ABSTRACT

HIDER, CLAIRE, ELIZABETH. Assessment of Digital Printing on Jacquard Woven Fabrics (Under the direction of Dr. Traci Lamar).

This research explored the concept of providing coloration through digital printing to jacquard woven fabrics. Specifically, the research objective was to determine expert response to inkjet digitally printed jacquard woven base cloths.

To address the research objective, three research questions were developed. [1] How do professionals in the textile industry respond to digitally printed jacquard woven fabric samples? [2] Are there differences in expert perceptions of a digitally manipulated photograph and a digitally manipulated painting as digital prints for jacquard woven base cloths? [3] Are there differences in expert perceptions of digitally printed jacquard woven samples based on whether the designs for weaving and printing were based on the same imagery or different imagery?

The research was approached in five stages. These stages were (1) develop jacquard woven base cloths for digital printing; (2) develop digital printing files; (3) digitally printing the jacquard woven base cloths; (4) design a survey for visual assessment of the printed jacquard samples, (5) gather, analyze and interpret expert responses to the printed jacquard samples.

Jacquard weaving and digital printing are both established methods to produce multiple colors and patterns in textiles, but their combination offers potential significance as an innovative fabric coloration method. To understand the capabilities of each of these methods and to find the most efficient processes of combining them, a literature review was developed. Initial pilot work explored techniques for fixing the ink onto the woven substrate

based on the loom setup and yarns used during the research. Additional exploration allowed determination of the optimal ink amount needed to provide adequate color saturation. Based on the learnings from the pilot work, three sets of six samples for participant review were created. Through the development of samples and expert assessment, some potential benefits to the textile industry and factors to consider were discovered.

Assessment of Digital Inkjet Printing on Jacquard Woven Base Cloths.

by
Claire Elizabeth Hider

A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the degree of
Master of Science

Textiles

Raleigh, North Carolina

2018

APPROVED BY:

Dr. Traci Lamar Committee Chair	Dr. Lisa Parrillo-Chapman
Dr. Marguerite Moore	Dr. Stacy King

DEDICATION

Dedicated to my parents, John and Karen Hider, who have not only supported me and encouraged me to strive for my loftiest aspirations, but also to stop and smell the roses along the way. Thank you, Mom and Dad, for everything you do and for your wisdom. I would also like to dedicate this thesis to my brother Alec Hider, who has always motivated me and inspired me to live each day doing what I love.

BIOGRAPHY

Claire Hider was born on September 11, 1994, in Cincinnati, Ohio and currently lives in Kernersville, North Carolina. She finished a Bachelor of Science degree at North Carolina State University in Fashion and Textile Design with a concentration in Textile Design. Claire enrolled in the Accelerated Bachelor's and Master's Program during her senior year, which allowed her to begin taking graduate and undergraduate courses simultaneously.

During her Master of Science education at North Carolina State University, Claire was awarded both a Graduate Teaching Assistantship and a Graduate Research Assistantship. In addition to completing her M.S. in Textiles, Claire also obtained a minor in Business Administration.

To gain industry experience in textile design and creation, Claire completed internships at Cotton Incorporated in Woven Product Development, Glen Raven in Custom Fabrics Design, and Valdese Weavers in Textile Design. To learn some textile marketing aspects, Claire was also a student consultant to Cotton Incorporated as part of the NC State Consumer Innovation Collaborative. Her current interests involve creating fabrics for a variety of markets.

ACKNOWLEDGMENTS

With the help and encouragement of many individuals, this thesis was completed. They have continuously been a reminder of the positive impact which comes when those within an ecosystem unite.

I would like to impart a special word of thanks to Dr. Traci Lamar, my committee chair, for her constant guidance and insight throughout my education at the NC State College of Textiles. I would also like to extend gratitude to Dr. Lisa Chapman, Dr. Marguerite Moore, and Dr. Stacy Wood, my committee members, for their support and assistance in completing this research.

The Nonwovens Institute and The NC State College of Textiles laboratory managers and technicians: Ms. Theresa White, Mr. William Barefoot, Mr. Tri Vu, Mr. Jeff Krauss, Mr. Brian Davis, Mr. Tim Pleasants, Ms. Jennifer Vekert, and Mr. Ming Wang, all of whom assisted with creating research samples and providing an excellent learning environment.

My fellow graduate students showed me the ropes and provided examples of thesis defense and preparation. Thank you all for your help and humor during this process.

I would like to thank emeritus professor and one of my undergraduate advisors, Nancy Powell, for her continued mentorship.

I would like to communicate my gratitude to those who agreed to participate in my research study and graciously contributed their expertise to this thesis.

And last but certainly not the least, a sincere thank you to my peers, Kendra Allgood, UiKyung Jung, Megan Moore, Drew Piland, and Nicole Villarreal.

Thank you, again. I am forever grateful.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

GLOSSARY

Fabric

Aesthetic – “Of, relating to, or dealing with aesthetics or the beautiful” (Merriam-Webster, n.d.a.).

Appearance – “Outward aspect;” “A sense impression or aspect of a thing” (Merriam-Webster, n.d.b.).

[Fabric] Substrate – The base cloth for printing. This base cloth can be constructed from a variety of yarns interlaced together.

Fabric Back/Technical Back – The wrong side of a fabric when the construction used has a distinct difference between the front and back of the cloth.

Fabric Surface/Technical Face – The top or front of a fabric, when the construction used during manufacturing has a distinct difference between the front and back of the cloth.

Upholstery Fabric – Textiles which are created for use in furniture covering. These textiles are typically heavier and have a higher resistance to wear than fabrics used in apparel.

Printing

Color Saturation – The depth of coloration added to the substrate. Different levels of depth can be achieved through factors such as the amount of ink added to the substrate, amount of fixation, and type of colorant.

Dye – A type of colorant that penetrates the surface of the fabric (Cie, 2015).

Inkjet Digital Textile Printing (DP) – A form of non-contact printing where droplets of ink are delivered onto fabric for coloration. This process was adapted from digital paper printing (Cahill, 2006; Cie, 2015).

Ink – The type of colorant that is used in digital printing which is dispensed from a print head to create the intended design on the substrate. Ink can be created from a pigment or a dye (Ballard, 2016; Cie, 2015; Freire, 2006).

Pigment – A type of colorant that is adhered to the fabric surface through the use of a binder (Cie, 2015).

Pretreatment – Chemicals used before digital printing that aid with color fixation and design clarity. Can also refer to any processes in which the substrate is prepared for digital printing (Hawkyard, 2006).

Posttreatment – Process or processes applied to the fabric after printing to aid with color fixation. Can also refer to any processes that the fabric is subjected to after printing such as laundering (Hawkyard, 2006).

Screen Printing – A type of printing that uses one or more screens to apply a single color at a time. This type of coloration can be either mechanical or by hand. (Carden, 2016).

Photographic Effects – A type of digital print design that has virtually as many colors as one would see in a photograph, which does not need the number of colors to be reduced before digital printing (Liao & Chen, 2011).

Fixation – The process to adhere the colorant to the substrate after printing. With cotton fibers printed with fiber-reactive dye-based inks, steaming is often used (Hawkyard, 2006).

Fiber-Reactive Dye – A type of dye that is commonly applied to cellulosic fibers. This dye is included in the ink when applied through digital printing (Hawkyard, 2006).

% owb – On Weight of Bath – a unit of measurement for continuous textile wet processing to determine the amount of a chemical in a solution, often defined in g/L (Ballard, 2016).

Weaving

Dobby Weaving – A type of weaving that can create more complex patterns than hand weaving or weaving with a limited number of harnesses but is not as complex as jacquard weaving (Seyam, 2011). Traditionally, a dobby loom contains up to 24 harnesses.

Ends Per Inch (EPI) – A unit of measurement used to calculate warp yarn density in weaving. When used with PPI, the resulting woven fabric's density can also be calculated.

Jacquard Weaving (JW) – A type of weaving where complex patterns can be created into the fabric during fabrication (Seyam, 2011).

Jacquard Patterning – A method of patterning which occurs during weaving. Each heddle can be lifted individually by the jacquard head and can create intricate designs (Seyam, 2011).

Picks Per Inch (PPI) – A unit of measurement used to calculate weft yarn density in weaving. When used with EPI, the resulting woven fabric's density can also be calculated.

Warp – The vertical set of yarns used in all types of weaving. These yarns are placed on the loom as a base for the weft (horizontal) yarns, which will be interlaced with the warp yarns to create woven fabric (Phipps, 2011).

Weft / Filling – The horizontal yarns used in all types of weaving which lie perpendicular to the warp (vertical) yarns. These yarns are inserted across the width of the fabric on the loom (Phipps, 2011).

Shed – The opening of the warp yarns to insert weft yarns and create fabric intersections which produce woven fabric. The shed can be opened and closed in differing sequences to create different weave structures in the fabric (Seyam, 2016).

Loom Setup – The method in which a loom is prepared for weaving. Some of the factors related to loom setup are the yarns used in weaving, the number of harnesses on a jacquard head, the fiber type and size of the warp yarns, and the width of the repeated pattern which can be woven into the cloth (Seyam, 2011; Seyam, 2016).

Weaving – An interlacing of yarns at right angles in different combinations to create fabric. The changing interlacing sequences produce different designs (Ng, Kim, Hu, & Zhou, 2014; Seyam, 2011).

Weave Structure – Specific interlacing sequences in weaving which create different effects on the fabric.

Weaving [Color] Layers – Due to the capabilities of weaving, some weave structures require yarns to be inserted in layers which thicken the fabric but allow for colors to be used in selected areas of a design (Seyam, 2016; Ng & Zhou, 2010; Ng et al., 2014).

<u>Yarns</u>

Bouclé Yarn – A type of yarn that has textured areas created from loops formed through wrapping yarns around a core. The amount of wrapping causes loops of different sizes (Gong & Wright, 2002).

Chenille Yarn – A fuzzy looking yarn created from the integration of inserting small fibers inside two yarns which hold the fibers together. This type of yarn can also be created by using a pile yarn which is twisted with the binder yarns and then the pile is cut and fluffed to exhibit a fuzzy texture. (Gong & Wright, 2002).

Novelty or Fancy Yarn – Type of yarns which have unique areas or purposeful defects, when compared to traditional yarns which are made from uniform strands and any deviation is not desired. (Gong & Wright, 2002).

Mercerization – A chemical process that can be applied to cotton which increases fiber uniformity, luster and dye uptake (Ballard, 2016).

Slub Yarn – A yarn with intentional thick or thin spaces which show on the surface and alter the diameter of the yarn in the uneven sections. (Gong & Wright, 2002).

Space Dyed Yarn – A yarn which is purposefully dyed different colors in different sections to create variegated surface appearances in the resulting fabric (Fabric Link, n.d.)

CHAPTER 1: INTRODUCTION

An undergraduate weaving project conducted by the Principal Investigator (PI) initiated this research. In the project, digital textile printing and jacquard weaving were combined to create fabrics with more precise and more unique surface designs than could be woven on the loom construction at North Carolina State University's College of Textiles during Fall 2016. The results yielded unexpected artistic elements that were considered to have the potential to be utilized on a larger scale than an academic project.

This research explored the capabilities of combining inkjet digital textile printing and jacquard weaving for application in the fabrics industry. One research objective was identified in this study: to determine expert impressions of digitally printed jacquard woven base cloths. Three research questions were identified to create specific areas for study.

1.1. Research Objective

The Principal Investigator (PI) established a single research objective which was explored in three questions. The research objective was: To determine expert response to digitally inkjet printed jacquard woven base cloths. The research questions were: [1] How do professionals in the textile industry respond to digitally printed jacquard woven fabric samples? [2] Are there differences in expert perceptions of a digitally manipulated photograph and a digitally manipulated painting as digital prints for jacquard woven base cloths? [3] Are there differences in expert perceptions of digitally printed jacquard woven samples based on whether the designs for weaving and printing were based on the same imagery or different imagery?

1.2. Significance of Research

Jacquard weaving has become an efficient way to provide fabric coloration during production. Digital inkjet textile printing is a method of applying coloration to the fabric after it has been produced through knitting, weaving, or nonwoven techniques.

Through the combination of these two methods, more novel surface aesthetics could be achieved than when only printing or only during fabric formation. A possible new approach to add interest to a jacquard woven base cloth is to print onto the fabric face digitally.

Although this is a combination technique which is not used on a commercial level, it has potential to create a positive impact for the home textiles industry. Potential impacts could be factors such as increasing the number of colors in a woven fabric without adding yarn complexity, consumption, fabric weight, or fabric stiffness.

