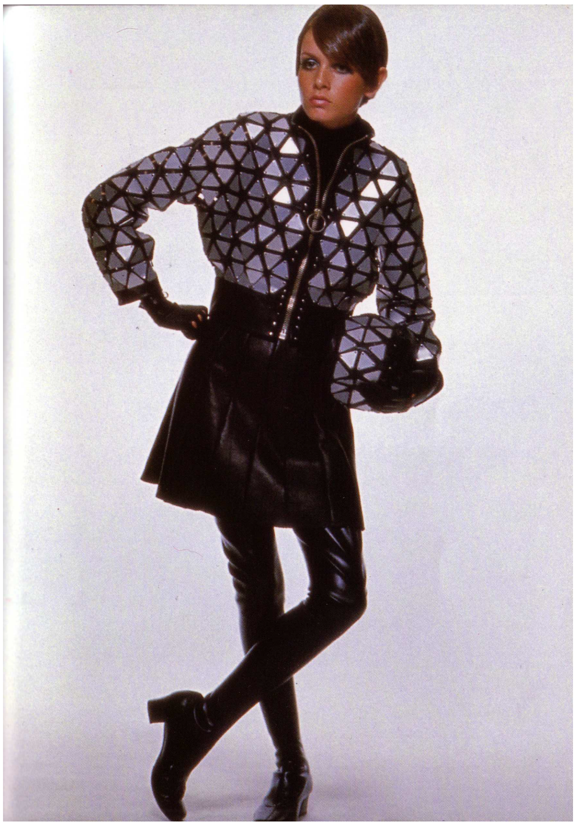


Figure 3.8: Paco Rabanne, jacket with aluminium triangles (Kamitsis 1999)

Figure 3.9: Paco Rabanne, dress, large rectangular plates and jump rings, 1976, aluminium and brass (Fukai, 2002)

Figure 3.10: Paco Rabanne, top and skirt, discs and jumprings, aluminium, metal wire, 1967 (Fukai, 2002)

Alexander McQueen has also incorporated metal in his couture. His futuristic creations use a whole range of traditional and innovative techniques to make the metal either flow over the body, or encase it like armour.

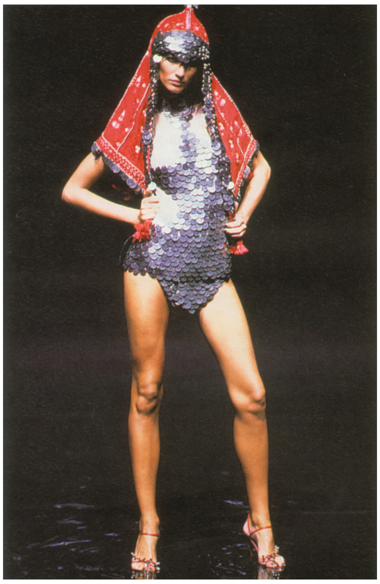


Figure 3.11: metal dress McQueen, Silver coins (Williams 2001, p. 52)

These examples are created in a fashion context, where decoration of the body is important. They are signature pieces. Their designers have dipped into the history of metalwork to find inspiration and the necessary techniques. Rather than actually protecting the body, they refer to protective wear to actuate the fragility of that human body. I am interested in these pieces because they demonstrate the sensual appeal of flexible wearable metal structures. The contrast between the hard metal and fluid movement draws our attention to the beauty of the physical shape and movements of the human body. They confirm that I can demonstrate the qualities of MFT best when it is applied to 'Wearable Metal Origami'. By making wearables, I can make the material come alive on the body.

In 2007 Houssein Chalayan created fashion that truly seems to come alive. He made a set of three dresses that change shape seemingly on their own; one cannot see what sets them in motion. This is very exciting work on the edge of fashion and art, and is a beautiful example of how a wearable piece can change appearance. There is a connection with the skirt I designed as part of my research (see chapter 7). Chalayan's work demonstrates what would be possible if the manual actuation would be replaced by a high-tech mechanism. For my research project I decided not to take the high-tech route, but to concentrate on what for me is the essence of 'Wearable Metal Origami': the tactile aspect of the interaction between the human body and MFT. Replacing manual actuation with a mechanism would remove the physical understanding, leaving us with only the visual surprise.

Figure 3.12: shape-changing dress by Hussein Chalayan, from the 2007 Spring-Summer collection (Chalayan, 2007)

Jewellery transformed into Wearables

There is a type of jewellery, different from the examples given above, that has been important for me in the creation of ‘Wearable Metal Origami’. This is the jewellery that broke with jewellery traditions because it was made with unusual materials and sometimes placed on unusual places of the body. Around 1980, Caroline Broadhead applied a textile technique to create shape-changing jewellery. She used nylon filament instead of traditional metals. Her sleeve can span the length of an arm, or fold down to a bracelet around the wrist. Paul Derrez made a neckpiece by folding a strip of PVC harmonica-wise, and keeping it in shape with steel wire. It looks more like a ruff than jewellery, yet is clearly a neckpiece.

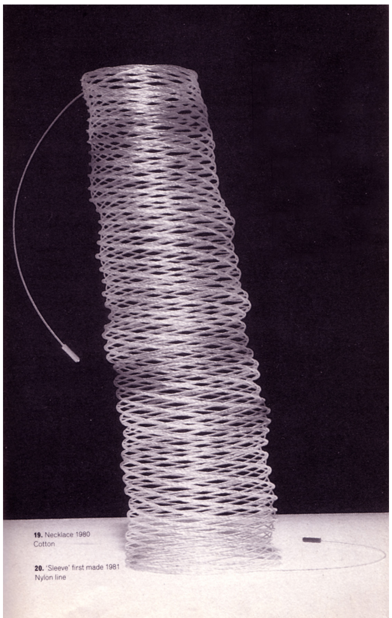


Figure 3.13: Caroline Broadhead, sleeve, 1981, Nylon (Houston 1990)

Figure 3.14: Paul Derrez, Neckpiece, 1982, PVC and steel, 400mm (Dormer, 1985, p.111)

Emmy van Leersum merged jewellery with clothing, like the silver collar that functioned as an elegant strap to hold up a dress. Van Leersum and Gijs Bakker also collaborated on costumes, where they inserted metal loops into a stretch fabric to distort the shape of the body.

Figure 3.15: Collar with dress, Emmy van Leersum, 1966, Silver and Acrylate (Joris, 1993)

Figure 3.16: Costumes by Emmy van Leersum and Gijs Bakker (Walgrave, 2000)

Van Leersum and Bakker introduced this work into a jewellery context, but dramatically transforming body-shapes through the use of costumes had been done before by the Bauhaus teacher of sculpture and theatre design, Oscar Schlemmer. Schlemmer found that through its shape, a stage costume could either express or change the body's identity, its nature and its conformity to organic and mechanical laws[1]. By choosing different types of shape-change the costume could morph the actor-dancer into a different entity. This idea that the body changing shape makes it change meaning is an idea that could be followed up with 'Wearable Metal Origami'. MFT being almost like a second skin, with its possibility of adjusting to the movements of the body but potentially changing its shape, can change the way the wearer is perceived.

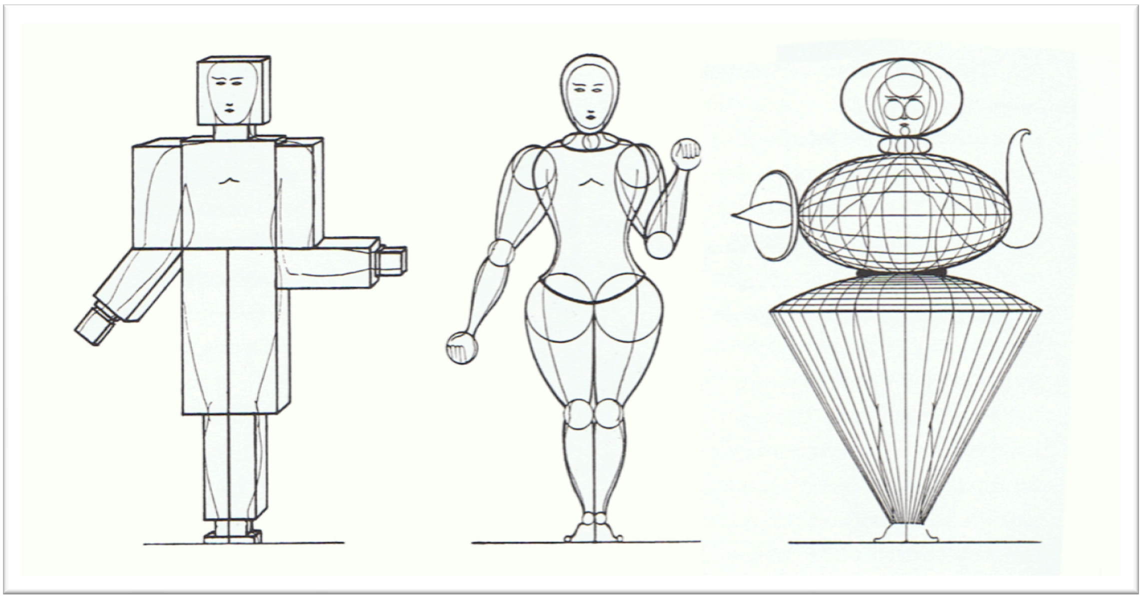


Figure 3.17: Three different ways of transforming the body with stage-costume according to Oscar Schlemmer. From left to right: ambulant architecture, the marionette and a technical organism. (Gropius, 1961)

Through their experiments with unconventional materials, shapes and dimensions Broadhead, Derrez, Van Leersum, Bakker and their contemporaries created work that was somewhere between fashion and jewellery. They influenced society's view on jewellery so thoroughly that my generation of jewellery makers never felt confined to the use of fine metals and traditional shapes only. We think outside the formal limitations of jewellery and experiment with materials and functions. It is this open view on jewellery that has allowed me to develop MFT in a metalwork and jewellery department, and take it into the territory of wearables. I feel that I am moving further along the path they made by not only creating pieces that bridge jewellery, accessories and fashion, but also constructing them with a novel material invented and developed by me.

Metallised Textiles

Clothes have been decorated with metal for centuries. Different techniques such as weaving in fine metal strands and embroidering with metal thread are traditional. Metal reflects light, so that the fabric shimmers and shines, making it more attractive.

Figure 3.18: Back of Kokoshnik Headdress, Red velvet, gold and silver thread, late 18th century, Historical Museum Moscow (Yefimova and Belogorskaya, 1987)

Most of these traditional techniques are difficult and time-consuming and make the fabric heavier and stiffer. Metal is expensive and threads are prone to breaking. Washing the fabric is problematical. For these reasons fabrics enhanced with metal used to be a luxury, only within reach of the wealthiest of society. With the development of modern techniques they have become more widely available. Since 1990 fashion designers such as Alexander McQueen and Reiko Sudo employ modern metallisation techniques to apply an ultra-thin layer of metal to the fabric. These techniques do not affect the textile's draping properties, but allow the metal to shine combined with the flow of the fabric. Synthetic textiles have also become more and more refined, so that fabrics with a metal sheen can now be found easily, and at a very low cost. This is visible in recent fashion trends, where gold and silver are omnipresent.

Figure 3.19: Alexander McQueen, dress, 1996 (Braddock Clarke and O'Mahony 2005)

Figure 3.20: Bronze Donna Karan Dress, worn by Jamie-Lynn Sigler at the Emmy Awards 2009 (InStyle, 2009)

These clothes draw attention because they have a shiny metal finish, but the metal has no great effect on the structure of the garment. The metallisation process becomes more exciting, and more relevant to me, when it used to structurally affect the textile.

The textile artist and researcher Dr. Frances Geesin, Reader at the University of the Arts London, has used the process of electroforming to stiffen fabric into shape and make it partially or completely conductive. She started this work during her PhD at the Royal College of Art (1990-'95). Geesin collaborates with artists, designers and scientists. She was one of the first people to make use of the conductivity of the electroformed fabric to create interactive pieces and wearable electronics. More recent work visualises nano science and biological processes in the human body.

Figure 3.21: Nanosphere, partially metallised, by Frances Geesin (www.francesgeesin.com)

Sarah Keith, a textile artist, started her PhD at the Duncan of Jordanstone College of Art and Design, University of Dundee in 2006, and uses shibori techniques to form, stiffen and locally electroform textiles.

Figure 3.22: Partly silver plated fabric, Sarah Keith (www.sarakeith.com)

With the development of MFT, I have taken the electroforming of textiles one step further. I am not stiffening the fabric into one fixed shape but create a folding laminate that I then apply to wearable pieces.

Folding and Pleating

MFT is closely related to folded or pleated textiles. It is the folding of MFT that makes it wearable, and the folding is only possible because it has textile as the core material; carrying the metal platelets and forming the hinges.

Folding and pleating are well-known techniques applied within fashion and textiles. They have been used through the centuries to make fabrics drape elegantly on the body: *" A piece of cloth was folded to form a chiton, a sari, a kilt, a burga or a skirt en soleil. It was folded to 'jump' in a demonstration by Issey Miyake on the occasion of "Pleats Please". A piece of cloth was folded, was folded again, and will be folded every time a sensitive person wishes to place this "piece of cloth" on the human body."* [2]

Folding in this context is used to describe how folds are pressed into the fabric to make them more permanent. This process is more commonly referred to as 'pleating'. It is these pleats that I am interested in. But the term 'pleating' implies the use of a pure textile, unstiffened by metal platelets. So while pleated fabrics have a close connection to 'Wearable Metal Origami', I refer to my work as 'folded' or 'folding' rather than 'pleated'.

The designers that inspired me most with their pleated clothes are Mariano Fortuny (1871-1949) and Issey Miyake (b. 1938). Mariano Fortuny's work was inspired by Ancient Greek statues showing female godesses in finely pleated clothing (Deschodt and Poli 2001). In 1909 he patented a technique to pleat silk for the creation of smoothly flowing dresses.

Figure 3.23: Delphos dress by Mariano Fortuny, 1924, Silk, Photo: James Abbe (Fukai, 2002)

Issey Miyake reinvented the technique more recently, making pleated pieces for his collections since the 1980's. The pleats are an integral part of the design to both Fortuny and Miyake, but not necessarily for the same reasons. Fortuny used the pleats to make the fabric flow over and accentuate the female curves. The dresses suited women of all shapes and sizes. Issey Miyake sometimes uses pleats for the same reason, but often achieves quite the opposite: the pleats in combination with the cutting pattern make the fabric stand up on its own in strange shapes, distorting the human figure of the wearer. The clothes turn the body into a moving sculpture.

Figure 3.24: Dress by Issey Miyake, Autumn /Winter Collection, 1989, Polyester organza (Holborn, 1995)

Similar to these pleated fabrics, MFT can be used either for accentuating or distorting the human body.

Miyake's clever use of polyester, which can be permanently pleated when heat-treated has inspired many contemporary textile designers, among which Maurizio Galante, Ann Richards, Reiko Sudo and Hiroaki Takekura. They have adapted the ancient Eastern technique of Shibori (a dyeing technique that involves the folding and binding of fabric to prevent the dye from reaching selected areas) to create their own versions of pleated fabrics. The pleats remaining in the fabric after the dyeing process are normally just a by-product, but when the folding and pleating techniques from Shibori are applied to synthetic fabrics, and dyeing is replaced by heat-treatment, the folds can be made permanent. The resulting folds can be irregular like crumpling, very geometric like the origami patterns I use for MFT, or anywhere in between. The company F. Ciment (Pleating) Ltd in Hertfordshire offers a wide variation of folding patterns that can be applied to fabrics brought in by the customer.

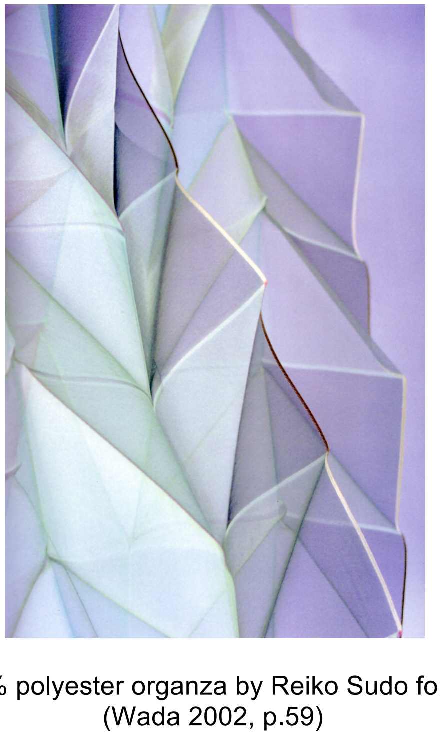


Figure 3.25: "Origami" 100% polyester organza by Reiko Sudo for NUNO Corporation, 1997 (Wada 2002, p.59)

Figure 3.26: Maurizio Galante, pullover, 1994, polyester (Holborn, 1995)

Figure 3.27: Inoue Pleats Inc., Pleated scarves polyester (Braddock, 2005)

By permanently pleating these textiles, they have become more sensual and alive. Because they are made from one uniform material, both the pleats and the material in between them is distorted when the fabric is handled. This means that they unfold in a different way to MFT, where any movement has to be situated in the textile hinges only because the stiff metal platelets will not easily distort. This contrast between stiff platelets and textile hinges, the crisp folding behaviour makes MFT behave in more unexpected ways, it seems more alive. This feel to the material cannot be replaced by pleated textile, but both materials could in the future be combined in one piece of Wearable Metal Origami.

Folding laminates

There are materials that closely resemble MFT in their composition as folding laminates. They are made with a textile core and stiffened platelets in either wood or plastic. "Magic Mountain" by Arash and Kelly has Perspex platelets applied onto fabric to create textile hinges such as those in MFT. The folding pattern is not a tessellating origami pattern such as those I use for MFT and so does not exhibit MFT's regular folding. Instead the pattern allows for the material to be draped into irregular shapes.

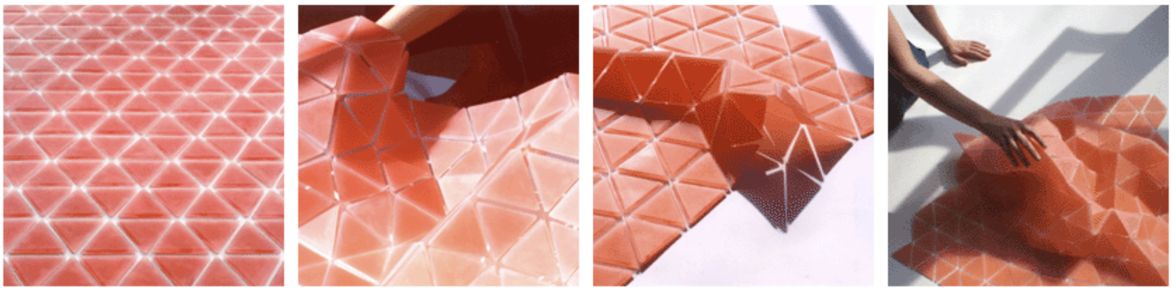


Figure 3.28: Magic Mountain by Arash and Kelly, 2002, Perspex and fabric (Sant [no date])

Similarly, the 'wooden textiles', recently developed by Elisa Strozyk, have wooden platelets glued onto a fabric backing. They closely resemble the plywood model-making material I developed in the course of this research. Strozyk uses the flexibility of these wood-textile laminates to make interior products such as carpets and furniture.

Figure 3.29: Wooden Textile by Elisa Strozyk, made in 2009-2010 (Strozyk, 2010)

Alucobond is of a totally different category, but shows remarkable similarities to MFT. It was first manufactured in 1969, and is now produced by Alusuisse Singen GmbH in Switzerland. Alucobond panels are made up out of a flexible synthetic central layer, covered on both sides with a layer of aluminium. This makes them lighter and stronger than plain aluminium panels of the same thickness. They can be scored through one layer of aluminium and consequently bent under sharp angles and into curves that would be very difficult to achieve in thick sheets of metal without tearing. Because of their thickness (minimum 2 mm) they are used for large applications such as the construction of folded metal displays and cladding for buildings.

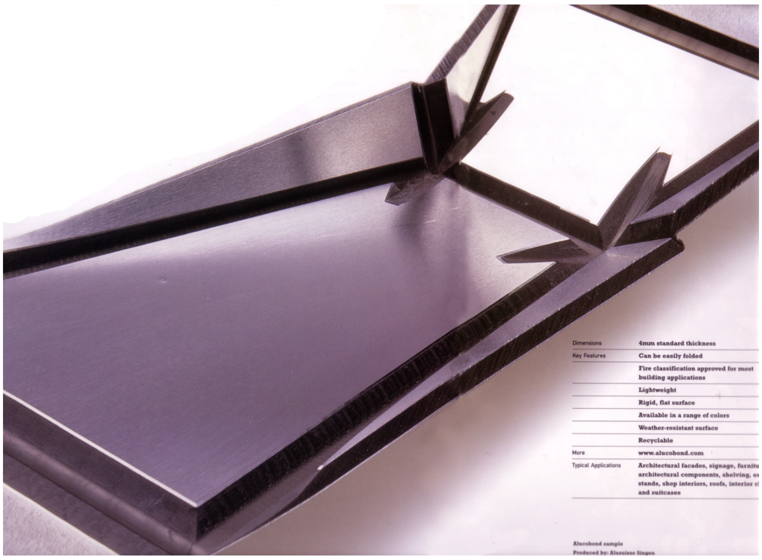


Figure 3.30: Detail of a 4mm Alucobond panel, scored and folded. (Lefteri, 2004).

In its composition, this material comes very close to MFT. However, it has been developed for purposes that are larger and of a more permanent character. It is meant to retain its shape rather than allow for repeated folding.

MFT is clearly not the only laminate with a flexible core and stiff platelets. It is however unique in using tessellating origami patterns to create a controlled flexibility that is ideally suited for the creation of wearables. The other laminates have been developed by people with backgrounds in different disciplines with other applications in mind. This is probably why they have not come up with the same combination of factors that make MFT unique: the metal platelets on a textile substrate, folded into tessellating origami patterns.

Conclusion

MFT is a product of its time: it fits in with the current demand for innovative materials and interactive objects. It is a new material, but its invention and the application to ‘Wearable Metal Origami’ build on a wide variety of traditional and contemporary precedents from textiles, fashion, jewellery and metalwork. I could not have invented this material if these precedents and time-spirit had not existed.

4. Folding Behaviour in Nature and Material Culture

I never took the time to properly investigate the context for MFT until starting my Research Degree. This project has given me the opportunity and the tools to gain a better understanding of what place MFT takes within a whole range of products and materials. Working with other people has made me realise that the context for MFT is much wider than I had first realised. They made me see the material through their eyes, adding their opinions on what it could be used for. This large area is mapped out briefly in this chapter. Apart from the obvious connections with pleated textiles, chain-mail and origami, MFT is also related to larger objects, such as solar panels for satellites, tents and tensegrity structures. Many of the folding patterns can be found in nature, and more and more designers are using different sorts of collapsible, foldable or adaptable principles for their designs. In fact, the context for MFT is so wide that I decided to narrow down my analysis and concentrate on the materials and structures that show a clear relationship with MFT, the ones that inspired me and the materials that are closest to my chosen method of applying MFT: "Wearable Metal Origami".

Folding in Nature

Nature is a source of a large variety of refined folding patterns. Biomimetics, a fairly new branch of science that looks at nature for solutions to engineering problems, has been studying some of those natural patterns to try and understand how their principles might be used. They have concentrated on a few groups of natural folding patterns and mechanisms. The first group consists of patterns that are used for deploying a structure, such as the budding tree leaf unfolding in the spring[1] or a plant stem[2].

Figure 4.1: Beech leaves at different stages of deployment.
Photos by Tine De Ruysser

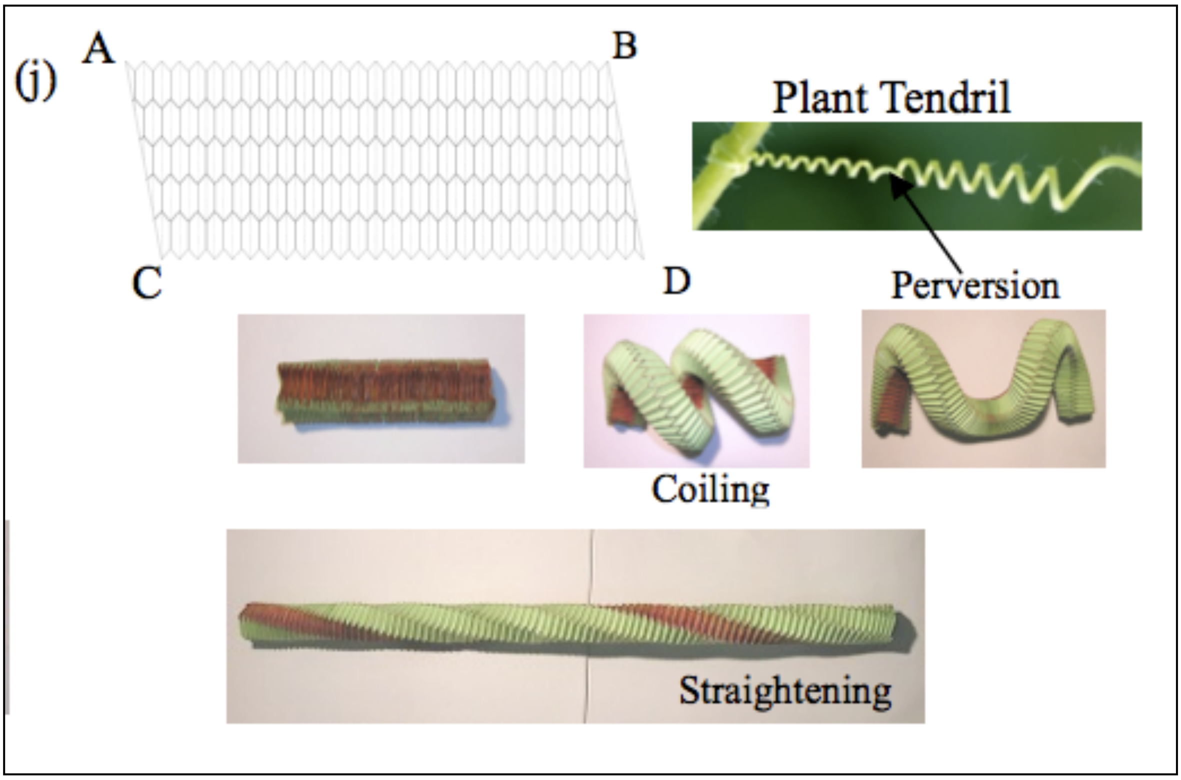


Figure 4.2: Movable model mimicking organic structure of plant tendril (Taketoshi, N. [no date] p. 19)

A second group of patterns allows for repeated folding and unfolding, like the wings of a beetle or ladybird, which are folded up underneath their shield[3,4].

Figure 4.3: The wings of an unknown beetle specimen are larger than the panels of the shield; they have to be folded away when not in use, quickly unfolded when needed and strong enough to carry the weight of the beetle. Photo by Tine De Ruysser

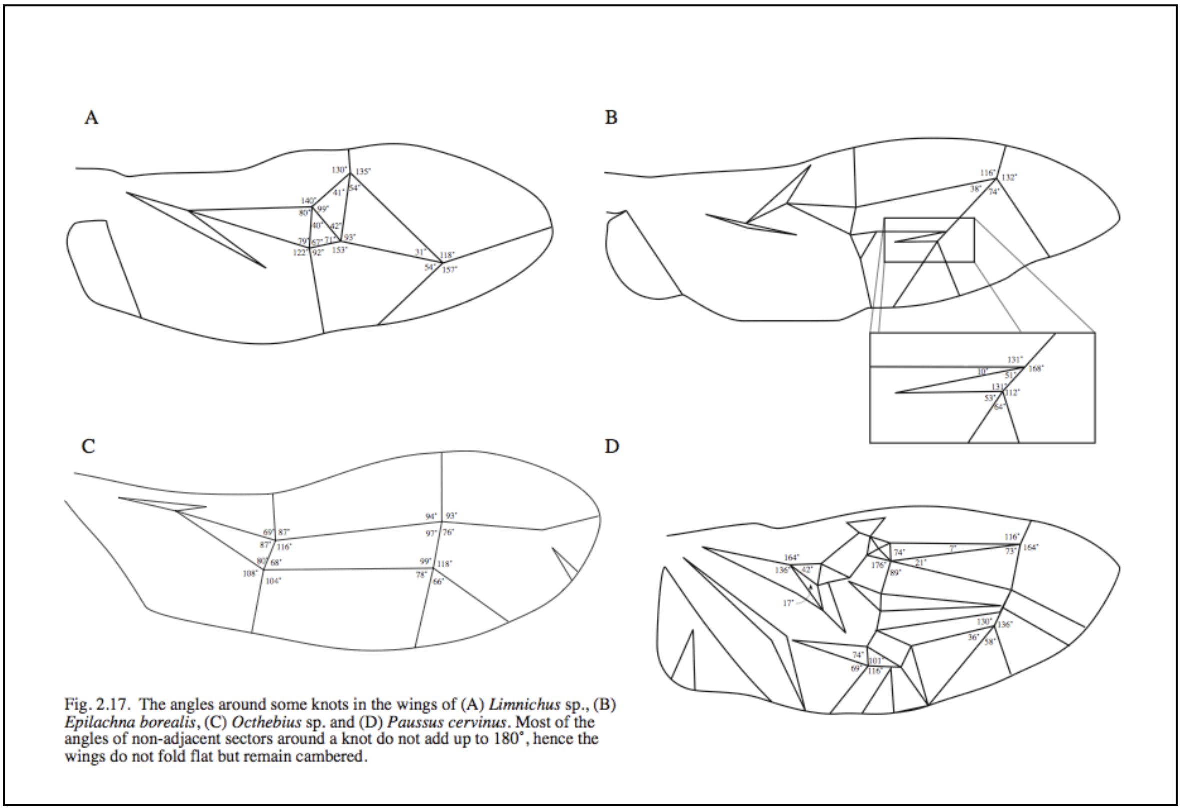


Fig. 2.17. The angles around some knots in the wings of (A) *Limnichus* sp., (B) *Epilachna borealis*, (C) *Octhebius* sp. and (D) *Paussus cervinus*. Most of the angles of non-adjacent sectors around a knot do not add up to 180°, hence the wings do not fold flat but remain cambered.

Figure 4.4: The folding angles around some knots in the wings of beetles. (Haas 1994, p.43)

The third group comprises the minuscule folds of our skin, which allow for movement while keeping the skin taut and smooth[5]. This is more clearly visible in the skin of reptiles, where the hardened areas of skin (the scales) and the folds in between those are all constructed of the same layer.

Figure 4.5: A sample of snakeskin, showing the scales and softer areas in between. There are irregularities in the pattern where larger scales adjoin smaller ones. Photo by Tine De Ruysser

Nature shows the full extent of what can be done through folding: giving both flexibility and strength and/or accomplishing a reversible or non-reversible shape change. The folding patterns found in nature are mathematical in principle, which is why many people have looked at nature for folding-inspiration for structural, mechanical or decorative purposes.

I had wanted to use folding patterns directly translated from natural patterns, but found that natural patterns almost always have some irregularity and the folded membranes (the leaf, wing or layer of skin) can normally not be unfolded to a perfectly flat sheet. Consequently, if I wanted to choose nature as a model, I had to simplify the crease pattern of the membrane (taking out the irregularities), and adapt it so that it can be reconstructed from a flat sheet material. When I looked up papers such as the folding of "Geometry and mechanics of hind-wing folding in Dermaptera and Coleoptera" [6], and when attempting to make an accurate drawing of the snakeskin pictured above, I realised that my mathematical and folding skills were not developed enough to enable me to do so. Gaining those skills necessary for reconstructing natural folding patterns would take too much time. As there are a large amount of origami patterns available (see chapter 5, "Principles and Practicalities of Folding for more details), I decided to concentrate on understanding the origami patterns as well as possible, thus leaving the natural patterns for a later stage.

However, studying the natural patterns did help me think about the different ways in which folding can be used. The basic qualities of singular or repeated deployment and flexible movement as found in nature, provided options for design choices in the stage of my research where I started to design applications and create "Wearable Metal Origami".

Man-made Folding Structures

There are innumerable man-made folding structures to be found which perform a variety of functions. Their main advantages are that they can be folded to form a relatively small packet for storage and transport, while being fully functional in their expanded condition. The shapes are unconventional when compared to rigid structures and buildings, which gives a sense of surprise and wonder. The movement between collapsed and deployed state adds to the amazement. Not all structures are designed to go through these motions repeatedly: some only need to deploy once and are then fixed in shape to perform their function. Others use their foldability over and over again. In our current society that is always looking for new experiences and novelty materials and objects, such structures are particularly attractive. Consequently, newly designed folding and deployable structures and objects appear in the media on a regular basis even if they do not always make it to the marketplace.

There are different ways of making objects collapse and deploy. Not all are strictly speaking a folding-up of the structure. But even the ones that use different principles are sometimes relevant to MFT as a source of inspiration, or because they can be combined with MFT. I have therefore looked at a whole range of such structures, also known as deployable structures. Within this enormous group of objects and products it is difficult to define the specific area relevant for my research. Seen in the broadest possible way the objects range from maps over air mattresses to tents, or from folding chairs to foldaway roofs for public buildings. Because of their practicality some of these structures have been around for a very long time. Umbrellas were invented more than 4000 years ago[7]; the Romans used tents for their travelling armies, and the Yurt has been used in Mongolia for at least 800 years. Recently, the combination of folding structures and modern materials has led to high-tech applications such as arterial stents for circulatory conditions and solar panels for space vehicles. Within this broad field there are many areas where MFT could be applied if its scale were altered. Although my PhD focuses on the relatively small-scale of the human body, I still wish to include a few related fields of larger-scale deployable structures that I researched for the DAS project and that have influenced my method of thinking about what can be achieved with MFT.

Tensile Structures

Tensile structures consisting of textile material kept in shape by tension are lightweight and can be mounted quickly. They are an adaptation of the tent structure, raising the roof higher in the air, making the structure more stable and spanning larger distances, covering larger surface areas. Tents were invented half a million years ago, when mankind consisted of hunter-gatherers who often travelled far for their survival. First tents were used within caves, but over time their construction became more refined, and the structures more complex and durable for outdoor use. Tents exist in various shapes and sizes and continue to be popular. Today tents are found worldwide, and are applied for a whole range of circumstances, especially when temporary shelter is required. With the introduction of synthetic fabric and lightweight elastic poles the construction has changed dramatically in the last few decennia. As a consequence they are lighter, fold down smaller, and are easier to set up. Tensile structures have evolved more recently. In 1896 one of the pioneers, Vladimir Shukhov, constructed a large pavilion for the Pan Russian exposition.

Figure 4.6: The Elliptical Pavilion of the Pan Russian Exposition during Construction, Nizhny Novgorod, 1896, (Wikipedia [no date])

Tensile structures have become increasingly popular, and are being used in both temporary and permanent architecture. A few famous examples are the Olympia Park in Munich (1972), the cloud-like structure in La Grande Arche La Défence in Paris (1989), and the Millennium Dome in London (2000).

Figure 4.7: View of Munich Olympic Stadium from the Olympic Tower.
Photo by Arad Mojtahedi, (Wikipedia [no date] b)

They are used for both permanent and temporary structures, mostly to provide shelter from the sun and rain. Their major advantages are the low cost and their capability to span large areas without internal obstructions. Their major disadvantage is that they have a fixed shape. The fabric material has been cut and sewn into a specific shape, and cannot be modified. In certain circumstances it would be better if the structure would be deployable, providing shelter when needed and becoming less intrusive when not.

I briefly studied tensile structures because I can see MFT, or a similar material based on the same principles of stiffened platelets and fabric hinges, being used on a larger scale for temporary adaptive structures. I think this could work by using MFT as the covering fabric, guided over cables in such a way that it could be contracted when no shelter is needed and unfolded when necessary. The folding principle would be related to that of a budding leaf, with a built in actuating mechanism. This scale of work was too large to include in the DAS project and my PhD, but the same principle can be used on a smaller scale. The idea of guiding MFT over cables to expand and contract when required has, although I greatly simplified the system, inspired one of my final designs: the skirt (see Chapter 7: Application of MFT to “Wearable Metal Origami”).

Tensegrity Structures

Tensegrity structures are related to tensile structures, because they depend on tension to keep them in shape. Made with struts and cables, and using the synergy between tension and compression, it almost looks as though the struts are floating in the air.

Figure 4.8: Needle Tower II by Kenneth Snelson, 1969, aluminium & stainless steel, 30 x 6 x 6m, Collection: Kröller Müller Museum, Otterlo, The Netherlands (Snelson [no date])

The first appearance of a basic unit for tensegrity structures dates back to 1921 in Moscow, at an exhibition devoted to construction. The name of the maker was Karl Ioganson. In 1948 Kenneth Snelson (b.1927) made 3 small tensegrity sculptures while he worked with Buckminster Fuller (1895-1984). It was the latter that came up with the name 'tensegrity', as a combination of 'tensile' and 'integrity'. There is some discussion on which of the two men was the actual inventor. Around the same time (in 1964) David Georges Emmerich (1925-1996) filed a patent application for what he called 'autotendants', a structural system that works just like the tensegrity structures. In any case, tensegrity structures are a fairly recent development. They exist in a range of different shapes and are often used as static sculptures, but they can also form deployable structures. By varying the length of the cables or folding the struts, the tension changes, and consequently their shape. This way they can transform from comparatively small stacks of rods and cables into large structures.

I am most interested in tensegrity structures when used as deployable structures. They could be applied as a supporting structure for MFT, or even be integrated into MFT, with the rods being replaced by platelets, and cables or strings providing the actuation. But even though the advantages of deployable tensegrity structures have been described by, amongst others, Buckminster Fuller, they remain theoretical. I have not been able to find any applications other than in sculptures and toys. They have been examined for their suitability for space masts[8] but this research did not come to a rounded-off design.

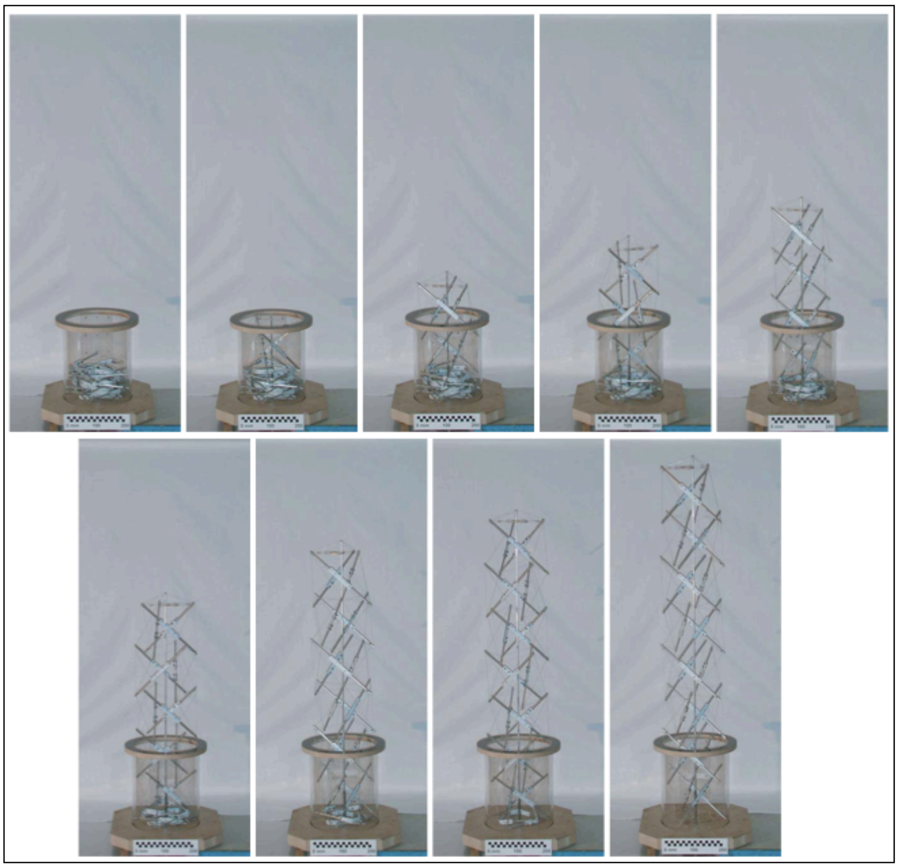


Figure 4.9: Rod-controlled deployment of the eight-stage mast by G. Tibert (Tibert 2002, p.102)

Their complex construction and unusual behaviour, which implies so many possibilities, seems to make the analytical thinking that is necessary to develop them into real applications extremely difficult. As a result, there remains a gap between the vision of what they could be, and what can be achieved in reality. This does not provide a good base on which to test their application possibilities for MFT. Nevertheless I wanted to see if I could come up with an idea so I made my own model of a simple tensegrity structure from straws, elastic bands and paperclips, as described by George Hart on his website[9]. It was surprisingly difficult to put together, and fell apart before I had a chance to take a picture. I decided that I was not likely to come up with a smarter idea than the tensegrity engineers, and ceased to continue on this trail.

Scissor Structures

Scissor structures are deployable structures, based on geometric rod structures, often geodesic domes. Each rod of the rigid structures has been replaced with a scissor mechanism, enabling the shape to contract and expand. Simple predecessors of these structures can be found in yurts (Gers), transportable dwellings originating in Mongolia. They are constructed of a lattice of wooden slats, bent around to form a cylinder. This forms the outer wall, and the truly deployable part of the Ger, on which a conical roof, also constructed with slats, rests. The whole structure is then covered with textile to provide for shelter. The whole ger is heavier and more complicated to put together than a tent, however it is much more stable and the space it contains can be larger.

Figure 4.10: First stage of setting up a ger: unfolding the lattice structure.
“Montage d’une Yourte” 2007, Mongolia, photo by: Alix Guillard (Wikipedia [no date] c)

Figure 4.11: Mongolian ger: with roof poles in place,
(Wikipedia [no date] c)

Figure 4.12: Mongolian ger: adding the outer cover, the inner cover can be seen underneath, the gers in the background are complete.
(Wikipedia [no date] c)

Chuck Hoberman took the principle one step further and invented the scissor structure. He is the founder of Hoberman Associates, a contemporary Company, founded in 1990[10] that develops deployable structures based on polygonal shapes. By applying scissor-like connections instead of rigid bars to construct the framework for these polygonal shapes they become deployable.

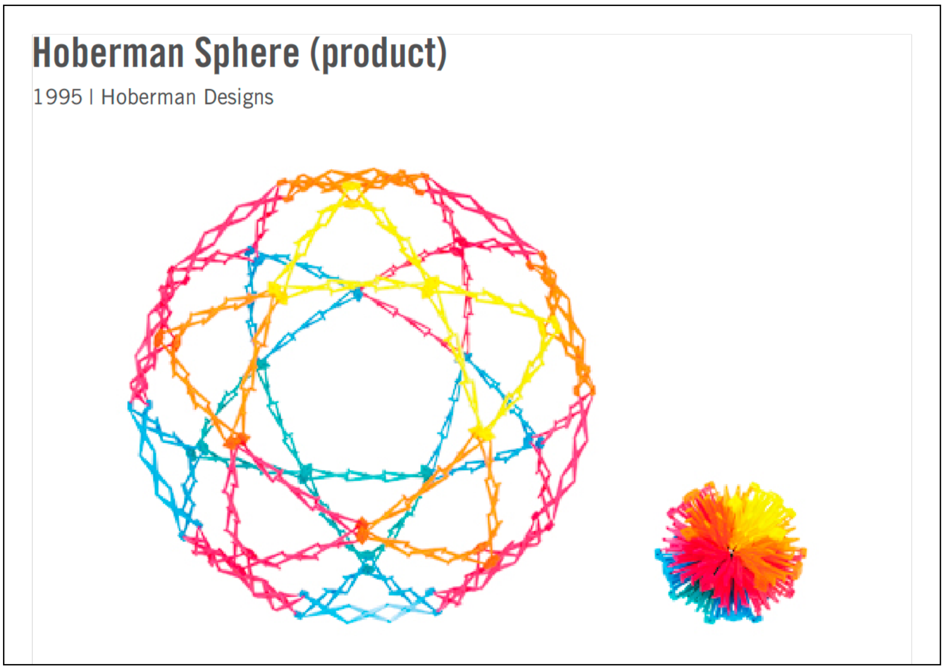


Figure 4.13: A Plastic Hoberman Sphere, sold as toy, shown here in both deployed and compressed form. (Hoberman 2005)

These scissor structures find use in a wide variety of applications, from toys to moving sculptures, and as a base on which panels or fabric are mounted to create roofs or tents. Hoberman Associates even propose their use for arterial stents.

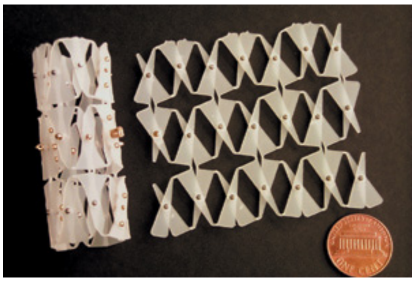


Figure 4.14: Design for Arterial Stent by Hoberman Associates (Hoberman 2005)

I am interested in scissor structures for the same reason as the tensegrity structures: they can maybe be developed to deploy MFT. Yet again I could not visualise how this could be done, and more importantly it did not seem appropriate for the Wearable Origami, but intend to develop this system in the future.

Origami Structures

The folding principles of origami, or the art of paper folding (In Japanese: 'oru' means 'to fold', kami means 'paper') can be applied to efficiently fold away objects made of sheet material. The information exchange between origami and design/engineering is in my view comparable to how biomimetics aims to influence engineering by studying nature. They are separate disciplines, but sometimes science uses the expertise of an origamist to help solve a problem. (The origamist of course built his expertise on mathematics and science, but applied it in his own way.) Origami relies on mathematical principles, which one needs to understand to be able to create new designs. This mathematical knowledge can be purely intuitive, even if only applied for simple models, but the experts in designing complicated models all consciously look for and follow specific rules. This knowledge of how to design the optimal folding pattern for a structure is useful when one needs to pack a large surface in a small container (such as folding up a solar sail into a space shuttle) in such a way that it is easily unfolded. The first official acknowledgement of the interchange between the different disciplines was the First International Meeting of Origami Science and Technology, held in Ferrara, Italy in 1989[11].

