CRANFIELD UNIVERSITY

HIND MOSFEER ALGAMDY

REVITALIZATION OF THE EMBROIDERY INDUSTRY USING ADVANCED TECHNOLOGY IN SAUDI ARABIA

THE SCHOOL OF AEROSPACE, TRANSPORT AND MANUFACTURING

PhD
Academic Year: 2017-2020

Supervisor: Dr Muhammad Khan
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This thesis is submitted in partial fulfilment of the requirements for the degree of PhD

ABSTRACT

The purpose of this study was to revitalize the traditional embroidery industry of the Hejaz region of the Kingdom of Saudi Arabia (KSA) by evaluating the possibility of using advanced technology, such as three-dimensional printing (3DP), in its manufacturing process. A mixed method methodology underpins this research in terms of collecting, processing and testing the data. An initial literature review revealed that factors such as an inability to meet current fashion trends, threats from global brands, lack of support from government and insufficient consumer interest are key challenges facing the traditional embroidery industry. Further qualitative evaluation pinpointed a lack of development in the manufacturing techniques of traditional embroidered clothing in the KSA as a key threat. An evaluation of existing technologies revealed that embroidery sewing machines attached to computer-aided design (CAD) software is the technology currently in use in the industry. However, due to inflexibility in adjusting to the demands of customization, it has not been able to mark any significant change. To this end, the current study proposed the use of the 3DP technique in the manufacturing process of traditional embroidered clothing but found that although 3DP has been used in the fashion industry, its use has been questioned because of wearability and quality concerns.

An evaluation of responses collected from 16 manufacturers attending the Souq Okaz Festival in the city of Taif, along with 45 responses from customers of traditional embroidered clothing in three different universities in the KSA, found that both sets of stakeholders showed concerns regarding the wearability of 3DP garments. The manufacturers also shared their concerns regarding the ease of use of the technology. As a backdrop to these findings, two experiments were conducted: a washing test and a peel tensile test.

The washing test revealed that 3DP embroidery designed and printed on silk, cotton and organza showed no impact from washing upon their brightness, roughness, shape or edge. However, the peel test revealed that, due to its irregular texture and shape, organza showed inconsistent adhesion of 3DP material comparative to cotton and silk. This led to the conclusion that 3DP embroidery objects present good long-term wearability, as long as the printing parameters are set up to meet the fabric architecture. Suitability, acceptability and feasibility in relation to the financial, human resource (ease of use) and supply chain aspects of 3DP embroidery clothing were also substantiated.

Keywords: Three-dimensional printing, Adhesion quality, Washing cycles, Peel test, Image analysis

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Identification and Significance of the Research Problem

1.0: Introduction

The Hejaz region of the Kingdom of Saudi Arabia (KSA) is known for its tribal embroidery-designed clothes (Ejeimi et al., 2018). This region is known for its skilled women workers and for their craft of sophisticated embroidered clothing. The importance of preserving the traditional embroidery industry of Saudi Arabia lies in the fact that it represents the desired look of the self; for instance, by representing modesty in dress and adherence to traditional fashion. Furthermore, traditional embroidered clothing possesses roots that connect the past to the present and is a reminder for the future generations of their cultural heritage (Alajaji, 2014). Similarly, Ellis (2015) reported that traditional handicrafts represent a unique cultural heritage of Saudi Arabia because of the variety of their elements, namely, sophisticated cutting techniques, decoration methods and ornamenting and the involvement of different materials, all of which translate the social, cultural, environmental, economic and religious factors of the Kingdom. Emmett (2014) further argued that the traditional crafts of a country also contribute positively towards that country's economic advancement, as they provide a means for the development of art and design. Despite the cultural, social and economic significance of the traditional embroidery clothing of the Hejaz region of the KSA, however, the industry is facing survival challenges due to old production techniques, the involvement of a large number of intermediaries, and a lack of organization, branding, awareness, marketing and customization (Valsecchi et al., 2012). Ejeimi et al. (2018) linked all these challenges to the lack of development in the manufacturing techniques of embroidered clothing, resulting in Western brands taking over the Saudi fashion industry and the slow demise of the traditional industry.

1.1: Research problem

The craft of traditional embroidery is important for Saudi society as it demonstrates the country's culture and values (Alajaji, 2014). Furthermore, traditional embroidery has also contributed towards the art, design and fashion industry of Saudi Arabia. However, traditional handicrafts in Saudi Arabia face survival challenges because of the mass customization of fashion designs and a lack of interest, particularly from young consumers (Alajaji, 2014). In their study on the globalization of traditional handmade products, Vadakepat and Al-Khateeb (2012) warned that low productivity in manufacturing techniques threatened the existence of traditional handicrafts globally. To support their argument, Vadakepat and Al-Khateeb (2012) suggested that the modern global textile industry was witnessing radical changes as technological advancements were helping to shift consumer behaviour. For instance, the fast fashion concept means that consumers seek customization, in less time. For the embroidery segment of the textile industry in Saudi Arabia to prosper, it is important that manufacturers are able to offer customers customized products in a given time frame. However, due to a lack of advancement in the manufacturing techniques of handicrafts, traditional embroidered clothing has not been able to compete against a sophisticated and technologically advanced supply chain of large multinational brands. There have also emerged online retailers such as Amazon and eBay, who possess the ability to bypass rural retailers and facilitate consumers in placing orders at relatively low prices (Hooda and Singh, 2018). Thus, from a macroeconomic perspective, the survival of the traditional embroidery industry depends upon integrating digital technologies into the manufacturing techniques of embroidered clothing.

1.2: Research objectives and questions

The overall aim of this study is to address the above-mentioned risk to Saudi culture and heritage by investigating how manufacturing techniques can be used in the future to improve the current state of the embroidery industry and make it competitive with Western clothing. To this end, the present study seeks to achieve the following objectives:

- To evaluate the challenges facing the traditional embroidery industry in the western region of Saudi Arabia.
- To identify the current manufacturing techniques for embroidered clothing in the western region of Saudi Arabia.
- To implement the use of three-dimensional printing (3DP) in adding embroidery to textile fabrics.
- To analyse the factors that could influence the adoption of 3DP in the embroidery industry in Saudi Arabia.

In the process of achieving the above objectives, the present research sought to answer the following research questions:

- What are the challenges facing the traditional embroidered clothing manufacturing industry in the western region of Saudi Arabia?
- What are the current manufacturing techniques for producing traditional embroidered clothing?
- How can 3DP be integrated into the manufacturing process of traditional embroidered clothing?
- What factors could influence the adoption of 3DP in the manufacturing of embroidered clothing in the Hejaz region of Saudi Arabia?

1.3: Research methodology

An enhanced review of the literature was conducted to identify trends in the current traditional embroidery industry in the western region of Saudi Arabia, known as Hejaz. The aim of the literature review was to identify the factors causing growth challenges for the traditional embroidery industry in Saudi Arabia.

Further literature was reviewed to assess the manufacturing techniques currently used in the Hejaz region of Saudi Arabia to produce embroidered clothing. The review of the literature resulted in identifying the techniques currently used by manufacturers, including the materials that are used to manufacture embroidered clothing, thus answering the second research question of this study.

In contrast, to answer the third research question on assessing the possibility of integrating 3DP into the manufacture of embroidered clothing, experiments were conducted for this research. To this end, a fused deposition modelling (FDM) technology-based 3D printer was used due to factors such as affordability, cost effectiveness and material availability (Leigh et al., 2012). Three types of fabric (cotton, organza and silk) were used to conduct experiments with 3DP embroidery clothing. A total of 27 3D printed samples of embroidered clothes were produced, which included nine samples of each of the three fabrics at different 3D parameters: layer thickness, nozzle temperature and bed temperature. Finally, a thermoplastic polyurethane (TPU) filament was used as printing ink as, comparative to other filaments, TPU is recognized for its flexibility, elasticity and strength (Tadesse et al., 2018). Computer-aided design (CAD) software was used to design embroidery that was then transmitted to an FDM printer for printing.

A quantitative methodology was used to answer the final research question on the factors that could influence the adoption of 3D printed embroidered clothing in the context of Saudi Arabia. This approach included two sets of surveys: one with customers and the other with manufacturers in the traditional embroidered clothing industry in the Hejaz region of Saudi Arabia. The aim of the customer survey was to identify consumer perceptions and attitudes towards traditional embroidered clothing. In contrast, the aim of the second survey was to ascertain the perceptions of manufacturers regarding introducing new technology into the manufacturing process of embroidered clothing and their readiness in this regard. It was anticipated that the findings of the surveys would result in identifying the challenges that the use of new technologies may face when producing 3DP embroidery clothes. Furthermore, two sets of experiments were conducted to evaluate the long-term wearability of embroidery-designed clothes produced using 3DP. The first experiment included a washing test, which was conducted under International Organization for Standardization (ISO) 6330. The results of the washing test were analysed using MATLAB software, against the following parameters: edge, shape, roughness and brightness. The second, long-term wearability test was aimed at testing the adhesion quality of 3D printed embroidery designs and was conducted using a peel test to assess the impact of a peeling force on the 3DP embroidery designs.

1.4: Research background

The Hejaz region of the KSA is located in the west of the country, starting from the north of the country, running parallel to the Red Sea and ending in the south of the Kingdom (Saudi Arabesque, 2016b). Traditionally, the Hejaz region has been home to both nomadic and settled communities. The region possesses multiple aspects of importance. Firstly, it is home to the sacred Islamic cities of Makkah, Medina and Taif, as well as other, commercially important cities such as Jeddah and Yanbu. Secondly, the Hejaz region is known for its traditional handicrafts. According to Azzi (1987), the Umayyad and Abbasid tribes have ruled the Hejaz region of Saudi Arabia for the past 3,000 years.

Two natural resources, frankincense and myrrh, have provided the people of the region with a comparative advantage. As with petroleum today, the aforementioned natural resources were a source of wealth for the Hejaz region. The collapse of the resin market resulted in bringing the Hejaz region into direct contact with merchants from Africa and then the luxurious markets of Southeast Asia. According to Azzi (1987), it was also that era that brought with it the textile business and thus laid the foundation for Arabic fashion as we know it today, such as its embroidered clothing.

The traditional embroidery or weaving industry is the only sector of the Saudi textile industry that produces locally, as goods in other sectors, such as apparel and footwear, are all imported from across the globe (Martinez, 2018). However, there are a handful of studies that address traditional clothing in Saudi Arabia. For example, Ross and Talbot (1981) attempted to provide an overview of the different regional dresses traditionally worn by Saudi women, alongside considering what Saudi men wore. According to Ross and Talbot (1981), traditional dresses in Saudi Arabia were designed in a structured form, with the stitches and motifs being different for everyday wear than for ceremonial use. Martinez (2018) identified a variety of materials that have been used to manufacture traditional embroidered dresses in Saudi Arabia, which include coloured glass, plastic beads, and stitches and threads known as *harir*, which come in various fabrics, including nylon, cotton, wool and rayon. Drawing on a report by Dubin (1988), traditional handicrafts in Saudi Arabia represent a variety of attractive articles of Arab clothing, such as the *thawb*, which is an ankle-length kaftan with long sleeves and is worn over *sirwal* (loose trousers). The headdresses and outer cloaks known as *bisht* that are worn by men are a few more examples of traditional embroidered clothes.

Drawing on Azzi (1987), the emergence of oil wealth in the KSA has, to a great extent, swept away demand for traditional embroidered clothing. However, Azzi (1987) did not simply blame the Westernization of clothing for the demise in demand for traditional embroidered clothing. Instead, he was of the view that developments in technology led to the entrance of air conditioning in Saudi society, leading to a preference for slimmer cuts in both men’s and women’s clothing. It is due to these reasons that traditional dresses are only worn by Saudi women on special occasions, such as religious festivities, or the embroidered dresses worn by brides (Anawalt, 2007). However, Chelladurai et al. (2013) linked the fall of traditional dresses from the eyes of Saudi consumers with the lack to meet emerging fashion trends. Furthermore, comparative to traditionalists, young people tend to possess a low degree of interest in traditional handicrafts, as this group of consumers is influenced by Western clothing designs, hence threatening the transmission of the Saudi heritage to the next generation (Valsecchi et al., 2012). In can thus be demonstrated that the identification of advanced technologies for the revival of traditional embroidered clothing is the need of the hour.

1.5: Organization of the thesis

This thesis is organized in seven chapters. In this first chapter, the research questions and rationale for the research have been set out, along with the research objectives and questions. Furthermore, information has been provided on the research background that identifies a gap in the literature and raises the need for the revival of the traditional embroidered clothing industry in the Hejaz region of Saudi Arabia. An overview of the methodologies used to answer each research question has also been presented.

The second chapter starts with a review of the literature on the current state of the traditional embroidered clothing industry in the Hejaz region, along with an assessment of the global trends in this regard. Moreover, challenges that 3DP might face while being integrated into the current manufacturing techniques of embroidered clothing are assessed and lay the foundation for designing the research framework. A comparative analysis of manufacturing techniques is used to identify possible technologies that could be used in embroidered clothing manufacturing techniques, which results in identifying 3DP techniques to produce embroidered clothing. The discussion also moves towards assessing the evolution of and challenges facing 3DP in the current fashion industry. The second chapter ends by summarizing the challenges currently in the embroidery industry in the Hejaz region of Saudi Arabia and presents possible solutions to address those challenges.

The third chapter presents the methodology that the present study used to address the research questions. To this end, the discussion starts by reviewing the literature on the available methodologies and identifying and selecting the approach deemed suitable to the present study. The chapter identifies the research philosophy, approach, methodological stance and research strategy. The chapter then identifies the data collection techniques used in this research, along with laying down the parameters of the research ethics. It was expected that the present study would use a mixed method methodology based on survey and experiment.

The fourth chapter presents an analysis of survey data trends and their discussions in order to determine the challenges that the introduction of 3DP would face while being integrated into the manufacturing process of traditional embroidered clothing. Moreover, it was also anticipated that the research would identify human resource-related hurdles that 3DP would face while the technology is integrated into the current manufacturing process of traditional embroidered clothing.

The fifth chapter then uses the technical hurdles identified in the previous chapter to outline the design of the experiment scheme. The results of the experiments are then analysed and discussed.

Chapter six presents evaluate of the suitability, acceptability and feasibility of 3DP as a manufacturing technique for producing embroidered clothing in the Hejaz region of Saudi Arabia. The discussion is expected to present a comprehensive analysis of both the technical and non-technical hurdles.

The seventh and final chapter sets out the implications of the findings for key stakeholders of the research, such as academics, the embroidery industry in Saudi Arabia and the government of the country. The chapter also provides a summary of the entire research with the aim of assessing whether it has achieved its objectives and answered the research questions. It also identifies the limitations of the findings presented in this study and thus the possibilities for future work in this regard.

1.6: Conclusion

The discussion in this chapter has set the foundation for the research in this study by establishing the research objectives and questions. The chapter also identified the rationale for conducting research into the revival of the traditional embroidered clothing industry in the context of the Hejaz region of Saudi Arabia. Furthermore, the discussion presented an overview of the methodology used in the present research to achieve its objectives and answer the questions it posed. The next chapter reviews relevant literature with the aim of further refining the research topic.

Chapter II

Literature Review

2.0: Introduction

The aim of this chapter is to present a critical review of the literature concerning the research questions posed in this study. Creswell (2012) signified the importance of reviewing the literature in an area of research in helping researchers to generate and refine their research ideas. Moreover, a critical literature review also assists in identifying relevant theoretical frameworks and research gaps that a study could aim to fill (Saunders et al., 2016). With the aim of evaluating a possible solution for the revival of the traditional embroidery industry in the Hejaz region of the KSA, the discussion in this chapter starts by assessing the challenges facing the sector in Saudi Arabia. To do this, the discussion evaluates the embroidery industry of the KSA from the perspective of its background, current state, customer trends, such as perceptions and attitudes, the need to preserve the craft, government support and, finally, the adaptability of craftsmen/ women in relation to new methods of manufacturing embroidered clothes. The discussion then moves to assessing new technologies available globally that could be used to manufacture embroidered clothing. Specifically, the discussion focuses not only on identifying new technologies, but also their cost effectiveness and quality, their ability to meet current fashion trends and, finally, the availability of the technology. The third section presents a comparative analysis of new technologies for manufacturing embroidered clothing, along with assessing the suitability of three-dimensional printing for this purpose. The fourth section further evaluates 3DP in the current global fashion industry and specifically for manufacturing 3D printed embroidery clothing. The chapter concludes by presenting the gap identified during the literature review that set the stage for establishing a methodological stance to fill that gap.

2.1: Challenges for the embroidered clothing industry of the KSA

2.1.1: Background of the embroidery industry in the Hejaz region of the KSA

Known as Hejaz, the western region of the KSA has both religious and economic significance (Tawfiq and Ogle, 2013). The religious significance of the region stems from the fact that it hosts two cities that are sacred in the Islamic religion: Makkah and Medina. Makkah is the birthplace of the Islamic Prophet Muhammad (P.B.U.H) and Medina is his resting place. Millions of Muslims visit those two cities to perform pilgrimage (Salaghor, 2007). In contrast, other cities in the Hejaz region, such as Jeddah, Taif and Yanby, are all recognized as commercial hubs of the KSA (Saudi Arabesque, 2016a). Particularly Jeddah, which is the coastal city of the Hejaz region.

Both the religious and commercial significance of the Hejaz region of the KSA have had an influence on the way people dress in that area (Ejeimi, 2016). According to Long (2005), due to the influence of Islamic values, both women and men are required to embrace modesty in their dress. Women are required to wear head scarf, long loose shirt and loose trousers known as *sirwal*. Furthermore, a long loose garment known as a *thawb* is worn by women beneath an outer cloak called an *abaya* (Anawalt, 2009). Figure 1 provides a pictorial example of traditional women's dress in Saudi Arabia.

Source: Radwan, 2018; Saudi Arabesque, 2016b

Figure 1: Traditional women's *thawbs*

In contrast, men wear a *bisht*, which is also a long loose shirt, and long loose trousers (*sirwal*). Furthermore, men are also required to cover their head with a *keffiyeh,* also known as a *shemagh*. Principally, the *shemagh* consists of a traditional square cotton scarf that is placed on the head and tied with a belt-like cord known as an *igal* (Ejeimi, 2016: P14).

The commercial influence on the clothing of the Hejaz region can be linked to the history of its textile industry (Saudi Arabesque, 2016b). Traditionally, merchants from the Hejaz region were involved in trading in regional textiles, such as importing cashmere garments from the Indian sub-continent, Turkey and France. Other textile-related trade included fabrics, such as Indonesian silk, wool and cotton from Egypt. In this study, silk, cotton and organza fabrics will be used for experiment purpose.

According to Losleben (2003), the embroidery craft of the people of the Hejaz region started in the era of the Bedouins, who were nomadic tribes of the Arabian region. Historians have written about the people of the Bedouin tribes as being spiritually tough but full of simplicity and down to earth (Scarce, 2014). It was due to their lack of desire for worldly goods that they developed self-reliant communities and handicrafts such as weaving played a central role in the pursuit of Bedouins to be self-sufficient. The women were usually involved in manufacturing handmade embroidered garments in their homes, which included rugs, hair or wool tents, known as *bait-al-sha'r*, curtains, cushions and other household accessories (Hariri-Rifai and Hariri-Rifai, 1990). Bedouin women used a variety of materials to produce embroidered clothing, such as sheep's wool, the hair of goats or camels and desert herbs. Tools made of wood were used for carding and spinning thread. Finally, grounded looms of wood or metal were used for weaving. Threads made of silk, metal and cotton were imported from Egypt, China and India to make more delicate shapes and embroidery designs were drawn geometrically prior to weaving them on fabric.

Over the years, the manufacturing of traditional embroidered clothes in the Hejaz region has witnessed very little adaptation in terms of materials, textures and techniques (Ejeimi et al., 2018: P20). For instance, as is traditional, women's *thawbs* from the Hejaz region are embellished with applique strips of a variety of coloured materials. Other materials used in embroidery on clothes include glass beads, mother-of-pearl buttons, lead beads on the cuffs, and coins. Placement wise, there is hardly any difference in the location of embroidery on clothes; for instance, embroidery on women's clothes would usually be found on the sleeve cuffs, neckline opening, bodice, hems and some embroidery stitching moving down from the waist (Topham et al., 1981). Other locations of a dress on which embroidery is embellished include the side seams, side panels and shoulders. Furthermore, *serwal* trouser cuffs are also embellished to match the embroidery on the shoulder sleeves (Topham et al., 1981).

Similarly, there have been no differences in the use of stitches. Rose (1981) identifies various types of stitches typically used in traditional embroidered clothes: stem, chain, Bedouin pinnacle, wave, Bedouin *waahed*, Bedouin *araba*, feather, blanket, black, cross, half-cross, flat, Cretan, dotting or seeding, couching and oya crochet stitches.

Likewise, no difference has been witnessed in the use of thread, as similar metallic silk, cotton or rayon threads are used to embroider different places on a dress. When it comes to embroidery designs, craftsmen/women tend to adhere to Islamic values (Tawfiq and Marcketti, 2017). In accordance with Islam, embroidery designs prohibit the use of any sort of human form or embroidery that would make the human body more visible in the design. Therefore, floral and geometric designs are usually used to embellish inner clothing, such as clothes worn beneath the *abaya* or *burqa,* but not for clothing visible when outside. Other designs used for embellishing include triangles, palm tree motifs, loops, polygons and squares. Religious motifs and ones that distinguish one tribe from another are also used in embroidery (Gillow, 2010). In addition, Ejeimi (2016: P24) did not notice any difference in the use of the materials used for traditional embroidered clothes. For instance, Hejazi embroidered clothes are manufactured using similar materials, which include silver bells for head scarfs, beads, buttons, sequins, coins, silver-plated thread, buttons made of mother of pearl, gemstones and metals. Finally, there has also been no difference in the use of thread, apart from replacing wool with sheer cotton (Sorber, 2001). However, recently, the use of gold-plated embroidery was also noted (Ejeimi, 2016: P25).

The discussion above demonstrates the methods and materials used by Hejazi women for producing embroidered clothes. It also demonstrates that there have been very few amendments in the manufacturing process of embroidered clothing. This matches the assertion of Kim (2016) that a lack of development in the manufacturing process has resulted in traditional embroidered clothing failing to meet emerging trends in the global fashion industry, such as increased customization and mass production. It is also due to these factors that there has been a lack of interest among young consumers towards embroidered clothing and thus the embroidery segment is facing the risk of extinction in the current global fashion industry.

2.1.2: Current state of traditional embroidery and the risk to its survival

The roots of the current deteriorating state of the traditional embroidery industry lie in two factors: history and environment (Azzi, 1987). Historically, the people in the Arabian Peninsula relied on natural resources for their commercial survival. For instance, the people of the region used to rely on sales of natural resources such as frankincense and myrrh, both of which were unique to the country and were only found in a desert environment. The region was the only source of those resources and brought the Arab market in touch with regional and international commercial markets. The collapse of the resin market led to the opening up of an era of bilateral trade between Arabs and people in other regions. This was also the era that led to Arabs realizing their strength in making fabulous textiles. Traders from other regions liked the embroidery designs and local Arabs were able to make money from their handicraft.

However, oil wealth swept away the achievements of the local textile industry. For instance, as Arabs became rich, they were able to buy air conditioning for their homes, which led to slimmer cuts in the traditionally loose attire of both men and women. These factors resulted in embroidered clothes only really being regarded as suitable for ceremonial occasions, such as weddings and men’s traditional dancing. The use of embroidered clothing on such occasions can be seen as an illustration of symbolic interactionist theory. Symbolic interaction theory was proposed by Eicher and Ling (2005) and defines the interpretation of the meanings that individuals apply to the world and share through social interaction. To this end, clothing is one of the aspects of life to which people assign meaning and thus it becomes a tool for the self-expression of identity (Stone, 1962). Therefore, traditional dress portrays a shared meaning, associating individuals with certain societies and assisting people in conveying their desired identities to the external world (Goffman, 1959). However, the reduction in the use of embroidered clothing on occasions such as religious festivities or weddings means that the use of traditional costumes has been reduced from a vehicle of self-expression to only being a part of rituals.

While changing levels of wealth had a somewhat negative impact on the traditional clothing patterns of Saudi society, globalization and technological innovation have also played a role. In drawing on a report by Market Line (2018), the retail apparel industry in Saudi Arabia has witnessed an increasing trend in online shopping that grew by 27.2% during 2017 alone and is forecast to rise by 153% by 2022. The irony of the situation is that it is mostly international brands that are sold through online channels; local brands are still sold through physical channels and, when it comes to traditional embroidered clothing, this is sold on the 'grey market' through carts or small shops (Kim, 2016). Furthermore, technological developments such as smart phones have also led to changes in the shopping behaviour of Saudi people. According to the report by Market Line (2018), 70% of the Saudi population was using the internet and that penetration was expected to rise, which will further improve online sales. Technological innovation has led to local people being inspired by Western culture, particularly the Western way of dressing, thus further decreasing their interest in traditional clothing. Salaghor (2007) argued that social changes in Saudi society accompanied by industrialization had caused changes in consumers' habits and clothing.

As a result of the above-mentioned factors playing their role in the elimination of traditional embroidered clothing in Saudi Arabia, voices have been raised to revive the industry. For example, a non-profit organization called Art Heritage has been trying to revive traditional vintage-style dresses by providing a platform for embroidered clothing manufacturers to showcase their talent (Rizvi, 2017). The management level of the charity has attempted to transform the traditional embroidered segment of the Saudi fashion industry by creating a database of embroidery designs. The database of designs contains information about the manufacturers and, in the event that a customer chooses to buy a replica, the management contacts the manufacturer and places an order. Despite the remarkable achievements of the charity in promoting traditional embroidery, the management of the charity still claims that a lack of development in production techniques is a key hurdle facing the sales of traditional embroidered clothing. For instance, despite the provision of an online sales platform in the shape of a database providing customers with the ability to customize their order, it takes a long time for manufacturers to produce an embroidered dress, which puts customers off buying such items.

Another reason for the demise of the traditional embroidered clothing industry lies in the lack of support from the country's fashion industry. In 2018, Saudi Arabia held its first fashion week, in the country's capital city of Riyadh (Paton, 2018). Although the aim of the event was to provide local designers and manufacturers with an opportunity to showcase their talent, according to Paton (2018), that did not happen, as most of the counters at the event were occupied by foreign luxury brands. While embroidered clothes were also present, including exquisite clothes with sleeves that were sequin-embellished with elaborate embroidery, they were presented by global brands, such as Gucci and others. In contrast, the textile festival of "Souk Okaz", which is held annually in the city of Taif in the Hejaz region, is the only festival that provides manufacturers of embroidered clothing with the opportunity to showcase their work. The Souk Okaz Festival provides both locals and tourists with a chance to experience Saudi Arabia's traditions and culture. Local manufacturers of embroidered clothes bring their products to the festival with the intention of acquiring contracts from local brands for future sales (Al-Kinani, 2019).

The discussion above on the current state of the traditional embroidery industry in Saudi Arabia shows that the craft is in danger. Old production techniques are the main reason for the current state of the traditional embroidery industry, as these have resulted in a once-dominant societal culture of Saudi society becoming a niche. It is also due to the lack of development in manufacturing techniques that traditional embroidery brands have failed to meet emerging market trends of customization, in addition to a lack of branding and awareness and a failure to meet the need for mass production. Furthermore, a lack of industry support is also to blame for the fall of the traditional embroidery industry, although the embroidery segment of the Saudi fashion industry also has itself to blame for its decline as it has failed to adapt to new manufacturing techniques. The emergence of global brands in Saudi society is also playing a role in altering the perception and attitude of customers towards embroidered clothing, as they are closing their eyes to the cultural art that used to represent their self-expression and identity.

2.1.3: Consumer perception and attitude towards embroidered clothing

There is consensus among past researchers regarding the lack of consumer interest, awareness and knowledge as one of the causes of the decline in the consumption of traditional embroidered clothes (Emmett, 2014; Qi, 2018). Specifically, in the context of Saudi Arabia, it is suggested that the Westernization of Saudi culture has led to an alteration in consumer behaviour in favour of Western brands, to the extent that the consumption of traditional costumes has become an occasional event, rather than part of everyday life (Tawfiq and Marcketti, 2016). With regard to the way individuals choose to dress, it is argued that clothing is an important tool that not only demonstrates an individual's self but is also used to express a person's association with particular social and cultural norms (Barnes and Eicher, 1992). Thus, the proposition that individuals in Saudi Arabia have ignored their cultural heritage or identity in favour of a Western dress code lies in consumer behaviour theory (Wilk, 1997).

Krades et al. (2015) defined consumer behaviour as a product of activities that consumers undertake while purchasing, consuming and disposing of products/services. By activities, Krades et al. (2015) meant the emotional, mental and behavioural responses that play a role in the purchase decision-making process. The way individuals dress in a society represents the emotional and mental perspectives of their personality. Dress also represents behavioural implications for people in communicating personal adornment and a need to represent a self that is different from others and to demonstrate social standing in society (Belk, 1988). Therefore, from a behavioural perspective, clothing is used as an instrument to express individual identity and for people to position themselves in the desired social class. Entwistle (2015) used social identity theory to express the relation between an individual's desire and the adoption of a particular style of dress. Social identity theory postulates that individuals' sense of who they are depends upon their association with a particular society, group or social class (Tajfel, 1969). For instance, when assessing the reasons for the convergence of the Indian middle class towards Western luxury fashion brands, Eng and Bogaert (2010) suggested that consumption of

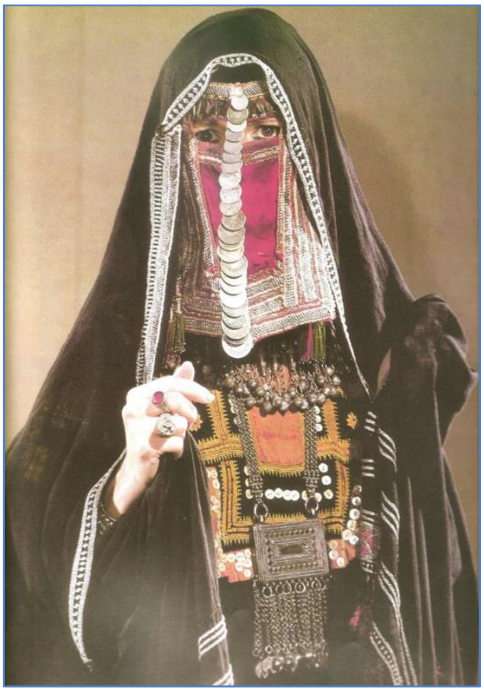
Western luxury brands by a rising Indian middle class could be linked to their desire for rarity, exclusivity and uniqueness. Similarly, in the context of Saudi consumers, it is argued that individuals wear Western clothes because this symbolizes their modernized self and expresses their lifestyle, socioeconomic status and education level (Yamani, 2004). Ejeimi et al. (2018: P1) linked the alteration in Saudi consumers' desire for Western brands to changing consumer perceptions and attitudes.

Consumer perception is defined in relation to a pattern of exposure and attention, both of which are aroused and constructed in the consumer decision-making process (Evans et al., 2009). In simple terms, perception is a process by which consumers select, organize and interpret socially transmitted information, such as through an advertisement or word of mouth, to form their own meaning of their surroundings (Kotler and Keller, 2006). Adnan and Khan (2010) went so far as to argue that perception is the first practical step in consumers' buying decision-making process and induces them to select stimuli from their surroundings. Here, a stimulus is defined as a unit of inputs, such as exposure, attention and interpretation. Stimuli that work as exposure include the nature of a product/service, the physical attributes of a product/service, brand name, packaging design, and use of reference points in the advertisement. Exposure then induces attention, although individuals will pay more attention to information that meets their expectations and needs and ignore that which does not meet these two factors. The strength of the exposure and attention then moves consumers into the organization of information stage, in which people tend to form a visionary image of the product/service they need. The constructed information is then interpreted by individuals, although the interpretation of the information tends to be unique to an individual and based on their past experiences (Schiffman and Kanuk, 2000). The diversion of Saudi consumers towards Western brands can be examined in terms of their perception of traditional embroidered clothes being old-fashioned and not meeting their desire for status and exclusiveness (Kay, 2015).