CHAPTER 2: LITERATURE REVIEW

2.1. History of Printing on Textiles

Digital fabric printing was developed from a long history of providing coloration to substrates. Early cave drawings are still found which provide examples of paint being applied to the walls to add design in a living space (Carden, 2016). Even before the concept of printing the same repeating design along the surface of the cloth was conceived (or cloth was even being made), patterns were being applied to surfaces for aesthetic enhancement (Carden, 2016). With the invention of repeatable tiles around the era of Ancient Greece, different styles could achieve a similar result, depending on the substrate (Carden, 2016). An early method of textile printing emerged from the woodblock technique which involved an artist creating a repeatable design and then was cut out of a block of wood for stamping onto the substrate (Carden 2016). Printing is believed to have been developed in China before the 9^{th} century when books were being created using carved blocks of wood (Carden, 2016).

Copperplate printing, which involved the design being etched into a metal plate, was invented in the 15th century, although it took approximately three centuries until it was used to print textiles (Carden, 2016). While this printing method is similar to woodblock, there are some significant differences (Carden, 2016). Woodblock printing required inks with a lower viscosity, or fluidity, which was applied to the block and placed onto the fabric (Carden, 2016). Copperplate printing created lines which were far finer than carved blocks, and the ink needed to be far more viscous, to fill the etching (Carden, 2016). The substrate was also placed onto the plate, which was opposite to woodblock printing (Carden, 2016).

Figure 1. Engraved Rollers for Rotary Screen Printing Machine (Laxmi, n.d.).

Around the 18th century, innovations in textile printing such as engraved roller printing, which allowed for more detailed designs than were previously commercially viable, were developed (Watt, 2003). Since this method required engraved rolls, the size of earlier repeats was limited to the size of the rolls being used (Carden, 2016). Similar to block printing, the fabric was placed under the printing medium, but the substrate could be fed under at a constant speed, which quickened production and lowered costs (Carden, 2016; Watt, 2003). An example of roller printing can be seen above in Figure 1.

Screen printing, or the printing of an image onto a textile through a screen, was a technology being used by the 1930s (Carden, 2016). Screen printing allowed an image to be printed directly onto the surface of the fabric by a paste that carried the colorant through the screen (Carden, 2016). An important notation is that, unlike woodblock printing, the design was developed on the screen in the negative (Carden, 2016). By the middle of the 20th century, rotary screen printing could also be produced (Carden, 2016). Rotary screen printing largely replaced the usage of engraved roller printing by late in the 1900s (Carden, 2016).

An example of the screen printing process, when applied by hand, can be seen below in Figure 2.

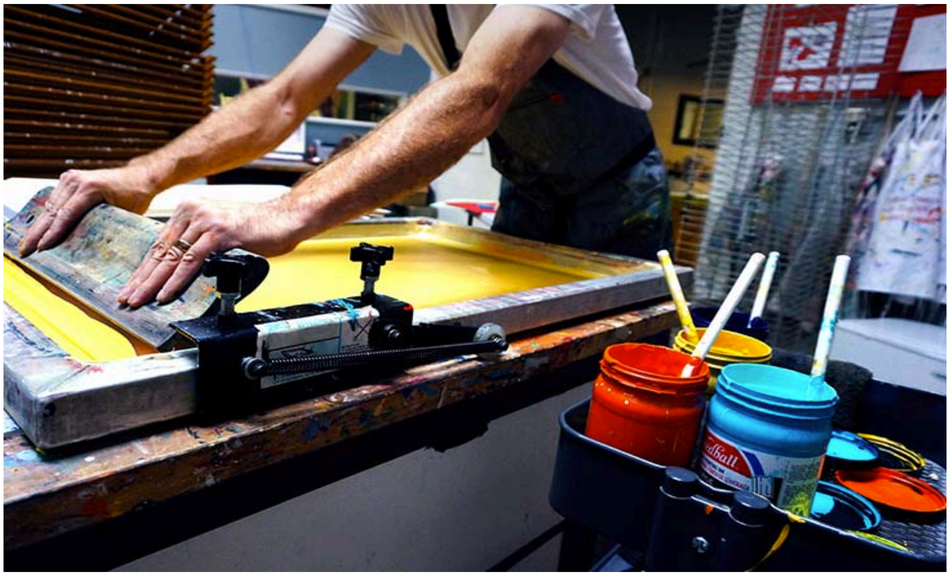


Figure 2. Process of Hand Screen Printing on Fabric (Threadbird, n.d.).

Paper digital printing emerged during the 1970s and was a method which used small droplets of ink sprayed onto the substrate without touching the surface (Pluck, 2017). Different colors of ink could be sprayed in an intended design (Kan & Yuen, 2012; Pluck, 2017). An illustration of the digital printing process can be seen on the following page in Figure 3.

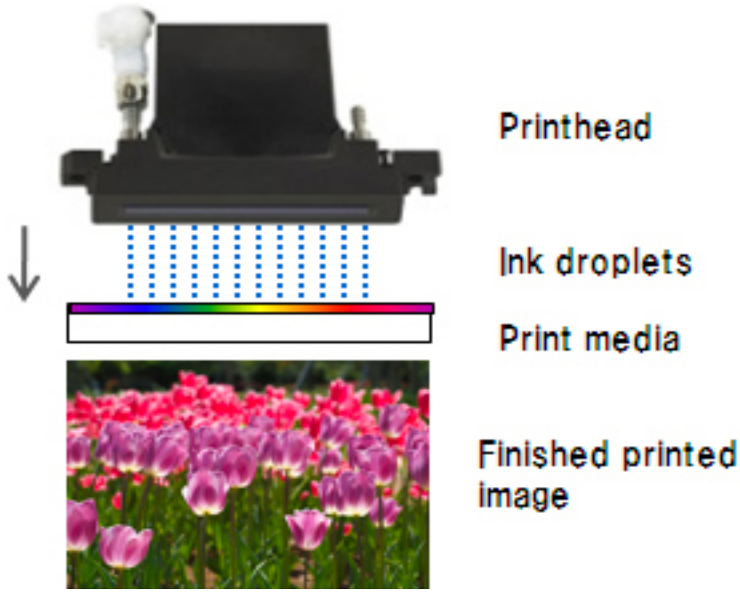


Figure 3. Example of Digital Printing onto A Substrate (Konica Minolta, n.d.).

Around the same time as the paper was being colored through digital printing, a similar technology was created by Milliken to apply digital printing to carpets (Cahill, 2006). This technology was released in 1975 and was called the Milliken Millitron (Cahill, 2006). A stream of dye was continuously projected from nozzles across the whole print bed width, and air jets were used to deflect unnecessary dye from the carpet to create the intended image (Cahill, 2006).

Throughout the rest of the 1970's, additional printing techniques such as sublimation and thermal were developed (Cahill, 2006). Sublimation printing involves the transfer of an image onto fabric by printing on a paper and thermal printing the heating of a stream of ink to create an image which could be transferred from a printing substrate to fabric (Cahill, 2006). The 1980's brought the innovation of printing directly onto the fabric surface (other than carpet) and other substrates such as large signage (Cahill, 2006).

At the 1995 International Textile Machinery Association, or ITMA, tradeshow, an early digital textile printer was seen, but it was not until ITMA 1999 that significant improvements were made to fabric printer design (Kan & Yuen, 2012). During the end of the 1990s and into the 2000s, significant improvements were made to digital textile printing, but the speeds at which fabrics could be printed were too limiting for commercial production (Cahill, 2016; Parrillo-Chapman, 2016).

At the ITMA 2007 tradeshow, printers were debuted which could print at approximately 150 meters per hour, squared (Parrillo-Chapman, 2016). While this increase in printing speeds was significant, it did not offer manufacturers a cost-effective way to print fabrics over medium-length printing runs (Parrillo-Chapman, 2016).

A notable textile industry development unveiled at the ITMA 2015 show was single-pass printing technology which allowed fabrics to be digitally printed at approximately 70 meters per minute (Parrillo-Chapman, 2016). Such speeds allow the productivity of digital printing to be compared on a similar level as rotary screen printing (Parrillo-Chapman, 2016).

2.2. Digital Inkjet Fabric Printing Characteristics

(a) (b)

Figure 4. Digitally Printed Dresses by Alexander McQueen. (a) (MJ Styling, 2013); (b) (Chamberlin, 2013).

Digital inkjet textile printing allows for more colors and photographic effects than in screen printing methods because no screens are needed (Liao & Chen, 2011). An example of some digitally printed dresses by Alexander McQueen can be seen above in Figure 4.

The complexity and size of the pattern can also be increased and is only restricted by the size of the printer's available width or the width of the substrate. This freedom of design allows for more detailed customization (Polston, Parrillo-Chapman, & Moore, 2015). Small digitally printed runs can also be produced at lower prices than screen printing which offers extended market potential (Polston, Parrillo-Chapman, & Moore, 2015). In addition to being unrestricted on the size of the repeat, color and design iterations can also be rendered much faster (Polston, Parrillo-Chapman, & Moore, 2015; Treadway, 2004).

2.2.1. Pretreatment Variables

An important notation is that digitally printed fabrics require pretreatments for effective color fastness after printing when using dye-based inks (Cie, 2015). These treatments can vary depending on fiber type (Kan & Yuen, 2012; Liao & Chen, 2011). Often for fabrics which are created from cellulosic fibers such as cotton, a pretreatment solution is developed from a type of thickening agent, alkali, and urea (Gorgani, & Shakib, 2013). Cotton fabrics are often pretreated with a solution that contains alkali to assist with forming covalent bonds between the dye and the cotton molecules (Gorgani, & Shakib, 2013).

Urea is added to the solution to swell the cotton fibers during the steaming process and quickly allow dye the space to penetrate into the fibers (Yuen, Ku, Choi, Kan, 2005). When the urea comes into contact with water, the combination creates a solvent and carries the dye into the fibers as the moisture is absorbed into the fibers (Yuen et al., 2005).

One type of thickener is alginate (Yuen et al., 2005). Alginate helps to regulate the flow of the ink ("print formulation") and aids with design clarity after printing (Yuen et al., 2005). Careful calculation of how much of each chemical is needed in the pretreatment solution is critical. Too much alginate, for example, can restrict the dye penetration or creates problems during padding (Yuen et al., 2005).

The pretreatment stage is necessary because some chemicals used to pretreat fabrics could cause damage to the print heads on the printer or limit the shelf life of the ink, if mixed with the ink and applied during printing (Gorgani, & Shakib, 2013). Pretreating cotton fabrics can also aid in keeping the printed design from bleeding (Yuen et al., 2005). Pretreatment formulas are also often applied to the substrate through the padding process (Yuen et al., 2005). Pretreatment allows the quality of printed design to be improved, but it is also an additional cost when producing fabrics, which can be expensive when producing small batches (Hawkyard, 2006).

2.2.2. Types of Inks

In addition to the fiber type, ink type can also be changed, depending on desired hand and product end use. The colorants used in digital textile printing can be both dye-based or pigments, depending on the fabric being used (Cie, 2015). For this paper, ink refers to all colorants used in printing. Dye-based inks and pigment inks, however, are not the same. A pigment is bonded by a chemical to the surface of the fabric or fiber while a dye penetrates the fiber (Cie, 2015). Dye-based inks require the fabrics to be pretreated while pigments can be applied to most fiber types (Kan & Yuen 2012).

Pigmented inks account for around half of all digitally printed textiles (Kan & Yuen, 2012). With digital textile printers, there is also potential to use new and unconventional printing chemicals which will impart capabilities such as antibacterial and conductive properties (Cie, 2015). Digital printing allows flexible electronic components to be applied to fabrics (Cie, 2015).

2.2.3. Digital Printing Substrates

Fabrics used for digital printing can vary depending on end use and on the pigments or dyes that are to be used in the printer (Cie, 2015). If a pretreated fabric must be used, then this can restrict the fabric selection for clients (Kan & Yuen, 2012).

Digital printing can print on both full-width pieces or sewn products, depending on need and end use. The printer type could vary if a product, such as a sweater or pair of pants, is being printed on instead of a flat piece of fabric (Mimaki USA, n.d.a.; Shima Seiki, n.d.a.). Inkjet digital textile printing can also be applied to substrates such as carpeting, as seen with the Milliken Millitron in 1975 (Cahill, 2006).

No matter the type of textile substrate, the fabric should be clean and free of dirt, loose threads, or other debris which could cause defects such as unprinted areas during printing (Hawkyard, 2006). Substrates must also be free of raised sections or curling edges to prevent any collisions with the printheads during printing (Kan & Yuen, 2012).

The substrate should also be scoured to remove surface oils or other impurities, which will aid in color penetration when using water-based solutions (Hawkyard, 2006). Scouring also helps to promote dye evenness and penetration (Ballard, 2016). Preparing the substrate should be performed for all kinds of printing (Hawkyard, 2006). Substrates should also be tested to determine their absorption levels since this directly affects the printed design (Hawkyard, 2006).