One example of how origami skills were applied for solving a design problem is the map[12]. Maps are generally made of large sheets of paper, to give the reader a good overview of the area that is mapped out. Yet, to transport the map, it has to be smaller to make it fit in a bag or pocket. The traditional way of folding a map does this well enough, but has two major flaws: it is difficult to unfold and refold the map, and it tears easily at the fold-lines. This has to do with the way maps are folded: the first folds are made along parallel lines to turn the map into a long strip comprising of several layers. Folding along long lines like these can only be done efficiently with two hands. Then all the layers created in the first step need to be folded as a bundle along a second set of lines, perpendicular to the first. The different layers of paper are consequently stretched in different degrees. The paper layer on the inside will receive a very sharp fold, possibly damaging the paper fibres; the paper on the outside will be stretched to span over all the layers underneath. Even more important: the already weaker folding lines of the first set of folds get stretched too, weakening the places where two folds cross. If the map is unfolded and refolded several times these weak places will easily tear.

The Miura-ori folding pattern gives a solution for both problems. It is one of the most basic accordion folding patterns. There is some discussion whether it was originally developed in 1970 by Dr Koryo Miura, or had already been created by a Bauhaus student previously[13]. Miura originally named it " the developable double corrugation surface" (DDC surface) and presented it as an alternative to the classical map fold.

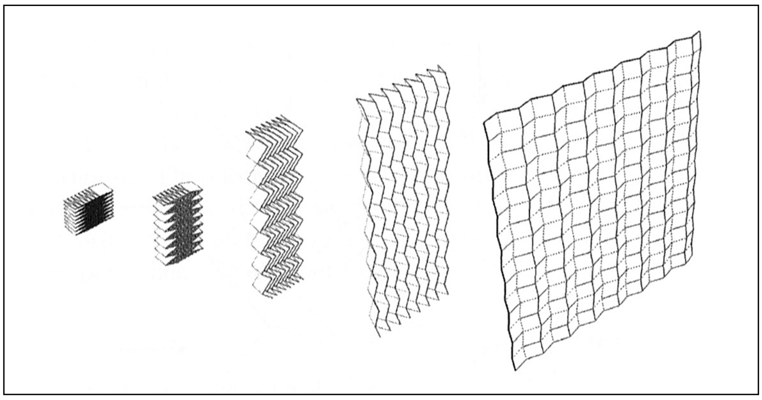


Figure 4.15: Deployment of Miura-ori (Miura, 2009)

The Miura-ori pattern can be opened and closed in one movement, by simply pulling the opposite corners of the map apart, or bringing them together. It is designed so that there never is a thick stack of paper that needs to be folded as a whole, thus it does not tear easily. At the same time as presenting the DDC as a solution for maps, Dr Miura also offered it as a solution for space structures such as solar sails and antennas. It is suitable for these because it packs up small for transport in a space shuttle; is unfolded in one movement thus only requiring a simple deploying mechanism, and none of its hinges is put under extreme tension, making it more structurally sound.

Since 1970 the Miura-ori has been put into use for both maps and space structures. The solar panel is in reality made from separate panels connected by hinges, using the angles and proportions of the folding pattern. Although the design seems ideal for maps, it is not often used because this system proves too difficult to mechanically fold from a flat sheet.

There are other prototypes of practical applications; such as origami patterns have been used to design arterial stents and curtains.

Figure 4.16: Curtains with platelets in a tessellating pattern, designed to fold in an irregular way, Cotton and Foam, Photograph from Hannah Allijn, (Allijn 2005)

In 2005 Hannah Allijn[14], a young product designer from the Netherlands designed curtains that can be pulled up into a corner of the window. The curtains are made from cotton and foam padding, with strings to pull them up. The folding pattern is tessellating, but not intended to fold away neatly. They are available on request only, indicating that she makes them individually when asked, rather than having a production line set up, and selling from stock.

Figure 4.17: Arterial Stents, designed by Kaori Kuribayashi
(Kuribayashi, 2004, p.172)

On a much smaller scale, Kaori Kuribayashi used folded memory material in her design for arterial stents while taking a PhD at Oxford University[15]. The stents are folded in memory metal, so that when they are in place and exposed to body temperature they unfold from a tiny cylinder into a larger one, keeping the artery from collapsing. Yet this system does not seem to have been progressed from the model stage as stents following this design do not appear to have been produced.

The major reason why origami does not seem to be applied more widely in the design of everyday objects is because it is a more complicated process than it appears. Even though in theory it seems a good idea to make objects from a single sheet of material, and folding appears to be a simple production method, in practice machines that can do the folding are lacking. The combination of having to hold the material efficiently; going through the sequence of different steps to achieve a finished model with folding lines going in different directions; and the accuracy needed for a good result are almost impossible to request from a machine. A few basic origami machines exist[16], and a machine has been invented for the folding of a continuous sheet material into a miura-ori pattern at the scale of corrugated cardboard[17], but no machines are available yet to take on the folding of larger scale and more complicated folds. Since more complex shapes have to be folded by the hands of trained labourers they often become too expensive to be taken into large-scale production.

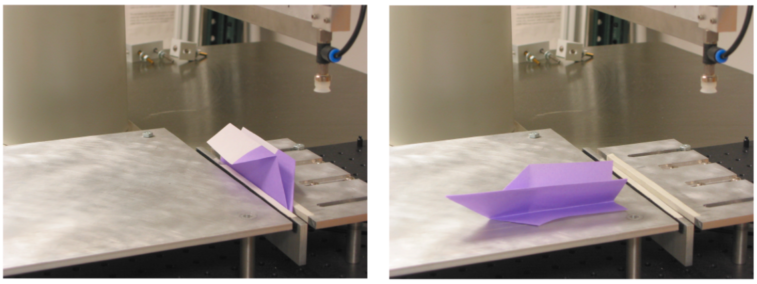


Figure 4.18: Robotic origami folding: the last steps of folding an airplane. The robot was developed at the Carnegie Mellon University, Pittsburgh, Pennsylvania in 2004.
(Balcom 2004 p.105)

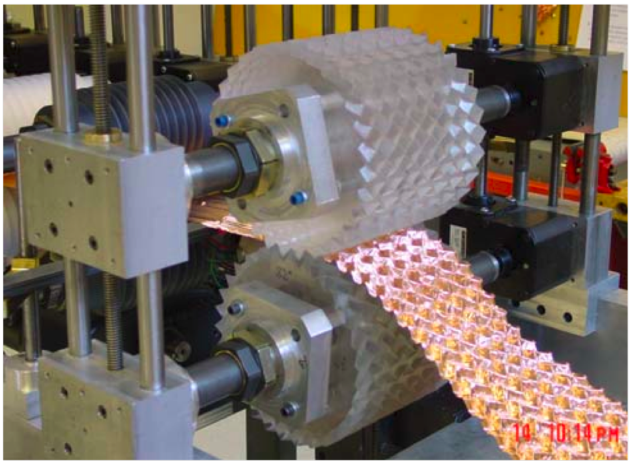


Figure 4.19: Image of a contiuous sheet folding machine, developed at the State University of New Jersey.
(Elsayed, E and Basily, B. 2008)

The limitations in the production of Tessellating origami objects do not mean that there is a lack of interest. There are many people intrigued by the shapes that can be created and by the many examples of Tessellating paper origami. Origami is used by artists, but is especially popular among mathematicians and scientists such as Alex Bateman, Chris Palmer, Dr Koryo Miura and Tom Hull, who enjoy studying the mathematical principles behind the folding in. Alex Bateman has even written a program, “Tess”, which anyone can use to design tessellating, folding patterns. There is a wealth of images, crease patterns and other information to be found on websites such as www.flickr.com, and a lively interaction between the users of those sites. Many variations on tessellating folding patterns are published, and even clothing is designed, but paper remains the only material used.

Figure 4.20: Paper dress, by Nathan Austin. Model: Emma Jaster, Photographer: Ariel Morales. The dress was made in 2009 for a short film, in which it is torn apart. (Chapman-Bell, 2009)

Figure 4.21: A laminated plywood-textile material by Tisch Decken that can be rolled up for storage and unrolled with the edges folded to turn into a table-top.
(Cigirac, S.,Herok, T., Klunker, S. [no date])

Origami patterns have found their way into art and design, but often remain at the stage of unique paper piece or prototype. Product designers, like scientists seem to have a difficulty in setting up the appropriate production lines. Maybe there is a gap here to fill by a crafts person?

The Practical Reality of Man-made Folding Structures

Man-made deployable structures are already available for a whole range of applications. Their construction often involves many different materials and it is a precise and sometimes complicated process. The advantages these structures offer are considered to be sufficient to make the effort worthwhile.

I do not think it is a coincidence that there have been so many new developments in folding structures as in recent years. In contemporary society we benefit from both a rapidly evolving technology, helping us to work out the intricate designs; and from the constant materialisation of innovative materials, allowing for the production of ever lighter and stronger constructions. We are constantly exposed to new, exciting materials, and have become so used to constant innovation that we desire to see new things as often as possible, even if their function is unclear. Deployable structures benefit from this attitude: they are popular because there is a certain attraction in the way they can magically change size and shape, seemingly without effort. So it seems to me that where deployable structures have already proven to be popular for decorative objects, the possibilities for functional objects will be almost limitless as soon as it is fully understood how they work and how they can be made efficiently.

Studying man-made folding structures has given me a vision of the various possibilities and more importantly has taught me how difficult it is to make the transition from idea or model to a finished product in suitable materials. This is shown by the divide between the implicated use for tensegrity structures and their actual applications and the limited amount of origami folded products that get into production. My desire for this research project was to bridge the gap between the promise of intricate paper models and the reality of applications available to the consumer. This meant I would have to understand the principles behind origami tessellations and the production techniques well enough for the application of MFT in “Wearable Metal Origami”.

5. Principles and Practicalities of Folding

Principles of Folding

Origami

The art of origami includes a wide range of models: from figurative models to cups and boxes, from modular geometric shapes to tessellating patterns.

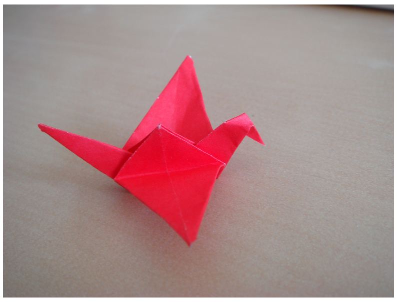


Figure 5.1: Figurative Origami, **Classical Crane**, folded by Tine De Ruysser

Figure 5.2 Figurative Origami, **Koi, opus 425**, Composed and Folded by Robert Lang, 2002, Size: 15" (Lang 2004)

Figure 5.3: abstract origami, **traditional cup and tray adjusted from traditional boat**, folded by Tine De Ruysser, 2004

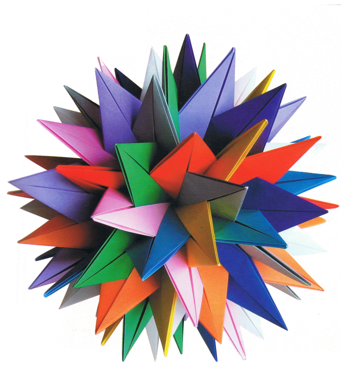


Figure 5.4: modular origami, (created from several sheets of paper, folded into identical modules), QRSTUVWXYZ, designed and folded by Meenakshi Mukhopadhay, (Robinson 2005, p.131)

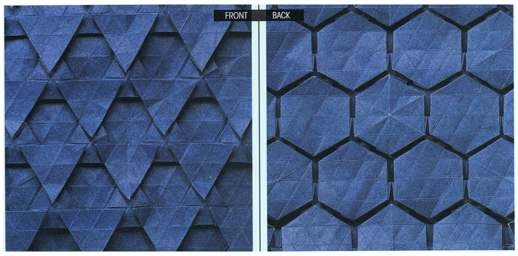


Figure 5.5: tessellating origami, front and back of stacked triangles by Eric Gjerde, (Gjerde 2009, p.83)

Origami is not only performed as a hobby or art form and used as a tool for teaching motorial skills, communication skills and geometry, but also as a model to understand the way organisms develop and grow. Consequently, it is studied and practiced by educators and mathematicians as well as scientists. In recent years conferences have been held and books published on the relationship between Origami and Science. Mathematicians and scientists such as Robert Lang have defined the principles behind folding, and some of this information is available in books or on the Internet. I do not claim to understand all the mathematics, but have gathered enough information to be able to construct my own tessellating folding patterns. I have achieved this by experimentation, by studying some of the mathematical principles and by examining and recreating existing models.

Definition of Origami

There are many different opinions on the definition of origami. The word itself is a combination of two Japanese words: Ori, meaning fold, and Kami, meaning paper. This is why origami is the 'art of paper folding'. Opinions vary on what can be included under this umbrella term.

The most constrained definition is the one that observes the basic rules of origami most strictly, which in simple terms permits folding a paper square, without cutting or the use of glue. There are 5 rules in this definition: 1, something is folded; 2, the material has to be paper; 3, the sheet has to be square; 4, one cannot further cut the paper to assist in the creation of the folded object; 5, one cannot use glue to keep the object in shape.

The broadest and most commonly used description of origami in fact discards four of these elements, but includes all objects that have some folding incorporated in their construction. In this sense the word origami is used as a catch-phrase to promote contemporary products.

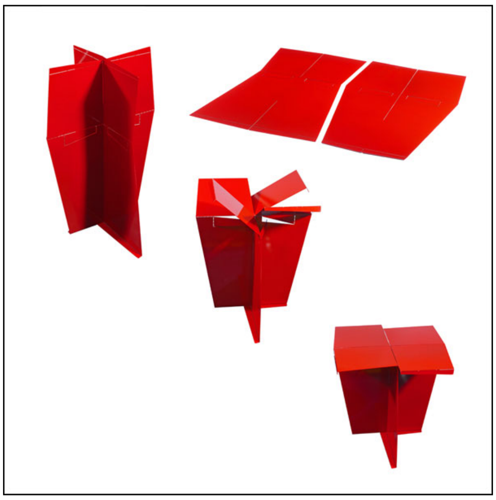


Figure 5.6: **Origami side table**, designed by Jaime Salm, Young Jin Chung (Mio [no date])

Figure 5.7: **Origami Dress** by Calvin Klein, Spring/Summer 2009, (Vriens 2009)

For the creation of “Wearable Metal Origami” I follow 2 out of the 5 rules of the constrained definition:

I obey rule 1: I fold.

I break rule 2: I make my models first in paper, but then divert into using textiles and metal.

I break rule 3: I rarely use a square sheet of material. For model making I use the paper that is to hand when I need it, often A4; when developing a folding pattern for an MFT application, I adapt the shape and size to fit the application.

I obey rule 4: even though I do sometimes pierce the sheet when turning it into an application, I do not make cuts to extend the folding possibilities.

I break rule 5: I use several ways of ensuring that a folded shape does not unfold if I don’t want it to, even though I use sewing and stringing rather than gluing.

For quite a while I was not comfortable with using the term origami for my work just because it only follows two rules. Somehow it seemed wrong to classify my work under “the art of paper folding” if I wasn’t even using paper. But in my opinion I am obeying the two most important rules and using the word origami conveys what I do best. This word seems to trigger understanding in people, they recognise the relationship between the paper models and “Wearable Metal Origami”. And I did start this whole project based on the principles of origami. The models that inspired me to create WMO followed four of the five rules (the only exception being that my paper was not always square). I had developed MFT to enable me to use the qualities of origami, but make it wearable and longer lasting. I had in fact made origami models wearable because I had made them in metal, in shapes adjusted to the body and with the use of constraints to keep them in shape. These adjustments were necessary to achieve the goal of wearability. I did not break the rules that I could obey by even when making this novel material. I decided that the connection was real enough, and titled my thesis as it is.

The “Origami” in “Wearable Metal Origami”

Origami encompasses a wide range folding patterns, including figurative models, modular models (created from several sheets of paper, folded into identical modules), abstract models and tessellating models.

For this research I limited myself to the use of origami folding patterns that allow for the creation of a large area of flexible material so that this material could be used to make adaptable pieces: the movement from flat sheet to folded model is at least as important as the folded model itself. Consequently, crease patterns for figurative origami or modular origami are excluded because they are designed to be static objects and do not have the necessary flexibility. The process is done step-by-step (folding one fold at a time), and there is no smooth movement from flat sheet to folded object. Abstract irregular shapes are excluded because even though some of them can be flexible, the pattern cannot be tessellated to create a large enough area. Additionally, it is not possible to classify them based on their folding behaviour in such a way that the classification can be used as a tool for the design of new pieces. The only patterns that do lend themselves to the creation of a large flexible material are tessellating origami patterns. I therefore limited myself to these for this project.

Learning how to fold tessellating patterns

My very first pattern (TDR1), designed at the Royal Academy of Fine Art in Antwerp, and developed into the first samples of MFT, consisted of parallel lines, were inspired by honeycombs and designed to create a three-dimensional hexagonal structure.

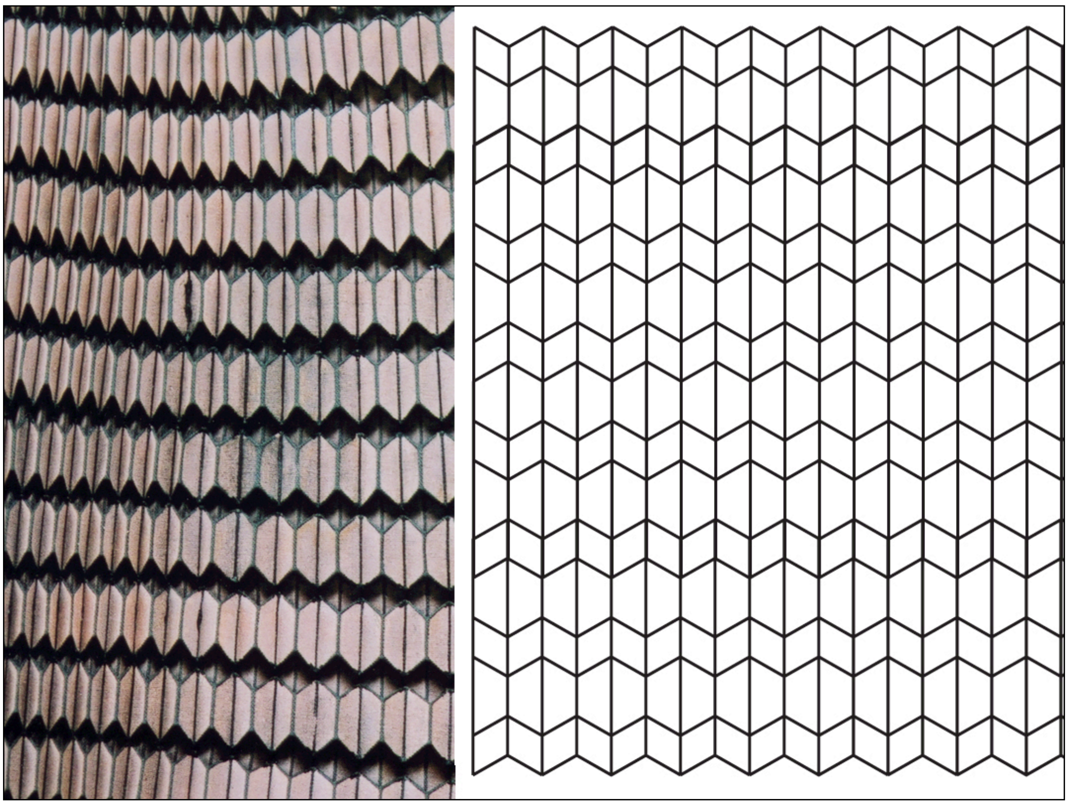


Figure 5.8: First pattern I designed, TDR1 (folded in MFT left, and folding pattern right)

I realised during my MA studies that I could adapt the pattern by making the long straight lines fan out from one point instead of having them run parallel.

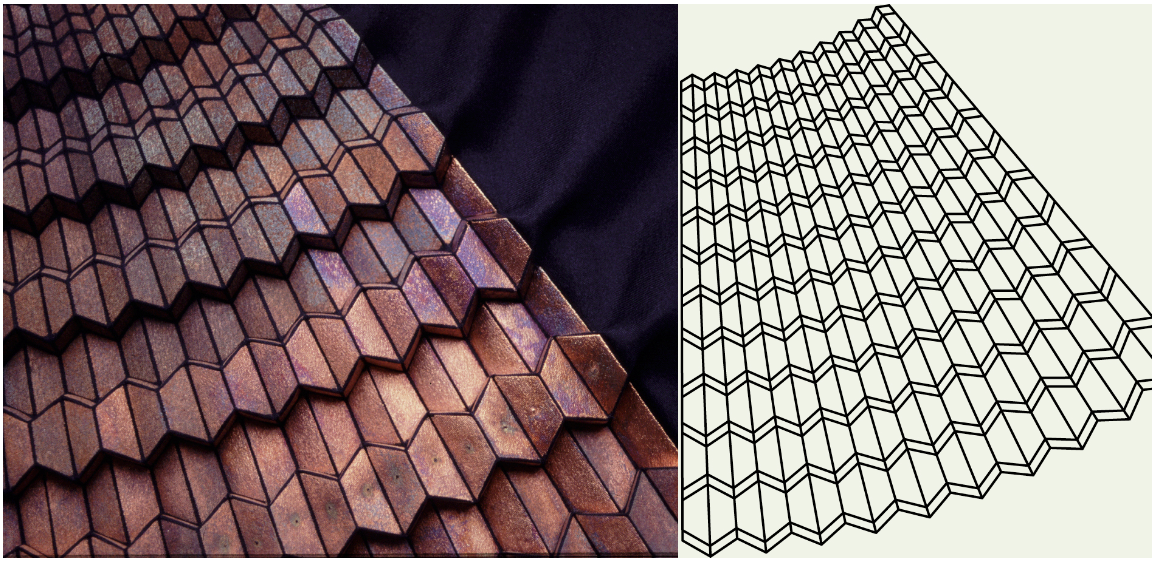


Figure 5.9: adaptation of first pattern, made during my MA. (Folded MFT sample left, and folding pattern right)

At the end of my MA course Prof. Julian Vincent showed me that my patterns were related to simple folds, derived from folding tree leaves. He folded two examples for me.

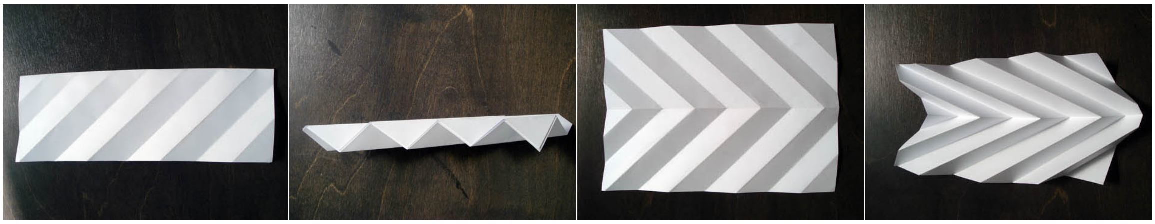


Figure 5.10: Different steps in folding a simple leaf-like pattern, resembling hornbeam leaves.

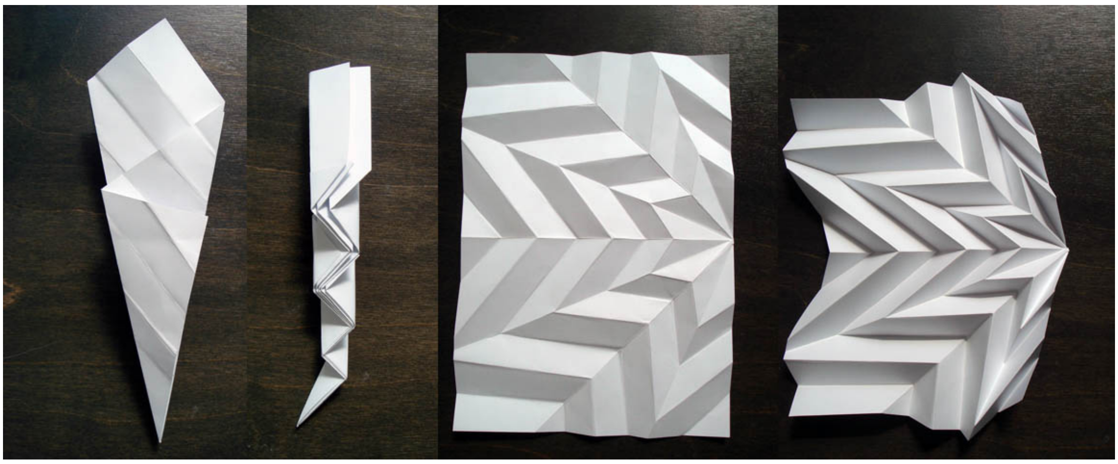


Figure 5.11: Different steps in folding a radial leaf-like pattern.

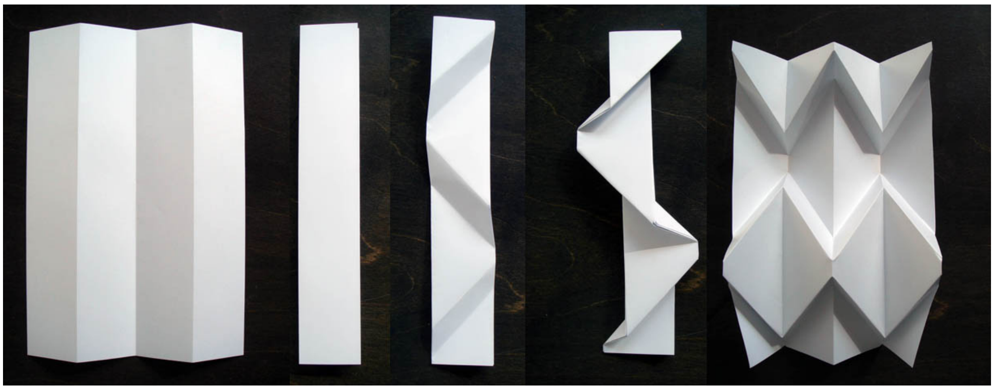


Figure 5.12: Different steps in which the TDR1 pattern can be reproduced by following similar steps as those for simple leaf and radial leaf.

These two examples made me realise that I could create a whole range of folding patterns by firstly folding the paper into an accordion along straight lines, from edge to edge, and then folding this strip into any shape I liked, unfolding it, and making the whole pattern into a multi-directional accordion.

Figure 5.13: Range of folding experiments, based on the technique explained in the previous figures.

There are limitations to the possibilities (the pattern has to be foldable, it is impossible to create a fold that would force the paper to penetrate itself), but this method allows for the design of a virtually infinite number of patterns. I used this method to design simple shapes for the creation of textile handbags and paper bowls.

Figure 5.14 White Bag by Tine De Ruysser, 2002, textile

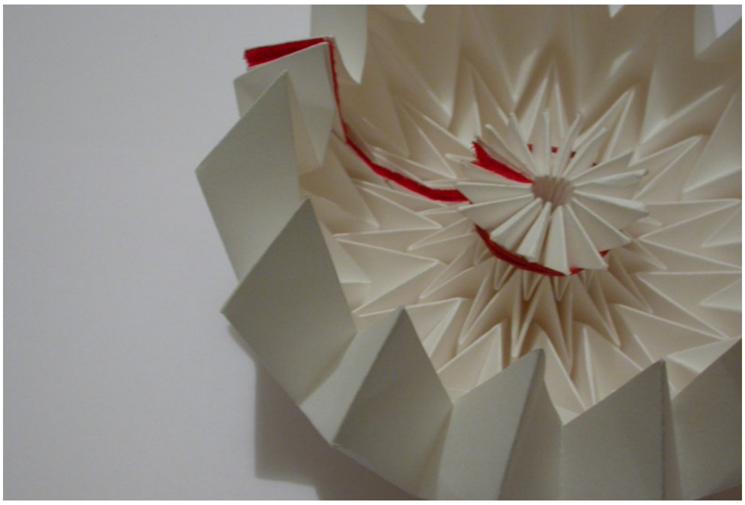


Figure 5.15 PliaBowl by Tine De Ruysser, 2004, paper and Velcro.

When I started my PhD, I began investigating other ways of designing tessellating folding patterns. I found many folding patterns on the Internet since this type of origami was at that time not to be found in origami books. I folded other people's designs if I could find the crease patterns and reconstructed those of which I could only find images of the folded piece. I also tried out the software "TESS" [1], created by Alex Bateman. All patterns were folded to see how they would fold and I created my own variation on the patterns using software such as Illustrator and Rhino. These variations were folded too.

Figure 5.16: A few examples of the folding patterns I made at the start of my PhD.

Origami Tessellations and Mathematics

Origami is closely linked with mathematics. The position of any folding line on the folded material can be described in a mathematical way, and mathematical rules are used to describe the constraints of foldable patterns. I presumed that this would be easily extended into defining mathematical rules for complete folding patterns. My aim was to find a set of equations that I would be able to use to design folded models with a specific form. I tried to work out how sides of platelets were related by trial and error, and consulted several mathematicians at the university of Bath, but none were able to help me generate a simple formula. A book about origami tessellations by Robert Lang was announced to appear in January 2010, but has not come out yet. My expectation is that when it does, it will contain some mathematical approaches to the creation of these patterns. Since the mathematics are not perfectly defined yet and also because the process of trial-and-error allows me to judge shape and proportions of the fold while I am working, I have decided to use the hands-on trial-and error process to my advantage rather than to spend my time trying to solve mathematical problems beyond my capability.

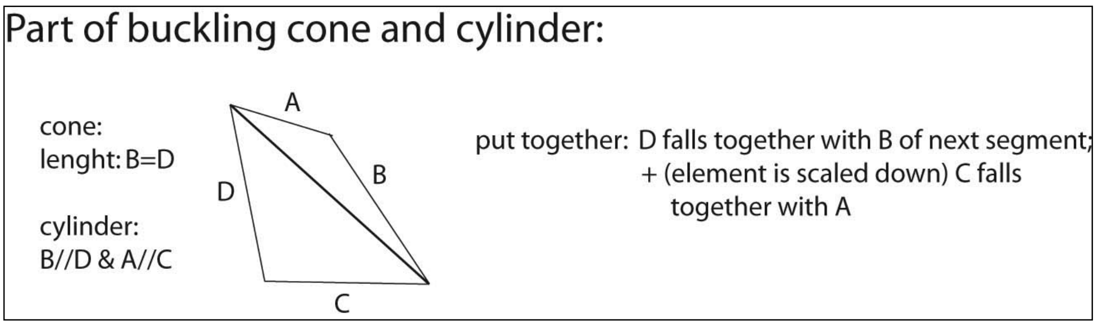


Figure 5.17: Attempt at defining one unit of a tubular pattern in mathematical terms.

Origami Tessellations and computer software

In the years that I have been working on this project there have been developments in the generation of software for origami. At the beginning, only TreeMaker from Robert Lang[2] (a programme for the generation of folding patterns for figurative models) and Tess from Alex Bateman (for the generation of tessellating folding patterns) were available. I never used Treemaker because it is not suitable for the design of tessellating patterns. I did successfully use Tess to generate some tessellating patterns. I find it very restricted in the options it gives for changing the different factors but it was very useful to learn how a tessellating patterns are constructed. Two years into my project, in February 2007, Tomohiro Tachi[3] published the results of a program he was developing - the Rigid Origami Simulator. It showed the folding process for a given folding pattern, going through the full movement from folding pattern to folded model. In October it became available for downloading. My colleague David Turtle tried it out for the simulation of folding structures for the DAS team project. I never tried it myself because it is of no real use to me: I am interested in the flexibility of the semi-folded model as much as the movement from flat to folded, and this is not demonstrated in the Rigid Origami Simulator. I prefer to fold a model in paper and feel the movement. Where the software especially available for origami has limited use for me, I do regularly use the technical drawing programme Rhino, both to design folding patterns and to generate accurate artwork for the creation of models and MFT.

Adapting folding patterns for Metallised Folding Textiles

Now I had a range of folding paper samples of tessellating patterns, but not all of them were useful for the creation of MFT. Because the metal platelets of MFT are rigid the patterns have to follow the rules of rigid origami to be practicable. All tessellating patterns that rely on the flexibility of their platelets for their movement cannot be used for MFT unless they are adapted in such a way that the platelets can remain rigid. Sometimes this can be done by dividing a platelet into smaller platelets.

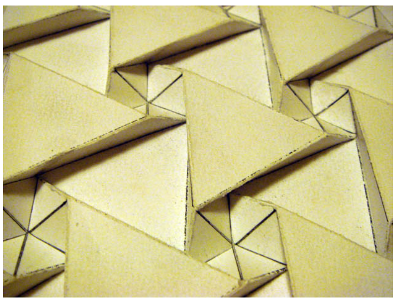


Figure 5.18: Hexagonal platelets are divided into smaller platelets to allow the pattern to be folded in MFT. In paper this is not necessary since the hexagons could flex through the folding process.

Sometimes inserting extra hinges will not work because the platelets need to curl up around each other to make the pattern fold. In this case I classify the pattern as unsuitable for MFT.

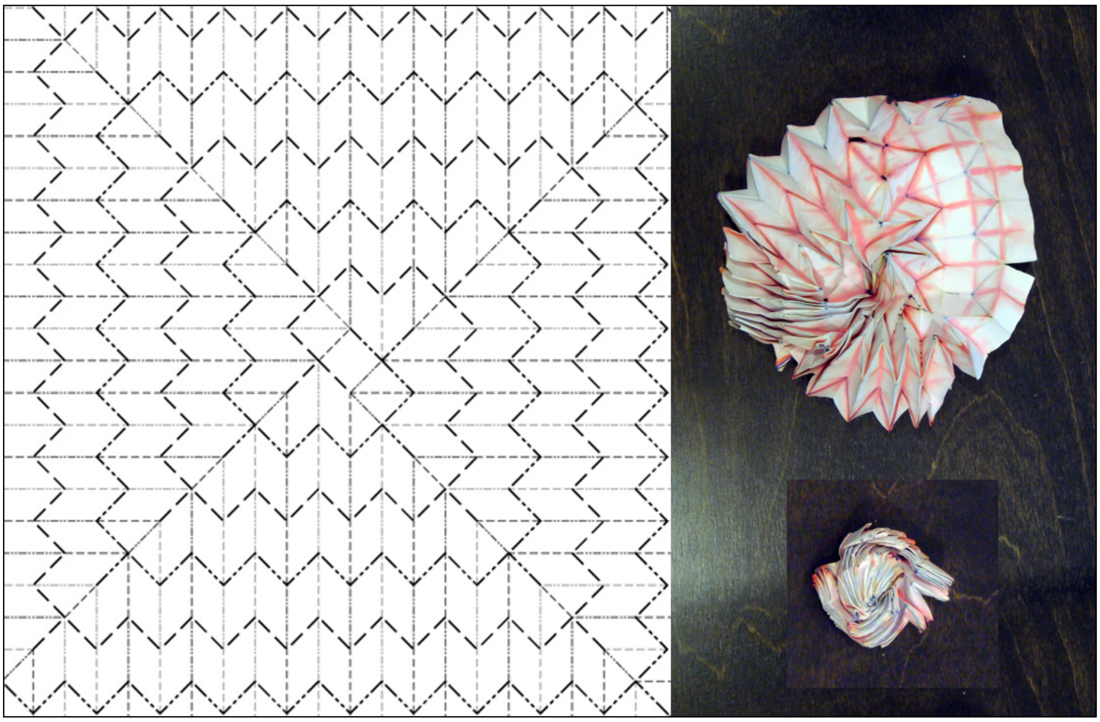


Figure 5.19: Flasher pattern, designed by Jeremy Shafer (Shafer [no date]). This pattern can only be folded if the platelets curl up around the centre. MFT platelets cannot curl like this.

A working classification

Even though I have chosen to use only tessellating folding patterns that follow the rules of rigid origami for the reason stated above, there are still uncountable variations possible. Each individual pattern has a specific way of moving and produces a specific folded model. For each pattern I need to know what those are so that I can choose the most suitable pattern for any specific application. Both movement and finished model depend on the folding pattern. It is consequently vital to understand as much as possible about the principles of origami and specifically about origami tessellations.

This is why I have created my own classification system, not unlike a family tree, to identify all the different patterns and how they behave. I have included the detailed version of my classification system as an appendix, and will give a step-by-step explanation of its structure here.

In my classification, the main distinction is that between accordion patterns, tubular patterns, plateau patterns and planar patterns.

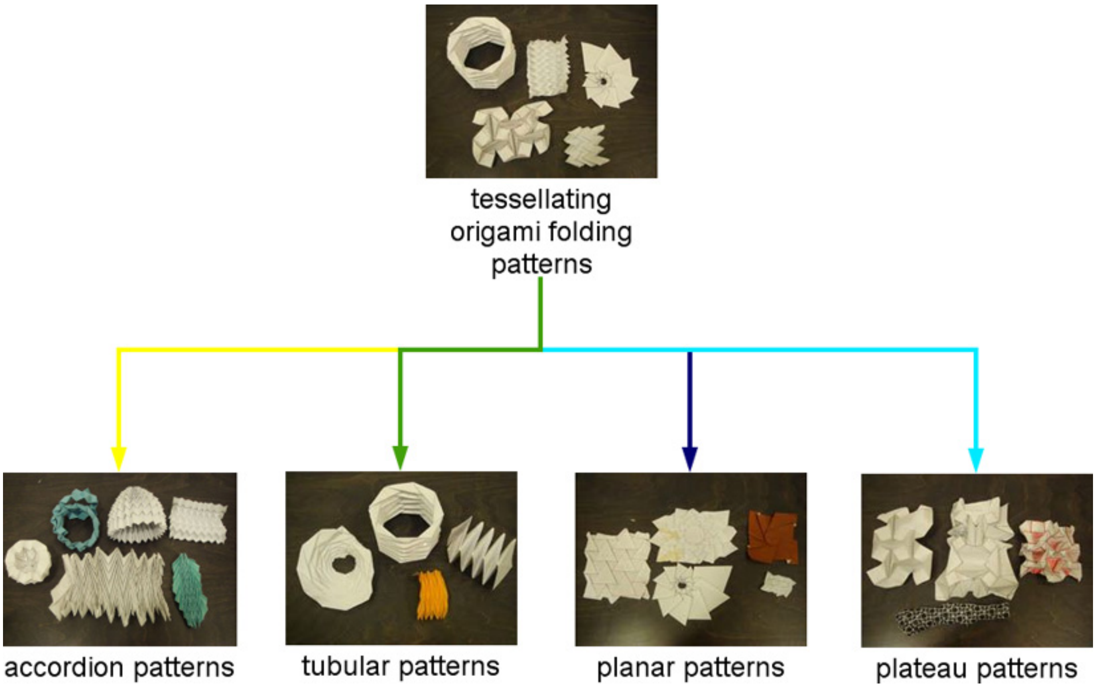


Figure 5.20: Tessellating origami folding patterns can be divided in four groups.

The groups are not always clearly divided from each other, there are folding patterns that can be classified under two groups. I did consider using a Venn diagram instead of a family tree because it shows better that the groups overlap.

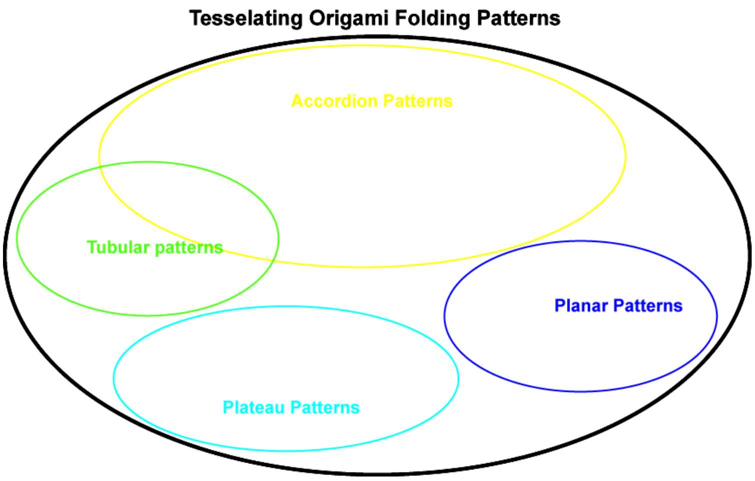


Figure 5.21: The four groups of origami folding patterns overlap.

However, a Venn diagram does not allow for easy distinction between patterns within each group. In a family tree I can more easily show how exactly patterns are related by showing which characteristics they have in common and which are different.

My classification is made on the appearance of the folded model and on how the material moves from the folding pattern to the folded model. Yet the descriptions on the tree are based on the folding pattern because this is the clearest way of defining them: it is hard to distinguish between two folded models with minor differences, but their folding patterns show differences in angles and size of platelets more easily.

Accordion models

These behave like an accordion: the simplest would be a row of parallel folding lines, equal distances apart, alternating valley and mountain folds. All accordion folds have a set of long straight lines running through them, often from one edge of the paper to another, dividing it into strips (see figs. 5.10, 5.11 and 5.12). They are most useful for objects that need extreme size-change or great flexibility.

This group can be subdivided in different subcategories. I will describe the different steps as grades (°), following the example of Ray Schamp[4]. The first subcategory is whether the straight lines of the 1st grade (1°) that create a simple accordion when folded are parallel or not, and if they are not parallel, whether they all fan out from a single point, or from several points.

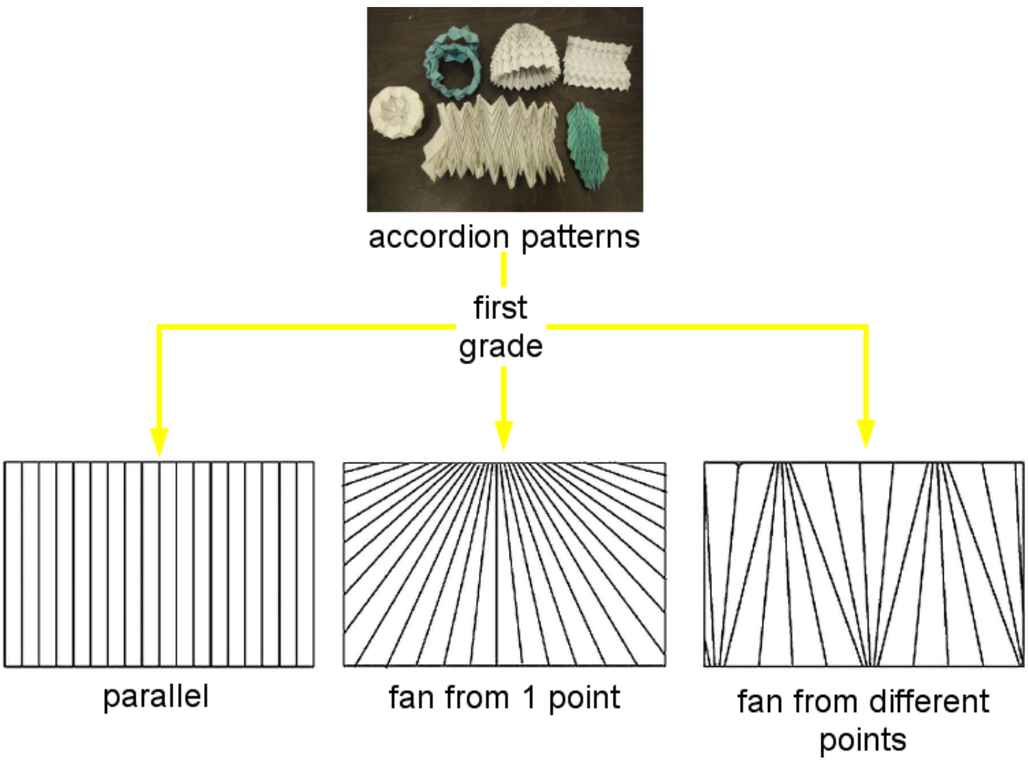


Figure 5.22: First distinction in accordion folding patterns: the first grade. Folding lines can be parallel (left); fan out from a single point (middle); fan out from different points (right); or any combination of those.

The 2nd grade (2°) fold lines form zigzag patterns perpendicular to the 1°. The angles around each vertex have to comply with a simple mathematical rule: the angle with which the zigzag line reaches the straight line on one side has to be equal to the angle on the other side of that straight line.

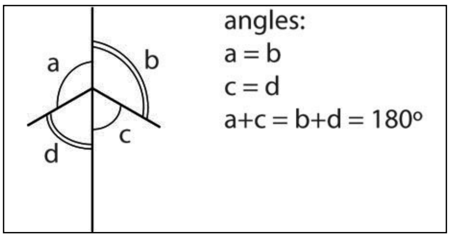


Figure 5.23: The relationship of angles around each vertex in an accordion pattern.

This can easily be achieved by folding paper along the folding lines of 1°, then folding the resulting multi-layered strip of paper at a chosen angle. When the paper is unfolded, the zigzag line becomes visible, with the angles around each vertex following the rule described above.

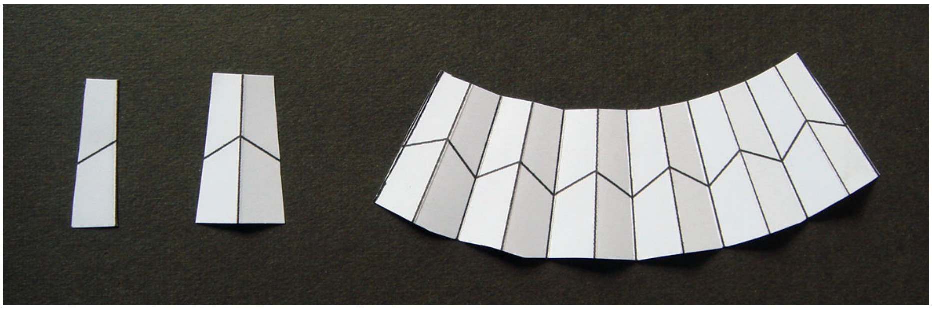


Figure 5.24: Achieving the correct relationship between angles when folding a piece of paper.

