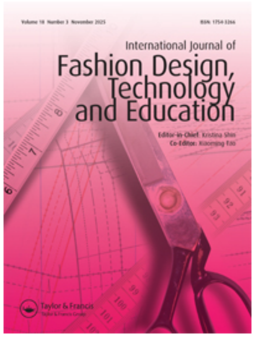

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Use of the Mobius Band structure to challenge 2D flat origins in zero-Waste pattern-making for fashion

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ABSTRACT

This practice-led research explores the Mobius Band structure's potential to challenge zero-waste pattern-making approaches that rely on 2D flat surfaces as a starting point. Addressing textile waste requires alternative methods that are mindful of circular design principles and embrace zero-waste pattern approaches. The Mobius Band structure provides a 3D fabric space for design development, offering the potential for multiple forms and wear possibilities that cater to individual wearer needs, while also contributing to innovations in sustainable apparel production. The experimental work presented in this paper focused on optimising the fluidity and multi-dimensional aspects of the Mobius Band using various materials, sizes, and dimensions, resulting in continuously changing surfaces and garment shapes. The outcomes demonstrate the potential of the Mobius Band method to enhance zero-waste pattern cutting by offering a 3D design framework that reduces cutting lines, prevents fabric waste, preserves fabric integrity, and creates versatile garments with an innovative design approach.

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Mobius band; zero-waste fashion; textile waste; creative fashion pattern-making; sustainability

1. Introduction

Textile waste has become a significant issue as a result of the rapid development of the fast-fashion industry, with more than 90% of all resources extracted and used squandered (Veldhoven et al., 2022). The amount of residual fabric and textile waste produced during garment manufacture may range from 25% to 40%, depending on the scale of the factory (Aus et al., 2021) and, in fact, every second, a truckload of textile products is dumped or burned somewhere in the world (EU, 2022). In 2019, the overall waste amount was reduced as the Covid-19 pandemic led to a serious global economic crisis (Guterres, 2020). However, with the recovery of the economy in the post-pandemic period the fast-fashion business is expected to grow at a rate of 19.0% between 2020 and 2025 (Wood, 2021). The amount of textile waste is increasing accordingly. Significantly, over 97% of the textiles used in garment production are new and only 1% of today's materials will be used in tomorrow's attire (Bozarth, 2022). The expansion of the fashion industry at the expense of the environment and our natural resources is not an acceptable transaction. It is imperative to develop innovative design and technical solutions that address the current issue of textile waste, creating versatile garments that extend their active-use and prolong their lifecycle.

Textile waste appears throughout the entire garment development, production, use and end-of-life processes, in both the pre-consumption and post-consumption phases: the fabric development process; the pattern-making and construction (cut and assemble) stage; the sampling/toiling and mass-production process; the deadstock or 'unusable' garment phase within a consumer's wardrobe; and then the garment's journey to second-hand, charity shops and the recycling factories. Ultimately, textiles are deposited in landfills or combusted (Abnett, 2016; Aus et al., 2021) as alternative energy in low-income countries (Roushan, 2021). This reflects an inadequate fashion production approach driven by a capitalist imperative for low costs and high profits, which has increased fabric waste-related environmental issues.

With the expansion of the ultra-fast-fashion industry to foster growing consumer demands, textile waste is expected to escalate significantly, exacerbating issues of overproduction and overconsumption. Circularity has become crucial in supporting the transformation of the current linear system (MacArthur, 2020), shifting the paradigm from the take-make-use-landfill approach

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to one that ensures resources remain active within the loop. The industry as a whole needs to shift their orientation towards restoring balance and giving back to nature. This necessitates a fundamental shift in how we approach apparel design, pattern-making, and construction to align with the growing need for sustainable practices.

Creative pattern cutting has recently gained increased attention in the development of sustainable fashion practices, as its potential can be harnessed to promote sustainable design and production that values the apparel itself while respects nature resources. In creative pattern cutting practices, designers continuously experiment with shapes and forms to explore additional potential uses for fabrics in fashion design, creating a relationship between visual and fabric forms (Townsend & Mills, 2013). Fabric engages with the human body in the most natural way possible when designers consider the relationship between each piece of fabric (Townsend & Mills, 2013). Utilising the entire width and length of the fabric when cutting and constructing clothing is known as zero-waste pattern cutting. This method lessens the amount of textile waste produced during the conventional fashion patterning process by 15% to 20% (Rissanen & McQuillan, 2016; Townsend & Mills, 2013). The production of a garment is inseparable from the pattern, as the pattern-making method affects the design outcomes intentionally or unintentionally. Creative pattern-cutting methods, such as zero-waste pattern-making, integrate the pattern-making and fashion design in contrast to the conventional linear system. These methods play a significant role in preventing textile waste during the pre-consume phase. Additionally, they highlight the importance of redefining fashion fundamentals to align with the needs of a sustainable future, moving away from the reliance on low-quality mass-production.

Conventional fashion pattern-making involves the process of constructing 3D garments from 2D flat fabric, which integrates the association of the 'pattern, the fabric, the shape, the body' to create garments (Townsend & Mills, 2013). During zero-waste pattern-making practices, designers often limited their creativity to specific flat fabric surfaces, striving to use the entire fabric to create one or more garments. It has been critiqued that with increased public awareness of sustainability, zero-waste designs are frequently misunderstood as only producing dull and boring garments (Joy, Sherry Jr, Venkatesh, Wang, & Chan, 2012; Wiederhold & Martinez, 2018). There are many existing zero-waste pattern-cutting designs that focus on achieving aesthetically appealing results within a rectangular flat fabric space (Rissanen & McQuillan, 2016). However, it can be argued that these flat patterns with multiple cut pieces often weaken the fabric's integrity for further use (Aus et al., 2021; Cumming, 2016). When confined to a flat fabric surface, minimal cutting lines and garment variety often exist at opposite ends of the spectrum. Future creative zero-waste pattern-making methods need to move beyond the 2D flat surface as the starting point, exploring greater opportunities for design, size variability and adaptability while extending the lifespan of both the fabric and the garment for the wearer.