2.2.4. Types of Digital Textile Printers

There are many digital textile printers currently available. These printers can be categorized into two general sections: flatbed and roll to roll. An example of a flatbed printer is the Shima Seiki SIP-160F3L, which can print textiles which are both open width and products (Shima Seiki, n.d.a.). An example of a printer which works with textiles on a roll is the Mimaki CJV150 Series (Mimaki USA, n.d.a.). Both of these digital textile printers can be seen in the images on the following page in Figure 5.

(a) (b)

Figure 5. Examples of Digital Textile Printers. (a) Shima Seiki Seiki SIP 160F3L (Shima Seiki, n.d.b.); (b) Mimaki CJV150 (Mimaki USA, n.d.b.).

When selecting a printer, criteria such as speed, substrates required, width, and resolution can vary (Mimaki USA, n.d.a.). Some additional inkjet textile printer manufacturing companies currently producing printers are Mutoh, Canon, MS Printing Solutions, Kornit, and Epson. The Federation of European Screen Printers Associations, or FESPA, issues information on many types and methods of printing. Their online publications can also show information such as speed. The Canon Océ Colorado 1640, for example, can print 159 square meters per hour when operating at normal efficiency (FESPA Staff, 2017a). Printing speeds on this model will vary, depending on the desired printing quality (FESPA Staff, 2017a; FESPA Staff 2017b). The Mimaki CJV150 can print at a maximum of 56.2 square meters per hour (Mimaki USA, n.d.a.). Both of these methods print flat width fabrics only. The Kornit Allegro can reach a printing speed of 200 square meters per hour (FESPA Staff, 2017b).

2.2.5. Types of Digital Printer Heads

An additional component to producing fabrics through digital printing is the print head, which dispenses the ink from the printer onto the substrate (Freire, 2006). On a high level, two different types of printing heads are often used to print textiles digitally (Freire, 2006). These are Continuous Ink Jet (CIJ) and Drop on Demand (DOD) (Freire, 2006). CIJ print heads dispense the ink using constant pressure and speed (Freire, 2006). CIJ print heads emit a constant ink stream that disperses into droplets after being emitted and are shaken into the intended design by movements from the print head (Freire, 2006). DOD print heads operate very differently than their CIJ counterparts. In DOD, the ink droplets are dispensed only when needed to create the desired design (Freire, 2006).

The type of print head factors into the type of images being printed since the volume of the ink droplet will determine the clarity of the resulting design (Freire, 2006). An important notation is that drop volume is not the same as resolution (Freire, 2006). A common form of resolution, dots per inch (dpi), refers to a grid which is defined in inches to measure the size of the printed droplet (Freire, 2006).

2.2.6. Posttreatment Variables

Posttreatments allow the fabric manufacturer or printer to assess the level of color fixation, wash off excess surface dyes, and also can cause the print to look more saturated if there was a color change during fixation (Hawkyard, 2006). When fixing the colorant to the substrate through heat, the fiber type will influence the time and temperature needed to achieve adequate color fixation (Hawkyard, 2006). When using heat for a fiber such as polyester, temperatures between 130-170 ºC can be used, depending if pressure is also a part of the process (Hawkyard, 2006). Pigmented ink types are fixed through the high-temperature air (Hawkyard, 2006). When fixing acid- and reactive dye-based ink in a steaming machine, 100 ºC and atmospheric pressure are often utilized (Hawkyard, 2006). The temperature can be lower than when fixing these types of dyes because the steaming process dissolves the dyes into the pretreatment chemicals quickly (Hawkyard, 2006).

2.3. History of Weaving Textiles

Early examples of Ancient Chinese woven fabrics with patterns woven directly into the cloth can be found from the Han Dynasty, which was from 206 B.C. to 220 A.D. (Becker & Wagner, 2014). Through pathways such as the Silk Road which stretched from China to parts of the Roman Empire, these fabrics reached many places in the ancient world (Becker & Wagner, 2014). Early weaving was performed by hand with a loom (Becker & Wagner, 2014). Tapestries, or woven fabrics depicting pictorial scenes, have also been found from Ancient Egypt (Becker & Wagner, 2014; Phipps, 2011)

These examples of patterned weaving were early stages of modern patterned weaving. In jacquard weaving, which is said to have been invented around 1801 by Joseph Marie Jacquard, a loom attachment could weave the pattern into the cloth through the use of punched cards which would raise specific warp ends (Geselowitz, 2016; Phipps, 2011). Jacquard weaving allows for extremely detailed and often intricate designs to be woven into the cloth (Ng & Zhou, 2013).

With the development of Computer Aided Design (CAD) and an electronic jacquard attachment, weaving files could be created on a computer, which saved production time and eliminated the need for punching cards (Phipps, 2011; Seyam, 2011). Similar to printing, weaving files could be altered much quicker than previous production methods (Seyam, 2011; Treadway, 2004). An example of a modern jacquard head attached to a loom can be seen in Figure 6 on the following page. Figure 6 depicts *Fragmented Memory* by Phillip Sterns and shows the fabric during the weaving process. The loom with jacquard head attachment can be seen.

Figure 6. Modern Jacquard Head Attachment and Loom During Weaving

Fragmented Memory by Phillip Stearns (Stearns, n.d.).

2.4. Jacquard Weaving Characteristics

Woven fabrics are created through perpendicularly interlacing horizontal and vertical yarns in a variety of sequences (Ng, Kim, Hu, & Zhou, 2014; Mathur, Hinks, Seyam, & Donaldson, 2009; Mathur, Seyam, Hinks, & Donaldson, 2008; Phipps, 2011). An example of a simple warp and weft sequence can be seen below in Figure 7.

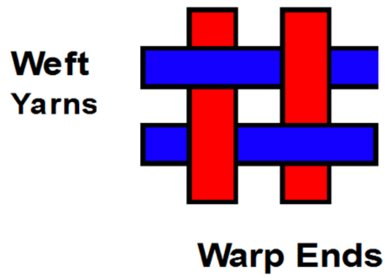


Figure 7. Flat View Simulation of A Plain Woven Fabric Structure (adapted from Mathur & Seyam, 2011a).

There are many loom setups that can be used to create woven fabrics and depending on the desired effect, many looms can fulfill the production requirement (Seyam, 2016). The number of warp beams, harnesses, and loom width are all important factors in creating the intended cloth (Seyam, 2016).

Jacquard woven fabrics are created through more complex loom setups than other woven fabrics such as dobby, a type of weaving which produces less detailed design effects (Mathur et al., 2008; Seyam, 2016). Jacquard patterning allows for increased productivity in fabric manufacturing (Ng et al., 2014). Many patterned fabrics are created with electronic jacquard heads attached to looms since they have the capability and flexibility to produce design changes quickly due to CAD software (Seyam, 2016).

It is important to note that the loom type is not the same as the type of head on the loom (Phipps, 2011). A jacquard head can be put on a variety of looms to produce jacquard fabrics and, its only limitation is the number of heddle wires on the loom (W. Barefoot, personal communication, 12 April, 2017). Stäubli produces many jacquard loom head types that can operate with looms between 64 and 36,864 hooks (Stäubli, n.d.). Some specialty loom heads can produce fabric constructions such as terry and velvet (Stäubli, n.d.).

2.4.1. Types of Yarns Used in Upholstery Weaving

In upholstery weaving, novelty yarns such as bouclé and chenille can be used (Gong & Wright, 2002). Novelty, or fancy, yarns have effects which add textural dimension to the fabric (Wright, 2013). When selecting novelty yarns for use in markets such as home furnishings, durability should be a salient factor (Gong & Wright, 2002). Chenille yarns can also give a similar appearance, luster and hand to velvet fabrics (Gong & Wright, 2002). Bouclé yarns can create a textured surface on the woven fabric (Gong & Wright, 2002). Fabrics for the home furnishings market can be woven with fancy yarns when surface dimension is desired (Wright, 2013).

An important notation is that not all yarns used in upholstery weaving need to be considered novelty. Yarns which are created with a uniform diameter are also used (Mathur et al., 2008). Another important weaving factor is that the yarns used must be able to stand up to the process and tensions of being woven into cloth (Ballard, 2016). The filling yarns should not often break during weaving to create fabrics which are higher quality (Ballard, 2016). The warp yarns are usually sized through a variety of chemicals also to stand the tensions of creating the warp and opening and closing the shed during weaving (Ballard, 2016). All yarn breakages require the loom to be stopped and lower production efficiency, which can both waste time and create defective fabrics (Seyam, 2016).

2.4.2. Fiber and Fabric Variables

Another factor of jacquard weaving which is comparable to digital printing is that many fibers can be used to create the fabric (Bae, Hong, & Lamar, 2015; Liao & Chen, 2011; Wong et al., 2009). When a woven fabric becomes the substrate for printing, the same considerations for fiber type, pretreatment, and the market must be made (Cie, 2015; Kan & Yuen, 2012; Polston, Parillo-Chapman, & Moore, 2015).

2.4.3. Jacquard Weaving Construction Variables

When three or more colors are used in a single design but only intended to be shown in certain areas of the fabric face or back to create a design, the unused weft yarns must be inserted behind the desired colors, resulting in woven layers between the fabric face and back which can be stitched or not, depending on end use (Seyam, 2016)

If more than one color layer is needed to produce the intended design, the number of layers affects the fabric's coloration, weight, yarn use, end use, and cost (Seyam, 2016). Additional fabric layers also increase the complexity of the fabric (Ng & Zhou, 2010).

To streamline efficiency when assigning weave structures in the design process, Mathur et al. (2009), researched optimum coloration effects when there are different yarn colors used in the warp and weft of the fabric to achieve a solid color when viewed from far away. This research was based off of tapestry-style weaving constructions with different colors in the warp and fill (Mathur et al., 2008; Seyam, 2011). From mathematical analyses which also included the creation of a geometric color prediction model, weave blankets were created which allowed weaves to be chosen for a specific color (Mathur et al., 2009). Through mixing yarn of different colors in the warp and weft, multiple color values were created (Mathur et al., 2009).

An important notation about jacquard woven fabrics is that although they can be aesthetically pleasing, they must also be functional (Seyam, 2011). Depending on their specific end use, there are certain qualities which the fabrics must possess to be functional in those market applications (Seyam, 2011). The weave structures used in design creation are factors in the fabric's capabilities for aspects such as strength, stability, and resistance to abrasion (Seyam, 2011).

2.5. Key Differences Between Digital Printing and Jacquard Weaving

Similar to printing, weaving has been used to color textiles for a long time. Unlike printing, however, weaving is also a method of fabrication (Carden, 2016; Ng & Zhou, 2013). In digital printing, color is laid down onto a substrate to develop the intended image following the subtractive color mixing system (Ballard, 2016; Ng & Zhou, 2013; Weeks-Atkin, 2015). When color mixing using the subtractive system, pigments are added to the substrate to mix colors from hues such as Cyan, Magenta, Yellow, and Black (Weeks-Atkin, 2015). As stated previously, digital printing allows for the design to be printed with little or no color loss from the original design which could be rendered either through hand painting, photography, or digitally (Polston, Parrillo-Chapman, & Moore, 2015; Treadway, 2004; Ng & Zhou, 2013).

In weaving, however, the design is directly impacted by the differences in weave structures, which place different previously dyed yarns in intended areas of the fabric to form the image (Ng & Zhou, 2013; Seyam, 2011). Through these different weave structures, yarns are placed in sequences which cause colors to appear through optical color mixing (Ng & Zhou, 2010). This process is similar to the concept of Pointillism, which was a fine art technique developed in the 19th century that juxtaposed small areas of variegated colors to create solid colors when viewed from a distance (Encyclopedia Britannica, n.d.). Since the design is literally part of the fabric and not placed on the fabric face, the quality of the finished design is limited to the number of yarns and the loom setup used in creating the cloth (Ng & Zhou, 2013). When the yarns used in the woven fabric formation are more coarse, fewer coloration effects can be created than when finer yarns are used (Seyam, 2011).

Similarly, to the substrates used in printed textiles, woven fabric structures can affect the coloration of the finished fabric (Bae, Hong, & Lamar, 2015). Warp-faced and weft-faced weaves could also appear very different when different colors are placed in each set of yarns (Ng & Zhou, 2010). An example of the tapestry style weaving technique with different colors in the warp and weft can be seen in Figure 8 on the following page. It is extremely important to factor in the color interaction between warp and weft when making choices in woven color ways (Ng & Zhou, 2010). The warp color (or colors) affects fabric color (Mathur et al., 2008).