These 2° lines can, when looked at like this strip of paper, all tilt up or all tilt down, or there can be a combination: some lines tilting up, others tilting down. If all lines tilt up, or all tilt down, this results in zigzag lines all pointing in the same direction in the full pattern when followed along 1 line of 1°. If there is a combination of lines tilting up and down then the zigzag lines in the full pattern will point in opposing directions.

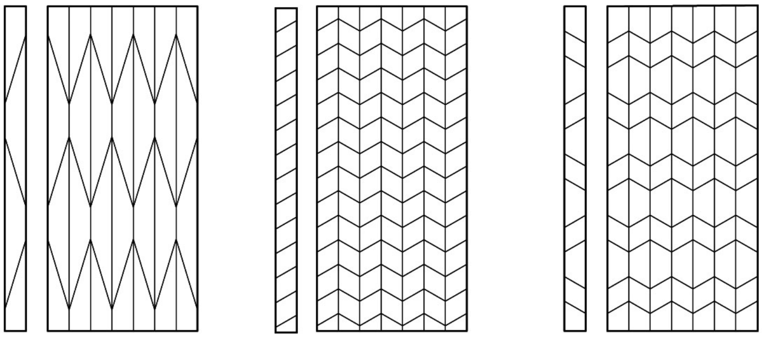


Figure 5.25: The direction of the 2º lines on a single strip of the folding pattern determines whether the zigzag lines will be pointing in the same direction or not.

When adding the 2º folding lines to the different patterns achieved after the first grade, each pattern can be folded in one of three ways: the zigzag lines all point in the same direction; two neighbouring zigzag lines always point in opposite directions, or a combination of those two.

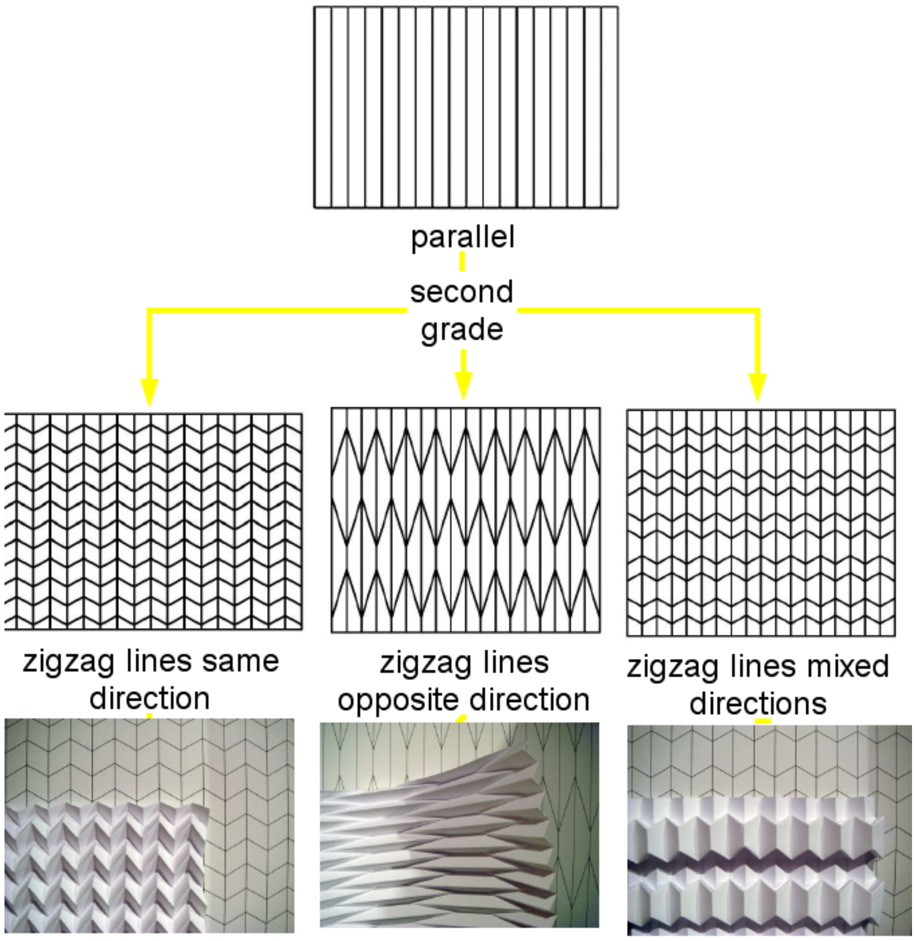


Figure 5.26: Folding lines of the second degree: different options for parallel lines in the first grade.

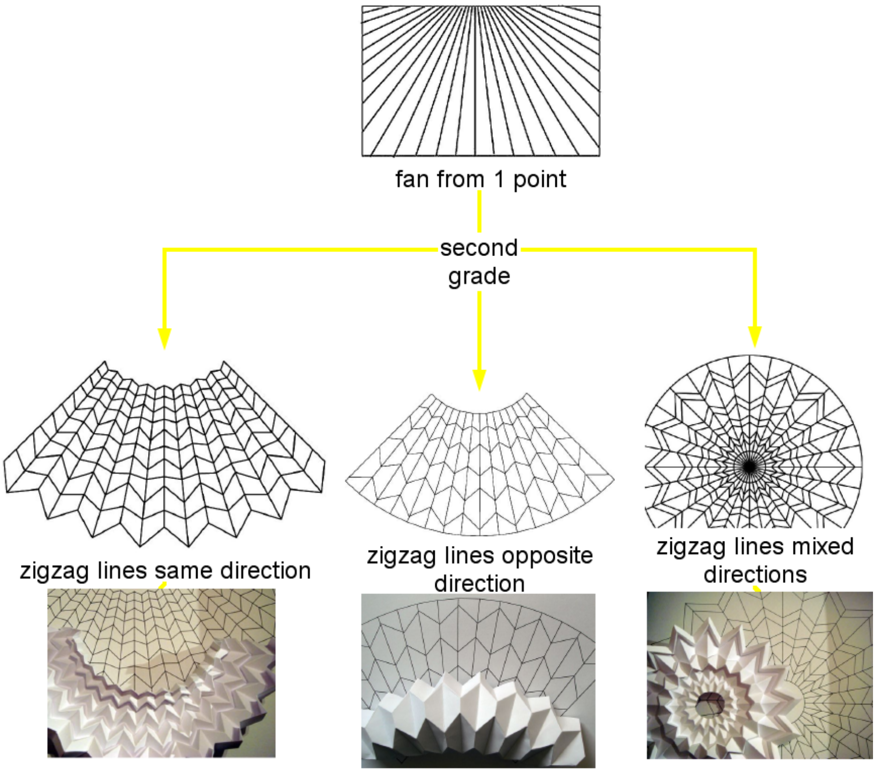


Figure 5.27: Folding lines of the second degree: different options for lines in the first degree fanning out from one point.

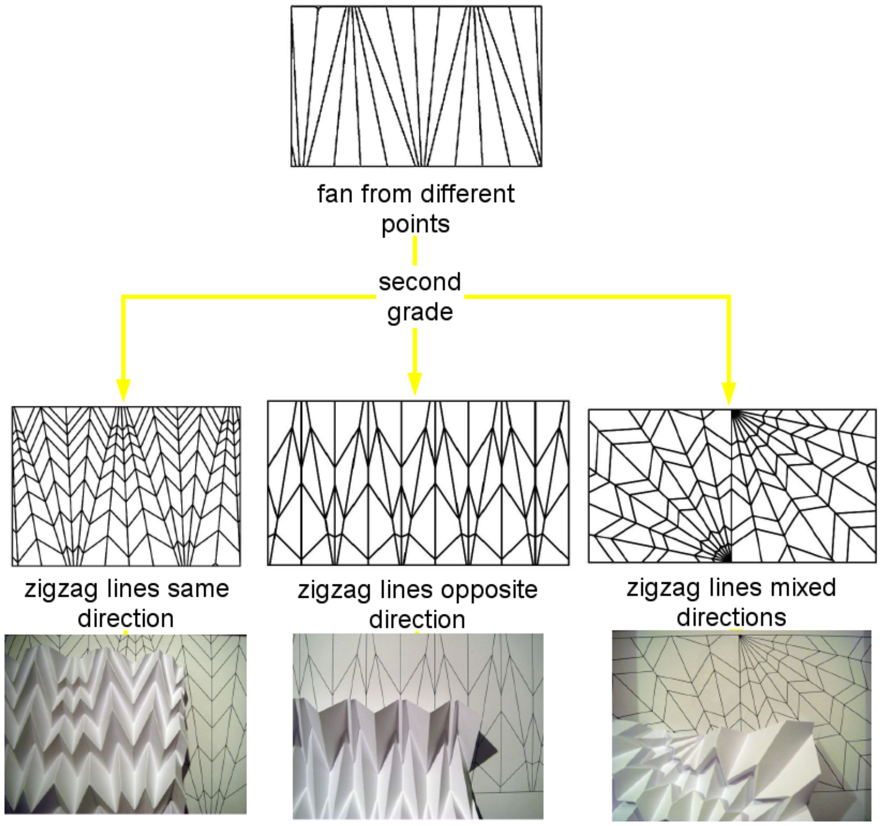


Figure 5.28: Folding lines of the second degree: different options for lines in the first degree fanning out from different points.

Tubular models

This group of patterns distinguishes itself from the others in that the two sides of the paper are fixed together to form a tube in both unfolded and folded form. The tube can be cylindrical or conical in shape. These patterns are most useful if I want to make a tubular object collapse into a shape with roughly the same circumference but diminished height, or if I want to create a tubular object from a flat sheet.

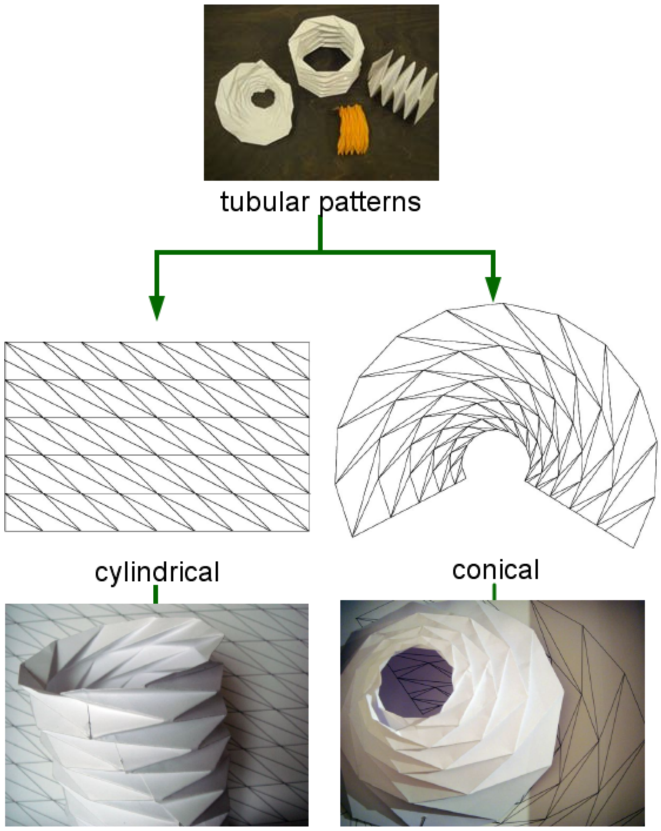


Figure 5.29: Tubular patterns can be divided in cylindrical and conical patterns

Cylindrical tubular patterns are a subgroup of accordion patterns, with parallel folding lines in the first degree. This can clearly be seen in the following figure.

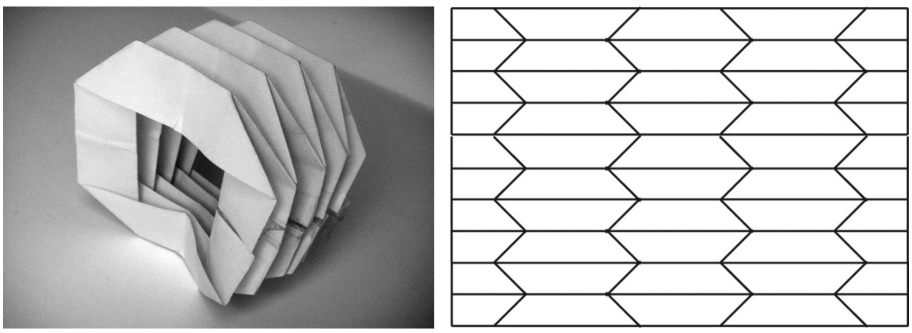


Figure 5.30: This folding pattern is both a tubular pattern (it forms a closed cylinder) and an accordion pattern (parallel lines in first grade, opposing zig-zag lines in second grade).

Planar models

This group consists of tessellations of clearly recognisable geometric forms, fitting together like Arabic decorations. They are true flat foldable patterns: the models fold flat into a plane. This group is subdivided depending on whether the tessellated units are all of the same size, or increase in size as they rotate around a centre to form concentric circles or a spiral pattern. Planar models are useful if I want to decrease the plane of visible area when the object is folded, without creating too much thickness. Unlike the other groups of patterns, they do not curve flexibly when in folded state.

The angles around each vertex in a planar model have to comply with the following mathematical rule: alternate angles have to add up to 180º.

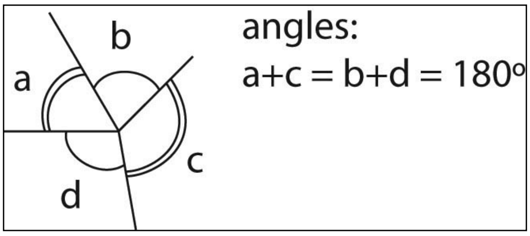


Figure 5.31: The relationship of angles around each vertex in a planar pattern.

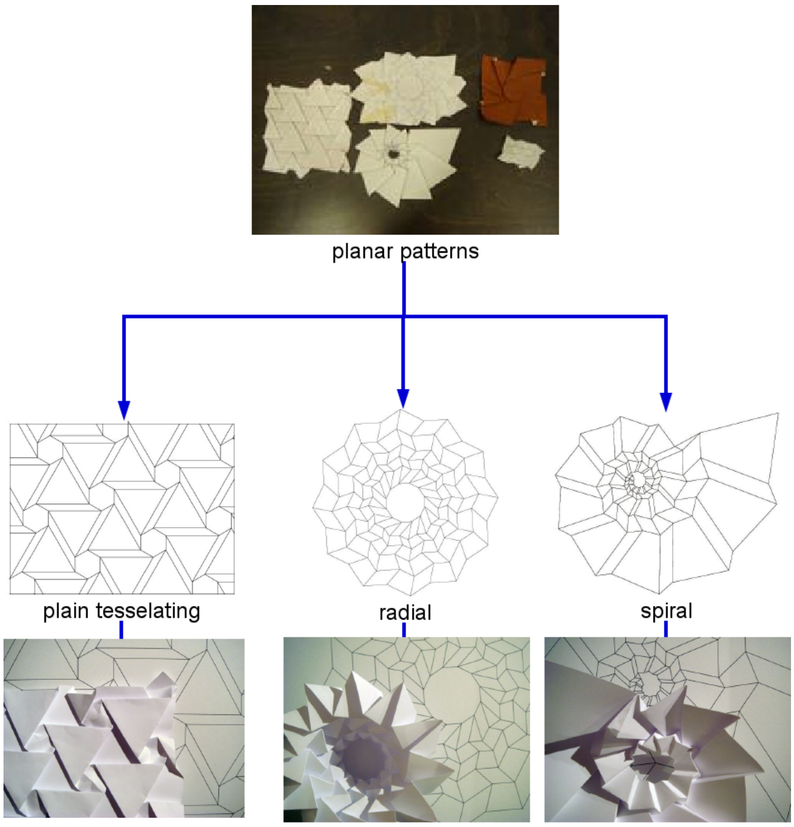


Figure 5.32: Planar patterns come in three variations: they can be plain tessellations, radiate from a centre or take the shape of a spiral.

Plateau models

This group resembles the Planar models since they are also constructed of tessellating units of geometric forms. They are not flat foldable but have platelets (plateaus) that rise up to higher, or sink to a lower plane while the platelets in between form walls perpendicular to the plateaus. This way a sort of box is created by each of the units, explaining why in literature these patterns are often called Boxy patterns. The subdivision is determined by the behaviour of the platelets that form the plateaus in the fold. These can all rotate in the same direction while being folded, or alternating in opposite directions. Plateau folds create visual depth and the empty spaces inside the boxes can be used to set stones without hindering the folding.

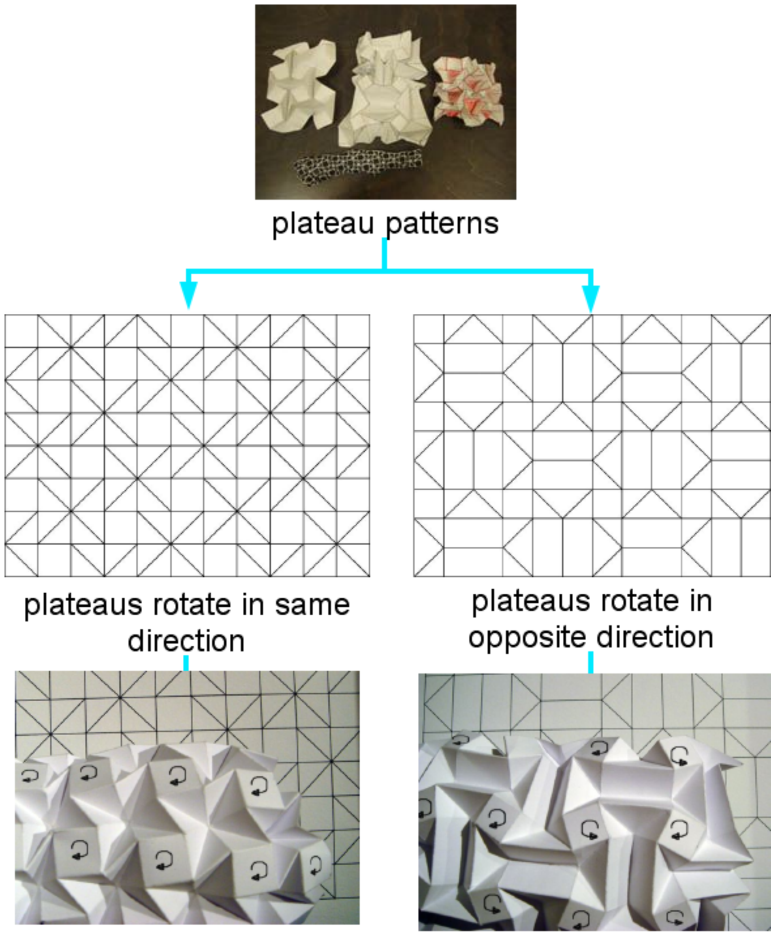


Figure 5.33: Plateau patterns can be divided into two groups, depending on the direction of rotation of the plateau-platelets.

A growing family tree

Many examples of all folding patterns can be found on the Internet, especially on Flickr, where a group named “origami tessellations” [5] is active. New folds appear there at a greater speed then I could possibly make them myself. I can now often see from a single image how its pattern is constructed, and how it is likely to move because I can compare it with the patterns I have folded and classified in my family tree.

My family tree also allows me to quickly find a pattern I need for a specific application because I know what form it should be and how it should move, and can find a pattern in the Tree that behaves more or less like the one I need. Then I only have to adjust it, to make it behave exactly as I want. This still involves some trial-and-error.

As more folding patterns are created both by others and me, I keep on discovering new aspects and relationships. The family tree described here is not a final version; it will be adapted as my understanding of the behaviour of folding patterns deepens.

Model Making

The rules of origami are a useful starting point for designing MFT, but they are not enough.

Even though paper origami and MFT seem to behave in exactly the same way, this is not really true. MFT is different from paper origami: paper is so thin it is virtually two-dimensional and paper folding lines can be creased so sharp that they have enough stiffness to remain folded even when the folded pattern is lifted up in one corner with its full weight hanging from that point. MFT on the other hand has platelets of a greater thickness, and the width of the textile hinges has to be sufficient to allow the material to fold.

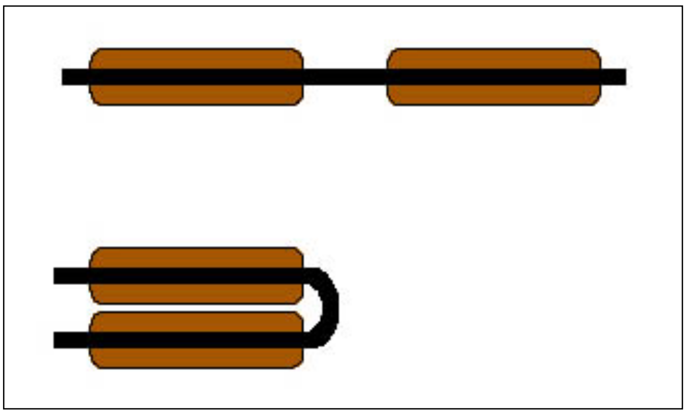


Figure 5.34: hinge width necessary between two platelets to enable folding of MFT.

Textile folds also have less tension, and need to carry the greater weight of metal platelets. MFT consequently unfolds much more easily under the effect of gravity than folded paper. Additionally, the unfolded areas of the folding pattern, or the ‘paper platelets’ are fairly flexible and can bend to accommodate for local deformation in the paper under tension during the folding process, whereas metal platelets are rigid and will obstruct the folding process if there is any such tension. Consequently certain patterns that can be folded in paper are impossible to fold in MFT without adjustments. In this case extra hinges have to be added: they can accommodate a necessary flexibility in the platelet during the folding process, and will go back to flat once the model is folded. This is important because it is the stages in between the flat material and the folded-up material that are important to create the flexible, shape-changing pieces for this project. The last difference between paper origami and MFT is the possibility for adjusting the folding pattern. In paper the pattern can be adjusted while it is being folded: a folding line can be moved if necessary because the whole sheet of paper is foldable. MFT does not allow for such last-minute corrections. If a folding line has been put in the wrong place it cannot be moved to a different position anymore because the metal platelets prevent this.

When all these seemingly minor differences between paper origami and MFT are added up, it becomes clear that I cannot rely on paper models alone to predict whether a pattern will be suitable for the creation of MFT. On the other hand, the process of making MFT is a long and complicated process, and I need to know with reasonable certainty whether a pattern will be successful or not before I start making a metallised piece. I have therefore found it necessary to adopt other ways of testing the patterns. These alternative processes have to incorporate the thickness of the platelets, their greater stiffness than that of paper, and the textile hinges. The models made with these processes have been useful for testing the optimal width of the hinges, the foldability of the patterns and the effect of gravity on the material.

I found new ways to make models and tried out several processes and materials. None of them behaves in exactly the same way as MFT, but some come close. They are all based on the same principle: the paper origami folding pattern is used as a basic drawing; the folding lines are offset on both sides with the thickness of the chosen material for the platelets plus a little extra as a safety margin. The original folding lines are then removed, the outlines of the platelets as they have to be cut remain, all properly spaced apart.

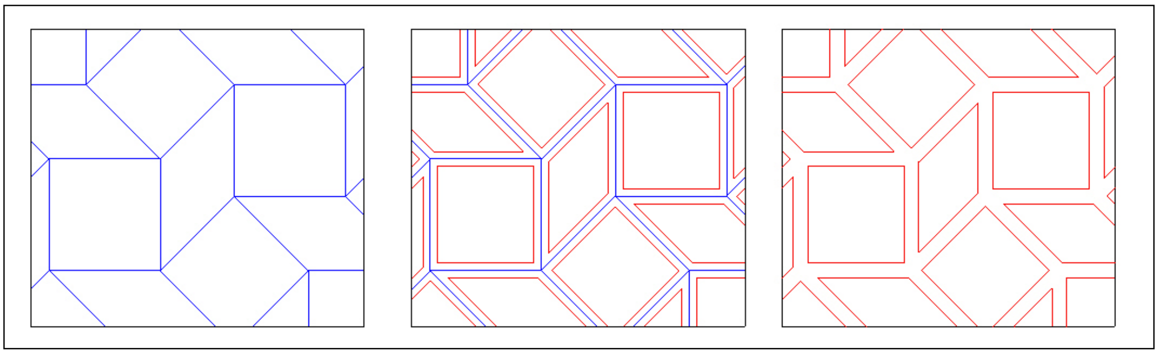


Figure 5.35: Adapting folding pattern (left) to cutting pattern for model making (right) by offsetting the folding lines (middle).

The platelets are then cut out in a chosen material along these outlines, using a vinyl cutter or laser cutter. With the help of a self-adhesive transfer foil that keeps them all in place the platelets are then transferred and bonded onto the textile substrate. The details of cutting, transferring and gluing differ from method to method, as described below.

Iron-on and self-adhesive vinyl platelets

For my first trials I cut ‘Canson iron-on T-shirt Transfer’ on the vinyl cutter, weeded (removed) the hinges from the backing sheet, laid the backing sheet carrying the platelets on the fabric, and fixed them in place by putting the whole in a heat press for 10 seconds at 180ºC. The resulting platelets were not stiff enough when the vinyl was single-sided. Lining up the platelets on front and back was a complicated process, and the resulting platelets were still not stiff enough to make it worth the effort.

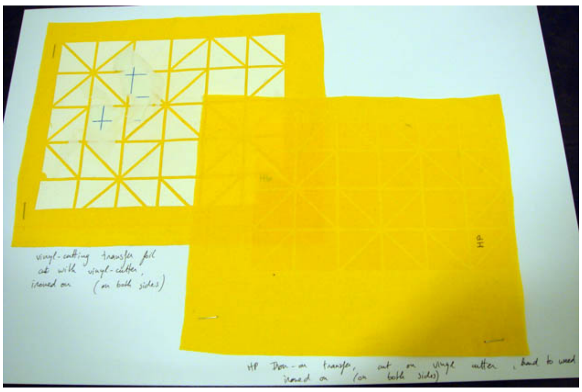


Figure 5.36: Testing iron-on vinyl on fabric.

The next set of tests was to stick plain self-adhesive vinyl onto textile. This provided a little more stiffness, but still not enough. Additionally, the vinyl did not have the correct glue to remain bonded to the fabric, so it peeled off while I was trying to fold it. Consequently I abandoned this method.

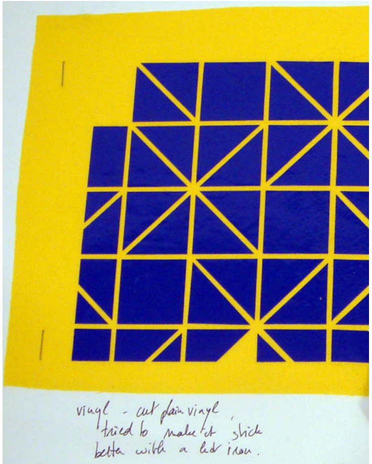


Figure 5.37: testing plain vinyl platelets on fabric.

The above methods were tested first because they were uncomplicated: only vinyl cutting was necessary, and some weeding, before the material could be adhered to the fabric in 1 or 2 simple steps. But since the results were very disappointing it became clear that a different method had to be found. Whereas I will not use plain vinyl for model making anymore, I can see the application of iron-on vinyl as a decorative element to be used alongside MFT.

I realised that I would need to use a material with greater stiffness than vinyl to make the platelets, even though this would make the model making process more complicated.

Stencilled platelets

I cut a grid of hinges from vinyl and used it as a stencil to paint different materials onto fabric. I tested varnish, synthetic enamel, emulsion paint, blackboard paint and PVA. None of these provided enough stiffness, and most of them bled through into the hinges, giving an untidy result.

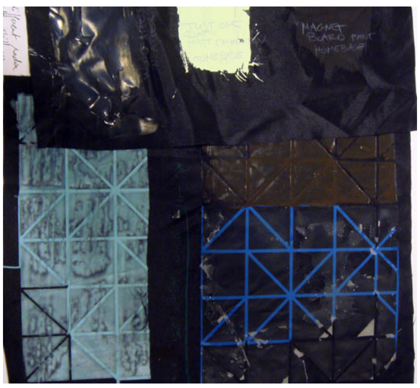


Figure 5.38: applying glue, varnish, paint and enamel through a stencil.

I then tried Devcon Titanium Putty. Because of its thick consistency, it had to be applied in a thicker layer, so I used a card stencil instead of a vinyl one. The resulting platelets were stiff, but quite brittle. Furthermore, because I had to remove the card stencil when the paste was still wet to make sure it would not be permanently fixed to the fabric, the edges became untidy and protruded higher than the rest of the platelets. This made it impossible to properly fold the material. I had to scale the pattern up to accommodate for the thicker platelets, and the fabric hinges were not strong enough to remain folded under the weight of the large platelets.

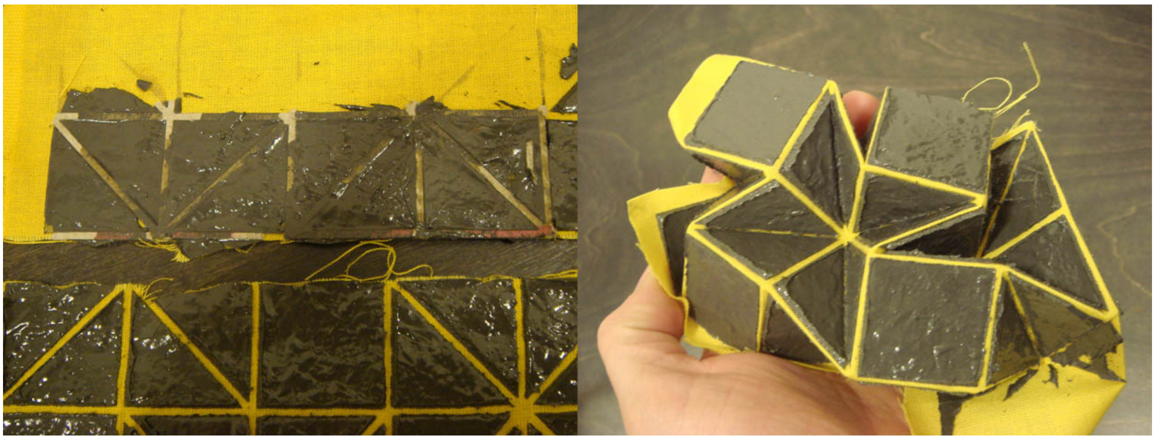


Figure 5.39: The application of Titanium Putty through a stencil, and the resulting model when folded.

Since none of these tests gave satisfactory results I decided to move on to a different approach.

Card and plywood platelets

The next option was to cut platelets from card on the laser cutter, and glue them to the textile. I tested a few different types of glue. Liquid glues were found unsuitable because I could not easily apply them to all the little pieces without the glue leaking into the gaps for the hinges, or the pieces getting stuck to the brush or roller that I used for applying the glue. Glues with a short drying-time dried before I had applied them to the whole pattern, and slow-drying glues dried so slowly that individual platelets would slide out of position before the glue had set. Spray-on glue was impractical because it also covered the edge of the card and parts of the transfer-foil underneath, making sticky stains on the textile hinges. In the end, the only glue that proved to be practical was iron-on glue. I tried different brands (HeatnBond, Steam-a-Seam2, and Bondaweb) and found HeatnBond Ultra to give the best results. I use it in my heat press at 150ºC for 10 seconds.

The pattern of platelets was cut by laser out of card that I had previously covered with a layer of heat-sensitive glue on one side. The aim was to get the platelets all cut out, lying on the laser cutter bed in their correct alignment and spacing, so that I could lift them all out with the aid of a self-adhesive transfer foil. The first trial did not work well: most of the little platelets had been blown all over the laser cutter bed by the air stream inside the machine and puzzling them back into the right position was a tedious job. I learned that I could reduce this problem by removing the funnel from the laser cutter nozzle and reduce the strength of the air stream.

The next difficulty was the transfer foil. This foil is commercially available. It is designed to transfer vinyl from its backing sheet to the surface it will be applied to. The adhesive is relatively weak, and will easily peel off after the vinyl has been stuck down. It is not designed to carry the weight of thicker sheets of paper or light card. It is consequently tricky to get all the pieces from the laser cutter to a table without them dropping off the transfer foil. If handled carefully, around 95% of the pieces will remain in place, so that I only have to reposition the few parts that have fallen off. Another disadvantage of the transfer foil is that it is not designed for use in a heat press: it is made from a plastic that distorts when heated. This means that the pieces can move slightly when heat is applied to glue the platelets to the fabric; consequently the finished sample will not be as accurate as the cut-out. I hoped to find a better way of transferring the platelets, using a heat resistant, non-distorting material with a stronger adhesive so that less platelets would fall off, and they would not move in the heat press. I tried repositionable photo mount on a cardboard or paper backing. Sadly, the photo mount became permanent under the influence of the heat, and I could not get the cardboard or paper to become unstuck from the platelets or the fabric. I attempted to find a heat-resistant transfer foil, but could not find one that was large enough/ strong enough. In the end I had to settle for the regular transfer foil and compensate for the possible sliding of platelets in the heat press by making the hinges 30% wider.

After various tests I settled on the process that works best for making a card or plywood and textile model: A sheet of card or plywood has a layer of heat-sensitive glue (HeatnBond Ultra) applied to one side by putting it in the heat press at 150ºC for 5 seconds. This material is then put in the laser cutter, with the glue facing up. The pattern of platelets is cut out with a minimum airflow to reduce the number of platelets being blown out of place. Any dislocated pieces are taken away. A piece of transfer foil is laid over the top of the whole sheet and smoothed down. The whole is then removed from the cutter, and laid upside-down on a table (sticky side of the transfer foil up, with the card or veneer on top). The dislocated pieces are put back in their correct position, and the raster of hinges is removed. A second transfer sheet is laid down, so that it sticks to the side of the card or plywood that has not been treated with HeatnBond Ultra. The whole pack (two layers of transfer sheet, and the platelets in between) is turned upside down again, so that the transfer foil stuck to the HeatnBond Ultra can gently be removed. A piece of textile substrate is laid out flat next to the heat press, and the platelets on their backing sheet are laid onto this fabric, with the glue side down. They are kept in place with a little tape or transfer foil around the sides. The whole is slid into the heat press, and pressed together at 150ºC for 10 seconds. When the heat press is opened, the fabric is removed and after cooling the transfer foil is peeled away. The sample or model is now finished. I tried using a wood veneer in the same way. I could apply it by using the same processes, but the resulting model was very fragile because the platelets cracked along the wood grain. Thin plywood (0.4 mm thick, triple-layered) proved to be a good alternative.

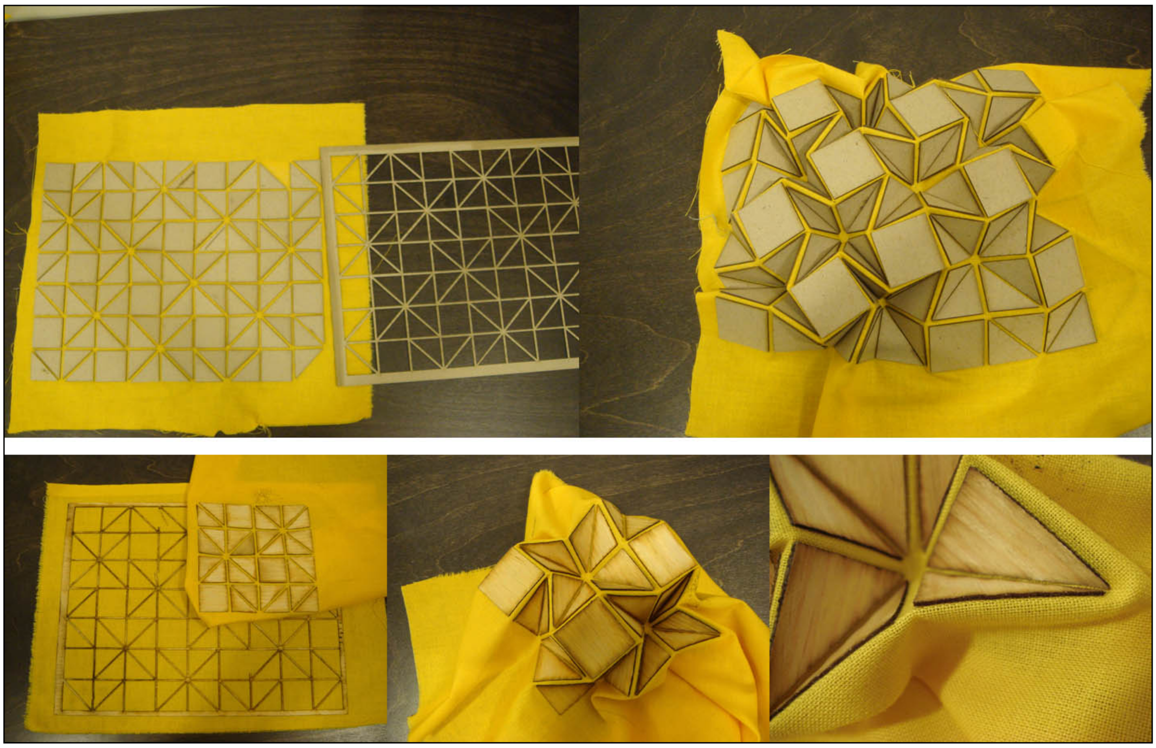


Figure 5.40: samples made from laser-cut card (top) and veneer (bottom), applied to fabric with heat-setting glue.

A variation on the above method is used when I want to create a model larger than the size of sheet material that is available. In this case I will split the complete pattern in smaller parts, and for each part cut out the platelets as above from a separate sheet, each group is stuck down on transfer foil, ready to be laid on the fabric. All these parts are lined up with the use of a separately cut stencil of the area where they meet. When the groups are accurately aligned, they are kept in position with transfer foil and the stencil is removed. The heat press is then used to fix all platelets to a fabric backing.

Iron-on flock

After developing the method for making a card-on-textile model I discovered iron-on flock that could be cut on the vinyl cutter. This flock can be cut on the vinyl cutter with a special knife, more suitable for cutting a thicker material, weeded and pressed straight onto the fabric in the heat press for 20 seconds at 175ºC. This method does not require the use of transfer foil because the backing layer of the flock serves as such. The disadvantage of this method is that it is not suitable for small platelets because the vinyl cutter cannot cut sharp angles in such a thick material. Straight lines also tend to become slightly wavy near the corners. This is not a problem for medium to large patterns. The flock platelets are a lot thicker than those of MFT, and more flexible, so I found that it is not the best way of modelling complex patterns for MFT. It works better for simple patterns, and on thin fabrics. Still, I really like the models as beautiful pieces in their own right and see this method as the possible beginning of a new project: making an entirely textile folding material.

Tabbed platelets

When I wanted to make a trial of a pattern with fine detail, none of the above methods were suitable. Small platelets blow away more easily in the laser cutter and are more difficult to reposition. In discussions with my colleagues we came up with another approach. In this case, the platelets are connected at every vertex by a tab.

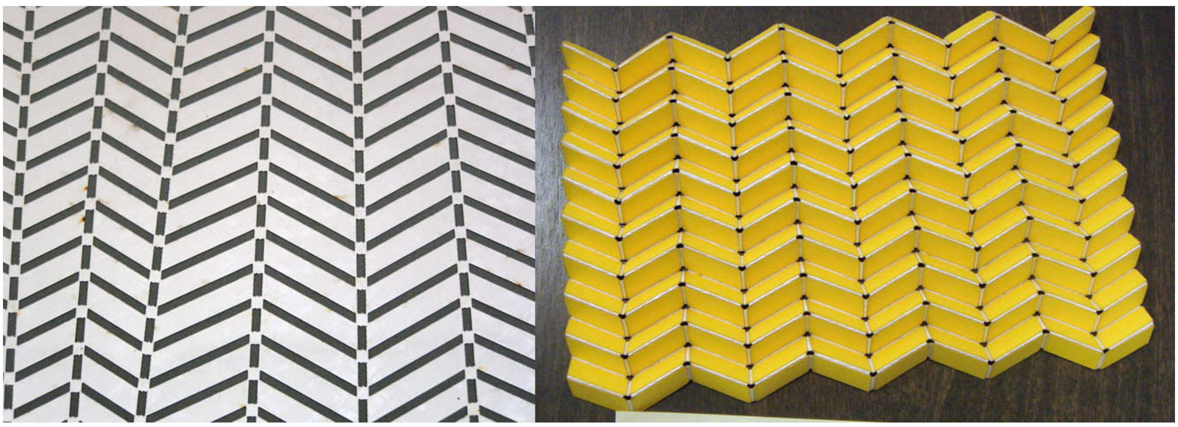


Figure 5.41: Creating a model with tabbed platelets: the hinges are cut away while tabs keep the platelets in place (left); finished model, with holes through the material where the tabs were (right).

This means that, after cutting the pattern out of a sheet of card pre-treated with heat-setting glue, they are all still connected as one big sheet, with only the hinges falling out. This sheet is then glued onto a thin TYVEK™ sheet, and replaced in the vinyl cutter. The tabs at the vertices are then cut away; creating a sheet that will fold like MFT, but has perforations at all its vertices. So even though it is an efficient method to see how a pattern will fold, it has a completely different visual effect: the holes become an additional visual element. Again, the material made by this model-making process seems to be worth following up as a method for making objects in its own right.

I tried to find a way to use this method without the holes. The first method I tried started with cutting the card, leaving all platelets connected with tabs. The heat-setting glue was applied after the cutting, at 130ºC for just 5 seconds. This way the partly cut out card platelets were given a backing of a continuous sheet of glue. The backing sheet of the glue was removed, and the glue and card sheet was put in the laser cutter to cut the card tabs away. The platelets were now kept in place only by the glue layer bridging the hinges. This sheet was laid glue-side down onto fabric, and put back in the heat press at a higher temperature. The model now had no holes through the substrate, but because the glue extended over the hinges it stiffened the fabric there to such an extent that it was not flexible enough for accurate folding. I then tried to use the method as first described, applying the glue before cutting away the hinges, but applying plywood to TYVEK™. If I initially used a low temperature (5 seconds at 130ºC) for temporarily fixing the whole sheet of platelets-connected-by-tabs to the TYVEK™ and then folded this sheet along the hinges, I could break the tabs at their connection point with the platelets and completely remove them by peeling them off the TYVEK™. When they had all been removed I put the sheet back in the heat press at a high temperature (10 seconds at 150ºC), permanently fixing the platelets in place. This process was not as successful on a textile backing because the glue had a much better grip on the fibres and as a result the tabs were not removed so easily.

Summary on model-making

The whole process of finding a good way of model making turned out to be a major part of my research. It took a lot of time to find appropriate methods, but I found it worth while because in the final stages of designing it saved me time: I was able to make models in less time and at a smaller cost than it would have taken to make pieces directly in MFT.

None of the model making methods is perfect, but each has advantages. Some are quick-and-easy, others are more accurate. So even though there is not one way of perfect testing, there are different methods that have their use for different purposes, as can be seen in the table on fig.Figure 5.42. I found that for a quick result, where accuracy does not matter and the pattern is simple, iron-on flock is very useful. When I need a more accurate result and I can spend a little more time, I will choose for plywood or card on fabric or thin TYVEK^{TM}.

Although I looked at the process of model making as a functional process rather than a way of creating visually pleasing objects, some of these have in my opinion become very beautiful in their own right. In the future, I intend to follow up the methods of plywood platelets, iron-on flock and tabbed platelets, and develop them into materials in their own right.

Model making techniques	time spent	ease of application	stiffness of platelets	Quality hinges	one-or two-sided	easy to fold?	keeping its shape	decorative effect
Vinyl cut Iron-on transfer	Quick	Difficult to weed, heat-applied: 10 seconds at 180ºC	Platelets not stiff enough	Good	Works slightly better when applied 2-sided	**no**, not enough difference between stifness textile and platelets	non-applicable	Drawings and colours could be printed before cutting
Vinyl cut plain vinyl	Quick	Easy: only weeding, transferring with transfer foil	Platelets not stiff enough	Good	one-sided	**no**, not enough difference between stifness textile and	non-applicable	
Vinyl mask Painted with varnish or paint	Medium: both weeding and applying varnish	Messy and vinyl has to be weeded.	Platelets not stiff enough	Bad: laquer bleeds	one-sided	**no**, not enough difference between stifness textile and platelets	Tends to fall flat again	Messy
Cardboard mask filled with Devcon Titanium Putty	Medium: drying time Putty	Messy to apply putty	Platelets too thick and brittle	Bad: Protruding edges	one-sided	**yes**	Tends to fall flat again	Messy
Laser-cut Paper, transferred with transfer foil, applied with HeatnBond Ultra, 150ºC for 10 seconds	Medium: many steps	Difficult to prevent paper from blowing away in laser cutter, or falling off the transfer foil, two steps of transfer foil needed	Good	Good	can be one-sided or two-sided	**yes**	Good	Easy to change colour by selecting colour
Laser-cut Cardboard transferred with transfer foil, applied with HeatnBond Ultra, 150ºC for 10 seconds	Medium: many steps	Difficult to prevent card from falling off the transfer foill, two steps of transfer foil needed	Good	Good	one-sided	**yes**	Very heavy platelets, tends to fall flat again	Looks a little rough (texture cardboard)
Laser cut Iron-on Veneer, transferred with transfer foil 150ºC for 10 seconds	Medium: many steps	Platelets blow away while cutting, difficult to prevent platelets from falling off the transfer foil, two steps of transfer foil needed	Breaks too easily	Good	one-sided	**yes**	Good	Looks a little rough, with breaking
Iron-on Flock 20 seconds at 175ºC	Quick	Easy to use: only weeding and heat-glueing needed	flexible, only useful on thin fabrics	Good	one-sided	**yes**, provided the fabric is thin enough	Good, heat-setting can be used to keep shape better	Colour choice possible, textile effect
Laser-cut Card applied with HeatnBond Ultra, tabs removed before glueing, 150ºC for 10 seconds	Medium: many steps, laser cutting needed twice	Platelets blow away while cutting, difficult to prevent platelets from falling off the transfer foil, card has to be placed back in lasercutter accurately.	Good	Bad: hinges too stiff from glue	one-sided	**No,** hinges too stiff	Good	Glue across hinges is messy
Laser-cut Card applied with HeatnBond Ultra, tabs removed after glueing, 150ºC for 10 seconds	Medium: many steps, laser cutting needed twice	Easy, card has to be placed back in lasercutter accurately.	Good	Good	one-sided	**yes**	Good	Holes provide extra effect
Laser cut plywood, applied with HeatnBond Ultra to textile, tabs removed after glueing, 150ºC for 10 seconds	Medium: many steps, tabs need to be removed by hand	Works well	Good	Good	can be one-sided or two-sided	**yes**	Good	The grain of the wood can be kept continuous

Figure 5.42: Chart comparing the different model making techniques

Conclusion on folding for “Wearable Metal Origami”

The long process of learning about the principles behind origami tessellations and those involved in creating models with thicker platelets has been a useful part of this research.