Therefore, the Mobius Band design method has been developed in the context of circularity, to design with the mindset that allows materials to actively flow within the closed-loop system. The aim of this research was to enrich the zero-waste pattern-making field by providing a Mobius Band method that combines zero-waste pattern-making with an infinity 3D fabric space. The purpose is to analyse the behaviours of the Mobius Band structure in the zero-waste pattern-making process using a series of drape practices with a variety of fabric sizes and cutting dimensions to examine the structure's potential. This paper focuses on the capacity of this zero-waste pattern approach to provide multiple design possibilities for the wearer(s) to explore during their garment life. The fluidity of the Mobius Band structure has been leveraged to ensure the garment's adaptability, offering greater versatility for a wide range of potential wearers compared to a conventional fixed-shape garment.

2. Literature review

Fabrics are integral in people's everyday lives and have become affordable, and accessible. The popularity of fast-fashion garments in past years indicates that, for most consumers, fabric is no longer significant and valuable. Fast-fashion garments are cheap, of poor quality, and have short lifespans (Fletcher, 2010), allowing consumers to dispose of them after every quarter or 'fashion trend' without a second thought. In addition, the inherent waste generated by the existing linear process makes textile waste appear to be an inevitable consequence of the current mainstream garment production methods. The mainstream pattern-making method was developed to align with the expansion of mass-production, originally intended to support the growth of the fashion industry and improve people's everyday life. However, this growth has become uncontrollable, further dividing knowledge and practice while intensifying the extraction of resources. The conventional practices have gradually isolated the design and production stage to accommodate the demands of fast paced, streamlined production, however, resulting in a dramatic increase in textile waste. Alternative methods are needed to disrupt the conventional mindset in design and practice, opening up new opportunities for a sustainable future which allows multiple approaches, modes and scales of production for industry. Achieving a sustainable future for the fashion industry requires systemic change (Dissanayake & Weerasinghe, 2022); this does not mean simply replacing the linear system with a single circular system. A circular system is not always an ideal solution, instead we need pluralistic approaches operating at different scales, and scenarios and tailored to local contexts.

Fashion pattern-making is important in the formation of fashion design as it influences outcomes in design, whether consciously or unconsciously. Fashion pattern-making, which involves a process of constructing 3D from 2D (Fig. 1), requires an understanding of the three-dimensional relationship between shape and body. There are now a complexity and variety of 2D pattern pieces or shapes compared with historical patterns (McQuillan, 2020), as current mainstream fashion design draws more attention to the finished 3D garment shape, not the pattern, the fabric and the body. The linear development process of fashion design, pattern-making, cut and assemble (construction), and finished garment (Rissanen, 2013), bolsters economic growth by reducing time and cost to improve efficiency. Fast-fashion shortens the process of designing-production-shipping from an average of 3 to 6 months to 12 days (Berg, Heyn, Rölkens, & Patrick, 2018). As a result, fabric and garments have been devalued, the connection between garments and wearer(s) has weakened, as the mass-production garment is not designed to achieve a long-term relationship with the wearer(s) or the environment, ultimately contributing to wastefulness.

The fabric usage life can be extended per ownership when the pattern is carefully designed to assemble the garment to meet the wearer's different needs (Fletcher, 2017 Townsend, 2011). To restore the connection between fashion design, pattern-making and the wearer, to restore the environment, future innovative practices need to ensure that the design and production are closely integrated rather than separated. This research utilising Mobius Band structure to explore the zero-waste pattern-making method contrasts to the conventional linear process, pattern-making is prioritised to fashion designing, pattern-making could be considered fashion designing. The Mobius Band provides the lens to review the conventional and creative pattern-making practices from a 3D design perspective, to contribute to enhanced connections of the design and production, the fabric, the garment and the wearer(s). The transition from fabric to the garment is where we need to eliminate textile waste, and strengthening the relationship of the garment and the wearer is how we support conditions for textile circularity.

This research is influenced by numerous designers' innovative pattern-cutting techniques or theories, which explore the application of Mobius Band structure in fashion zero-waste pattern-making. There are several highlighted with particular relevance including bias cutting (Bryant, 1993), zero-waste jigsaw puzzle use (Rissanen, 2013), 'zero + one' pattern cutting (Cumming & McQuillan, 2018), subtraction cutting (Roberts, 2014), and Flat Textile-form methodology (McQuillan, 2020). Draping techniques are commonly utilised in these innovative approaches, either as a dominant method for guiding the design and production iterations or for

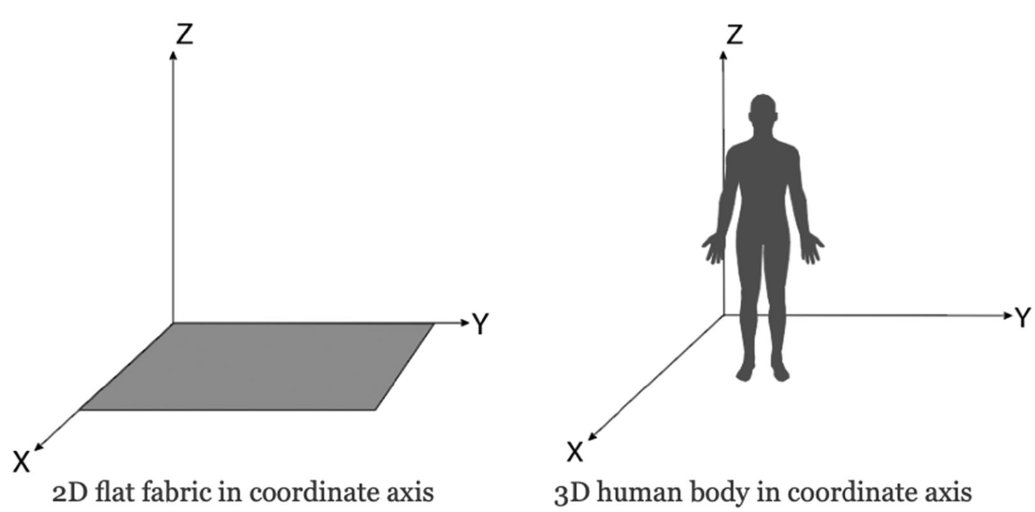

Figure 1. 2D to 3D in fashion pattern-making.

refining the specific details to achieve the goal of eliminating the textile waste. This research also employed draping techniques to drive exploration and observation of the Mobius Band structure's application in zero-waste pattern-making while purposefully reducing the number of cut-and-sew procedures. Draping techniques emphasise valuing the natural form of the fabric, offering a distinct approach compared to the conventional flat pattern-making, which is based on fashion technical drawings and focused on predetermined outcomes. Although creative approaches and the draping process sometimes carry the characteristic of unpredictable results, they are often perceived as opportunistic. Opportunism stands in opposition to the principle of standardisation in mass production, becoming one of the reasons for the limited adoption of innovative methods at a massive or large market scale. However, the unpredictable process and results are crucial during the exploratory stage for transition towards sustainable future, especially when there is an urgent need to shift the design and production model to respect nature and resourcing.