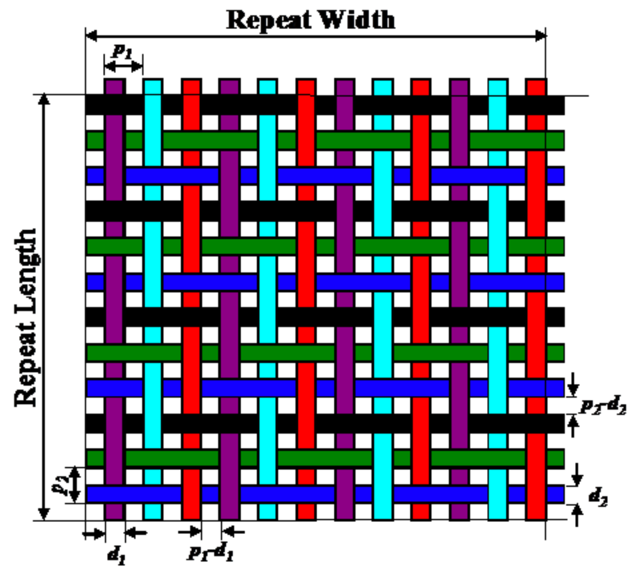


Figure 8. Simulation of Woven Structure with Multiple Yarn Colors (Mathur & Seyam, 2011b).

An example of some jacquard woven fabrics created by Valdese Weavers and a line of digitally printed garments by Mary Katrantzou can be seen in Figure 9 on the following page. Each is a beautiful line and showcases the capabilities of both coloration techniques. The lack of textural surface dimension in the prints can be seen, and the limited range of colors in the woven base cloth is also evident. The potential to integrate textural surface dimension and multiple coloration effects by combining the techniques can be seen.

(a top) (b bottom)

Figure 9. Comparison of Digitally Printed and Jacquard Woven Textiles. (a) Mary Katrantzou Fashion Line (Fashion Translated, n.d.); (b) Valdese Weavers Fabrics (Williams, 2016).

2.6. Advantages for Printing on Jacquard Woven Fabrics

Since this is a concept which is not utilized on a commercial level, there is limited data on the advantages and disadvantages of digitally printing onto jacquard woven fabrics. A factor which needs to be researched is the cost of digital printing over the base cloth. Until recently, digital printing, in itself, was typically more economical for printing smaller runs than other printing methods, although CAD systems can change designs quickly (Liao & Chen, 2011; Seyam, 2016). In traditional weaving, colors can be added through layers, which can thicken the fabric significantly (Seyam, 2016). Additional surface interest could be provided to jacquard fabrics through topical treatments while not requiring additional color layers.

Fabrics could also have varying print designs for customized runs or different textile markets. Due to the methods used in printing over the woven cloth, more digitally printed products could potentially be for sale in the upholstery industry. This could allow companies who are seeking to use previously purchased printers in a new way or allow weaving companies to expand into other markets.

Printing over the woven jacquard substrate could quicken the product development and production time to manufacture novelty yarns such as space dyed or slub because these effects could be printed instead of created during yarn formation.

Susan Brandeis said in 2003 that "The digital prints looked more like paper than cloth. They seem flat, literal and not tactile." (Brandeis in Treadway, 2004, p. 272).

Through the combination of digital printing on jacquard woven substrates, there is potential to create unique tactile surface dimensions with virtually unlimited coloration effects (Liao & Chen, 2011; Polston, Parrillo-Chapman, & Moore, 2015; Treadway, 2004).

2.7. Summary

When selecting fibers to weave into jacquard woven base cloths which will be used for printing, the type of ink must be considered to help create an effective print. Pretreatment and posttreatment methods are also important considerations when digital printing. Additional noteworthy factors are the fabric's weave structures, yarn types, and color of the resulting base cloth. When digital printing, the style of printer being used is also an important element in the design process.

Textile printing and weaving have become conventional techniques to impart color and patterning effects. Through the combination of jacquard weaving and digital inkjet textile printing, there are multiple opportunities to create fabrics which are both innovative and commercially viable. By themselves, these types of fabric coloration create beautiful effects. Together, they have the potential to increase textural surface interest and attainable color effects.

CHAPTER 3: METHODOLOGY

3.1. Research Design

In the research study, the objective was to create digitally printed jacquard woven fabric samples and have them assessed by experts in the textile industry. Two artworks were created, one through photography and one through painting. From these two artworks, files were made for both jacquard weaving and digital printing.

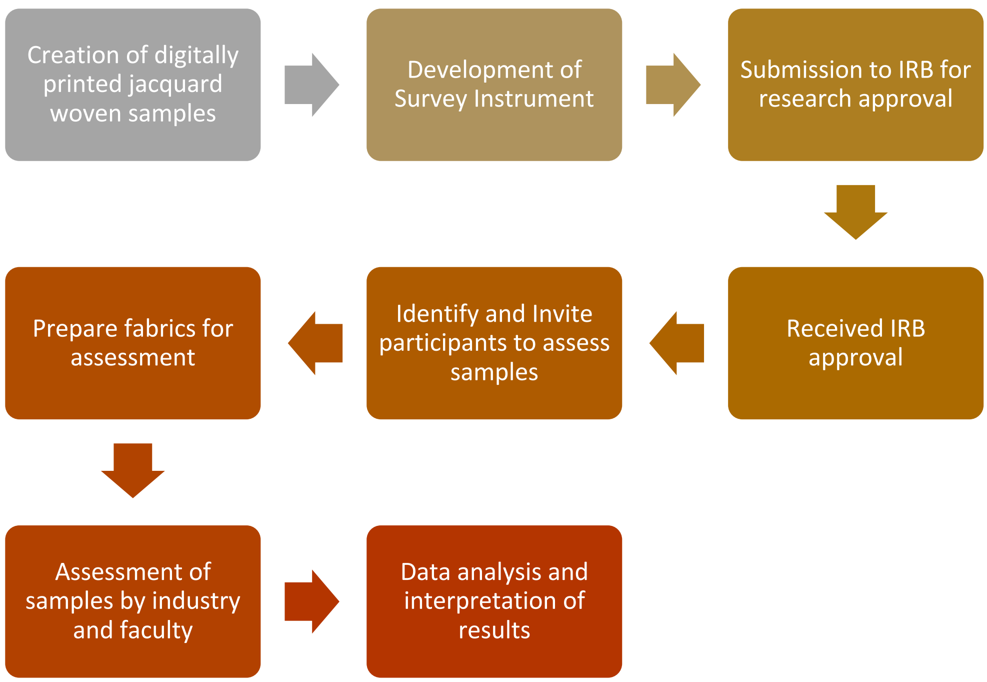


Figure 10. Full Methodology Workflow for Thesis Research Process.

3.1.1. Research Objective and Research Questions

Research Objective: To determine expert response to inkjet digitally printed jacquard woven base cloths. The workflow created to study this question can be seen above in Figure 10. Research Questions: [1] How do professionals in the textile industry respond to digitally printed jacquard woven fabric samples? [2] Are there differences in expert perceptions of a digitally manipulated photograph and a digitally manipulated painting as digital prints for jacquard woven base cloths? [3] Are there differences in expert perceptions of digitally printed jacquard woven samples based on whether the designs for weaving and printing were based on the same imagery or different imagery?

3.1.2. Research Stages

Following pilot work, five research stages were identified: (1) develop jacquard woven base cloths for digital printing; (2) develop digital printing files; (3) digitally printing the jacquard woven base cloths; (4) design a survey for visual assessment of the printed jacquard samples; (5) gather, analyze and interpret expert responses to the printed jacquard samples.

In Stage 1, artwork for both the digital printing and the jacquard weaving designs was created using digital manipulation. One artwork was created through photography and one through hand painting, for a total of two different artworks. The artwork creation was the first step in the process so that files could be made for both digital inkjet textile printing and jacquard weaving. After artwork creation, the color reduced files required for weaving were created from the original artworks and the jacquard woven base cloths were created. Weaving was the first fabrication process used.

In Stage 2, the digital printing files were developed. The files for digital inkjet printing were created after weaving to account for potential shrinkage. The files were not color reduced to include the ranges of colors in the original artwork. The artworks used to create the digital printing files also needed to be edited from the originals to make their color saturation more suitable for printing.

In Stage 3, the jacquard woven base cloths were prepared for printing and digitally printed. The fabrics needed to be cut into individual samples and overlocked to prevent edges from fraying and loss of surface area. The fabrics also needed to be scoured to remove any waxes or oils which could have been added to the yarns during production or added during weaving. To brighten the fabrics and achieve a better color saturation after printing, the samples were scoured, and color stripped in a paddle machine. Once these steps were completed, the fabrics were pretreated and printed.

After printing, the fabrics were steamed for color fixation and washed to remove any residual surface dye or fabric pretreatment. Once all of the samples were finished, labels were attached for identification during the assessment.

In Stage 4, a survey was designed for participants to offer a critique of the samples and to rate them on a set of predetermined variables. The participants were experts in the textile industry from a variety of area of such as color matching, woven fabric development, and digital printing. Educators and industry professionals both were invited to garner a wider area of expert responses.

In Stage 5, data was collected by administering the survey to the experts in small groups. Twenty-two total participants completed the assessment and survey including seventeen industry members and five North Carolina State University faculty members. After the assessments were completed, the data was analyzed and interpreted. The sample creation workflow used during Stages 1 to 3 can be seen on the following page in Figure 11.

3.2. Pilot Work for Adequate Printing Fixation

Before undertaking preparation of the research samples, pilot work was performed in the College of Textiles at North Carolina State University. The pilot work was necessary to determine effective methods for color fixation onto the woven fabric.

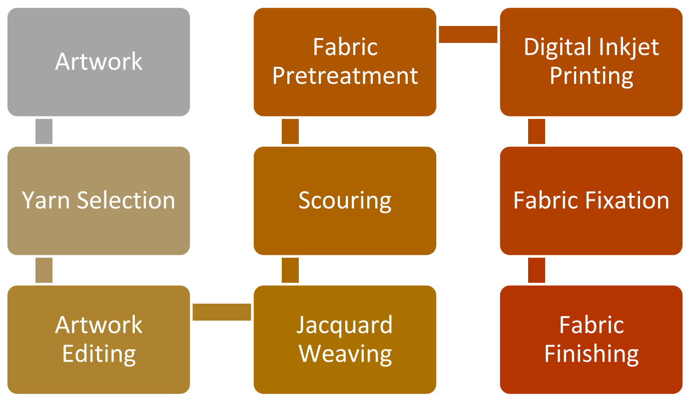


Figure 11. Fabric Sample Creation Workflow to Create Digitally Printed Jacquard Woven Samples for Assessment.

3.2.1. Pilot Work Research Steps

The following sections outline the pilot work steps used to create three trials which were evaluated for pretreatment and printed design quality.

3.2.1.1 Weaving

The artwork was created by painting an abstract pattern with gouache paints and then photographed. After photographing, the artwork was digitally manipulated into separate files for both weaving and printing. Once the artwork for weaving was color reduced and converted into a file which could be read by the jacquard head, the file was woven. Slub yarns were used in the woven fabric formation to study how the novelty yarn effect would take up dye. The file was woven three times for a total of six samples (the file was set up to weave two identical designs across the loom width).

3.2.1.2. Overlocking

Once the fabrics were woven, it was important to overlock all edges to secure loose filling yarns, and so damage would not occur in the washing machine. This also allowed the printing process to run more smoothly since stray yarns could be interpreted as folds by the printer and prohibit printing. It was also necessary to overlock the selvage edges to mitigate problems during printing. The unevenness of the selvages could have been read by the printer as fabric defects or caused the print head to collide with the fabric, which would have been potentially deleterious for the printer.

3.2.1.3. Scouring

For the first two trials, the woven fabrics were scoured in a washing machine with approximately 6g of *ApolloScour*. The washer was set to a hot/cold cycle with an extra rinse for effective scouring and removal of any residual *ApolloScour*. For the third trial, the fabrics were scoured twice with 5-7g of *Tergal SW*, another scouring agent, in a washing machine on the same cycle to determine if this would affect the final printed coloration.

3.2.1.4. Pretreating

The fabric needed to dry completely before the pretreatment step could be performed so that the chemical was not diluted. The Shima Seiki SUM 100 pretreatment machine sprayed the Shima Seiki chemical onto the fabric through a nozzle system. After spraying, a spray bottle filled with the same pretreatment was sprayed in seams, uneven spots, and harder to reach areas on the fabric surface due to incomplete coverage by the pretreatment machine. None of the fabric could be left untreated, or the dye would not become fixed to the fabric in those areas, and the print would be steamed away.

For the first trial, the fabrics were dried after pretreatment to keep the ink from potentially migrating during printing. For the second and third trials, the fabric was printed while still slightly damp. Printing occurred both when the fabrics were slightly damp or completely dry to see if the dampness would hinder the design clarity, but this did not seem to have any effect on the printed image. More detailed images or designs with more lines would need to be printed to explore the percentage of design crispness for each method. Since the printed texture is a bit abstracted, the clarity was difficult to assess visually if any bleeding occurred.