Learning the principles behind origami tessellations has allowed me to develop a wide range of folding patterns that I can use for the creation of “Wearable Metal Origami”, given me an understanding of how they deploy and taught me methods to create my own custom-made patterns for specific applications, or how to adapt existing ones. The development of this knowledge has been supported by studying existing patterns and basic origami rules, the experience of generating computer drawings of patterns and folding those drawings in paper, freehand paper folding, and classifying the patterns into families.

I have learned how to use models to test individual patterns for their suitability and will be able to use them to during the design process, making it faster and more accurate.

I have not reached the limits yet, and as I keep on using the principles and practical methods described in this chapter in the future, I will keep on learning more about folding patterns, develop new ones and become better at adapting them to their application in “Wearable Metal Origami”.

6. Production of Metallised Folding Textiles

Improving the production processes necessary to make Metallised Folding Textile (MFT) was an important part of creating “Wearable Metal Origami”. These processes revolve around the preparation of the fabric for electroforming, or preproduction; the electroforming itself, where metal is deposited on the fabric; and the postproduction, where the material is cleaned up, folded, and prepared for use in a design. The most complicated part is the preproduction, where I was hoping to find a single reliable method that I could easily use each time I wanted to make “Wearable Metal Origami”. I learned about the electroforming process through practice and tested a range of processes and technologies for both preproduction and postproduction on their suitability for making MFT in a studio environment.

Introduction to electroforming

Electroforming lies at the base of MFT: I learned about this process first, and then realised I could use it for the creation of MFT. It is a simple process. It is almost identical to the plating process, where objects are given a silver, gold, chrome or other metal finish. They are both electrodeposition processes, where a metal layer is deposited onto an object by suspending it in a chemical solution and passing an electric current through it. The only real difference between the two is the thickness of the layer: Where the layer is extremely thin for plating onto an object (5 to 25 microns)[1], electroforming is used for creating a thicker layer that becomes a self-supportive object when it is removed from the mould[2].

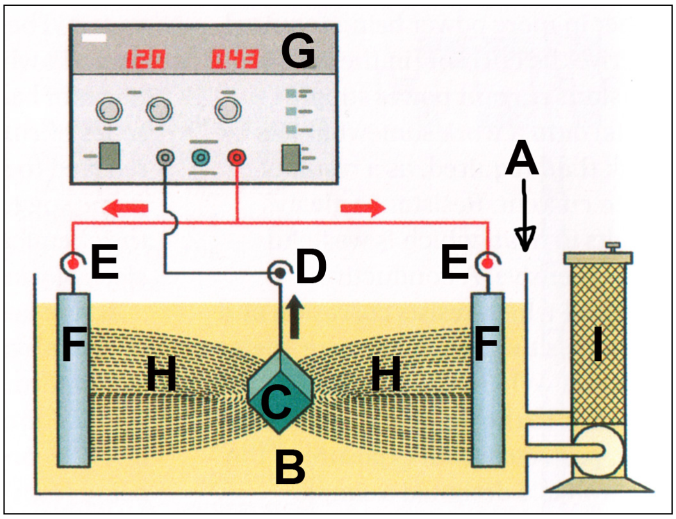


Figure 6.1: The basic set-up for electroforming. (Curtis, 2004, p. 48)

The basic set-up for electroforming

Tank (A): a waterproof and acid-proof container, containing the **Solution (B)** (an acidic or cyanide-based liquid, containing dissolved metal-particles as metal salts).

Object to be plated (C): has to be conductive, or have conductive top-layer, so that the electric current can pass through. Where there is no current on the surface, there will be no metal build-up.

Cathode bar (D): This bar is positioned above the solution, and connected to the negative pole of the rectifier. The object to be plated is suspended from this bar.

Anode bars (E): These bars are also positioned above the solution, but connected to the positive pole of the rectifier. The **Anodes (F)** are suspended from these bars.

Rectifier (G): provides a one-way electrical current, moving **Metal Particles (H)** from the anodes (metal objects, often made of the metal that will be deposited in the electroforming process) through the solution until they are deposited onto the object to be plated.

Pump (I): Is used to filter the solution.

In the electroforming process any conductive surfaces that are connected to the cathode bar will receive a metal layer, any non-conductive surface will remain bare.

Strictly speaking, the term electroforming is only used for objects that were built up through this process, and have then been separated from the object (or mould) they were formed on. But when textile is used as the initial object it is left in place and the resulting object is generally still referred to as having been electroformed.

This knowledge about electroforming was the basis on which the technical development of preproduction, production and post-production was started.

Preproduction Processes

Preparing the fabric for electroforming involves treating the fabric to make it locally conductive and non-conductive to create respectively platelets and hinges, attaching the cathode-wires, and keep the fabric taut and flat in the tank.

Previous knowledge

During my MA I had already gained some experience in how to make MFT. I had found one workable method, but it was a labour-intensive and time-consuming one. There were still quite a few unresolved problems, and this was my chance to find solutions.

Methods

My knowledge at the start of this project consisted of the tests I had carried out during my MA. I had tried out three methods: the first was to make the whole surface of a non-conductive fabric conductive by spraying it with conductive paint (water based copper paint), electroforming the whole surface and then etching away lines to allow for folding. This gave an unsatisfying result: the fabric had been stretched onto a frame to keep it flat but it was not flat enough to apply a clear image for photo etching. Additionally, the metal layer was not of a consistent thickness, having built up more near the edges, which meant that in the central areas the metal was etched away more quickly. In these areas the etching liquid penetrated the fabric and attacked the platelets from underneath, making them peel off the fabric.

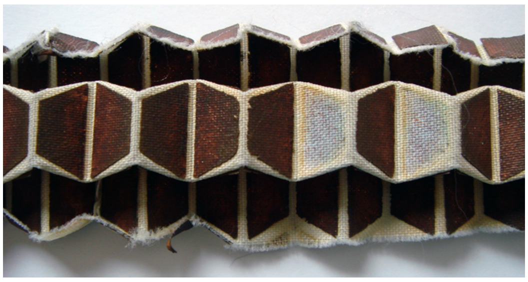


Figure 6.2: Sample of MFT with etched hinges: platelets peel off.

The next method I tried was to make the whole of the surface of the non-conductive fabric conductive as in the first method, and then to apply a medium such as wax, permanent marker pen or Lacomit™ to stop metal from building up in the places where I wanted hinges. I found out that wax and Lacomit™ worked as stop-offs, but the permanent marker pen was unsuitable: it had not prevented the copper from building up. Worse was that the copper platelets peeled of the fabric on both sides. The metal layers just had not adhered to the fabric at all. This could be a consequence of the conductive ink having been applied too thickly so that it would be the paint peeling off the fabric, taking the metal platelet with it.

Figure 6.3: Sample of fabric made conductive with dag, and hinges stopped off with wax and marker pen.

I then changed the process completely: I decided to leave the fabric non-conductive where I wanted hinges and only to apply conductive ink to the areas that I wanted to metallise (the platelets). I sourced screen-printable conductive ink, consisting of silver particles in a resin medium. But I realised that if the platelets were unconnected there would be no current going through them, and consequently no metal would be deposited. I added little tabs, connecting each platelet with at least two of its neighbours, in such a way that they were all part of one electric circuit. This allowed for metal build-up on all platelets but would also have metal building up on the tabs, and that would make folding of the hinges difficult. Even though the tabs could be bent, the metal would break with repeated flexing, creating sharp burrs that would damage the fabric and would be unpleasant to the touch. To prevent this from happening each tab had to be covered with an isolating layer, preventing metal build-up while allowing for the current to pass from one platelet to the next through the tab underneath the stop-off layer. Applying this stop-off layer was done by hand because it had to be done on both sides of the fabric, and I could not think of a way to line up accurate printing on the front and back.

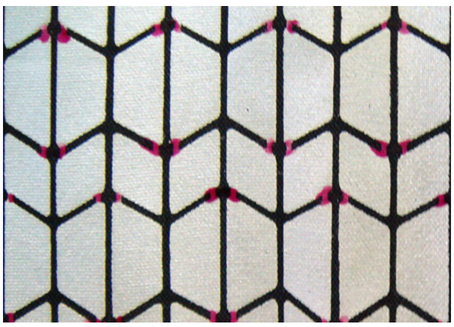


Figure 6.4: Pattern for electroforming: separate platelets printed in conductive ink, connected with tabs which are stopped-off with lacomit.

Even though this method was laborious, it was successful and I used it for my final collection.

I was not convinced that this process was the best way of making MFT. Not only was it time consuming and labour intensive, it also caused slight deformation in the platelets. I had done the printing at the Textiles department, on their screen-printing tables, so the fabric had not been stretched on a frame beforehand. For the electroforming process however, it did have to be kept flat and stretching it onto a frame after printing proved to be impossible. I could not stretch the fabric on a four-sided frame because this distorted the printed pattern. I had consequently chosen to clamp the fabric along the top and bottom only, onto separate rails. I suspended the top rail from the cathode bar and hung a weight from the bottom rail so that the fabric would be kept taut under the influence of gravity.

Figure 6.5: Clamping fabric at top and bottom to immerse in solution.

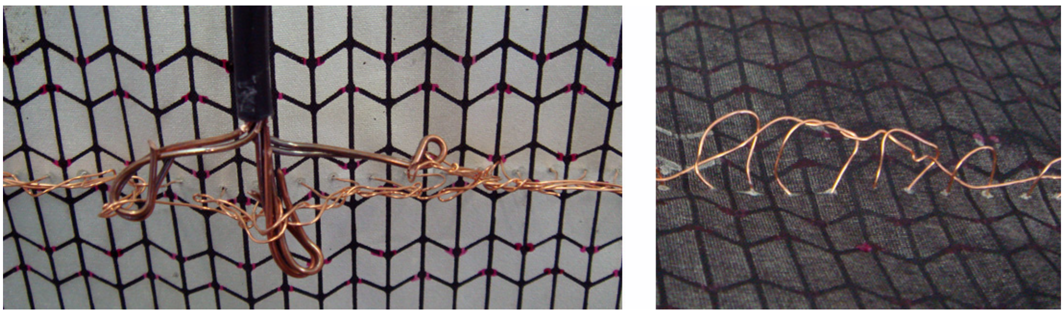


Figure 6.6: The connection of the printed pattern to the electric circuit was made by threading a copper wire through rows of platelets.

This kept the fabric reasonably flat, but the fabric soaked up a little of the solution when it was immersed in the tank, making it stretch a little. In the vertical direction this was not a problem: the weight at the bottom pulled the fabric taut again. In the horizontal direction there was no such force and the platelets curled up slightly. This sometimes prevented the hinges from folding. Another disadvantage of this method is that because I had attached the conductive pattern to the electrical circuit of the tank by threading a copper wire through rows of platelets, all the platelets in these rows had a hole. These holes were not immediately visible because I had placed them in platelets that were partly hidden, but I would be better if they were not there at all.

Materials

Near the end of my MA I had discovered the existence of conductive fabrics. Those are normally used as shielding material, to protect sensitive material or people against radiation and static electricity. The only materials I could find at that time were polyester fabrics with a mesh of carbon fibres running through it, or nickel-plated textiles. The fabrics with a carbon fibre mesh were not suitable for use because the copper would only build up around the mesh rather than forming complete platelets.

Figure 6.7: Four samples of electroformed textiles with carbon fibre mesh (left) and tree samples of nickel -plated textiles (right).

The nickel plated fabrics were well suited for building up smooth layer of copper, but the nickel layer would be bare at the hinges, making the piece unsuitable for wearing on the skin.

A new start

Because of the work I had done during my MA I had a working method for producing MFT at the start of my research project, but I wanted to find a better one. I wanted it to be faster, more reliable and accurate, so that I could use it for producing work in a studio practice at a reasonable cost. This meant that I would have to reconsider my choice of materials and the method for applying the pattern to the fabric. I also wanted to improve the way the fabric was connected to the electric circuit of the electroforming tank and the way the fabric was held taut and flat when immersed in the solution. These issues were all interwoven: when I made a choice for one, it would affect the possibilities for the others. To prevent unnecessary failures it would be necessary to think through the whole process before starting a test.

Choice of materials

I had the choice between conductive and non-conductive (plain) textiles. This choice then determined whether I only needed a stop-off to cover all the hinges, or both a conductive pattern and stop-off over the tabs.

Non-conductive textiles

Because the copper electroforming-solution is acid-based it will dissolve organic materials. This meant that I could not use cotton or any other cellulose-based textiles. Silicone contaminates the solution. This meant that my best choice for easily available fabrics was polyester, a good option because it is available in a wide range of colours, qualities and textures.

Polyester, nylon and silk are suitable for use in the department's cyanide-based silver-electroforming solution; cellulose-based fibres are not.

There are electroforming solutions that do not dissolve organic materials. Using these would allow me to use a wider variation of textiles but those solutions are more difficult to maintain than the ones available at the department, and are only used in commercial companies. For my research I wanted to control the whole process and also had to protect the intellectual property rights of the DAS team project, so I decided not send samples out to these companies. It does remain a possibility to try this out in the future.

Conductive textiles

There are three types of conductive textiles. Firstly there are textiles woven from fine strands of metal. Even though these can be made very fine and flexible the metal will harden and eventually break when they are bent repeatedly. This makes these metal textiles unsuitable as a substrate for MFT. The second type of fabric is the polyester and carbon blend that I tested during my MA. Those fabrics do not have a uniform conductive surface, making it impossible to build up uniform platelets. Consequently they are not suitable for use in MFT either. The third type consists of metal plated synthetic textiles. I found the German company Statex, that sells silver and copper plated textiles rather than nickel plated ones, so that I could use them for wearable objects. Unfortunately the textile they use for this Shieldex® range is made from nylon. They were prepared to plate a fabric of my choice, as long as it was made from nylon too. But the copper electroforming process within the department is not suited for electroforming nylon, since the solution weakens the fabric. Because I wanted to test the possibilities of this kind of conductive material, I did use the copper process a few times. I also used it for testing the silver electroforming process, where the cyanide does not affect the nylon.

The fabric samples I tested were Shieldex® Köln, a copper plated non-woven; Shieldex® Bonn, a silver plated non-woven and Shieldex® Bremen SX, a silver plated 'parachute silk' (nylon).

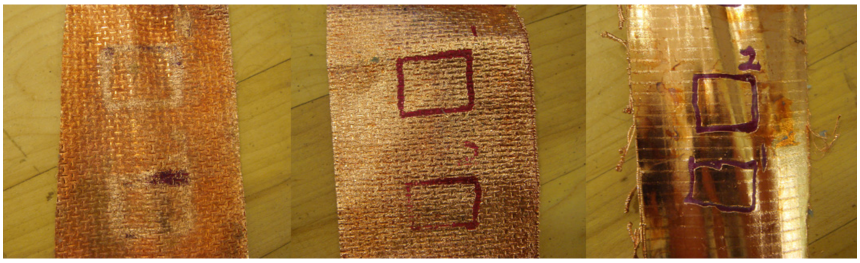


Figure 6.8: Initial test copper electroforming on three samples of conductive fabric: Shieldex® Köln (left) Shieldex® Bonn (middle) Shieldex® Bremen SX (right)

After this first test, I only continued testing on Shieldex® Bremen SX because it gave a satisfactory result after plating: the copper build-up was even, strong and shiny. The other two fabrics had a greater thickness and more felt-like texture, which soaked the stop-off into the fabric, making it ineffectual.

Conductive media

If I wanted to prepare a non-conductive textile for electroforming, I had to make the area of the platelets conductive. This had to be done with a medium that would adhere well to textile, even when wet. I tried four types of conductive media. One was a liquid, water-based copper paint (from 'Safer-Solutions'). Two were liquid, solvent-based silver lacquers: Electrodag 1415M, which is thin enough to be used for painting or spray painting, and Electrodag 418 SS, which is more viscous and has the correct consistency for screen-printing. The fourth conductive medium is a thin copper-foil with a self-adhesive backing. The water-based copper paint from 'Safer-Solutions' partially washed out of the fabric when immersed in the electroforming solution, so that metal build-up was very irregular. Since the patterns I use are very detailed, and have to be complete for the folding to work, I decided not to continue using this paint. I will discuss the way the other media were applied respectively in "1-sided screen printing electrodag", "1-sided vinyl mask for spray painting electrodag" and "vinyl cutting copper foil".

Non-conductive media

I tested a range of non-conductive media to stop metal from building up on conductive surfaces. The most obvious and also the most effective one is Lacomit, which was developed for the plating industry. Lacomit is available both as a lacquer, which has to be painted on by hand and as a pen. I had used the lacquer during my MA course, so I knew it would work. The Lacomit in the pen is diluted to make it flow through the nib. When tested, it proved to be too thin to stop off the metal build-up well enough.

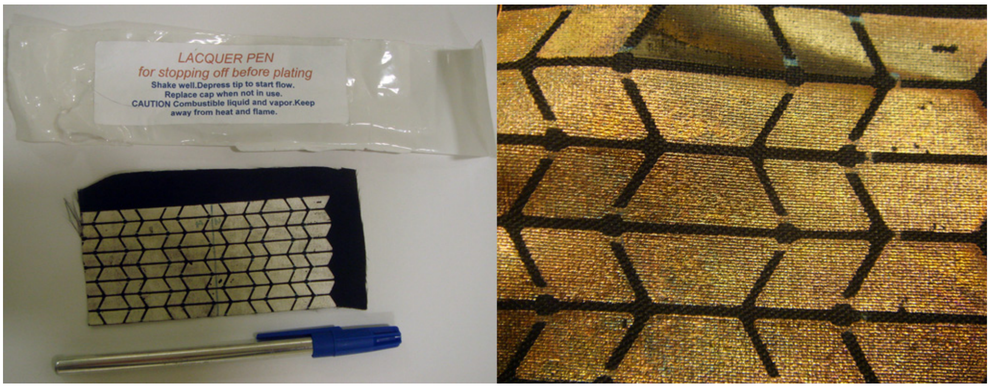


Figure 6.9: Testing the Lacomit pen. Treated sample before electrofotming (left) and close-up of sample after electroforming (right). The tabs have not been stopped off.

I also tried some media that are not commonly used for electroforming because they could be more easily applied. The first was a photo-sensitive screen blocker, normally used for the preparation of a printing screen. The second was a screen-printable stop-off lacquer, designed for the etching of copper. The third was a photo-sensitive film, used in the electroforming industry. The process of applying these media is described below in the relevant subchapters of “Choosing an application method”.

Stretching the fabric on a frame

When preparing the fabric for electroforming, it is important to think ahead and plan the way it will be suspended in the electroforming solution. The fabric has to be held taut in the tank to insure the platelets will be flat when they stiffen. The method I used during my MA was to clamp the top and bottom edge, and weigh the bottom down. But as explained above, this method was not reliable enough. Ideally, the fabric would be clamped on all four sides with a system that would accommodate for any stretching of the material when it was immersed in the solution.

I received the help from professor David Watkins and David Turtle for the design of electroforming frames. First I tried a screen for test-samples in which the fabric was clamped at the top and bottom only, with one adjustable side, sliding up and down a set of strong bolts. This prevented the fabric from moving or stretching along the bias, which helped prevent the platelets from distorting. I could adjust the tension to accommodate for any lengthwise stretch in the fabric by adjusting the bolts. Yet, I still had no way of keeping the fabric taut in the width, so the platelets were still curling up in that direction. Many options for more refined screens, with the possibility of adjusting the fabric on all four sides, were discussed and rejected because they were too complicated to construct.

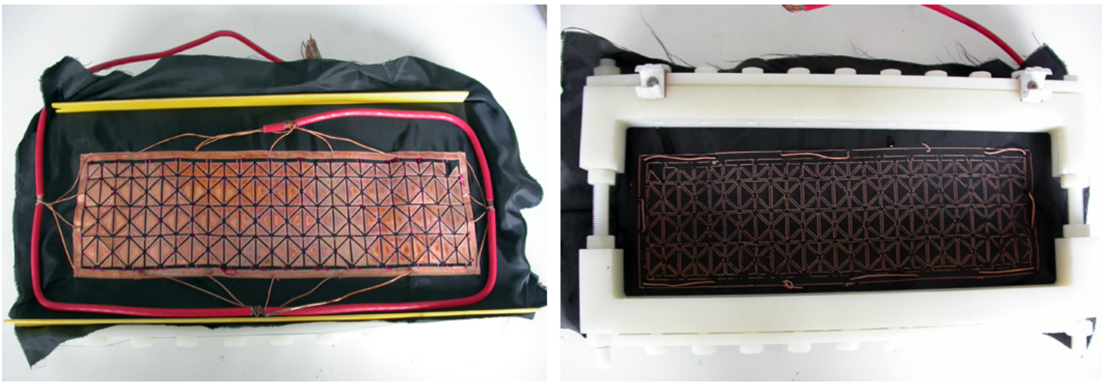


Figure 6.10: Front and back of adjustable nylon frame. The height can be adjusted by turning the bolts on the sides. Bolts on top and bottom keep the fabric in place.

We decided to use a different approach, and bought a screen stretcher normally used to stretch the mesh for a printing screen. This frame was used to stretch the fabric before gluing it to an electroforming frame. To prevent the fabric from sagging on its frame when immersed in the solution, it was made wet three times, and each time tightened a little further to accommodate for the stretch in the fabric. When the fabric was wetted the third time, there was hardly any stretching of the fabric anymore. After the fabric dried completely, the electroforming frame was glued onto the fabric, and the fabric was cut around the frame to release it. I used either acrylic or stainless steel frames and tried out superglue, 2-component acrylic glue and Araldite. Of these three only Araldite gave consistently good results, keeping the fabric glued down. The pattern was applied to the fabric after it was transferred to the electroforming frame.

Figure 6.11: The fabric is pre-stretched on a screen stretcher (yellow frame in left image), and electroforming frames are glued on the stretched fabric (left). Weights are applied to keep a good contact between the frames and the fabric. When the glue has dried, the frames are cut out, and are ready to receive a pattern (right).

When Mick Stokes printed stop-off on both sides of the fabric I had to add an extra step in the pre-stretching of the fabric: Mick needed the fabric to be stretched on a large frame so that fabric would remain flat while he printed on the front and the back, fitting his screen inside the frame. I therefore glued the fabric to a frame much too large for the electroforming tank, and after Mick printed the stop-off pattern twice I glued smaller electroforming frames around the printed patterns, which were then cut out to go into the tank.

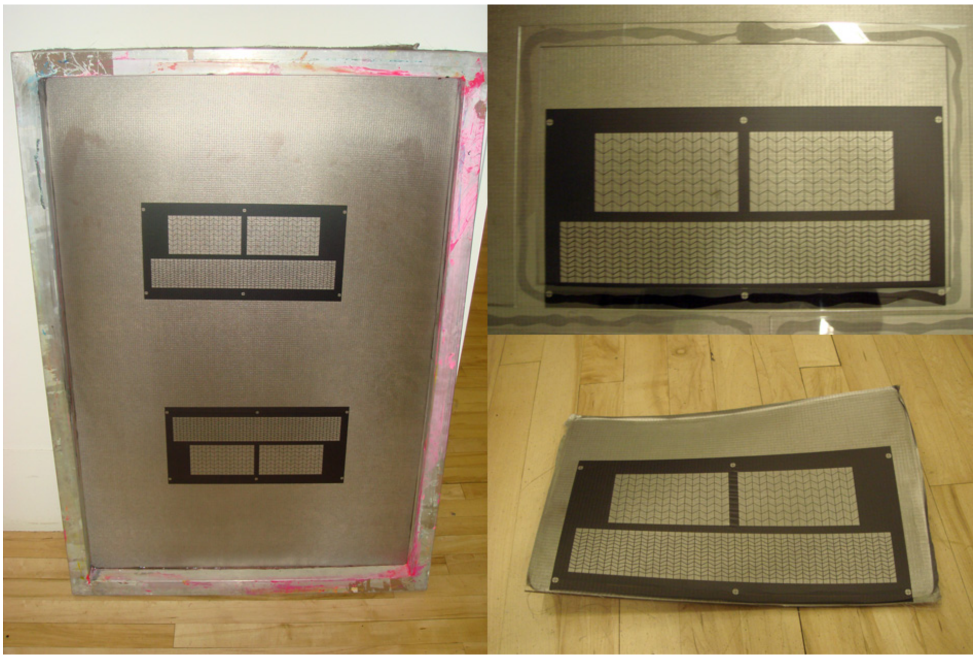


Figure 6.12: Frames needed for two-sided printing of stop-off: large frame (left) to allow room for printing screen, and small acrylic frame for electroforming (top right). The tension of the fabric makes the plastic frame warp (bottom right)

Suspension of the electroforming frame

When the electroforming frame is immersed in the tank, it has to be suspended from the bus-bar with hooks or copper wire. It has to hang down vertically to get an optimal position compared to the anodes. If the frame is made from a heavy material, it will hang vertically, if it is made from a light material a weight is added to the bottom to keep it immersed vertically.

Material of frames

The first, adaptable, frame was made from nylon. I then found out that nylon is not suitable for use in the copper solution. PVC, acrylic and stainless steel were the only other options because they are chemically inert to the chemicals in the tank. For smaller frames I used acrylic, because it is light and easy to cut to the desired size with the department laser cutter. PVC cannot be cut on the laser cutter and was therefore much more difficult to cut to size, so I did not use it. For large pieces Acrylic was not stiff enough: the enormous tension from the fabric made it warp. I chose to use stainless steel instead because it made the frames heavy enough to keep them immersed vertically without the need to attach extra weights. The first of these frames was constructed from square tubing 4 cm thick and welded together. It was strong enough to prevent warping, but uncomfortably heavy, so a second one was made from square tubing of 2 cm. This lighter frame was easier to handle and still sufficiently strong to withstand the tension. Since stainless steel is conductive I had to take care to insulate these frames from the cathode bar. The hooks used to suspend the frames from the bar were insulated, and a layer of tape was wrapped around the bar where the frame touched it to prevent copper from building up.

Once the fabric was stretched on a frame, the next step of the preproduction process could begin: applying the pattern.

Application of the pattern

To make Metallised Folding Textile, a chosen textile has to be prepared for electroforming by applying a (combination of) media in such a way that the surface of the fabric is conductive where platelets are wanted, and non-conductive where the hinges will be. There have to be conductive connections between the platelets, to allow the current to run through all the platelets: if one platelet would be unconnected to the others, it would have no current running through and would consequently not have any metal building up. These connections should not be on the surface of the hinges; otherwise metal will build up, preventing the hinge from working well.

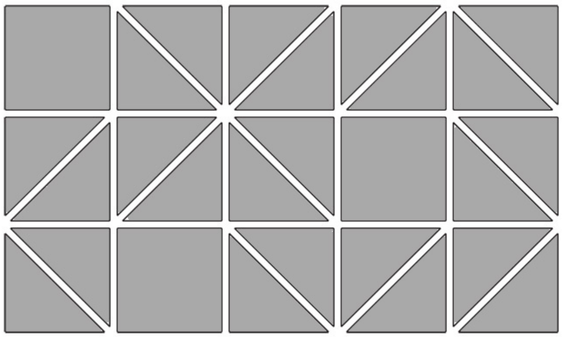


Figure 6.13: The surface of the fabric after any application process would have to be conductive where platelets were wanted (the grey areas), and non-conductive where the hinges would be (the white areas). Underneath the non-conductive areas there have to be conductive connections between the platelets.

Drawing up the pattern

The basic printing pattern was always determined from the start: it had been tested through the model making process as described in the previous chapter. The hinge width was determined by the thickness of the metal layer and the fabric. It then had to be adapted to the application method, as is described for each application method individually. Even though the patterns I used for the actual tests varied, in this chapter I have used one pattern only to explain the differences between the application methods.

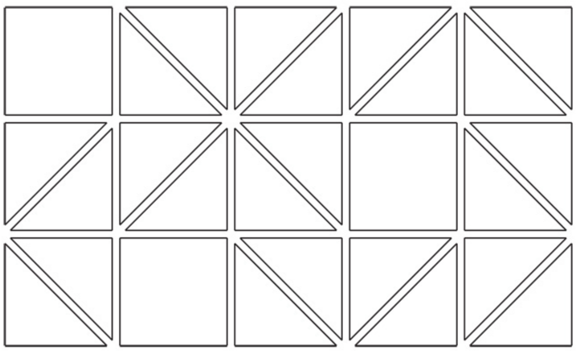


Figure 6.14: The basic pattern consists of the outlines of the platelets.

Choosing an application method

The first factor in choosing an application method is the chosen substrate. When choosing a conductive textile, a suitable stop-off layer has to be applied. When using a non-conductive textile a conductive medium has to be applied to form the basis of the platelets and to connect them all into a conductive circuit. Then a second step to apply a stop-off over the tabs has to be taken. I had already used the method of screen-printing onto non-conductive textile, in combination with hand painting over the tabs during my MA, but wanted to find a faster and more flexible method.

Any method used a selection of the materials and textiles described earlier in this chapter, and had to take into account that once the fabric was prepared, it would have to be immersed in the electroforming tank. This immersion in the tank caused its own problems, as are described in detail later on in this chapter, the essence being that the fabric has to be kept flat and cannot be allowed to float freely in the tank.

1-sided screen-printing: conductive electrodag on non-conductive textile

This is the method I had used as an MA student. It makes use of a plain polyester fabric and the electrodag 418 SS, which has the correct consistency for screen-printing.

Adapting the pattern.

Since the pattern is applied to a non-conductive textile, the platelets have to be connected with conductive tabs. Electrodag is used to print both platelets and tabs.

A printing screen has to be prepared using a photo-tool. The photo tool consists of a clear plastic sheet, of which the areas that will later be printed with electrodag are made black, the areas that should not receive electrodag remain clear.

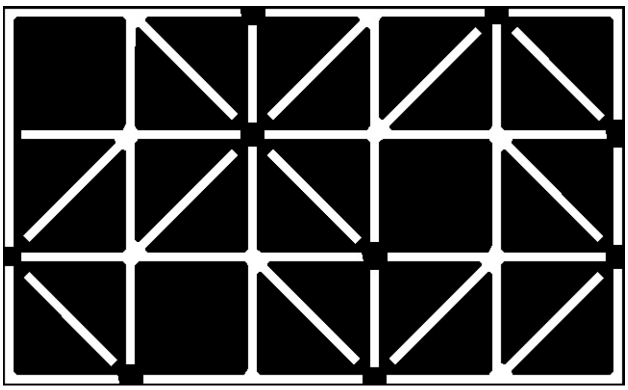


Figure 6.15: Adapting the pattern for screen-printing electrodag. This pattern is printed on clear acetate.

The screen is treated with a photosensitive screen blocker and with the use of the photo-tool the clear areas are fixated with light. Where the photo-tool was black, it stopped the light from reaching the screen blocker, so that that can be rinsed out. The screen is now porous where the pattern was black, allowing the electrodag through.

Applying the medium

The pattern is printed on polyester fabric, and the tabs are covered with Lacomit on front and back.

Electroforming results

Screen-printed electrodag makes the copper grow both on the printed side and through the fabric onto the reverse. The texture on front and back are slightly different, like a positive and negative of the fabric. Platelets can be kept very thin, or built up to a greater thickness. This method works well for both patterns with small details and patterns with large platelets.

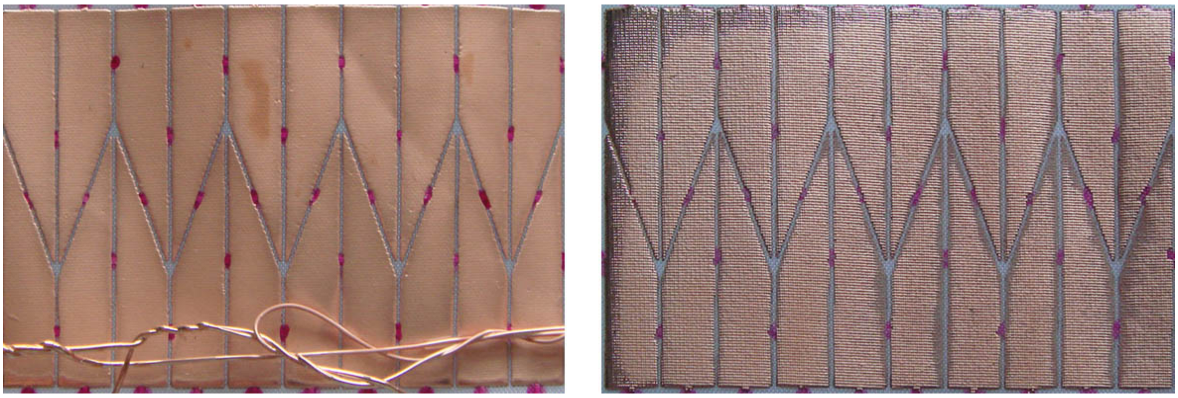


Figure 6.16: Sample of MFT, prepared with Electrodag 418 SS, front (left) and back (right).

Usefulness and ease of use

Screen-printing demands a lot of preparation and cleaning the screen after printing takes a lot of time. This is worth the effort if the pattern is printed several times, to prepare for several identical pieces of MFT at the same time. If only one piece is needed, this process is too costly (because of the wasted electrodag in the screen) and time-consuming. Painting the Lacomit by hand also takes a lot of time.

Spray-painting electrodag on non-conductive textile

Since the department had just purchased a vinyl cutter, I decided to find out how I could use it to my advantage. A test showed that the vinyl was not suitable to use as a mask in the electroforming tank: it peeled of the fabric as soon as the fabric was immersed in the tank. But it was possible to cut a very accurate stencil from the self-adhesive vinyl, and use this when spraying a layer of electrodag onto the fabric.

Adapting the pattern

This method is used on polyester fabric, and the applied medium is the liquid electrodag 1415M. To ensure that the electrodag will only be sprayed where needed, the vinyl mask has to block off the hinges, but keep tabs free. The pattern shown below is cut from self-adhesive vinyl on the black lines, and the white areas are then removed.

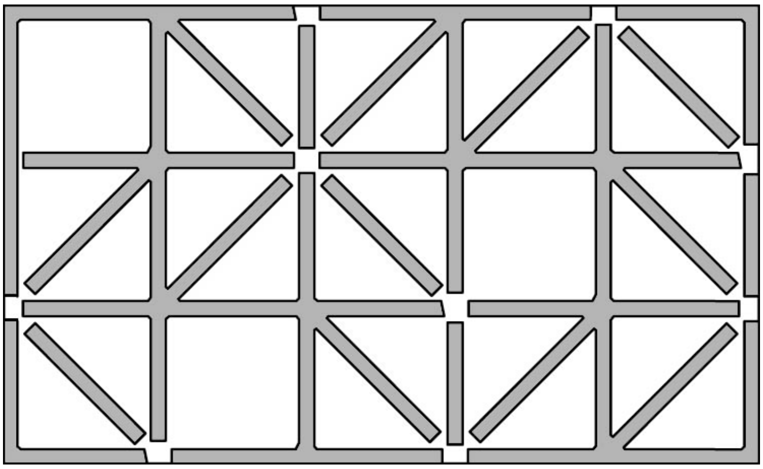


Figure 6.17: Adapting the pattern for screen-printing electrodag. The pattern is cut from self-adhesive vinyl on the black lines, the white areas are removed.

Applying the medium

The grey parts are transferred onto the pre-stretched fabric, and serve as a stencil. Electrodag is air-brushed over the whole surface, ensuring an even coating. When it has dried the vinyl is removed from the fabric, leaving a conductive pattern like the one achieved through screen-printing. The only difference is that electrodag M1415 penetrates the fabric deeper than its screen-printable variant 418SS.

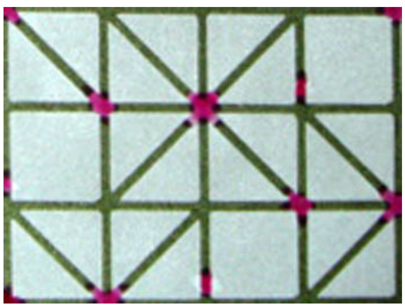


Figure 6.18: Spray-painted electrodag

After removing the vinyl, Lacomit is applied by hand on front and back to stop off the tabs.

Electroforming results

Spray-painting electrodag gives the same results as screen-printing: it makes the copper grow on both sides, with the texture on front and back slightly different. It works well for both patterns with small details and patterns with large platelets.

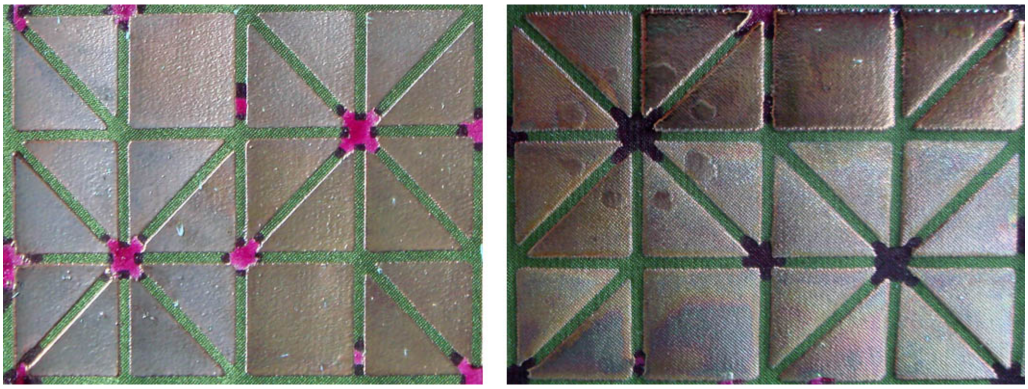


Figure 6.19: Electroformed spray-painted electrodag, front (left) and back (right). The irregular dots seen on the image of the back are places where I touched up the conductive pattern with a paintbrush.

Usefulness and ease of use

The most time-consuming part of this method was "weeding" the vinyl, carefully removing all the parts that should not be applied to the fabric, without disturbing the parts that did have to be laid down. After spraying it also took some time to remove the vinyl from the fabric. Still, the weeding took less time than preparing and cleaning a screen, so this method proved useful for patterns that only needed to be electroformed once. The original problem of having to apply stop-off by hand on both sides still remained, and all tabs had to be examined before applying the Lacomit to ensure that the conductive layer was thick enough to work. Deficient tabs were painted over with electrodag before being stopped off.

Vinyl-cutting Copper foil Stuck onto Non-conductive textile

The company that sold us the vinyl cutter also offered a self-adhesive copper-foil, thin enough to cut with this machine. This "Cutronic" foil is normally used for making simple PCB's in a classroom environment.

Adapting the pattern

I cut out the same pattern that I had used for the vinyl-stencil and weeded out the parts where the hinges would be, but leaving tabs for the connectivity.

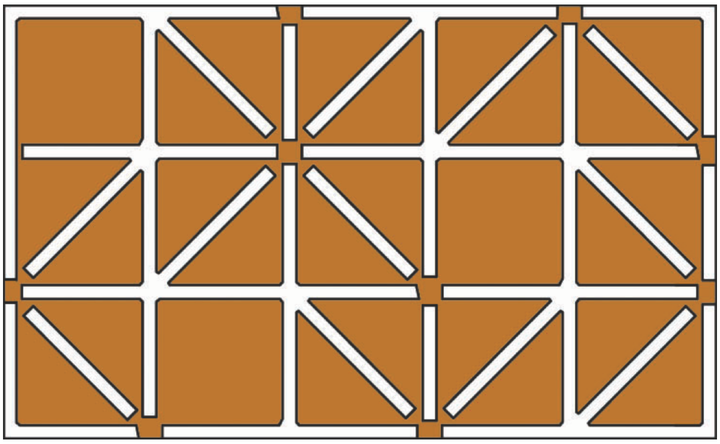


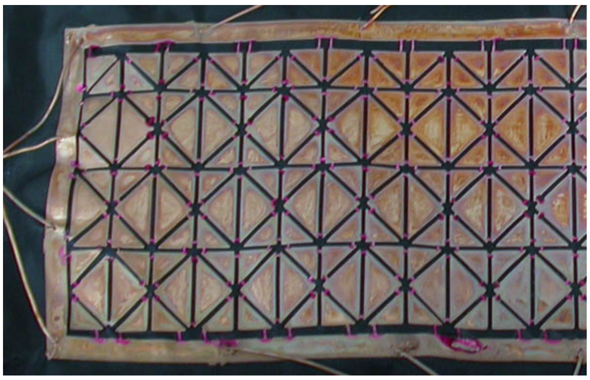
Figure 6.20: Pattern for self-adhesive copper foil. The pattern is cut from the copper foil on the black lines, and white areas are removed. The foil is then transferred onto pre-stretched fabric.

Applying the medium

The copper foil is simply transferred onto pre-stretched fabric, and Lacomit is applied on the tabs on both sides.

Electroforming results

The adhesive backing is non-conductive, which means that it will stop the copper from building up through the fabric except for at the edges. MFT made with this copper foil will consequently look very different from the front and the back. On the front the platelets are smoother than the printed platelets, not taking on the fabric texture. At the back they are nearly invisible, with only a line of copper showing around the edges. This makes this medium especially useful for objects made from MFT that need to have smooth platelets on one side, or for objects that benefit from a strong difference in visual appearance between one side and the other. Because the copper only builds up through the fabric at the edges of the platelets, they are not as strongly fixed to the fabric as platelets built up on electrodag.



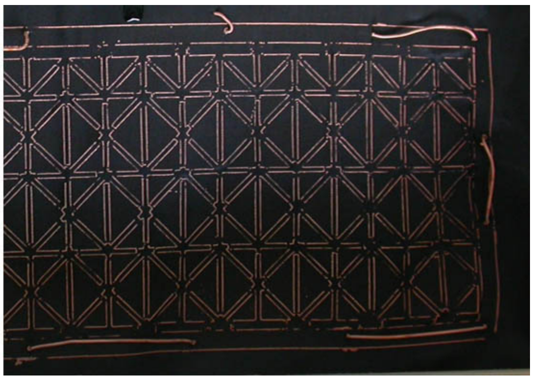


Figure 6.21: Sample of MFT, prepared with self-adhesive copper foil, front (left) and back (right).

Usefulness and ease of use

Even though I applied stop-off over those tabs, the copper foil was of a sufficient thickness to make folding the sample difficult, and the tabs quickly broke, creating sharp burrs that made the sample useless for a wearable object.

I adapted the Cutronic foil method, by removing the hinges completely and painting on tabs by hand in conductive ink, then stopping them off again by hand. This gave a neat result, and is useful if an almost one-sidedly metallised MFT is needed, but because of the time involved in manually applying tabs and stop-off it is not suitable for pieces with many platelets.

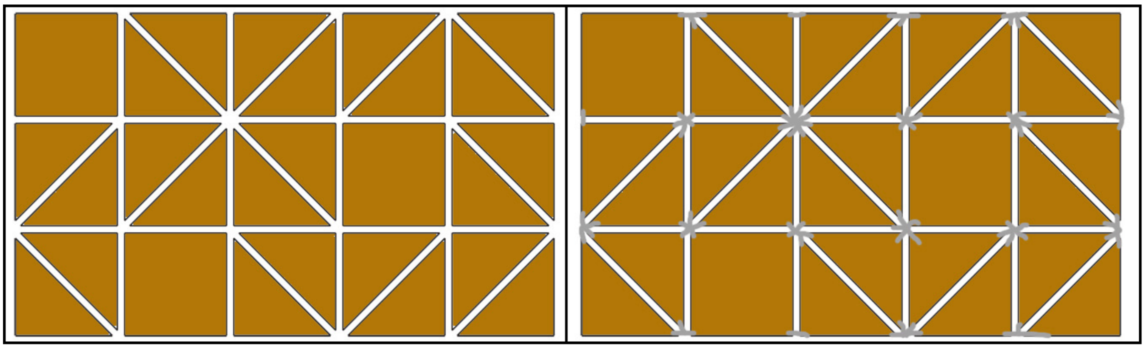


Figure 6.22: Pattern for self-adhesive copper foil, with tabs hand-painted with electrodag. Pattern cut from foil (left), with painted tabs (right).

One side application photosensitive screen blocker on conductive textile

Photosensitive screen-blocker is normally used to prepare a screen-printing mesh. The screen is coated one side with the screen-blocker to from a uniform layer that penetrates all pores and is then exposed to light to fix it. Where it has not been exposed to light it remains water-solvable and can be rinsed out. I wanted to try this process on conductive textile, using the screen blocker as a stop-off.

Adapting the pattern

Since I would use a conductive textile, I did not have to worry about tabs: the whole surface was conductive, and I only had to apply a stop-off medium to the hinges. Since I wanted to use a photo-sensitive stop-off, I had to create a photo-tool that would let light through to fix the screen-blocker stop-off on the hinges, but not where the platelets would be, so that it could washed away where electroforming was needed.

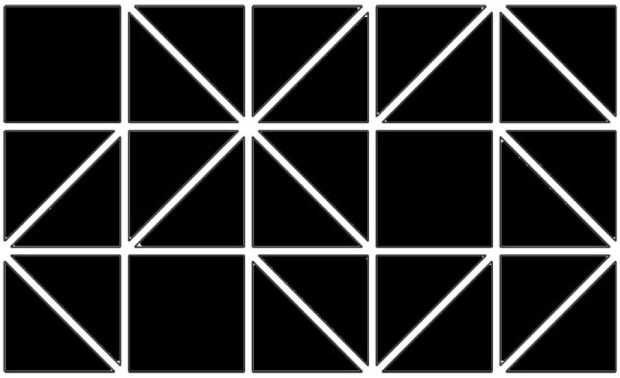


Figure 6.23: Pattern for photo-sensitive stop-off. The black areas are not fixated by the light, so will wash away and expose the conductive surface.

Applying the medium

I coated the pre-stretched conductive fabric with screen blocker on both sides to make sure that all strands of the fabric were completely covered. Unfortunately, the frame on which the fabric had been stretched stopped me from lighting the fabric on both sides. I could only use a light source on one side of the fabric, so the coating on the back of the fabric did not get fixed and was washed away. I decided to electroform this sample anyway, and resolve the problem with the frame later on.