To achieve this, we may have to rethink and approach fashion creation in ways that oppose conventional practices focused on fast-paced, streamlined mass-production. Preventing the misuse or adaptation of innovative sustainable methods to further support ultra-fast mass-production is a critical consideration when introducing alternative approaches to address current issues. The current mainstream garment creation process begins with flat fabric, leading pattern-making methods, including the innovative approaches, to primarily focus on the transition from 2D to 3D. However, this research questions whether a 3D to 3D approach deserves attention in the current and future context, to creating garments that are resource cognisant, flexible, versatile, and capable of responding to diverse wearer(s) needs. In order to analyse the demands for pattern designing under a 3D design framework, the investigation concentrated more on techniques primarily connected to the spatial connectivity of the body and the fabric. Approaches to eliminating pre-consumer textile waste and consumer longevity are critically studied to shaping the Mobius Band pattern designing method that meet the adaptive and circular design goals.

Madeleine Vionnet's Bias cut method allows us to rethink how we design a garment. There is not necessarily a need to start from drawing or flat pattern-making. Even the placement/layout of fabric when cutting the pattern piece won't always be parallel to the grainline, as bias cut refers to cuts on the fabric at 45 degrees to the grain (Bryant, 1993). Vionnet did not always use true bias, as some of the cuts are partial bias grain (Bryant, 1993), demonstrating her thorough knowledge of and freedom to use the fabric's grain and bias when designing garments to fit and collapse from the concave and convex shapes of the body. Vionnet's bias cut highlights the close connection between the fabric, the cutting line and the garment shape, as she 'created dresses where the inherent structure of the textile gave shape to the dress' (Druesedow, 1987). However, the bias cut method could also be an expansive way of using the fabric by considering the fabric usage and durability of the weave structure after the cut. Can zero-waste pattern design that transitions from 3D to 3D effectively utilise the fabric's bias while maximising fabric usage and eliminating pre-consumer textile waste?

Jigsaw puzzle and geometric shape methods in zero-waste pattern-making practices enable designers to utilise the entire space of the selected fabric, often incorporating pattern pieces with mixed grainlines. Pattern pieces often share the same cutting line, highlighting the importance of individual pattern shapes and their interactive relationship with one other (Rissanen, 2013), the selected fabric space, and most importantly, the human body. Jigsaw puzzle and geometric shape methods often begin with existing pattern blocks, then developing and draping the pattern further to minimise fabric waste during production or reproduction for fabric circularity. The nature of the fabric including the behaviour of the bias and grain has been prioritised in this process, however, the design thinking is still limited to 2D–3D, or 3D–2D–3D to assemble a zero-waste garment. Transfer between 3D and 2D often involves a significant amount of cutting and construction lines that affect the fabric's integrity for upcycling or recycling the garment after initial use. How can we ensure that the fabric is integrated for future applications while ensuring that textile waste is eliminated in the initial design and production?

The Zero + One project by Deb Cumming and Holly McQuillan combines one-piece cutting technology with zero-waste design to create apparel that is made from a continuous piece of fabric. The one-piece cutting technique, which demonstrates minimalism, can minimise cutting and sewing while guaranteeing new aesthetics for the apparel (Cumming & McQuillan, 2018). This approach improves fabric integration, allowing the garment to be unpacked and reversed back into a square piece of the fabric without requiring the original pattern to reassemble the individual pieces when repurposing the garment. Three coats were designed in Zero + One project, which aimed to reduce fabric waste and enable post-consumer design disassembly and pattern reconstruction by fusing minimal cut lines for textile recycling. By draping the flat fabric over the live body, this project focuses on the interior space between the body and the garments, specifically examining and considering the fit and functional body movement, mostly in the double sleeves (Cumming & McQuillan, 2018). The objective is to make it possible for garments to satisfy the rising demand for clothing in terms of both aesthetics and utility. Pattern and construction techniques have also been modified for the alternative design approach. For instance, there are alternative double fabric folds in areas to compensate for no interfacing and to stabilise the seam and pocket. Retaining the selvage and applying tape to the original fabric shape along stitching lines to avoid overlocking gave the garment a tidy finish and a graphic textile appeal. However, because the cutting lines were dispersed throughout, the fabric's integrity was compromised (the fabric area between the cutting lines is small and irregular). Even if these cut lines can be re-fused, the fabric will still be directly affected. Above all, the result emphasises the need for 3D thinking to be more deeply embedded in zero-waste pattern-making to enhance the reusable space of fabric for future and multiple uses. Could Mobius Band zero-waste pattern design method start with draping a flexible 3D structure that employs a minimum number of cutting lines to maintain fabric integrity, while providing sufficient zones for updating garments after initial use?