3.2.1.5. Printing

For each of the three trials, printing was performed on the Shima Seiki SIP-160F3L flatbed printer. The digital printing file created from the original artwork was used to maintain the color range of the painting. Before printing, edges which were curling needed to be taped down to the print bed using masking tape. Once the fabrics were sufficiently taped down to the print bed, the camera system on the print head scanned the bed to aid with lining up the woven design with the print. After the pictures were recorded, the designs were loaded into the Shima Seiki printing software. The patterns needed to be lined up correctly with the fabric. Some of the images needed to be scaled because the fabrics shrank during scouring and pretreating. When aligning the printed design is required, time must be taken to ensure the design is properly aligned. Printing occurred very quickly, so if any fabric had been not carefully lined up, it would have been wasted. On a larger scale such as in production, the same design would be printed many times, so fabric shrinkage and image scaling would need to be recorded for accurate and repeatable printed results.

3.2.1.6. Drying

The fabrics were dried flat for approximately 24 hours after printing so that inks would not become smeared and the surface dye could dry on the fabric and make handling during the steaming process simpler. Not all of the fiber reactive dyes penetrated into the fiber even after the fabric was allowed to sit, so careful handling of the printed fabric after 24 hours was necessary to keep the design crisp.

3.2.1.7. Steaming

Steaming was necessary to set the dye-based inks into the fabric. This also removed some of the excess dye on the fabric surface and allowed the real color of the print to be seen (the excess dyes sometimes made the fabric design look dark and flat). Steaming occurred for an hour and a half, with approximately thirty additional minutes for heating up and cooling down. The steamer used was the Shima Seiki SSM 100. Once steaming had completed, the fabrics were left to dry before washing.

3.2.1.8. Washing

Trial 1 was machine washed, Trial 2 was not washed, and Trial 3 was hand washed. The machine-washed fabric in Trial 1 was not as saturated as the hand washed sample from Trial 3. The machine-washed fabric was also dried in a dryer while the hand washed fabric was air dried after being spun in a circular dryer. The Trial 2 sample which was not washed served as the control. Since the machine-washed sample from Trial 1 lost color saturation, an additional pretreatment formulation from Huntsman (D. Clark, personal communication, 28 August, 2017) was tested after the pilot work and found to be effective in additional trials with fabrics similar to the samples created in Stage 1.

3.2.2. Conclusions from Pilot Work

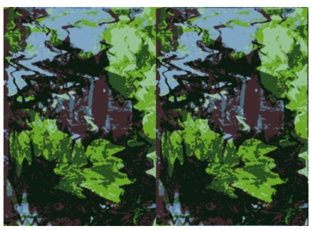
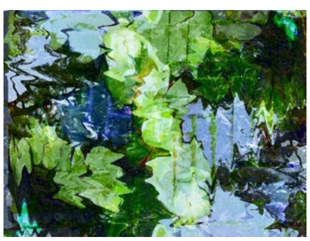
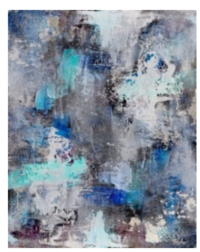
It was found that the pretreatment method currently used to treated knitted fabrics for flatbed printing at North Carolina State University was not effective for woven fabrics due to the denser construction of woven textiles developed for use in upholstery. When conducting the pilot work, three trials were printed with a color booster setting of 150. The color setting in the Shima Seiki printer software controlled the amount of ink which was being sprayed on the substrate. For the yarns chosen to weave the fabrics, this color setting was found to be adequate after fixation.

Once the samples were washed, the color saturation was not as effective as was believed after steaming, which was indicated by color loss and dulling of color. Once the knitted pretreatment product was found to be ineffective, a pretreatment recipe created by Huntsman (D. Clark, personal communication, 28 August, 2017) was also tested and found to be effective for proper fixation of woven fabrics created using the current NC State loom setup and available cotton yarns. This formula can be seen below in Table 4 in section 3.5.3. Once the pilot work was completed and satisfactory print fixation achieved, Stage 1 began.

3.3. Research Stage 1: Develop Jacquard Woven Base Cloths for Digital Printing

In the first stage of research, artwork was developed which became the designs used in jacquard weaving. All base cloths used for digital printing were also woven from the resulting artwork. To provide clarity, the digitally manipulated artwork which originated from a photograph when used in weaving will be referred to as Artwork A. The hand painting which was photographed and then digitally manipulated when used in weaving will be referred to as Artwork B. When used for the digital printing files, Artwork A will be referred to as Artwork 2A and Artwork B as Artwork 2B. The original files will be referred to as Artwork 0A and 0B, respectively. The Artworks can be seen in Table 1, on the following page, with images of each file.

Table 1. *Artwork Nomenclature*

Artwork A	Artwork B
Original: Artwork 0A (Photo) 	**Original:** Artwork 0B (Painting) 
Weaving: Artwork A (Photo) 	**Weaving:** Artwork B (Painting) 
Printing: Artwork 2A (Photo) 	**Printing:** Artwork 2B (Painting) 

3.3.1. Developing Jacquard Woven Base Cloths

Although the textile pattern scale was different on each of the two base cloth designs created in Artwork A and B, the size of the sample pieces was kept identical so that the physical sample size would be constant throughout the study. A relevant notation is that the designs were engineered repeats and did not repeat evenly. The sizes of the base cloths after finishing was 22 x 16 inches, which is not a common textile industry repeat size for home furnishings fabrics. This size was chosen so the size of the sample and incomplete repeat would not potentially factor in the participant's evaluations during the visual assessment. The Artworks A and B were created to follow trends from the Fashion Snoop Fall/Winter 2018/2019 Home forecast, *Terra* (Fashion Snoops, 2017).

For Artwork A, the artwork was photographed with an Apple iPhone 5 by the PI in a Shanghai, China botanical garden and digitally manipulated in Adobe Photoshop using filters and other digitally-based design tools (developed in multiple stages to create Artwork 0A). A detailed description of the woven design process can be found in Appendix D. Artwork 0A can be seen in Table 1 on the previous page.

For Artwork B, the original artwork (0B) was hand painted on a canvas using acrylic paints and silver foil. Different brushes and palette knives were used to create texture within an abstracted style composition. Once the painting was complete, it was photographed using a Nikon 3300 Digital Camera using an 18mm-55mm lens and digitally manipulated in Adobe Photoshop. The 0B artwork can be seen in Table 1 (on the previous page).

Both of the designs were color reduced in Adobe Photoshop and saved as separate TIFF files from the original Photoshop files. *EAT Designscope Victor*, or EAT, required files to be imported in JPEG or TIFF formats. EAT was the software used to create weaving files which could be read by the loom.

In EAT, the resolution for Artwork A was converted to the necessary resolution of 84 ends per inch (EPI), and 84 picks per inch (PPI). Artwork B converted to 84 EPI and 72 PPI to allow for weaving on the NC State loom setup and with the yarns chosen for use in this study. For Artwork A, a 54-inch template was used with the design placed twice on the template, so each sample was 27-inches wide. The weaving file was 4800 ends x 3452 picks, or 54” x 38.84.” During weaving, the file was started at 1,685 picks instead of at 0. The sample size was altered during weaving to save yarn. This made the woven fabric pieces approximately 20 inches tall for Artwork A.

For Artwork B, a 27-inch template was used, so the artwork repeated twice across the cloth without needing to be manually placed. Since the artwork measured 27” x 34” per piece, the weaving dimensions translated to 2400 ends x 2500 picks for each piece or 4800 ends x 2500 picks for the two pieces woven next to each other on the loom. Artwork B was created with 72 PPI density for the weft yarns. The 84 EPI in the warp remained fixed for all samples.

All of the jacquard woven base cloths for Artwork A and Artwork B were produced on a Dornier 54-inch rigid rapier loom with 4800 hooks. The loom has been equipped with a Stäubli jacquard head (the technology which allows patterning to be woven into the fabric). The warp was set up so that 84 ends are in each inch. The warp was comprised of 100 percent 30/2 Ne cotton yarns in an ivory, red, green, and indigo blue color rotation. The Red, Green, Blue (RGB) color values for the individual warp yarn colors can be seen in Table 2 below. The RGB and Pantone color values were derived from scans using a spectrophotometer linked to the *Apex SDS One* color software. The combination of the spectrophotometer and the Apex software allowed for more accurate color measurement than if conducted visually.

Table 2. *Warp Yarn Color Values*

Yarns	Colors	RGB Values	Pantone Color
30/2 Ne Cotton	Ivory	RGB: 221, 203, 173	Pantone: 13-1009 TPG
30/2 Ne Cotton	Red	RGB: 168, 048, 070	Pantone: 19-1759 TPG
30/2 Ne Cotton	Green	RGB: 076, 118, 083	Pantone: 18-6330 TPG
30/2 Ne Cotton	Indigo Blue	RGB: 062, 074, 091	Pantone: 19-4110 TPG

The filling yarns were designed for a density of 84 PPI on the current jacquard weaving setup used at NC State. The NC State four-color filling rotation of black, yellow, blue, and pink was modified for both of the base cloths. The modified filling sequence was needed to both accommodate the incorporation of the novelty yarns and to use the ivory colored 30/2 Ne yarns in the other filling positions. Ivory yarns were used since these yarns would be easier to color strip during Stage 3. Each of the adaptions can be found in Appendix G along with a more detailed explanation of the filling rotation process.

(a) (b)

Figure 12. Images of Novelty Yarns used in Sample Weaving. (a) Bouclé Yarn Close Up; (b) Cotton Chenille Yarn Close Up.

3.3.2. Yarns

Both Artwork A and Artwork B were woven using the NC State four-color rotation, with the traditional yarn colors switched to natural colored yarns. In Artwork A, a tan 1.25 KP cotton bouclé yarn (named Mocha by the manufacturer) was used in the second position.

A 30/2 Ne Ivory yarn was used in the first, third, and fourth positions. This was the same yarn as was in the ivory position in the warp color rotation. In Artwork B, a 1400 Yards Per Pound (YPP) Organic Cotton Chenille (named Cork by the manufacturer) was used in the second position. The same 30/2 Ne Ivory yarn was used in the first, third, and fourth positions as in Artwork A. Photographs of the specialty yarns used during base cloth creation can be seen in Figure 12 on the previous page.

3.3.3. Weave Structure Selection

When creating the jacquard woven base cloths, weave structures which would be enhanced by the chosen novelty yarns were used. Weaves which hid the novelty yarns were also used in places for more textural dimension on the fabric face and back.

On the NC State 4-color filling rotation which uses black, yellow, blue, and pink yarns inserted into the filling, a weave blanket was made which allowed for maximum color utilization. Since this study needed the color to come from the digital print and not from dyed yarns, experimentation was conducted into developing blankets with other colors and styles of yarn inserted into the filling. The goal was to create fabrics with as little color as possible. Weave blankets were created with both natural colored yarns and novelty yarns to determine ideal pick densities and ideal weaves. The weave blankets developed by the PI (adapted from the 4-color blanket used at NC State) can be seen in Figure 13 on the following page.

Figure 13. Weave Color Blankets Fabricated for Research and Used to Select Weaves.

In Artwork A, 10 colors were included in the color-reduced file, but only five weaves were used. It was found that the pattern needed simplified when using the chenille yarn since the fuzzy nature of the yarn hid some of the weave structure detail. The chenille yarns needed larger fabric surface areas of the same weave structures for a more even insertion into the shed created during weaving.

For Artwork B, the design was color reduced to two colors, and two weaves were used. Earlier experimentation by the PI found that weaving files developed from abstracted paintings needed simplified to create a cleaner woven fabric surface. More detailed explanations of the weaves used for both base cloths can be seen in Appendix F.

3.3.4. Weaving

Artwork A was woven at 84 PPI. The JC5 file was woven six times (two samples weaving side by side) to create a total of 12 Artwork A fabric samples. Artwork B was woven at 72 PPI, although Artwork A was woven with a chenille and Artwork B with a bouclé. Since the chenille was a finer yarn than the bouclé, the pick density did not need to be the same for each to weave effectively. Artwork B was also woven six times (with two samples woven side by side) for a total of twelve samples. In each set of samples, the warp was set to 84 EPI. The warp density is fixed on the set up used throughout the process. In total, 24 fabrics samples were created, 12 of each design. The technical specifications used in during weaving can be seen below in Table 3. It is important to note that Ne is a unit of measurement for yarns created with cotton fibers.