Electroforming results

The screen blocker worked well to begin with, but did not stop the copper build-up for long enough: by the time the platelets were thick and strong enough metal had been deposited on stopped-off areas too. This made me decide that it would not be worth finding a way of lighting both sides of the fabric.

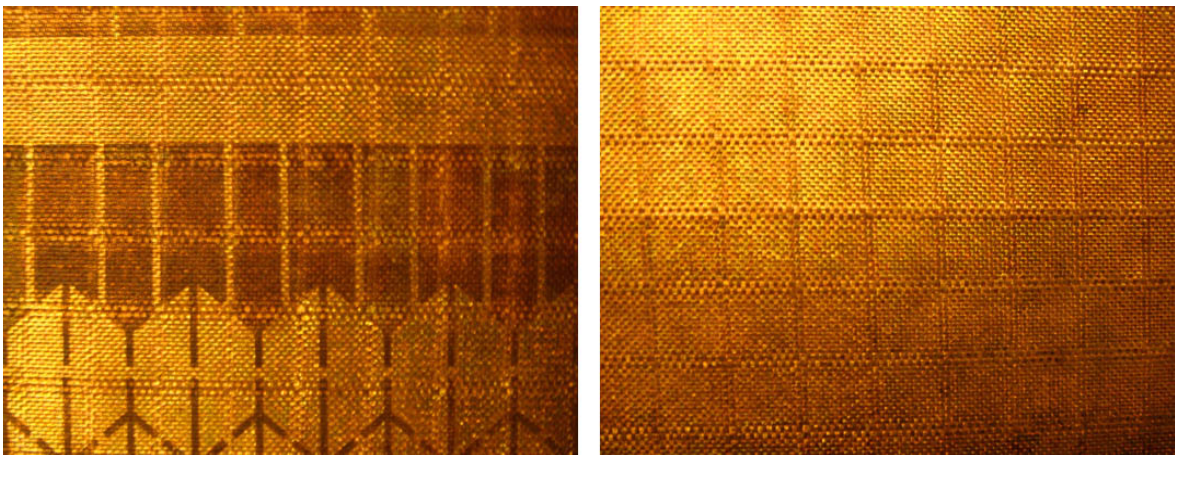


Figure 6.24: The electroformed sample of conductive fabric, treated with screen-blocker, front (left) and back (right). Darker areas are stopped off, but the copper comes through.

Usefulness and ease of use

This method would have been quick and easy, but it did not work.

Photo-sensitive stop-off on conductive textile, PGE-Adenco

I contacted the Belgian company PGE-Adenco, specialised in high-precision electroforming of micro-sized objects. They were willing to prepare a sample of conductive textile with the stop-off they use when electroforming small components for the electronics industry. They normally use this material on a metal sheet.

Adapting the pattern

The pattern needed for this method was identical to the one used for the photosensitive screen blocker.

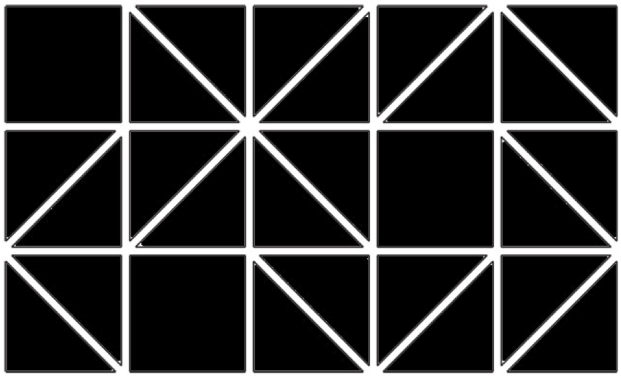


Figure 6.25: Pattern for photo-sensitive stop-off.

Applying the medium

I had sent PGE-Adenco my pattern and two samples of the conductive fabric. They covered both samples with their photosensitive stop-off on both sides, but did not apply the pattern I had given them. Instead they prepared both patterns with their company logo. The stop-off had cracked and peeled off in some places, it was clearly not meant to be applied to a flexible backing such as textile.

Electroforming results

The stop-off layer dissolved in the electroforming tank.

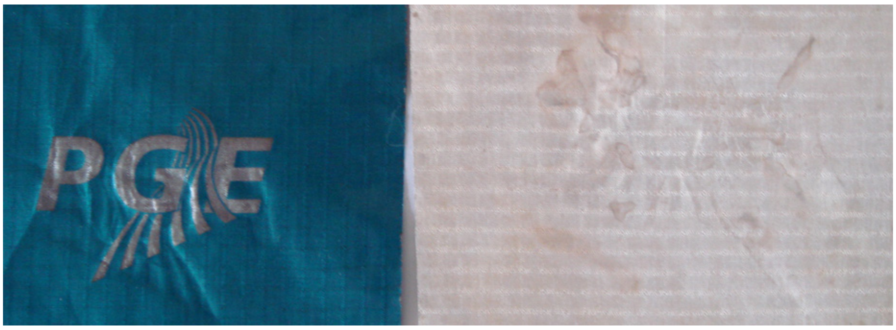


Figure 6.26: Sample of PGE-Adenco before and after electroforming.

Usefulness and ease of use

Since the stop-off did not work, this method was useless.

Screen-printing non-conductive ink on conductive textile

With the help of Mick Stokes from the Printmaking Department I tried out screen-printed etching-lacquer on conductive textile. He had experience with two-sided screen-printing on sheet metal to prepare it for etching, and was willing to try it on textile.

Adapting the pattern

Two printing screens would have to be prepared: one for the front of the fabric, and one for the back. This meant that two photo-tools were needed, in which the area of the hinges was black, and the platelets were clear.

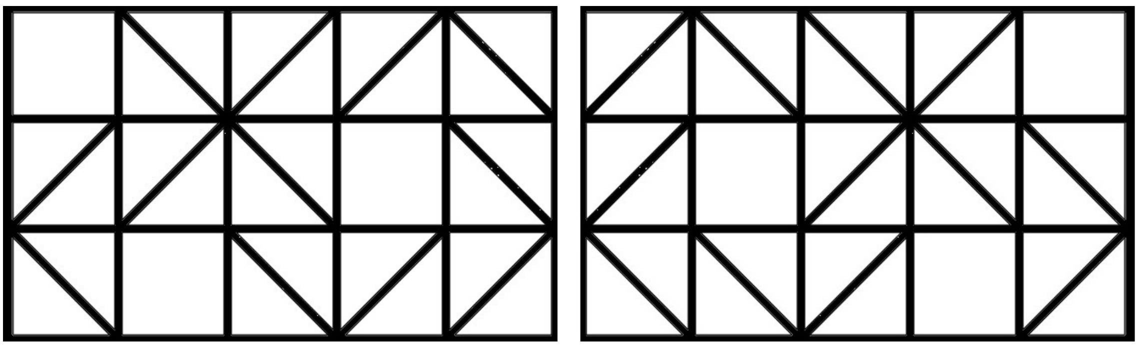


Figure 6.27: Patterns for double-sided screen-printing of stop-off. One is the mirror image of the other. These patterns were used to make two photo-tools, with which two screens were prepared (one for the front of the fabric, one for the back).

Applying the medium

Mick managed to print a small pattern (170 x 345 mm) two-sided, accurately lining up the front and back. He told me that larger patterns would not be possible because the conductive textile deformed slightly under the pressure of the squeegee. This deformation was only mild for a small pattern, but would increase for larger patterns. Since front and back each deformed separately, large patterns would not line up anymore.

Electroforming results

There was some metal build-up on stopped-off areas, which might be resolved by applying a thicker layer of lacquer. Apart from that, the results were good: an even layer was deposited on both front and back. The platelets did not peel easily.

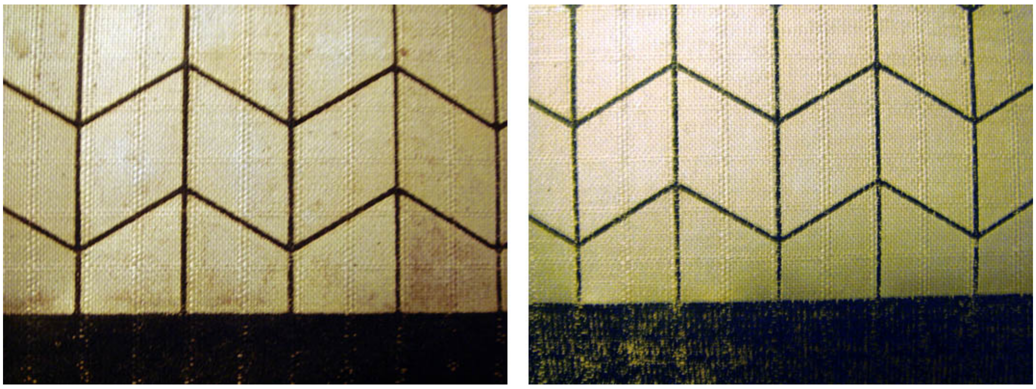


Figure 6.28: Two-sided screen print after electroforming (silver), front (left) and back (right).

Usefulness and ease of use

This method requires the preparation and cleaning of two screens and the skills of an experienced screen printer to achieve accurate results. Even then, the size of the pattern is limited. I consider this method too difficult and limited to use.

Applying pattern on one side, blocking back uniformly

Since double-sided screen-printing was ruled out as a method, I wondered whether it would be possible to print on only one side of the conductive fabric and completely cover the other side. I decided to do a few quick little tests. I painted the patterns on by hand so that I could see whether the method would use before having to ask for Mick Stokes help again.

Adapting the pattern

The pattern I needed for this method consisted of the hinges, printed in stop-off. I made the tests by hand, so that I could test a variety of materials on a small piece of stretched fabric. Because I applied the pattern by hand, I did not follow a strict pattern, but applied a grid of lines.

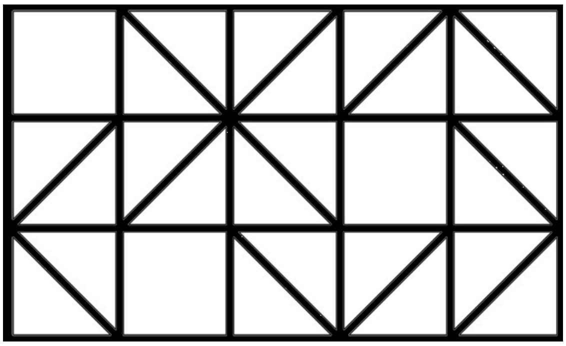


Figure 6.29: Pattern to apply to conductive fabric if printed on one side only.

Applying the medium

I tried two methods. One was to I cover the back of the frame completely with a sheet of acrylic; this left a gap in between the acrylic and the fabric. The other was to apply a variation of stop-off media straight to the back of the fabric.

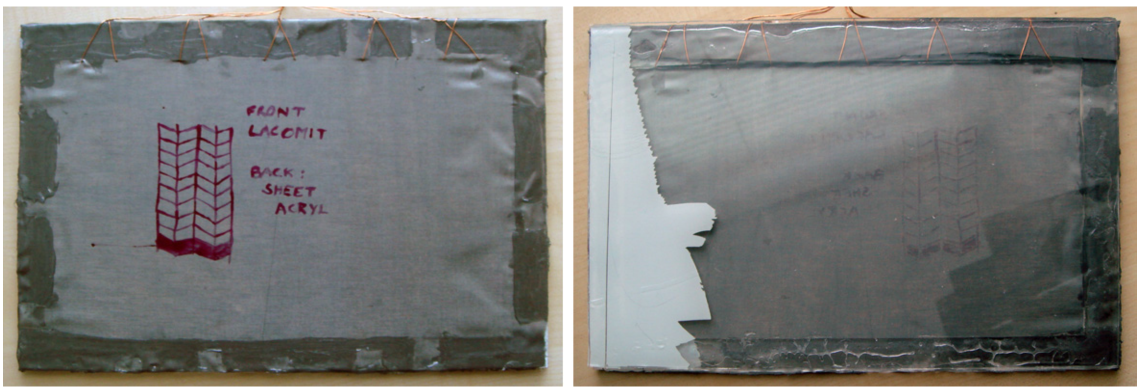


Figure 6.30: Applying the pattern one-sided, covering the back with acrylic sheet. A gap remains between the fabric and the acrylic backing.

Figure 6.31: Applying the pattern one-sided, covering the back with a variation of materials, directly applied to the textile.

Electroforming results

The sample with a gap in between the acrylic backing and the fabric had copper building up on the back of the fabric. This made this method unsuitable for me. Its platelets also peeled off easily, a second reason to abandon this method.

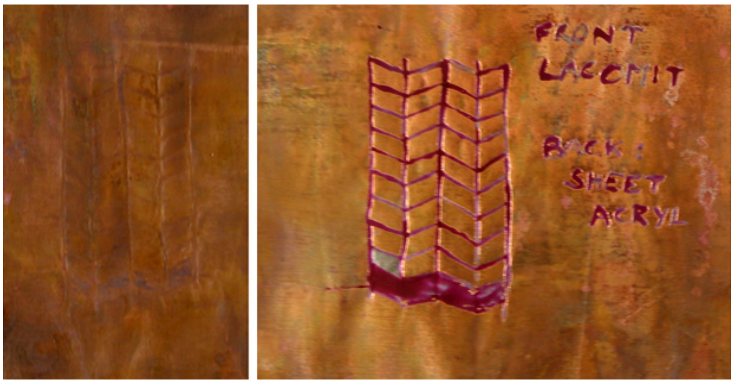


Figure 6.32: When a gap is left at the back, copper is deposited on the back of the hinges. Platelets peel off easily.

The sample with different media applied directly to the back of the fabric had no copper building up on that side on most media. The Lacomit did have small grains of copper coming through, but these were rubbed of easily. Even though this method appeared promising, the platelets that had built up on the front of the fabric peeled of very easily, making this method unsuitable.

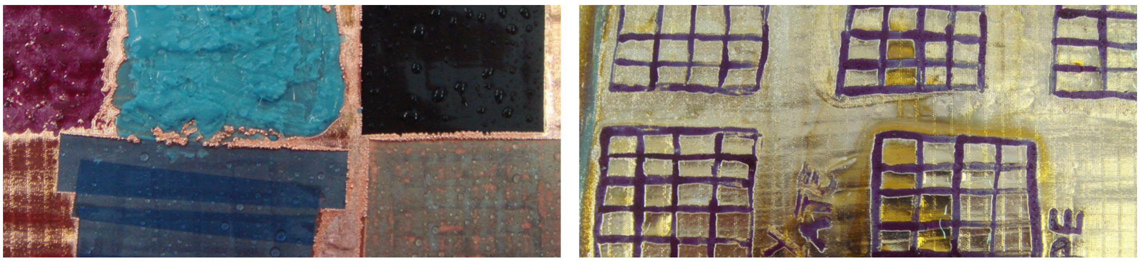


Figure 6.33: When the back is covered with different media directly on the fabric, copper does not deposit on the back of the hinges. Platelets peel off easily.

Usefulness and ease of use

Both methods are useless, because of copper building up on the back of the fabric or because the platelets peel off too easily.

Testing a stainless steel backing

Industrially made copper foil can be made through the process of electroforming[3]. In this case, a steel cylinder is immersed in the electroforming solution, and slowly rotated around its axis. A thin layer of metal is deposited on its surface, and is peeled off once it comes above the solution. Because the cylinder keeps on rotating, a continuous sheet of metal is formed. This process inspired me to do some experiments with non-conductive textile stretched over a stainless steel backing. My hope was that the metal would build up through the fabric onto the steel, creating a metal sheet around the textile. If this were possible, then the hinges could probably be drawn on the cylinder in stop-off, allowing for individual platelets to build up without the need for connecting tabs on the fabric. The initial experiments, without textile, were promising: metal build up in a reasonable even layer and peeled off the stainless steel without any trouble.

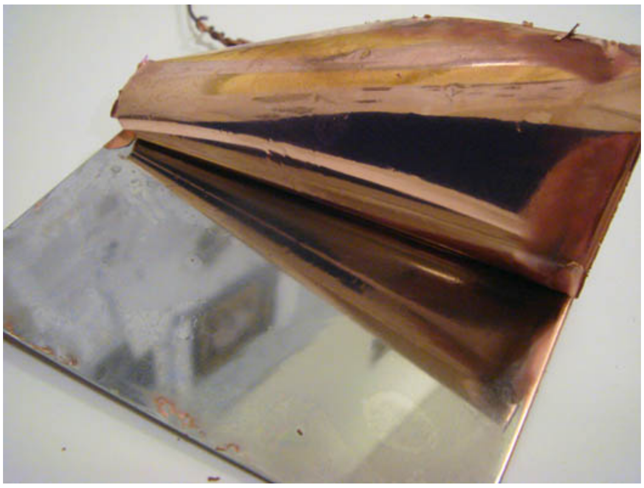


Figure 6.34: Initial test on stainless steel: a thin copper foil is easily removed.

Adding a textile layer was possible, and the copper did build up through the textile, but the texture of the metal was not as expected: the copper was not forming a rigid layer of metal on both sides, but a very fine foil on the side of the stainless steel, and a brittle build-up through to the other side. This meant that the result was a limp material rather than a stiff sheet.

Figure 6.35: Electroforming onto textile stretched over stainless steel: the side touching the steel (right) is a bright foil, the other side (left) is brittle and grainy.

I decided to try adding stop-off to create a foldable pattern anyway because the stiffness might be sufficient for small platelets. The results were disappointing. I had tried applying stop-off either on the top of the fabric, or in between the fabric and the stainless steel. Where the stop-off was applied over the fabric, copper built up as a continuous sheet underneath. Where the stop-off was applied in between the textile and the stainless steel there was not much copper penetrating the fabric: it seemed as if the copper layer pushed the fabric away from the stainless steel while it was building up. Whenever there was a build-up of copper through the fabric, it was extremely brittle. I examined the top of the fabric to see why. When I used a loupe it became visible that the copper was coming through the pores of the fabric as separate bubbles that did not successfully join up to become a continuous layer again.

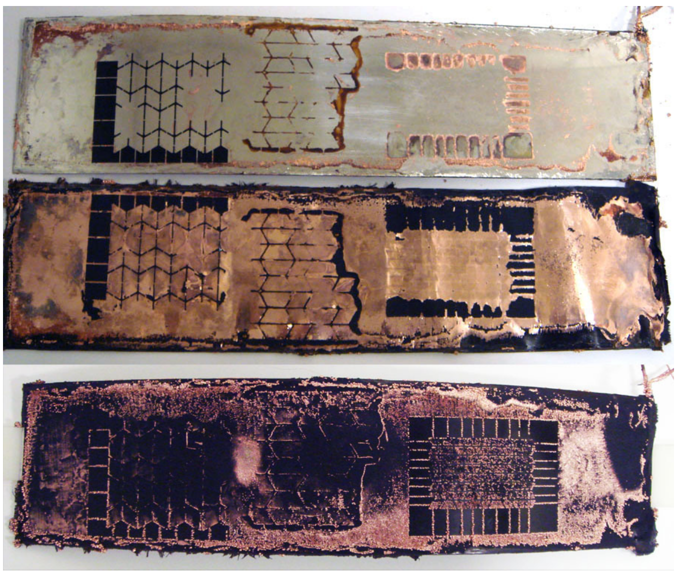


Figure 6.36 Fabric electroformed over stainless steel. Stop-off pattern applied in between fabric and stainless steel: with vinyl on the stainless steel (left), varnish on the stainless steel (middle). Stop-off applied on top of the fabric: vinyl (right).

In some areas the copper had come through in a more regular way, forming connections between the grains in parallel lines along either the warp or the weft of the fabric. Since the sample had been cut out of a leftover of fabric I am not sure which one. Sometimes the parallel lines would grow together, giving some stiffness. I could not find a reason why this more regular build-up had happened in these areas, and not in other places.

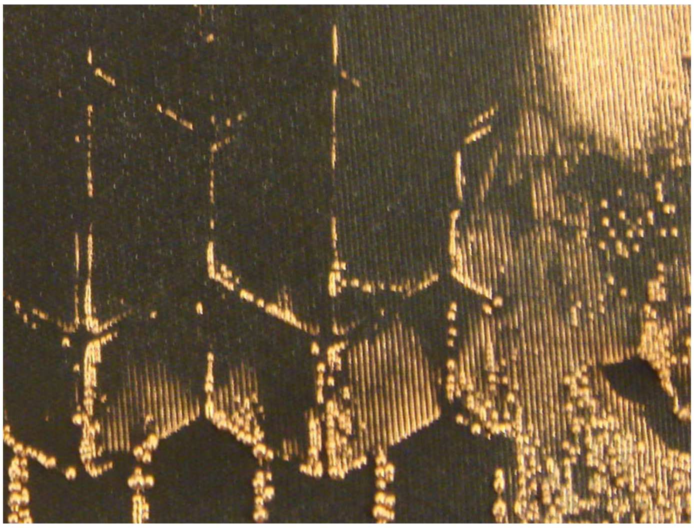


Figure 6.37: Detail: copper built up through the fabric in lines and grains.

The combination of the copper building up without adding stiffness to the platelets and the unreliable penetration of the fabric made me decide to give up on this method as a way of making MFT.

Fabric preparation process	**Fabric stretched on (type of frame)**	**Time needed**	**Process suitable for copper?**	**Process suitable for silver?**	**Process suitable for one-offs or multiples?**	**Ease of use**	**Accuracy**	**Pattern details**
Etching lines after EF whole sheet	Prestretched fabric, glued on perspex frame	Slow	**No,** not accurate enough	**No**				
1-sided screen printing conductive dag on non-conductive textile	Prestretched fabric, glued on steel frame	Relatively quick	**Yes**	**Yes**	**Best for multiples.** Time gain: the more prints are made in one run, the more time- and material-efficient this process becomes.	Stop-off has to be applied by hand on both sides of the textile	Accurate if the fabric is stretched on a 4-sided frame.	Fine details possible.
Spray-painting conductive dag on non-conductive textile (through vinyl-masking)	Prestretched fabric, glued on steel frame	Relatively quick	**Yes**	**Yes**	**Both.** No gain in making multiples: each piece will take the same material and time as a unique piece made with this process.	Stop-off has to be applied by hand on both sides of the textile. Weeding can be tedious	Accurate if the fabric is stretched on a 4-sided frame.	Fine details possible.
Vinyl-cutting Copper foil Stuck onto Non-conductive textile	Prestretched fabric, glued on steel frame	Quick	**Yes**	**Yes,** but the work would have to be clearly labelled as copper base with thick silverplating.	**Both.** No gain in making multiples: each piece will take the same material and time as a unique piece made with this process.	Both tabs and stop-off have to be applied by hand.	Accurate if the fabric is stretched on a 4-sided frame.	Limited details
Photosensitive screen blocker (for silk screen) on conductive textile	Prestretched fabric, glued on perspex frame. (Thin frame needed for treatment in lightbox.)	Quick	**No.** Difficulty in lighting on both sides; does not stop off well enough	**No**				
Photosensitive stop off (PGE-Adenco)	No frame, photo-tool works as stiffener	Quick	**No.** stop-off dissolves	**No**		Applied by PGE-Adenco		
Two-sided screen printing non-conductive dag on conductive textile	Prestretched fabric, glued on steel frame before printing, transferred to smaller perspex frame for electroforming	Relatively quick	**Yes.** Only for small pieces	**Yes**	**Both,** Time gain for multiples: the more prints are made in one run, the more efficient this process becomes.	Has to be done by an experienced screenprinter	Only accurate for small pieces. Due to distortion of fabric large pieces cannot be made	Fine details possible.
1-sided pattern on blocked-off back (3 mm space between fabric and backing)	Prestretched fabric, glued on perspex frame, backing glued to other side of frame.	Quick	**No.** Copper builds up around the back on stopped-off areas	**No**				
1-sided pattern on blocked-off back (backing applied directly to fabric)	Prestretched fabric, glued on perspex frame	Quick	**No.** Platelets peel off	**No**				
Stainless steel backing	fabric stretched over stainless steel sheet	Quick	**No.** Copper layer brittle and bendy. Also inaccurate: build-up of copper where not wanted.	**No**				

Figure 6.38: Chart comparing the different preproduction (fabric preparation) techniques.

Attaching the conductive pattern to the circuit of the electroforming tank

Once the pattern was fully prepared with conductive and stop-off media, the conductive parts had to be wired up so they could be connected to the electrical circuit of the electroforming tank. I wanted to prevent having to make holes in the platelets, like I had done in my MA. I felt that the most reliable way to attach the copper wire leading to the electrical circuit to the fabric was to thread the wire through a conductive part of the fabric. If I did not want to do this through the platelets, I had to do it through a conductive edge around the pattern. This was a good solution for samples and pieces of "Wearable Metal Origami": where the fabric can be cut out around the pattern, but not suitable for pieces where I wanted to apply MFT to the centre of a larger piece of fabric. I found a supplier of copper tape with a conductive adhesive, and decided to test its suitability for replacing the copper wire. This would make it unnecessary to thread the copper wire through the fabric, and consequently save time. I taped the copper wires onto the conductive edge of the next piece I made, but with no success: there was no current, so the electroforming did not work. If I did not want a conductive frame around the pattern, I had to keep on using the method of threading wire through the platelets.

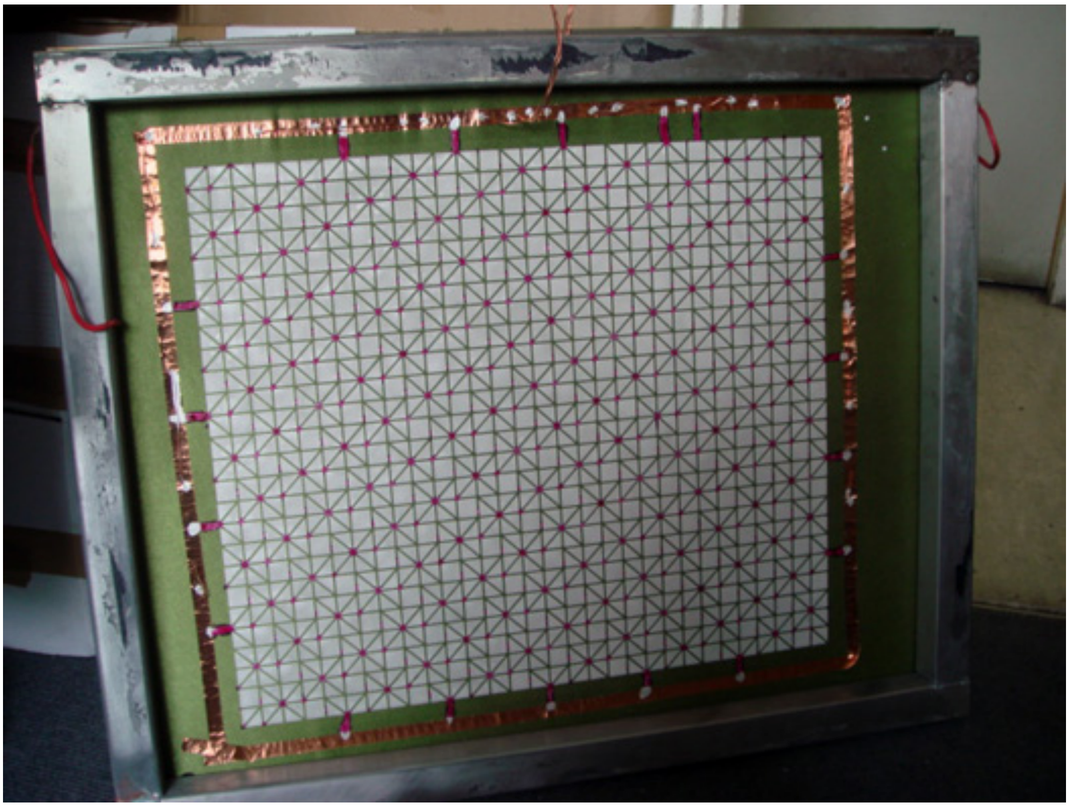


Figure 6.39: A conductive edge around the pattern is used, so that the copper wire does not have to be threaded through the platelets, but can be attached to the edge instead.

When using conductive fabric, the connection is much easier: the copper wire can just be threaded through an area of the fabric outside the pattern that will be cut away later.

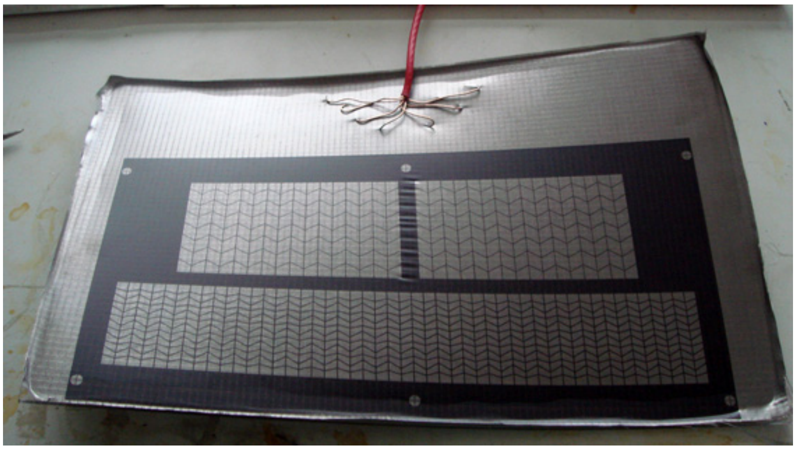


Figure 6.40: Conductive fabric can simply be connected by threading the copper wire through part of the fabric that will be cut away later.

Including functional elements in the pattern

If I want to use MFT for the creation of a functional object I might want to have holes in particular places, or have small elements attached to the platelets. In these cases the pattern can be adjusted to take these into account.

If, for example, I want to string a ribbon through a row of platelets for easy gathering, all the platelets in that row need to have a hole to pull the ribbon through. I could drill these holes after the electroforming process, but holes made this way will have sharp edges. It can therefore be better to provide for a hole before the electroforming process. I can adapt the pattern by including non-conductive areas where I want holes in the platelets. There will then be no metal build-up in these places, but the fabric will be left intact throughout the electroforming project. After electroforming I can easily remove the fabric from the holes with a fine-tipped soldering iron, burning it away so that no frayed edges stayed behind. This not only gives a tidier result than drilling a hole, it is also quicker, and the softer edges do not damage the ribbon as badly.

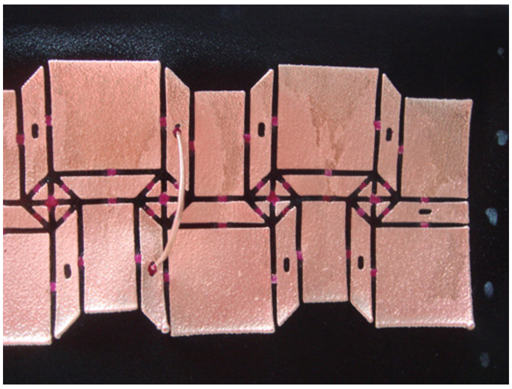


Figure 6.41: The fabric is not made conductive where holes are needed later on. I used these 'holes' for threading the copper wire so that it would not leave traces on the pattern.

If I want to attach a small object to MFT, and make it appear as if was 'set' in the fabric, I can glue it in place before electroforming, and partially cover it with electrodag so that metal will build up around it. This metal layer will then make the object look more integrated to MFT, as well as strengthening the bond.

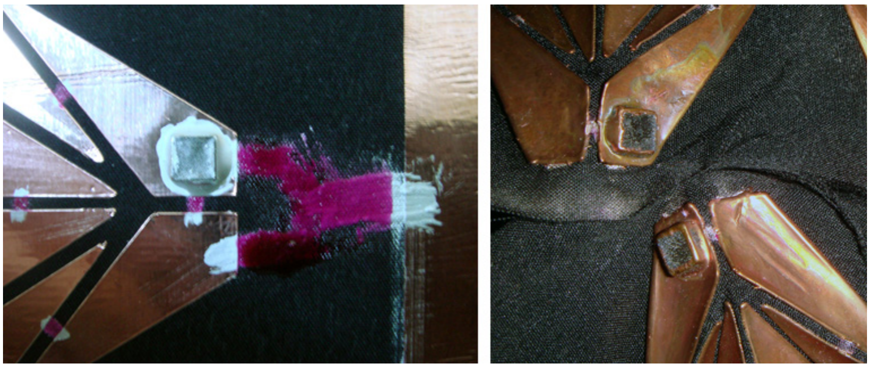


Figure 6.42: Magnets are glued on the fabric before electroforming and their sides are covered with electrodag (left). The magnets then appear 'set' on the platelets after electroforming (right).

Electroforming Process

Once the fabric has been prepared, it can be electroformed. The electroforming process was not the focal point of my research. I did need to have direct access to this process so that I could see how successful the preproduction process had been. I had to make sure that the whole of the pattern was receiving a layer of copper, that platelets were not peeling off, and control the thickness of the platelets. This meant that I needed a basic knowledge of how the process works so that I could safely use the equipment and get optimal results.

Electroforming different metals

The process of electroforming can be used for a variety of metals. I used mainly copper for the creation of MFT, and had a few pieces made in silver. Other metals could be used, but were not tested at this stage for both financial and Intellectual Property Rights reasons.

Copper electroforming

Copper is in many ways the most suitable metal for the creation of MFT. First of all, it is a relatively cheap metal, allowing me to make large pieces at a reasonable cost. Secondly, the acid-based Cuprasol solution is not as harmful as the cyanide-based silver solution, and easier to maintain. The combination of cost, relative safety and maintainability makes it possible to install a large electroforming tank, which in turn allows me to make larger pieces. Since I was in charge of my own copper electroforming I could also monitor the process from start to finish. For these reasons, I made most of my MFT samples and “Wearable Metal Origami” pieces in copper.

Silver electroforming

The department also has a silver-electroforming tank, which deposits fine silver. This process uses a cyanide solution, so I could not do the silver electroforming myself for Health and Safety reasons. Peter Musgrove kindly did this part for me.

Other electroforming

It is possible to make sterling silver, fine gold and different grades of carat gold through electroforming too. Testing these different metals would have given me a more spectacular range of samples but would not have added any new knowledge to this project. Since I had already proven that the electroforming process works for both copper and silver, it would also work for the other metals. This is why I decided not to spend precious time and resources on these tests, or risk endangering the intellectual property tied up in my project by having to hand over samples to commercial companies.

Controlling the electroforming process

The basics of electroforming are simple: all that is needed are a battery, simple chemical solution, anode and conductive object[4]. But when accurate results are needed, a little more knowledge and some better equipment are required.

I started this research project without any specific knowledge about the electroforming process because I had never really been involved in it when I was an MA student. Because of Health and Safety reasons it was then, and still is, prohibited to MA students to use the electroforming tanks without the direct supervision of a technician. It is also the technician's responsibility to maintain the tank and the solution. I was given a bit more freedom than the average student when I did my MA, and was allowed to put my own work in the tank. Still, I only suspended the fabric in the tank, and set the current to run through the fabric to what I was told would probably be best. I did not know what is important to get good electroforming results.

So when I started my research project, I read up on electroforming and found out that this seemingly simple process is not quite that simple. The chemical balance of the solution has to be maintained within certain limits for optimal results. The thickness of the metal layer is determined by the time the piece was immersed and the current that was sent through it. The amount of current going through the tank depends on the conductive surface area of the piece that is being electroformed. The metal layer builds up more quickly on protruding edges than on flat surfaces, and hardly on hollow parts. The distance between the anodes and the piece influences the result, as does the temperature of the solution. Finally, the solution has to be filtered and agitated when in use to take out impurities and keep the chemical balance equal throughout the whole of the solution. There are basic rules for all these elements, but none of them is set in stone. In the end, the electroforming process is almost an alchemist's job: a little magic and good luck are required. I have followed discussions on the yahoo-group on electroforming, and even experienced professionals often do not agree on what is going wrong with a job, or how the problem is best rectified.

The electroforming process did not always work well for me. Sometimes I could understand what went wrong, be it that I had used too much or too little current, or that I had used an inappropriate preparation method. Sometimes I did not know what had gone wrong. It was difficult to get uniformly good results, and this was frustrating. I kept a log of all the pieces I electroformed to keep track of the different factors that could influence the outcome, and through time I did become better at achieving reasonable results. A selection of pages from this log can be found in appendix B. I will keep track of the process this way, and as I gain more experience I will keep on improving the results.

Rinsing MFT after electroforming

It is important to rinse the work well once it has come out of the electroforming tank: no traces of the electroforming solution should be left behind. This is especially important for MFT because of its textile layer, which could entrap the solution in its fibres. The copper electroforming solution is acidic, so I decided to add an extra step to the rinsing process to neutralise any acid that might remain. Every time I removed a piece from the copper electroforming tank I would do the following: first I would rinse it in water to remove as much of the electroforming solution as possible; then I immersed it in water with sodium bicarbonate and let it soak for at least 15 minutes; then I rinsed it a final time under running water. I would then carefully wipe most of the water off, and leave the work to dry further in the chemical room.

Postproduction processes

Finishing techniques

Once MFT has been electroformed, but before it is folded, it can be treated with different processes to change the appearance of the platelets.

Matt surface

Depending on the fabric, the platelets can come out of the electroforming tank with a high gloss smooth finish or with a texture like the fabric underneath. The surface can then be matted with a brush and pumice powder very carefully to minimise damage to the textile hinges.

Patination

Because patination is a simple way for creating changing the colour of copper, it was suitable for experimentation with different effects. I started with colouring the whole of MFT, by treating the whole surface with the readymade “Silberbelag” solution from Augusta Labor. With the next sample, I covered up some platelets with a vinyl mask before patination. This allowed me to create patterns of coloured and uncoloured (still the colour of copper) platelets. Depending on the platelets I decided to colour, I could create different effects.

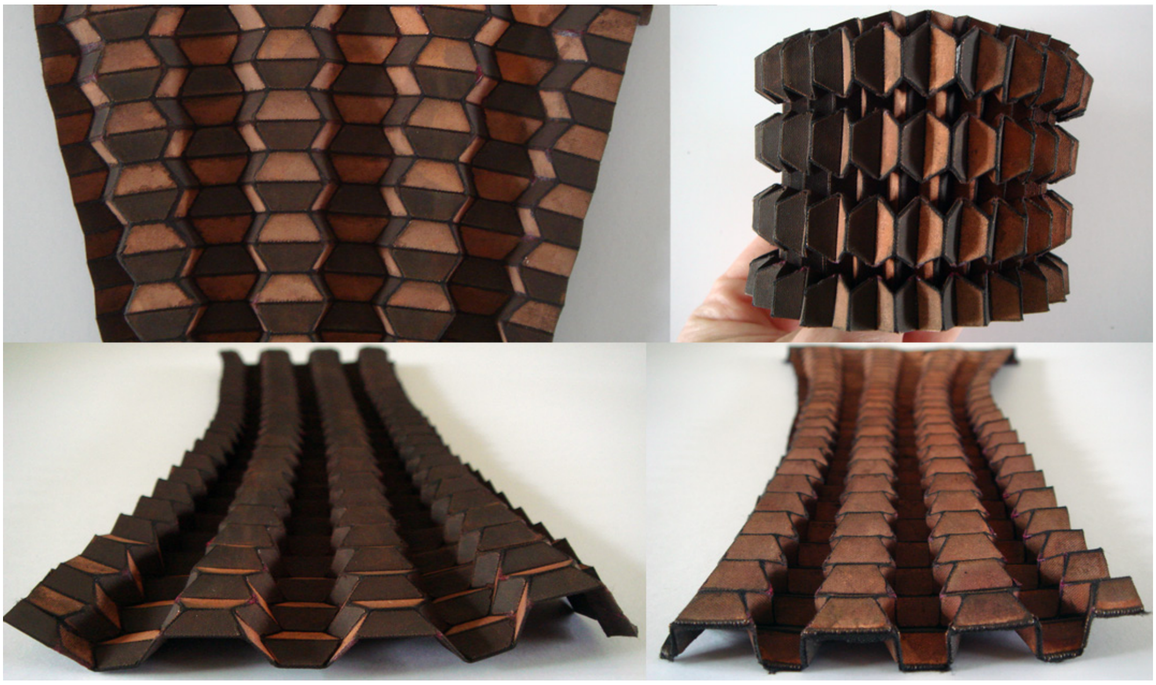


Figure 6.43: Patinated sample, top view (top left), view along the surface in opposing directions (bottom left and right), sample curled into cylinder (top right).

Some samples seemed to change colour when looked at from different angles, in other ones the patination created greater visual depth. The design for the vinyl mask was adapted from the drawing for applying the conductive/non-conductive pattern and cut on a vinyl cutter. This did not take too much time, and weeding was quick as well. With the help of transparent transfer foil it could be accurately applied, giving a good result. The only disadvantage was that if I was not careful, the edges of the vinyl came loose, making the patination bleed onto platelets where I did not want any.

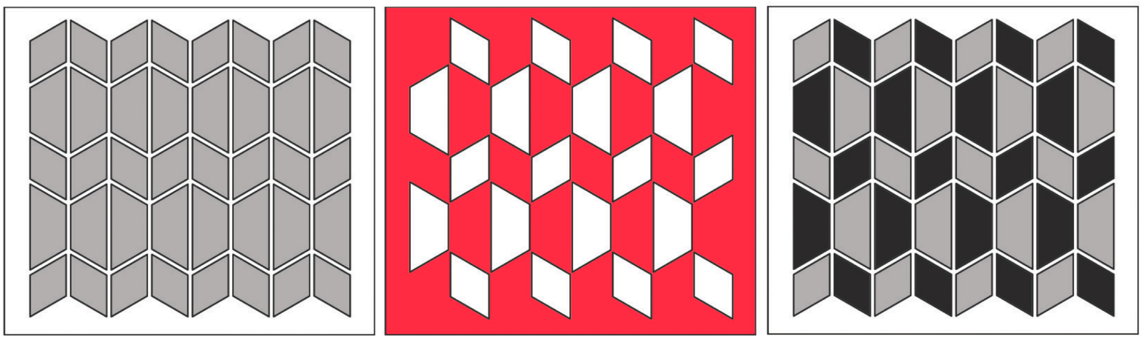


Figure 6.44: Method for applying local patination. Basic printing pattern (left), Vinyl mask for patination (centre), cut on black lines, and white areas removed. The vinyl mask is applied to MFT before it is folded, and patination liquid is applied. Resulting patination pattern (right).

Plating

Peter Musgrove plated one sample in gold and another in silver. Both samples came out well. Where the plating was folded the colours became even more stunning: each platelet reflected the colour of the platelet it was folded towards. This made the gold colour much deeper: it turned a deep peach although it had been yellow when unfolded. Silver became yellowish.

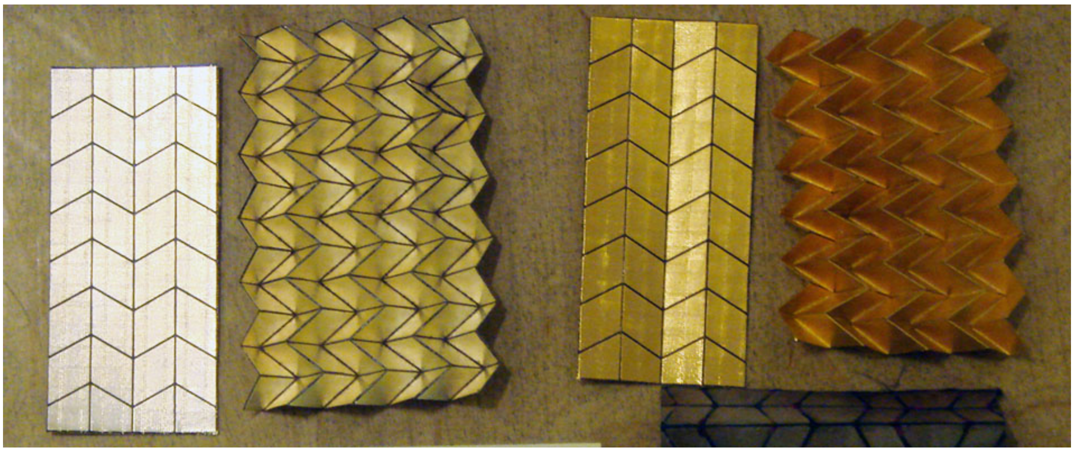


Figure 6.45: Silver plated samples, flat and folded (left). Gold plated samples, flat and folded (right).

Lacquering

I was seduced to try this technique by the samples from the Belgian company ASP BVBA that made casting metal look like anodised titanium. They claimed that the layer of lacquer was minimal, which convinced me to give it a chance. I tried to lacquer a sample myself, applying Plasti-Kote fast dry enamel with a fine brush. The copper colour was successfully covered, but the enamel stiffened the fabric hinges. When the sample was folded the enamel on the hinges cracked unevenly, making the MFT unappealing and unpleasant to the touch. But since ASP BVBA promised a minimal layer of lacquer, maybe their result would be better. I masked off a few of the hinges with tape and sent off a sample. It came back just as stiff as my in-house sample and the masking tape had peeled off the hinges, not offering adequate protection, so I decided that lacquering just was not suitable for MFT.

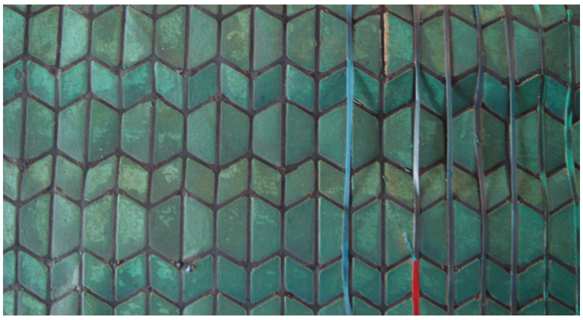


Figure 6.46: Lacquered sample, as returned from ASP BVBA.