The Subtraction Cutting method introduced by Julian Roberts is an alternative method that skilfully emphasises the void between the garment and the body (Roberts, 2014), thus to design in a 3D space with the integration of the 2D flat patterns. Instead of developing a new pattern or block, it does, however, continue to utilise a standard block. The 'Tunnel' technique is important to the Subtraction Cutting method (Roberts, 2014) and entails using the cloth to create a tubular body, leaving passageways/ holes for the body to pass through. Instead of focusing on shapes, fit, and measurements as in conventional patterns designs, or ensuring fabric usage in other creative pattern-making methods, the tunnel technique allows designers to alter the design by exploring how individual holes can be joined and stacked in different configurations. Once the hole is defined, the designer concentrates on analysing the shape during the design process. It enables the designer to reconsider how fabric, the human body, and patterns interact, without predetermining the design outcome, where risks and opportunities coexist. The benefit of the Subtraction Cutting technique is that it lessens dependence on and limits pattern component numbers and dimensions while increasing options for innovative results in the final shape pattern-making (Roberts, 2014). While this method is not intended to achieve zero fabric waste during the initial design and production stage, its crucial aspect lies in the spatial interaction between the garment and the body, offering the potential for adaptable and transformable clothing that can suit the diverse needs of a wide range of wearers. Significantly there are no fewer than five different ways to wear Julian Roberts' Sub-Cut garment (Rissanen & McQuillan, 2016). Customers can use this option to own 'multiple pieces' while just purchasing one item of clothing (McQuillan & Rissanen, 2011). This approach reduces the amount of fabric that individuals purchase by the fabric's useful life. However, this method significantly uses more fabric than is typically required for similar clothing styles. How could the Mobius Band approach utilise the 3D space and the fluidity feature of the bias fabric to support adaptative approaches and allow garments to evolve with the needs of the initial wearer and it future wearers?

McQuillan's Flat Textile-form design T-shirt (iteration three) recently included a stitch-less method through sliding and folding, in which the shape is woven into the fabric and released when it is cut (McQuillan, 2020). Overall, only two seam lines were required to make this T-shirt; however, McQuillan believed that if the loom could weave more layers, it would be possible to omit the two stitch lines at the sides (McQuillan, 2020). McQuillan integrated existing 3D garments into 2D flat weaving forms and utilised folding and unfolding among layers to reduce seam lines and construct new 3D garments. This involved utilising the woven nature of the cloth to separate it into several 2D flat layers that aimed to construct the individual flat pieces to become a 3D garment. Textile-form design significantly pushes the boundaries of zero-waste pattern cutting, integrating deeply not only with fashion design and production but also with the textiles themselves (Hallnäs, 2019). However, the durability and density of woven fabrics vary when layers are separated or unfolded in accordance with individual patterns. If pattern-making design thinking remains limited to building the 3D structures from 2D surfaces, it may still require multiple cutting lines to unfold layers to create space, raising concerns about fabric integrity and the durability of the garment. Although emerging innovative textiles and smart fibres could help to address the technical gaps and deficiencies in the development of fully fashioned weaving. A 3D design framework remains crucial to support future technological advancement in zero-waste design and pattern-making fundamentals. In response to the need for adaptive garment design and close-loop production, we must ensure that our fundamental thinking regarding design and production is experimental and innovative aligned with the opportunities and needs created by 3D technology.

The transformation process between 2D fabric and 3D garment formation in fashion pattern-making is still prevalent in conventional and most alternative methods in creating garments. By adhering to this conventional mindset we face challenges on two fronts. On one hand, it becomes difficult to reduce the use and impact of cutting lines when striving for zero textile waste in design and production. On the other hand, this mindset creates a barrier to reshaping the linear model to align with the shift towards sustainability goals in the industry and education sector, as flattening 3D designs or garments becomes an unavoidable step. This research aims to explore the potential of zero-waste pattern-making when transitioning from 3D to 3D by utilising the Mobius Band structure. It seeks to address the issues of textile waste, focus on the interconnections and transformation processes within the design and pattern-making practices (Kaye, 2016), and provide a 3D design framework that emphasises material efficiency and flexible of form, allowing for responses to diverse needs of wearers and align with the circular design principles of incorporating repurposing strategies.

2.1. Mobius band history and uses

The discovery of the Mobius Band is attributed originally to the German mathematicians Johann Benedict Listing and August Ferdinand Möbius in 1858 (Thulaseedas & Krawczyck, 2003). A twisted, non-orientable, two-dimensional surface with a one-dimensional edge is known as a Mobius Band (Guo, Guzmán, Carpentier, Bartolo, & Coulais, 2023). Since its discovery, the Mobius Band has appeared in different fields including mathematics, engineering, science, and even art and magic (Thulaseedas & Krawczyck, 2003). The Mobius Band is frequently used in engineering as the shape for pulley belts since both sides will be used equally (Starostin & Heijden, 2016). When utilised in architectural design Mobius Band can allow people to experience wonderful spatial and visual changes when walking around the structure without being turned upside down. This transformational character can create an intermingling of external and internal space (Thulaseedas & Krawczyck, 2003), such as the work of Peter Eisenman's Max Reinhardt Hau (Hodge, Mears, & Sidlauskas, 2006; Thulaseedas & Krawczyck, 2003).

The performance of the Mobius Band structure reveals a lack of stability and indicates how one order of architectural space depends on another as there is no clear distinguishing line between internal or external space (Kaye, 2016). However, this instability could generate an opportunity for innovative fashion pattern-making practices for versatile apparel design. The Mobius Band could help to strengthen the interconnection within the fabric itself, blurring the 'right' and 'wrong' sides of the fabric. The twisted feature of the Mobius Band connects the fabric selvedge, enabling design from a 3D perspective that challenges the conventional definition of using the correct sides of the fabrics. This approach has potential for garment repurposing practices, as it maximums the use of existing fabric by treating both sides as equally valid within the sustainable design context. The infinite and fluid nature of the Mobius Band also supports zero-waste fashion pattern creation, allowing the fabric to flow naturally on the body with an open, form-changing silhouette and internal shaping, providing a variety of wearing options to align with the goal of prolonging fabric's lifespan and enhancing its sustainability.

Fashion designer J. Meejin Yoon's conceptual project 'The Mobius' takes the shape of the Mobius Band to create a felted A-line shape dress (Hodge et al., 2006). The wearer can zip up the Mobius to create the dress around the body, and it becomes a structured fabric loop on the floor when unzipped (Hodge et al., 2006). This was a direct use of the Mobius Band to construct a garment without cutting and any subsequent fabric waste. However, the weight, width and non-woven structure of the fabric caused reduced fluidity of the fabric, therefore, increasing the difficulty of wrapping the fabric around the body causing issues for wearability. To advance the infinity fluidity and flexibility inherent in Mobius Band structure for zero-waste pattern design practices, this research focuses on testing patterns using light to medium weight, medium to high drape woven and knitted fabrics.