In his study on consumer culture in Saudi Arabia, Al-Dossry (2012) found that there existed tension among Saudi consumers between being inclined to observe religious values while at the same time desiring to be recognized as modern, showing an inclination towards luxury cars, modern technology, such as smart phones, and, of course, Western fashion. An article in *The Economist* (2015) also conforms to the findings of Al-Dossry (2012), as it suggests that the dress code, particularly for females in Saudi Arabia at public gatherings, is expected to adhere to the teachings of Islamic Sharia law. However, the impact of globalization or revolution brought about by technology has led to women in the country showing displeasure with shapeless shrouds and appearing to be attracted to comparatively fitted coats (Quamar, 2016). The extent of the Westernization of fashion in Saudi Arabia can be ascertained from the fact that human rights activist Mashael Al-Jaloud recently defied social norms by shunning *abaya* and wearing trousers and a shirt in a Riyadh shopping centre (Jewell, 2019). Furthermore, the extent of the Westernization of the Saudi textile industry can be ascertained from the fact that in 2001 the country surpassed liberal Dubai to become the largest importer of Western fashion brands (Henry and Springborg, 2010). It is the shift in the perception of Saudi consumers that has resulted in diminishing demand for traditional handmade dresses. Ejeimi et al. (2018) have further asserted that oil money has also resulted in changing consumer perceptions of life in Saudi Arabia. For instance, the government has used oil revenue to build infrastructure such as large shopping centres, which has resulted in Saudi women opting to go to those centres rather than the old way of women (i.e., the manufacturers of traditional clothes) going to their homes to sell their handicrafts. Thus, it can be argued that there has been a psychological shift in the perception of Saudi consumers that is motivating them to adopt a Western method of self-expression (Alzahrani and Copeland, 2017).

In contrast to perception, consumer attitude is about the extent to which individuals' feelings, thinking and way of life are influenced by their environment (Blackwell et al., 2006). It is perceived that consumers' attitudes influence their emotional, motivational, perceptual and cognitive processes, which then shapes their thoughts and responses to the external environment. Individuals' attitude towards an object can be either negative or positive but is a direct result of their cognitive, affective and behavioural responses (Schiffman and Wisenblit, 2015). The cognitive component of attitude is concerned with the individual's belief about a particular object or situation. It is perceived that individuals will pay more attention to objects that interest them. The cognitive response of an individual is formed as a result of their past experience or their association with a particular social class (Schiffman and Kanuk, 2000). From the cognitive perspective, the way an individual dress represents various aspects of their personality, such as the communication of personal adornment, differentiating themselves from others and social standing. However, the use of a particular form of dress also showcases the cultural statement that an individual desire to make. Kacen and Lee (2002) asserted that since individuals live in a particular culture, their attitude towards dressing is influenced by the settings of that culture. It is also due to the influence of culture that homogeneity in dress code is not possible, since in the case of the KSA, the dress code differs from one tribe to another, even in terms of fabric, the colouring of threads, shapes, patterns, embroidery designs and the fit of the dress to the body. The example of the Harb and Hundayl tribes in the KSA can be used here as, due to their tribal associations, their styles of dress vary considerably in terms of embroidery and attire elements, as shown in Figure 2.

Woman's dress of the Harb tribe



Woman's dress of the Hudhayl tribe

Source: Saudi Arabesque, 2016c; Saudi Arabesque, 2016d

Figure 2: Differences in dresses of two tribes in Saudi Arabia

The situational element of the cognitive component of individual attitude tends to conform to the assertion made by Tawfiq and Marcketti (2016) that the use of traditional dresses in the KSA has been reduced to occasions such as weddings. However, wedding dresses also tend to differ from one area to another in the Hejaz region. Figure 3 demonstrates the difference in the attitude of brides from different cities in the Hejaz region of the KSA towards their bridal dresses. From left to right, brides in the Najdi area like to wear a heavily embellished voluminous overdress known as a *thawb maugassab* and *dafat-al-arus*. However, brides from Makkah wear a dress known as a *sharqiyah*, which is usually made using gold coloured embroidery made by gold plated thread. Finally, brides from Madina wear a *thawb* known as a *marhadan*.

Figure 3: Differences in bridal clothing in the Hejaz region

Drawing on the affective components of consumer attitude, which states that individuals' expressions on an issue are evaluated in relation to their needs (Wells and Prensky, 1996), it can be argued that it is Saudi consumers' need to conform to the requirements of each situation that results in their using different dresses for different settings. For instance, whereas Saudi women would use a complete veil while outside, such as in a shopping centre or other public places, when attending family occasions such as family sittings or with next of kin such as cousins, women may not wear a veil (Tawfiq and Ogle, 2013). In a nutshell, it can be argued that, attitudinally, women's appearance in the KSA depends upon the need to conform to particular settings and their concepts of self-presentation, such as wearing Western clothes in normal life but traditional clothes for religious or other events.

Finally, the behavioural component of attitudinal theory asserts that consumer knowledge and feelings induce the reaction to a particular scenario (Wells and Prensky, 1996). To this end, the findings of a study by Martinez (2018), who, although disagreeing with the conviction that traditional embroidery is dying out in the KSA, agreed that there was indeed a trend for merging traditional designs with Western fashion. For instance, brides in the KSA have been found to be wearing white gowns that are embellished by traditional embroidery patterns. Moreover, Western brands have also been integrating traditional embroidery in their products. For instance, as part of its think-global, act-local strategy, Zara Inditex has developed networks with locals in Saudi Arabia to dye, embroider and sew fabrics or design embroidery for use on accessories (Crofton and Dopico, 2012). Ejeimi et al. (2018) also supported the idea that, as a result of consumers' perceptual and attitudinal association with traditional dresses, the idea of traditional embroidered clothing has not yet died, as young women in the KSA have shown their willingness to embrace traditional dress if they can meet current trends and are not heavy to wear. Therefore, it would not be wrong to suggest that to preserve the traditional embroidery handicraft of the Hejaz region, there is a need for development in the manufacturing techniques, even if this means eliminating the use of materials such as metal thread, glass, beads and applique, as these make dresses heavy and are perceived as cumbersome to wear by consumers (Ejeimi et al., 2018). Discussion on the perception and attitude of consumers towards traditional embroidered clothing presents a clear shift in the taste of consumers towards Western designs that threatens the survival of traditional embroidered clothing altogether, hence raising the need to preserve those skills.

2.1.4: Preservation of skills in embroidery and the lack of formal training

Hand embroidery is a traditional craft that enhances fabrics so that the materials used look beautiful (Abdulghader-Fairak, 2013). A variety of materials are used in embroidery, including beads and sequins, and using a sharp needle with threads made of silk and metal requires unique skills (Ejeimi, 2016). The craft of embroidery requires expert skills and thus is recognized as an art of yarn and sewing that is usually passed down from one generation to another, such that the young people of a family, usually the females, learn the skills from their elders, such as their mother or grandmother (Tarlo, 1996). People usually start to learn the art from a very young age and, as they become older, they achieve an expert level of skills through practising. In this way, each individual leaves their own mark of implicit knowledge, making each embroidered cloth unique in its own manner and different from any other. Despite its uniqueness, the craft of embroidering clothing has seen continuous decline in the past three decades as a result of globalization, which has led to the standardization of clothing (Ejeimi et al., 2018). Similarly, the standardization of clothing means that decoration on dresses is no longer in demand (Eicher and Sumberg, 1995).

Standardization of clothing has been linked to globalization that has led to diminishing of ethnic differences in dressing (Gilow, 2010). According to Ejeimi et al (2018: P2) Saudi Arabia has witnessed impact of western culture on the way women dress as mostly in private situations women prefer to wear westernize clothing. Abu-Nab (2019) in her study on women's fashion consumption in Saudi Arabia evaluated differences in categories of fashion worn by women in Saudi Arabia in various social settings underneath abaya such as special occasions and parties, workplace and university, Eid clothing and at home. Author found large use of local and foreign brands by women in most of settings and traditional dress being almost eliminated. According to the survey by Abu-Nab (2019) when it comes to special occasion and parties, 96.18% of respondents claimed to wear customized clothes and 3.36% opt for brands. By customized authors meant locally produced known brands or western style clothes and global luxury brands. On the other hand, when it comes to workplace and university 54.73% and 43.73% of respondents claimed to wear fast fashion westernized and global luxury brands respectively. For Eid day, 48.62% and 40.83% of respondents claimed to wear fast fashion and global luxury brands. Finally, when it comes to clothing at home, 60.55% and 38.99% of respondents claimed traditional dress and western clothes respectively. Overall, findings of Abu-Nab (2019) approves the argument made by Ejeimi et al (2018) Gilow (2010) about influenced of western clothing on Saudi females hence globalization has indeed led to standardization of clothing meaning western clothing being worn by women in Saudi Arabia.

However, it is the lack of technological advancements in the manufacturing techniques that is proving to be the last nail in the coffin of the traditional embroidered clothing segment, as machines continue to replace humans in the production of clothes with more customization and the benefit of scalability (Gillow, 2010). Traditional techniques have fallen short in meeting customer demands for increased customization of clothes and embroidered dresses have seen a decline in customer preferences (Taylor, 2009). The discussion above not only identifies the need to preserve traditional craft skills in Saudi Arabia, but also identifies a lack of formal training programmes for local craftsmen/ women to address the lack of development in manufacturing techniques.

2.1.5: Government support and policies to support traditional embroidery handicrafts

A lack of government support has also been identified as one of the causes of the demise of traditional crafts in the KSA. In another research context, Douglass (2016) studied the challenges facing traditional Korean crafts and found that artists were of the opinion that a lack of government support was the root cause of a declining interest from both manufacturers and consumers. Similarly, Kakiuchi (2014) asserted that a lack of organizational supervision and funding from government had led to a decline in traditional crafts in many countries. Nevertheless, given the cultural significance of traditional handicrafts, governments can no longer ignore this sector. According to Scrase (2003), government support for traditional handicrafts in Saudi Arabia is important as the embroidery segment of the Saudi fashion industry is going through an evolutionary process and facing the challenges of globalization and industrialization. Furthermore, due to a lack of development in skills and manufacturing techniques, local craftsmen/women find themselves at a disadvantage, as they are unable to compete with foreign brands that possess sophisticated technology and the ability to customize and mass produce. Thus, local craftspeople usually have either to sell their products at a lower cost or be exploited by middlemen who sell their products to foreign brands. Foreign brands will then place their own price tag on the finished products of local craftsmen/women and sell those items at double or triple the price in the local market (Kumar and Rajeev, 2014). In addition, the standardization of fashion is resulting in traditional crafts losing their market share

(Cohen, 2000) and thus the government also has a moral duty to safeguard local craftsmen/women from exploitation.

As part of its National Vision 2030, the Saudi government has sought to diversify its economy, which includes supporting local innovative industries, investing in local businesses, establishing funding programmes for local crafts, increasing the value of exports, and improving the employability of Saudi nationals (*The National*, 2019). Particularly for the development of local handicrafts, the government has established the Saudi Commission for Tourism and National Heritage (SCTH) under Resolution #9 12/1/1421 H (SCTH, 2016). The SCTH is responsible for supporting the development of the handicraft sector in order to preserve the cultural authenticity of the nation. The scope of the SCTH involves providing employment opportunities for all segments of society and increasing their well-being. To this end, the SCTH has initiated various programmes that include issuing bulletins and publications on the types of craft that the country produces and supporting their development at both local and international forums. Another initiative adopted by the SCTH is to collaborate with the Saudi Postal Corporation to provide an online sales platform for products crafted by locals, thus providing local craftsmen/women with access to a wider customer base at both the local and international levels.

Particularly for the embroidery craft, the SCTH has initiated the National Handicraft Development Programme, referred to as “Bari”, under which it organizes training sessions for female artisans in Riyadh (Hassan, 2017). The Bari programme is run in collaboration with a non-governmental organization called the Turquoise Mountain Foundation (TMF) to support local artisans, organize skills-based training programmes for female artisans and educate local artisans about designing and pricing their crafts. As of January 2019, 900 craftsmen/women had graduated under the Bari programme, resulting in converting traditional handicrafts into a growing money spinner for the Kingdom (Arab News, 2019). Evidence has been presented of the positive impact of the Bari programme on the development of skills in local handicrafts, which has included local craftsmen/women gaining contracts from Saudi hotels and airlines, thus demonstrating that Bari has directly contributed towards the development of the KSA economy. Regulating the local handicraft sector is another development of the Bari programme that has resulted in integrating a traditional handicraft in the national economy. The regulatory framework also provides protection to local craftsmen/women from exploitation from foreign brands and middlemen, thus providing them with fair opportunities to practise their craft. The key objectives pursued by the SCTH under the Bari programme are as follows:

- Laying down a framework for the development of the handicraft industry in the KSA.
- Providing monetary support to develop the skills of local craftsmen/women.
- Investing in traditional handicraft businesses to integrate the industry in the national economy.
- Supporting the long-term viability and sustainability of craftsmanship.
- Providing local craftsmen/women with a marketing platform.
- Supporting third-party involvement in the development of local handicrafts (Saudi Crafts, 2019).

Although the work of the SCTH has produced some positive results for the development of traditional handicrafts in the KSA, the author found that all the programmes established by the Commission, such as Bari, are focused in the capital city of Riyadh, ignoring key regions of the traditional embroidery industry, such as Hejaz. Furthermore, other than providing an online sales platform, the SCTH has failed to address the limitations of the manufacturing techniques of the traditional embroidery industry. The main reason behind the lack of development of the industry is that it cannot compete against foreign brands. Thus, there is a need to spread the operations of the SCTH outside Riyadh to cover the Hejaz region, as that is the area that is known for traditional embroidery handicrafts in the KSA (Ejeimi, 2016).

2.1.6: Adaptation to new technology

According to Kim (2016: P3), the lack of adoption of new technology is one of the key causes for the decline of the traditional handicraft industry globally. Take the example of traditional Asian craft industries, which declined tremendously during the early 1980s because they failed to adopt the technological innovations of the millennium and were thus unable to compete against multinational firms and keep pace with the requirements of globalization, such as mass production (Beamer, 2010). Similarly, when studying key hurdles in the development of the Pakistani handicraft industry, Yang et al. (2018) identified lack of innovation and technology adoption as one of the key barriers. According to Yang et al. (2018), lack of technological innovation in the handicraft industry of Pakistan resulted in producers lacking new product development capability. Consequently, the manufacturers of traditional handicrafts are facing unprecedented challenges in a highly competitive globalized textile industry, as traditional methods of production do not meet the dynamics of modern lifestyles and demand for traditional handicrafts is declining dramatically.

The need for the manufacturers of traditional embroidered clothes to adopt advanced technologies lies in various factors, such as rapidly changing consumer demand for innovative designs and a highly competitive fashion industry (Shafi et al., 2019). Therefore, the ability of traditional craftsmen/women to learn and adapt to using new technology is imperative for the survival of the traditional handicrafts of the Hejaz region. In his study on technology transfer and sustainability in the context of Saudi Arabia, Al-Thawwad (2008) identified various hurdles, such as cultural, environmental and geographical location factors.

According to Chatterji (2016), culture is one of the most powerful factors that have an impact on the success of technological transfer. Culture provides individuals with a set of social ingredients, of which art, such as traditional embroidery in the Hejaz region, tends to be an important element (Soares et al., 2007). It is the adherence of individuals to traditional ways of producing embroidered clothes that prohibits such manufacturers from adopting new technology. Different countries tend to possess different cultural values that could hamper the adoption of new technology. To illustrate this, Hofstede (1991) presented his framework of cultural dimensions, whose components of uncertainty avoidance and power distance can be used to explain cultural reasons for the lack of adoption of technology among traditional craftspeople in the KSA (Huang et al., 2019). Uncertainty avoidance is explained as the degree to which members of a society tend to be threatened by an uncertain situation. Saudi culture scores high for uncertainty avoidance, which means that its people would prefer to maintain rigid codes of belief and behaviour and will avoid unorthodox ways of working. Therefore, since the adoption of technology would mean a complete transformation in the way embroidered clothing is produced, this justifies a lack of adoption of new technologies in the manufacturing process of embroidered clothes.

Similarly, the power distance cultural dimension of Hofstede's (1991) model demonstrates the degree to which people accept authority in a society. Saudi Arabia scores high on the power distance cultural dimension, indicating that the people of the country accept a hierarchical order. According to Martinez (2018), traditional embroidery is a home-based activity that is usually passed from one generation to another, thus clearly indicating reasons for the non-adoption of new technology by craftsmen/women. Those craftspeople have not known any way of manufacturing embroidered clothes other than the traditional handmade method and have an emotional fear of losing their craft if they adopt new technology.

According to Todaro (2002), the effective transfer of technology requires receptiveness in the local environment. Key environmental factors that prohibit technological adoption in the KSA include a lack of technology, training and development programmes for craftsmen/women in the Hejaz region. The unavailability of funds is another factor in the lack of adoption of new technology. Ejeimi et al.(2018: P3) further stated that craftsmen/ women tend to lack formal education, which is another key environmental factor that prohibits them from adopting new technology in their craft.

Finally, geographical proximity has been recognized in enhancing technology transfer (Al-Thawwad, 2008: P4). Districts that are near to the cities in the KSA tend to have easier access to technology compared with those that are not. Craftsmen/women in the Hejaz region usually reside in rural areas, thus making it difficult for them to access new technology. Furthermore, most of the craftsmen/women tend to be poor with a lack of access to transportation facilities and thus it not only becomes cumbersome for them to gain access to new technology, but also costly.

2.2: Global trends in embroidery and their impact

The embroidery segment of the global fashion industry is making a comeback, as reported by Macalister-Smith (2016) in her article in the UK's *Telegraph* newspaper. Recently, for example, Taylor Swift has been noted as having worn clothes that had her nickname, TayTay, embroidered on her dress (Macalister-Smith, 2016). Similarly, American rapper and singer Belcalis Marlenis Almánzar, known as Cardi B, chose, in her red-carpet appearance at the Cannes Film Festival in France, to wear an embroidered costume designed by Lebanese-based Saudi Arabian fashion house Ashi Studio (Venkat, 2019). Similarly, a report by the British Council (2019) argued that immigrant fashion designers living in the UK were bringing the taste of the traditional embroidery designs of their hometowns into Western culture and that this was not only appreciated by ethnic minorities living in the UK, but also by British people. Other evidence of a traditional craft making a comeback in the modern fashion industry can be ascertained from one of the world's most prominent museums, the V&A (the Victoria and Albert Museum) in London, displaying various templates of embroidered women's clothing, which included traditional handmade productions, natural motifs and modern accessories such as jewellery (V&A, 2019). The principal idea behind displaying modern fashion designs embellished by traditional crafts at the museum was to demonstrate that traditional handicrafts were influencing modern fashion trends. However, embroidery designs are generally printed onto modern clothes in pieces, rather than making a full traditional embroidered dress of the types shown in Figures 1, 2 and 3 above. Furthermore, instead of using traditional handmade methods for drawing embroidery, new technologies have been utilized.

2.2.1: New technologies used for embroidering clothing

The methods used for embroidering clothing have evolved over time as a result of developments in technology (Hinshaw, 2000). According to Shete (2013), the embroidery segment of the global fashion industry has been subject to regular and systematic change over the past four to five decades. Although traditional embroidery handicrafts have existed for hundreds of years, the use of technology such as machine embroidery entered the arena in the early 1900s (Andreadis et al., 2015). Crane (2000) has argued that the requirement for mass production led to the invention of machine embroidery. However, today, machine embroidery is also playing a central role in creating a demand for embroidered clothing. Machine embroidery designs include the use of very advanced techniques that can render applications such as automated digital 3-dimensional (3D) effects and multiple sequencing (Esther, 2018). Rendering the application of the machine embroidery technique assists in the fine finishing of the embroidery designs, thus increasing the commercial value of the embroidered clothes (Akinwumi, 2017). The operations of embroidery machines include manual embroidery, whereby the embroiderer runs the machine and competently moves firmly hooped fabric under the needle to create the design. The embroiderer also develops the embroidery design manually using the machine settings for running stitch and fancier built-in stitches. It is due to the involvement of manual labour in the process of creating patterns using the free motion principle that machine embroidery has been criticized for not producing exact sketches (Troncoso et al., 2007).

Computerized sewing machines have been developed against the backdrop of criticism of traditional embroidery. Computerized controlled embroidery machines are specifically designed for commercial use (Esther, 2018: P62) and are driven by computers that transmit digitalized embroidery designs to them. Digital designs are usually created using special software. Scott (2017) stressed that computerized embroidery machines are special-purpose machines that create elaborate embroidery on fabric by following a design created with software.

The first computerized embroidery machine was launched in the global embroidered clothing manufacturing industry in the early 1990s (Lemon, 2004). At that time, machines came with their own database of embroidery designs that users could choose from to conduct embroidery onto the clothing. Fixed embroidery designs were also key limitations of the embroidery machines of the 1990s, so users were able to make their own creative art. Another limitation of the embroidery machines of the 1990s was that they were not only expensive, but also provided no empowerment to the manufacturers for creating their own designs. Thus, they lacked the requirements of the post-Ford era of flexible specialization and decentralization of production, as a high level of employee empowerment over the manufacturing process was needed to meet consumers' requests

(Kumar, 1995). Figure 4 below presents an example of an embroidery design being placed on fabric using an embroidery machine whereby the design was crafted manually and then transmitted to a machine to conduct the embroidery onto the fabric.

Source: Adiji and Ibiwoye, 2017

Figure 4: Embroidery design embellished using a manual embroidery machine

To overcome the flexibility issue with regard to creating embroidery designs, two key factors were noted during the early millennium: developments in the hardware of embroidery machines and the introduction of CAD software (Wang, et al., 2016). From the hardware perspective, embroidery machines have been equipped with single and multi-heads and can fit up to 56 heads in one run of sewing (Esther, 2018: P63). Multi-heads allow multiple coloured threads to be fitted to the machines, thus allowing more elaborate embroidery designs on fabrics. However, it is the development of CAD that has transformed the work of embroidery machines in the contemporary fashion industry (Esther, 2018: P63).

CAD technology works on the principle of computer graphics and involves skilful development of images through the creation, manipulation and computation of data (Malhotra et al., 2001). CAD is defined as a specialized software that aids in the formation, alteration, examination and optimization of designs electronically. Drawing on Saha (2018), it has been suggested that the development of CAD does not completely eliminate the use of hand drawing; instead, it further strengthens the traditional way of drawing by assisting in further modification without having to draw the design all over again. Key advantages of using CAD over traditional methods of creating designs include convenience, reduced time and cost effectiveness (Saha, 2018). The significance of CAD in the contemporary global fashion industry can be ascertained from the fact that there is almost no research in the industry that does not involve the use of CAD (Villanueva, 2018). CAD has transformed the process of the ideation and actualization of design, from the development of a concept to the formation and printing of an actual design onto fabric. Figure 5 below presents a CAD-enabled embroidery sewing machine that was made available commercially in the early 1990s.

Source: Adiji and Ibiwoye, 2017: P236

Figure 5: CAD-enabled embroidery sewing machine

Kim (2016: P5) coined a proposition to introduce 3DP to the operations of traditional crafts. However, his study fell short of identifying the technical and human-related complications that would need to be overcome to utilize 3DP in the traditional embroidery craft. However, Kim's (2016) findings made a clear statement that, due to its ability in terms of speed and free form, technology could transform the work of traditional craftsmen/women and enable them to meet the current requirements of fast fashion in the global fashion industry that the embroidery machines currently used at the commercial level have not been able to achieve. Other advantages of using 3DP in embroidery include the integration of the production and embroidery design processes, the quick formation of designs and a low level of waste (Whittow, 2016). Overall, Kim (2016) stressed the need to present actual samples to show firstly the applicability of 3DP for producing embroidered clothes and secondly demonstrating whether embroidered clothes produced using 3DP could represent the same meaning as those produced by traditional handmade crafts.

2.2.2: Cost effectiveness and quality

The use of computerized embroidery machines provides various advantages, such as automating the process of embroidery, providing more efficient and accurate high-quality results and helping in mass customization and production (Esther, 2018: P63). Furthermore, unlike the traditional handmade method of embroidery, which tends to be labour intensive, most of the processes in machine embroidery are conducted using a computer. Effective planning is another advantage of using machine embroidery over the traditional method, which leads to a reduction in cost and improved quality.

2.2.3: Technology meeting fashion trends and needs

The familiarization of fashion designers with computerized embroidery machines has resulted in various international brands using the invention to add value to designs and thus meet key market trends, such as innovation and fast fashion (Adiji, 2016). In particular, CAD software is assisting designers in producing customized embroidery designs on a mass scale. Embroidery machines are largely used to produce household products, such as rugs, automotive fabrics, products for resorts and other items, but less so in producing actual embroidered clothing, such as apparel or accessories.

2.2.4: Infrastructure and skills development

Esther (2018) concluded that although the use of machine embroidery-based methodology offers a variety of advantages, embroiderers producing embroidered clothing at home rarely utilize these new technologies. Reasons for the lack of use of embroidery machines by traditional craftsmen/women include the devices being expensive, lack of awareness and knowledge, and traditional craftsmen/women lacking certain skills. Particularly in the context of embroiderers in the Hejaz region of the KSA, most of the craftsmen/women reside in rural areas with access to very basic education and no access to communications technology and thus they lack awareness of the existence of these new machines, let alone having the skills to operate them (Al-Thawwad, 2008). It is generally the case that embroiderers are poor people, and most are elderly women who do embroidery in their homes. As the younger generation is not showing an interest in learning traditional crafts, those elderly women will not have access to transportation to travel to urban areas of Jeddah to shop around for embroidery machines, and so embroidery is mostly done in the home by hand (Ejeimi et al., 2018). Similarly, Adiji and Ibiwoye (2017: P234) argued that operating computerized embroidery machines requires mastery skills to conduct the actual measurement of the design, identify locations on the fabric and ensure the appropriate finishes on an actual dress. Whereas the international brands producing embroidered dresses possess infrastructure and run training and development programmes for their employees to operate machine embroidery, it is not possible for embroiderers to have the resources to run embroidery machines in their homes.

2.2.5: Comparison of new manufacturing technologies

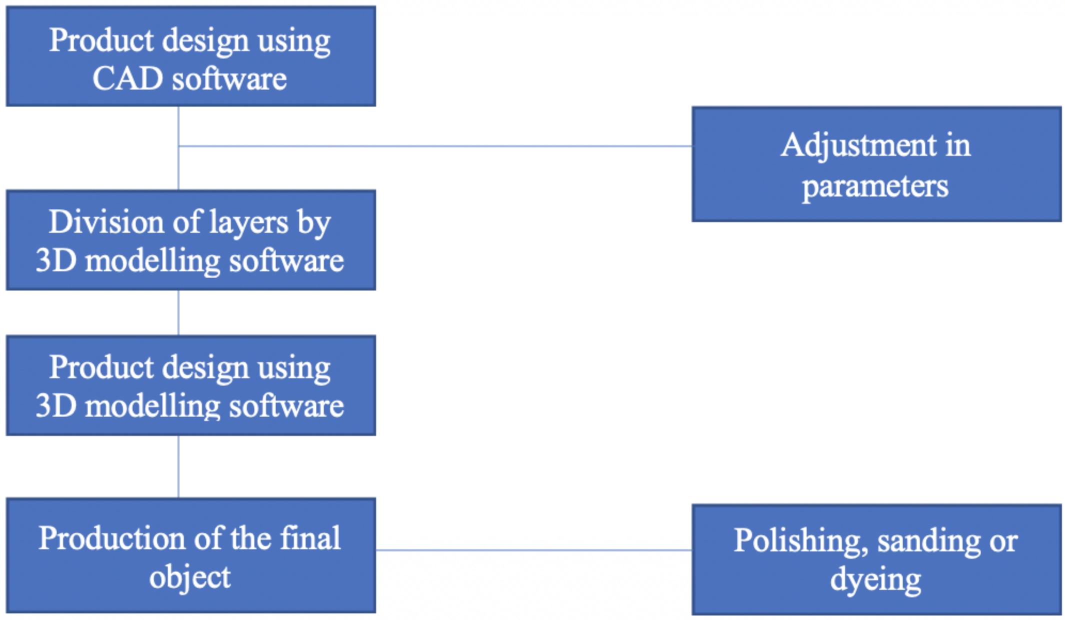
The discussion on new embroidery technologies above identifies eight key advantages: better quality, cost effectiveness, process, convenience, speed, accuracy, scalability and customization (Adiji, 2016; Esther, 2018; Malhotra et al., 2001; Saha, 2018). In comparison between three technologies, 3DP appeared to have the better options in terms of seven of the identified benefits of using new technology, apart from the quality of the product. The reason for the lack of information on the quality of 3D printed embroidery clothing is due to the gap in the research about the use of 3DP in the embroidery segment of the global fashion industry. Therefore, the present research aims to test the potential of using 3DP for embroidered clothing.

2.2.6: Evolution of three-dimensional printing (3DP)

Charles W. Hull created the first 3D printer in 1984 and named it StereoLithography Apparatus (Vanderploeg et al., 2017). In its early days, the technology was very expensive and was thus not available generally on the market. However, this changed with the turn of the century and allowed 3DP to find its way into several industries. 3DP works on the same principle as that of an inkjet printer but, rather than printing layers of ink on paper, 3DP uses materials to build three-dimensional objects (Berman, 2012). Also known as additive manufacturing (AM), 3DP is described as a process of producing three-dimensional solid objects of any shape using digital computer models (McCormick et al., 2020). The key principle of 3DP is that it prints by layering, superimposing layer after layer, one on top of the other and converting the aggregate state of the material tends to change it from a liquid or powder into a solid form. It is the layering process of 3DP that differentiates it from two-dimensional printing (2DP) or traditional printing methods.

2.2.6.1: Process of 3DP

The process of 3DP involves designing a product on CAD software (Hornick and Roland, 2013). Designs created on CAD software can be altered using computational algorithms to ensure that designs fit into the specific size parameters demanded by consumers. To this end, a CAD-related modelling program, such as Rhino, is used as a design tool. The benefit of using the Rhino program lies in the ease of use, such that even non-experts can use it for writing code. The Rhino program also offers efficiency and convenience, as it allows the creation of multiple designs using a single code (Yap and Yeong, 2014). Upon completion of the design step, the next stage of 3DP is to divide the object, such as an embroidery design, into horizontal layers. In the third step, data from the files are communicated to the printer and then a 3D printed product is developed via each divided layer (Mellor et al., 2014). Once the object is printed, sanding and polishing of the embroidery design is carried out to improve the surface and reduce the appearance of printed lines. Finally, a visual inspection is conducted to ensure the aesthetic quality of the printed design, since appearance tends to have a significant impact on consumer perception. Figure 6 below presents the general design and production process of 3DP. One of the key limitations of the 3DP process is that it tends to be difficult to print an entire garment or large accessories in one go (Reilly, 2014). Thus, multiple runs of printing are conducted to ensure the formation of a final design, which could also involve the use of adhesive interlocking of different components.



Source: Vanderpleog et al., 2017
Figure 6: Process of the 3DP method

2.2.6.2: Types of 3D printer

With the evolution of technology, various types of 3DP have been developed, such as selective laser sintering (SLS), fused deposition modelling (FDM) and stereolithography (SLA) (Gojanović and Nikolić, 2015).

Selective laser sintering was invented by Carl Dekard at the University of Texas in Austin in the 1980s (Prince, 2014). SLS uses a laser to liquidate powder to produce a 3D printed object. The object is then cooled to produce a solid, shaped object. The process of SLS uses powder as a material, a liquidating temperature and, finally, carbon dioxide (CO_2) laser power. To conduct SLS-based printing, a layer of powder is first established, followed by sintering the material by laser, which results in lowering the supporting plate as the thickness of the layer increases. Afterwards, a new layer of powder is applied, and the sintering process is repeated. This process continues until all the layers are sintered and the desired object is printed. One of key advantages of using SLS is that it allows the reuse of residual powder, thus reducing waste.

Fused deposition modelling is the most commonly used form of 3DP because, comparative to other types of available 3DP, it is more affordable (Huang et al., 2013).