Finishing edges

MFT can be placed on a larger piece of fabric, or be used as a stand-alone material. In the first case the conductive pattern is applied onto a piece of fabric of the appropriate size, and left in place after electroforming. In the second case, the fabric base only has to be large enough to fit on a frame, and after electroforming the fabric is cut away with a hot pyrotechnic tool or soldering iron around the edges of the pattern. In my opinion it is best done with a margin of approximately 1 mm around the metal (the width of the hinges), using a hot tool so that the fibres of the polyester fabric are fused together to prevent fraying. If the fabric edge is left longer, it will curve into rounded shapes, breaking the regularity of the straight folding lines, making the edge look sloppy. If the fabric is cut immediately along the edge of the metal platelets, the fibres tend to melt a little deeper into the hinges, so that the edge is not straight anymore. It is also possible to cut through the metal platelets, but since they are only around 0.3 mm thick, the cutting creates sharp edges that are unpleasant to the touch.

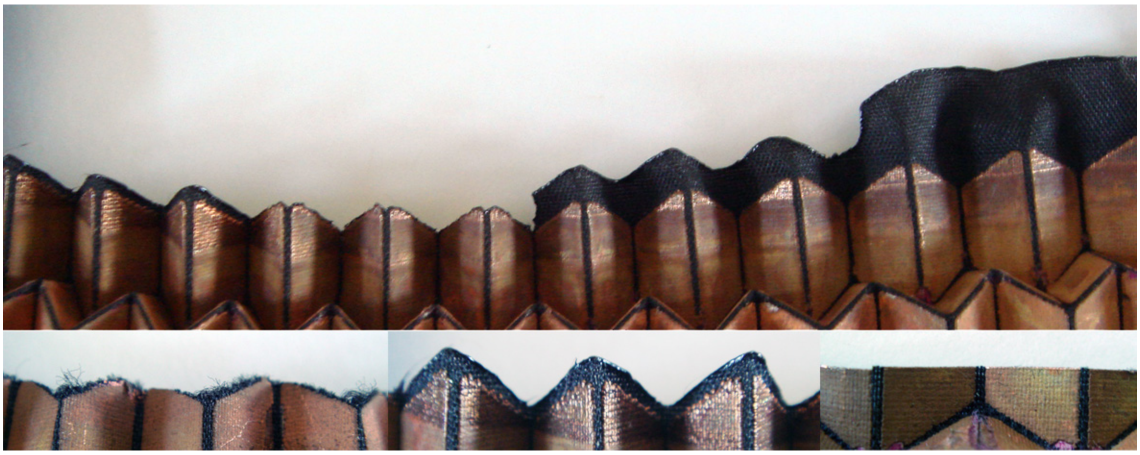


Figure 6.47: Finishing edges.
Top row all cut with hot tool, left to right: ideal distance of 1mm from edge; fabric cut too close to platelet; fabric cut too far from platelets.
Bottom row, left to right: fabric cut at ideal distance with plain scissors (fraying), ideal edge, cut through platelets.

Controlling the behaviour of MFT

The combination of the relatively weak textile hinges and the combined weight of all the platelets of a piece of MFT often makes the material unfold under its own weight, especially if it is a large piece. Sometimes this is an advantage, but at other times I need the material to remain folded. MFT can also unfold locally, when a lot of pressure is put on a small area. Once it has been unfolded it often does not fold back in the right way. I had to find ways of constraining MFT so that it would only unfold when, where and as far as I wanted it to.

Size of platelets

Larger platelets need to be thicker than small ones to make sure they are stiff enough. This puts more strain on the hinges, making them unfold more easily. One way of preventing the unfolding is consequently to reduce the size of the platelets, scaling down the whole pattern. Since this has a strong effect on the design, both visually and functionally, this method is not always suitable.

Constraining specific areas

MFT can also be prevented from unfolding completely by constraining a few smaller areas throughout the material. This can be done in two ways: either by keeping a single hinge or vertex fixed in completely folded state, or by limiting the distance two vertices can move apart.

A single vertex or hinge can be constrained by sewing through the hinges, or by riveting two platelets together. The advantage of this method is that it can be done almost invisibly; the disadvantage is that in this vertex there is absolutely no flexibility left.

Figure 6.48: Constraining one vertex by sewing through the hinges.

To limit the distance two vertices can move apart, a piece of thread as long as the maximum distance can be fixed with one end onto the first vertex, and the other end onto the second one. This can be done in a continuous line, fixing a whole row of vertices in place. The advantage of this method is that some flexibility still remains in MFT as long as the string between two vertices is longer than the minimum distance between them. The disadvantage is that the thread will be visible on one side of MFT.

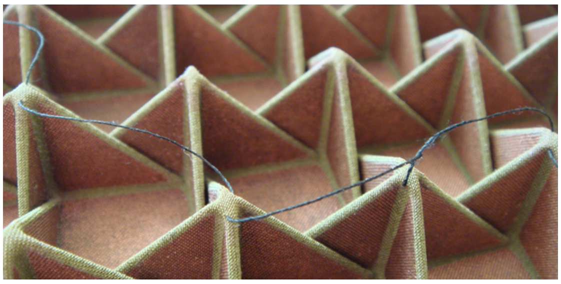


Figure 6.49: Constraining the distance between vertices with thread.

Constraining the edges

Keeping the edges of MFT in a folded position will also prevent the piece from unfolding. The middle can sag or even unfold locally, but because it is surrounded by folded material it cannot completely unfold. The edges can be kept together by sewing, like described above, or by pulling a wire through the outer platelets, and closing it into a loop not much longer than the circumference of the piece of MFT. This can be a good method to keep MFT folded temporarily, by using a pull-cord that can be released when unfolding is allowed.

Connection techniques

When MFT is used for the creation of an object it is important to find efficient ways of closing seams, attaching closures, stones, findings and other elements. Metal techniques can be used on the platelets and textile techniques on the hinges.

Textile techniques

I find the textile technique of sewing most suitable for “textile manipulations” such as closing seams and restraining MFT from folding (which is almost like putting a dart in clothing). Sewing can be done both when MFT is unfolded and when it is folded. This makes it possible to close seams before folding, keep MFT in shape after folding and add findings, such as hooks-and-eyes and snap buttons at different stages.

Metal techniques

The most useful metal techniques for MFT are riveting and piercing, but care must be taken that the thin platelets are not damaged. Riveting can be used for connecting two platelets to each other, connecting findings or closures to a platelet and for setting stones, using a setting that can be riveted onto thin sheet. Soldering or any other process that needs high temperatures cannot be used because high temperatures would melt the fabric, destroying MFT. I though that laser welding might be a possibility since the laser beam only heats up a small area and the hinges can de avoided. When David Turtle did a test, the results were disappointing: the textile hinges were not damaged, but the laser beam burned through the platelets. This probably happened because the platelets are not of a sufficient thickness.

Conclusion

There were many materials and processes to be tested for this project. It was hard to prioritise because I not only wanted to find the perfect preproduction process, but also had to learn about electroforming and wished to learn how MFT could be finished, how its deployment could be controlled and how it could be turned into objects. I therefore chose to do a wide range of tests, each one sufficient to decide whether a certain material or process would be viable or not. To remain in control of the whole process, with all the different techniques (computer drawing, screen printing, vinyl cutting, electroforming), I decided to use mostly those techniques that I could apply myself.

Maybe I spread myself too thin on this part of my research. If I had concentrated on fewer processes and techniques, I could have gained a deeper knowledge of those. But I had set out to prove that MFT can be made in a studio environment, and for me this involved testing the processes that are available to the studio jeweller for their suitability for MFT. The wide range of tests for the preproduction process was meant to lead me the one perfect preproduction process that I was looking for. I would then have tested that process in greater detail. Since I did not find this perfect process, I kept on searching and broadening the research. I did discover two new reliable preproduction methods, not much easier or faster than the process I used for my MA project work, but each with its own advantages (see table in fig.Figure 6.38). I used them both for the creation of the “Wearable Metal Origami” described in Chapter 7.

I now have a lot of material on all three parts of the production that I can follow up on in depth in further investigations. I will also keep on looking for the “perfect preproduction process”.

7. Application of Metallised Folding Textile to "Wearable Metal Origami"

Why use Metallised Folded Origami for the creation of wearable pieces?

The development of MFT as a material was a whole journey in its own right, but I wanted to go one step further: demonstrating its novel appearance and its properties of flexibility and shape-change. I did this by making objects, more specifically wearables. The process of making objects with the material not only proved that MFT can be used for a practical purpose, but also allowed me to better understand what its possibilities and limitations are, and demonstrate those to others. MFT can be applied in many ways, some of which were investigated by my colleagues at the "Deployable Adaptive Structures" Research Project. They concentrated on interior objects such as lighting and blinds, but were also looking at small actuated pieces. I decided that I needed to focus on one type of application for myself: by exploring the qualities of MFT within the constraints of one discipline, I would give myself the best chance of gaining a certain depth of understanding this material, setting foundations on which I could then expand into other fields later on.

There are several reasons why I chose to concentrate on wearable applications for MFT. First and foremost, I invented MFT because I wanted to make a folding metal material to be worn. I started with making jewellery, but quickly decided that MFT would show its properties better on a slightly larger scale, and be more effective if it was allowed to cover a larger part of the body. That is why I chose to make wearables and to include but not constrict myself to the traditional jewellery forms such as bracelet and necklace. This way I could build on my existing knowledge of jewellery, and expand into the not so familiar territories of accessories and clothing. I believed that this moving from the known into the unfamiliar would give my creativity the best possibility of developing. Secondly, working on this scale allowed me to make MFT myself using the department's facilities, as described in the previous chapter, this gave me maximum freedom to experiment. This scale is also ideally suited for MFT, keeping it light enough so that it can still support its own weight, yet being large enough that it will fold neatly. Thirdly, the body really provides an ideal environment for MFT: it counters its tendency to unfold under its own weight and by providing a good support gives it shape and actuates it. Wearables are also ideal for demonstrating MFT's flexibility (it can move along with the body), its possibility to change shape and the potential for transforming one object into another because they are worn close to the body and can be actuated by the wearer. Additionally, its metal appearance and the possibility to use silver and gold as well as copper make MFT suitable for precious wearable pieces. The cost of these materials as well as the labour intensive production process is accepted in the marketplace of exclusive jewellery and high-end fashion. Lastly, examples can be found in both jewellery and fashion design of flexible metal wearable pieces that have become popular in their fields. The success of Tone Vigeland's jewellery and Paco Rabanne's chain-mail dresses give an encouraging example for me to build on. I wanted to use MFT to take that sort of work one step further, and offer a new look that refers to traditional chain-mail and armour, but is applied in a contemporary way. Also, my approach to wearable pieces formed a nice contrast with the architectural and actuated work of colleagues DAS, while both could still inform each other.

How use Metallised Folding Textiles for the creation of "Wearable Metal Origami"?

Using MFT for the creation of "Wearable Metal Origami" meant that I had to consider practical and design issues on how this could be done. Some of the issues were generic, they would have come up in the design process for any product made with MFT, others were specific to designing wearables. Trying to design for Metallised Folding Textile felt to me like learning a new craft discipline, only there were no teachers to teach me the necessary skills. I had to find out how flexible the material is; how to make it fold the way I wanted to (see Chapter 5, Principles and Practicalities of Folding); how to keep it in shape when necessary and how to integrate it in an overall design. I could start designing only after I had established the basic characteristics as described in previous chapters, and then expanded my knowledge as I went through several design case studies.

A critical aspect to the design of a "Wearable Metal Origami" object was choosing the folding pattern. As described in "Chapter 5, Principles and Practicalities of Folding", the different types of patterns behave in different ways. All the patterns described in that chapter are suitable for the creation of "Wearable Metal Origami", with the choice of a specific pattern depending on the object I wanted to make, or which part of the body it will cover. Different parts of the body move in different ways, determining which groups of patterns can be used, then the ideal pattern is selected or created based on a process of trial and error.

I needed to consider where on the body “Wearable Metal Origami” could be worn. There are practical limitations I had to take into account. Firstly, the platelets have a minimum size, making it difficult to design small objects such as rings. Secondly, folded MFT can be damaged by crushing it, which makes it unsuitable for use on the soles of the feet and the bottom. Lastly, the thickness of the material when it is folded is impractical for places where there is a lot of friction, such as the armpits.

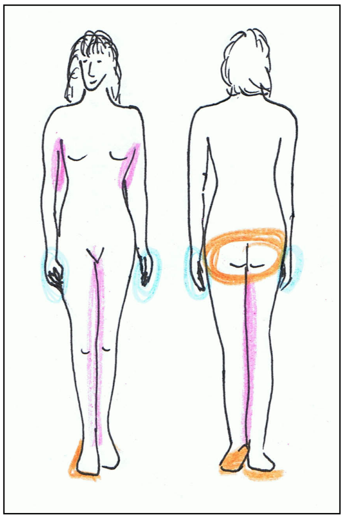


Figure 7.1: Problem zones for wearing “Wearable Metal Origami”.
Orange zones: MFT will be crushed by walking or sitting down.
Pink zones: The thickness of MFT will cause too much friction.
Blue zones: the minimum size of the platelets makes it difficult to use for small objects.

I wanted to make a range of objects that would demonstrate the functionality of MFT, how it can be used to make object behave in different ways depending on the chosen folding pattern. I wanted to show that it was not only possible to make a piece that would take on the shape and movement of the body, but also to make a piece change shape or size, and to transform one object into another.

The easiest way for me to make objects from MFT is to take a piece of this material, hold it in my hands, look at how it moves and take inspiration from this to decide which object I can make by just sewing the edges together and maybe adding a few extra bits. It was tempting to stick with this method because it gives good results, but it does limit me in my design possibilities. I also wanted to be able to work to a brief in which a specific object is needed. To achieve this the folding pattern of MFT would have to be adapted to the desired shape and movement of the object. Approaching the design of an object in this way meant that I had to understand the folding patterns well enough so that I could select a pattern that had the right type of folding and consequently adapt it to fit the specific design requirements.

Making “Wearable Metal Origami” also meant that I had to find out how it can be pieced together and choose suitable closures. The edges had to be finished in an appropriate way.

All these design elements were addressed through the process of designing and making “Wearable Metal Origami” in different ways. I set myself 4 design briefs, trying to approach the designing in different ways, and aiming to achieve results that would show the different qualities of flexibility, changing shape, size and function. The choice of folding pattern, location on the body and other design elements would be addressed while working on these briefs.

Four Case Studies

As mentioned above, I chose to set myself four case studies to test the design processes needed to turn MFT into “Wearable Metal Origami” and to see whether I could use MFT for the range of products that I wanted to create. Each case study revolves around an attribute of MFT, and each time I set myself the approach I would take: either taking an existing pattern for MFT to inspire me for the design (from MFT to concept) or to work from a design idea towards a pattern for MFT (from concept to MFT).

Adapting to shape and movement of the body

Shoulder Cape

Setting the brief

Aim: to design an object that would take on the shape and movement of the body.

Method: working from MFT to concept.

The design process – choosing the folding pattern

Even though the design process started from MFT, I had an idea of the kind of wearable piece I wanted to create. It is important to me to have some idea of what I am going to make when I start, so that I have a direction and framework within which to make decisions. In this case I wanted it to take maximum benefit from the piece being worn on the body: the body should dictate its shape and its movement. I hoped that this would provide for a piece that would be actuated in an interesting way simply by being worn. I wanted it to be bold, creating maximum effect with a simple approach.

I had decided to approach this design process starting with MFT, so my first action was to choose a sample to work with. For the DAS project I had made a few samples of a square planar pattern, for this reason I was familiar with the way it moves. It curves into a spherical shape when it is partly unfolded, which seemed an ideal shape for the shoulder so I tried putting one of the samples on the shoulder of a mannequin. It took on the shape well, and I liked the smooth surface implied by the squares and interrupted by star shaped indentations.

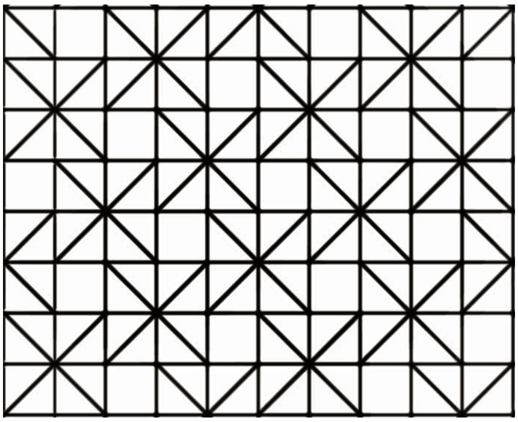


Figure 7.2: Crease pattern for the selected sample of MFT.

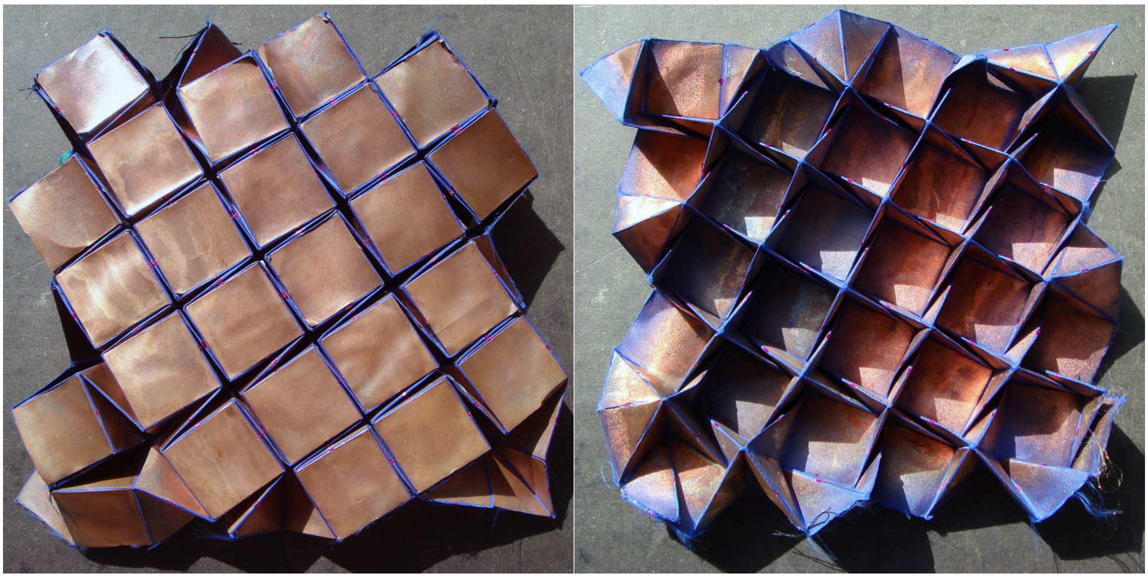


Figure 7.3: Folded sample of MFT, seen from front and back.

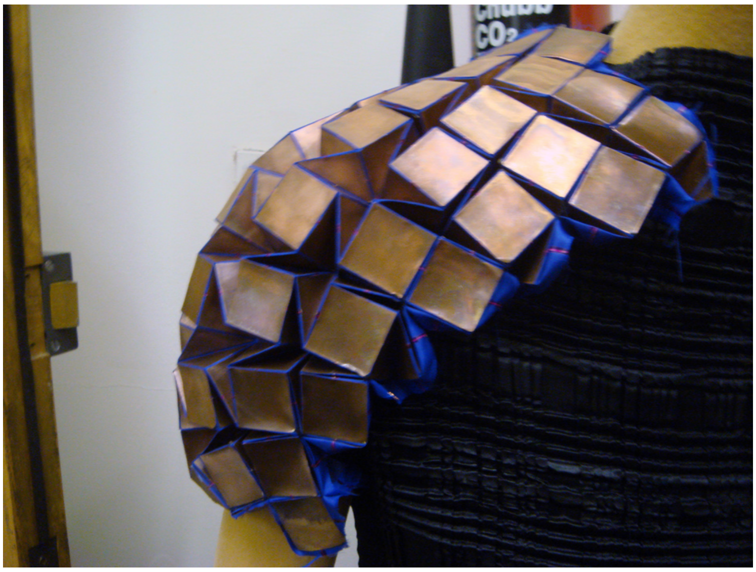


Figure 7.4: Folded sample of MFT, draped over a shoulder.

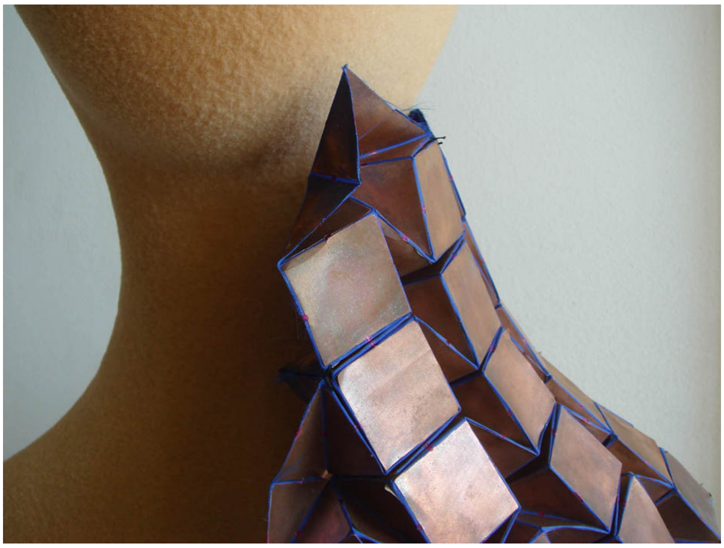


Figure 7.5: Folded sample of MFT, failing to fold smoothly around the neck.

The design process – modifying the folding pattern

I liked the way this pattern curved over the shoulder, but also wanted it to go up the side of the neck. This meant it had to curve in the opposite direction, but the pattern would only curve one way: with the star shaped pyramids pointing inwards. Its movement comes from the folding of the pyramids and if they are all pointing in the same direction then the flexibility only works in that one direction. I decided to try inverting the direction of some pyramids, so that there would be a few pointing to the front, the rest pointing to the back, hopefully making the pattern flexible in both directions. I made paper samples to try this idea.

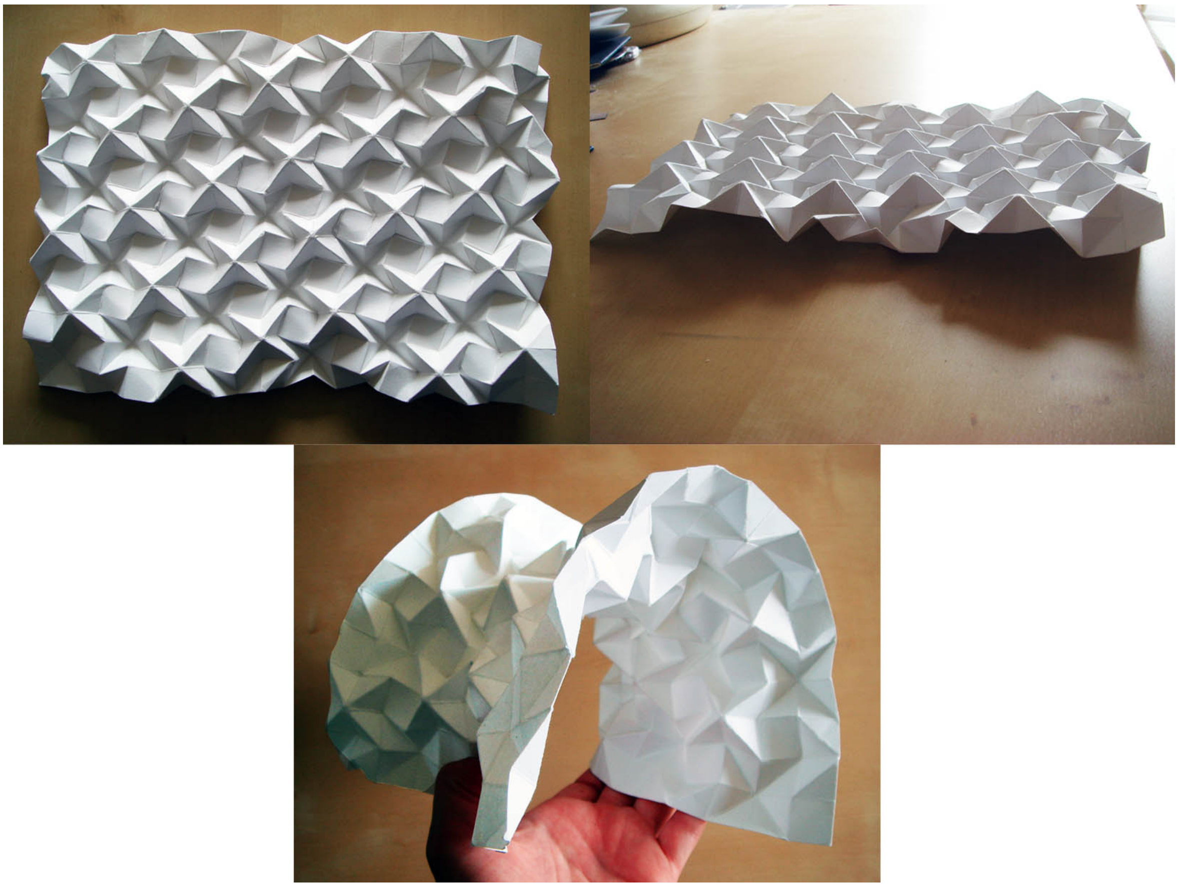


Figure 7.6: Adapted pattern, half of the pyramids have been inverted, equally spread out.

My first attempt was to alternate front and back in a regular pattern throughout the whole piece of MFT. I thought this would have made the whole pattern curve in both directions, but it proved to be counter-productive: its natural tendency was to lay down flat, and when forced into a curve this was anticlastic rather than spherical.

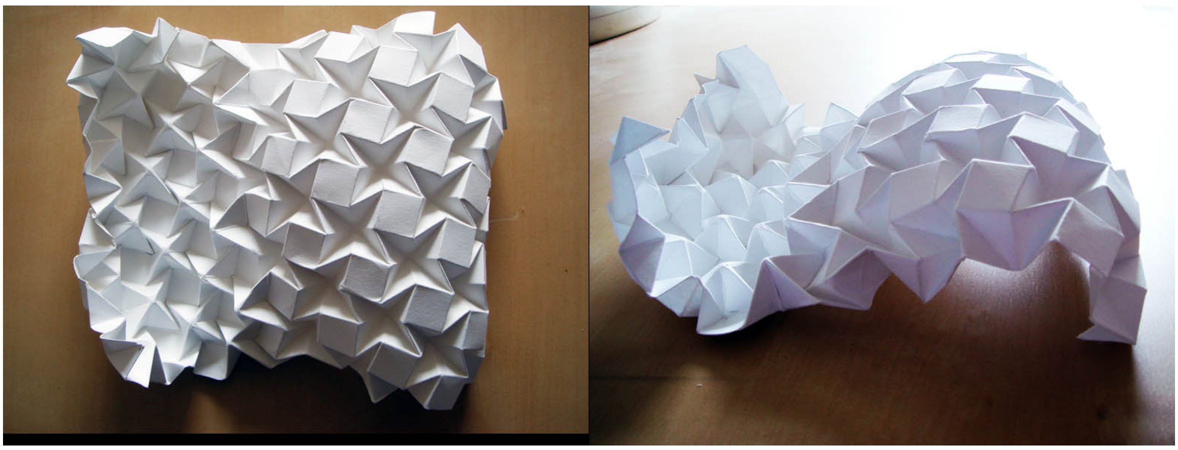


Figure 7.7: Adapted pattern, half of the pyramids have been inverted, grouped together on one half of the model.

I then tried to have all pyramids on one half of the sample pointing one way, and all those on the other half pointing the opposite way. This worked: both halves were now curving in opposite directions, just as I needed. I proceeded to try this out in MFT, using a second sample that I had previously made for a technical test.

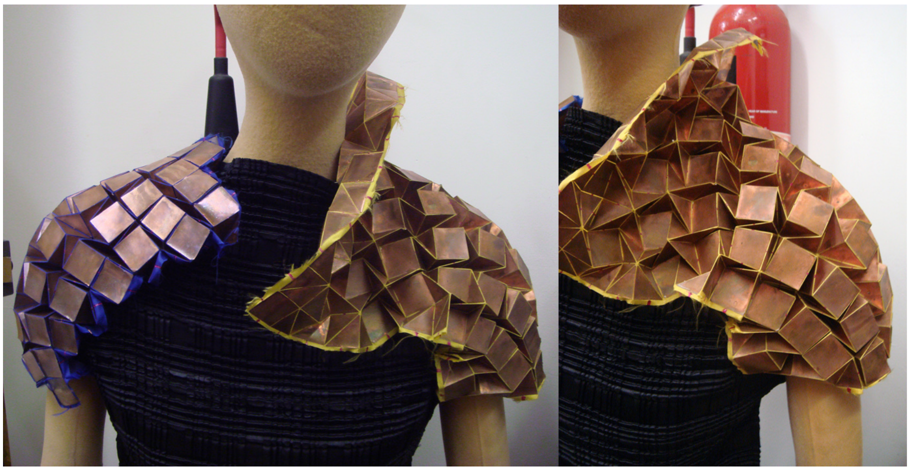


Figure 7.8: Trying out the changed direction with the sample of MFT.

The result was satisfactory: I knew I could use this folding pattern for the Shoulder Cape. Now I had to decide on the scale of the folding pattern, and the size of the cape. I wanted the scale of the pattern to be slightly smaller so that it would fit better around the shoulder, but did not want it to loose its robustness. I made the decision to reduce the side of the squares from 30 mm to 20 mm, ensuring that the pattern was still clearly visible and the squares would not easily be mistaken for sequins. I wanted the area covered by the cape to be as large as possible. The samples I had used were almost the maximum size that I could make in the electroforming tank, and I wanted to cover the shoulders more than that. This meant that I would have to piece the cape together from at least two parts. Since the edge of the samples came up at the middle of the back of the neck it seemed a natural choice to create a seam there, joining the two samples together, so I choose to make the cape in two parts, one for each shoulder. I proceeded to draw up the new pattern, making it as large as I could fit in the electroforming tank. I made the pattern for the left shoulder the mirror image of the right so that the cape would be symmetrical.

The design process – model making

Figure 7.9: The plywood on TYVEK™ model, in the first stage of folding: the part around the shoulders.

To try out the new pattern I made a plywood on TYVEK™ model, and created a seam of an arbitrary length, around 1/3rd of the width of the pattern there. I first folded the parts that would curve around the shoulders, so that I could decide where to make the transition to fold it the opposite way for the neck.

Figure 7.10: The plywood on TYVEK™ model, folding the part around the neck. The transition line of folding the pyramids back to folding the pyramids to the front on the left and right are not symmetrical yet.

I then folded the part around the neck, and later made both parts symmetrical by making the transition follow the same lines.

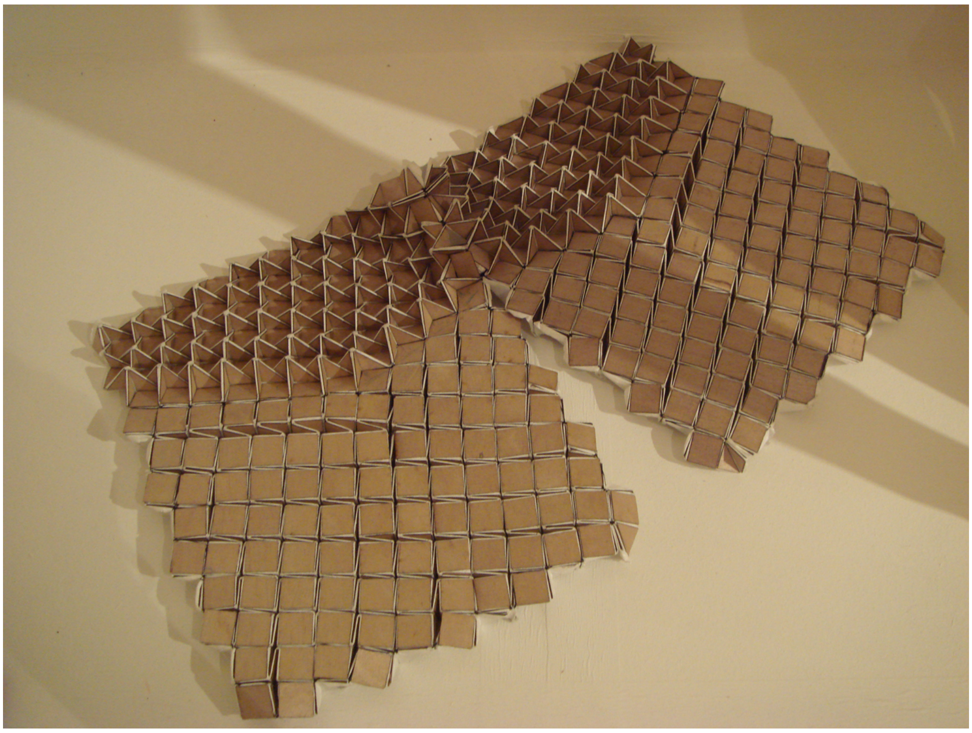


Figure 7.11: The plywood on TYVEK™ model laid out flat. Left and right are made symmetrical

I was happy with the result and went on to make the cape in MFT. I chose to use the preproduction process of spraying electrodag through a vinyl stencil because I wanted to keep the textile texture and only wanted to make one shoulder cape.

Outcome: "Wearable Metal Origami" Shoulder Cape

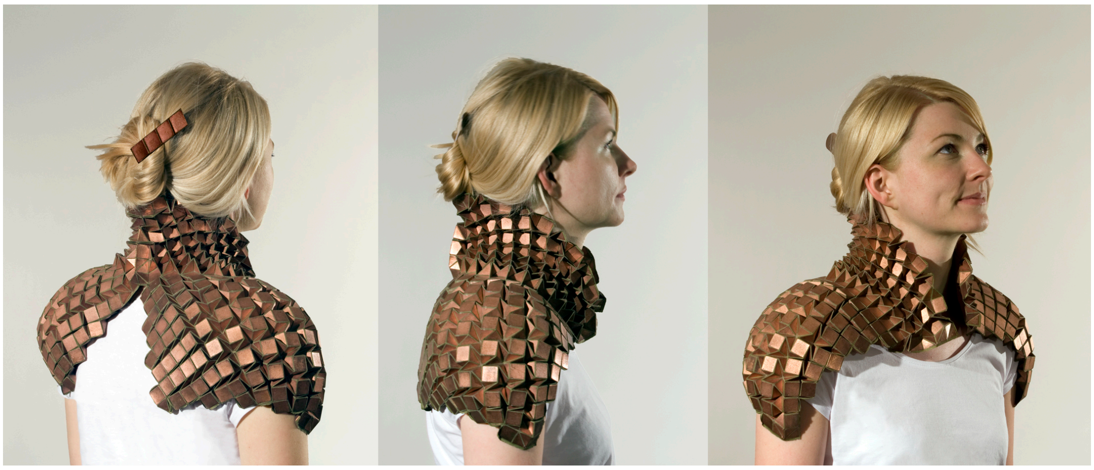


Figure 7.12: "Wearable Metal Origami" Shoulder Cape, back, side and front view on model.

The Shoulder Cape drapes well over the shoulders of the wearer. It subtly moves along with the movements of the wearer.

Reflection on the design process and its outcome

The design process for this piece was simple, straightforward and enjoyable. Because I started from an existing pattern I could let my decisions be guided by intuition and coincidences. I was happy with the outcome and the Shoulder Cape was the most popular piece in my display at the RCA SHOW 2009. In my opinion I reached the intended result: the cape was a bold piece that took its shape from the body.

Looking back on the design process I can now see some missed chances for making the Shoulder Cape better than it is. If I had taken more time to try out different variations instead of choosing the most obvious option I would most likely have created a more refined and better-finished result. I would now try what the cape would look like if I closed the gap at the back, even if that meant that it had to be made from more than two pieces. I would also try what happened if I changed a rectangular outline of the folding pattern to give the cape a smoother edge. These options did not even occur to me at the time because the design process went so smoothly that I did not take a step back to reflect on the options. In the design process I also neglected the movement of the pattern on the body. Having started with a pattern that shaped well to the body but did not have a very impressive motion, I just did not know what to do to improve this aspect.

By starting with MFT and moving on from there the design process became linear: every decision led to the next. Because every step I took towards a solution gave me a following simple question to which I could easily find an answer. Each decision that I took was appropriate at the time that I took it, but this gradual progress never compelled me to reflect on the steps taken to get me to that point. The pleasant simplicity of this approach had the disadvantage of giving a result that was not as well thought through as it could have been.

Size-change

Skirt

Setting the brief

Aim: to design a wearable that would change its size depending on the wearer's wishes.

Method: working from concept to MFT.

I wanted to design a piece of clothing that could change shape or size through the folding of MFT. More specifically, I wanted to design a skirt that could either be worn as a long skirt, or as a short one.

The design process – choosing the folding pattern

I wanted to use a folding pattern that would remain relatively flat when folded, because I wanted to draw attention to the change in length rather than add a three-dimensional element. I thought this would be more practical for a skirt. This idea immediately pointed towards the group of planar folding patterns.

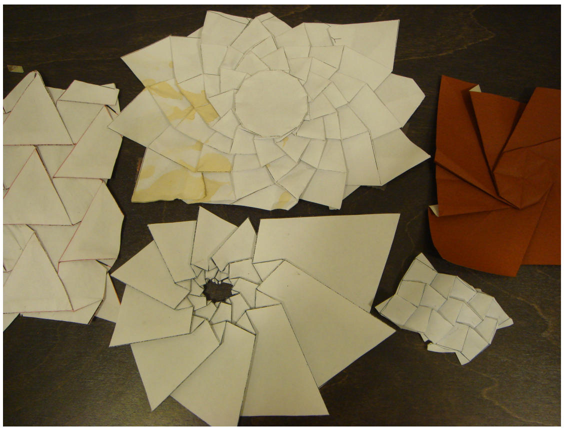


Figure 7.13: a selection of planar patterns

Of this group I chose a pattern that was straightforward in how it folds up. Using a square meant that I could be sure that the decrease in width when folding would be identical to the decrease in height.

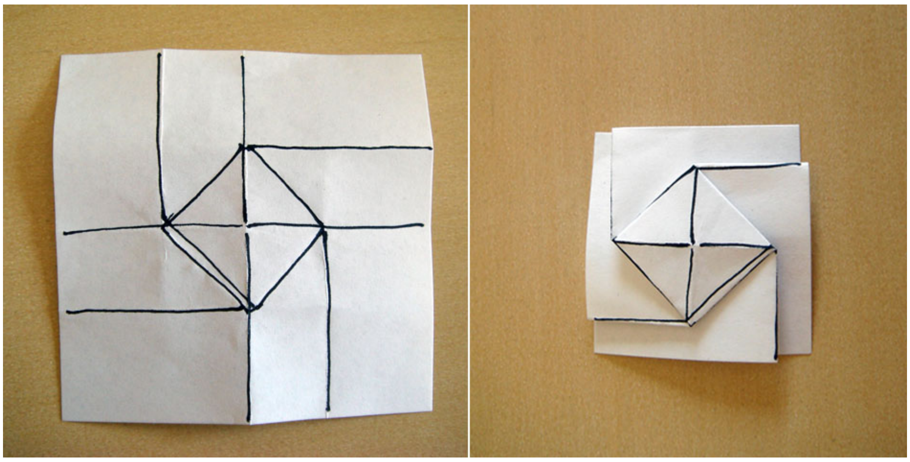


Figure 7.14: Square planar pattern, one unit, flat and folded

The design process – modifying the folding pattern

I tried this pattern on a paper cut-out of a simple A-line skirt and realised that I wanted to shorten the skirt by a long length, but that I could not allow it to become narrower to the same extent. I could therefore not just increase the size of the square, to increase the length-change. I could however line op a series of squares vertically, so that only one fold had to be made in the width of the skirt to shorten it many folds vertically. It also gave the added benefit that the wearer would be able to choose just how much shorter she wanted the skirt to be by choosing the number of squares she folded.

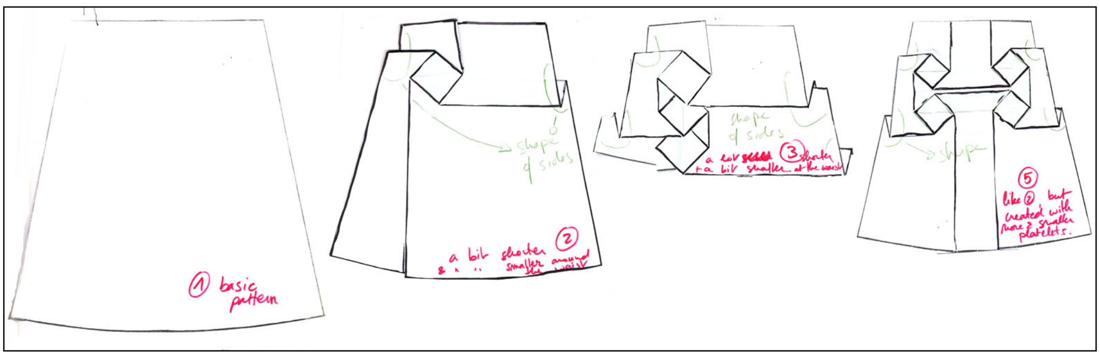


Figure 7.15: basic pattern A-line skirt, unfolded and with three folded variations

Making these models in paper made me worried about how the sides deformed when folded. Later I realised that in fabric this is not an issue, but I could not see that then. I did realise that my knowledge of clothes making was not good enough to solve this problem on my own so I had a tutorial with Anne Toomey, Deputy Head of Department at the School of Fashion & Textiles, to help me with this aspect. She advised me to use a 1/4th life-size mannequin to try out initial models, as well as a full size mannequin to test life size models. She lent me a very simple wrap-around skirt, designed by Allison Willoughby, so that I could study its cutting pattern and use it as inspiration for my skirt. She also advised me to make any awkward shapes that came from the folding process part of the design rather than to hide them.

I studied Allison Willoughby's skirt, which basically consisted of a quarter circle of fabric, with a cut-out at the centre so it could be wrapped around the waist. This design was ideal for my first trial to make a "Wearable Metal Origami" skirt since there were no darts or seems that would complicate the design.

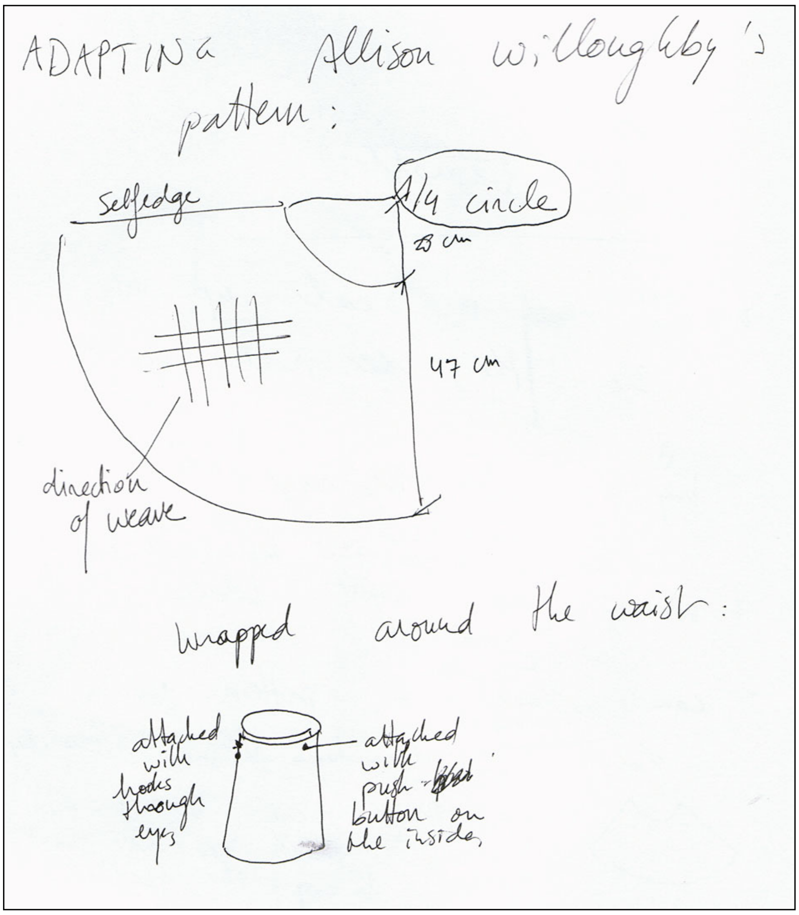


Figure 7.16: Pattern of skirt by Allison Willoughby

I then adapted this pattern to the size of my small mannequin, and tried out different placements and directions for the folding pattern.

Figure 7.17: Folding the wrap-around skirt, pattern and folded model with 1 square

Figure 7.18: Folding the wrap-around skirt, pattern and folded model with 2 squares

Placing the pattern on this shape of skirt was not as simple as placing it on the A-line skirt: the lines that were horizontal on the A-line started spiralling down the circular skirt. This meant that I could no longer work out on the principle of a row of platelets to shorten the skirt without making it narrower. I lost faith in this pattern and drew some patterns on the computer. These patterns were meant to cover the whole skirt, and would consequently be impossible to electroform in our tank because the skirt was too large to go in one piece. Covering the whole skirt would also make it less interesting because the whole surface would be uniform and it would be nearly impossible to make it fold and unfold as desired.

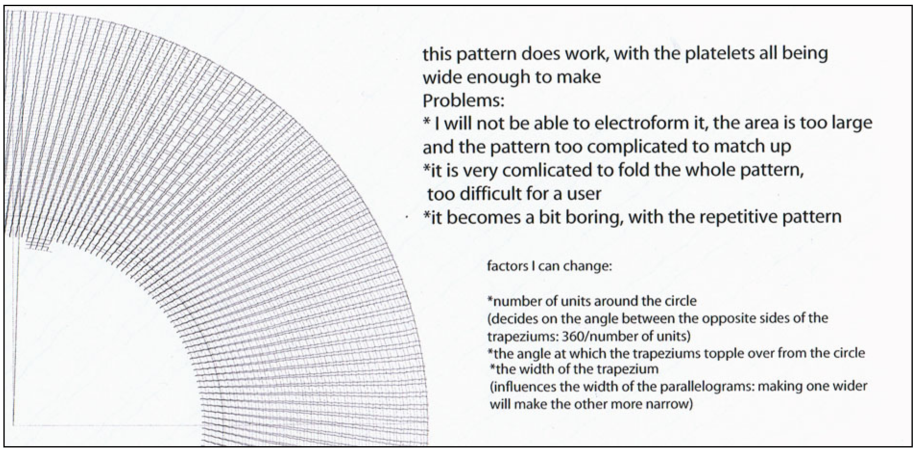


Figure 7.19: design for folding pattern covering whole skirt.