Vionnet's Mobius Band scarf involved cutting the pattern piece on the bias and assembling it to a Mobius Band structure (Kirke, 1998). Vionnet's design demonstrated the utilising of a bias cut and the Mobius Band structure in fashion pattern-making to increase the potential for versatile wear options. However, a deeper integration of the Mobius Band in fashion pattern design is still needed to further explore the relationship between the Mobius Band, the pattern, and the body from a 3D design perspective for sustainability. This study specifically focuses on deriving versatile garment designs using the Mobius Band, emphasising minimal fabric cutting and sewing lines to facilitate disassembly and reproduction again with the vision of a pluralistic circular future. On reviewing the relevant literature it is asserted that innovative creative and zero-waste pattern cutting appears to be built on a knowledge of the connection between 2D flat patterns/fabrics and 3D bodies, which is where it seems to receive its creative energy. As such the broader research question asks: Could we design in 3D fabrication to 3D garment(s), developing processes within an alternate dimensional space to re-evaluate conventional and alternative pattern design methods, minimise traditional cut-and-sew lines, and preserve the fabric's integrity to the greatest extent for future applications?

3. Methodology

This is a practice-led research study that employs action research methodology. Action research generates new avenues for action beyond the designer's embedded personal experience and perspective. It is a response to a challenge, conundrum, or uncertainty that practitioners face in their work (Swann, 2002) and is also a practice approach that combines 'reflection in action and reflection on action' (Swann, 2002). Therefore, designers can incorporate greater awareness of action, practice, and purpose during this reflective practice by critically documenting the practice experience (Reason & Bradbury, 2001). The description of and reflection in and on action of the creative practice process undertaken in this research has been careful and methodical, resulting in a self-evaluation that will underpin the next stage of the work.

The following criteria were used to facilitate the design development process:

- Fabric choice in relation to size and structure
- Zero -waste fabric usage
- Mobius Band behaviours concerning the fabric, the shape and the body
- Mobius Band pattern for the versatile garment
- The construction of the Mobius Band pattern
- Size variance within a garment

Many explorative iterations were carried out but some of the fundamental samples are described here which were instrumental in leading to outcomes highlighting the potential and versatility of the Mobius zero-waste patterns for fashion designs. The design works first start with understanding the Mobius Band's behaviour with paper explorations. Toiles #1 and #2 (half scale) formed a Mobius Band using square and rectangular low-stretch woven fabrics to explore the fluidity feature of the Mobius Band in relation to the bias of the fabric, the cutting line and the body form. Full-size toiles #3 and #4 tested the infinity moveability features of the Mobius Band with knitted fabrics that respond to versatile wear and body measurements. The experimental works #1 to #4 evidence the adaptability of the Mobius Band structure in zero-waste pattern-making to eliminate textile waste both woven and knit fabric, while providing versatile wear options with reduced cutting lines. Sampling #5 utilise the findings from the previous to develop a Mobius Band pattern with in-depth analysis of the patterns in both woven and knit fabric. The full-scale construction process and it differences with conventional methods were investigated and outlined.

4. Design development process

A common cylinder meets two parallel points, but the Mobius Band meets two opposite corners, that is, along the diagonal of a rectangle (Figure 2). This proves that any point existing within the Mobius Band has a larger spatial span than a cylinder in terms of fashion zero-waste pattern-making.

4.1. Mobius band: the fluidity in relation to size and structure

The girth and width of the Mobius Band structure need to be carefully considered in relation to the specific garment outcomes, particularly when draping with non-stretch or low-stretch woven fabrics. The Mobius Band dress #1 using light weight calico to wrap around the body tests the fluidity feature of the structure with only one cutting line to allow the armhole (Figure 3). The size of this square shape fabric close to the bust and hip girth of the mannequin, resulted in a close fit to the body. Unlike the conventional zero-waste methods that organise fabric space with multiple cutting lines to shape the body, the Mobius Band has the potential to enable low-stretch woven fabric to closely fit the body with minimal cutting lines, ensuring the fabric's integrity for further recycling and upcycling. Designing the initial use with flexible and versatile features to align with the needs of the initial wearer(s) requires extending one direction of the fabric size to enable it to flow around the body in a multi-dimensional manner. The experimental practices in #2 (Figure 4) highlight this aspect. Although with a medium weight fabric in use, the space between the Mobius Band and the body is guaranteed by extending the grith of the Mobius Band. Depending on the specific type of garment, the width of the fabric can be reduced to shorten the length of the garment as the diagonal line of the Mobius Band will be increased thus helping to ensure the fluidity of the Mobius Band when draping.

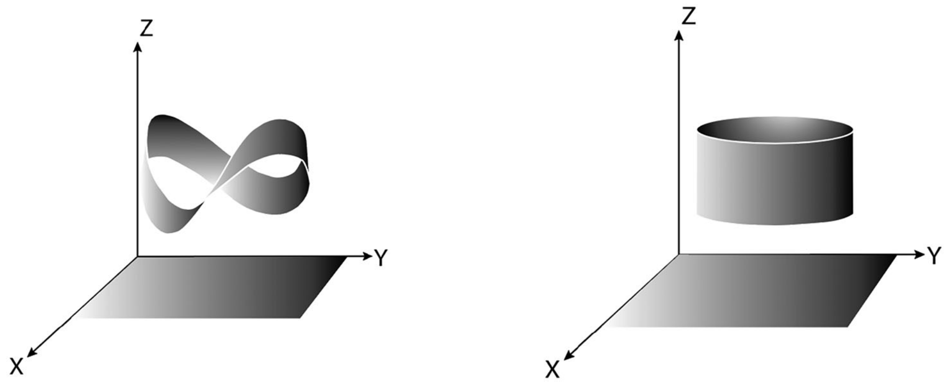

Figure 2. Transfer a 2D flat rectangle surface to the Mobius Band and the tubular.