Table 3. *Weaving Technical Specifications*

Loom Type	Dornier 54-Inch Rigid Rapier Loom
Jacquard Head Type	Stäubli JC5 Electronic Jacquard Head
Warp Yarn Fiber Content	30/2 Ne Cotton Yarns (Non-Mercerized)
Warp Yarn Color Rotation	Tapestry Rotation: Ivory, Red, Green, Blue
Warp Yarn Density	84 EPI
Filling Yarn Rotation & Fiber Content (Traditional NC State Setup)	Black (8/1 Ne Cotton), Yellow, Blue, Pink (15/1 Ne Cotton)

Table 3. *Continued*

Filling Yarn Rotation (Artwork A)	30/2 Ne Ivory, 1400 YPP Golden Organic Cotton Chenille, 30/2 Ne Ivory, 30/2 Ne Ivory	
Filling Yarn Rotation (Artwork B)	30/2 Ne Ivory, 1.25 KP Bouclé Tan, 30/2 Ne Ivory, 30/2 Ne Ivory	
Weft Yarn Densities	**A** 84 PPI	**B** 72 PPI
JC5 File Names	**A** CLT5.jc5	**B** CA2.jc5
EAT DesignScope Victor Nomenclature	**Artwork A**	**Artwork B**

3.4. Research Stage 2: Develop Digital Printing Files

Once the base cloths were woven, the additional artwork was created for digital printing. The digital printing files began with the original artwork (0A and 0B) and were saved into separate files, which created Artwork 2A and Artwork 2B. The files were resized from the originals to mirror the size of the woven fabrics after the shrinkage that resulted from scouring, washing and pretreating and posttreating. Artwork 2A also needed to be cropped since the original artwork was cropped during weaving.

Appendix E contains a detailed explanation of the digital printing file preparation for Artwork A. Artwork 2B was created in a similar design process.

3.5. Research Stage 3: Digitally Printing the Jacquard Woven Base Cloths

In the third stage of research, the samples were developed through the combination of digital printing and jacquard weaving. In this stage, the samples were also prepared for digital printing through scouring, color stripping, and pretreating.

3.5.1. Overlocking

Since all of the samples for Artwork A and all of the samples for Artwork B were woven at the same time (but on different days for each set of 12), the two fabrics needed to be cut into individual pieces. After the samples were separated, the pieces were overlocked to prevent any yarn loss during the next stage of the process.

3.5.2. Scouring and Color Stripping

Once the fabrics were overlocked, it was necessary for them to be scoured, color stripped, and pretreated to prepare for printing with fiber-reactive dye-based inks. Since most of the yarns that were used during weaving had color previously applied to them, color stripping chemicals added to the scouring process made the samples brighter. Brighter samples allowed the digital prints applied in Stage 3 also to be brighter and more like the colors that were seen on the computer monitor during the design stages. A Burlington Paddle Machine was used for the reduction process. A relevant notation is that the samples were scoured and color stripped at the same time. The Burlington Paddle Machine can be seen in Figure 14 on the following page. The image on the left shows the full machine and the image on the right a close-up of one of the chambers inside the paddle machine.

(a) (b)

Figure 14. Sample Color Stripping Process Preparation. (a) Burlington Paddle Machine; (b) Close Up of A Chamber Inside the Burlington Paddle Machine.

The first set of 12 fabrics to be scoured and color stripped was Artwork B. The Artwork B samples were added to the paddle machine with three samples going into the four chambers for a total of 12 fabric pieces. Brightening the samples for Artwork B took three trials to be successful. In the first trial, 60 liters of water were added and brought to a boil (100 ºC). A solution of 400g Hydrogen Peroxide (bleaching agent), 60g of *Tergal SW* (nonionic surfactant), and 200g of Sodium Carbonate (alkali) were added to the boiling water with a dwell time (length of time the fabrics spent in the bath) of approximately 40 minutes.

A second trial using the same 12 fabrics was conducted by adding alternative chemicals to the bath in the paddle machine. 240g of Hydrogen Peroxide, 120g of Sodium

Hydroxide, and 40ml of *Huntsman UVITEX BHV* LIQ (optical brighter) were added and left in the machine for another approximately 40 minutes. This trial had similar results to the first, and the fabrics were not noticeably brighter.

A third trial was conducted with the sample 12 samples by adding alternate chemicals to the bath. 300g of Soda Ash and 300g of Thiourea-Dioxide were used with a dwell time of approximately 40 minutes. The samples were noticeably brighter than before. To preserve the bath, the samples were removed from the Burlington Paddle Machine and taken to the Whirlpool Cabrio washer and rinsed. The washer used to rinse the Artwork B samples can be seen directly below in Figure 15.

Figure 15. Rinsing Artwork B Samples Preparation. Whirlpool Cabrio Washer.

No additional soap was needed during the rinsing process due to the *Tergal SW* in the bath. After rinsing, the samples for Artwork B were dried in an American Dryer Corp. (ADC) model ADS50 tumble dryer.

After the process for the Artwork B samples was completed, the Artwork A samples were also scoured, and color stripped. The 12 samples for Artwork A were scoured and color stripped in a bath with alternative chemicals. Similar to Artwork B, three panels were placed in each of the four chambers in the paddle machine. A solution of 300g of Thiourea-Dioxide, 300g of Soda Ash, and 3.0 mL (or 1.5% owb) of the optical brightener was added and the same dwell time of approximately 40 minutes was used. The Artwork A samples were color stripped in one bath.

Once the brightening process was completed for Artwork A, the samples were rinsed in the paddle machine. After the rinsing, the samples were spun out in a Bock Centrifugal Extractor (circular dryer) and dried in the same ADC tumble dryer as the Artwork B samples. Images of the ADC dryer and Bock extractor can be seen below in Figure 16.

(a) (b)

Figure 16. Dryers Used for Sample Pretreatment Preparation. (a) ADC Model ADS50 Tumble Dryer; (b) Bock Centrifugal Extractor.

3.5.3. Pretreating

Since the type of ink that was used for digital printing was dye-based, pretreatment was necessary to allow for adequate color fixation and saturation after posttreatment. The pretreatment recipe can be seen directly below in Table 4. An important notation is that the samples A2 mentioned in Table 4 are versions of Artwork A which were woven with the whole design and not halved during weaving.

Table 4. *Pretreatment Calculations*

Chemical/Name	Volume/Mass	Calculation	Total
Huntsman Prepajet PIJ (Alginate)	100 g/liter	100x300 = 3000	3,000 g (1504.75 + 1501.15 actual)
Urea	100 g/liter	100x300 = 3000	3,000 g (1500.10 + 1500.74 actual)
Soda Ash	40 g/liter	40x300 = 600	1,200 g (600.28 + 601.48 actual)
Water			22.80 Liters
Weight of Samples (Dry)	B (Each) = 351g	A (Each) = 180g A2 (Each) = 354 g	5.3kg (5.19kg actual)

Table 4. *Continued*

Weight of Samples (Wet)	B (Each) = 729g	A (Each) = 366g A2 (Each) = 729g	
Liquor Ratio	Samples = 5.3kg Bath = 30L	30/5.3 = 5.66	5.66kg/L
Weight of Total Bath			30 Liters
Wet Pick Up (%WPU)	B (%WPU) = (((729-351)/315) x100)	A (%WPU) = (((354-180)/180) x 100) AA (%WPU) = (((729-366)/366) x 100)	B = 107.69% A = 103.34% A2 = 105.93%

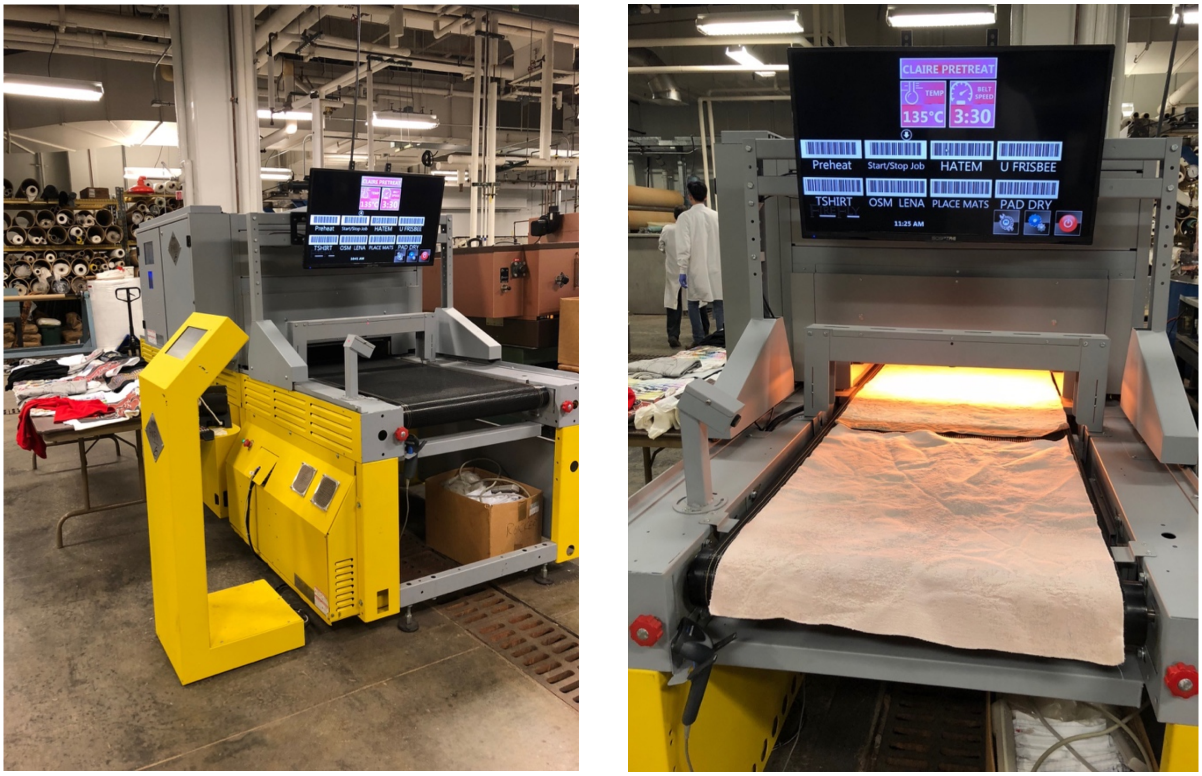
Once the pretreatment solution was prepared, the samples were submerged in the chemical bath to ensure thorough and even saturation into the substrate. All 18 of the Artwork A and B were pretreated at the same time in the same bath.

After the samples were coated, a Mathis HVF model padding machine set to 2.2 bars of pressure was used to squeeze out the excess pretreatment solution. The amount of pressure was determined through the calculation of wet pick up which can be found in Table 4 on the previous page. Although the excess was removed, the samples still needed to be dried for digital printing. The Mathis padding machine used in the process can be seen in Figure 17 below both before padding and during use.

(a) (b)

Figure 17. Padding Samples After Pretreatment. (a) Mathis HVF Model Padding Machine; (b) Mathis Padding Machine During Use.

Since too high a temperature would destroy the pretreatment chemical and cure the fabrics before printing (which would inhibit the desired fixation), the samples were dried in a Brown Digital FireFly Infrared (IR) Dryer to remove the majority of the moisture and then left out to air dry overnight.



(a) (b)

Figure 18. Drying Samples After Pretreatment. (a) FireFly Infrared Dryer; (b) IR Dryer During Use.

All of the 18 samples were dried at the same time for consistency within the experiment and IR dryer settings can be found in Table 5 on the following page. The lab being used was not climate controlled. The IR dryer can be seen above in Figure 18 both before drying the samples and while drying one of the Artwork B samples.

Table 5. *Infrared Dryer Information*

Machine: Brown Digital FireFly Infrared Dryer				
Artwork A	135 ºC for 4:00 Minutes	Bulb Power: Bulbs 1-4 at 100%, Bulbs 5-9 at 75%	1 Pass	Still Damp, Air Dried
Artwork B	135 º C for 3:30 Minutes	Bulb Power: 100%	1 Pass	Still Damp, Air Dried

It was found that the chemicals used during pretreatment made the samples very rigid, which set some wrinkles into the fabric that could not be removed by smoothing by hand. To press the samples and create a smoother surface (which creates a more uniform and even print), a Klieverik heat press was used. The settings used were 4.0 bars of pressure, a dwell time of 60 seconds, and a temperature 80º Celsius. The effect on the fabric was noticeably smoother.

3.5.4. Flatbed Digital Printing of Base Cloths

All of the eight inks used to print the Artwork A and B samples were fiber reactive dye-based inks. Since all of the yarns used in to create the base cloths were made of cotton, there were no difficulties with printing on the woven fabric base cloths with reactive dyes after pretreatment. The printer used to print the Artwork 2A and 2B images was the Shima Seiki SIP-160F3L Flatbed Printer previously mentioned and seen on the following page in Figure 19. Since fabrics can have different thicknesses due to different filling yarns or fabric constructions, this printer had a moveable head height. A relevant notation is that 18 of the 24 samples were digitally printed, since the other six were left unprinted to serve as the control fabrics during the assessment. Four unique fabrics were printed: Artwork 2A on both jacquard woven substrates. Artwork 2B was also applied to both substrates. Each fabric was printed three times for a total of 12 research samples. An additional six samples were printed to test adequate print head height and color booster settings.

Figure 19. Flatbed Digital Printing Preparation. Shima Seiki SIP-160F3L Flatbed Digital Printer.