I went back to the square planar pattern to see if I could make it work. After many trials in paper I realised that I had always thought of the skirt in paper terms: as if I had to always fold the whole surface. I had not thought about the fact that textile drapes and that it was therefore possible to only fold a strip of the skirt. I consequently decided to apply vertical bands of MFT to the skirt, leaving the fabric in between them bare. This would enable me to electroform the strips separately onto the fabric while still allowing the whole skirt to change in length. I chose to use rows of the square pattern, and now had to decide on the outline of the MFT strips, their length and their location on the skirt. I used flock-on-textile models for the initial tests and a plywood-on-textile test next so that I could work out a system to adjust the length of the skirt.

Figure 7.20: Flock-on-textile model to decide on location MFT strips.

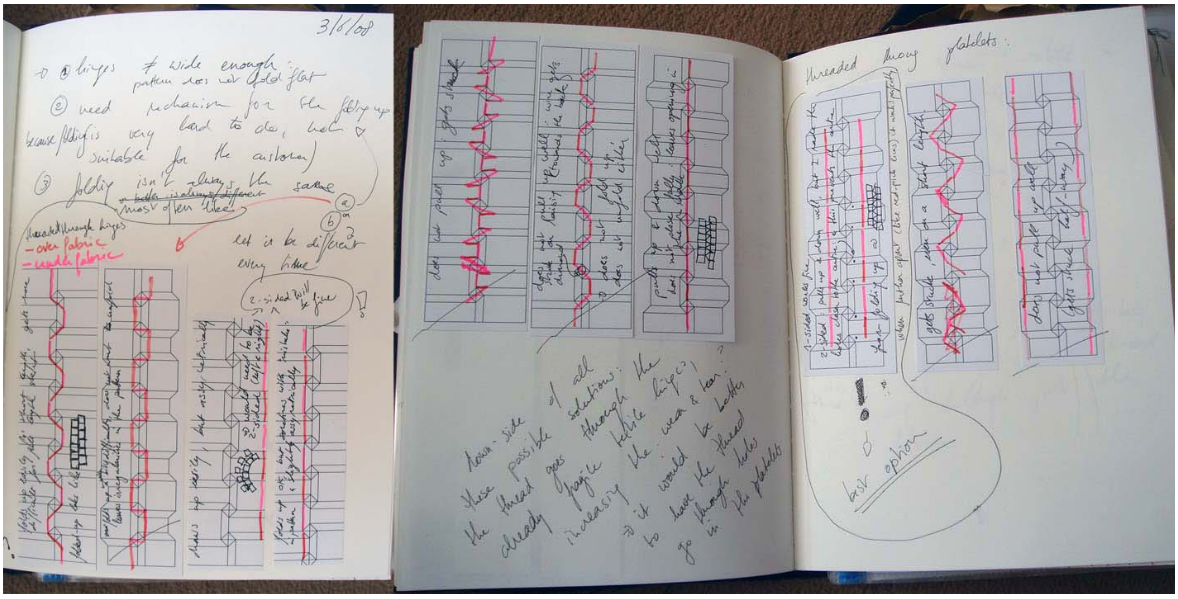


Figure 7.21: log of stringing systems for changing length, as tried on model.

Figure 7.22: One option for fixing strings to skirt at desired length: snap-buttons.

Figure 7.23: Other option for fixing strings to skirt at desired length: wrapping around a cleat.

I also tested four different fabrics to see which one would be most suitable for this skirt. One part of these tests was to see how well I could electroform on them; the other part was to see how well they draped around the folded pattern.

Figure 7.24: Samples of electroforming on a range of fabrics (heavy satin, medium satin, gauze and velvet).

Figure 7.25: Models to test draping of fabrics (heavy satin, medium satin, gauze and velvet) around folded MFT.

Once all these details were decided on I proceeded to make the skirt. It was made out of one piece, but since it was too large for the electroforming tank, the bands were electroformed in pairs with the rest of the skirt tied up. This meant that I had to apply the strips in pairs: if I would have applied them all at once the two strips that were not electroformed during the first run would have been damaged by exposure to the solution. The best preproduction process was consequently spray-painting.

Outcome: "Wearable Metal Origami" skirt

Figure 7.26: "Wearable Metal Origami" skirt, long, with detail of mechanism for fixing strings.

Figure 7.27: "Wearable Metal Origami" skirt, short, with detail of mechanism for fixing strings.

Each strip of MFT can easily be folded separately by pulling on the ribbons. The skirt can therefore not only be worn long or short, but with different lengths for each folding strip. The ribbons can be wrapped around the cleat at any desired length and fixed in place with a snap-button.

Reflection on the design process and its outcome

The skirt shows how MFT can be used to change the shape of "Wearable Metal Origami". I had achieved this result by addressing the design elements of pattern, body placement and finishing: I used an appropriate folding pattern, was careful where to place the MFT strips on the body, avoiding the back of the skirt where they would hinder sitting down, applied appropriate finishing of edges and designed custom-made cleats for the ribbons. I worked through the design process starting from the concept.

I had also been able to work around the limitation of the tank-size by only turning parts of the fabric into MFT, and leaving the rest as plain fabric. The resulting soft “draped folds” accentuate the strictly defined patterns of the MFT strips.

Because I was so focussed on proving that MFT can be used to make a piece change shape, I neglected to explore different possibilities for the folding pattern. I chose a pattern that would work in a straightforward way, and although I experimented with the placement of the pattern on the skirt, the pattern itself was not adapted. I now think the skirt would have benefitted from some experiments in changing the shape of the pattern to make the skirt drape more interestingly.

I had first chosen the concept for this case study, and selected the folding pattern next. This meant that I was so focussed on the concept that I did not approach the pattern for MFT with enough attention.

Change of function

Bracelet-Bag

Setting the brief

Aim: to design an object that could change function.

Method: working from concept to MFT.

Just before starting this research project I had designed a bag that could change size, and be transformed from a handbag into a shopping bag or vice versa. The bag was based on the same folding principles as MFT, but was entirely made in textile materials.

Figure 7.28 Handbag that changes into shopping bag, Inspiration for shape-changing Wearable, Tine De Ruysser, 2005, cotton and felt

For this research I wanted to take this design idea one step further, and make an object that could turn into an entirely different object. It would have to be easily transformed from the one into the other, be able to maintain either shape when needed and be functional in either state.

This meant that it would have to be easy to fold and unfold and I would have to find a way to keep the object folded in one position and in the other position.

Now I had to choose which to objects I wanted to combine. I liked the idea of having one of the two being a decorative item, such as a scarf or bracelet and the other having some sort of practical function, such as a bag or purse. This way the object could be worn as decoration until it was needed in its practical form.

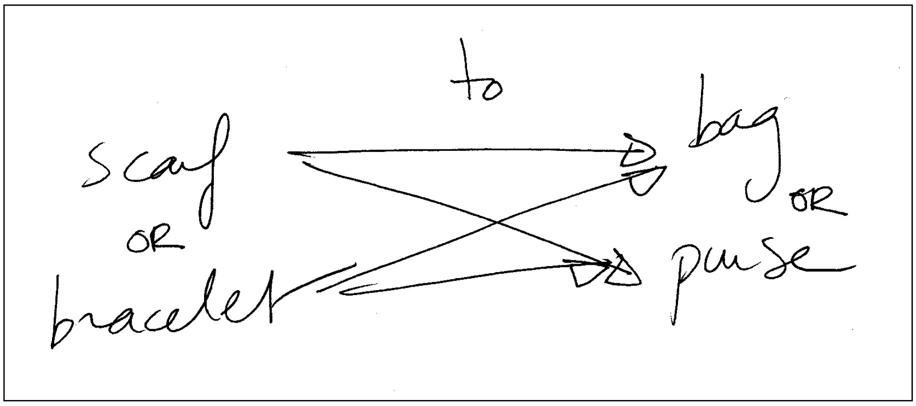


Figure 7.29: Possible combinations for a function changing piece of “Wearable Metal Origami”.

Between the scarf and the bracelet I chose the latter because I considered it a more interesting and challenging object to work with. A bracelet would have to be given a shape and was consequently more true to the idea of making “Wearable Metal Origami” than the scarf, which would be a totally flat unfolded piece of MFT. I considered the bag and purse to be two almost identical objects, with the only difference that a bag could be much larger. I thought it would be more spectacular to turn a bracelet into a “large” bag than into a little purse. (It would also be more practical if one did some unexpected shopping…) I now had the combination of two objects that I would design: a Bracelet-Bag.

I decided that the size of bag I wanted to make was more or less an A3 when laid out flat. I choose an A-size because this would make the model making easier, since I could use standard size paper. The A3 size seemed a reasonable size of bag, but also small enough that turning it into a bracelet would not be too difficult. I did give myself the freedom of slightly adjusting that size in case I needed to make practical changes. The size of the bracelet had to be so that it would fit around an average wrist (I would use my own to try it out), and I wanted it to be as narrow and flexible as possible.

The design process - finding possible solutions

I started by sketching a few ideas for how I could transform a bracelet into a bag.

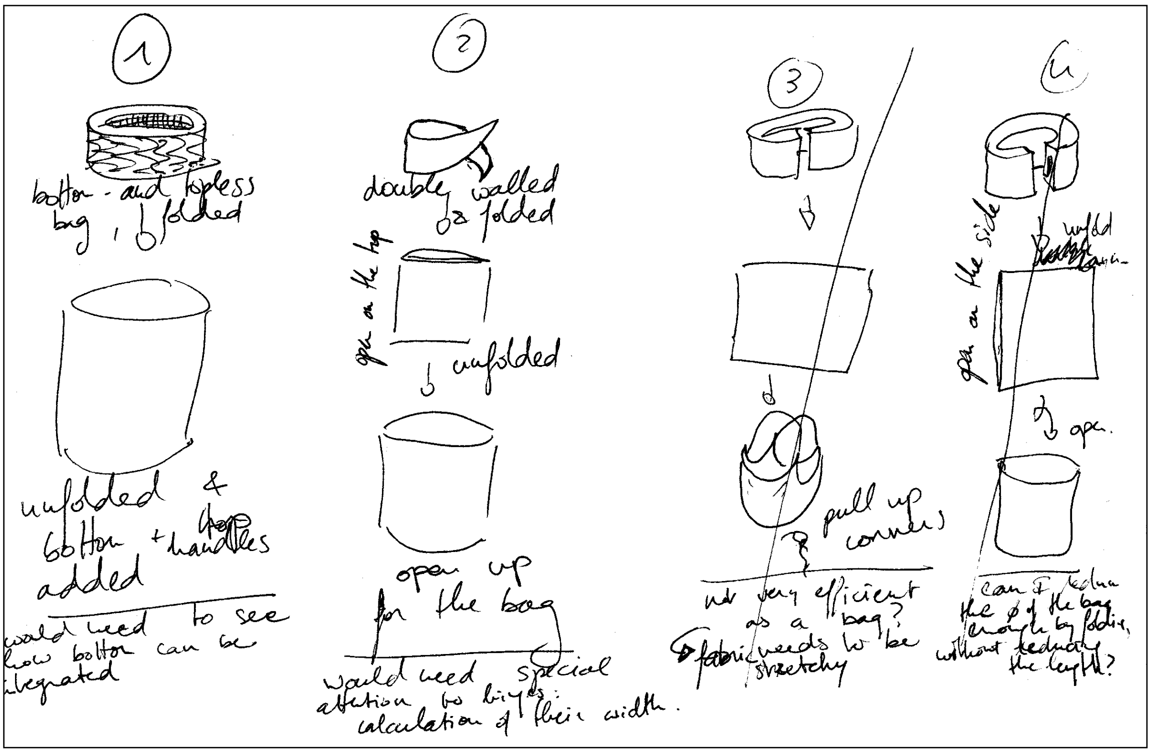


Figure 7.30: Possible methods for transforming a bag into a bracelet.

I came up with four possibilities. The first was to make a tube that could be folded down to a bracelet in a similar way that my bag from 2005 folded down to a handbag. When unfolded it would then need to have a bottom attached as well as handles. The second I was to sew two identical layers of MFT together on three sides, so that the object could be opened on the fourth side to turn it into a bag, or the two layers could be folded as one into a bracelet. The third option was to attach pull up the four corners of a flat sheet of MFT, so that anything lying in the middle could be carried around. I did not think this was a good solution: since MFT has little stretch in it because of the metal platelets it would not form itself into a suitable bag. The fourth and last option I could think of was to fold down a tubular bag much like in the first method, but in such a way that a very long and thin tube would be created, and then wrap that around the arm. I did not think it was possible to fold down the width I needed for a bag to a sufficiently narrow tube for a bracelet, so ruled out this method too. I now had 2 methods left two to work with (method 1 & method 2).

The design process – choosing the folding pattern

I went on to select the sort of patterns that might be suitable to fold an A3 into a bracelet, and came up with a large group of accordion folds. From this group I selected a few that represented all the possibilities.

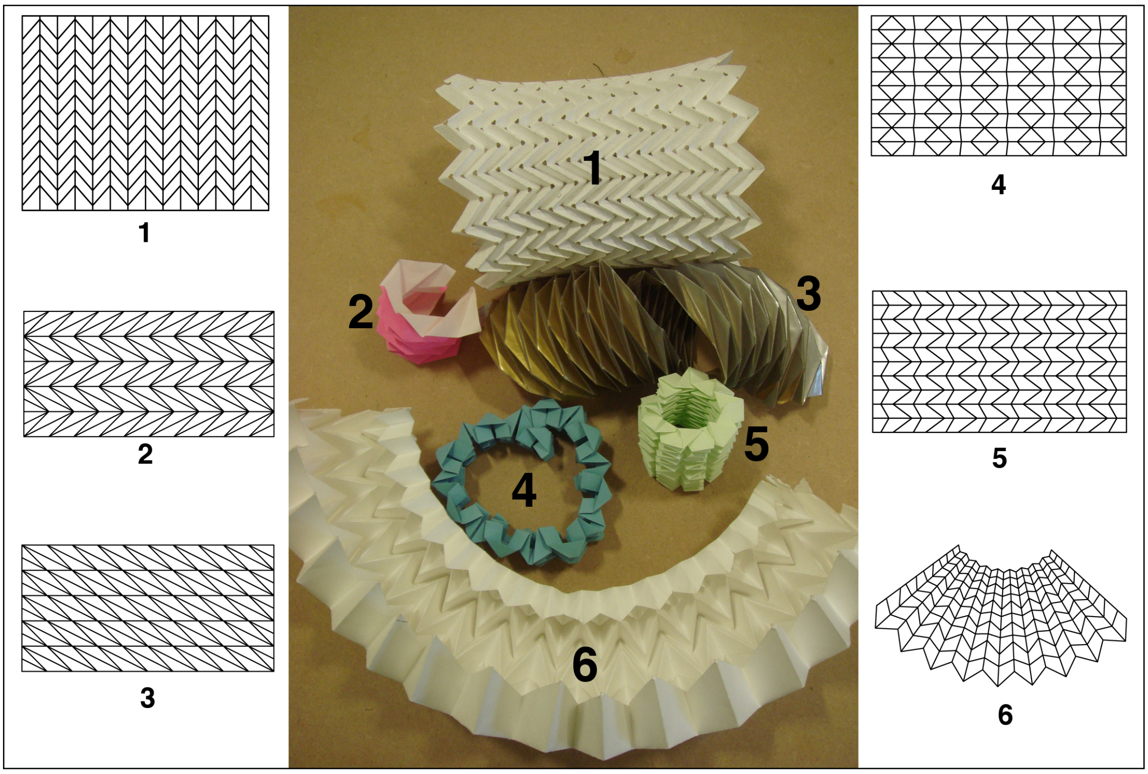


Figure 7.31: Selected patterns that might be used for the creation of a bracelet bag. Crease patterns on left and right, folded models in the middle.

I then studied these patterns more closely. I wanted to narrow down the choice so that I could develop one or two ideas well, and would not spend too much time on trying out too many different things. I immediately ruled out pattern number 1 because it did not conform to the sort of bracelet I wanted to make: it would not fold down enough in the length and create a long, stiff armband. Pattern number 6 unfolds to a segment of a disc rather than to a rectangle. In my opinion this would not make the bag anymore interesting, but it would make the design and production processes much more difficult. I decided that the challenge of creating a Bracelet-Bag was big enough without adding this extra trouble, and decided not to use this pattern. Patterns 2 and 3 are similar, but I find 2 visually more interesting, so I decided that I would not follow up on 3. Patterns 4 and 5 work in a similar way, I think 4 is visually the most attractive of the two, so I would choose that over 5. I now had two remaining patterns: 2 and 4. I decided to try out both, and to begin with 2. (Once in the process of developing pattern 2, this gave me so much to work on that I had only 1 attempt at trying out pattern 4 before deciding that following up this second line of investigation would double the time I needed to spend in this case study. It raised a whole different set of design questions, and would have led to the design of a completely different Bracelet-Bag. In chose to I design only one finished object for this case study, so that I would have enough time left to spend on the other ones. I will consequently not mention pattern 4 anymore.)

The design process – modifying the folding pattern

Now that I had selected the type of folding pattern I wanted to use I could start adapting it to fit the shape I needed. First I folded A3 paper into a narrow strip 42 cm long (the longest side of the paper), and 1/8th of the shorter side.

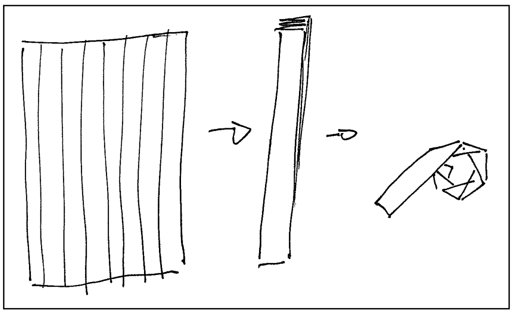


Figure 7.32: Sketch of method for first attempts at folding a bracelet from an A3 sheet of paper.

I then folded it into a circular shape that would fit around an arm. I tried out a few variations; all folded “freehand”, the next three based on measurements of the first. The ‘freehand’ pattern gave a bracelet that was roughly oval. I thought I wanted to try making a round bracelet, so I measured the platelets of the part of the first model that looked like it was curving with the right radius and drew them out on a second piece of paper. When I folded this pattern it gave me a bracelet that was much to small, and I had a long length of paper left. I adjusted the dimensions of the platelets and made model 3. This bracelet was still too small, and had too much paper left at one end. I readjusted the platelets and made model 4. This used up the total length of the paper, but made too large a circle to function as a bracelet.

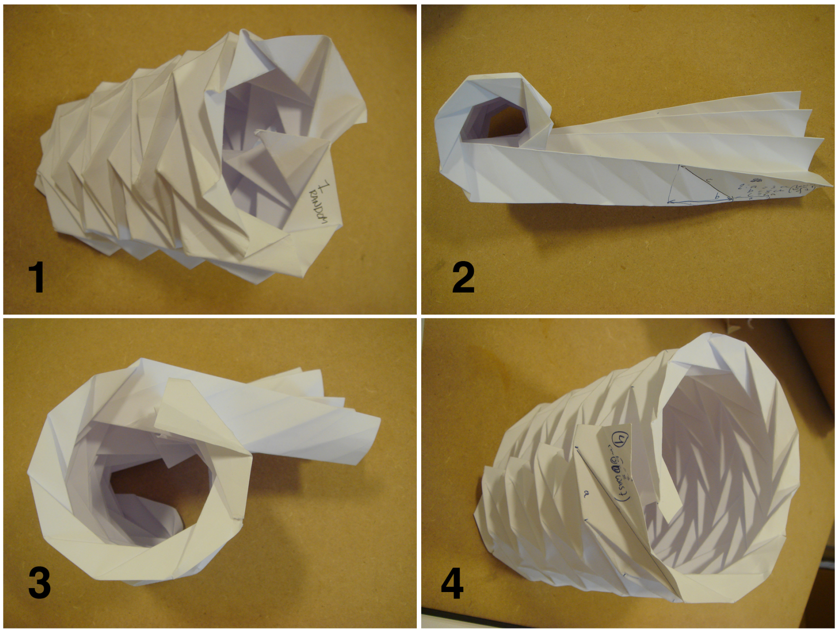


Figure 7.33: Folded models made from A3 paper, folded according to the first method.

To solve the problem of the paper strip being too long I decided to rotate the page and fold it in strips of 29.7 cm long (the short side of an A3), but keeping the width of the first set of strips.

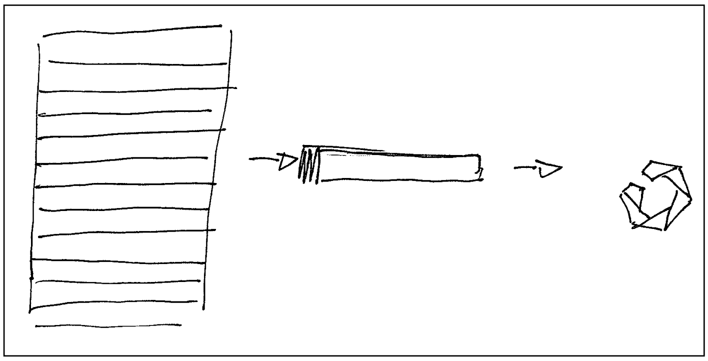


Figure 7.34: The direction of the folding pattern was rotated by 90º.

I also realised that I liked the oval shape for the bracelet better than the round one. I wanted to recreate this shape with the shorter length paper strip, and started by measuring all the platelets and drawing them out. This is why I kept the strip the same width: it meant I would not have to calculate any difference in size for the platelets. I made the drawings on a single strip only, this showed me the critical information of the shape the bracelet would take while cutting out the extra work that would go into folding the whole bracelet.

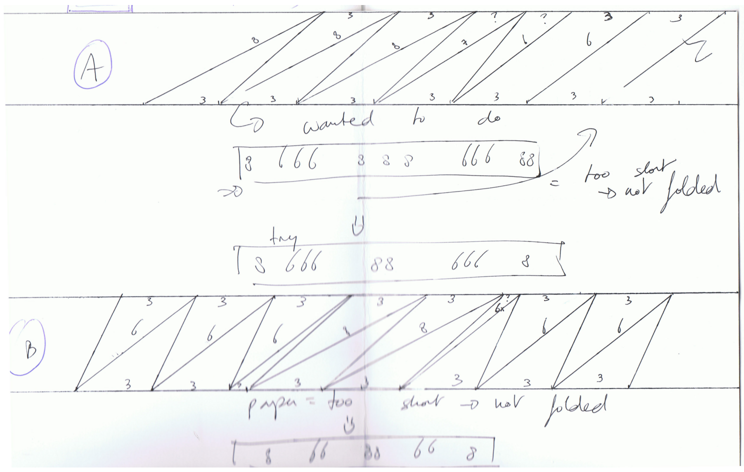


Figure 7.35: Attempts at trying to draw out the folding pattern by hand, using a ruler.

My first attempts to draw out the pattern were done by hand (A & B). This was a slow process and made it difficult to make small changes because any change meant that I had to redraw the whole pattern. I decided to use Rhino for the following drawings, making it easier to make adjustments and keep track of them.

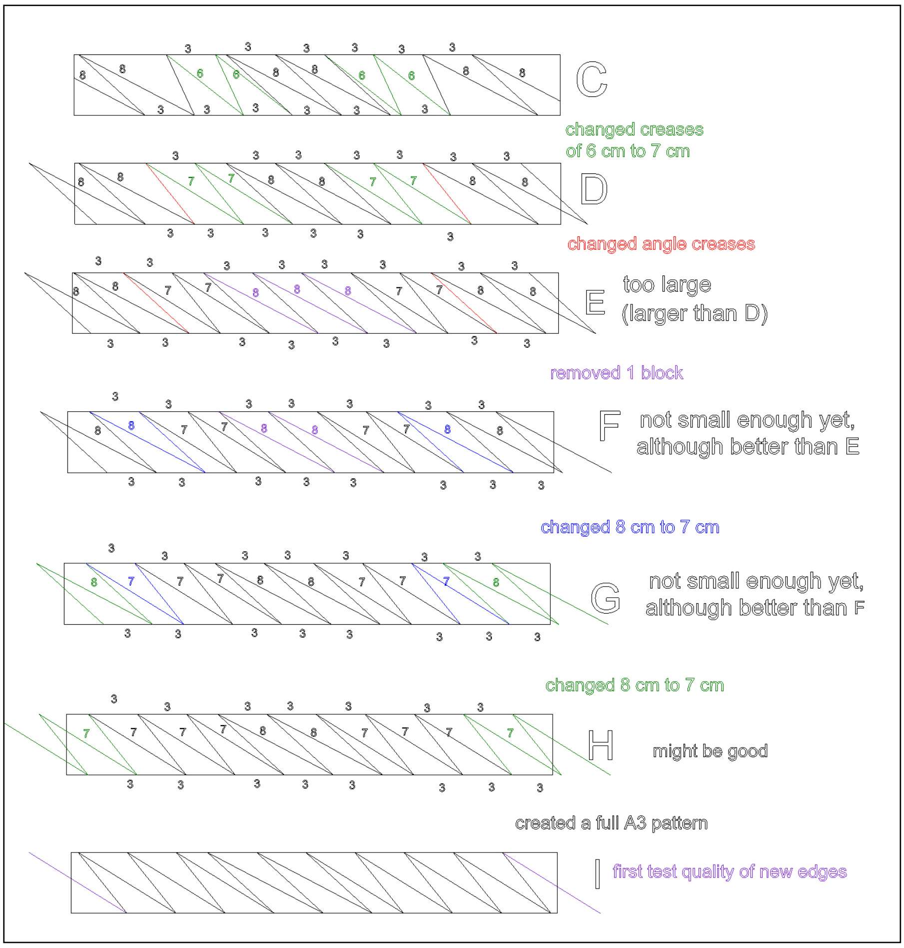


Figure 7.36: Drawing the crease patterns using Rhino. Each pattern was tested and judged, the necessary adjustments were made in the next pattern.

Each drawing was printed (C to I) out and folded to see the shape of the bracelet.

Figure 7.37: Folded models of the crease patterns in fig. 7.37.

When I was happy with the shape (pattern I), I used the single-strip pattern to create a full-size pattern (J).

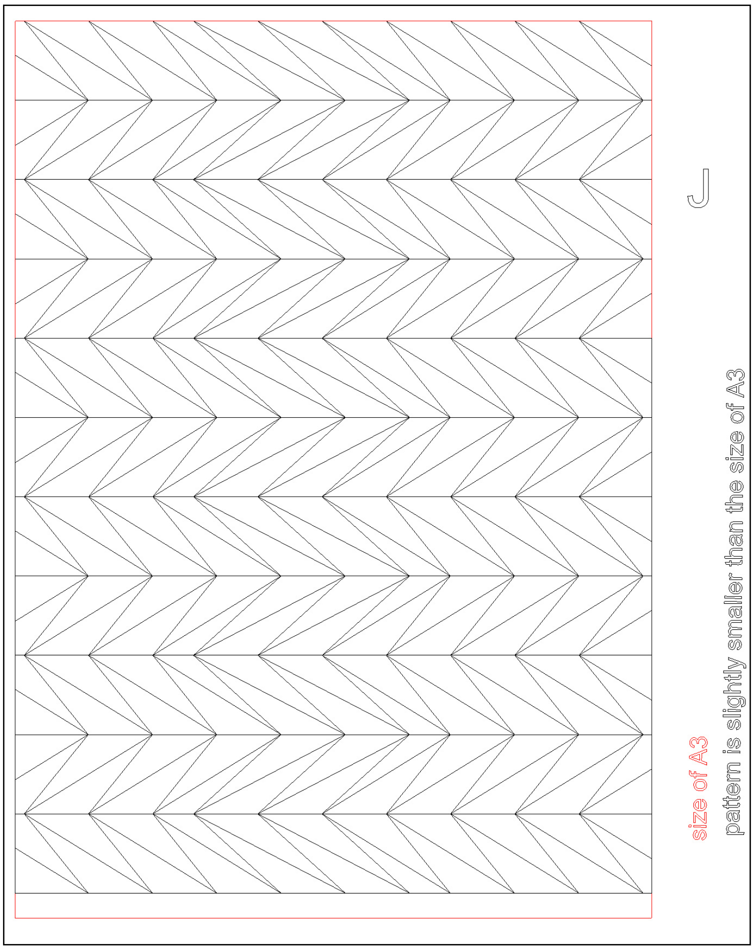


Figure 7.38: The most successful crease pattern was expanded to the full size of the Bracelet-Bag.

Figure 7.39: Crease pattern as shown in fig. 7.39 was tried in paper.

This pattern was printed and folded, I was satisfied with the result and decided to use this folding pattern.

The design-process – model making

Now that I was satisfied with the shape, tested through making a paper model, I wanted to know if this pattern would work in MFT. I made a model with a combination of thin TYVEK™ as the textile and card for the platelets. The model was double walled but did not have any handles yet, or any sort of system that would facilitate the folding process from bag to bracelet.

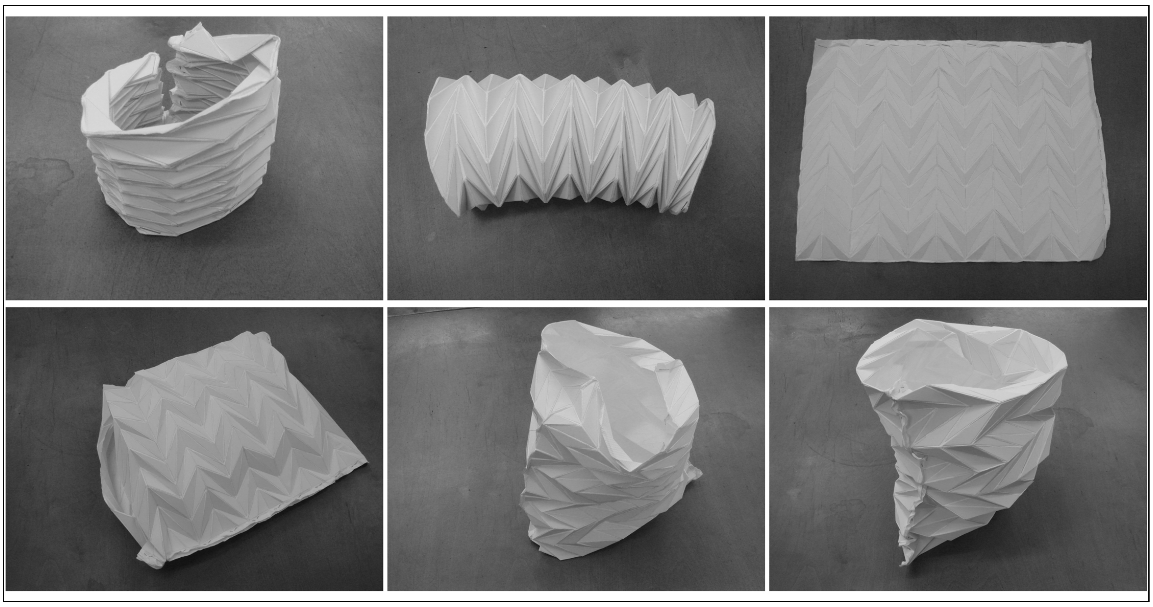


Figure 7.40: Crease pattern from in fig. 7.39 was tried out in a card-on- TYVEK™ model.

Figure 7.41: The edges did not fold well.

The model worked well, but I found it hard to fold the edges neatly, they tended to have platelets sticking out, which made the bracelet look untidy. When they poked out towards the inside of the bracelet they even impeded wearing it. I also discovered that in this flexible material the size of the bracelet was too large.

I decided to simply scale down the folding pattern to make the bracelet the right size. This would also reduce the size of the bag, but only by a few centimetres. The other alternative would be to redesign the folding pattern, a time consuming process that I did not think would be worth the effort.

I was unsure how to make the edges fold more easily or how to attach handles to the bag. I considered a few ways of attaching handles, one of which was a drawstring. This could possibly double as the folding mechanism, facilitating the folding of the edges. The other feasible option was to cut out holes to create handles. I disregarded the options where I would have to attach separate handles because they would be awkward in the bracelet mode.

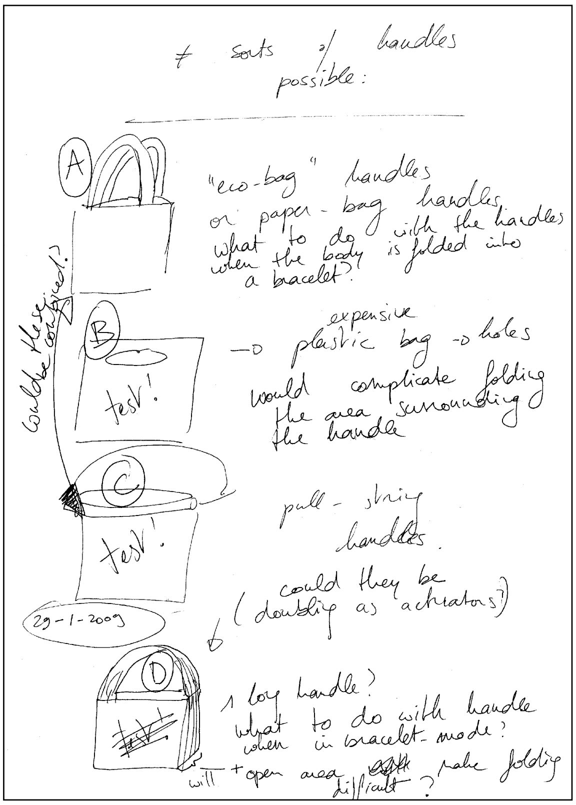


Figure 7.42: Brainstorming on possible solutions for handles for the bag. Option 1 and 4 were ruled out, options B and C would be tested

I decided to test the drawstring handles and the hole handles.

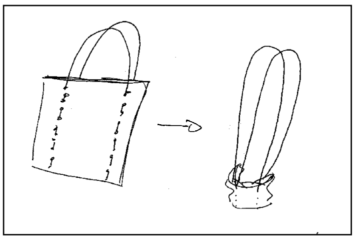


Figure 7.43: The ideal direction for pull strings to close the bracelet, doubling as handles for the bag.

For the drawstring handles I had to work out how to pull it through the bag. It would have to pull through vertically to help with the folding, but I had to choose where to put them.

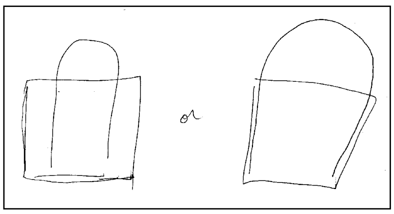


Figure 7.44: sketch to judge the best location for the pull strings.

If I put the pull string near the middle I would need it to go through each layer separately, otherwise I would not be able to open the bag. This would make the two layers want to come apart while folding, making it harder rather than easier to turn the bag into a bracelet. This location for the handles would not be helpful for folding the edges either. If I pulled the string through the edges, I could pull it through both layers at the same time, which would make folding easier and would also help with the folding of the edges. I decided to try this out.

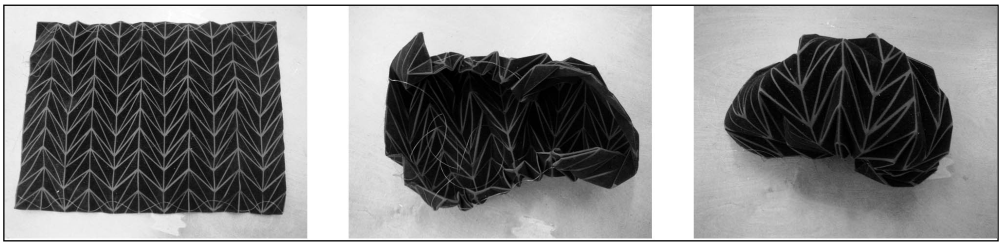


Figure 7.45: Model to test pull strings, iron-on flock and cotton

The materials I chose for this model (iron-on flock on cotton) were not ideal. The flock did not provide enough stiffness in comparison to the cotton hinges, so the model did not fold up neatly unless I folded it very carefully by hand. I could not draw any conclusions on the suitability of the drawstring.

I had made a model of the second option for handles at the same time. This was consequently made in the same unsuitable materials. Yet the model was good enough to realise that the area around the handle could not be folded up neatly even if I was very careful. The hole interrupted the folding pattern so that the area above the handle would have to be folded separately from the rest. This was impractical, so I decided not to use this type of handle.

Figure 7.46: Model to test cut-out handle, flat and folded. The handle does not fold well. Iron-on flock and cotton.

With the failure of these models, made in materials that had worked perfectly fine before, I suddenly started worrying whether this design would work when the Bracelet-Bag was made in MFT. Even though I knew that the design would most likely change, I decided to make a sample in MFT to reassure myself. I wanted to spend a minimum of time on this, so I choose the method of cutting self-adhesive copper foil platelets, using the electroforming process to stiffen them and key them onto the fabric. I prepared the piece for electroforming, and while it was in the electroforming tank continued on the design process.

Since I was not sure yet whether the drawstring would be efficient, I decided to try if I could constrain the edges of the bag, preventing them from unfolding completely and thus folding up more easily. I tried two sorts of restraints on the card-on- TYVEK^{TM} model that I had made before.

Figure 7.47: Testing restraints to stop the edges from unfolding completely.
Top: Fixing two adjoining platelets together (A).
Bottom: Making a connection across the edge (B)

Neither of the restraints worked very well to make the edges fold up neatly: both of them still had loose corners sticking out.

Figure 7.48: Restraints (A) from in fig. 7.48 do not keep the edges folded.

Figure 7.49: Restraints (B) from fig. 7.48 do not keep the edges folded.

Not only were the restraints unsuccessful in helping the edges fold up neatly, they also prevented the bag from opening up to its full extent: because they kept the edges partially folded the bag could not be completely laid out flat, and could consequently not be opened.

Figure 7.50: Restraints (A and B) from fig. 7.48 prevent the bag from opening properly.

I decided to take a different approach to the edges. Instead of trying to force them into folding up, could I not find a way that would make them unobtrusive if they did not fold? Could I allow them to become irregular? If I took this approach I had to take care that the irregular edges would not impede wearing the bracelet. I decided to try removing some platelets from the folding pattern, leaving triangular areas of the fabric bare at the edges. These could then fold into soft irregular textile folds. I decided to try three variations.

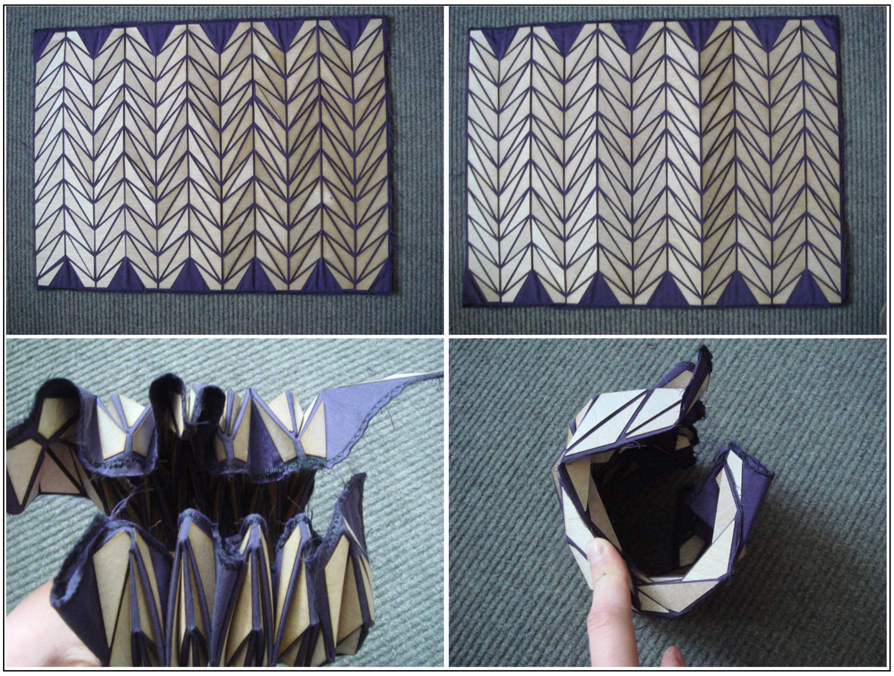


Figure 7.51: Testing edges with removed platelets, first variation (1 platelet removed from each row on either side, front and back identical). Plywood on textile.

For the first variation I removed only one platelet on each row on either side and made a plywood-on-textile model. Front and back of the bag were identical. This pattern folded up neatly at the edges.

Figure 7.52: Testing edges with removed platelets, second variation (2 platelets removed from each row on either side, front and back identical). Plywood on textile.

For the second variation I made a second plywood-textile model where I removed two platelets of each row on both edges. Front and back of the bag were identical. The edges did not fold up as neatly: there were platelets protruding into the centre of the bracelet.

Figure 7.53: Testing edges with removed platelets, third variation (2 platelet removed from each row on either side on the front & all platelets removed from the back of the bag). Plywood on textile.

For the last of these models I used plywood on textile to make a bag that had platelets only on one side of the bag, the other side was plain fabric. This solution was too irregular: not only did the edges still have protruding platelets, the bare fabric back did not fold up at all, and had to be stuffed inside the bracelet.

Of these three models the first one clearly worked best, I decided to use this solution for the folding of the edges.

In the meantime the electroformed model had come out of the tank, and I sewed front and back together to see how it worked.

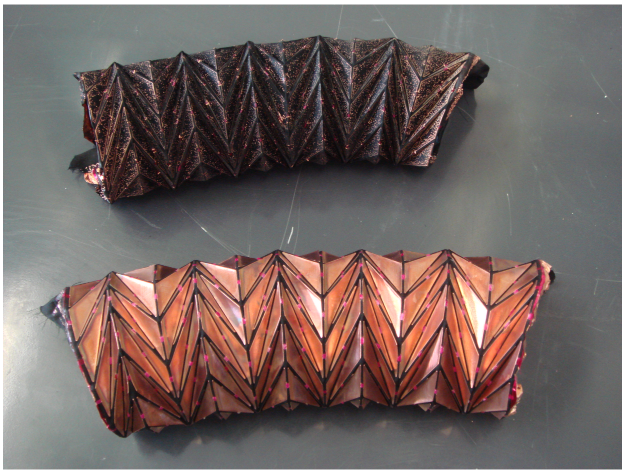


Figure 7.54: two halves (front and back) of the MFT model before they were put together.

Figure 7.55: MFT model with both halves pieced together.

The model proved that the Bracelet-Bag could be made from MFT. It gave me some unexpected results too: the back of the fabric did not look like I had anticipated. When I had used this method before, there had always just been a line visible around the edges of each platelet. This time the foil came from a different supplier and must have had a different adhesive because apart from these lines a random pattern of copper dots appeared all over the surface. The dots gave this side a subtle sparkle. I had wanted to make the Bracelet-Bag in MFT prepared by applying silver dag, but liked the contrast of this model, with its copper outside and black, sparkling inside so much that I decided to use this method for the finished piece.

By handling the plywood models and the model in MFT I realised that the bracelet did not remain in folded position: it unfolded itself and would consequently fall of the arm. I had to find some way to keep it folded. The drawstring, going through holes in the platelets nearest to the edge, was a natural first choice to try since the previous model for this system had failed to prove or disprove its usefulness.

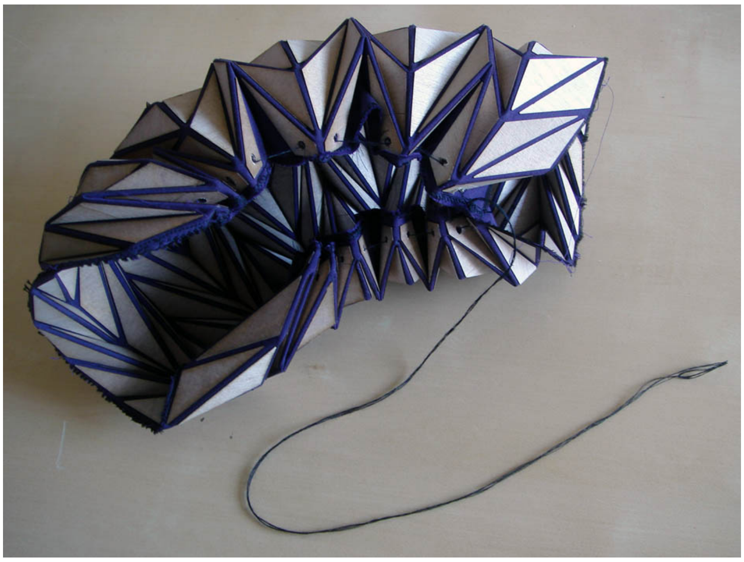


Figure 7.56: The bracelet, as folded with the drawstring.

I was not happy with the result: the drawstring gave the impression to make folding easy, but did not work well enough. The middle of the bag would not fold up with the edges, and I had to release the string to fold the bag by hand anyway. Additionally, the length of string that hung from the bracelet was very long and awkward. It hung loose from the edge and I could not think of a neat way of incorporating it into the design.

I reconsidered which issues I still had to solve. I had to find a way to incorporate handles for the bag and introducing some system to keep the bracelet folded. I had given up on the idea that I could find a system that would solve more than one problem at once, as I had hoped to do with the pull-string, and decided to concentrate on both issues separately.

Since I had already tried and failed to solve the problems with folding and handles, I decided to tackle the system to keep the bracelet folded first. This system would have to be something that would be easy to put in place and easy to take apart again. I briefly considered a pull-string criss-crossing over the bag like the laces in a corset, but quickly realised that this would be impractical. A lace like this would be a hindrance both on the bag because it would always tend to fold up, and as too long a string hanging from the bracelet.

Figure 7.57: Criss-cross pull string is hindrance for both bag and bracelet.

I considered hooks-and-eyes, but these would be too difficult to use. Then I thought of magnets. Magnets would be easy to put together, and easy to pull apart. I tested some Neodymium (Rare Earth) magnets, and after a few failed attempts managed to glue them down with their polarities aligned so that they worked. I realised that they would work better if they did not just keep each edge folded separately, but kept both edges together too. I could easily achieve this by lengthening the platelets on the edge. The magnets could be attached to MFT before electroforming, so that a copper layer could build up around them, creating a setting.