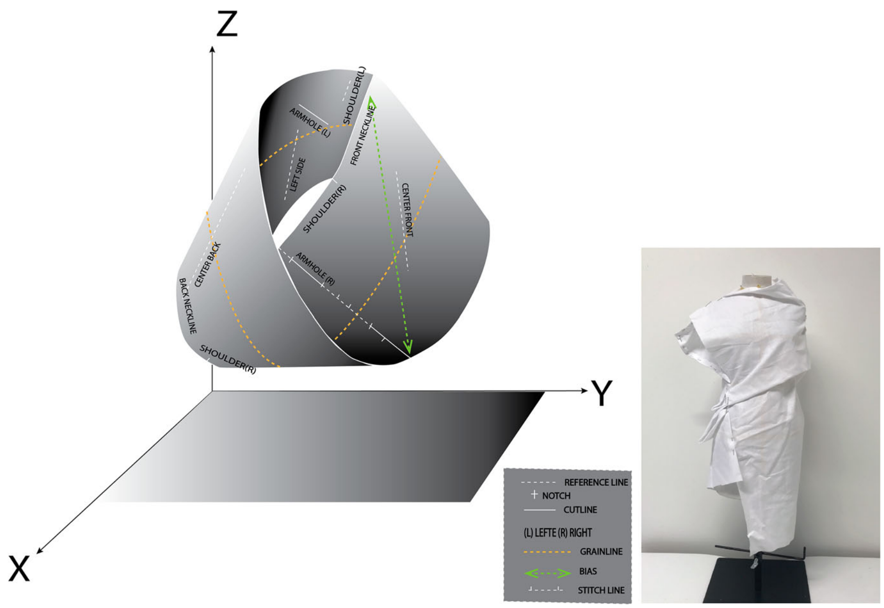

Figure 3. # 1 Mobius Band zero-waste pattern design experiment.

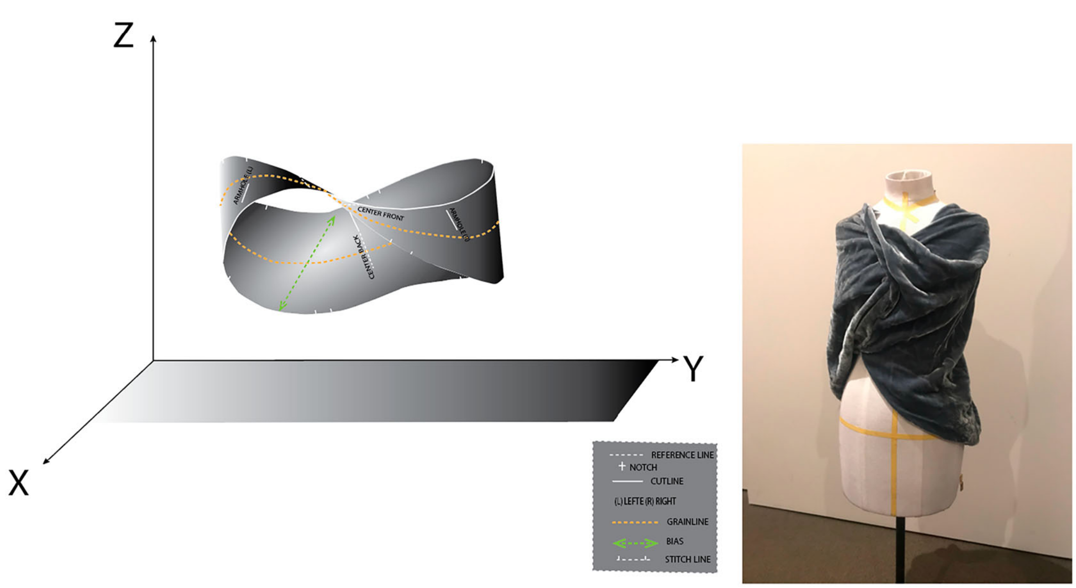

Figure 4. #2 Mobius Band zero-waste pattern design experiment.

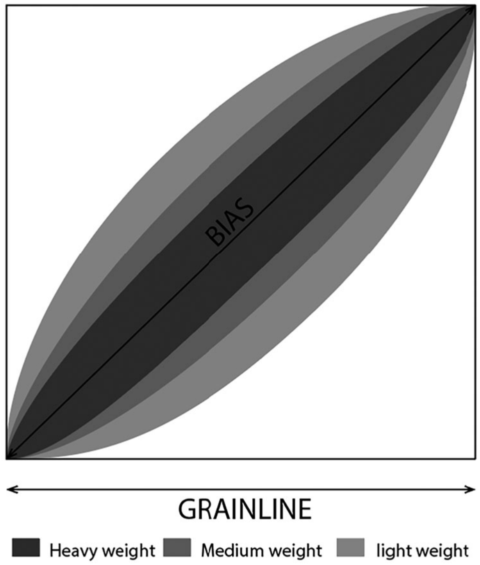

Figure 5. Bias-affected area in relation to different weights of fabric.

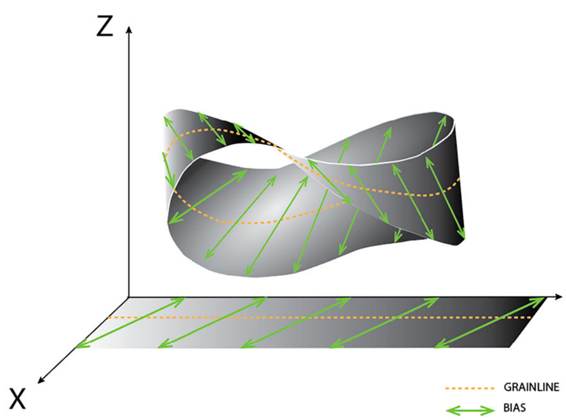

Figure 6. Bias in 3D Mobius Band and 2D flat fabric.

In 2D flat pattern-making, stretch close to the designated bias line impacts the subsequent number of increased cut lines needed to shape the garment (Figure 5). The bias in Mobius Band pattern-making however behaves as a loop with perpetual motion (Figure 6), which means changes made in one section will directly affect other places around this loop. Utilising the Mobius Band structure in pattern-making enhances fabric fluidity while avoiding the introduction of unnecessary cutting lines, aligning with contemporary design approaches that support textile circularity.