Materials used in FDM 3D printers usually include wax, metals and ceramics. Two major types of filament are used for printing purposes: acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA). Arostegui et al (2006) described ABS as an engineering thermoplastic polymer comprises of amorphous-continuous phase and rubbery-dispersed phase. With regards to 3DP, ABS is one of the filaments that have been used since the beginning of the 3DP methodology itself. Key attributes of ABS material that makes it suitable for 3DP includes its sturdiness, high heat, wear resistance and relative low cost (AMFG, 2018a). Comparative to PLA, ABS is considered to possess stronger mechanical properties linked to its toughness, durability and ductility thus making it resistance to wear and tear of 3D printed design. Another advantage of ABS comes from its post processing credentials. According to AMFG (2018) ABS can assists in variety of post processing techniques such as sanding, painting, gluing, milling, drilling and cutting. Another benefit of using ABS material lies in its usage to create new materials with improved properties such as biocompatibility, conductivity and translucency, all of which present better mechanical properties such as heat resistance. Finally, ABS is lauded for its dimensional printing. However, ABS also come with some limitations such as it is hygroscopic meaning that it can absorb moisture from the air that adversely impacts quality of print. Additionally, 3DP designs printed through using ABS material can be damaged when exposed to prolonged sunlight hence further adversely impacting quality of print and questioning long-term wearability. Moreover, printing of design through using 3DP require accurate temperature management that can be time consuming. Finally, there are also health related concerns linked to using ABS material such as heating of ABS has been found to emit intense and smelly dumes that can cause irritation and headaches among users.

In contrast to ABS, ease of use and minimal warping needs makes PLA filament compatible for using in 3DP particularly in FDM based 3DP technology (AMFG, 2018b). Unlike ABS's adverse impact on environment, PLA is recognized to be environmentally friendly along with advantages of low cost and availability of large number of assortment of colours and blends. With regards to 3DP, PLA material provides variety of advantages such as low printing temperature, ease of use, variety of colour and blended opportunity, easy post processing and finally biodegradability. Comparative to ABS, PLA require low temperature for printing for instance while ideal printing of ABS material is registered to be around 250°C as compare to 180°C of PLA (AMFG, 2018b). Low need for temperature of PLA makes 3DP easier as relative to ABS, which is likely to wrap and clog to nozzle, PLA does not do that. Furthermore, PLA is recognized to be easiest material to use in 3DP because of its ease of adherence to variety of surfaces and due to low requirement of temperature PLA does not emit smelly fumes during printing as does by ABS. Moreover, while PLA is available in variety of colours and also it can also be mixed with wood, carbon and other metals to get other coloured materials such as luminescent or glittery filaments. In terms of post processing, PLA can be sanded, polished and painted that allows for improved finish with little efforts. Finally, PLA is eco-friendly because it is biodegradable. However, PLA also comes with some limitations such as it is low heat resistance thus making it prone to damage in the event of exposure of high heat. Moreover, PLA tends to have low tensile strength as compare to ABS thus reducing quality of 3DP design. Finally, 3DP designs made through using PLA has been found to prone to oozing means that extruder of 3D printer can leak out while moving to make design thus creating strings between the areas hence reducing quality of print.

In contrast to both ABS and PLA, Thermoplastic Polyurethane (TPU) offers unique potential of producing elastic and highly durable 3DP designs. TPU is made of both rubber and plastic material thus making it more elastic and easier to compressed (AMFG, 2018c). Relative to ABS and PLA, TPU forms more flexible 3DP designs due to its softness. Additionally, 3DP designs made through using TPU material has been identified to be resistant to variety of solvents including oil and greases thus increasing long-term wearability of 3D printed dresses. Key benefits of using TPU in 3DP that cannot be achieved in ABS and PLA includes elasticity and softness, stretch-ability of TPU, chemical resistance, good impact resistance, resistance to shock, low warping and shrinkages. It is due to these credentials of TPU materials that makes it suitable for printing complex designs such as embroidery designs in relatively less time and low requirement of material. However, low temperature requirement of TPA has been identified to make it reducing accuracy of printing. Relative to PLA and ABS, TPU is a novel material however with high potential for embroidery clothing because embroidery designs require flexibility and potential of resistance to externalities such as tensile and washing therefore more suitable for present study. In recognition of above-mentioned properties of TPU material, Pie (2015) also used TPU filament while investigating adhesion of polymer materials printed through using 3DP. Koerner (2013) also recognized compatibility of TPU with 3DP because of its flexibility, durability and mechanical wash-ability. Article by AFMG (2019) found that thanks to favourable range of attributes of TPU filament, substance has been used in variety of fields such as medical, consumer and industrial applications.

The process of FDM 3DP starts with heating the liquid thermoplastic filament at one degree above its boiling point, followed by its dispersion on a building platform in a thin layer using an extruder. The dispersion process results in instant hardening of the material and binding to the layer beneath it. After finishing the layer, the building platform is lowered to make space for the next layer. According to Melnikova et al. (2014), FDM is capable of printing glossy, flexible, lace-like fabrics with soft PLA polymers.

Stereolithography uses an ultraviolet (UV) laser ray to harden the 3D printed object using a photosensitive liquid material (Gojanović and Nikolić, 2015: P193). After completion of one layer, the vessel with the polymer is lowered to repeat the process until the object is completely printed. Although the process of printing in SLA is less expensive comparative to SLS and FDM, the materials used in SLA are more expensive. Laminated object manufacturing (LOM) is another type of 3DP that uses plastic sheets or plastic materials fused together through using high temperature and pressure to create intended shape (Jasveer and Jianbin, 2018). Key advantages of LOM lie in the fact that it is not only low cost but also is easily available. Additionally, LOM does not involve any chemical process. However, one of the key drawbacks of LOM based 3DP that makes them incompatible for using in embroidery clothing is their inability to create complex embroidery designs. Digital light processing (DLP) is another type of 3D printer that is while similar to stereolithography however while DLP uses light but stereolithography uses ultraviolet laser ray (Jasveer and Jianbin, 2018). DLP uses conventional lights to cure photo sensitive polymer resin into the object. There are multiple advantages of using DLP such as high accuracy and resolution of printing, require shallow vat of resin to support printing process resulting in low waste and running costs. Additionally, comparative to stereolithography, DLP tends to be faster in processing. DLP uses photosensitive resin plastic that makes it suitable to print highly detailed artworks and patterns. However, DLP need for processing of objective to remove unnecessary support structure makes DLP expensive. Furthermore, use of plastic material means DLP lacks needed flexibility to print complex geometric designs such as embroidery (Kadry et al., 2019). Table 1 below provides a comparative analysis of the three 3DP techniques to illustrate their drawbacks and benefits.

Table 1: Comparison of three types of 3DP

3DP types	Maximum printing size	Materials	Benefits	Drawbacks
SLS	80 mm × 95 mm	Metal powder	• Conducts a high-quality surface finish • Object is printed in a compact size • Faster lead time	• Small printing size • End users require sophisticated skills to operate the machine
FDM	200 mm × 250 mm × 150 mm	PLA or ABS	• Flexible materials • Object printed in a compact size • Can print multiple products at once • Quality level can be adjusted	• Requires support raft • Lead time is slower • Limited printing size

			• Inexpensive • User friendly	
SLA	2 m	Photopolymer resins	• Can print large objects • Fast lead times • User friendly • High-quality surface finish	• Requires support raft • Expensive materials • Requires a large space
LOM	32mm × 22mm × 22mm	Plastic sheets	• Low cost • No chemical reaction	• Inability to print complex geometrical designs
DLP		Photosensitive resin plastic	• High accuracy • Semi-flexible • High resolution	• Require post processing increasing cost and waste

				• Incompatible for printing 3DP designs

Source: Vanderploeg et al., 2017: P7: Jasveer and Jianbin, 2018: Kadry et al., 2019

2.3: Evolution of 3DP in the fashion industry

Since its emergence in 1982, 3DP has left its mark on almost every industry, ranging from the military, aviation, research, medicine, engineering to automobiles, etc. and the global fashion industry is not immune to this influence (Lipson and Kurman, 2013; Sun and Zhao, 2017; Wang and Chen, 2014). According to Fitzgerald (2013), 3DP meets the current trends of the modern fashion industry. For instance, it can be used to develop prototypes and allows the customization of products which offer customers an interactive choice-driven experience. Furthermore, 3DP requires fewer raw materials as, compared with traditional computer control-based machines, the additive manufacturing process of 3DP means only the prints required are produced. Similarly, from the perspective of designing and mapping, 3DP can save time and costs, since it excludes the step of making a mould for casting or manually drawing sketches from the production process, thus making the 3DP process flexible enough to meet sudden changes in market requirements. Another advantage of using 3DP in the fashion industry lies in the standardization of the quality of the products, even if they are produced in different locations (Sun and Zhao, 2017).

Moreover, the evolution of 3DP in fashion has also resulted in empowering consumers. For instance, consumers are not only able to choose designs from the available database, they can also create their own and have them printed either through the retailer or directly from the manufacturer (Sun and Zhao, 2017: P7). From the sustainability perspective, the use of 3DP provides customers with environmental, social and economic benefits. The key sustainability advantage of using 3DP in the fashion industry is that it directly contributes towards eliminating waste and reducing by-products (Lipson and Kurman, 2013). For instance, 3DP builds objects onto fabric from CAD software and only applies material onto fabric where an object is required, thus eliminating waste. From an environmental perspective, a report by the US Department of Energy claimed that the use of 3DP in the fashion industry could reduce energy consumption in the industry by 50% of that used by the traditional subtractive manufacturing method (Gebler et al., 2014). Finally, from a social perspective, it has been forecast that the use of 3DP could reduce CO_2 emissions by the global fashion industry by 5% by the end of 2025 (Gebler et al., 2014).

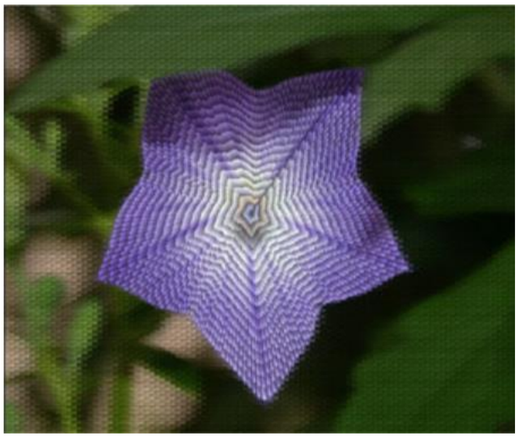
In the global fashion industry currently, 3DP has been used to design and print various products, ranging from bikinis to shoes to dresses (Kholiya, 2016). Global apparel brands have used 3DP to produce prototypes. For example, Nike used the technology to manufacture the Vapor Laser Talon American football boot for players during the 2013 season (Kholiya, 2016). On the other hand, with the increasing affordability of 3DP, technology has also paved the way for new start-ups (Leighton, 2017). According to one article, Business Insider found that the members of a recent business start-up called the Ministry of Supply (at MIT) used a 3D printer in their homes to enter the fashion industry (Leighton, 2017). However, Kim (2017) suggested that the increasing affordability of 3DP was resulting in a rise in legal issues related to intellectual property (IP) rights infringement and counterfeiting. Sun and Zhao (2017) called for the provision of legal protection for products made using 3DP to safeguard the IP rights relating to garments and accessories. However, in their investigation into the development of fashion products using 3DP, Kim et al. (2019) identified various products, such as jackets, dresses, shoes and accessories, produced by renewed designers such as Danit Peleg, Maria Alejandra Mora Sanchez and others and adopted by global brands such as Zara and Adidas.

Despite the above-mentioned well-founded economic, social and environmental benefits of using 3DP in the global fashion industry, concerns about the long-term wearability of clothes produced using this technology remain unanswered (Sedhom, 2015). With regard to wearability, the aesthetic and perceived value of clothes, shoes and accessories produced using 3DP have been questioned. Garments produced using 3DP have been accused of being uncomfortable to wear due to the material used in printing the design, which results in consumers having the feeling of discomfort as the stiffness of the clothes limits the ease of body movement (Jacobson, 2017; Perry, 2017). The principal challenge of 3D printed garments lies in the fact that 3DP material is far more inflexible than fabrics on which an object is printed, thus resulting in the risk of objects being shattered even when used for the first time (Jacobson, 2017). Similarly, Valtas and Sun (2016) questioned the maintainability of 3D printed garments and accessories; here, maintainability means the lack of an adhesion mechanism, especially for knitwear products. According to Valtas and Sun (2016), after being washed, 3D printed clothes tend to deteriorate quickly, due, for example, to de-sizing, a reduction in brightness and even fabric and 3D printed objects starting to rip. Likewise, Sun (2016) recognized that 3D printers use synthetic materials, such as polylactic acid, that are not comfortable and flexible enough to provide customers with ease of use.

2.4: 3DP in the embroidery industry

Although the existing literature demonstrates the need to develop new technologies to revive the embroidery industry, there is a lack of research testifying positively to the use of 3DP for producing embroidered clothing. Cui et al. (2017) presented an image-based method to stimulate the traditional embroidery craft. Their method combined stroke-based rendering and a Phong lighting model to establish picturesque embroidery-like images. Phong lighting model is identified as an empirical of domestic illumination that uses three components to calculate approximate requirement of illumination at every point of surface of a stitch such as diffuse reflection, specular reflection and ambient reflection. The processing of the input image in Cui et al. (2017)'s experiment further revealed that 3DP is capable of performing fine embroidery simulation with bright effects of lighting and shading, as shown in Figure 7 below on the next page, a result of the input to the system and its output.

Input **Output**



Source: Cui et al., 2016

Figure 7: Input and output of 3DP for traditional embroidery

Although Cui et al. (2017) acknowledged the success of their proposed method of converting an image into uniquely stylized embroidery stimulation, they questioned its ability to deal with the complicated images that come with embroidery. Moreover, in their method, Cui et al. (2017) selected a stitch manually, which may be inconvenient for an unskilled person. For example, if customers are allowed to select the material and design, the compatibility of the chosen stitches for 3DP could be a problem, since the selection of stitches when using 3DP in embroidered clothing requires sophisticated segmented algorithms that may not be possible without a high level of understanding of segmented regions and texture.

While the findings of Cui et al. (2017) raised questions regarding a 3D printer's ability to produce clear images, others, such as Martens and Ehrmann (2017), queried the aesthetic aspect of objects printed using 3DP. Specifically, their study aimed to assess why 3DP is not used for creating large components of clothes. Using FDM-based 3DP and two different printing materials, FilaFlex and ABS, the authors produced samples of 3D printed fabrics. Afterwards, a washing test was conducted to assess the adhesion of the 3DP object. Their findings revealed that although the washing and peeling tests did not have an impact on the adhesion and flexibility between the FilaFlex material and the textile, this was not the case when it came to the ABS material, as the 3DP object could be pulled apart if a stronger mechanical force was applied. Although Noorani (2017) acknowledged scalability, convenience and reduced labour cost advantages of using 3DP in the fashion industry, they nonetheless suggested that it caused significant amounts of waste, as the final products were still required to be finished manually by cutting the edges and improving the roughness, brightness and shape of the 3DP object.

Another vital issue regarding the use of 3DP in the fashion industry stems from the lack of knowledge and skills in how to use this sophisticated technology (Vanderploeg et al., 2017). Human resource problems facing 3DP technology in the fashion industry have also been identified by the manufacturers of embroidered clothing in the KSA, and most of the interviewees in this research argued that they lacked skills, knowledge and experience in using the new technology for manufacturing embroidered clothes. Similarly, a lack of skills and motivation and certain technical difficulties in the use of technology in the manufacturing process of embroidered clothing have been identified as key hurdles to the adoption of technological solutions (Ejeimi et al., 2018; Eng and Bogaert, 2010; Venkataramanaiah and Nidugala, 2016). In a study conducted to identify the effect of modern technology on the production of embroidered clothing in South-Western Nigeria, Esther (2018) conducted a survey to identify perceptions of manufacturers of embroidered clothing with regard to using advanced technologies. Esther's (2018) findings concluded that the majority of embroiderers lacked knowledge and skills in using CAD software, let alone running 3DP, further demonstrating the need to develop the skills of embroiderers to ensure the survival of this traditional craft.

Another dimension of the introduction of 3DP in the manufacturing process of embroidered clothing is related to consumer perception and attitude. The discussion in section 2.1.3 above states that there is a lack of interest among consumers in the KSA towards embroidered clothing because of the influence of Western culture (Ejeimi et al., 2018; Tawfiq and Ogle, 2013). In their study on psychological and cultural insights into the consumption of luxury Western brands in India, Eng and Bogaert (2010) identified conspicuousness, uniqueness, quality, hedonism, self-expression and quality perception as factors having an impact on consumers' adoption of products. Conspicuousness is the degree to which a fashion is popular and affordable. In contrast, uniqueness is about the extent to which embroidered clothing produced using new technology such as 3DP would be considered as exclusive or rare. Hedonism is about the extent to which technologically produced embroidered clothes conform to the current fashion trends or consumer tastes. Quality perception is concerned with the extent to which embroidered clothes produced using 3DP would provide customers with aesthetic benefits, and social prestige is the extent to which embroidered clothes produced using 3DP would meet social acceptance. Finally, self-expression is about the degree to which 3D printed embroidery clothes would assist consumers in expressing themselves in their social class. Eng and Bogaert (2010) were of the view that embroidered clothes produced using 3DP would only be accepted in society if they meet all the above-mentioned behavioural, perceptual and attitudinal factors.

2.5: Conclusion

The discussion presented in this chapter has resulted in answering the first, second and part of the third research questions. Discussion on the current state of the traditional embroidery industry in the KSA clearly indicated that there is a need for the revival of the industry, as this traditional craft is facing challenges from Western brands, and thus answered the first research question of this study. Moreover, the literature also acknowledges that a lack of development in the manufacturing techniques of traditional embroidered clothing is the principal cause of its demise, as traditional manufacturing methods do not meet the current market trends of customization and mass production. The literature also recognizes that while machine embroidery technology has indeed provided some impetus for the growth of the traditional embroidered clothing industry, these technologies have insufficient ability to meet mass customization, despite meeting mass production trends, and thus the second research question has been answered. To this end, the present study proposes using 3DP technology because it will not only enable the traditional embroidery industry to meet current challenges, but will also provide various other environmental, economic and social advantages. However, there exists a gap in the existing research with regard to whether 3D printed embroidery clothes would meet the aesthetic demands of customers, such as long-term wearability. A review of experimental studies in this regard revealed that there is a shortage of research that could justify the use of 3DP for manufacturing embroidered clothes. With regard to aesthetic and comfort-related issues with using 3DP in embroidered clothing, a key factor prohibiting the use of

3DP in the fashion industry involves the adhesion of the object onto fabric. It has been found that 3D printed objects on fabrics tend to deteriorate after washing, to be rigid, causing problems for the free movement of the body, and require maintenance in terms of the edges, roughness, brightness and shape of the embroidery. Although findings on the process and development of 3DP in the fashion industry answer part of the third research question, as they identify a general overview of the use of 3DP in the current embroidery industry, the implementation of 3DP to produce embroidered designs is yet to be evaluated.

In addition to technical complications related to the integration of 3DP in the manufacturing process of traditional embroidered clothing, the review of the literature also identified human-related hurdles. For instance, it has been found that manufacturers of traditional embroidered clothes lack skills, knowledge and know-how in using technology. Finally, the literature also finds that the success of the end product of 3D printed embroidery clothes would depend upon consumer attitude and behaviour. In particular, the end product should meet conspicuousness, uniqueness, quality, hedonistic, self-expression and quality perception psychological factors of consumer behaviour.

Overall, the discussion in this chapter found that the success of the integration of 3DP in the traditional embroidery industry of the Hejaz region in the KSA would depend upon three factors: the aesthetic nature of the end product, which would need to fulfil long-term wearability tests; the manufacturers' perception of using new technology in the manufacturing process; and consumer acceptance of the end product. To this end, the present study aimed to conduct an experimental and survey-based statistical investigation to evaluate the technical applicability of 3DP in the manufacturing process of traditional embroidered clothing and assess manufacturer and customer perceptions of using new technology in the process. This is a novel contribution. To revive the embroidery industry, no published data can provide information about how adaptable relevant stakeholders are to new techniques, and especially 3DP.

Chapter III

Methodology

3.0: Introduction

The purpose of this research is to assess the possibility of reviving the traditional embroidery handicraft industry in the Hejaz province of the KSA by integrating 3DP in the manufacturing process. The review of the literature presented in the previous chapter revealed that success in introducing 3D printed embroidery clothes cannot be possible unless stakeholders such as manufacturers and consumers express a preference towards using 3DP in the manufacturing and wearing of this type of clothing, respectively. Moreover, the technical hurdles related to producing 3D printed embroidery clothes, such as wearability and adhesion, need to be assessed. Thus, the methodology outlined in this chapter aimed to seek answers to the following questions:

- How can 3DP be integrated into the manufacturing process of traditional embroidered clothing?
- What factors could influence the adoption of 3DP in the manufacturing of embroidered clothing in the Hejaz region of Saudi Arabia?

After identifying the overall research design, the discussion in this chapter is divided into two sections. The first section identifies the frameworks used to collect the survey data and the various protocols followed, such as the questionnaire design, sampling technique, the internal validity and reliability of the questionnaire and the data analysis method. The second section then moves towards laying down the framework used for conducting the experiments aimed at producing 3D printed embroidery clothes and further tests to evaluate the wearability of the samples.

3.1: Research design

To achieve the above-mentioned objective, the present exploratory research was designed to adopt a quantitative approach. Saunders et al. (2016) differentiated between quantitative and qualitative methods of research by arguing that while the former is about collecting numerical data, the latter involves collecting non-numerical data. The exploratory nature of the present research, such as investigating the possibility of reviving the traditional embroidered clothing industry of the Hejaz region of the KSA, fits into a quantitative research design (Nardi, 2018).

Furthermore, a quantitative research design also fits the context of this research because it requires multiple data collection techniques. For instance, data needed to be collected to ascertain manufacturers' and customers' opinions on the integration of 3DP clothing, and an analytical technique was needed to examine the wearability of 3D printed embroidery clothing. Thus, the present research falls within the range of multiple methods. Bryman (2006) praised the use of multiple data collection techniques, as this results in strengthening the conclusions derived. Under a multiple method quantitative methodology, the present research adopted survey- and experiment-based research strategies.

3.2: Survey framework

A survey strategy of data collection was suitable for the present study because it helps in assisting in answering "What"-related questions (Saunders et al., 2016: P181), such as what factors could influence the adoption of 3DP in the manufacturing process of embroidered clothing in the Hejaz region of the KSA? The present study conducted two sets of surveys: one with manufacturers and the other with customers.

3.2.1: Manufacturer survey

The aim of the manufacturer survey was to identify manufacturers' perceptions of the adoption of 3DP technology. To this end, a face-to-face questionnaire method was used to collect data. Under this method, the author met respondents in person and asked them questions face to face. The survey was conducted in the city of Taif in the Hejaz province of the KSA, which was held on 21st July 2018. The Souq Okaz Festival is held annually in Taif as part of the festival known as the Taif season and is famous for inviting locals to showcase their talents at the event; traditional embroidery clothing lines are one of those talents (Al-Kinani, 2019). To gain access to the research population, a permission request letter was sent on behalf of the author by the supervisor of this thesis and permission was granted (see Appendix 1).

3.2.1.1: Factors used in designing the questionnaire

Drawing on Boynton and Greenhalgh (2004), a survey questionnaire must represent an objective means of collecting the intended information about people's knowledge, beliefs and attitudes. The purpose of the manufacturer survey was to evaluate perceptions of integrating new technology in the manufacturing process of embroidered clothing. This would allow the collection of data regarding behavioural and attitudinal factors that could influence manufacturers to adopt new technology. One of the theoretical models that has been recognized as being effective in predicting the adoption of different technologies at both the individual and organizational levels is the technology acceptance model (TAM) (Marangunić and Granić, 2015). The theoretical foundation of the TAM emerged from the theory of reasoned action (TRA), which asserts that the behavioural intentions of individuals are linked to the belief that performing certain actions will lead to attaining a favourable outcome (Fishbein, 1967).

Enlarging on the proposition of the TRA model, Davis (1989) proposed the TAM, which uses perceived usefulness (PU) and perceived ease of use (PEOU) as a yardstick to demonstrate an individual's orientation towards adopting a certain technology. PU is defined as an individual's perception that the use of technology will lead to improving their performance and PEOU is the extent to which individuals find technology easy to use. It is perceived that external variables, such as support, accessibility and the experience of individuals, influence PEOU and PU factors that, in return, have an impact on an individual's attitude and behaviour towards the actual use of a system.

Various past researchers have used the TAM model when investigating the adoption of 3DP in the manufacturing process, including the home setting and the fashion industry (Lee and Koo, 2018; Wang, Q. et al., 2016). Drawing on the literature on 3DP presented in section 2.3 in the previous chapter, it is evident that the PU of 3DP in the manufacturing process of embroidered clothing would include the convenience of drawing the design and mass customization (Lipson and Kurman, 2013; Sun and Zhao, 2017). However, the existing literature questions the skills and capability of traditional embroidered clothing manufacturers in using new technology such as 3DP (Al-Thawwad, 2008), thus constituting the significance of the PEOU element of the TAM model. Furthermore, the literature review also revealed concerns raised about the wearability of clothes made using 3DP, particularly their aesthetic maintainability, as it is argued that clothes and accessories made using 3DP tend to lose their aesthetic capability over time and to be uncomfortable (Jacobson, 2017; Perry, 2017).

Other factors that have been identified as having a negative impact on the use of new technology in the manufacturing process of traditional garments include the lack of awareness among manufacturers of current customer trends and tastes and little overall awareness of the availability of the technology itself (Al-Thawwad, 2008). Based on the analysis of the literature, the questionnaire for the survey was designed based on five factors to test the perspective of embroidered clothes manufacturers in the Hejaz region of the KSA towards integrating new technology: perception, usefulness of using technology, awareness, wearability and ease of use.

3.2.2: Customer survey

The second survey was designed to assess customers' perceptions of using clothes manufactured by employing advanced technologies, such as 3DP. To this end, students studying in three universities, Umm Al-Qura University in Makkah, King AbdulAziz University in Jeddah and Taif University, were targeted. As with the manufacturer survey, the customer survey was also conducted face to face. Access to the research population was made possible using the author's personal relations with the three universities. Factors for predicting customers' orientation towards using embroidered clothes made using new technology were developed using a study by Eng and Bogaert (2010), who suggested that consumers' adoption of new fashion depends upon behavioural and perceptual factors, such as conspicuousness, uniqueness, quality, hedonism and self-expression, as discussed in section 2.4 of the previous chapter.

3.2.3: Questionnaire design

With regard to questionnaire design, Saunders et al. (2016: P452) identified open and closed questions as two methods. Open-ended questions allow respondents the flexibility to respond in their own way and closed-ended questions tend to provide respondents with a number of options from which to respond to a question. The present study used closed-ended questions in the questionnaire because of a range of advantages: responses in close-ended questionnaires tend to be easier to interpret since they are predetermined, they consume less of the respondents' time, and are, overall, cost effective (Reja et al., 2003). A closed-ended questionnaire provides researchers with six types of design under which a questionnaire can be generated: list, category, ranking, rating, quantity and matrix (Saunders et al., 2016: P452). In the context of the present study questionnaire, both the manufacturer and customer surveys were designed in relation to a rating or Likert-style questionnaire. A Likert-style questionnaire suited the present study, since the aim of both surveys was to gain respondents' opinion of the possibility of reviving the traditional embroidery industry through the integration of new technology in its manufacturing process. Saunders et al. (2016: P457) supported the use of Likert-style questionnaires when the aim of the survey is to collect opinion-related data. To this end, five scale Likert-style questions were used in both surveys, in which respondents were presented with a statement for each of the variables and were asked to respond under a predetermined scale of strongly agree, agree, neither agree nor disagree, disagree and strongly disagree. Appendices 2 and 3 present the questions contained in the manufacturer and customer surveys, respectively.

Questions related to the cost and price of traditional embroidered dresses were designed in relation to multiple-choice questions. The rationale behind using multiple-choice questions to assess the cost and price of traditional embroidered dresses compared with opinion-based questions lies in the fact that this thesis required more specific answers with regard to cost and price in order to make a comparative analysis with the cost and price of 3DP embroidery dresses.

3.2.4: Sampling technique

Conducting a face-to-face survey by attending the Souq Okaz Festival and targeting local manufacturers of embroidered clothing made the case for adopting a probability sampling method. According to Henry (1990), the probability sampling technique is most commonly used in survey research strategies as it allows researchers to interface directly with their sample to collect responses, thus ensuring the effective achievement of the research objectives. Therefore, the target of the manufacturer survey was the embroidery manufacturers attending the Souq Okaz Festival. It was easy to identify all the samples because there was one specific location at the festival for local embroiderers.

One of the key limitations of probability sampling is that it demands the targeting of all the possible samples available. For instance, in the case of this thesis, it would have meant targeting all the embroidered clothing manufacturers in the whole of the Hejaz region. Given that the manufacturers of embroidered clothing usually live in rural areas and work from home, it was not practically possible to target each and every member of that population. Thus, attending the Souq Okaz Festival was found as an alternative. The author found that 16 stalls had been allocated to local embroidery manufacturers at the Souq Okaz and thus she collected data from all 16 stalls, which included 50 people. Considering that embroiderers at Souq Okaz had come from different locations of the Hejaz region, this approach improved confidence in the data, as it reduced the generalizability error (Saunders et al., 2016: P279).

Similarly, in the customer survey, a probability sampling technique was utilized, as students studying in the textile faculty were specifically targeted. The choice of three universities in the Hejaz region was influenced by those institutions specializing in the textile field. It was expected that students studying in the textile faculties of those universities would have a better understanding of fabrics and the technicalities of using 3DP. Therefore, the target population of this study was composed of students in the textile faculties of the three universities.

3.2.5: Internal validity and reliability of the questionnaire

Internal validity is the ability of a questionnaire to measure what it is intended to measure (Roberts et al., 2006). There are three measures under which the internal validity of a questionnaire can be assessed: content validity, criterion validity and construct validity. Content validity is the degree to which a questionnaire in a survey offers appropriate coverage of all the factors identified in the survey framework. Appendices 2 and 3 show that separate statements were set under each factor of both surveys, thus gaining content validity.

In contrast, criterion validity is about ascertaining the ability of a survey tool to make accurate predictions (Saunders et al., 2016: P450). In the case of the manufacturer survey, criterion validity concerned the extent to which manufacturers would prefer to use new technology in the manufacturing process of traditional embroidered clothing. Criterion validity in the context of the customer survey was about the extent to which customers would be willing to buy technologically produced embroidered clothing.

Finally, construct validity refers to the degree to which a questionnaire measures the construct that the researcher intended it to measure (Saunders et al., 2016: P450). The construct validity of the questionnaire was attained through having an external view of the questions. To this end, not only the views of the supervisor of this thesis, but also opinions from three PhD students were sought regarding the questionnaire's ability to measure the intended results.

In contrast with validity, the reliability of a questionnaire is about the robustness of the instrument, such as whether or not it will produce consistent results (Mitchell, 1996). The reason for testing the reliability of a questionnaire lies in the approach of ensuring that the respondents understand the content of the questionnaire in the same manner as the researcher intended them to. To this end, the findings of the survey were compared with those of relevant past researchers to obtain a reasonable argument about the consistency of the data.

3.2.6: Data analysis

Data for both the manufacturer and customer surveys were analysed using an exploratory data analysis (EDA) method. Saunders et al. (2019) described EDA as a useful approach to exploring and understanding data in order to identify relationships within quantitative data. EDA is also praised for providing researchers with the flexibility to introduce new findings (Hoaglin et al., 1983). In order to conduct EDA in the current research, raw data were processed using Microsoft Excel software. Percentages of responses to the five-point Likert rating scale (strongly agree, agree, neither agree nor disagree, disagree and strongly disagree) were calculated and presented in the shape of tables for exploratory analysis. The key aim of using EDA was to identify the highest concern(s) that manufacturers demonstrated regarding the integration of 3DP in the manufacturing process of traditional embroidered dresses, such as their perception, the usefulness of the technology, awareness, ease of use and wearability. Similarly, the aim of the exploratory analysis of the customer survey was to identify the highest concern(s) that customers demonstrated towards using embroidered dresses produced using technology, such as conspicuousness, uniqueness, self-expression, hedonism and quality.

3.3: Experiment framework

The purpose of the experiments conducted in this research was test the long-term wearability of embroidered clothes made using 3DP technology. Two experiments were conducted: a washing test and a tensile test. Both experiments started with the production of samples of embroidered clothes made using 3DP. To this end, a 3D printer based on FDM Ultimaker 2+, CAD software and a TPU 95A filament were used. The reason for using an FDM-based 3D printer lies in the fact that it is not only relatively affordable, but also because of the availability of its materials (Leigh et al., 2012).