Although both substrates were created with different novelty yarns (chenille and bouclé), all of the samples were printed at 7.0 millimeters and a color booster of 200 plus 100 to equal 300. A screen shot of the printing software after scanning the print bed can be seen on the following page in Figure 20. Printing the fabric twice created the desired level of color saturation. All samples created for the expert assessment were created on the same day during the same session, although three printings were needed to print all the samples.

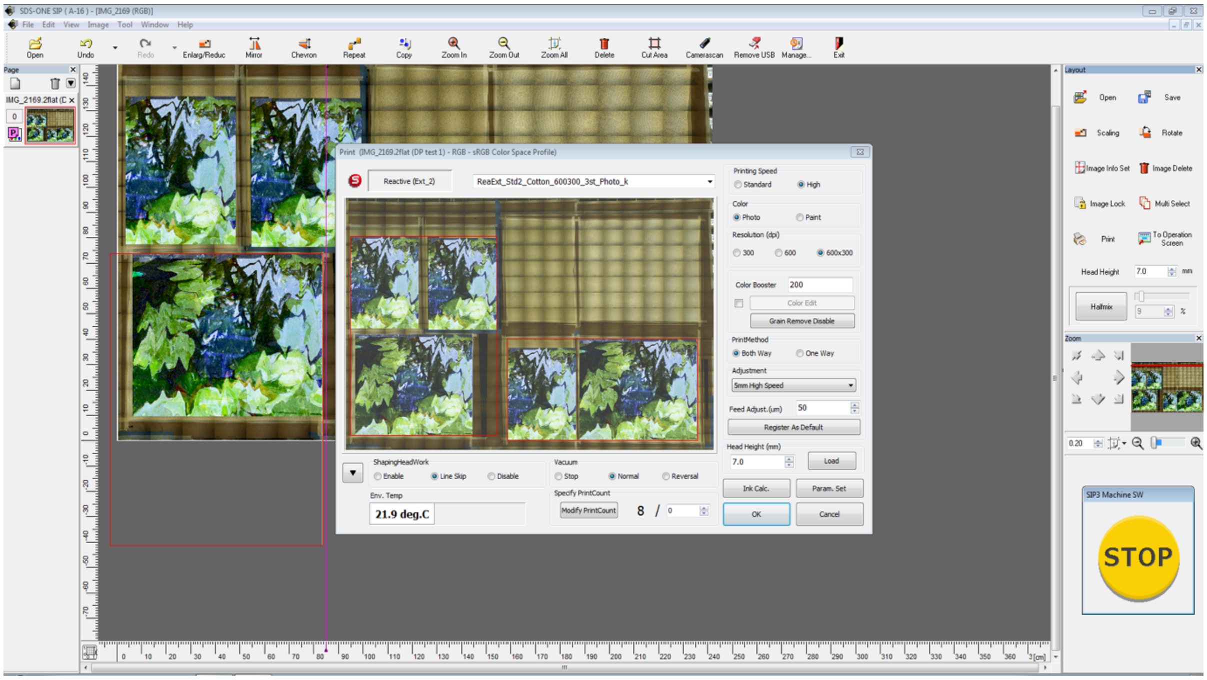
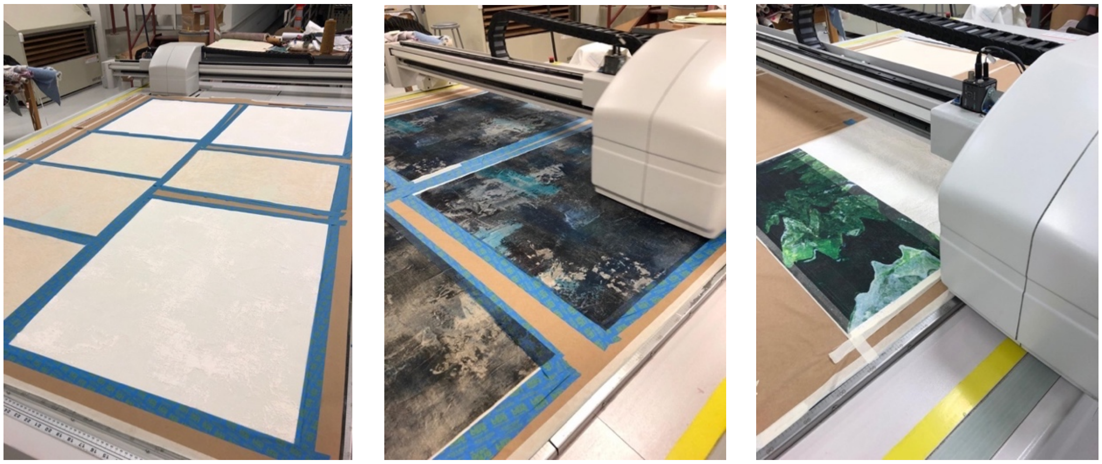


Figure 20. Screen Shot of Shima Seiki Printer Settings for First Printing Pass for Auden and Zinnia.

All of the Artwork 2B print designs were printed before 2A. When the printer was powered on, the print heads were cleaned twice. The print heads were also cleaned one time in between each printing. Photographs made during the printing process can be seen on the following page in Figure 21. The digital printing specifications can also be seen on the following page in Table 6.



(a) (b) (c)

Figure 21. Digital Printing on Jacquard Woven Base Cloths. (a) Preparing to Print on Shima Seiki Flatbed Printer; (b) Printing Renato and Loris; (c) Printing Zinnia.

Table 6. *Digital Printer Technical Specifications*

Printer Type	Shima Seiki SIP-160F3L Flatbed Digital Inkjet	
Type (for ink lay down)	2-Passes	
Ink	Fiber-Reactive Dye-Based Inks	
Ink Color Rotation	8 Color Position: Black (1), Yellow, Magenta, Cyan, Black (2), Orange, Red, Blue	
Color Booster	**A** 200+100 = 300 (total - 2 printings)	**B** 200+100 = 300 (total – 2 printing)
Print Head Height (millimeters)	**A** 7.0 (for all A fabrics)	**B** 7.0 (for all B fabrics)

3.5.5. Fixation and Posttreatment

After printing, the fabrics were left in room temperature conditions in the lab (which was not climate controlled) for approximately three days to allow the surface dye to dry. Allowing drying time mitigated ink smear and increased design clarity after fixation. Once drying time was finished, the fabrics were steamed in a Shima Seiki SSM 100 Steamer. The fabrics were steamed at 100 ºC for 32 minutes. The steamer can be seen below in Figure 22. Three sessions were needed to steam all 18 samples.

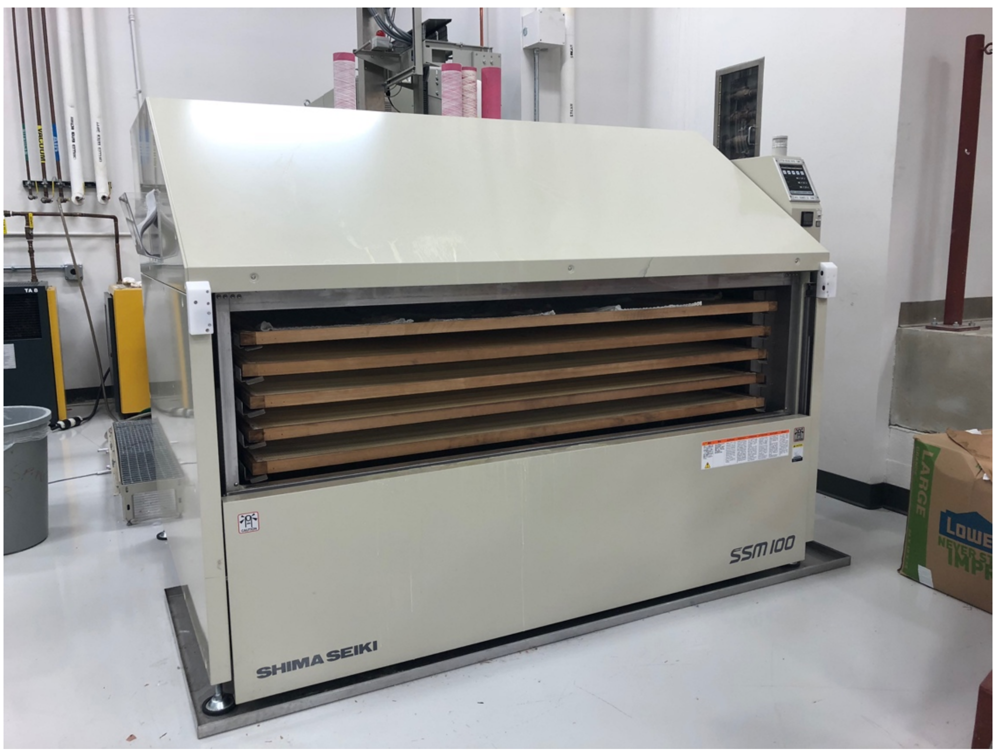


Figure 22. Steaming Fabric Samples Preparation. Shima Seiki SSM 100 Steamer.

Once steaming was completed, the fabrics were allowed to air dry in the same room temperature conditions before washing. Steaming made the printed design much brighter. Close up images of Renato before and after fixation through steaming prior to washing are shown below in Figure 23. After the fabrics dried, the samples were washed in a GE home washer using two teaspoons of *Grab Green* Bleach Alternative detergent (there were three loads in all). The samples were washed using the hand wash setting and cool water for the first washing and then a second rinse and spin cycle in cool water.

(a) (b)

Figure 23. Close Up Images of Renato Before and After Steaming.

After laundering, the samples using Artwork B were ironed to remove some of the wrinkles in the fabric. The samples were dried in a GE home dryer for 20 minutes, and then the Artwork B samples were dried for an additional 10 minutes. This cycle was repeated twice to wash and dry all the samples, including the base cloths which were not printed. The unprinted samples were washed and dried in separate loads from the printed fabrics to ensure no potential residual surface dye stained the samples.

3.5.6. Visual Assessment Preparation

To keep the samples organized and allow for identification during the visual assessment, cardstock labels were made with the name of each sample. Six samples were created in triplicate for three assessments to occur simultaneously, for a total of 18 samples. The samples were overlocked using light grey yarns to reduce the potential influence of the stitch color affecting the research.

Each sample received a label with its name. The names were chosen to give the samples an identifiable label without potentially implying order or rank. A light grey background was printed on the cardstock to eliminate the white of the cardstock, and the letters of each name were printed in black. Once the labels were prepared, they were stapled to the lower right-hand corner of each sample. The sample names in alphabetical order were Auden; Delsie; Jovany; Loris; Renato, and Zinnia. An example of which base cloth was printed with which digital print can be seen beginning below in Table 7.

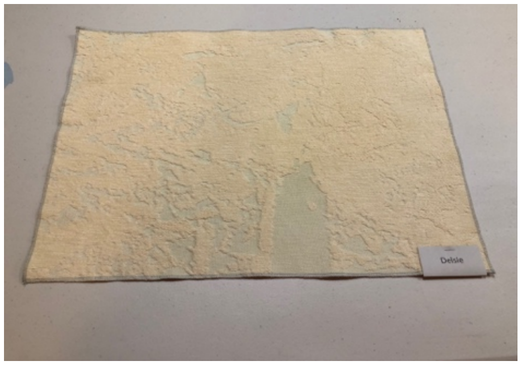
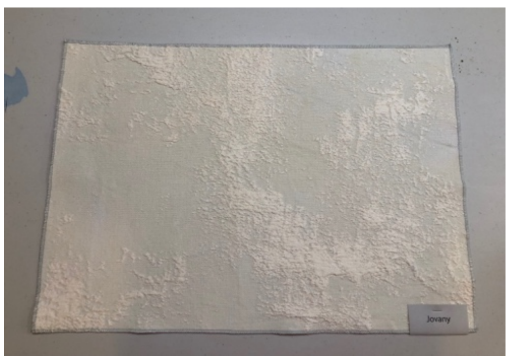
Table 7. *Photographs of Samples*

Sample Name	Finished Fabric Photograph	Type of Base Cloth/Print
Auden		Base Cloth: Artwork A (Photo) Print: Artwork 2A (Photo)

Table 7. *Continued*

Zinnia		Base Cloth: Artwork B (Painting) Print: Artwork 2A (Photo**)**
Loris		Base Cloth: Artwork A (Photo) Print: Artwork 2B (Painting)
Renato		Base Cloth: Artwork B (Painting) Print: Artwork 2B (Painting)

Table 7. *Continued*

Delsie		Base Cloth: Artwork A (Photo) Print: N/A
Jovany		Base Cloth: Artwork B (Painting) Print: N/A

To keep the sample order random during the assessments and prevent potential order bias, sample presentation orders were created on *Randomizer.Org*. Each sample was assigned a numerical value for randomization. The samples were numbered in alphabetical order. The resulting order can be found in Appendix H.