4.2. Mobius band: the infinity moveability to accommodate versatile wear options

To facilitate versatile wearer options within a one-piece-cut zero-waste pattern, the fabric space needs to be viewed flexibly. The infinity moveability and non-orientable features of the Mobius Band allow the fabric to shift and reposition around the body, adapting to various garment forms. When using medium stretch knitted fabric, the length of the fabric could be similar to the total of the widest girth measurements of the body that the garment needs to cover. For instance, for a crop top, the fabric length could be 152 cm including the selvedge (close to a total measurement of a size 12 women's bust girth plus two biceps measurements) (Cloake, 2000). According to the experimentations, the length of the fabric is also influenced by the width of the Mobius Band and the orientation (horizontal, vertical or undetermined), thus, it is better to consider adding extra ease when selecting fabric size to allow for greater moveability. Compared to existing pattern-making method that let the cutting lines dominate the central of the fabric, the Mobius Band method concentrating design features and stitching lines along the fabric's edge, with focus on fabric reuse and shape transformation. This way creates more space in the fabric's centre for future design and production.

The Mobius Band method can also be applied to more complex situation, such as the tubular knitted fabric. When integrating the Mobius Band into a tubular fabric, variations are more likely to be achieved without the need for fasteners, as more holes and dimensions are created. For instance, toile #3 (Fig. 7) uses the vertical dimension of the cylinder as a reference line, cutting a specific distance from both ends of the fabric to the middle, ensuring that a portion of the middle remains connected, allowing further testing of deformation of the Mobius Band structure. Two Mobius Bands, and therefore two twists, arise in this fabric shape since a predetermined distance is planned in the middle. This garment has five holes of various sizes, including two sizes that may be adjusted without additional trimmings due to the Mobius Band's impact. In comparison to the Tunnels technique of the Subtraction pattern cutting, which cuts holes freely across the fabric to allow the body to move across the fabric surface (Roberts, 2014), the Mobius Band could emphasise utilising the natural drape and edges of the fabric to shape the holes. Thus, allowing the holes to flow freely around the body in multi-dimensional way. During the construction process, the Mobius Band method blurs the common definition of the right and wrong side of fabric, as the edge of the fabric is joined to shape the twist, it enables fluidity and moveability. Extra cover stitches are recommended to be applied to strength the fabric turning area.

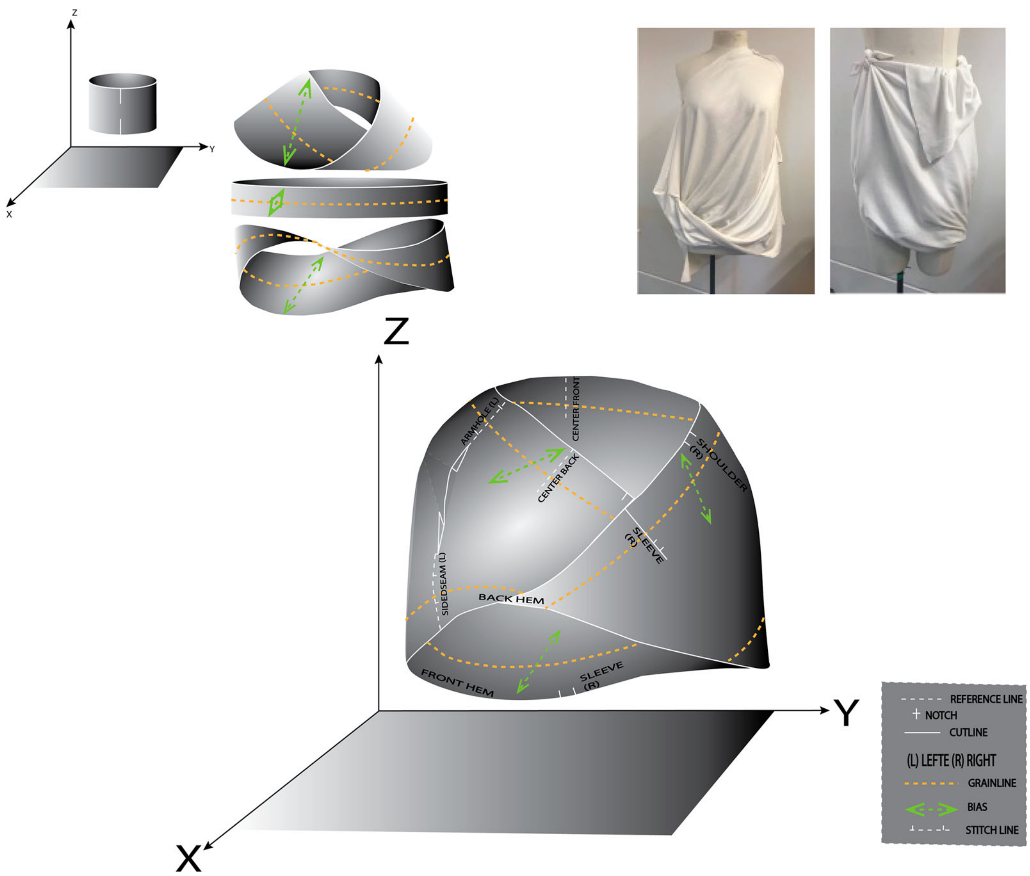

Figure 7. #3 Mobius Band zero-waste pattern design experiment.

A Mobius Band full-length dress (Figure 8) that covers the entire body has been developed to test the application of the Mobius Band with a large piece of fabric. The length of the fabric selected was 142 cm, and its overall width was 163 cm, including the selvedge, by taking into account the bust, hip, and bicep size, as well as the lengths from the neck to the back waist, the waist to the knee, and the floor. Both non-stretch woven and high-stretch cotton fabrics have been used to demonstrate that the same Mobius Band pattern can be adapted to different types of fabric, showcasing the consistency of the pattern for further development to meet recycling goals. Reuse and recycling the same pattern with varied textiles is an approach that reduces the amount of fabric waste generated during the pattern development and sample-making processes. Fabric with different prints, colours, weights and drapes may result in the wearer experiencing a different appearance and feel, even though the garments are made from same pattern.