Preferring to use TPU 95A over other available materials, such as ABS and PLA, lies in the fact that TPU 95A not only offers additional movement, but also allows printing on flexible, glossy lace-like fabrics. Tadesse et al. (2018) praised TPU material over others for offering more elasticity and higher strength attributes, thus making it ideal for embroidered clothing, as such designs require greater strength to stick on fabric.

For this study, the embroidery designs were prepared on CAD software. Three types of fabric were used to produce 3D printed embroidery samples: plain cotton, plain silk and plain nylon organza. Practical reasons for using these three types of fabric lie in the fact that most of the embroidered clothes in the Hejaz region are produced using these types of cloth (Ejeimi et al., 2018). The mechanical and technical rationale for using these three types of fabric is that the ability to combine 3D printed materials with textiles depends upon the degree of interface between the fabric structure and the type of material. Printing 3DP objects on textile fabrics could require novel mechanical properties of 3DP parameters, such as nozzle temperature, nozzle size, layer height and bed temperature (Dopke et al., 2017). The industrial-level application of 3DP is yet to be ascertained due to the different mechanical, structural and pattern-related differences in fabric (Grimnelsman et al., 2018), thus warranting the use of three types of material to investigate the possibility of using 3DP to produce embroidery designs.

Various parameters were used to produce the 3D printed samples. Table 2 below shows the different thicknesses chosen because layer thickness plays a significant role in the visibility of an embroidery design on the surface of the fabric. The nozzle size was kept constant at 0.4 mm, and the nozzle was heated to 240 °C, 245 °C and 250 °C to melt the filament. Different nozzle temperatures were used in order to identify the most effective temperature at which the melted filament could create the strongest bond with the fabric surface. Finally, the bed temperature was set at 70 °C for all the tests, as suggested by the technical datasheet for the Ultimaker 2+ 3D printer.

Table 2: 3DP parameters used to produce samples of embroidered clothes

Fabric	Layer height	Number of samples	Nozzle temperature	Nozzle size	Bed temperature	Filament
Plain cotton	0.25 mm 0.50 mm 1.00 mm	9	240 °C 245 °C 250 °C	0.4 mm	70 °C	TPU
Plain silk	0.25 mm 0.50 mm 1.00 mm	9	240 °C 245 °C 250 °C	0.4 mm	70 °C	TPU
Plain nylon organza	0.25 mm 0.50 mm 1.00 mm	9	240 °C 245 °C 250 °C	0.4 mm	70 °C	TPU

TPU 95A filament has been used in this study described by supplier as a highly versatile for use at industrial level. Discussion in section 2.2.6.2 above already explained various features of TPU95 filament and its suitability for using in 3DP, therefore here mechanical and thermal properties of the TPU 95A filament used in this study will be explained. Table 3 below identified mechanical properties of TPU 95A filament used in this study.

Table 3: Mechanical properties of TPU 95A filament

Mechanical properties of TPU 95A	**3D Printing typical value**
Tensile modulus (Tensile modulus measures the resistance to elastic deformation that TPU 95A material has)	26 MPa (MPa = megapascal, 1 megapascal = 1,000,000 pascals)
Tensile stress at yield	8.6 MPa
Tensile stress at break	39 MPa
Elongation at yield (Elongation is the degree of stretching that a material undergoes while pulled in tension)	55%
Elongation at break	580%
Flexural strength (It is concerned with the maximum bending strength that can be applied before material yield)	4.3 MPa
Flexural modulus (It is an intensive property computed as a ratio of stress to strain in flexural deformation)	78.7 MPa
Izod impact strength, notched (at 23C) (Notched Izod impact test measures material's resistance from swinging pendulum)	34.4 kJ/m^2 (Kilo joule per meter square)
Charpy impact strength (at 23C) (It is a high strain-rate test involves striking a standard notched specimen)	-
Hardness	95 (Shore A) (Shore A measures range of material types from very soft, flexible to semi rigid plastic) 46 (Shore D) (Shore D measures hard rubbers, semi rigid and rigid plastic)
Abrasion resistance	0.06g

Source: Ultimaker, 2018a

Table 4 below explains thermal properties of TPU 95 A.

Table 4: Thermal properties of TPU 95A

Thermal properties	**Typical value**
Melt mass-flow rate (MFR)	14.9 g/10 min
Heat detection (at 0.455 MPa)	74C
Heat detection at 1.82 MPa)	49C
Vicat softening temperature	-
Glass transition	~ 24C
Coefficient of thermal expansion	100.10^{-6} C^{-1}
Melting temperature	220 C
Thermal shrinkage	-

Source: Ultimaker, 2018a

Apart from above mentioned properties of TPU 95 A in tables 3 and 4, TPU 95A filament has also been identified to be risk free with regards to heath of users. However, handling procedure for the material identifies following measures:

- Avoid eye contract through using safety glasses while conducting prolonged staring during printing
- Minimize skin contact particularly when material is heated through wearing gloves to protect against thermal burns
- Maintain airborne concentrations below recommended exposure limited or to an acceptable level. Furthermore, an approved respirator must be worn while conducting clinical trials or using material in industry (Ultimaker, 2018b)

3.3.1: Washing experiment

Figure 8 below presents the framework used for the washing test. From Figure 8 it can be seen that the process of testing long-term wearability was divided into five steps: printing the 3DP specimen samples, visual tests, washing tests, image capturing and reading, and conducting data analysis against edge, shape, roughness and brightness.

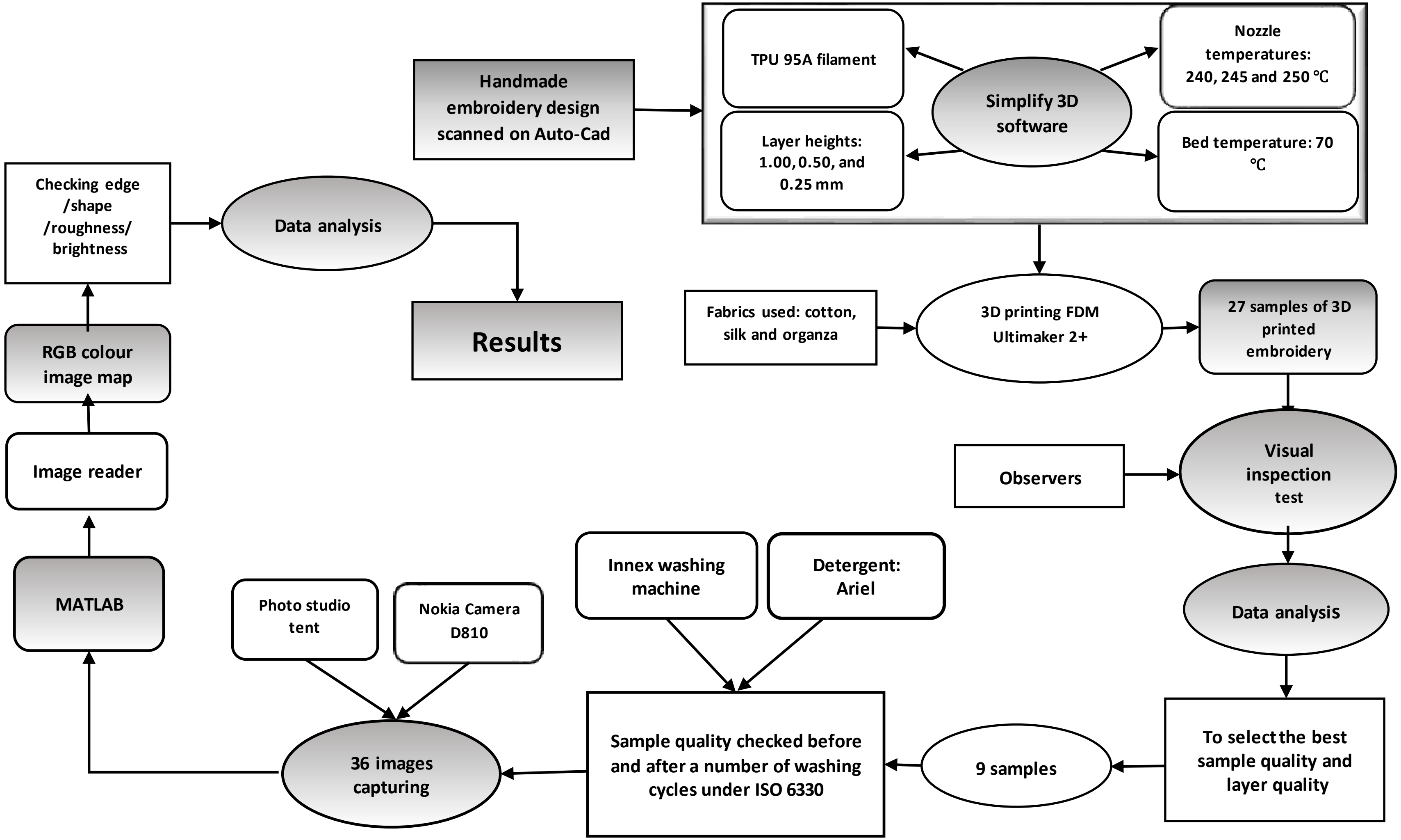


Figure 8: Washing test framework

To carry out the long-term wearability test, 27 samples of 3DP embroidery designed garments were first produced: nine samples of each fabric (cotton, silk and organza) using the 3D printing parameters identified in Table 3 above. The second step was to subject the 3DP embroidery samples to a visual test. Pei et al. (2015) acknowledged that a visual test was better than mechanical tests for identifying the quality of 3D printed objects. Moreover, a visual test provides the researcher with the flexibility to examine samples from the perspective of both an overview and a detailed inspection (Drury and Watson, 2002). A visual test is very simple in nature, as it uses the unaided eye as a sensing mechanism to ascertain and make a judgement on the quality of adhesion. Gauging the quality of 3D printed embroidery designs through a visual test was carried out by the author using a Likert rating scale (from 0 to 5) against the criteria of edge, shape, brightness and roughness. The higher the score, the better the specimen in terms of the edge, shape, roughness and brightness criteria. A value of 0 would represent the lowest score and 5 the highest. To ensure the reliability and validity of the score given, not only was the scale applied for the visual test, but a ranking was also given to each sample. The different parameters of the visual test were shared with students specializing in 3DP technology. A similar strategy was adopted by Pie et al. (2015) when conducting visual tests as part of their investigation into the adhesion of 3DP polymers directly onto textiles, thus further adding to the credibility of the visual test conducted in the present thesis. Key to conducting a visual test was identifying the fabric and thickness levels that presented the acceptable results in terms of edge, shape, roughness and brightness, which then became the baseline for conducting the washing test. For example, if a 3DP embroidery design at either 1 mm, 0.25 mm or 0.5 mm and a particular fabric type (cotton, organza or silk) presented the acceptable results in terms of edge, shape, roughness and brightness, that specific sample of fabric at that layer thickness was selected for use in testing long-term wearability under the washing test.

Having identified the best fabric and layer thickness, a washing test was initiated to subject the 27 samples of 3DP embroidered clothes to three washing cycles. ISO 6330 was utilized for the washing test, using Ariel household detergent powder and an Innex washing machine. The framework for the washing test was adapted from Spahiu et al. (2017), with a difference in the Standard used: Spahiu et al. (2017) used DIN 53530 and the present study used ISO 6330. The rationale for preferring ISO 6330 lies in that Standard having been recognized internationally for investigating a wider range of textile quality and performance, such as the appearance of smoothness, dimensional changes after washing, stain release as a result of washing, the extent of the water resistance and repellence of fabric, and colour fastness to domestic laundering (International Organization for Standardization, 2019a). Table 5 summarizes the different parameters used in the washing test.

Table 5: Parameters of the washing test

Washing machine	**Machine model**	**Program**	**Detergent**	**Temperature**	**Spin speed**	**Standard**
Innex	XWSC 61251	Push & Wash	Ariel	30 °C	1200 rpm	ISO 6330

The study utilized both hardware and software to conduct its analysis of the washing test results. The process of the washing tests started by taking snaps at different stages, such as zero wash, first wash, second wash and third wash. To this end, a photo studio tent was used, along with a Nokia D810 camera with a Sigma 105 mm F2.8 EX DG OS HSM macro lens. This lens was selected because it uses macro-photographing techniques to obtain sharp images of samples for scientific purposes. The specific properties of this lens and the Nikon D810 camera are available from DXOmark Laboratories. MATLAB software was utilized to evaluate the impact of washing cycles on 3D printed objects, with the aim of assessing four parameters: edge, shape, roughness and brightness. An image file reader read the debris of the images file using a pre-specified file folder and created a Red, Green and Blue (RGB) colour map in the MATLAB software workstation. The boundary determiner section of the MATLAB software detected possible changes in the images using the RBG colour map created and saved by the image reader. The results of the washing test were analysed against the four factors (edge, shape, roughness and brightness).

To determine the edge, shape, roughness and brightness regularity of different shapes after each washing cycle, a sequential covering algorithm was developed on the

MATLAB software. Processing by the MATLAB software was further divided into two steps, in which two sets of algorithms were produced: one for detecting the impact on edge and shape and the other for identifying the impact on roughness and brightness. It was assumed that any irregularity in the images would be detected by the MATLAB software, as this would cause abrupt changes in the shape and edge of the 3D printed embroidery objects. In order to detect the impact of a washing cycle on the roughness and brightness of 3D printed shape texture, a texture colour detector was implemented in the MATLAB software. The image processing methodology to conduct an evaluation of 3DP embroidery images was adapted from Khan et al. (2008).

To describe and compare the extent to which the results of the washing tests differed from their means in relation to edge, shape, roughness and brightness, coefficient of variation (CV) analysis was used. According to Saunders et al. (2016: P531), the CV has been identified as a useful statistical method for comparing the results of different tests with various measures or values. For instance, in the context of the washing test conducted in this study, it was expected that the MATLAB results could vary with respect to fabric type and nozzle temperature. The CV was calculated as a ratio of the standard deviation to the mean, as shown in equation 1 below:

$$\mathrm{CV} = \frac{\mathrm{SD}}{\overline{\mathrm{X}}} \times 100 \qquad \text{Eq: (1)}$$

Where,

CV = coefficient of variation

SD = standard deviation

$\overline{\mathrm{X}}$ = mean

CV analysis assisted in identifying which fabric was producing the best results at which temperature. The rule of thumb with the CV analysis was that in the event that the distribution of the results of the different samples stayed within the prescribed range or scale, that result would be accepted as presenting an acceptable edge, shape, roughness and brightness. To this end, ±10% margin of error was set. According to Saunders et al. (2016), the authenticity of data analysis depends upon the tolerance towards the margins of error, as this determines the accuracy of the results. It was expected that MATLAB analysis would generate a large amount of data, suggesting the need to use statistical inference to deal with the volume of data. Saunders et al. (2009) proposed using a 90% level of certainty as an acceptable margin of error. In the case of the current research, this means that of the 36 samples, at least 90% of the data would present an acceptable level of edge, shape, roughness and brightness. Therefore, this meant that ±10% margin of error could be used to accept or reject the results. Here, the baseline results would be the results of the visual test. As stated above, the key to conducting a visual test was to identify a fabric and thickness level that presented the best results in terms of edge, shape, roughness and brightness that would then become the baseline for conducting a washing test. For instance, if organza fabric at 1 mm thickness demonstrated the best results in the visual test, then the MATLAB results for the organza fabric would be used as ±10% base scale for analysing the CV results.

3.3.2: Framework for the adhesion test

An adhesion test was performed as a further assessment of the wearability and sustainability of 3D printed embroidery objects on fabrics. By wearability and sustainability of 3DP embroidery object in this study means ability of 3DP object to sustain normal day-to-day life that would complement aesthetic and perceived value of clothes. The justification for conducting an adhesion test is linked to a study by Malengier et al. (2017), which argued that although 3DP presents possible innovative, cost-effective and dedicating ability in the customization of designs for the production of garments, questions have been raised about the adhesion capability of 3D printed objects on textile substrates, leading to the prevalence of a good/bad perception of the quality of 3D printed objects. To this end, Malengier et al. (2017) proposed conducting a tensile test for to assess the adhesion strength of a 3D printed object attached to a garment.

The aim of the tensile test was to evaluate the adhesion properties between a 3DP object and a textile substrate. Three types of tensile test can be conducted to test the adhesion properties of 3DP objects: perpendicular tensile tests, shear tests and peel tests (Malengier et al., 2017). The perpendicular tensile test has been recognized as one of the most effective versions of the tensile test, as it possesses the ability to identify accurately the maximum force needed to detach a printed object from a textile (Huang et al., 2018). However, Geng et al. (2017) have criticized the perpendicular test for its limitation in only being suitable for pawn-shaped objects, and not for geometrically designed shapes such as embroidery designs. In contrast, a shear tensile test aims to measure the adhesion of a printed object by measuring the maximum force that can be applied before the object is destroyed (Malengier et al., 2017: P3). Although the shear tensile test falls under European Standard EN 1373 and is identified as one of the most commonly used methods for testing the adhesion of printed objects (Wolfs et al., 2019), the results of shear tensile tests have been questioned for not being indicative of the shear properties of printed specimens, such as the TPU material used in this study (Cantrell et al., 2017). In simple terms, in their experiment on identifying the mechanical properties of 3D printed objects, Cantrell et al. (2017) found that the values of shear modulus and shear yield strength varied by at least 33% when tested on 3D specimens printed using ABS material, thus raising questions regarding the accuracy of the adhesion force results yielded under the shear test.

In contrast to both the perpendicular and shear tests, whose aim is usually to identify the adhesion force of an object spread over a fabric, the peel test presents flexibility in testing the adhesiveness of an highly localized object on a piece of fabric, as the peeling force is usually applied to the linear front of the printed object (Malengier et al., 2017: P4). According to Malengier et al. (2017: P4), although the set-up of a peel test is similar to that of a shear test in the dimension of the specimen, a peel test can specifically target a 3D printed object, thus providing more accurate results regarding the adhesive ability of that object. In this study, the peel test was used because of its ability to measure the maximum force that would be needed to detach a 3DP object from the surface of a piece of fabric (Narula et al., 2018).

The peel test conducted in this study was based on ISO 11339:2010, the Standard for an adhesive T-peel test designed for flexible-to-flexible bonded assemblies (International Organization for Standardization, 2019b). The Standard specifies the T-peel test for determining the peel strength of adhesion by measuring the peeling force of a T-shaped bonded assembly of flexible bonded adherends. Figure 9 below shows the procedure for conducting the peel test in this study, which started by the production of 27 samples of 3D printed objects on two pieces of fabric in such a way that the TPU filament would create bonding between the two fabrics. To this end, the dimension of the TPU filament was kept at 80*20 mm so that the researcher would be physically able to grab the two pieces of fabric. Finally, the peel test was performed using an Instron machine to apply a load of 95 kilonewtons (kN) and a speed of 20 mm/min, as specified under ISO 11339:2010. The results of the peel test were recorded in load (N) versus extension in millimetres (mm).

The results of ascertaining the quality of adhesion of a 3D printed object were analysed against three parameters: the fabric type and the two parameters used for producing 3DP embroidery samples (temperature and layer thickness), as shown in Table 2 above. Regression analysis was used to analyse the results.

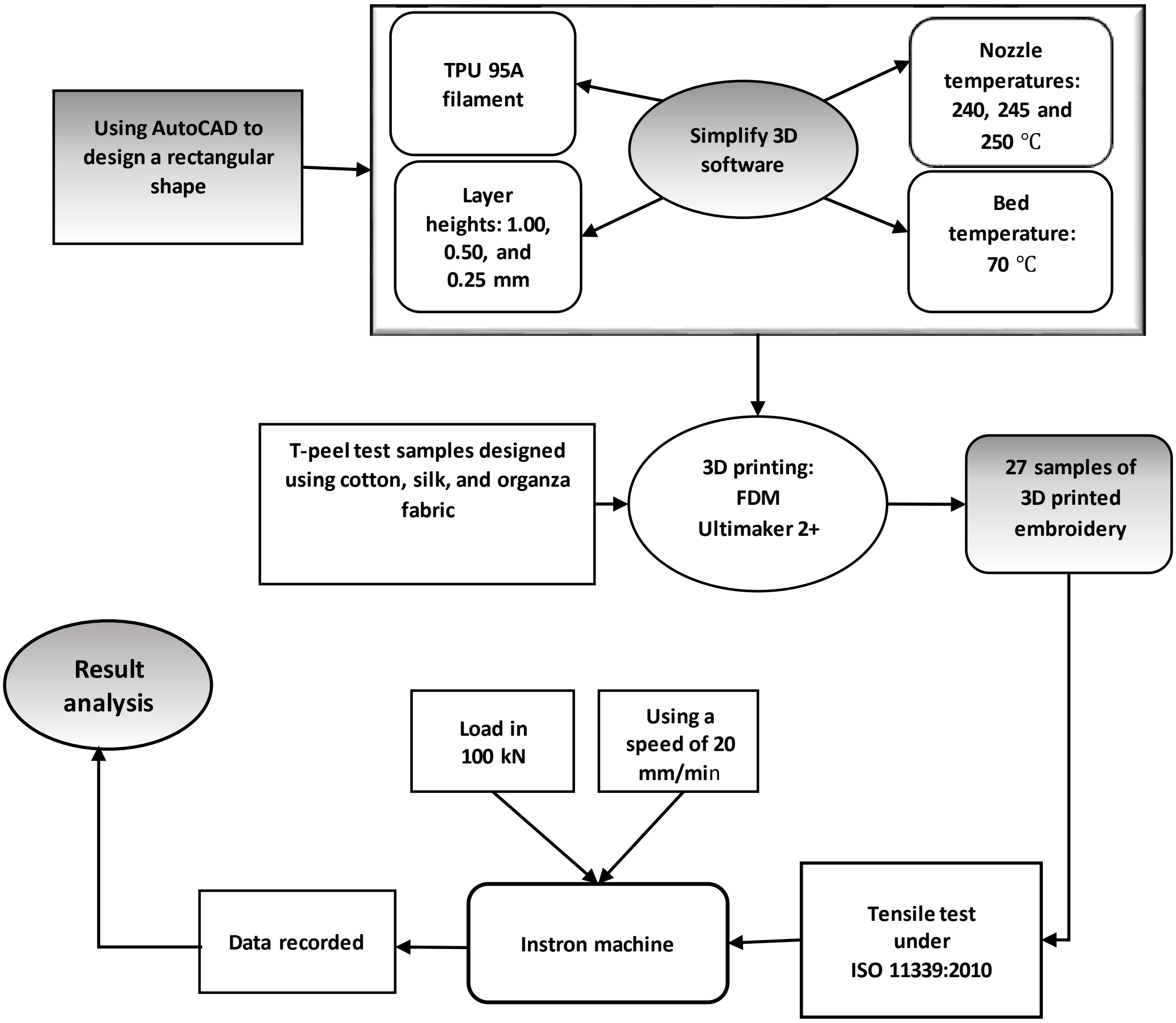


Figure 9: Peel test framework

The components of the regression analysis, such as the standard deviation and maximum values, were used with the rule that the maximum peeling force and the lower standard deviation represented good adhesion quality, whereas a high standard deviation with a low/high maximum peeling force represented inconsistency in the adhesion force.

3.4: Research ethics

Cooper and Schindler (2008) define ethics as a standard norm that guides an individual's behaviour and relationships with others. Similarly, ethics in the context of research is about the way the researcher aims to formulate and clarify his/her research topic and design, gain access to the research population, collect, store and interpret data, and when writing up the thesis (Zikmund, 2000). Therefore, research should not only be methodologically sound, but also morally defensible. Being morally defensible relates to the behaviour that will affect the stakeholders involved. The context of this research followed a deontological view that asserts that ends such as the possibility of reviving the traditional embroidery industry using technological means can never be served if the author uses unethical research practices (Gatignon, 2019). In order to ensure that the present research conforms to ethical norms, the following steps have been taken:

- Cranfield university allowed supervisor to provide ethical approval prior to starting her project
- A risk assessment was undertaken to ensure that the experiment would be conducted in line with academic norms (see Appendix 5).
- A letter of permission for data collection was sought from the administration of the Souq Okaz Festival in Taif in the Hejaz region of Saudi Arabia (see Appendix 1).
- Every participant was provided with a participant information sheet (see Appendix 4).

- Research protocols were followed by securing data safely in a password-protected folder on the author's personal computer.
- Data have not been shared with any irrelevant party.
- The researcher did not and would not seek any commercial benefit from the research.
- Apart from being provided with a participant information sheet, each respondent was also informed verbally of their rights.

3.5: Conclusion

The discussion in this chapter showed that, to achieve the final objective of this study of identifying factors that could influence the adoption of 3D printing in the embroidered clothing industry in the Hejaz region of the KSA, multiple quantitative methodologies were used. To this end, multiple surveys and experiments were conducted. The aim of the surveys was to assess the perception and attitude of the manufacturers and customers of embroidered clothes with regard to integrating advanced technologies into the manufacturing process and consuming technologically produced embroidery clothes, respectively. The manufacturer survey was designed using the TAM model as a framework and was designed to consider five variables: perception, usefulness of using technology, awareness, wearability and ease of use. The target population of the manufacturer survey was local manufacturers showcasing their garments at the Souq Okaz Festival in Taif in the Hejaz region of the KSA. In contrast, the framework for the customer survey was designed using factors identified by Eng and Bogaert (2010), who asserted that individuals' use of fashion depends upon five factors: conspicuousness, uniqueness, quality, hedonism and self-expression. The questionnaires for both surveys were designed using a five-point Likert rating scale. Probability sampling was used to target the research population because it allows a direct interface with the respondents to collect data. Data for both the manufacturer and customer surveys were analysed using an exploratory data analysis (EDA) method.

Two experiments were conducted to investigate the long-term wearability of 3D printed embroidery clothing. For the purpose of conducting the experiment, 27 samples of 3DP embroidery samples were produced of three types of fabric, plain cotton, silk and nylon organza (nine samples of each), using FDM Ultimaker 2+, CAD software and a TPU 95A filament. Various 3DP parameters were set: three types of layer height (0.25 mm, 0.50 mm and 1 mm) and three different nozzle temperatures (240 °C, 245 °C and 250 °C) with a constant nozzle size of 0.4 mm and a bed temperature at 70 °C.

A washing test was conducted to test the long-term wearability of the 3D printed clothes. The washing test consisted of five steps: printing the 3DP specimen samples, a visual test, washing, image capturing and reading, and conducting data analysis against the edge, shape, roughness and brightness using CV analysis. The purpose of the visual test was to set the baseline for an acceptable quality of a 3DP specimen for the washing test. The washing test parameters were set under ISO 6330 using an Innex washing machine. The parameters of the washing machine were as followed: The Push & Wash program, Ariel household detergent powder, a 30 °C temperature and 1200 rpm. The findings of the washing test were analysed to evaluate the impact of washing on edge, shape, roughness and brightness. To do this, snaps of the fabric at no wash, and at the first, second and third washes were taken using a Nokia D810 camera with a Sigma 105 mm F2.8 EX DG OS HSM macro lens. The results of the snaps were then processed using MATLAB software. The MATLAB results were then subjected to CV statistical analysis to test whether the edge, shape, roughness and brightness of a specimen after being washed stayed within the range of ±10% of the results of the specimen selected in the visual test. It was anticipated that if the results stayed within the range of ±10%, they would be considered acceptable; otherwise, the results would be rejected.

To further assess the wearability of the 3D printed embroidery clothes, an adhesion test was performed using a tensile test. To this end, a peel tensile test was used under ISO 11339:2010, which is recognized for conducting adhesive T-peel tests. Three parameters were used: a TPU filament of 80*20 mm width and an Instron machine with a load of 100 kN and a speed of 20 mm/min.

The next chapter presents the findings of the survey results and their analysis, followed by the experiment results and analyses in subsequent chapters.

Chapter IV

Survey-based investigation

4.0: Introduction

The aim of this chapter is to present and critically analyse the data collected from the two surveys carried out for this research: one with manufacturers and the other with customers. The chapter is divided into two sections: the first section presents the trend analysis of the manufacturer and customer surveys, followed by statistical analysis of the findings from the discussion in the second section.

4.1: Survey results

4.1.1: Manufacturer survey results

As mentioned in the previous chapter, local manufacturers of traditional embroidered clothes attending the Souq Okaz Festival were targeted for this research. Overall, 16 responses were collected from manufacturers to five questions that aimed to ascertain their opinion of the possibility of integrating new technology into the manufacturing process of traditional embroidery. The five questions were intended to gain perspectives regarding five factors: perception, awareness, usefulness of using technology, wearability and ease of use. Based on closed-ended questions, the manufacturer survey was divided into three sections: demographic, opinion-based and cost- and price-related questions. Three demographic, five opinion-based and four cost- and price-related questions were asked of the respondents. In total, 20 questionnaires were distributed, and the same number of complete responses were collected from manufacturers of traditional embroidered clothes in the Hejaz region of the KSA, thus reporting a 100% response rate.

4.1.1.1: Demographic findings

The demographic information revealed that all the respondents were female. Age wise, the respondents mostly fell into the middle age range: 32%, 28% and 26% of the respondents reported being in the age bands of 25-30 years, 30-35 years and 35 years or over, respectively. When it came to asking about experience of working with embroidered clothing, 38% and 40% of the respondents claimed to have experience of 10-15 years and 15 years or over, respectively, thus enriching the reliability of the responses collected in this study.

4.1.1.2: Opinion on integrating technology in the manufacturing process

Table 6 shows the five statements prepared to investigate the manufacturers' opinion of the possibility of integrating new technology in the manufacturing process of traditional embroidered clothes, thus offering one statement for each of the five factors considered.

Table 6: Opinion of manufacturers on the possibility of integrating new technology in the manufacturing process in the KSA

Factors	Statements	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
Perception	Embroidered clothes made using technology will meet customer taste.	38%	42%	4%	9%	7%
Usefulness of using technology	Speeding up the process, ease of creating designs and large-scale production are key benefits of using technology in embroidered clothing.	44%	32%	6%	16%	2%
Awareness	Manufacturers are aware of the availability of technology that can be used to manufacture embroidered clothes.	32%	41%	4%	15%	8%
Ease of use	Lack of know-how and training are key hurdles to the use of technology in the	52%	29%	2%	7%	10%

	production of embroidered clothes.					
Wearability	Wearability and washing are key concerns regarding the use of technology in embroidered clothes.	54%	34%	2%	8%	2%

From Table 6 above it can be seen that to assess the perception of manufacturers on whether technologically produced embroidered dresses would meet customer taste, the respondents were presented with the statement: "Embroidered clothes made using technology will meet customer taste". In response to perceptual factors, the majority of the respondents chose the strongly agree (37%) and agree (42%) options, demonstrating manufacturers' confidence in the ability of technologically produced embroidered dresses to meet customer taste. Similarly, the respondents were presented with the statement "Speeding up of the process, ease of creating designs and large-scale production are key benefits of using technology in embroidery clothing" to evaluate their opinion on the usefulness of integrating technology into the manufacturing process of traditional embroidered dresses. In response, a large majority of the respondents chose the strongly agree (44%) and agree (32%) options. Thus, in this study, the manufacturers of traditional embroidered dresses acknowledged the various benefits that can be gained using technology in the manufacturing process of traditional embroidered dresses. The third statement in the manufacturer survey was that "Manufacturers are aware of the availability of technology that can be used to manufacture embroidery clothes". In response, the majority of the respondents chose the strongly agree (32%) and agree (41%) options, demonstrating that manufacturers were aware of the availability of advanced technologies that could be used in the manufacturing process of traditional embroidered dresses.

Discussion of the findings of the first three elements of the survey (perception, usefulness of using technology and awareness) shows that not only did manufacturers possess a positive perception of technology for meeting customer trends, they were also aware of both the benefits and availability of advanced technologies for manufacturing embroidered dresses. However, according to the literature review presented in the second chapter of this study, a lack of development in manufacturing techniques is a key hurdle in the evolution of the traditional embroidered dress industry in the KSA. The reason behind the lack of adoption of technology by manufacturers might be linked to ease of use and wearability factors, as respondents to the manufacturer survey largely demonstrated their concerns regarding those two factors.

Table 5 above shows that to investigate whether manufacturers of traditional embroidered dress found it easy to use advanced technology, the respondents were asked to respond to the statement that a “Lack of know-how and training are key hurdles in the use of technology in the production of embroidered clothes”. In response, a large majority chose the strongly agree (52%) and agree (29%) options, making ease of use one of the key hurdles perceived to be facing the integration of advanced technologies into the manufacturing process of traditional embroidered dresses. Ease of use is an important factor, as the easier an individual find it to use technology, the more eager he/she will be to adopt it (Holzmann et al., 2018). Vanderploeg et al. (2017) and Yeh and Chen (2018) in their respective studies also emphasized the need to increase the ease of use of 3DP by improving the skills and knowledge of manufacturers in using this novel technology.