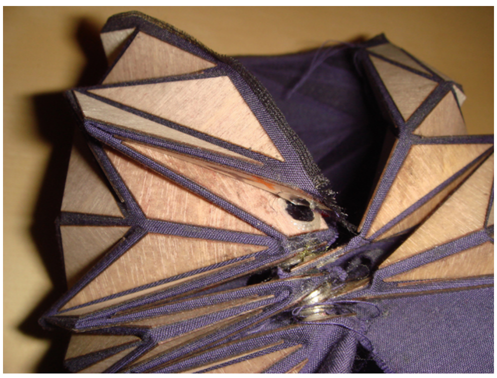


Figure 7.58: Testing magnets to keep bracelet closed.

I turned back to the attachment of the handles, and looked at the attempts I had made. I realised that if I adapted the cut-out handle I could make it work: I could make the handle itself from fabric so that, unlike the metallised handle, it would not have to fold.

Figure 7.59: Handle: extra strip of fabric with narrow slit.

Since I felt that I had now resolved all design issues well enough, I proceeded to make the Bracelet-Bag in MFT.

I am not sure what exactly went wrong next. I used the same copper foil as I had for the model, only changing the quality of the fabric, but this piece did not electroform well. While in the tank the platelets curled up and peeled of the fabric at the corners. I made this piece shortly before the RCA SHOW, and had no time to reorder my materials in time to make the piece again.

Figure 7.60: MFT bag with magnets could not be used because the platelets are peeling away at the corners.

Since I did want to show the Bracelet-Bag in the RCA SHOW to show the possibility to create a function-changing piece of “Wearable Metal Origami”, I adapted the MFT model I had made before and placed this in the exhibition.

Outcome: “Wearable Metal Origami” Bracelet-Bag

Figure 7.61: Bracelet-Bag as displayed in the SHOW

The Bracelet-Bag as displayed at the SHOW was functional as a bag but not as a bracelet because I had to use an earlier sample instead of the finished design.

Reflection on the design process and its outcome

The Bracelet-Bag as it was presented at the SHOW did attract some attention. It was recognisable both as a bag and as a bracelet. The piece clearly works a bag, but it is not as convincing as a bracelet and the folding process from one to the other is not as easy as I would have liked. This was partly because it was not the finished design, but an earlier model finished as well as possible. Apart from that I had not taken into account how difficult it would be to design a “Wearable Metal Origami” object that had to be successful as two objects. By trying to design a bi-functional object I had also set myself a very complicated task. Every decision I took during the design process had to take both functions into account as well as the transformation from one to the other, and this stretched me to the limit of my current abilities to design with MFT.

The Bracelet-Bag as it was designed to be is functional in both states, as such it demonstrates that it is possible to design “Wearable Metal Origami” with changing function, but the proof is shaky because I was unable to make a finished piece. This demonstrates one of the difficulties of making “Wearable Metal Origami”: the production process is not always totally reliable. I will make the Bracelet-Bag again, to the finished design to allow me to better judge it.

Traditional jewellery: using precious materials, testing a small scale

This case study was built on the collaboration with the Jewellery Company Links of London (Links) in the context of the Deployable Adaptive Structures Research Project. Professor David Watkins had approached Links, and they had shown an interest in working with us to develop MFT into a new collection for their outlets. We worked for them during two years, proving with samples that MFT can be made to a small enough scale; that it can be made in silver; that the patterns can be adjusted to create jewellery that looks almost classical so that it would fit in with their other collections; that stones could be set, that different colours of textile and different surface qualities for the metal could be used. Professor David Watkins was even in negotiation with the Essay Office, taking steps towards their agreement to hallmark this material and had a sample made to prove that it is possible to apply a laser-hallmark. This work was done by a team of people from the DAS research project, including three assistants that came in to help with the designing. Negotiations were under way for Links to buy the licence to make jewellery with MFT. This licence would have given them the exclusive use of this material for the design and sale of jewellery, and would have extended the collaboration for a further six months beyond the end date of the DAS project with RCA staff being paid by Links. These negotiations survived a change of the design team at Links and a change of directors. Unfortunately these internal changes at Links were then followed by the Credit Crunch in the Autumn of 2008, and the licence agreement fell through completely.

I will not describe all the work we did for Links in this Thesis because it was a team project and I couldn’t possibly claim it as my own. I will however describe how I start designing a bracelet during the Links project. I continued on it afterwards to demonstrate the possibilities for the application of MFT in jewellery. This bracelet was only one of many designs we worked on for Links. I chose to describe this specific design here because it was wholly designed and developed by me, even while the collaboration was in progress.

Setting the brief

Aim: to design jewellery

Method: working MFT to concept.

The design process – choosing the folding pattern

During the Links project, we had been looking for readily available patterns that could quickly be adapted to make a sample range of jewellery. One of the patterns I chose I had previously used for a handbag.

Figure 7.62: The folding pattern for this handbag formed the basis for this design process.

I scaled the pattern down, and extended it in length so that it would be long enough to fit around the wrist.

Figure 7.63: Scaled down pattern of the bag, as folding pattern and paper model.

The design process – modifying the folding pattern

I thought the pattern was ideal for a bracelet, but did not like the way the edges were cut straight so I experimented with different ways of finishing the back.

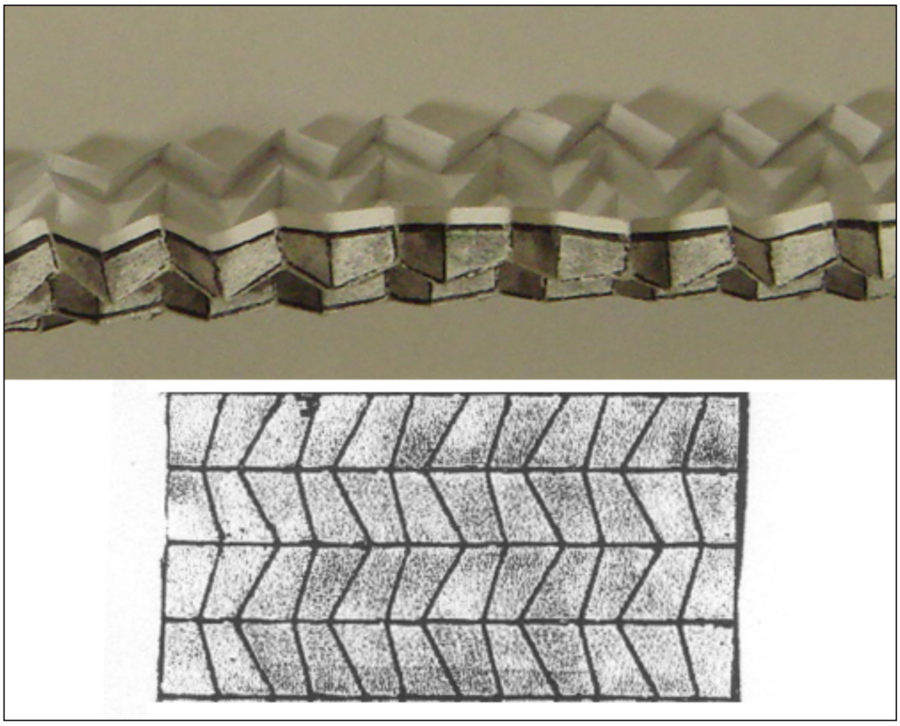


Figure 7.64: Original model with straight edges, with folding pattern.

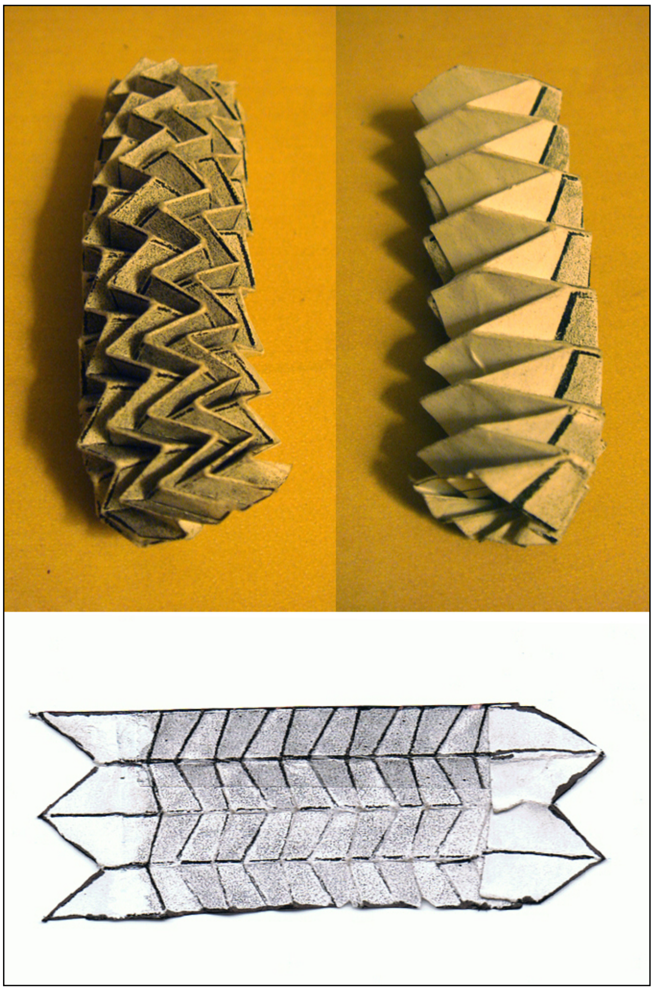


Figure 7.65: Paper model with closed back, seen from front and back and part of folding pattern

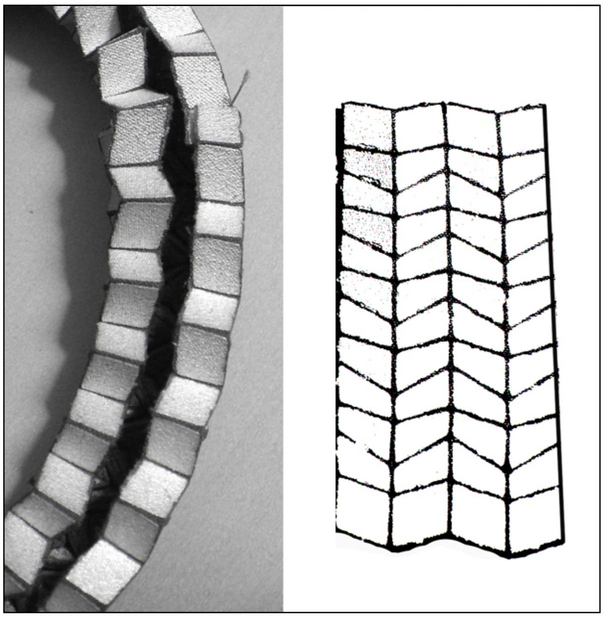


Figure 7.66: Paper model with zigzag back, seen from back and part of folding pattern

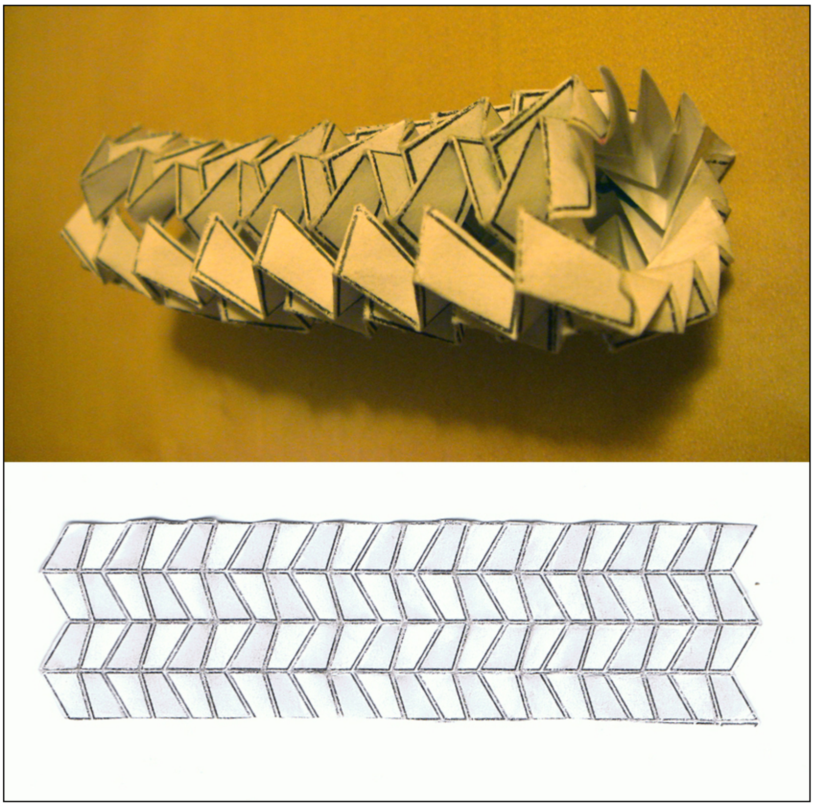


Figure 7.67: Paper model folded round, seen from front and part of folding pattern.

Turning the edges into a zigzag line by offsetting the last folding line was a huge improvement, the edge looked more elegant and in character with the folding pattern. I could see just a little bit of the folding pattern from the inside through the gap in between them.

Another option was to extend the edge platelets until they met in the middle, then folding one side over the other to close the back of the bracelet. I really liked the solid appearance of the paper model, but realised that this design would be much more difficult to make in MFT. Overlapping the edges was necessary so that I could sew them together along a folding line but this meant that the bracelet would loose a lot of its flexibility because the platelet-thickness would be double in this area, restricting the folding. In fact, the extra thickness would restrict the folding so much that the bracelet would not have much flexibility left.

For the third possible solution I extended the pattern so that it would come full circle. The bracelet then became too thick to my liking, and I would have the same problem for connecting the edges as for the bracelet with extended, overlapping edges.

I felt that my only choice was to go with the zigzag edges, and proceeded to draw up this pattern. I wanted to show the possibility to make jewellery in fine metals, so decided to make two bracelets in silver, and have one gold plated, I would also make a necklace and bracelet in copper.

The silver and gold plated bracelets could not be made in one piece because the size of the departmental silver-electroforming tank was not big enough to accommodate the full length. I therefore drew the pattern up three times: once for the silver bracelet, once for the gold plated bracelet, and once to extend both to a wearable size. The copper necklace would also be pieced together from two pieces, for the same reason: the copper tank was large enough to make a bracelet in one length, but not a necklace. I chose to use the preproduction process of spray-painting because it makes the electrodag penetrate the fabric more deeply, ensuring a better adhesion of the platelets.

I considered making clasps for the bracelets but could not work out how best to do this, so decided to simply connect the ends by sewing them together.

Outcome: "Wearable Metal Origami" Jewellery

Figure 7.68: Necklace, copper (left) and three bracelets (right) from top to bottom: silver, copper, gold plated silver)

Reflection on the design process and its outcome

This small collection of jewellery showed how small the platelets of MFT can be. It also demonstrated that fine metals can be used. The pieces were popular at the SHOW because they were clearly recognisable as jewellery.

Even though I had proven the applicability of MFT for “Wearable Metal Origami” jewellery, I was not satisfied with the pieces. Because I had so easily found the folding pattern, I had thought that I could quickly make these pieces. I had rushed through design process and had not taken enough time to think through the consequence of my decisions. This meant that the edges were fraying and prone to tearing, the pieces easily flattened out and lost their shape, and clasps were missing. These details are critical, especially when making jewellery, and I had overlooked them because I had concentrated on the shape and folding patterns.

When I return to the creation of “Wearable Metal Origami” jewellery I will make sure to integrate edge-finish, custom-made clasps and built-in constraints to keep the pieces in shape into the design process.

Comparing the Case Studies

All four case studies were completed to the extent that each time a “Wearable Metal Origami” object was made demonstrating the aspect of MFT that I wanted to prove. Together they show a wide range of MFT’s qualities and its possible uses. Each case study also taught me more about the properties of MFT through the design processes involved in working with this material.

Case Studies	Wearable Metal Origami objects:	Aim	Method Used	Length design process	Complication design process	Production method chosen	Outcome: achieved Aim?	Suggestions for improvement
Adapting to shape and movement of the body	Shoulder cape	To design an object that will take on the shape and movement of the body	From MFT to concept	Short	Easy: only a few adaptations necessary to folding pattern, linear design process	Spraying silver electrodag because unique piece	Yes: shape lies flat when not on body, shapes well around shoulders and neck when worn	Changing edges of pattern (not plain rectangular) and filling gap at the back
Size- change	Skirt	To design a wearable that will change its size depending on the wearer's wishes	From concept to MFT	Long	Complicated: designing shape skirt and going through several stages of testing and adapting pattern and finding actuation mechanism, often having to think back over previous decisions (loops in design process)	Spraying silver electrodag because unique piece	Yes: wearable (placement of MFT in suitable areas); wearer can adjust length of each strip of MFT individually to change length skirt	More interesting pattern could be chosen for MFT-strips, to make the skirt fold/ drape more interestingly
Change of function	Bracelet-Bag	To design an object that could change function	From concept to MFT	Long	Complicated: going through several stages of testing and adapting pattern and finding actuation mechanism, having to consider both functions at every step during design process often having to think back over previous decisions (loops in design process)	Copper foil: because of different front and back of MFT the insideof the bag looks different from the outside.	Almost: object is more succesful as bag than as bracelet, folding and holding mechanisms are not easy enough to operate	Better actuation and holding mechanisms need to be found; Electroforming problems on copper foil need to be solved
Small scale and precious materials	Jewellery: bracelets and necklace	To design jewellery (small scale, silver electroforming, gold plating)	From MFT to concept	Short	Simple: building on knowledge and designs from previous project, only minor adjustments; linear design process	Spraying silver electrodag because best keying to fabric	Yes: small, made in both copper and silver, one bracelet also gold plated	Better finish of edges to minimalise wear and tear; Introduce clasps

Figure 7.69: Comparing the different case studies

I approached the design process in two ways: looking back, I am not sure there is such a strict divide between the two. Maybe this was because I had a concept in mind even when I started from MFT, and consequently did not give myself the freedom to concentrate on the sample of MFT, to see how it works and let the design evolve from there. To truly test the design process from MFT to concept it would have been better if I had not set myself any aspect to demonstrate and just see where the process took me. This working without any concept of where I want to go is unnatural to me, I always work towards some sort of brief. Maybe that is why I set myself a concept even when I wanted to work just with the material. Maybe I was too focussed on demonstrating certain aspects of MFT to let go of that control. If I were to start testing the design process again, I would allow myself to start one case study based solely on a sample of MFT, without any preconceived concept of what I want to make. As it is, in all four projects I always had both concept and material in mind with every step I took. The case studies where the emphasis was placed on the concept from the start were more complicated to work through because I was extremely aware of the concept throughout the whole design process. The case studies were MFT was given priority moved along more smoothly, but at times I lost sight of the concept, which made it lose some of its strength.

The practical questions involved with designing “Wearable Metal Origami”, such as which folding pattern to use and where to place it on the body, fell into place as I went through the design process. The choice of finishing techniques was less straightforward. I had not done quite so much research on this aspect beforehand, and consequently had fewer options to choose from. For example, I had assumed that I could use textile seams and hems, only to realise when I was making the objects in MFT that I could not because they double or triple the textile layers, making the MFT unfoldable in that area. I therefore chose to heat-seal the edges, which was successful in the Skirt and Shoulder Cape, but less so in the Jewellery and the Bracelet-Bag. I will have to pay more attention to this aspect in the future, finding more appropriate solutions.

Is this all?

I believe I have made a good start at designing “Wearable Metal Origami” pieces on the intersection of clothing, accessories and jewellery. Interest does come from the different disciplines: since the SHOW pictures of my work have been requested by the trends and insights consultancy “The Future Laboratory”; the online fashion magazine “fashion156.com” shows the Shoulder Cape on a dress designed by Balenciaga and I have won the Armourers and Brasiers’ Company award for Innovative Metalwork. It is encouraging that the work is recognised as innovative by these organisations, but this does not mean that the work is finished.

Even though “Wearable Metal Origami” has taken a good start, there is much more to do before it can truly compare itself with the work of those people that have inspired me. It is not yet of the quality of Issey Miyake’s pleats please collection, or has the visual impact of the dresses by Pacco Rabanne and McQueen.

Through the case studies I have come a long way in understanding my approach to the design process. I have been able to create pieces that demonstrate the qualities of adaptability, movement, shape change, function change and preciousness of MFT. To take “Wearable Metal Origami” further I now have to find a better balance between working with the folding pattern and working towards a concept. I also need to pay more attention to details such as edge finishes and closures and test them before I execute the design in MFT as a finished piece. “Wearable Metal Origami” needs stronger shapes with a clear function and better finishing.

I have been working in a jewellery studio environment and have consequently designed unique pieces, designed from a jeweller’s point of view. To take “Wearable Metal Origami” out of this context will involve either working in collaboration with industry, as it had almost happened with Links of London, or teaming up with designers from a fashion or accessories background. I hope to do so in the future.

So this is not the end of “Wearable Metal Origami”, but the beginning. I will become better at the design process through practice, and know which elements to pay particular attention to. In working with others the work will become more relevant to the different disciplines of wearable accessories, jewellery and fashion.

8. Conclusion

This research project has proved to be a real learning experience. I have learned so much more than just how to make “Wearable Metal Origami”. I had never before been challenged to continuously re-evaluate not just the results of my work, but also the working methods that allowed me to reach those results. I learned new skills, from handling new software and craft processes to writing and basic project management. I learned to find my place in a design team and improved my communication skills with regard to a range of audiences.

I had set out to improve the production processes for MFT, to expand the range of folding patterns and to apply MFT to the creation of “Wearable Metal Origami”. I have made progress on all three counts. I have found two new ways of applying the pattern for MFT to the fabric before electroforming, gained a better understanding of the electroforming process itself and have explored some postproduction options. I have greatly expanded the suitable range of folding patterns, and have discovered the basic rules to create more. I have explored the design process and created four “Wearable Metal Origami” pieces that demonstrate the qualities of MFT. Unexpectedly, I also developed model-making materials that are beautiful in their own right.

‘Wearable Metal Origami’ is innovative because it combines three elements. Firstly there is the strictly controlled selective electroforming; then the non-metallised parts are used to fold the whole like tessellating origami to create a deployable, adaptive material; and finally this material is applied to wearable pieces. It is a creation of current society, where boundaries between disciplines have faded and the demand for novel products is high. It is firmly based in a craft context, builds on historical and contemporary precedents and is closely related to the field of innovative materials, yet I have not been able to find any material that possesses the same combination of materials and qualities.

I have used craft practice to create the innovative material MFT and, because of its affinity with the human body, to apply it to wearables through ‘Wearable Metal Origami’. MFT is also applicable to a range of other disciplines, as was shown in the DAS project.

I claim that this research is unique because it provides material innovation and research into design processes for this new material in a craft environment. I therefore hope that it has made some contribution to the positive perception and the future of the discipline of craft.

Even though I might have benefitted from their expertise there were times when consulting external experts was problematic because I did not wish to endanger the intellectual property rights of my colleagues and myself. But I did not discover a patentable production method during this research, and the methods I did find would not be suitable for industrial use. I therefore do not mind logging the existing processes in this thesis, and will now start communicating with experts more freely when needed to improve my studio practice working methods.

I will continue my development of MFT and refine the design approach for the creation of objects. I will start working together with others. My approach to the technical aspects and creative processes involved in the creation of “Wearable Metal Origami” is limited to my own knowledge and experience. To improve the material and its applications, I will seek the advice of experts to improve technical processes and collaborate with designers more used to the field of accessories to expand and improve the design possibilities.

New challenges lie ahead: I will keep on searching for new folding patterns and improved production processes and I will keep on making “Wearable Metal Origami”. Additionally, I want to expand into the design of tableware and I want to start developing the model making materials both on their own and in combination with MFT. I will be looking for designers to collaborate with and for companies that can help with the production. Working with MFT will be a true lifelong learning project.

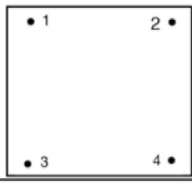
Appendix A – Family tree of tessellating folding patterns suitable for “Wearable Metal Origami”

Family tree of tessellating folding patterns suitable for “Wearable Metal Origami”

Appendix B – Extracts from electroforming log

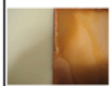
A sample selection of technical data-sheets

Test Sheet ID	3	
Date	26/01/2007	
Workpiece ID	stainless steel test 1	
start_time	16.20	
end_time	17.30	
tank temp	9	°C
Job area	1	dm2
Target current density	2.5	amp/dm2
current	2.5	amp
job thickness before		mm
thickness - sample point 1	0.025	mm
thickness - sample point 2	0.021	mm
thickness - sample point 3	0.029	mm
thickness - sample point 4	0.029	mm



Images


stainless1-complete


stainless1-edge1


stainless1-edge2


stainless1-peeling1


stainless1-peeling2

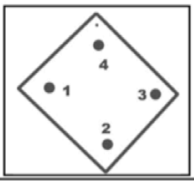
Add Image

notes

testing the possibility of plating the stainless steel & peeling off the copper afterwards.
It works.
Measurement of thickness is done on the Cu sheet after it was peeled off the steel.

New Record

Test Sheet ID	5	
Date	26/01/2007	
Workpiece ID	stainless steel test 2 (with fabric)	
start_time	18.55	
end_time	19.55	
tank temp	10	°C
Job area	1	dm2
Target current density	4	amp/dm2
current	4	amp
job thickness before	0.051	mm
thickness - sample point 1	0.084	mm
thickness - sample point 2	0.073	mm
thickness - sample point 3	0.083	mm
thickness - sample point 4	0.071	mm



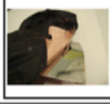
Images


stainless2-complete


stainless2-edge1


stainless2-edge2


stainless2-peeling1


stainless2-peeling2

Add Image

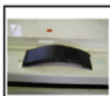
notes

test to see if a piece of fabric stretched over the stainless steel will be caught in the plating.
It seems like the plating actually pushes away the fabric, and plates underneath. Only the edges, where contact between fabric and stainless is very strong has Cu coming through the fabric, making it adhere there.
On the surface there are a few unplated areas (holes).

New Record

Test Sheet ID	6	
Date	02/02/2007	
Workpiece ID	stainless steel test 3	
start_time	13.00	
end_time	16.00	
tank temp	15	°C
Job area	8.4	dm2
Target current density	2.5	amp/dm2
current	21	amp
job thickness before		mm
thickness - sample point 1		mm
thickness - sample point 2		mm
thickness - sample point 3		mm
thickness - sample point 4		mm

Images


stainless3-stretched


stainless3-front-and-back


stainless3-detail-back


stainless3-detail-front

Add Image

notes

Current was set to 21 Amp initially but at return after 1 hour had dropped to 10 Amp. No way to determine how long this had occurred. Second and third hour done at 21 Amp
63 Amp hours in total

New Record

Test Sheet ID	7	
Date	14/02/2007	
Workpiece ID	stainless steel test 4	
start_time	12.00	
end_time	18.00	
tank temp	14	°C
Job area	4.2	dm2
Target current density	2.5	amp/dm2
current	12	amp
job thickness before		mm
thickness - sample point 1		mm
thickness - sample point 2		mm
thickness - sample point 3		mm
thickness - sample point 4		mm

Images

Add Image


complete-test-back


complete-test-electroformed1


vinyl-on-fabric-electroformed-back1


varnish-under-fabric-electroformed-back1


vinyl-on-fabric-back

notes

Bubbly result
in some areas the copper has come through in large bubbles.
In other areas it has not come through at all.
There is creeping of the copper in places where it shouldn't be.

After the first hour the Amps had gone up to 20 instead of the 12 as I set them in the beginning. I set it back to 12.

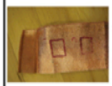
New Record

Test Sheet ID	10	
Date	14/05/2007	
Workpiece ID	conductive textiles (1)	
start_time	15.15	
end_time	18.50	
tank temp	13	°C
Job area	10	dm2
Target current density	1	amp/dm2
current	10	amp
job thickness before	varies	mm
thickness - sample point 1		mm
thickness - sample point 2		mm
thickness - sample point 3		mm
thickness - sample point 4		mm

Images

Add Image


3strips-front


copper-nonw-front


parachutesilk-front

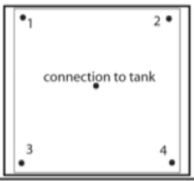

silver-nonw-front

notes

The non-woven fabrics soak up the Lacomit, so it becomes less effective.
Lacomit is effective on parachute-silk
Electroforming the non-wovens makes them thick, rough and unpleasant to touch
Electroforming results on parachute silk are good (shiny and smooth).

New Record

Test Sheet ID	12	
Date	24/05/2007	
Workpiece ID	conductive textile 2	
start_time	15.39	
end_time	17.10	
tank temp	17	°C
Job area	2	dm2
Target current density	1	amp/dm2
current	2	amp
job thickness before	7.5 1/100	mm
thickness - sample point 1	7.5 1/100	mm
thickness - sample point 2	7.5 1/100	mm
thickness - sample point 3	7.5 1/100	mm
thickness - sample point 4	7.5 1/100	mm



Images


cond-text2-before


cond-text2-after


cond-text2-detail1


cond-text2-detail2

Add Image

notes

front and back of the piece: each 1 dm2.

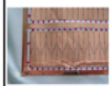
piece is out of the tank very often, for taking measurements: taken out every 5 minutes. total time in the tank is 1 hour.
point1: 7.5/9/9/9/9.5/10.5/11.5/12/13.5/13.5/14
point2: 7.5/9/9/9.5/10/11/11/12/12.5/12.5/13.5
point3: 7.5/9/9/9/10/12/13/14/14/14/14
point4: 7.5/9/10/10/10.5/11/11.5/12.5/13/13.5/14
second set of photo's: taken at 9th measurement

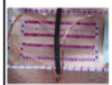
New Record

Test Sheet ID	16
Date	10/07/2007
Workpiece ID	links patterns 1
start_time	11.15
end_time	17.25
tank temp	17 °C
Job area	21.2 dm2
Target current density	1 amp/dm2
current	21 amp
job thickness before	mm
thickness - sample point 1	mm
thickness - sample point 2	mm
thickness - sample point 3	mm
thickness - sample point 4	mm

Images


links11


links13


links19


links21


links22

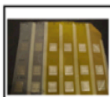
Add Image

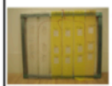
notes

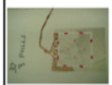
New Record

Test Sheet ID	20	
Date	28/11/2007	
Workpiece ID	fabric density and dag thickness	
start_time	11.49	
end_time	16.15	
tank temp	22	°C
Job area	10	dm2
Target current density	1	amp/dm2
current	10	amp
job thickness before		mm
thickness - sample point 1		mm
thickness - sample point 2		mm
thickness - sample point 3		mm
thickness - sample point 4		mm

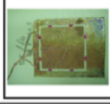
Images


density-whole-before


density-whole-before-onframe


density-detail-32-2


density-detail-90-3


density-detail-55-4

Add Image

notes

testing fabric density and number of pulls through silkscreen
denser fabric gives smoother electroforming result, like a high polish; more open fabric gives rough result, when mesh is too open the electroforming does not work.

used air agitation instead of cathode-bar movement.
so 76 amphour used.

New Record

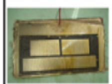
Test Sheet ID	21	
Date	10/12/2007	
Workpiece ID	first printed conductive textile	
start_time	10.55	
end_time	16.20	
tank temp	23	°C
Job area	14	dm2
Target current density	1	amp/dm2
current	14	amp
job thickness before		mm
thickness - sample point 1		mm
thickness - sample point 2		mm
thickness - sample point 3		mm
thickness - sample point 4		mm

Images

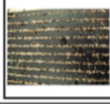
Add Image


print-stop-before-back


print-stop-during-detail


print-stop-after-front


print-stop-after-back


print-stop-after-detail

notes

from 445 to 530 amphour = 85 used

pictures taken at 462 amphour (11.50): copper starts coming through the stop-off where the rip-stop structure shows.

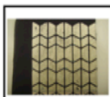
pictures taken at 494 amphour: more copper coming through at the same locations

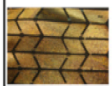
New Record

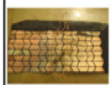
Test Sheet ID	22	
Date	10/12/2007	
Workpiece ID	lacomit-pen	
start_time	16.30	
end_time	16.40	
tank temp	23	°C
Job area	1	dm2
Target current density	1	amp/dm2
current	1	amp
job thickness before		mm
thickness - sample point 1		mm
thickness - sample point 2		mm
thickness - sample point 3		mm
thickness - sample point 4		mm

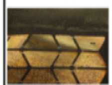
Images

Add Image


pen-before-1


pen-before-2


pen-after-1


pen-after-detail


pen-after-back

notes

lacomit pen does not work:
most tabs have copper built up.

1 amphour used, now 531 showing on meter.

New Record

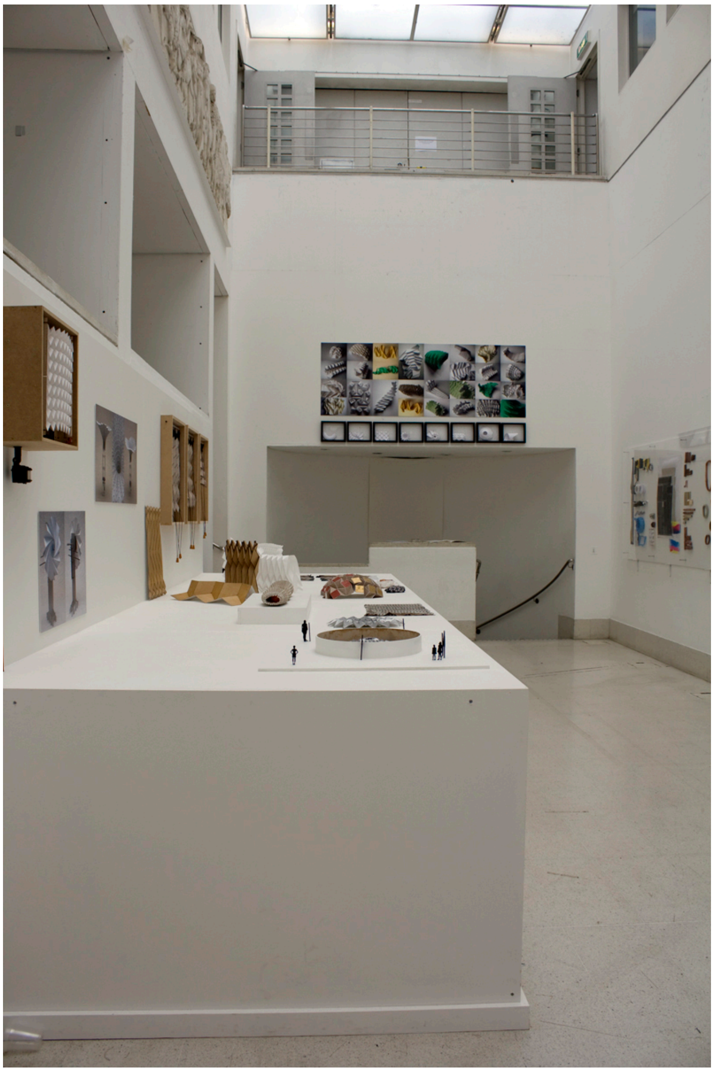
Appendix C – Exhibiting "Wearable Metal Origami"

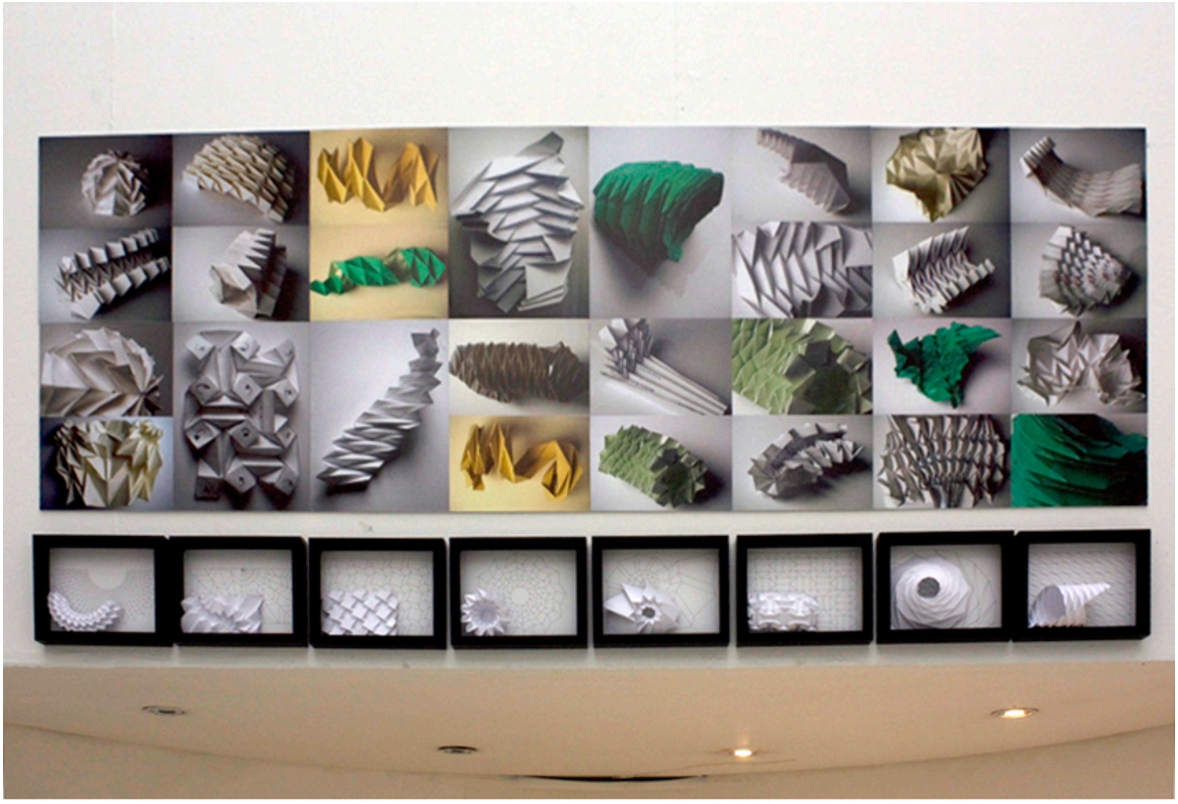
Images of "Wearable Metal Origami", as presented at the Royal College of Art SHOW ONE, 29 May -7 June 2009.

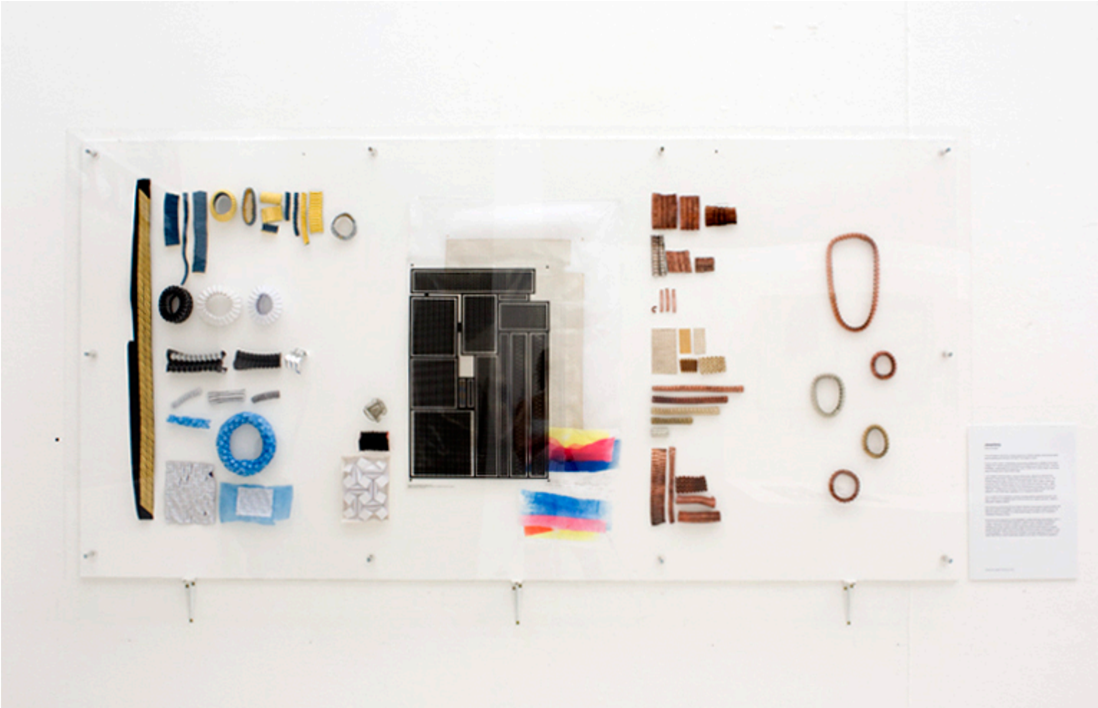

Wearable Metal Origami
Tine De Ruysser
PhD by Project student
Through research into materials and production processes, I developed an innovative flexible metal-textile composite: Metallised Folded Textile. It has the appearance of a rigid multi-faceted metal object because most of the surface consists of metal platelets, yet is extremely flexible since it contains textile hinges. I found that it is possible to use a range of folding patterns, leading to different flexible movements. I tested its properties and suitability for use in a range of design disciplines by designing a series of wearables.
The flexibility allows me to make objects that can take on the shape of the human body and move with its movements and objects that can change shape, size, or even function.
Sponsored by:
design flanders
Arts & Humanities Research Council

Images of “Wearable Metal Origami” as presented in the context of the Deployable Adaptive Structures team project, Hockney Gallery, Royal College of Art,

25 -28 June 2009







Glossary of Terms

Conductive textiles are textiles made from, or coated with, an electro-conductive material, so that they will conduct electricity.

Electrodag is another word for an electro-conductive paint.

Electroforming is an elctrodeposition process, used to deposit a metal layer an object by suspending it in a chemical solution and passing an electric current through it. Electroforming is used for creating a thick layer that becomes a self-supportive object when it is removed from the mould. (Curtis, 2004, p.48)

DAS The 'Designing and Making Deployable Adaptive Structures based on the Deposition of Metals on Textiles' (DAS) project ran for three years (from 2005 to 2008). It was set up by Professor David Watkins and sponsored by the Arts and Humanities Research Council. It employed from three to five part-time research staff, and had me on board as the full-time research student. In this context we looked at the same folding patterns and a range of materials similar to Metallised Folding Textiles. We investigated how they could be applied to objects such as sunscreens and water fountains; how the objects could be actuated mechanically; and how the movement might be predicted through virtual models. We also worked with a London based jewellery company to see if we could get MFT integrated in their collections. The results of this research project were shown in an exhibition at the Royal College of Art, Hockney Gallery, 25 -28 June 2009. (Images of this exhibition can be seen ain appendix B)

Flat folding, an origami term. The rules of flat folding ensure that a folding pattern can theoretically (in case the thickness of the paper was 0) be folded up to make a model flat enough for it to be stored in between the pages of a book without having to make more folds.

There are 4 characteristics that define flat foldability:

- Counter change: the areas between folds (the platelets) can be filled with one of two colours, in such a way that no two adjacent platelets have the same colour.
- Two folds never intersect (whether mountain on mountain, valley on valley or mountain on valley) but must come together at a vertex.
- The number of mountain folds and valley folds at a vertex always differs by two. For example, when four folds meet there are two possible combinations: one mountain fold with three valley folds, or one valley fold with three mountain folds.
- Alternating angles at a vertex add up to 180º.

Not all tessellating origami patterns are flat foldable. It is not a necessity for their use in MFT that they should be so, but in certain cases it is desirable. Flat foldability offers the best chance to pack something up as small as possible (such as the Miura Ori, used for maps and space solar panels), and consequently the greatest movement from flat to fully folded and back. If those qualities are needed, then a flat foldable pattern is most likely to be the best choice. If on the other hand one needs hollow spaces in the folded model, for example to insert objects (such as lights for an architectural application), then a non flat foldable pattern will be more suitable.

Foldability determines whether a folding pattern will actually fold or not. For a pattern to be foldable folds have to meet at vertices and the paper must not need to intersect itself when the model is being folded.

Folded model, the result after folding, when all the crease lines from the crease pattern have been folded.

Folding pattern, the blueprint of the design, it shows along which lines the object will be folded (the crease lines or fold lines)

Laminate: a rigid or flexible material made by bonding a number of different layers together. (Shorter Oxford English Dictionary, 2002)

MFT stands for ‘Metallised Folding Textiles’, the folding textile-copper laminate I invented, developed for this PhD, and used for the creation of ’Wearable Metal Origami’.

Mountain fold, an Origami term. In origami, there are two types of fold. Mountain fold, and Valley fold. A mountain fold has the folding line pointing up, as if it were a mountain ridge. When one looks at the paper from one side and sees a mountain fold, then this fold turns into a valley fold when the paper is turned over, and looked at from the other side. When creating an origami model it is consequently important to choose one side of the paper to be the front, and determine all the folds from that side.

Origami tessellation, the tessellation of foldable units. In this case not only the perimeters of the folding units have to line up, the folds have to come together in a foldable way too.

Stop-off, a lacquer or paint used to cover part of an electrically conductive surface from exposure to the electroforming solution to prevent metal building up in that part.

Techno Textile. ‘Techno’ is an abbreviation of technological (Shorter Oxford English Dictionary, 2002). Techno Textiles are textiles that have a technological aspect in either their appearance, their production, or their function.

Tessellation, describes (as in tiling) how a basic unit is repeated to fill a plane. The shape of this unit has to be such that it can be fitted together on the plane without gaps.

Rigid origami, used for the theoretical mathematical modelling of origami. It presumes that the platelets are rigid and have zero thickness, that the folding lines are perfect hinges with zero width, and that the model cannot intersect itself at any moment during the folding process.

Valley Fold, the reverse of a Mountain Fold. A valley fold has the folding line pointing down, creating a valley in the paper.

Vertex, the point at which several folds meet. Each folding pattern will normally have several vertices.

'Wearable Metal Origami', the name for one object, or a collection of objects, made from MFT.

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