In conventional 2D flat pattern-making, each pattern piece has an assigned grainline that is usually parallel, against, or biased. In the majority of zero-waste pattern cutting methods, a mix of individually oriented grainlines is used depending on placement. The one-piece-cut method often uses the centre front or centre back line as the grainline, starting the pattern development with this guideline and designing the rest according to the body's movement. Zero + One integrates the feature of one-piece cutting with zero-waste pattern-making to eliminate textile waste in design, while emphasising body movement and contour. Cutting lines become unavoidable in this case. The fabric's grainline behaves as a non-orientated loop in the Mobius Band zero-waste pattern design method. Therefore, the one-piece-cut approach can be integrated while minimising cutting lines for considering the fabric integrity. By designing with this 3D structure, the fabric's fluidity and moveability are enhanced in draping which relies on a non-orientated perpetual loop of the Mobius Band.

4.3. Mobius band design and technical outcomes

Garment variations influence the selection of alternative fastenings and stitch types. For example, the strap that is fastened to the left side may be used as a waist belt and alter the way a garment looks. The design look is altered when belt loops are added to the neckline and sleeves and a strap is used to link them to holes in the garment, such as the holes on the right sleeve and the side waist (Figure 9). The garment made by the #4 pattern could

Figure 8. #4 Mobius Band zero-waste pattern design experiment.

be flipped and worn upside down as the central grainline is maintained in this Mobius Band pattern to support the position and measurement changes around the bust, waist, and hip girth and hem length, while retaining aesthetic appeal. The stretch fabric's elasticity is naturally beneficial for creating versatile garments with minimal cutting lines and the Mobius Band structure helps to enhance this feature. The utilisation of the Mobius Band in non-stretch woven fabric, however, is worth further investigation as it pushes the boundaries of relying on cut and sew to effectively arrange the fabric space around the body.

4.4. Guidelines for practitioners

4.4.1. The fabric selection

The fluidity and moveability features are accommodated well with low to medium weight, or medium to high drape, or low to high stretch fabrics. If a heavier or thicker fabric is used, it must have high stretch to avoid the need for additional cutting lines beyond conventional methods. Non-stretch and low-drape fabrics can be used with this method, but the ability to design for versatility and flexibility is considerably reduced.

To calculate the required fabric size, the following formula can be considered as an example. Additional length may need to be added depending on the envisioned complexity of the garment shape.

Top with sleeves, medium weight and drape, low-stretch fabric:

$$(1 \times \text{bust girth} \; + 2 \times \text{biceps girth}) \times 1.5 \\ = \; \text{length of the fabric}$$

Figure 9. #4 final outcome, front, side, alternative wear options.

Top with sleeves, medium weight and drape, high stretch fabric:

$$(1 \times \text{bust girth} + 2 \times \text{biceps girth}) \times 1 = \text{the length of the fabric}$$

The fabric width can vary, but it is recommended to keep it within a 10 cm difference from the intended garment length for a fitted design.

4.4.2. The pattern designing

Twisting and join the fabric to become the Mobius Band structure before draping is essential, which blurs the boundary between the front and back of the fabric. There is no set selvedge or grainline in the pattern development process. The pattern can be developed and generated using digital pattern-making software like CLO3D. However, this requires a basic understanding of how the Mobius Band interacts with the fabric and the body(s) to ensure that the 3D digital representation closely matches the physical outcome.

4.4.3. The construction processes

The construction finishes for the Mobius Band garment only differ slightly from those of conventional production. However, forming the fabric to become the Mobius Band is always the first step and sequencing can vary. The self-cover stitch and double turn stitch were used to ensure that both the edge and the cutting line of the fabric are finished to appear professional. In order to limit the amount of sewing thread needed, overlock stitching is avoided. A standard sewing machine is sufficient for this method. Cutting or turning points are reinforced by hand stitching to help strengthen the corners. A machine zigzag stitch can be used as a substitute for hand stitching if needed. Fabric straps and a thread chain were chosen for garment fastening instead of a buttonhole to ensure the integrity of the fabric.

5. Conclusion

The objective of this study is to expand creative possibilities in the field of zero-waste pattern design by exploring the use of the Mobius Band structure in zero-waste pattern cutting. This study focuses on developing the Mobius Band as an innovative method that addresses the gap in pattern-making methodologies. Fundamental changes need to be addressed to disrupt the existing linear manufacturing workflows to provide variants of design production to fit localised and adaptable contexts of scale.

This study demonstrates the viability of pattern design within a 3D framework. The explorations of the Mobius Band structure aim to alter and advance pattern designing with a 3D structure in a 3D space around the body. This involves rethinking the relationship between fabric, body and garment. If the 2D fabric is a straight line, then the Mobius Band is a circle with an angular tilt, and this tilt angle is one of the main factors that produce variables within garment designs and size dimensions. This study, utilising the non-oriented perpetual loop feature of the Mobius Band reinforces the advantage of using bias for garment form changes instead of cutting the fabric. Further research is needed to explore the full potential of the Mobius Band method in pattern design, particularly in relation to size inclusivity and the adaptability of garments across diverse designs, body shapes and measurements. This study only introduces the use of Mobius Band as a single and double loop. To enrich the method, further exploration is needed such as, dividing the Mobius Band into two loops, cutting it in thirds, and joining double Mobius Bands together. However, based on numerous garment explorations it can be asserted that the infinite fluidity inherent in the Mobius Band method creates extensive draping opportunities, maximising the use of limited fabric dimensions when designing garments for versatile wear options. In comparison to existing zero-waste pattern designs relying on cutting or folding to shape garments without waste textile from a 2D flat surface, the Mobius Band method focuses on a 3D perspective to develop versatile garments with minimal cutting lines to ensure fabric integrity for future application. This study provides an alternative zero-waste pattern design perspective, aiming not only to eliminate textile waste in pre-consumption stage but also extending the material and garment life. The Mobius Band pattern design method allows for flow within the directional fabric pieces, enabling versatile wear options without extensive use of cutting and sewing techniques. Fluidity in the silhouette and internal shape allows it to adapt to varied garment creation and changing fit needs of wearers.

This study envisions a sustainable future that the industry and the education sector can evolve multi-dimensional approaches to address textile waste. The Mobius Band provides an alternative pattern design method and thinking in fashion practice to support the sustainable model of circularity with technical innovation. Further practise research is needed to continue questioning the prevalent assumptions of fashion design processes for production in order to re-define 'mass-production' in the current context of design for sustainability.

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