In addition, to evaluate whether or not wearability was creating hurdles to the adoption of technology in the manufacturing process of traditional embroidered dresses, the respondents were asked to respond to the statement that “Wearability and washing are key concerns regarding the use of technology in embroidered clothes”. In response, the majority of the respondents chose the strongly agree (54%) and agree (34%) options, thus making wearability one of the key concerns of manufacturers regarding the integration of technology into the manufacturing process of traditional embroidered dresses.

Literature on investigating the applicability of 3DP in the fashion industry corroborates findings on the wearability factor identified in Table 5 above. For instance, in their investigation of the adhesion properties of the direct 3DP of polymers on textiles, Sanatgar et al. (2017) concluded that the efficient adhesion of a 3D printed design onto fabrics is yet to be determined, as it depends upon a variety of factors, such as the extruder temperature, platform temperature and printing speed; it is also due to the lack of adhesion of 3DP designs on textiles that the long-term wearability of clothing designed using 3DP is still very much in question. Similarly, in their empirical investigation of the effects of 3DP on textile fabric, Spahiu et al. (2017) tested 3DP designed dresses against wearability and washing tests and concluded that the tests had provided preliminary results on the adhesion of 3DP designs on textile, but that a full-scale investigation was still pending.

4.1.1.3: Cost and price of traditional embroidered dresses

In this section of the survey, four questions were asked of the manufacturers. The first question in this section of the survey was based on assessing factors that have an impact on the time period required to manufacture an embroidered dress. Following a multiple-choice-based methodology, the respondents were provided with four options from which to choose to respond to the first question in this section of the survey: fabric, thickness of embroidery stitches, number of designs, and all of them. Figure 10 below shows that the majority of the respondents (56.25%) chose the 'All of them' option, suggesting that fabric, thickness of embroidery stitches and number of designs have a collective impact on the time it takes to manufacture embroidered dresses.

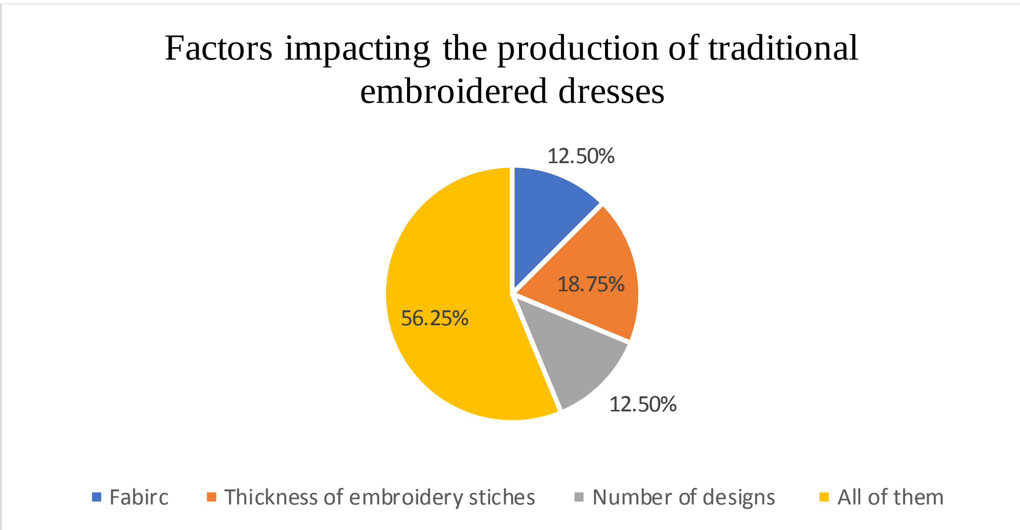


Figure 10: Factors in the time period for producing traditional embroidery dresses

In the next question, the respondents were asked about the time it takes them to produce one traditional embroidered dress. The respondents were provided with four options from which to respond: 10 days to 15 days, 15 days to 20 days, 20 days to 25 days, and 25 days to 30 days. In response, the majority (75%) of respondents chose 25 days to 30 days, as shown in Figure 11 below.

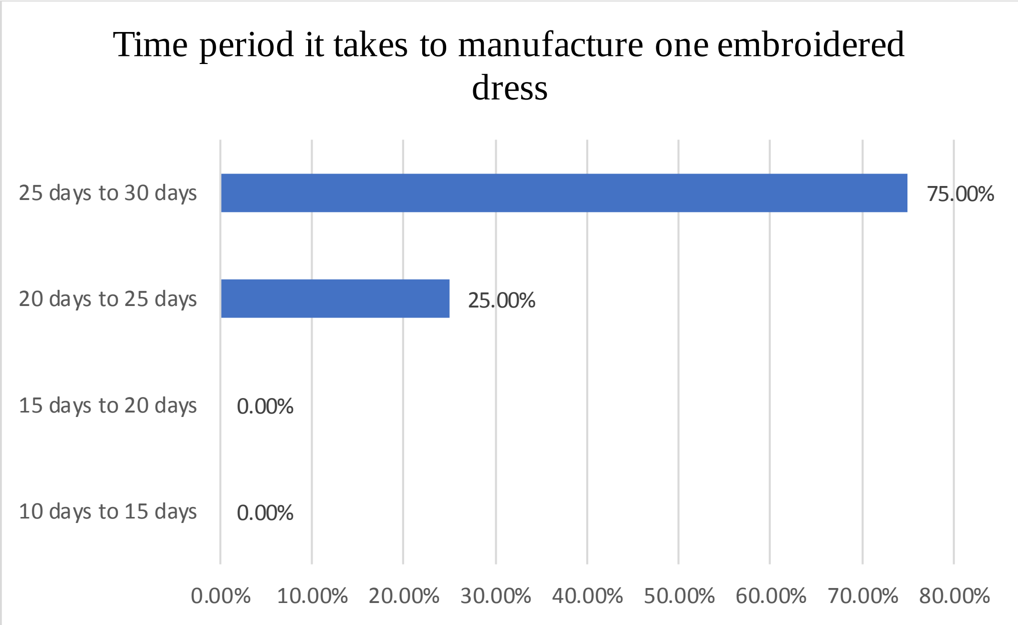


Figure 11: Time taken to produce one traditional embroidered dress

The next question in the survey was designed to assess the approximate cost to manufacturers of producing one dress. The respondents were provided with five options from which to choose (SAR = Saudi Arabian Riyal): SAR 200 to SAR 400, SAR 400 to SAR 600, SAR 600 to SAR 800, SAR 800 to SAR 1,000, and SAR 1,000 or over. The findings presented in Figure 12 below on the next page show that 81.25% of the respondents chose the SAR 1,000 or over option.

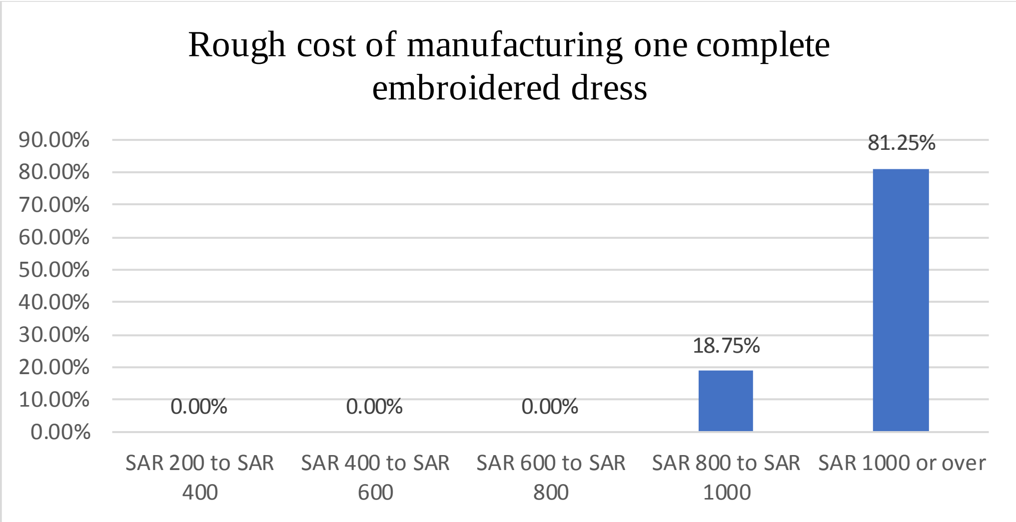


Figure 12: Cost of producing one traditional embroidered dress

In the final survey question, the respondents were asked about the price range of traditional embroidered dresses sold on the market. The respondents were provided with five options from which to choose: SAR 500 to SAR 700, SAR 700 to SAR 900, SAR 900 to SAR 1,100, SAR 1,100 to SAR 1,300, and SAR 1,300 or over. In their responses, 68.75% of the respondents reported that customers were prepared to pay SAR 1,300 or over for traditional embroidery dresses. Only 18.75% and 12.50% of the respondents chose the options of SAR 1,100 to SAR 1,300 and SAR 900 to SAR 1,100, respectively, as shown in Figure 13 below.

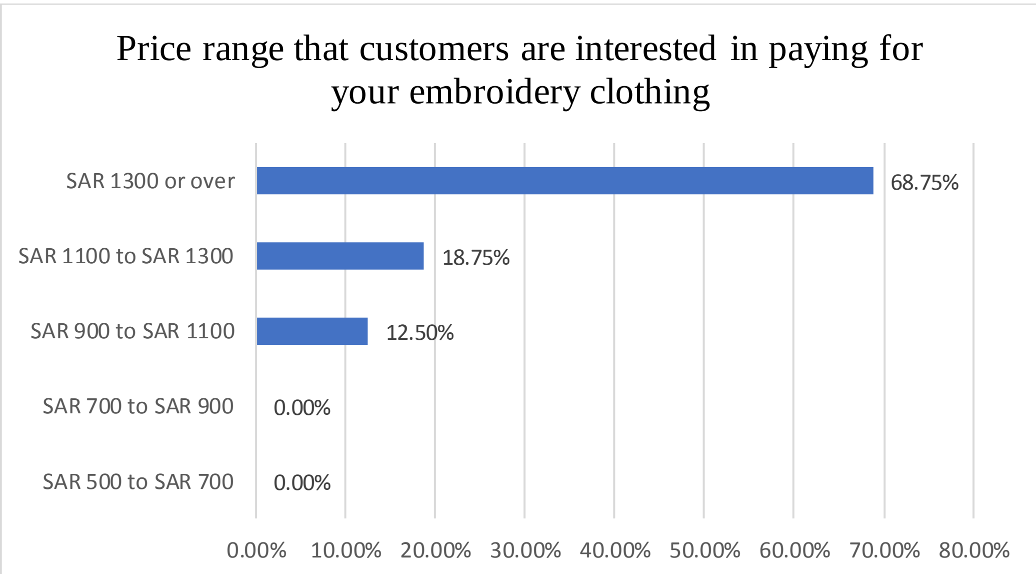


Figure 13: Price range of traditional embroidered dresses

4.1.2: Customer survey results

As with the manufacturer survey, the customer survey was divided into two sections: demographic and opinion-based questions. In total, 50 questionnaires were distributed among students and 45 complete and usable responses were collected, which means that a 90% response rate was achieved.

4.1.2.1: Demographic responses

Three sets of demographic questions were designed: age, gender and level of education. The responses regarding age revealed that the majority of the respondents were young people, as 36%, 42% and 16% of the respondents were in the age groups of 18-20 years, 20-25 years and 25-30 years, respectively. Moreover, while all the respondents were female, only 4% and 2% of the respondents came from the age groups of 30-25 years and 35 years or over, respectively.

4.1.2.2: Opinion of consumers on technologically produced traditional embroidered clothes

To assess the opinion of consumers on the possibility of consuming technologically produced traditional embroidered clothes, five statements were designed to assess the five factors that were identified as influencing consumers' adoption of a new fashion: conspicuousness, uniqueness, self-expression, hedonism and quality. Against the conspicuousness factor, the respondents were presented with the statement that "Traditional embroidered clothes meet current fashion trends". In response, the majority of the respondents chose the disagree (47%) and strongly disagree (37%) options, which suggests that 84% of the respondents supported the argument that traditional embroidered clothing does not meet modern fashion trends, as shown in Table 7 below on the next page.

Table 7: Possibility of the use of technologically produced embroidered clothes by consumers in the KSA

Factors	Statements	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
Conspicuousness	Traditional embroidered clothes meet current fashion trends.	0%	16%	0%	47%	37%
Uniqueness	Integration of technology in the manufacturing process of traditional embroidered clothes will maintain the unique taste of embroidery clothes.	57%	32%	2%	7%	2%
Self-expression	Embroidered clothing made using technology will meet current fashion trends.	43%	27%	4%	15%	11%
Hedonism	I would recommend my friends and family to wear embroidered clothing made using new technology.	42%	44%	2%	7%	5%
Quality	Embroidered clothing made using technology would conform to comfort/originality/aesthetic features.	2%	1%	1%	54%	42%

To assess whether the use of technology in the manufacturing process of traditional embroidered clothes would maintain garment uniqueness, the respondents were presented with the statement that the "Integration of technology in the manufacturing process of traditional embroidered clothes will maintain the unique taste of embroidered clothes".

In response, the majority of the respondents chose the strongly agree (57%) and agree (32%) options, as shown in Table 6 above. These results imply that consumers believed that there was a need for development in the manufacturing process and that technologically produced embroidery on dresses would not have an impact on the uniqueness of embroidered clothing.

To assess their opinions on whether technologically produced traditional embroidered dresses will meet the self-expression of customers, the respondents were presented with the statement that "Embroidered clothing made using technology will meet current fashion trends". In response, the majority of the respondents chose the strongly agree (43%) and agree (27%) options, as shown in Table 6 above. These findings imply that customers of traditional embroidered dresses in the KSA believed that the integration of technology in the manufacturing process will not have any impact on their self-expression and that they would be willing to use such dresses in their social lives.

When it comes to examining the hedonism factor, the respondents were presented with the statement that "I would recommend my friends and family to wear embroidered clothing made using new technology". In response, 42% and 44% of the respondents chose the strongly agree and agree options, respectively. These findings imply that hedonism is not going to be an issue for customers in relation to using technologically produced embroidered dress.

Finally, to assess the perception of customers of the quality of technologically produced embroidered clothes, the respondents were presented with the statement that "Embroidered clothing made using technology would conform to comfort/originality/ aesthetic features". In response to this statement, 54% and 42% of the respondents chose the disagree and strongly disagree options, respectively. This suggests that 96% of the respondents argued against the quality of embroidered dresses produced using technology. Analysis of the findings presented in Table 6 above clearly conforms to that of Ejeimi et al. (2018), who argued that consumers in the KSA were still interested in traditional embroidered clothes as long as such clothing met quality elements.

4.2: Discussion

The analysis of both the manufacturer and customer surveys presented above corroborates the findings of past researchers who stressed the need to explore new technological advances in order to regain customers' acceptance of traditional handicrafts (Devi et al., 2017; Ejeimi et al., 2018; Eng and Bogaert, 2010; Khaire, 2011, Qi, 2018; Venkataramanaiah and Nidugala, 2016). Previous researchers have been of the view that increased global competition and technological advancements in the fashion industry have left traditional handicrafts at a significant disadvantage from manufacturing, distribution and marketing perspectives. However, lack of skills and motivation and technical difficulties in the use of technology in the manufacturing process of embroidered clothing have been suggested as key hurdles in the adoption of technology. Despite being at a disadvantage, traditional handicrafts have not lost people's interest; however, their re-acceptance in society would require a technological transformation of the entire supply chain to enrich and substantiate the quality of technologically produced traditional embroidered dresses.

4.3: Conclusion

From the discussion of the manufacturer and customer surveys presented in this chapter, it can be asserted that there exists the potential of reviving the traditional embroidered clothing industry in the Hejaz region of the KSA by the integration of technology. Ironically, the analysis of both the manufacturer and customer surveys found agreement on one common point: both sets of stakeholders demonstrated their reservation regarding the quality and wearability of technologically produced embroidered dresses. Thus, the present study aimed to investigate the possibility of using 3DP technology in the embroidered clothing manufacturing process from both the technical and customer acceptance perspectives. To this end, various previous researchers, such as Abdulghader-Fairak (2013) and Ejeimi (2016), proposed the use of collaborative technology in the manufacturing process of embroidered clothing to quicken the process and empower customers over the selection of garments and designs.

Furthermore, the findings presented in Tables 5 and 6 above also conform to those of past researchers who argued that despite the various transformative benefits that advanced technologies such as 3DP could offer to the manufacturing process of garments, to date, concerns have been raised about the long-term wearability of garments produced using technology (Ejeimi et al., 2018; Jacobson, 2017; Perry, 2017). However, Sheikh et al. (2019) suggested that 3DP in the fashion industry is still in an early evolutionary stage and empirical evidence that could demonstrate the long-term wearability of dresses designed using 3DP is lacking. Similarly, wearability/quality and ease of use remain the most important elements for manufacturers and the former has also been acknowledged by customers in this study.

The next chapter presents the results of experiments conducted to investigate the long-term wearability of embroidery designs printed using 3DP.

Chapter V

Experimental investigation (suitability of 3DP for textile fabrics and embroidery)

5.0: Introduction

The objective of this chapter is to present the results of investigating the long-term wearability of embroidery designs printed using 3DP. The discussion is divided into three sections. The first section presents the 3D printed embroidery samples. The second section presents and discusses the results of the visual test and washing test based on the following factors: edge, shape, roughness and brightness. The final section presents and discusses the results regarding the adhesion strength of the 3DP embroidery objects on different fabrics under the peel test.

5.1: 3DP specimens of embroidery

Using FDM-based 3DP, 27 samples of embroidery specimens were produced: nine samples of each of the three fabrics tested (cotton, organza and silk). Process of 3DP started through scanning the embroidery sample prepare through using traditional method (as shown in figure 14 below) and image was uploaded it into CAD software.

Figure 14: Original embroidery design scanned and uploaded into CAD

Several steps were taken to process uploaded embroidery design image into CAD software starting by use of spline tool to draw the outline of the design as shows in figure 15 below on the next page.

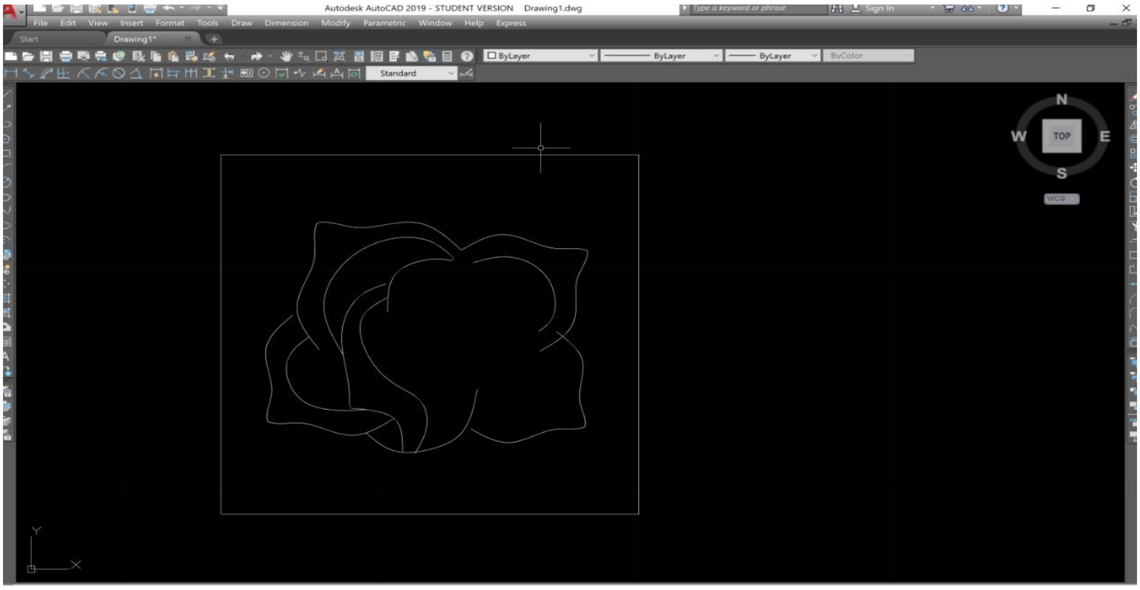


Figure 15: Processing embroidery image through using spline tool of CAD software

To improve the scanned image on CAD software accuracy of design lines were made more visible through using extend and trim tool of CAD software. This step also included modifying of edges of the design and removal of unwanted lines. Figure 16 below shows that result of using extend and trim tool of CAD software on the image such as it made picture more visible and resemble the original embroidery design shown in figure 14 above.

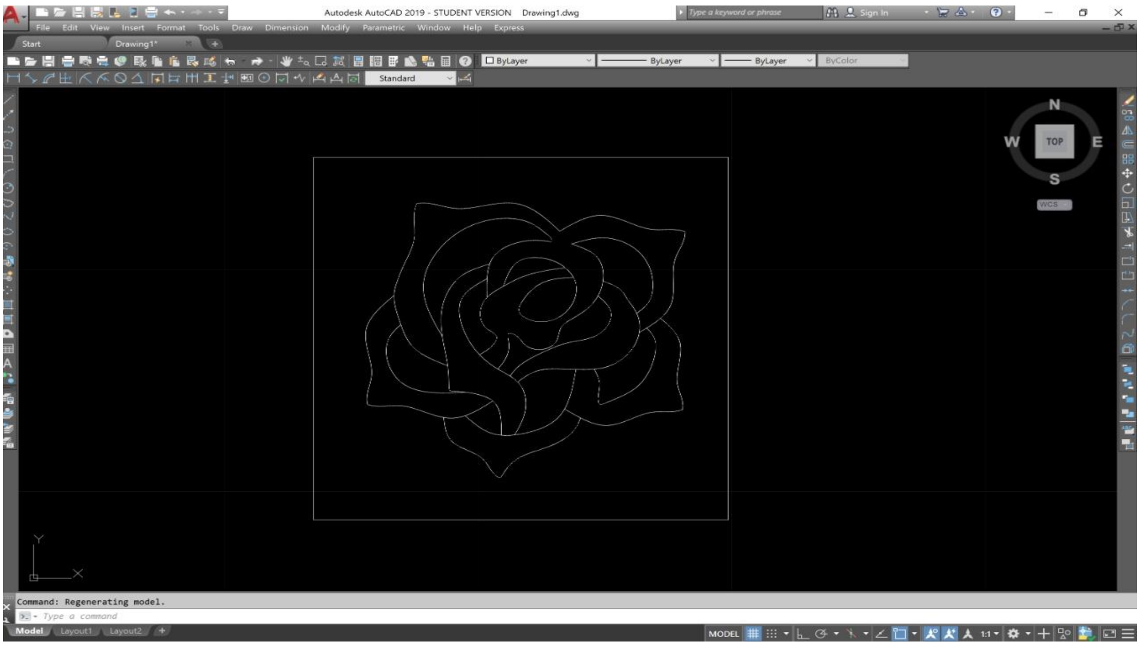


Figure 16:Output of image of CAD software

Output image shown in figure 16 above was then saved as STL format so that image can be uploaded on Simplify 3D software. At this stage various dimensions of the image such as length, depth and thickness of the embroidery shape were set. were set at 100mm, 65mm and three-layer thicknesses. Figure 17 below shows that length was set at 100mm, depth at 65mm wide and finally three-layer thicknesses such as 0.25mm, 0.5mm and 1.00mm were set.

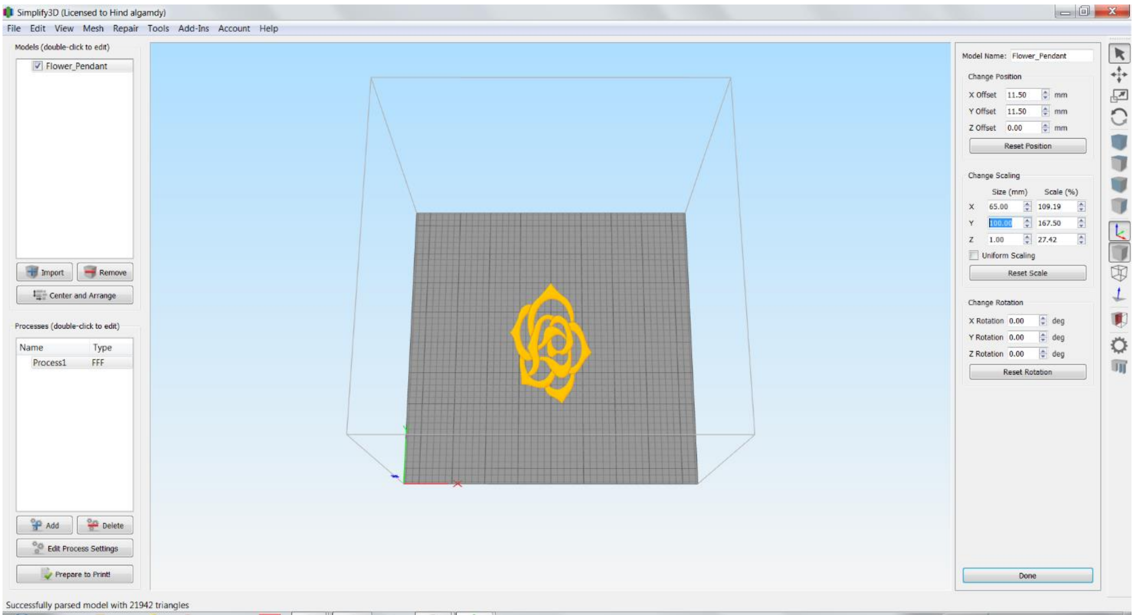


Figure 17: Dimensions of embroidery design on 3DP software

Figure 18 below on the next page shows output of samples of the embroidery designs produced on 3DP. The objects printed on all three fabrics were 100 mm long and 65 mm wide. The embroidery objects were of floral and geometric designs to ensure that they resembled those of traditional handmade embroidered clothes (Ejeimi, 2016).

The process of 3DP involves designing a product on CAD software (Hornick and Roland, 2013). Designs created on CAD software can be altered using computational algorithms to ensure that designs fit into the specific size parameters demanded by consumers. To this end, a CAD-related modelling program, such as Rhino, is used as a design tool. The benefit of using the Rhino program lies in the ease of use, such that even non-experts can use it for writing code. The Rhino program also offers efficiency and convenience, as it allows the creation of multiple designs using a single code (Yap and Yeong, 2014).

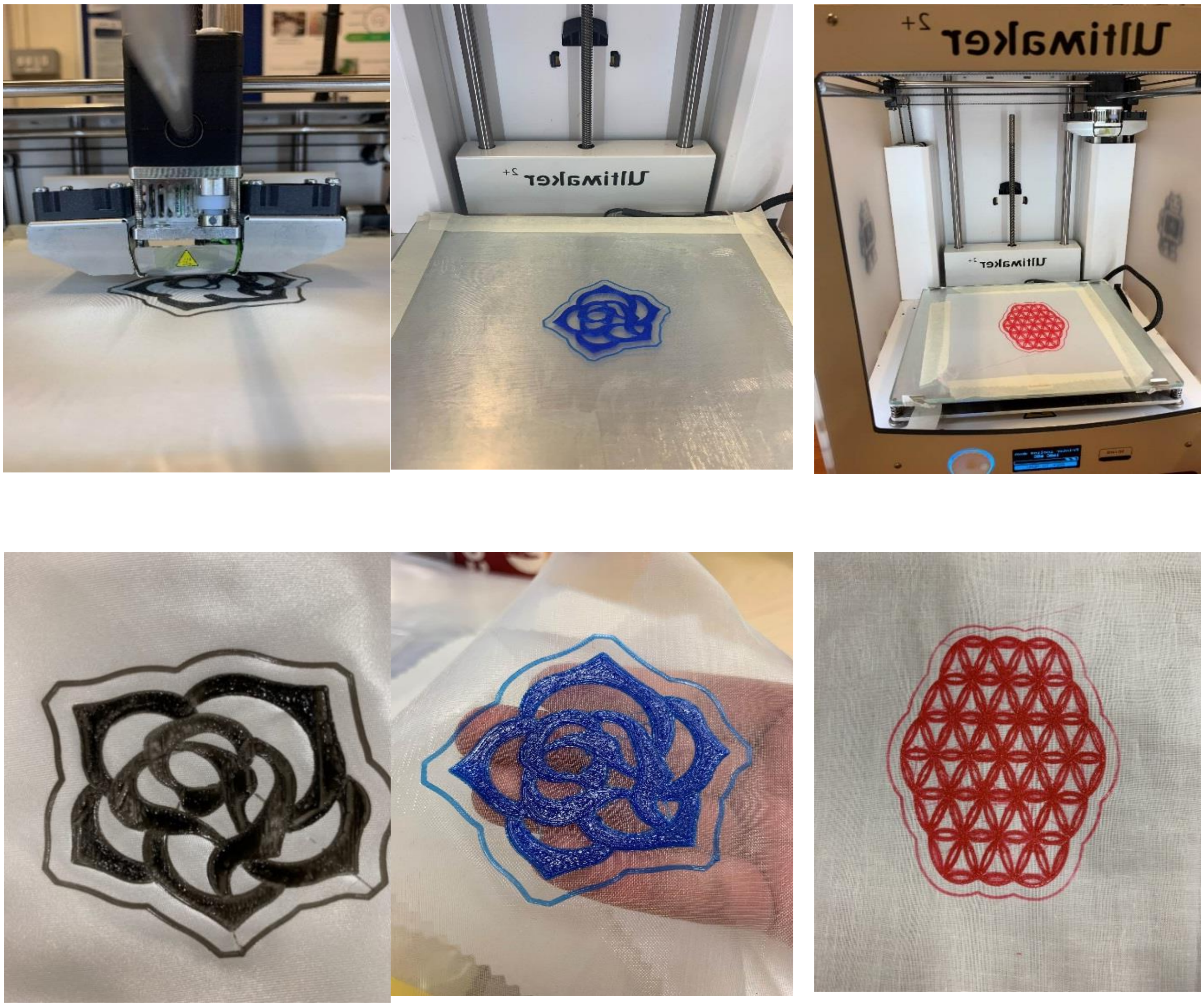


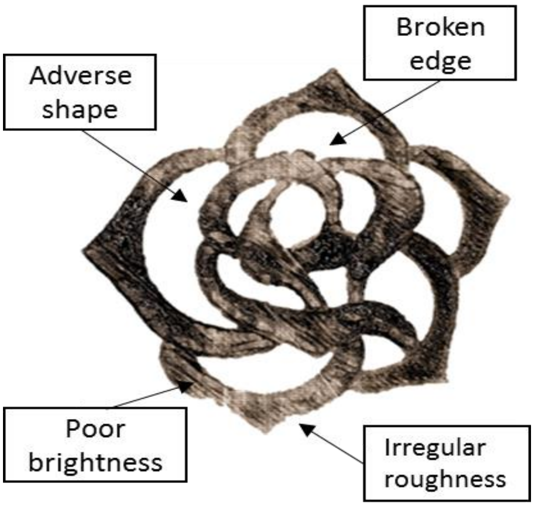
Figure 18: 3DP embroidery design output

5.2: Long-term wearability test results and analysis

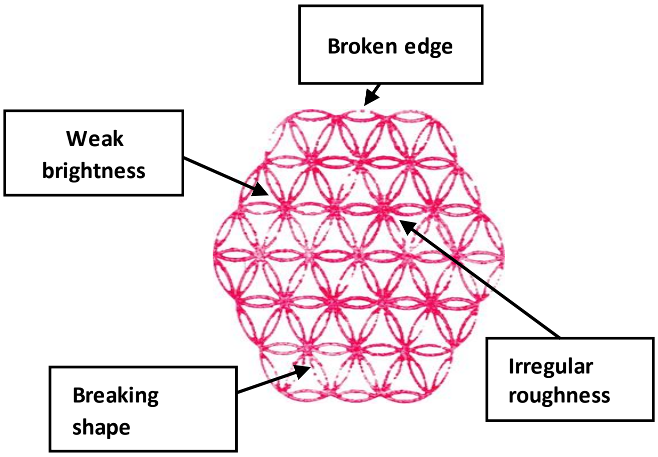
The experiment framework presented in Figure 8 in the third chapter was used to investigate the long-term wearability of 3DP embroidery samples under a washing test. The test started by subjecting the above-identified samples of 3DP embroidery objects (Figure 14) to a visual test and three washing cycles.

5.2.1: Visual test results and analysis

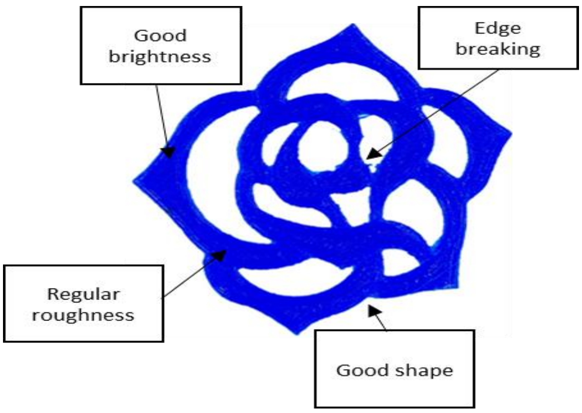
A visual test was performed by the author with the assistance of experts in the textile field in order to evaluate the quality of 3D printed objects on cotton, organza and silk fabric. Each sample was given a rating between 0 and 5, with 0 presenting the lowest quality and 5 the best quality in terms of edge, shape, roughness and brightness. Appendix 8 provides detailed analysis of the scale used for rating of samples. In order to make an informed decision, layer thickness was used as an independent variable. Figure 19 below shows that, relative to 0.25 mm and 0.5 mm layer thicknesses, samples of 1 mm thickness presented the acceptable results in terms of edge, shape, roughness and brightness.



(a) Cotton 0.25 mm



(b) Cotton 0.5 mm



(c) Cotton 1 mm

Figure 19: Photographs of cotton samples at different layer thicknesses

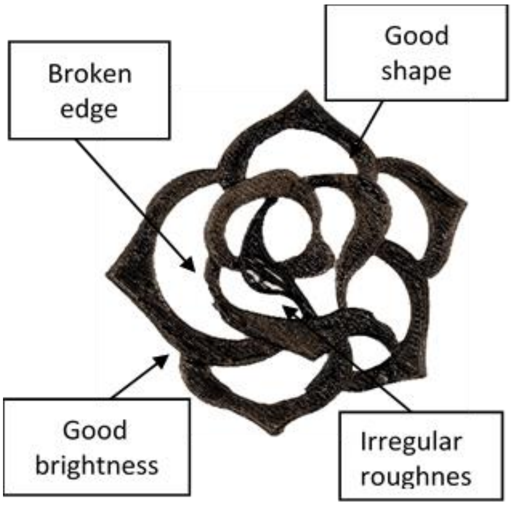
Table 8 below presents the findings of the rating results as part of the visual test. Table 8 presents the rating score given to 3DP embroidery designs printed at 240°C, 245°C and 250°C against edge, shape, roughness and brightness. It can be seen from Table 8 that cotton fabric presented the highest average value in terms of edge, shape, roughness and brightness at a 1 mm layer thickness comparative to thicknesses of 0.25 mm and 0.5 mm.

Table 8: Visual test of Cotton samples at 240 °C, 245 °C and 250 °C at different thicknesses

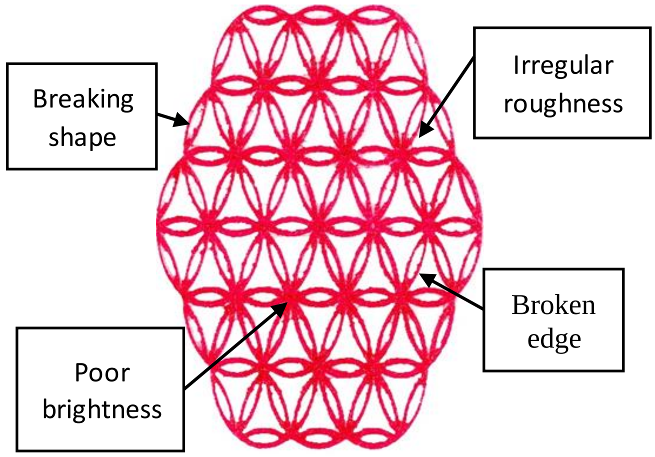
Samples	Edge	Shape	Roughness	Brightness
0.25 mm thickness				
Cotton 240 °C	2	2	1	3
Cotton 245 °C	3	2	2	3
Cotton 250 °C	1	1	2	3
Average	2.00	1.67	1.67	3.00
0.50 mm thickness				
Cotton 240 °C	1	1	1	1
Cotton 245 °C	3	3	2	3
Cotton 250 °C	3	3	2	2
Average	2.33	2.33	1.67	2.00
1 mm thickness				
Cotton 240 °C	3	3	3	4
Cotton 245 °C	4	4	4	5
Cotton 250 °C	3	3	6	4
Average	3.33	3.33	4.33	4.33

Source: See appendix 8

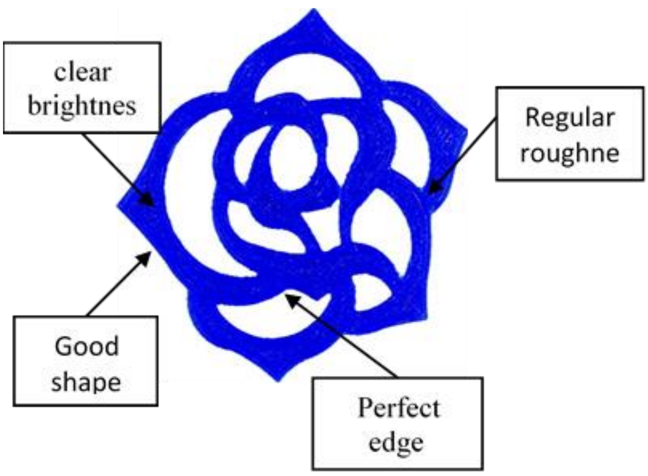
As with the cotton fabric, organza also presented better results in terms of shape, edge, roughness and brightness at a 1 mm thickness when compared with thicknesses of 0.25 mm and 0.5 mm, as shown in Figure 20 below.



(a) Organza at 0.25 mm



(b) Organza at 0.50 mm



(c) Organza at 1 mm

Figure 20: Photographs of organza samples at different layer thicknesses

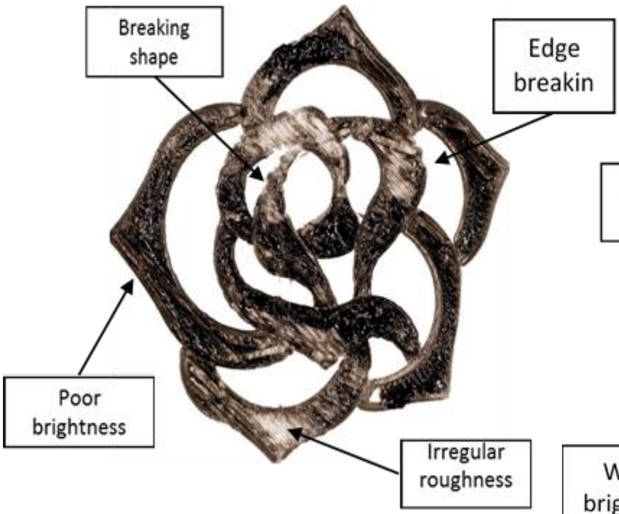
Table 9 below further supports the findings of the visual test presented in Figure 16 above. Specifically, Table 9 presents the rating scores given to samples of 3DP embroidery samples printed at 240°C, 245°C and 250°C on organza fabric. From Table 9, it can be seen that comparative to thicknesses of 0.25 mm and 0.5 mm, 3DP embroidery samples printed at a 1 mm layer thickness on organza fabric presented the best average quality in terms of edge, shape, roughness and brightness.

Table 9: Visual test of Organza samples at 240°C, 245°C and 250°C at different thicknesses

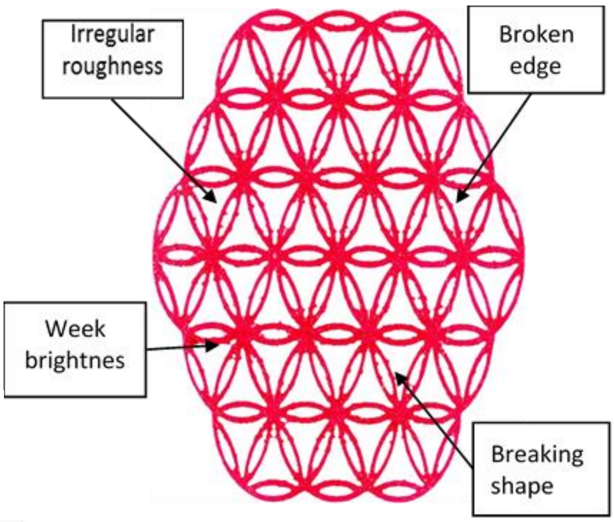
Samples	Edge	Shape	Roughness	Brightness
0.25 mm thickness				
Organza 240 °C	3	2	2	4
Organza 245 °C	4	4	4	5
Organza 250 °C	3	3	2	4
Average	3.33	3.00	2.67	4.33
0.5 mm thickness				
Organza 240 °C	2	2	2	2
Organza 245 °C	3	3	3	3
Organza 250 °C	3	3	3	3
Average	2.67	2.67	2.67	2.67
1 mm thickness				
Organza 240 °C	4	5	5	5
Organza 245 °C	4	4	4	5
Organza 250 °C	3	4	4	4
Average	3.66	4.33	4.33	4.66

Source: See appendix 8

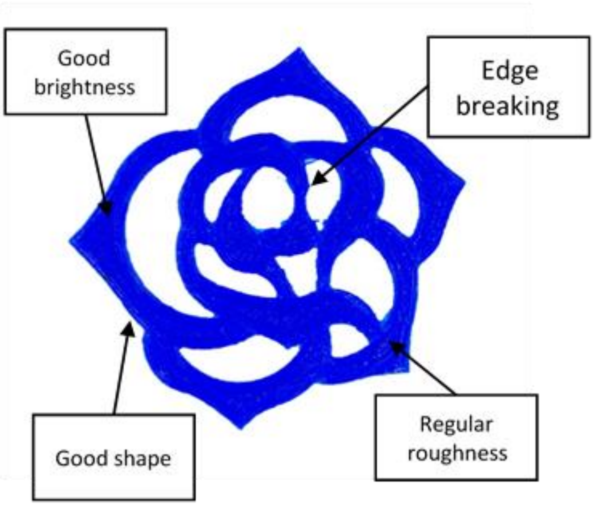
Figure 21 below presents the results of the visual test conducted for the samples of silk fabric at different layer thicknesses. The visual test showed that by looking at the silk samples with an unaided eye, it appears that 3D printed embroidery samples of 1 mm thickness presented the best edge, shape, roughness and brightness.



(a) Silk at 0.25 mm



(b) Silk at 0.50 mm



(c) Silk at 1 mm

Figure 21: Photographs of silk samples at different layer thicknesses

Table 10 below presents the individual rating scores and their averages given to the samples of silk fabric against edge, shape, roughness and brightness. It can be seen from Table 10 that, on average, samples of 3DP embroidery on silk fabric also presented the highest results at a thickness of 1 mm compared with thicknesses of 0.25 mm and 0.5 mm.

Table 10: Visual test of Silk samples at 240°C, 245°C and 250°C for different thicknesses

Samples	Edge	Shape	Roughness	Brightness
0.25 mm thickness				
Silk 240 °C	4	3	3	4
Silk 245 °C	1	1	1	2
Silk 250 °C	2	3	2	2
Average	2.33	2.33	2	2.67
0.5 mm thickness				
Silk 240 °C	2	2	2	2
Silk 245 °C	2	2	2	2
Silk 250 °C	1	1	1	1
Average	1.67	1.67	1.67	1.67
1 mm thickness				
Silk 240 °C	3	3	4	3
Silk 245 °C	3	3	3	4
Silk 250 °C	3	3	4	4
Average	3	3	3.66	3.66

Source: See appendix 8

Overall, from the results of the visual test presented in Tables 8, 9 and 10, it can be seen that for all three fabrics (cotton organza and silk), the embroidery shapes printed at a 1 mm layer thickness presented acceptable visual test results against edge, shape, roughness and brightness. Reason behind 1mm thickness 3DP object giving acceptable results can be linked to technical complexity of 3D printing. For instance, when printed on smaller layer thicknesses, such as 0.25mm and 0.5mm in the case of this experiment, filament tends to get blocked to high degree when pressed through the nozzle hence adversely impacting quality of the surface of 3DP object. A thicker layer in 3DP tends to provide better printing results compared with printing in a thinner layer. The results of printing using a thinner layer produce uncomfortably rough surfaces. Therefore, samples at 1mm thickness were selected for long-term wearability test of 3D printed embroidery design under washing environment. However, organza fabric at a 1 mm layer thickness demonstrated the highest visual quality, as reflected in its results. Therefore, the visual test results for organza fabric at temperatures of 240°C, 245°C and 250°C were used as a base scale for analysing the results of the washing test. This meant using temperature as a corresponding factor as a reference value of the edge parameter for organza fabric at 240°C and later comparing this with cotton and silk fabrics.

5.2.2: Washing test results and analysis

The washing tests were performed under ISO 6330 using the parameters presented in Table 4 in the third chapter of this thesis. Images of the washed samples were sent to an image file reader from the prescribed folder in the image file reader, which resulted in creating an RGB image map, as shown in Figure 22 below.

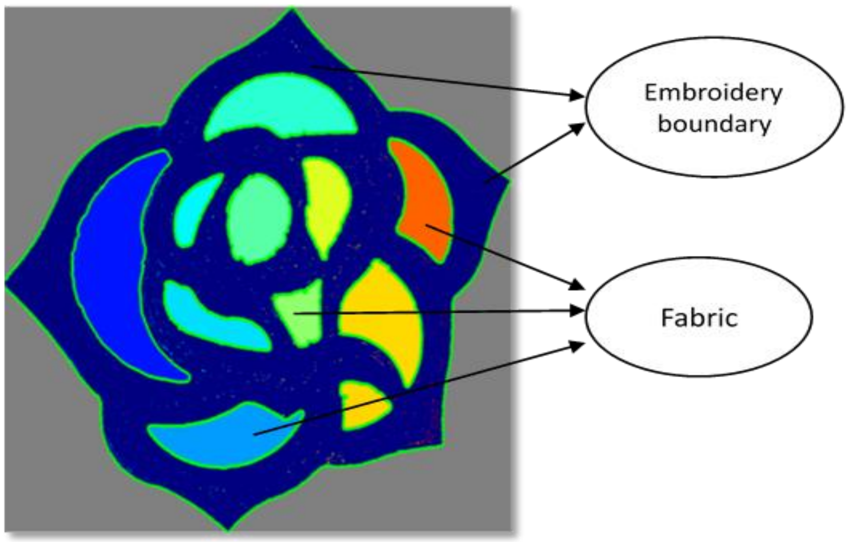


Figure 22: MATLAB sample image

Appendix 6 presents the fuzzy image analysis results of cotton, organza and silk fabrics at 240°C, 245°C and 250°C. Table 10 below presents the descriptive analysis of the fuzzy image analysis results for cotton fabric at zero to three washes for edge, shape, roughness and brightness at 240 °C. It can be seen from Table 11 that the standard deviation (SD) for all four factors (edge, shape, roughness and brightness) are close to the mean, which suggests that the values are linearly distributed. Furthermore, Table 11 presents favourable results because smaller SD values tend to represent a higher quality, particularly when this tool is used in manufacturing and for quality control purposes

(Rumsey, 2019). Smaller SD values also mean that there was a significantly low or minimum impact of washing on the four parameters of the 3D printed object. However, the question that arises is whether the edge, shape, roughness and brightness improved or deteriorated as a result of the washing cycles. This required further statistical analysis, the results of which are presented later in this chapter. Descriptive data for the other fabrics at the three temperatures presented a similar pattern to that presented in Table 11 and as shown in Appendix 7.

Table 11: Descriptive analysis of fuzzy image analysis results for cotton fabric at 0 to 3 washes at 240 °C

	Mean	Standard deviation
Edge	0.09	0.01
Shape	0.08	0.01
Roughness	1.99	1.22
Brightness	5.50	0.01

To evaluate the impact of washing on edge, shape, roughness and brightness, CV statistical analysis was applied, as demonstrated in chapter three. The findings of the visual test and the results of the CV statistical analysis of organza fabric at a 1 mm layer thickness were used as a baseline, as this had been identified as presenting the acceptable results in terms of edge, shape, roughness and brightness in the visual test (see section 5.2.1 above). Table 12 below presents the results of the CV analysis for edge, shape, roughness and brightness for organza fabric at 1 mm thickness. ±10% Scale was applied to the values presented in Table 12 for edge, shape, roughness and brightness to further evaluate the fuzzy image analysis results for the other fabrics in order to assess their long-term wearability.

Table 12: Baseline for CV analysis

Samples	Edge	Shape	Roughness	Brightness
Organza 240 °C	18.55%	16.03%	9.27%	0.53%
Organza 245 °C	2.89%	4.37%	12.96%	1.25%
Organza 250 °C	8.35%	9.67%	6.94%	0.57%

Having identified the baseline (Table 12), the fuzzy image analysis results for each fabric (Appendix 7) were then subjected to CV analysis. Table 13 below presents the values for the CV for all three fabrics at 240 °C after three washing cycles.

Table 13: CV analysis for 240 °C

Samples	Edge	Shape	Roughness	Brightness
Cotton 240 °C	17.22%	17.59%	9.79%	0.95%
Organza 240 °C	19.00%	16.00%	9.00%	1.00%
Silk 240 °C	18.21%	15.00%	8.50%	1.00%
+10%	20.90%	17.60%	9.90%	1.10%
-10%	17.10%	14.40%	8.10%	0.90%

The results in Table 14 show that there was no significant impact of washing on embroidery design in terms of edge, shape, roughness or brightness, even after successive washing, as all the values stayed within the ±10% margin. Similarly, from the results in Table 14 below, it can also be seen that all the results stayed within the ±10% scale, thus suggesting that 3DP embroidery designs presented an acceptable edge, shape, roughness and brightness after washing for all the fabrics tested when produced at 245°C.

Table 14: CV analysis for 245 °C

Samples	Edge	Shape	Roughness	Brightness
Cotton 245 °C	3.20%	3.62%	12.52%	0.93%
Organza 245 °C	3.00%	4.00%	13.00%	1.00%
Silk 245 °C	2.90%	4.33%	13.86%	0.95%
+10%	3.30%	4.40%	14.30%	1.10%
-10%	2.70%	3.60%	11.70%	0.90%

Likewise, from Table 15 below, it can be seen that the CV for embroidery designs printed at 250°C for all fabrics stayed within the ±10% acceptable range against the standard of organza fabric. Therefore, it can be argued that 3DP embroidery designs printed at 250°C presented an acceptable edge, shape, roughness and brightness for all the fabrics after three washing cycles.

Table 15: CV analysis for 250 °C

Samples	Edge	Shape	Roughness	Brightness
Cotton 250 °C	7.13 %	10.43%	7.41%	0.97%
Organza 250 °C	8.00%	10.00%	7.00%	1.00%
Silk 250 °C	8.41%	9.43%	6.75%	0.94%
10%	8.80%	11.00%	7.70%	1.10%
-10%	7.20%	9.00%	6.30%	0.90%

Overall, the washing test showed that the 3D printed embroidery objects appeared to pass the test of long-term wearability. Specifically, washing did not have any major impact on the edge, shape, roughness or brightness of 3DP embroidery designs for the three fabrics when printed at a 1 mm layer thickness. These findings also corroborate those of a washing test in Sabantina et al. (2015), in which the authors concluded that 3DP objects can be easily formed onto the surface of fabrics and can maintain their texture and design main ability after washing test. Spahiu et al.'s (2017) study on the effect of 3D printing on textile fabric also supports the findings of the washing test, as those researchers revealed that washing 3DP textile fabrics did not cause any modification of the adhesion forces. Similarly, while investigating the possibility of creating composite designs on fabrics using 3DP, Martens and Ehrmann (2017) concluded that washing the fabric did not have an impact on the adhesion of 3DP material such as TPU and the textile. Therefore, since the findings presented in this study resemble those of previous researchers (Martens and Ehrmann, 2017; Sabantina et al., 2015; Spahiu et al., 2017), it can be argued that the results presented in this study as part of the washing test are both reliable and valid.

5.3: Tensile test results

A peel tensile test was conducted to investigate the strength of adhesion of 3D printed embroidery designs on different fabrics. As with the washing test, the process of the peel test started by producing samples of 3DP embroidery designs on cotton, organza and silk fabrics. The samples were then subjected to a peel test, which included a T-shaped test to determine the strength of adhesion to measure the peeling force of a T-shaped bonded assembly. The test employed an Instron machine, as shown in Figure 23 below.

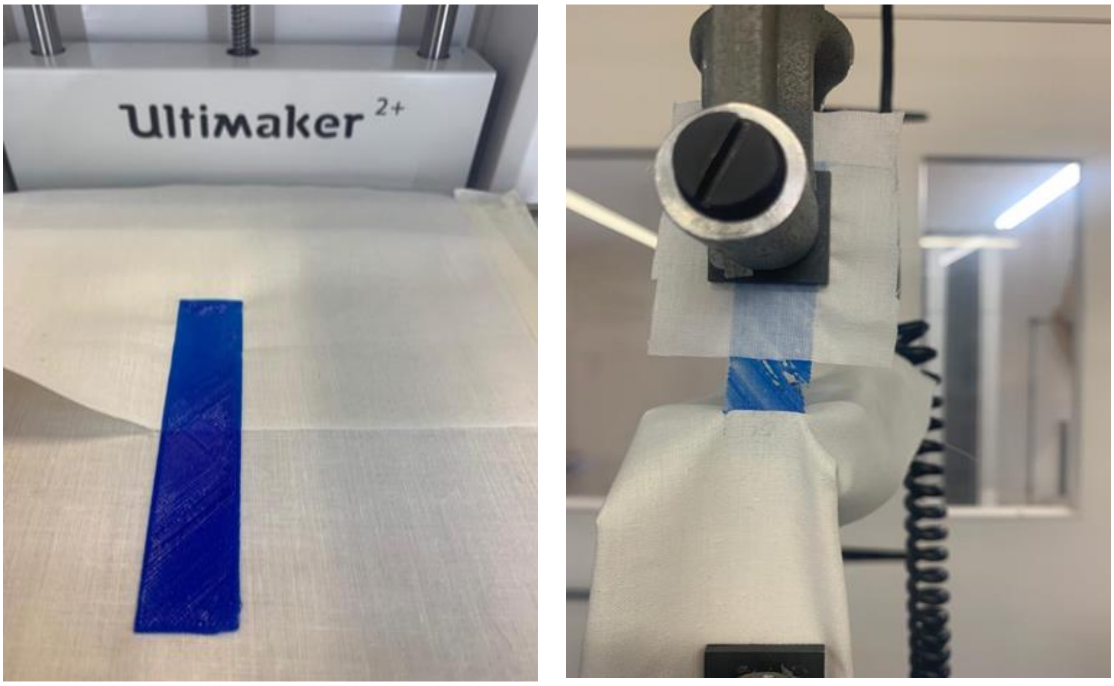


Figure 23: Procedure for the peel tensile test

The results of the peel test were assessed against three parameters: fabric type, printing temperature and layer thickness. With regard to the three fabrics being tested (cotton, organza and silk), the quality of adhesion was measured by assessing the impact of a peeling force on the 3D printed embroidery design. The impact of different nozzle temperatures (240°C, 245°C, and 250°C) on the adhesion strength of 3D printed embroidery designs was also tested. Finally, the impact of a peeling force on the adhesion of the 3D printed embroidery designs was tested regarding different layer thicknesses: 1.00 mm, 0.5 mm, (0.25mm) layer thickness does not qualify for adhesive testing since as a result of application of peeling force filament detached from the fabric and left gaps in design. Therefore, peeling test results of all fabrics at 0.25mm layer thickness were nullified. Thus, analysis of peeling test results by fabric type, layer thickness and temperature will eliminate samples of 0.25mm layer thickness. Regression analysis was used for the data analysis with the scale that a maximum peeling force and a lower SD represented good adhesion quality. Consequently, a high SD with a low/high maximum peeling force represented inconsistency in the adhesion.

Figure 24 below shows that, compared with silk and cotton, organza demonstrated the highest peeling force with the highest SD, indicating that the adhesion force was inconsistent. This may be due to the rough texture of the fabric. It could also be because melting the filament on organza fabric causes stretching and then cooling, thus giving adhesive force. As a result of the roughness of the texture, the filament was placed on the fabric in a non-uniform manner, thus giving inconsistent results. This is consistent with the investigation by Busiliene et al (2015), who argued that the adhesion of printed objects depends upon the chemical nature of the fabric, as well as its texture. Thus, if the fabric has an irregular surface, the filament may be forced into an irregular shape prior to hardening, which could, in turn, weaken the adhesion force. In contrast, the other fabrics in this study (silk and cotton) had a smooth texture and thus testing revealed a low SD even at the maximum peeling force, representing good adhesion. Therefore, it can be argued that the texture of a fabric has an impact on the strength of adhesion.

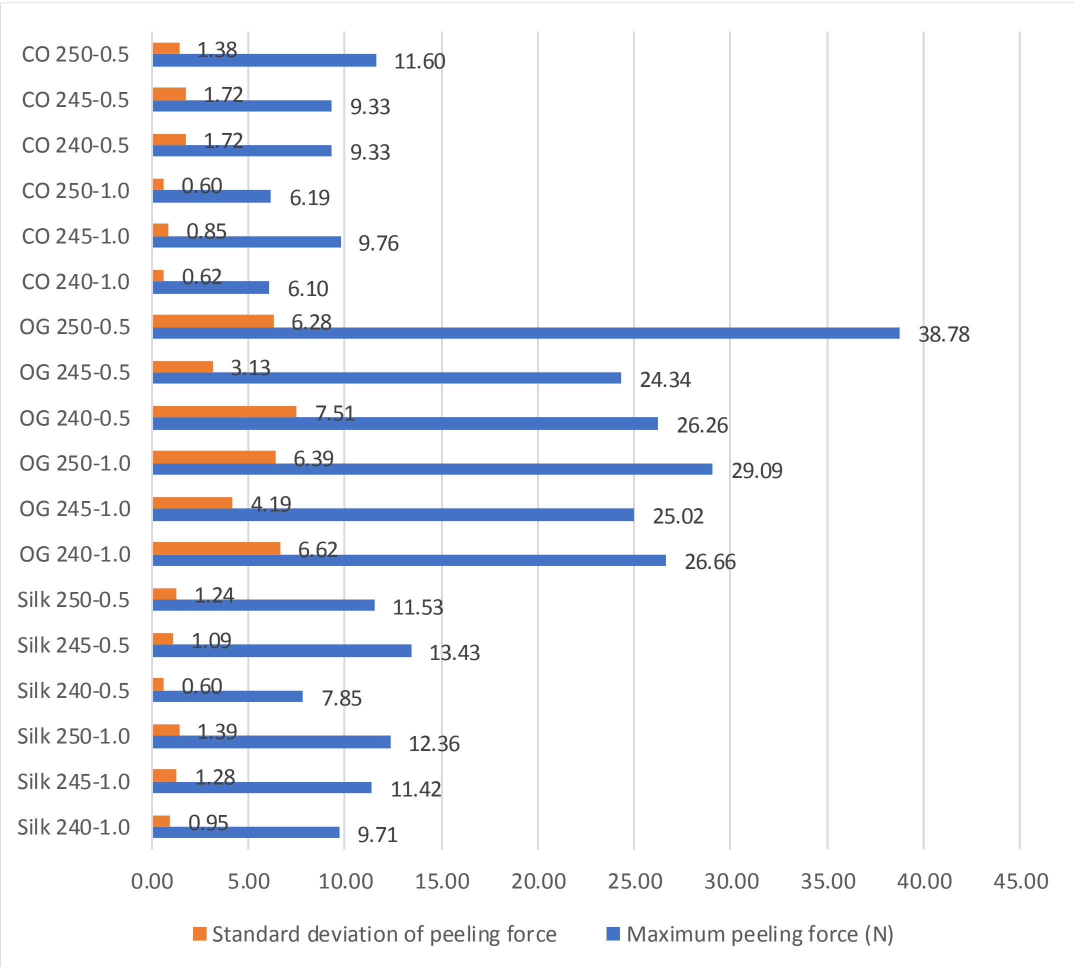


Figure 24: Impact of peeling force on adhesive quality by fabric type

The quality of adhesion with respect to layer thickness (Figure 25) shows that while standard deviation of cotton and silk fabrics presented lower standard deviations at 0.5mm and 1mm layer thicknesses. However, variations have been noted with regards to organza fabric as shown in (Figure 25) below. Specifically, comparative to silk and cotton fabric, standard deviation of organza fabric is higher at 1mm and 0.5mm layer thickness. Low standard deviation of silk and cotton fabrics can be linked to uniform properties of the fabrics thus test is producing consistently low standard deviation. While investigating influence of layer thickness on adhesive impact property of 3DP material, Abbas et al (2018) reported that higher layer thickness can lead to high adhesive strength. Additionally, reason behind high adhesion of 3D printed material on organza fabric at higher layer thickness can also be linked to fabric structure and weight. To this end, due to its light weight and tight structure, higher layer thickness is required to ensure diffusion of printing material into the fabric however once diffusion of printing material has taken place on organza fabric thus giving inconsistent results.

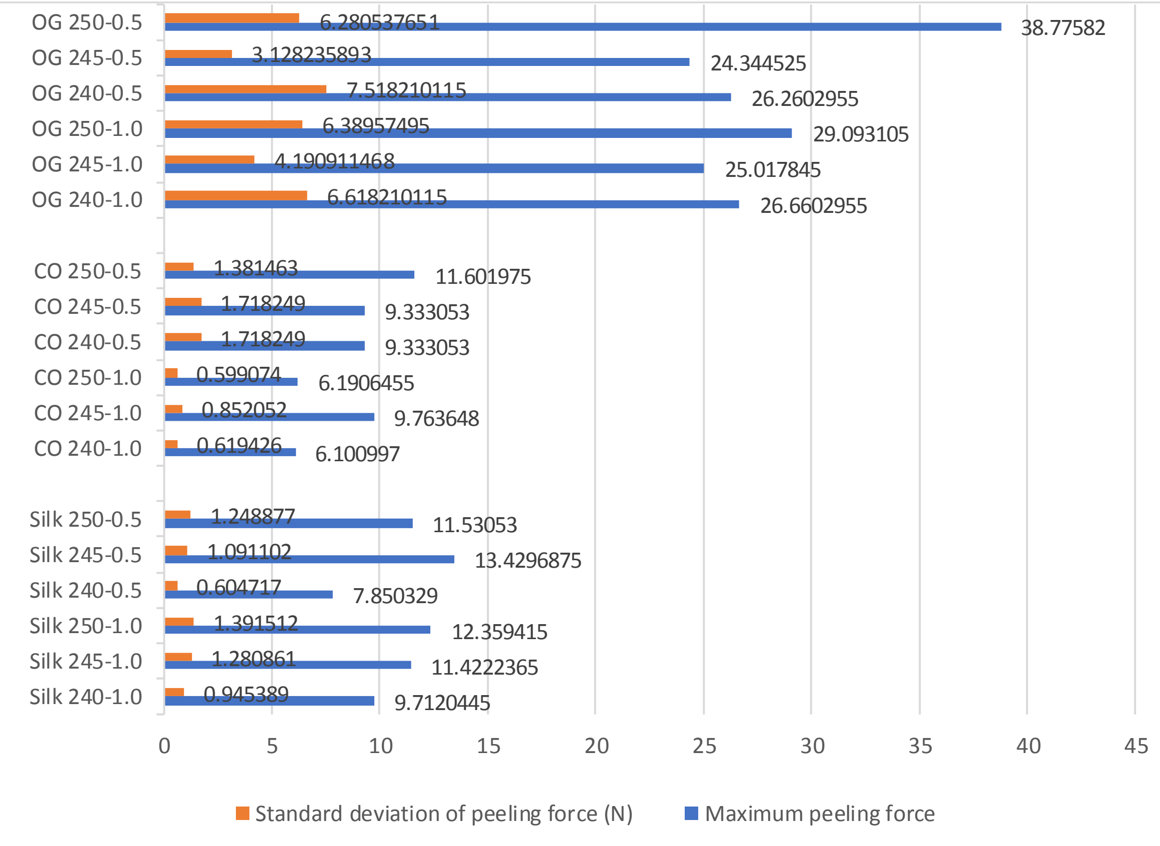


Figure 25: Quality of adhesion with respect to layer thickness

Figure 26 below shows that both silk and cotton fabrics representing maximum peeling force with low standard deviation at all sets of extruded temperatures (240C, 245C and 250C) however, this is not the case with organza fabric. Specifically, organza fabric demonstrated inconsistent adhesion because results shows that on all sets of extruded temperatures (240C, 245C and 250C) organza procured high standard deviation with high peeling force. The adhesion quality depends upon multiple factors and extruding temperature during 3DP is one of them. For instance, in the cases of both cotton and silk higher extruding temperature leads to increase softening of fabrics thus making stronger interface between TPU and fabric surface structure hence good adhesion.

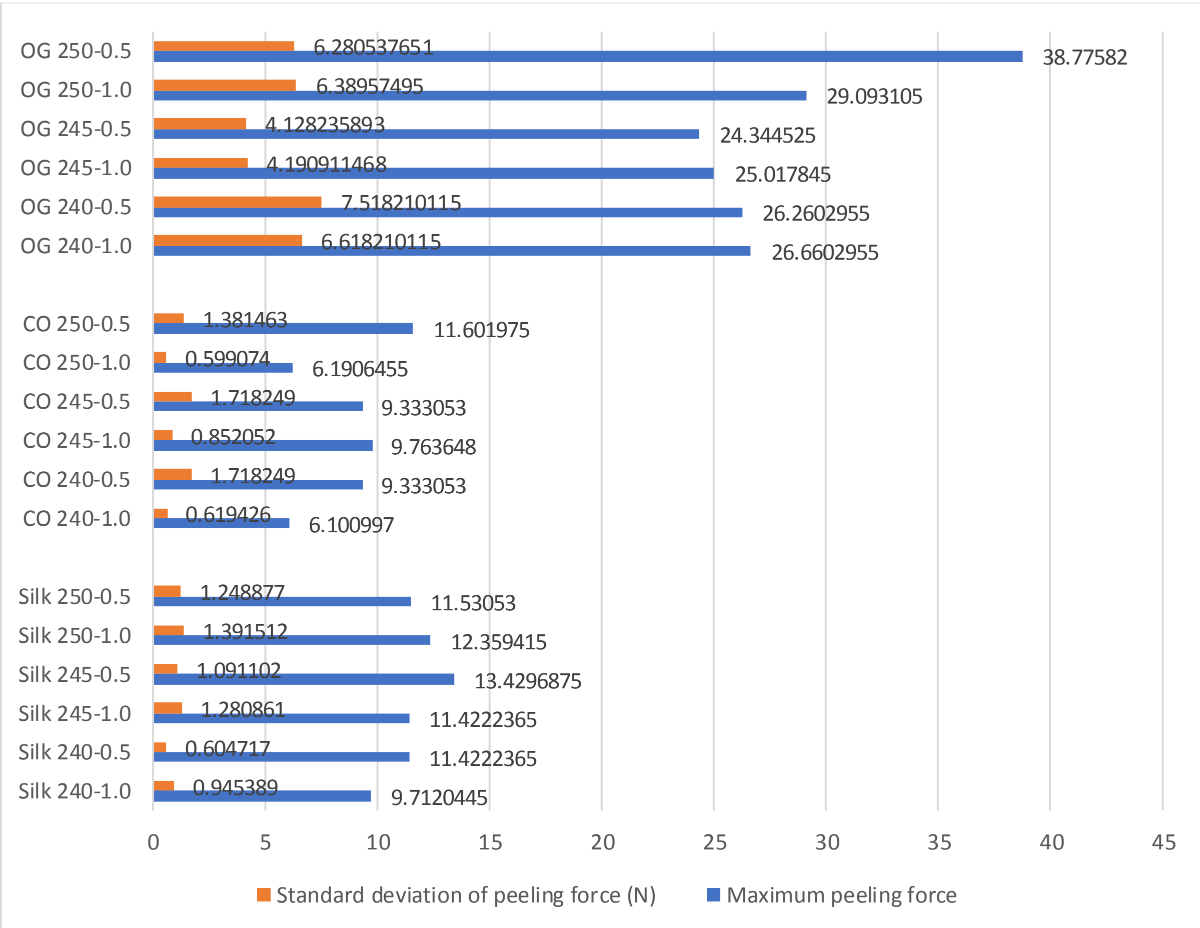


Figure 26: Quality of adhesion at different nozzle temperatures

However, with organza fabric high extruding temperature leads to deterioration of not only 3D printed object but also resulting in ripping up of fabric as shown in (figure 27) below. Specifically, figure 27 below shows that Organza fabric at 240C, 245C and 250C results in destruction of embroidery object. Reason behind destruction of embroidery design at specified temperature can be linked to the fact that organza fabric being not strong enough to stand the peel test. Ripping of organza fabric at 250C can be explained in the light melting temperature of organza fabric. According to Haar (2011) temperature nearer to 250C and above organza fabric start to melt. Thus, explained the reason for high standard deviation of peeling force at 240C, 245C and 250C with abnormal maximum peeling force.

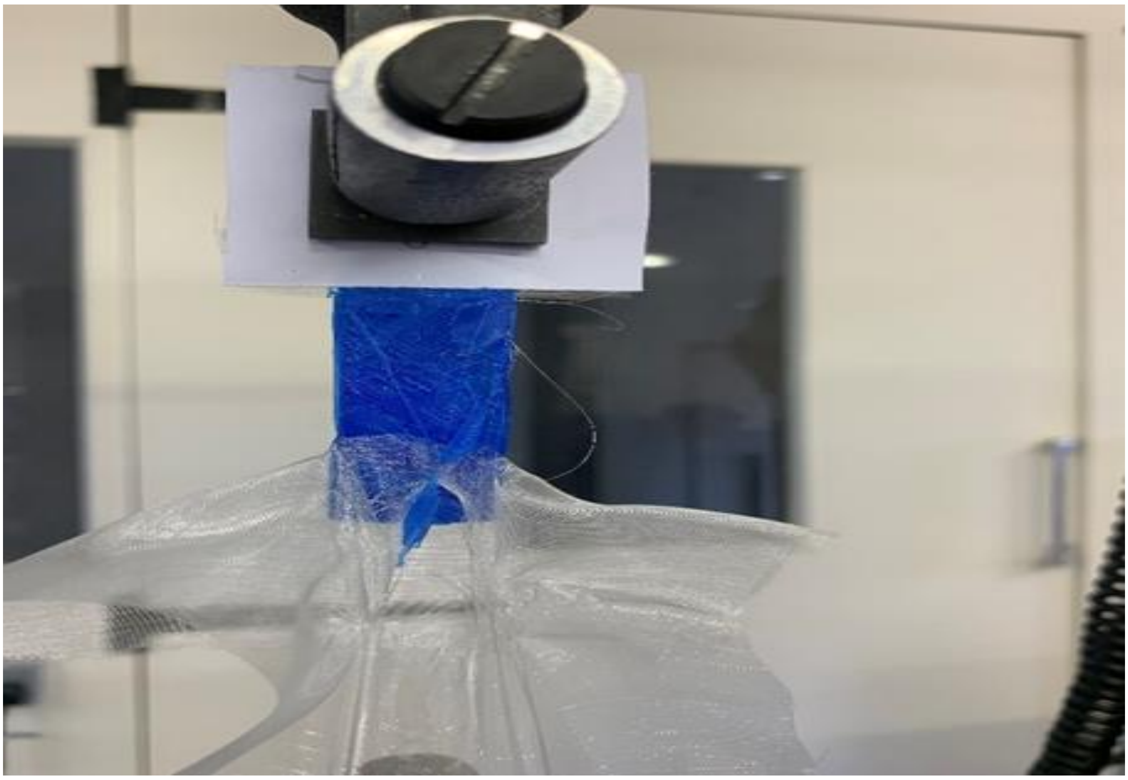


Figure 27: Impact of extruder temperatures on quality of adhesion on organza fabric

5.4: Conclusion

The findings of the multiple experiments presented in this chapter demonstrate the long-term wearability of 3DP embroidery clothing and, therefore, could be used to address the concerns of both customers and manufacturers about the long term raised in the previous chapter. The discussion in this chapter started by outlining the production of 3DP specimens of embroidery designs that were then used for testing long-term wearability and for conducting a tensile test. The long-term wearability of 3DP embroidered clothes was tested under a washing test. A visual test was conducted to identify the specimen offering the best printing quality, the results showed that embroidery shapes printed at 1 mm thickness offered good quality on all three fabrics. However, organza was identified as presenting the highest quality among the three fabrics at a 1 mm thickness. Therefore, the 3DP embroidery designs at 1 mm thickness on all three fabrics were chosen for further tests in terms of washing. The results of the washing test were processed by capturing images of the samples at no washing and at the first, second and third washing cycles, and then processed in MATLAB software to identify the impact of washing on edge, shape, roughness and brightness. The statistical results of the CV of organza fabric were used as a baseline against ±10% margin of error to evaluate the impact of washing on the edge, shape, roughness and brightness parameters of the samples. The implementation of a CV statistical method and a comparison of the results with ±10% margin of error revealed that washing did not have any major impact on the edge, shape, roughness or brightness of 3DP embroidery designs for all three fabrics when printed at a 1 mm thickness.

The results of the peel tensile test revealed that, due to fabric structure, chemical nature and weight, organza fabric showed differentiated features of adhesion quality as compare to silk and cotton fabrics. Silk and cotton, due to their smooth texture, showed high adhesion of 3DP objects but enough peeling force to withstand rigorous washes. In contrast, organza fabric appears to not support 3DP embroidery objects at any of the temperatures used in this study. This comparison does not necessarily indicate that 3DP is not possible on organza instead organza fabric has differentiated nature that allowed good adhesion quality only at specific 3DP parameters.

Therefore, from the findings presented in this chapter, it can be argued that, overall, 3DP embroidery objects present good long-term wearability as long as the printing parameters are set up to meet the fabric architecture. Having justified the long-term wearability of 3DP embroidered dresses, the next chapter moves towards evaluating the strategic suitability, acceptability and feasibility of launching 3DP embroidered dresses in the Hejaz region of Saudi Arabia.

Chapter VI

Evaluation of the suitability, accessibility and feasibility of using 3DP embroidery clothing in the Hejaz region of Saudi Arabia

6.0: Introduction

The previous chapters quantitatively demonstrated the scope of using 3DP embroidery dresses in the Hejaz region of Saudi Arabia. Specifically, the discussion in the fourth chapter identified the scope for 3DP embroidery dresses in the market, such as customer demand for the product, but also acknowledged possible hurdles in the manufacturing process, such as concerns regarding long-term wearability and the adhesion of 3D printed embroidery designs to fabrics. The discussion in the fifth chapter then moved to addressing the concerns of both customers and manufacturers about long-term wearability, using the results of experiments conducted for this research that presented promising outcomes under washing and adhesion tests. This chapter now aims to use the findings from the fourth and fifth chapters to evaluate the suitability, acceptability and feasibility (SAFe) of reviving the traditional embroidery industry in the Hejaz region of Saudi Arabia. To this end, the discussion starts by presenting the theoretical background of the SAFe framework, prior to implementing it in the context of this study.

6.1: SAFe framework

Johnson et al. (2014: P372) proposed the SAFe model for evaluating the strategic direction of an organization. The SAFe framework has largely been used in strategic management and project management strategy, with businesses using the tool to evaluate the suitability, feasibility and acceptability of a strategic initiative or new product/service. Hassan and Mahdzir (2016) used the SAFe framework when investigating socioeconomic indicators for the Ocean Thermal Energy Conversion (OTEC) transformation project. Similarly, Lwembe et al. (2016) used the SAFe model to evaluate the possibility of using celebration card interventions in primary care to enhance the vaccination process for children. The advantage of using the SAFe framework for assessing a proposed strategic initiative or new idea lies in the ability to screen a proposed strategy/idea from both monetary and non-monetary perspectives (Johnson et al., 2014: P363). Using the lack of manufacturing development in the existing traditional embroidery industry in the KSA as a market gap, the discussion below uses SAFe criteria to assess the suitability, acceptability and feasibility of using 3DP embroidery clothing in the KSA.

6.1.1: Suitability

According to Johnson et al. (2014: P372), suitability refers to an assessment of the extent to which a novel idea, in this case using 3DP in the manufacturing process of traditional embroidered dresses, addresses the market opportunities and threats facing an organization/industry. The suitability factor of the SAFe framework in this study aims to assess the extent to which the idea of integrating 3DP in the manufacturing process of traditional embroidered clothing will help in exploiting opportunities in the fashion industry of the KSA. Secondly, it will help in identifying ways in which the idea of using 3DP can assist in revitalizing the currently collapsing traditional embroidery sector of the Saudi fashion industry.

As stated in the discussion in section 2.1.2 of the second chapter, the traditional embroidered dress industry in the Hejaz region of Saudi Arabia is under threat because of factors such as the following: little customer interest in traditional clothing; the influence of Western styles of dress; a lack of support from the fashion industry in Saudi Arabia for traditional clothes; little in the way of development in manufacturing techniques and flexibility in the manufacturing process; the inability of traditional embroidered clothing lines to meet the challenges of the fast fashion concept; the long waiting times for customers; and the lack of customization available for embroidered clothes (Emmett, 2014; Paton, 2018; Qi, 2018; Rizvi, 2017; Tawfiq and Marcketti, 2016). In summary, it has been found that a lack of development in the manufacturing process of traditional embroidered clothing has led to consumers losing interest in the craft, leading to the potential demise of the industry. The idea of using 3DP in the manufacturing process of traditional embroidered dresses appears to be a ready-made solution to the problems identified in the industry. For instance, as stated in section 2.3 of this thesis, 3DP possesses the ability to develop customized prototypes of apparel designs (Lipson and Kurman, 2013), which would directly address the customization needs of customers. However, the core suitability of launching 3DP embroidery clothing lies in its production convenience. It is estimated that the production of a complete 3DP embroidery dress would take around 4.35 days (with an 8-hour working day) (see Appendix 8) compared with a 25- to 30-day production time for traditional embroidered dresses. Therefore, the use of 3DP in the manufacturing process would directly address the customization, flexibility and convenience opportunities presented by the market. Under Porter's (1985) model of generic competitive strategy, it can be argued that the 3DP embroidery dress sector of the Saudi fashion industry requires a product development strategy for its revival. Porter defined a product development strategy as one in which an organization aims to deliver a modified or new product in an existing market (Johnson et al., 2014).

6.1.2: Acceptability

The acceptability factor of the SAFe framework is aimed at assessing the extent to which a proposed idea will meet the expected performance outcome and meet the expectations of the wider stakeholders (Johnson et al., 2014: P379). In the context of introducing 3DP into the traditional embroidery industry of the KSA, the key stakeholders include manufacturers, customers and the government. In acknowledging the importance of acceptability among the key stakeholders, this thesis gathered responses from both manufacturers and customers with regard to the idea of introducing technology into the manufacturing process of traditional embroidered dress. The discussion on the data gathered presented in chapter four revealed that although both manufacturers and customers acknowledged the need to re-engineer the manufacturing process of traditional embroidered dresses, they demonstrated concerns about the quality and long-term wearability of technologically produced embroidered dresses. The manufacturers also went beyond long-term wearability concerns to argue that the ease of use of the new technology could create hurdles for them. The author of this research acknowledges those ease of use concerns given that most of the manufacturers of traditional embroidered dresses come from rural areas and have little or no literacy background and resources. Therefore, it can be argued that the introduction of 3DP faces three types of risk: quality, long-term wearability and ease of use.

To address the above concerns, multiple experiments were conducted for this research, including washing and peel tests, the results of which (see chapter 5) indicated that all the specimens indicated acceptable edge, shape, roughness and brightness after three washing cycles. However, the peel test results showed that, due to inconsistency in roughness and fabric texture, 3D printed embroidery did not present strong adhesion when compared organza with cotton and silk fabrics. Therefore, the experiment results in this study have addressed the long-term wearability and quality concerns of customers and manufacturers, thus fulfilling the acceptability factor of the SAFe framework.

6.1.3: Feasibility

In the SAFe framework, feasibility is concerned with assessing the practicality of a novel idea (Johnson et al., 2014: P391). The main aspect of feasibility is whether there exist the resources and competencies to bring a new idea into practice. The feasibility of the idea of implementing 3DP in the manufacturing process of traditional embroidered dresses was assessed against three elements: finance, human resources and the supply chain.

6.1.3.1: Financial feasibility

A cost-benefit analysis was conducted in order to assess the financial feasibility of the concept of 3DP embroidery dresses. The underlying idea of the cost-benefit analysis conducted in this research was whether integrating 3DP into the manufacturing process of traditional embroidered dresses would provide higher profits than the level of the costs involved. In order to evaluate the financial feasibility of 3DP embroidery dresses comparative to traditional embroidered dresses, the findings of the manufacturer survey presented in section 4.1.1 were used. In particular, the findings showed that the fabric, the thickness of the embroidery stitches and the number of designs had an impact on the time needed to produce a traditionally embroidered dress. The time period for producing a 3DP embroidery dress is also affected by certain factors, as the completion of one complete embroidered dress will depend upon the number of 3DP embroidery designs needed.

The experiment in this study revealed that 3DP takes 17 minutes to print one embroidery design. Based on the assumption that one complete embroidered dress would require 30 designs, the process would take 510 minutes (17 x 30 = 510). Given that there are 60 minutes in 1 hour, it would take 8.5 hours to print one complete 3DP embroidery dress (510/60 = 8.5). Applying one working day (eight-and-a-half hours) to the printing time of 3DP means that it would take one day to print one 3DP embroidery dress thus, the requirement of a large number of designs would mean that the number of days needed to produce a 3DP embroidery design would rise. Table 17 below shows that, comparative to traditionally embroidered clothes, 3DP embroidery dresses possess an edge in terms of production time.

Table 16: Variable and fixed costs associated with 3DP embroidery dresses

	Fabric (SAR)	**Filament (SAR)**	**Thread (SAR)**	**3DP overhead cost per dress (SAR)**	**Labour cost (SAR)**	**Total cost (SAR)**	**Time to print one dress (days)**
Cotton	235	137	9	31.25	100	512.25	1 day
Silk	250	137	9	31.25	100	527.25	1 day
Organza	409	137	9	31.25	100	686.25	1 day
Average cost						**575.25**	

To conduct a comparative analysis of the cost of a 3DP embroidery dress against that of a traditional dress, the variable and fixed costs associated with using 3DP for manufacturing an embroidered dress were identified. It was found that variable cost elements included fabric and labour. It is expected that the manufacture of one complete embroidered dress requires 3 m of fabric. Conducting online research revealed that 1 m of cotton, silk and organza costs SAR 45[1], SAR 50[2] and SAR 103[3], respectively. This means that the cost of the fabric for manufacturing a 3DP embroidery dress on cotton, silk and organza would be SAR 135 (3 x 45 = 135), SAR 150 (50 x 3 = 150) and SAR 309 (103 x 3 = 309), respectively. Labour was assumed to cost SAR 100 to print one 3DP embroidery dress. Therefore, the total variable cost of printing one embroidered dress on

[1] Desert Cart. 2019. Plain Royal-Blue 100% Cotton Fabric 150cm wide per metre. Available at https://saudi.desertcart.com/products/47976202-plain-royal-blue-100-cotton-fabric-150-cm-wide-per-metre [Accessed on 22nd Nov 2019].

[2] Desert Cart. 2019. Plain Royal-Blue 100% Cotton Fabric 150cm wide per metre. Available at https://saudi.desertcart.com/products/47976202-plain-royal-blue-100-cotton-fabric-150-cm-wide-per-metre [Accessed on 22nd Nov 2019].

[3] Desert Cart. 2019. Plain Royal-Blue 100% Cotton Fabric 150cm wide per metre. Available at https://saudi.desertcart.com/products/47758145-minerva-crafts-two-tone-crystal-organza-dress-fabric-kingfisher-blue-per-metre [Accessed on 22nd Nov 2019].

cotton, silk and organza fabrics would be SAR 235 (SAR 135 + SAR 100), SAR 250 (SAR 150 + SAR 100) and SAR 409 (SAR 309 + SAR 100), respectively.

The next part of the calculations involved identifying the elements of the fixed costs. An evaluation of the experimental process revealed that there were filament, thread, a 3DP machine and a sewing machine to be considered. With regard to filament and thread, one could argue that these two elements should be recognized as variable instead of fixed costs. However, it is important to note that both filaments and thread can be bought in bulk and their costs identified with precision. For instance, one pack of filament contains 90 m of filament; however, preparing one embroidery dress only requires 45 m. One 90 m pack of filament can be bought for SAR 273.89. Thus, the cost of 1 m of filament is SAR 3.04 (SAR 273.89/90 = 3.04). Therefore, the cost of 45 m of filament is SAR 137 (SAR 45 x 3.04 = 137). Hence, the total cost of filament for printing one full embroidered dress (30 designs) was found to be SAR 137.

Similarly, one pack of thread can be bought in Saudi Arabia for SAR 451[4]. One pack of thread includes 50 rolls; however, the sewing for one embroidered dress only consumes one roll. Therefore, the cost of one roll or the sewing for one embroidered dress is SAR 9 (SAR 451/50 rolls = SAR 9).

Moving to the calculation of the fixed costs related to a 3D printer, it was found that one FDM 3D printer can be bought in Saudi Arabia for SAR 22,500[5] with a life of 10 years. The application of a straight-line depreciation method revealed that the annual overhead cost would be SAR 2,250 (SAR 22,500/10 = SAR 2,250). As stated above, it takes one working day to print a complete 3DP embroidery dress. Given that there are usually 295 working days in Saudi Arabia (312 working days minus 17 religious and national holidays), this means that in a single year, one 3D printer could print 295 dresses. As noted above, the annual depreciation cost of a 3DP is SAR 2,250 and, therefore, the overhead cost for printing one dress would be SAR 31.25 (SAR 2,250/295 = SAR 0.131).

[4] Desert cart. 2019. Coats XP All Purpose thread kit 50 Spool Box Assorted. Available at https://saudi.desertcart.com/products/2383466-coats-xp-all-purpose-thread-kit-50-spool-box-assorted [Accessed on 26th Nov 2019].
[5] Souq Amazon. 2019. 3D printer. Available https://saudi.souq.com/sa-en/3d-printers/ultimaker/a-7/l/?page=1 [Accessed on 22nd Nov 2019].

Table 17 below summarizes both the variable and fixed costs associated with printing 3DP embroidery dresses on cotton, silk and organza fabrics. From Table 17 above, it can be seen that the average cost of manufacturing one embroidered dress would be SAR 575.25.

Table 17 shows that it is expected that one 3DP embroidery dress would cost SAR 408.02, compared with SAR 1,000 or more for a traditional dress. Consequently, if we add a 100% mark-up to the expected cost of a 3DP embroidery dress, it would only cost customers SAR 816 compared with SAR 1,300 or more for a traditional embroidered dress available on the market. Thus, not only are 3DP embroidery dresses better than traditional embroidered dresses in terms of time of production and cost, but also in relation to price range.

Table 17: Cost-benefit analysis of 3DP embroidery and traditional embroidered dresses

	Traditional embroidered dress	**3DP embroidery dress**
Time to prepare one dress	25 to 30 days (manufacturer survey) (75% of respondents in Figure 11 above).	one day (8-hour working day)
Price range	SAR 1,300 or more (68.75% of manufacturers in Figure 13 above).	SAR 816 (if 100% mark-up added to the average cost of SAR 408.02)
Average cost of manufacturing one dress	SAR 1,000 or more (81.25% of manufacturers in Figure 12 above).	SAR 408.02

Source: Appendix 8

From Table 17 above, it can be seen that the use of 3DP would mean that manufacturers would be required to incur a fixed cost of SAR 23,580.5. Given that this cost does not include renting or buying premises, manufacturers from rural areas may find it difficult to find the financial resources to integrate 3DP into their manufacturing process. To this end, it is suggested that manufacturers utilize the Small and Medium Enterprise Loan Guarantee Programme offered by the Saudi government for new start-ups and small businesses (Saudi Industrial Development Fund, 2020).

6.1.3.2: Human resource feasibility

As mentioned in section 6.1.2 above, the manufacturers of traditional embroidered clothing have demonstrated their concerns regarding the ease of use of technology. Ease of use is one of the factors of the TAM that aims to identify behaviours that assist in the acceptance or non-acceptance of new technology (Lai, 2017). With regard to ease of use, the TAM indicates that for people to adopt a new technology, it is important for those individuals to believe that they possess enough knowledge to use it. However, as stated above (section 6.1.2), most of the manufacturers of traditional embroidered clothes come from modest backgrounds, with little or no literacy, which means that 3DP could present challenges for them. The ease-of-use hurdle could be overcome by utilizing government-funded training programmes (*The National*, 2019). Section 2.1.5 of this thesis highlights various training programmes initiated by the Saudi government to support the development and growth of the local handicraft industry in Saudi Arabia. However, most of such programmes are limited to Riyadh. An application would be needed to request that the government extends the access of such programmes to the western region of Saudi Arabia, such as Hejaz, so that the revival of the traditional embroidery industry could be realized by the integration of new technology in the manufacturing process.

6.1.3.3: Supply chain feasibility

The supply chain feasibility of 3DP embroidery dresses concerns the distribution channel strategy. A distribution channel is a marketing concept that, in this case, identifies the places from which 3DP embroidery dresses would be sold to customers. To this end, it is suggested that traditional distribution channels, such as small shops, could be used. Moreover, given the rising use of social media for commercial activity, it is also suggested that this platform is used to sell 3DP embroidery dresses.

6.2: Conclusion

The discussion in this chapter has demonstrated that 3DP embroidery dresses would meet the suitability, acceptability and feasibility requirements of the embroidery industry in the KSA. From the suitability perspective, it was found that the integration of 3DP could directly address current market trends, such as the need for flexibility in the manufacturing process to meet customer needs and convenience in terms of the time it takes to manufacture one embroidered dress. The results of the washing and tensile tests demonstrated that customers' and manufacturers' concerns about the adhesion of 3D printed embroidery designs on fabrics could also be addressed. Finally, the feasibility of a 3DP embroidery dress was demonstrated from the financial, human resource and supply chain perspectives. Financially, it was found that 3DP embroidery dresses would be better than embroidered dresses made using the traditional method in terms of the length of time required to prepare a dress, price range and average cost (see Table 16). In terms of human resources, it was suggested that manufacturers could avail themselves of government-funded programmes to gain knowledge of how to use 3DP technology to manufacturer embroidered dresses. Moreover, the Saudi government's initiative to provide loans to small businesses could be used to cover the cost of 3DP. Finally, both physical and digital distribution channels can be used to sell 3DP embroidery dresses. Thus, 3DP technology has been identified as an appropriate solution to the revival of the traditional embroidery sector of the Saudi fashion industry.

The next, and final, chapter presents the findings of the research and its implications and contributions. The limitations of the research are also outlined, and recommendations offered.

Chapter VII

Conclusions, contributions, limitations and recommendations

7.0: Findings and implications

The purpose of this exploratory study was to ascertain the possibility of reviving the traditional embroidery industry in the Hejaz region of Saudi Arabia through the integration of 3DP technology in the manufacturing process. As a result of the historical, commercial, tribal and religious significance of the Hejaz region, the dress code of both women and men is influenced by traditional embroidered clothing. This thesis was developed to evaluate the challenges facing the traditional embroidery industry in the Hejaz region with specific attention to identifying ways in which the challenges identified could be overcome through the integration of advanced technologies such as 3DP.

A mixed method methodology was used to identify the challenges facing the traditional embroidery industry, followed by an assessment of the potential presented by advanced technologies, and further testing to support the inclusion of the proposed technology in the manufacturing process. To this end, various frameworks were developed that guided the process of data collection from the participants and the experimentation schemes. Overall, the research was guided by the following questions:

- What are the challenges facing the traditional embroidered clothing manufacturing industry in the western region of Saudi Arabia?
- What are the current manufacturing techniques for producing traditional embroidered clothing?
- How can 3DP be integrated into the manufacturing process of traditional embroidered clothing?
- What factors could influence the adoption of 3DP in the manufacturing of embroidered clothing in the Hejaz region of Saudi Arabia?

The above-mentioned research questions developed in this thesis sought to fulfil four objectives. The four objectives guide the discussion presented in the following sections of this chapter.

Objective I: Evaluate the challenges facing the traditional embroidery industry in the western region of Saudi Arabia

Qualitative methodology was used to achieve the first objective of this research. A review of the literature found that the traditional embroidery industry is facing the risk of demise, largely because of a lack of development in production techniques. It is due to such weaknesses in the production techniques of traditional embroidered clothes that their use has become limited to formal occasions, such as religious events, wedding parties and men's traditional dancing. Global brands have taken advantage of the industrialization of global business to fill the gap in the manufacturing techniques of traditional clothing in the KSA and launched their own embroidered dresses in the country. However, the core blame also lies in the lack of support provided to traditional embroidered clothing by both the fashion industry in the KSA and the Saudi government.

From a customer perspective, the review of the literature concluded that despite not wearing traditional embroidered dresses, consumers' perceptual and attitudinal associations with traditional clothes has not died. Instead, consumers have shown their willingness to use traditional dresses given that their manufacturing techniques could be re-engineered to meet current trends in the market.

Reasons behind the lack of development in the manufacturing techniques of traditional embroidery clothing have been linked to the non-availability of formal training. The review of the literature revealed that embellishing dresses requires expert skills that were usually transferred from one generation to another; thus, there exists a lack of involvement of external stakeholders in the development of the craft. The literature also identifies a lack of government support. Although the Saudi government has recognized the need for reviving traditional crafts in the country through the SCTH, which runs a variety of training and development workshops for local craftsmen/women, such as the Bari programme, it has proven to be too little too late. For instance, the target of most such programmes is the centre of the country, mainly Riyadh, rather than other parts of the country, such as the Hejaz region. Moreover, the government's programme of preserving traditional crafts is largely focused on providing sales platforms to avoid their exploitation by large firms and not on developing manufacturing techniques.

Objective II: Identify the current manufacturing techniques for embroidered clothing in the western region of Saudi Arabia

Similar to the approach taken to the first objective, the second objective of this study was also achieved using qualitative means. Currently, traditional embroidered dresses are produced using handmade techniques, such as stem, chain, Bedouin pinnacle, wave, Bedouin *waahed*, Bedouin *araba*, feather, blanket, black, cross, half-cross, flat, Cretan, dotting or seeding, and couching stitches. The variety of materials used in the production of traditional embroidered dresses includes glass beads, mother-of-pearl buttons, lead beads on the cuffs, and coins. Embroidery is usually placed on various locations of the dress, such as the sleeve cuffs, neckline opening, bodice, hems and some embroidery stitching running down from the waist. However, these production techniques do not meet current fashion trends, such as the fast fashion concept, the customization of design and mass production.

Ironically, the literature review also noted that the embroidery segment of the global fashion industry has witnessed technological adaptation, such as the use of machine embroidery designs that have been lauded for keeping traditional embroidered clothing alive today. In particular, rendering the application of machine embroidery technology assists in the finishing of embroidery designs, along with its capacity for mass production in less time. However, machine embroidery has been criticized for lacking the flexibility needed to meet current market trends. Computerized sewing machines have been introduced into the embroidery segment of the fashion industry globally. These machines are identified as possessing the capability to transmit digitally produced designs to sewing machines using software. Although these machines became popular in the 1990s, they are criticized for not meeting components of the post-Ford era, such as flexible specialization, decentralization of production and employee empowerment. This led the discussion to early millennium-era development in the hardware of embroidery techniques, such as the emergence of CAD software and single and multi-headed sewing machines. CAD has transformed the process of the ideation and actualization of designs, from the development of a concept to the formation and printing of an actual design onto fabric. However, the lack of ability of sewing machines to adjust to the changing demands of customers in modern business has resulted in a continued downward trend in combining CAD with sewing machines for the purpose of embroidery.

Against the backdrop of the lack of compatibility of CAD and sewing machines, Kim (2016) proposed the induction of 3DP into the operations of traditional crafts. Despite identifying various benefits, such as cost effectiveness, mass production, and flexible design and printing, its use in embroidered clothing has not taken place. Table 1 in chapter two indicated that although 3DP has been recognized as outweighing machine and CAD-enabled machine embroidery in terms of cost, convenience, speed, accuracy, scalability and customization, its quality element is unknown.

Objective III: Implement the use of 3DP in adding embroidery on textile fabrics

The third objective of this study was also achieved using qualitative methodology. In the first qualitative analysis, the process and evolution of 3DP in the fashion industry was evaluated. The process of 3DP was identified as being divided into four steps: laying out the design on CAD software, followed by modelling the layers on 3D software, product design and, finally, production. The researcher also found that 3DP has been used in the fashion industry since 1982, for producing prototypes, customizing products and offering customers an interactive choice-driven experience. As a result of its range of benefits, 3DP has been used by various global brands, such as Nike. Despite its recognized cost-related flexibility and customization of design and mass production, however, questions have been raised about the long-term wearability of garments produced using 3DP technology. A key criticism of 3DP clothing stems from the stiffness of 3DP designs, leading to the risk of the garment itself ripping apart as a result of washing. Similar questions have been raised regarding 3DP garments losing their brightness and shape after successive washing cycles.

Although widespread use of 3DP in the fashion industry has been noted, its employment in producing embroidery designs is scarce. Those who have attempted to use 3DP in embroidery have questioned the ability of technology to deal with complicated embroidery designs (Cui et al., 2017). Similarly, Martens and Ehrmann (2017) raised questions regarding the ability of 3DP materials, such as ANS, to maintain adhesion on fabric in the wake of applications of force. Finally, the lack of knowledge of embroidered clothing manufacturers about using 3DP technology has also been identified as one of the reasons behind the lack of use of this technology in this segment of the fashion industry globally (Vanderploeg et al., 2017; Yeh and Chen, 2018). In addition, Eng and Bogaert (2010) raised questions regarding consumers' attitudes towards conspicuousness, uniqueness, quality, hedonism, self-expression, and the perception of the quality of 3DP embroidery clothing.

The discussion relating to the third objective of this study raised both perceptual and technical concerns about the ability of 3DP to produce embroidery designs on dresses. Thus, the next objective of this study was aimed at assessing those concerns within the embroidery sector.

Objective IV: Analyse the factors that could influence the adoption of 3DP in the embroidery industry in Saudi Arabia

A quantitative methodology was used to achieve the fourth objective of this thesis. Firstly, the thesis aimed to evaluate manufacturers' and customers' perceptions of using advanced technology in the manufacturing process of traditional embroidered dresses. Two sets of surveys were organized. The manufacturer survey was based on a mix of Likert-style and multiple-choice questions. The Likert-style statements were designed to assess the opinion of manufacturers on the adoption of technology based on components of the TAM. To this end, Likert-style questions were designed to evaluate manufacturers' opinion of using technology, on the usefulness of using technology, their awareness of the availability of advanced technology such as 3DP, ease of use, and the wearability of embroidered dresses produced using technology. The second section of the manufacturer survey was designed to assist this thesis in conducting a cost-benefit analysis of traditional and 3DP embroidery dresses. To this end, respondents were asked for their opinion on factors that have an impact on the production of traditionally embroidered dresses, the time it takes to produce an embroidered dress using a handmade technique, the cost of producing embroidered dresses using traditional methods and, finally, the price quoted for an embroidered dress produced by hand. In contrast, the customer survey was designed on the basis of Likert-style questions to assess their opinion of technologically produced embroidered dresses based on factors of conspicuousness, uniqueness, quality, hedonism, self-expression, and quality perception.

An exploratory analysis of the survey results revealed that both manufacturers and customers showed interest in integrating technology in the production of traditional embroidered dresses. However, the manufacturers raised concerns about the ease of use of the technology and both customers and manufacturers raised the issue of the wearability and quality of embroidered dresses produced using advanced technologies such as 3DP.

To address the above-mentioned concerns of the manufacturers and customers, the research conducted two experiments, both of which were aimed at evaluating the long-term wearability of embroidery on dresses produced using 3DP. The aim of the first experiment was to test the impact of three washing cycles on edge, shape, roughness and brightness. The experiment included a range of equipment, such as FDM-based 3DP, CAD software, an Innex washing machine and three types of fabric: cotton, silk and organza. The following 3DP parameters were set: layer heights of 0.25 mm, 0.50 mm and 1.00 mm, nozzle temperatures of 240 °C, 245 °C and 250 °C, a nozzle size of 0.4 mm, and a bed temperature of 70 °C. Moreover, TPU printing material was used due to its elasticity and higher strength attributes. Using the aforementioned 3DP parameters, 27 samples of 3DP embroidery clothes were produced, nine for each type of fabric (cotton, silk and organza). Embroidery was shaped into floral and geometric designs to ensure that it resembled the designs of traditional hand-embroidered clothes. Prior to placing the embroidered textiles in the washing machine, a visual observation of each sample was conducted to evaluate the best samples for washing. Analysis of the visual test revealed that embroidery shapes printed at a 1 mm layer thickness presented the best visual test results against edge, shape, roughness and brightness. However, organza demonstrated the highest visual quality. Thus, the results of 3D samples printed on organza fabric at 1 mm thickness were used as a base scale for the purpose of analysing the results of the washing test. The washing test was conducted using ISO 6330 and the results were analysed under fuzzy image analysis software. Statistical analysis of the results revealed that washing did not have any major impact on the edge, shape, roughness or brightness of 3DP embroidery designs on the three fabrics when printed at a 1 mm layer thickness.

Secondly, a tensile test was conducted to assess the adhesion of embroidery shapes on the three fabrics. The peel test conducted in this study started with the production of 27 samples of 3D printed objects on two pieces of fabric in such a way that the TPU filament would create bonding between the two fabrics. The dimensions of the TPU filament were kept at 80*20 mm so that the researcher would be able physically to grab the two pieces of fabric. Finally, the peel test was performed using an Instron machine that applied a load of 95 kN at a speed of 20 mm/min, as specified under ISO 11339:2010. The results of the peel test were assessed against three parameters: fabric type, printing temperature and layer thickness. The results of the peel tensile test revealed that, comparative to silk and cotton, organza presented inconsistent adhesive forces, attributable to the rough texture of organza fabric. It is suggested that fabric texture has an impact on the adhesion force of 3DP embroidery designs. For instance, the smooth texture of silk and cotton resulted in a low SD, even when the maximum force was applied, presenting good adhesion. However, the same could not be said for organza due to its irregular shape. In contrast, all the samples demonstrated strong adhesive force at all layer thickness. However, while the adhesive forces were highest for organza and cotton fabrics when printed at 250 °C, the maximum adhesive force for silk was noted at 250 °C. Overall, the experiments revealed that 3DP embroidery objects presented good long-term wearability and quality as long as the printing parameters are set up to meet the fabric architecture.

Addressing the long-term wearability of 3DP embroidery samples in the experiments resulted in being able to establish the suitability and acceptability of 3DP for producing 3DP embroidery dress. The feasibility of 3DP embroidery dresses has been substantiated on the basis of financial, human resource and supply chain factors. An assessment of financial feasibility revealed that 3DP embroidery dresses would have an advantage over traditional methods of producing embroidered dresses in terms of time, price and average cost (see Table 1). The hurdle of ease of use can be overcome through an expansion of the Saudi government's initiative of reviving the embroidery industry in the KSA. Finally, 3DP embroidery dresses are also feasible in relation to the supply chain as they can be sold not only in traditional shops, but also by using digital distribution channel platforms, such as social media.

7.1: Contributions

The present study has made four core contributions: towards addressing challenges in reviving the traditional embroidery industry in the KSA; towards knowledge of using 3DP for embroidery on textiles; towards identification of the behaviour of fabric in relation to 3DP; and towards social development in Saudi Arabia, particularly in terms of women's empowerment.

7.1.1: Contribution towards the revival of traditional embroidered clothing

The present study has highlighted key challenges facing the traditional embroidery industry in the KSA, along with presenting solutions for its revival. In particular, it has identified that lack of development in the manufacturing process is a key reason behind the downturn in the traditional embroidery industry in the KSA and that it can be revived through the integration of new technology. Traditional embroidered garments possess significance for Saudi traditions, history and culture. Thus, by presenting solutions for its revival, the present study is directly contributing towards the preservation, development and growth of the industry.

7.1.2: Contribution towards knowledge of using 3DP for embroidery

The present study has demonstrated the applicability of 3D printing for embroidery on different textile fabrics. 3DP has been used in textile industry since 1982. However, it has not been used in the production of embroidery clothing. Through testing, applicability of 3DP to manufacture embroidery clothing, the present study will open a new era in the history of 3DP and it is a key contribution of this research.

7.1.3: Contribution towards the behaviour of fabric towards 3DP

The peel test results in this study revealed that the adhesion of 3DP material depends upon the behaviour of the fabric. For instance, due to their plain structure, both cotton and silk fabric showed strong adhesion to the 3DP material; however, due to its rough structure, organza showed inconsistent adhesion. To this end, this thesis proposes that an in-depth investigation of the behaviour of organza fabric is required in future research, since adjustment to 3DP parameters could improve the adhesion of 3DP material on organza.

7.1.4: Contribution towards social development in Saudi Arabia

The final contribution of this thesis stems from social factors related to the empowerment of women in Saudi Arabia. As part of its Vision 2030, the Saudi government has embarked on an ambitious programme of strengthening the contribution of women in the society and economy (Arab News, 2018). Considering that it is largely women who are involved in the manufacturing of embroidered clothing in Saudi Arabia (Ejeimi et al., 2018), the elimination of the embroidered clothing industry in Saudi Arabia could effectively result in women in the Kingdom losing their businesses. Thus, by identifying ways to revive the industry, the present study will directly contribute towards the social and economic role of women in Saudi Arabia and to fulfilling the Vision 2030 of the Saudi government.

7.2: Limitations and recommendations

The principal focus of this study was to revitalize the traditional embroidery industry in the Hejaz region of Saudi Arabia by the enhancement of manufacturing techniques. In this study, visual testing was used to select the best 3D printed sample for the purpose of conducting a washing test. However, visual tests have been criticized for their descriptive nature and technical flaws. In particular, the technical flaws of visual tests have implications for conclusions derived from a washing test. According to Chisholm (1995), one of the key limitations of a visual test is that it could impair the judgement of the researcher for various reasons, such as a failure to integrate fabric flaws and the impact of light and shade, neither of which are possible to identify with the naked eye. As the result of a lack of resources, the author of this study was unable to create, not only the environment needed for conducting a visual test, but also experts with appropriate knowledge of fabrics were not accessible. By virtue of the application of ±10% scale for testing the washing test results, however, any weakness in the visual test has been addressed. However, future research could further strengthen the conclusions derived in this research by using appropriate protocols for a visual test.

Geographical location was limited to the Hejaz region of Saudi Arabia because of the author's association with the area. However, this reduced the sample size and findings could lack generalization when considering that the fashion industry in the centre of Saudi Arabia, such as in Riyadh, is more advanced when compared with the western region of the country (Paton, 2018). For instance, in 2018, Riyadh held its first fashion week. Similarly, programmes organized by the Saudi government to support the development of traditional handicrafts, such as the Bari programme, are largely focused on Riyadh. Thus, there is a need to extend the geographical location of this research to the centre of the KSA, as there exists the potential that the results of a similar study may well differ completely.

Other limitations of this study stem from the use of face-to-face surveys compared with online surveys. Therefore, another recommendation of this study would be to structure future research in a way that would result in the engagement of a wider range of stakeholders by using an online survey. The present study only targeted university students studying in the textile faculties of three universities: Umm Al-Qura University in Makkah, King AbdulAziz University in Jeddah, and Taif University. It is contended in this research that as they are students of textiles, the students who took part would be in an appropriate position to understand the technical nature of using 3DP in a manufacturing process. It is the assertion of this study that there is a need to conduct co-design projects that would include the customer view of different phases of producing 3DP embroidery clothes, such as drawing a design, the final printing, and gaining an opinion on washing test results. The use of an online survey could be appropriate for such a study since it would not only reduce the resources required for data collection but would also allow the gathering of a larger number of responses.

Another limitation of this study is that it did not produce prototype garments, such as a complete 3DP embroidery dress, but small samples of 3DP embroidery clothing. The use of a prototyped 3DP embroidery dress would provide appropriate results by which to assess the suitability, feasibility and acceptability of 3D printed embroidery clothes. Future research could replicate the 3DP parameters and experimental schemes of this study to investigate the possibility of integrating 3DP technology in the manufacturing process of embroidered clothing. Such an addition to this study would allow the investigation of manufacturer and customer satisfaction with regard to the functional and aesthetic nature of 3DP embroidery clothing.

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APPENDICES

Appendix 1: Letter of permission from the Souq Okaz Festival management

Through Life Engineering
Services Institute
School of Aerospace, Transport and Manufacturing
Building 50
Cranfield University
Cranfield
MK43 0AL

www.cranfield.ac.uk

To Whom It May Concern

6th Jun 2018

Dear Sir/Madam,

One of my PhD student named Hind Algamdy is pursuing her research on the topic " To revive the traditional embroidery using advanced technologies in the Hejaz region in Saudi Arabia" at Cranfield University. In her research, she requires to perform field study by conducting interviews and survey with the relevant experts including the Handicraft manufacturers and the makers.

The student has made a plan to travel Saudi Arabia and collect the relevant data from the Handicraft participants of the "Sooqokaz at Taif city,and Handicraft makers at Saudi Handicraft Programs at Saudi Arabia". Her intended date of travel will be from 02/07/2018 to 02/10/2018.

I will appreciate if you can support her in This.

Yours faithfully,

Muhammad

Dr Muhammad Khan
Senior Lecturer - Fatigue and Damage Tolerance
E: muhammad.a.khan@cranfield.ac.uk
T: +44 - (0)1234754788

Permission granted by the management of Souq Okaz to conduct a survey

الموضوع : تقديم الدعم

سعادة الدكتور محمد خان سلمه الله

جامعة كرانفيلد

السلام عليكم ورحمة الله وبركاته ،،،

إشارة إلى كتابكم الوارد لنا بتاريخ ١٥ مايو ٢٠١٨ م المتضمن تسهيل مهمة المواطنة هند الغامدي في عمل دراسات وإجراء مقابلات مع الخبراء والمختصين في مجال الحرف والصناعات اليدوية في المملكة العربية السعودية

نحن في البرنامج الوطني للحرف والصناعات اليدوية " بارع " نرحب بتقديم ما يدعم مشروع المواطنة هند الغامدي وقيامها بالمقابلات مع الخبراء والمختصين في مجال الحرف والصناعات اليدوية المشاركون في مهرجان سوق عكاظ وزيارة الحرفيين الغيرمشاركين وذالك عبرالبرنامج الوطني للحرف والصناعات اليدوية (بارع) وذالك من تاريخ ٢/٧/ ٢٠١٨ م الى٢/١٠/٢٠١٨ م .

مع تمنياتنا لكم بالتوفيق والنجاح ،،،

المدير التنفيذي

على البرنامج الوطني للحرف والصناعات اليدوية

د . شرف بن قاسم العبدالوهاب

Saudi Crafts 'BAREA' |Saudi Commission for Tourism and Antiquities| |Office +966 118808853| Fax +966 11 8808844 |

Translation

Dear Dr Muhammad Khan at Cranfield University.

Regarding your letter of 15 May 2018 about your PhD student named Hind Algamdy for collecting data and holding interviews with handicraft manufacturers and the maker's participants of the Souq Okaz at Taif city, we at the Saudi Handicraft Programme can support her study. And give her permission to do this.

Appendix 2: Manufacturer survey

Title

To revive traditional embroidery using advanced technologies in the Hejaz region in Saudi Arabia

Aim

The overall aim of this study is to address the mentioned risk to Saudi culture and heritage by investigating how future manufacturing techniques can be used to enhance the current state of the embroidery industry and make it competitive with existing Western clothing.

Demographic questions

Gender				
Male				
Female				
Do not want to mention				
Age				
18-20 years				
20-25 years				
25-30 years				
30-35 years				
35 years or over				
Experience				
0-5 years				
5-10 years				
10-15 years				
15 years or over				

Opinion on integration of technology in manufacturing of embroidered clothes

Factors/Questioners	**Strongly agree**	**Agree**	**Neither agree nor disagree**	**Disagree**	**Strongly disagree**

Perception					
Q2: Embroidered clothes made using technology will meet customer taste.					
Awareness					
Q3: Manufacturers are aware of the availability of technology that can be used to manufacture embroidered clothes.					
Usefulness of using technology					
Q4: Speeding up of process, ease of creating designs and large-scale production are key benefits of using technology in embroidery clothing.					
Wearability					
Q5: Wearability and washing are key concerns regarding the use of technology in embroidering clothes.					
Ease of use					
Q6: Lack of know-how and training are key hurdles in the use of technology in the production of embroidered clothes.					

Appendix 3: Customer survey

Title

To revive traditional embroidery using advanced technologies in the Hejaz region in Saudi Arabia

Aim

The overall aim of this study is to address the mentioned risk to Saudi culture and heritage by investigating how future manufacturing techniques could be used to enhance the current state of the embroidery industry and make it competitive with existing Western clothing.

Demographic questions

Age				
18-20 years				
20-25 years				
25-30 years				
30-35 years				
35 years or over				
Education level				
Undergraduate				
Postgraduate				
Doctorate				

Opinion on use of embroidered clothing produced using 3DP

Factors/Questioners	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
Conspicuousness					
Q1: Do you think that traditional embroidered clothes meet current fashion trends?					
Uniqueness					
Q2: Do you agree that embroidered clothes made using technology will present taste and results as unique as that with traditional clothes?					
Quality					
Q3: Do you agree that embroidered clothing made using technology would conform to comfort/originality/ Aesthetic features?					
Hedonism					
Q4: I would recommend my friends and family to wear embroidered clothing					

made using new technology.					
Self-expression					
Q5: Do you think that embroidered clothing made using technology will meet current fashion trends?					

Appendix 4: Participants' information sheet

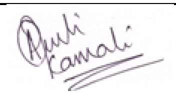
Hi, I am Hind Mosfeer Saeed Al-Gamdy, a PhD student at Cranfield University in the UK. As part of my final thesis, I am investigating the possibility of reviving the traditional embroidery industry in the Hejaz region of Saudi Arabia, under the title "To revive traditional embroidery using advanced technologies in the Hejaz region in Saudi Arabia". To this end, I would like to request you to please provide me with your feedback on the following questions. You can be assured that your identity will be kept anonymous throughout the process of this research and that responses you provide with neither be shared with any third party nor used to gain any commercial benefit. Moreover, you possess the complete right not to participate in this survey entirely or to skip some questions. If you have any other inquiry, please do not hesitate to contact me at Hind.m.algamdy@cranfield.ac.uk.

Appendix 5: Risk assessment for the 3DP experiment

Risk Assessment Form
CU-SHE-FORM-3.01
V3.0

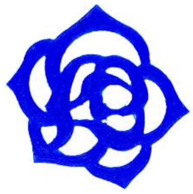
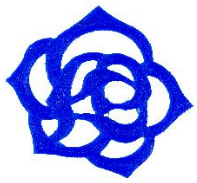
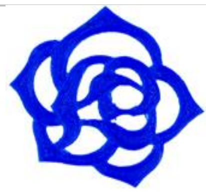
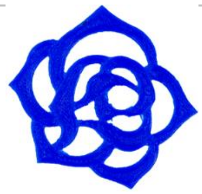
Risk Assessment Number:		**Task/Activity assessed:**				
Name/job role of people consulted during assessment:	Kirkwood, Leigh Research Fellow in Competitive Engineering -SATM		**Date of Assessment:**	28-11-2018	**Review Date:**[4]	

Acknowledgements, Sign off and Authorisation	Acknowledgement	Name	Signature	Date
Risk Assessor:	By signing this risk assessment I acknowledge my responsibility as the Risk Assessor for conducting this risk assessment in accordance with CU-HAS-PROC-3.01, Risk Assessment Procedure.			
Checked by: (where required)	By signing this risk assessment I acknowledge my responsibility as the checker for this risk assessment in accordance with CU-HAS-PROC-3.01, Risk Assessment Procedure.			
Authorising Person:	By signing the risk assessment, I acknowledge my responsibility as the Line manager/Supervisor for reviewing and approving this risk assessment and communicating controls and any additional controls to staff/students (as appropriate).			

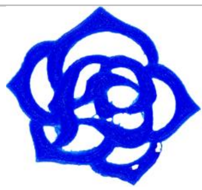
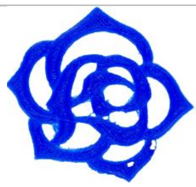
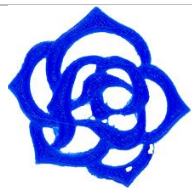
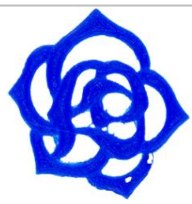
Tasks/Operational steps/Sub tasks/Events:		Significant hazards – • What could happen and why?	Who is affected and how – • Who might be hurt? • How bad could it reasonably be?	What are your existing controls? (Reference all Safe Systems Of Work (SSOW), Standard Operating Procedures (SOP) and Emergency Procedures)	Existing Risk Rating (Consequence x Likelihood = Total)			Are additional controls needed? Y/N (If Yes, RAMP required)
					C	**L**	**TOTAL**	
1	Heating up of 3D printers	Might burn hand if touched unintentionally	Student conducting experiment. it could be bad since it could result in damaging skin	Wearing gloves to ensure safety of hands. Having first aid box nearby to provide first aid to the student in the case of hand burn.	5	1	5	N
2	Removing the 3DP object from 3DP bed	Might burn hand if 3DP is not closed	Student conducting experiment. it could be bad since it could result in damaging skin	Ensuring that 3DP is turned off. Also wear gloves for the safety of hands.	5	1	5	N
Supervisor: Dr Muhammad Khan								

Appendix 6: Fuzzy image analysis results for edge, shape, roughness and brightness at 0 to 3 washes

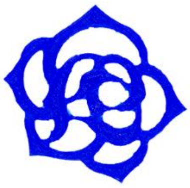
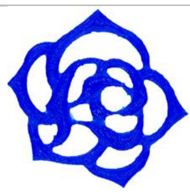
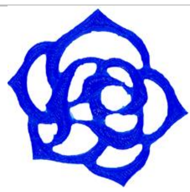
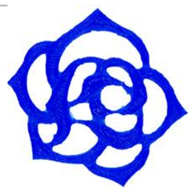
Cotton 240 °C

Samples	**Edge**	**Shape**	**Roughness**	**Brightness**	**Images**
0 Wash cotton at 240 °C	0.0649	0.0571	1.1625	5.4862	
1 Wash cotton at 240 °C	0.0909	0.0817	1.7859	5.5094	
2 Wash cotton at 240 °C	0.0872	0.0757	1.7524	5.5066	
3 Wash cotton at 240 °C	0.0995	0.0881	1.2607	5.5053	

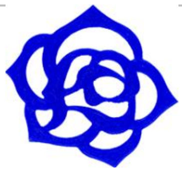
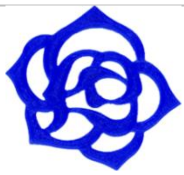
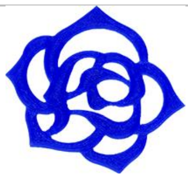
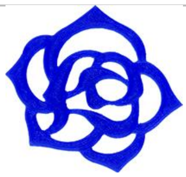
Cotton 245 °C

Samples	Edge	Shape	Roughness	Brightness	Images
0 Wash cotton at 245 °C	0.247	0.1711	1.9321	5.4833	
1 Wash cotton at 245 °C	0.2408	0.1743	1.4383	5.5125	
2 Wash cotton at 245 °C	0.2597	0.1912	1.3405	5.5147	
3 Wash cotton at 245 °C	0.257	0.1891	1.9829	5.5106	

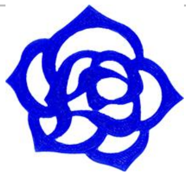
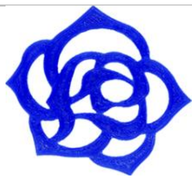
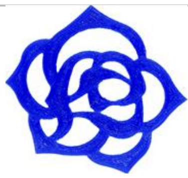
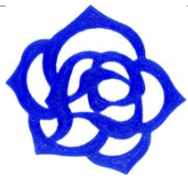
Cotton 250 °C

Samples	Edge	Shape	Roughness	Brightness	Images
0 Wash cotton at 250 °C	0.0866	0.0824	1.9011	5.6522	
1 Wash cotton at 250 °C	0.0639	0.058	1.1262	5.6698	
2 Wash cotton at 250 °C	0.0761	0.0686	1.5407	5.6694	
3 Wash cotton at 250 °C	0.0699	0.0632	1.8381	5.6682	

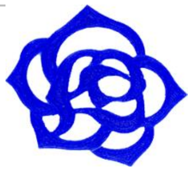
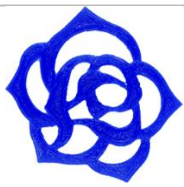
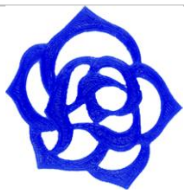
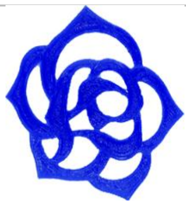
Organza 240 °C

Samples	Edge	Shape	Roughness	Brightness	Images
0 Wash organza at 240 °C	0.0966	0.0824	1.2658	4.8906	
1 Wash organza at 240 °C	0.0639	0.058	1.1987	4.8875	
2 Wash organza at 240 °C	0.0761	0.0636	1.2864	4.8905	
3 Wash organza at 240 °C	0.0699	0.0632	1.0411	4.838	

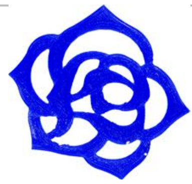
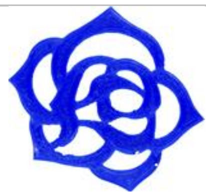
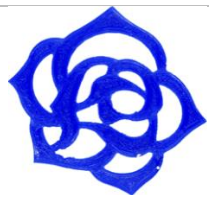
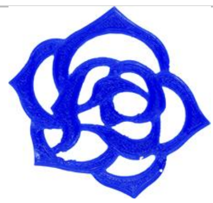
Organza 245 °C

Samples	Edge	Shape	Roughness	Brightness	Images
0 Wash organza at 245 °C	0.087	0.0784	1.4061	4.952	
1 Wash organza at 245 °C	0.0914	0.0844	1.4995	4.9525	
2 Wash organza at 245 °C	0.086	0.0764	1.4149	4.9542	
3 Wash organza at 245 °C	0.0902	0.0814	1.0992	4.8297	

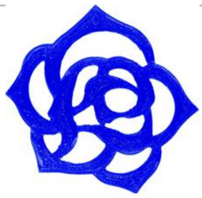
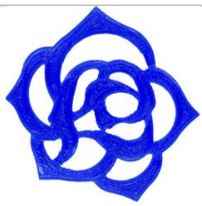
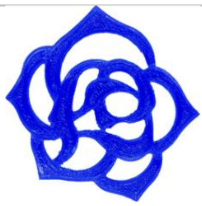
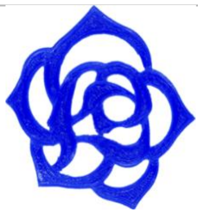
Organza 250 °C

Samples	Edge	Shape	Roughness	Brightness	Images
0 Wash organza at 250 °C	0.0861	0.0751	1.4499	4.9312	
1 Wash organza at 250 °C	0.0877	0.0777	1.4173	4.9346	
2 Wash organza at 250 °C	0.0924	0.0841	1.4591	4.9301	
3 Wash organza at 250 °C	0.0755	0.0664	1.252	4.8759	

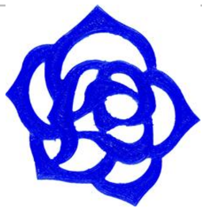
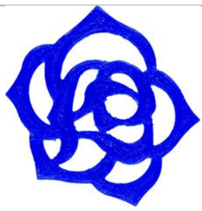
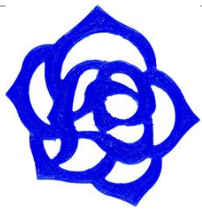
Silk 240 °C

Samples	Edge	Shape	Roughness	Brightness	Images
0 Wash silk at 240 °C	0.0813	0.0697	1.4472	4.9573	
1 Wash silk at 240 °C	0.0774	0.0631	1.4062	4.9608	
2 Wash silk at 240 °C	0.0753	0.0669	1.3378	4.9597	
3 Wash silk at 240 °C	0.0699	0.0638	1.2895	4.8766	

Silk 245 °C

Samples	Edge	Shape	Roughness	Brightness	Images
0 Wash silk at 245 °C	0.0784	0.0698	1.4828	4.9491	
1 Wash silk at 245 °C	0.0611	0.0603	1.4524	4.9458	
2 Wash silk at 245 °C	0.0709	0.0639	1.4412	4.9446	
3 Wash silk at 245 °C	0.0913	0.0878	1.0821	4.8068	

Silk 250 °C

Samples	Edge	Shape	Roughness	Brightness	Images
0 Wash silk at 250 °C	0.0822	0.0778	1.3571	4.9076	
1 Wash silk at 250 °C	0.0881	0.0793	1.3953	4.8939	
2 Wash silk at 250 °C	0.0881	0.0802	1.4152	4.8942	
3 Wash silk at 250 °C	0.0881	0.0802	1.3953	4.8942	

Appendix 7: Descriptive analysis of fuzzy image processing results

Descriptive analysis of MATLAB results of cotton fabric at 0 to 3 washes at 245 °C

Criteria	**Mean**	**Standard deviation**
Edge	0.25	0.008
Shape	0.18	0.01
Roughness	1.67	0.81
Brightness	5.5	0.14

Descriptive analysis of MATLAB results of cotton fabric at 0 to 3 washes at 250 °C

Criteria	**Mean**	**Standard deviation**
Edge	0.07	0.04
Shape	0.06	0.01
Roughness	1.40	0.21
Brightness	5.66	0.08

Descriptive analysis of MATLAB results of organza fabric at 0 to 3 washes at 240 °C

Criteria	**Mean**	**Standard deviation**
Edge	0.07	0.01
Shape	0.06	0.01
Roughness	1.19	0.11
Brightness	4.87	0.02

Descriptive analysis of MATLAB results of organza fabric at 0 to 3 washes at 245 °C

Criteria	**Mean**	**Standard deviation**
Edge	0.08	0.02
Shape	0.80	0.03
Roughness	1.35	0.17
Brightness	4.92	0.06

Descriptive analysis of MATLAB results of organza fabric at 0 to 3 washes at 250 °C

Criteria	Mean	Standard deviation
Edge	0.08	0.007
Shape	0.07	0.007
Roughness	1.39	0.09
Brightness	4.91	0.02

Descriptive analysis of MATLAB results of silk fabric at 0 to 3 washes at 240 °C

Criteria	Mean	Standard deviation
Edge	0.07	0.004
Shape	0.06	0.003
Roughness	1.37	0.07
Brightness	4.93	0.04

Descriptive analysis of MATLAB results of silk fabric at 0 to 3 washes at 245 °C

Criteria	Mean	Standard deviation
Edge	0.07	0.004
Shape	0.07	0.003
Roughness	1.34	0.07
Brightness	4.91	0.04

Descriptive analysis of MATLAB results of silk fabric at 0 to 3 washes at 250 °C

Criteria	Mean	Standard deviation
Edge	0.08	0.002
Shape	0.07	0.001
Roughness	1.39	0.02
Brightness	4.89	0.06

Appendix 8: Analysis of scale for rating the

Scale	**Edge**	**Shape**	**Roughness**	**Brightness**
1	Worse (4 different places in the Edge broken)	Worse (4 different places in the Shape broken)	Worse (irregular Roughness in 4 different places in the design)	Worse (weak brightness in 4 different places in the design)
2	Bad (3 different places in the Edge broken)	Bad (3 different places in the Shape broken)	Bad (irregular Roughness in 3 different places in the design)	Bad (weak brightness in 3 different places in the design)
3	Good (2 different places in the Edge broken)	Good (2 different places in the Shape broken)	Good (irregular Roughness in 2 different places in the design)	Good (weak brightness in 2 different places in the design)
4	Very good (1 place in the Edge broken)	Very good (1 place in the Shape broken)	Very good (irregular Roughness in 1 place in the design)	Very good (poor brightness in one place in the design)
5	Excellent (no Edge has broken)	Excellent (no place in the Shape has broken)	Excellent (Regular Roughness in all the area in the design)	Excellent (no a weak brightness in any places in the design)