3.6. Research Stage 4: Survey for Visual Assessment of the Printed Jacquard Samples

In the fourth stage of research, a survey was created for assessment of the samples by textile industry members. Once the survey was developed, it was submitted to the North

Carolina State University Institutional Review Board (IRB) for the approval to begin the research study. The letter of exemption can be seen in Appendix A. Once IRB approval was achieved, research participants were invited to participate. The IRB approved invitation email can be seen in Appendix B.

The survey was created in Qualtrics since this was a sophisticated survey software which allowed a single reusable and anonymous survey link to be used each time, even though the samples were set out in random orders during the assessment. The survey contained logic flows to allow the participants to select each sample from a list, which would bring up the correct survey questions for each sample. Appendix C contains a full copy of the survey from Qualtrics.

3.6.1. Determination of Survey Variables

To determine whether the combination of jacquard weaving and digital printing could be an effective way to color fabrics intended for use in the home furnishings industry, certain variables were identified for inclusion in the survey.

Six different samples were prepared with two being the unprinted base cloths (Delsie and Jovany) and four being the printed samples (Auden; Loris; Renato, and Zinnia). For all six samples, participants were asked to rate each individually on 11 qualities determined by the PI and faculty sponsor. Eight of these characteristics were the same for all six samples, and three were different depending on whether the sample was printed or left unprinted.

The eight qualities which remained consistent were “Aesthetic Appeal;” “Surface Texture;” ‘Weaving Technique;” “Yarn Choice;” “Fabric Hand;” “Fabric Weight;” “Appropriateness for Upholstery,” and “Potential for Markets Beyond Upholstery.” For the unprinted fabrics, named Delsie and Jovany, the additional three variables were woven design clarity, appropriateness for printing substrate, and integration of fancy yarns. For the printed samples, named Loris, Auden, Zinnia, and Renato, the additional characteristics were printed design clarity, printed color saturation, and integration of woven and printed designs. The parallel in wording between the three questions which differed for each set was intentional.

3.6.2. Creation of Survey Questions

The first question in the survey was an informed consent where participants could accept to begin the survey or not accept. If the consent letter was not accepted, the survey would terminate immediately.

The second question of the survey asked participants which sample they were reviewing. The sample name was picked from the list. Since the samples were in a random order, the sample first was evaluated first was not fixed.

Depending on the order of samples, the questions related to one of the two unprinted control fabrics or one of the four printed samples. For example, the sample Delsie, which was the name of the unprinted Artwork A base cloth, will be used. The 11 qualities mentioned above were displayed, and the participants were asked to rank these from 1 to 5. A ranking of 1 corresponded with “Very Poor” and 5 with "Very Good,” considering potential end use in home furnishings. At the end of the survey block, there was a section which asked for an overall impression of Delsie. This free response question was optional. In the next question, the participant was asked if they considered the utilization of jacquard weaving in the sample to create an effective base cloth for digital printing. This question allowed for yes; maybe;

no, or unsure to be selected. For maybe and unsure, participants were able to leave an open response if desired. The free response sections were important in case they had additional evaluations which did not fit in the standardized 1-5 answer format. Once this question was completed, the participant saw the original question again which asked them to select the sample currently being reviewed.

For the printed samples, a similar survey block with the 11 qualities listed above was shown. For example, Auden, one of the printed samples, will be used. After the participants had completed the block, they were asked to leave overall impressions of Auden, if desired. The following question asked if they considered the utilization of digital printing technique in the sample to be an effective coloration method for jacquard woven base cloths. Similar to Delsie, the participants could select yes; maybe; no, or unsure and leave responses for maybe and unsure.

Once the participant had evaluated all six samples, there was a free response question where they could leave insight about the fabric collection as a whole reviewed that day. They could either leave a response or click that they did not have any additional impressions.

Once the free response question was completed, there was a series of demographic questions. These questions were included to show that textile industry experts from a variety of companies and areas of work participated in the study.

The first question asked for them to select the range in which their birth year fell or fill in if their birth year was not included. The second asked for name and address of their company. The third demographic question asked the participants to select their current area of work from the list provided. They were allowed to select multiple options or to write in an area which was not included. The areas provided were woven fabric design; woven fabric product development; woven fabric research and development; textile screen printing; digital inkjet textile printing; yarn design; textile consultation, and color matching.

The fourth question asked if they were directly involved in fabric line decisions. If they selected no, the fifth question did not appear. If they selected yes, then the sixth question, which asked how long they had been involved in fabric line decisions, was shown. The choices were under 3 years; 3-5 years; 5-10 years; 10-20 years; over 20 years, and other if their involvement did not fit in one of the ranges provided.

The seventh question asked participants to select in what aspect of the fabric line were they involved. The participants could select multiple and/or select other if their involvement was not included on the list. The included aspects were color; pattern design; line development; construction; quality control; production; sales, and marketing. At the end of the list was also the option to select that they were not involved. If this option was selected, the eighth question was skipped.

The eighth question asked participants to select their frequency of engagement with the fabric line. Each respondent could select one answer from the provided list. The answers were once a day; two or more times a day; once a week; two or more times a week; once a month; two or more times a month; once a quarter; two or more times a quarter; once a year, and rarely (less than once a year). An option to select other was also included in case their frequency of engagement was not reflected in the list.

The ninth question in the demographic question and the final question of the survey asked participants to consent to their responses to be recorded. If they did not consent, the survey would have terminated. When consent was achieved, the survey would record the participant’s responses.

3.6.3. Survey Instrument

During the assessment, the participants completed the survey on iPad devices with the anonymous survey link. There were three iPads in total so that the survey could be completed during the visual assessment by each participant. The survey was created on Qualtrics and allowed for anonymous responses to be recorded. The IRB approved survey can be seen in Appendix A. The unprinted samples were evaluated using the same questions and the printed samples were evaluated using a similar survey, with some of the questions adjusted to ask about the printed design. All of the printed samples were evaluated with the same questions. Each sample's questions allowed for free responses to be added if desired. The end of the sample assessment section of the survey also allowed for free responses to the collection as a whole, if desired. Following the sample assessment section was a demographic section.

3.6.4. Sample Assessment Protocol

Eighteen samples were created to allow for three participants to evaluate a set of six samples at the same time. Since all of the samples were overlocked to the same size dimensions, the samples were placed in random orders to prevent sample order bias.

The participants were allowed to pick the sample stack they evaluated when they entered the assessment room. They were told before beginning the assessment to stay at their sample stack for the entire session, and when they were finished evaluating the entire set and had submitted the survey, they were finished. An example of one of the three sample evaluation stations (station B) can be seen in Figure 24 on the following page.

Figure 24. Assessment Station Example, Station B.

3.7. Research Stage 5: Gather, Analyze, and Interpret Expert Responses to the Printed Jacquard Samples

Participants who were knowledgeable in the area(s) of woven fabric design, woven fabric product development, woven fabric research and development, digital inkjet textile printing, textile screen printing, yarn design, textile consultation, and color matching were identified for invitation to participate in the research study. Participants were also invited who attended the AATCC/SGIA Digital Printing 2.0 Conference in November, 2017. The PI and faculty sponsor gave a presentation along the same vein as the research study (digital printing on jacquard woven base cloths). The proximity of potential participant's places of work was also considered so that participants would not have to travel too far when attending the assessment at the NC State College of Textiles.

In the final stage of research, the study participants provided an expert response to the samples through visual assessment of the samples and completion of the survey.

Samples were created in triplicate so that three participants could participate in the survey at the same time, but still evaluate the fabrics individually. A room in the College of Textiles was set up so that three tables were set apart from each other in a horseshoe style setup. The fabrics were placed in a random rotation after each assessment so that the study could be free of sample order bias.

This sample presentation order was completed each time a new set of participants took the study, for a total of nine times and twenty-two participants.

3.7.1. Invitation of Potential Participants

Participants were invited to participate in the assessment through an email which was approved by the IRB before sending. Forty-eight participants were invited through email with twenty-nine participants responding to the email and twenty-two participants completing the assessment. A few of the respondents forwarded the invitation email to their colleagues, which assisted with obtaining the final number of twenty-two participants.

3.7.2. Assessment

The twenty-two participants came to the College of Textiles at North Carolina State University to evaluate the samples and complete the survey. Seventeen participants were industry members and five participants were faculty of North Carolina State University. Ten companies/institutions were represented.

The assessments were conducted nine times over four days, two days each week for two weeks. The same days and times of the week were used. Each session took approximately a half hour to complete. Since the assessment was held over four days, the room set-up was carefully photographed to make the lighting and viewing positions as identical as possible. Photographs of the assessment room can be seen in Figures 25 and 26 on the following page.

Four assessment groups were conducted with three participants evaluating a stack of samples individually. Due to scheduling, five groups were conducted with two participants. The same two stacks were assessed using the same setup and same sample set in each of the two participant assessments. For the groups with three participants, the same setup and samples were also used each time. The two sets which the researcher judged to be the most similar were used in the two-person assessments. For two groups that had two participants, the third set of samples was left out because a third person was expected. The third stack was not used, though, for consistency.

Figure 25. Sample Assessment Room View from Main Door, Closest to Station A.

Figure 26. Sample Assessment Room View Facing Main Door, Nearest Station C.

CHAPTER 4: RESULTS AND DISCUSSION

4.1. Discussion of Fabric Pilot Work Trials

The most significant finding through the pilot work trials was the effect pretreatment had on the quality of the digitally printed jacquard woven fabrics. When the fabric was not pretreated effectively, there was insufficient color saturation of the design after laundering which resulted in prints which looked dull and faded. Through experimentation, a pretreatment formula developed by Huntsman (D. Clark, personal communication, 28 August, 2017) was tested and found to be successful with the fiber content and fabric construction. This formulation can be seen above in Chapter 3, section 3.5.3.

4.2. Participant Demographic Data

Twenty-two participants agreed to be a part of the research study and completed the assessment. These participants were from a total of ten companies/universities and nine areas of work (including a category for other). Seventeen of the participants were industry professionals and five educators/professors at NC State. All twenty-two participants were asked to select the range in which their birth year fell. The respondents' selected ranges can be seen on the following page in Table 8. An itemization of the respondents' occupations can be seen in Table 9, also on the following page.

Table 8. *Participant Birth Year Ranges*

Year Range	**Number of Responses**	**Percentage**
1940-1949	2	9.09%
1950-1959	1	4.55%
1960-1969	6	27.27%
1970-1979	3	13.64%
1980-1989	5	22.73%
1990-1999	5	22.73%
Total	22	100%

Table 9. *Participant Occupation*

Occupation	**Number of Responses**	**Percentage**
Industry/Professional	17	77.27%
Educator/Professor	5	22.73%
Total	22	100%

Participants were asked to select their current area(s) of work from the list provided. There was an option to select multiple areas if desired. An option for other was also provided. In the selection marked other, a free response section was included for participants to write in their area of work. Table 10 (below) contains their answers. Since the participants could select multiple areas of work, there were eighty-five responses from the twenty-two participants.

Table 10. *Participant Area(s) of Work*

Current Area(s) of Work	**Number of Responses**	**Percentage**
Woven Fabric Design	14	16.47%
Woven Fabric Product Development	14	16.47%
Woven Fabric Research and Development	8	9.41%
Textile Screen Printing	9	10.59%
Digital Inkjet Textile Printing	12	14.12%
Yarn Design	6	7.06%
Textile Consultation	5	5.88%
Color Matching	9	10.59%
Other	8	9.41%
Total	85	100%

To establish that the participants were experts in the textile field, they were asked to select the range which included the number of years they had been involved in fabric line decisions. If they were not involved, this was also an option which could be selected. Fifteen of the twenty-two total participants responded that they were involved in fabric line decisions. The respondents who were involved in line decisions accounted for 68.18% of the participant population. The responses for participant involvement with the fabric line can be seen below in Table 11. The participants were asked to also include in which aspect of the fabric line they were involved. This question also allowed for multiple choices to be selected. Ninety-one responses were recorded from the fifteen participants who responded that they were involved in the fabric line decisions. These responses can be seen on the following page in Table 12. Although this question was not shown if the respondent selected “no” when asked if they were involved in fabric line decisions, “I am not involved” is also shown on Table 12 to represent the entire participant population.

Table 11. *Participant Involvement with Fabric Line Decisions*

Responses	**Number of Responses**	**Percentage**
Yes	15	68.18%
No	7	31.82%
Total	22	100.0%

Table 12. *Participant Area(s) of Involvement with Fabric Line*

Areas of Line Involvement	**Number of Responses**	**Percentage**
Color	15	16.48%
Pattern Design	13	14.29%
Line Development	11	12.09%
Construction	15	16.48%
Quality Control	10	10.99%
Production	8	8.79%
Sales	4	4.40%
Marketing	8	8.79%
Other	2	2.20%
I Am Not Involved	5	5.49%
Total	91	100%

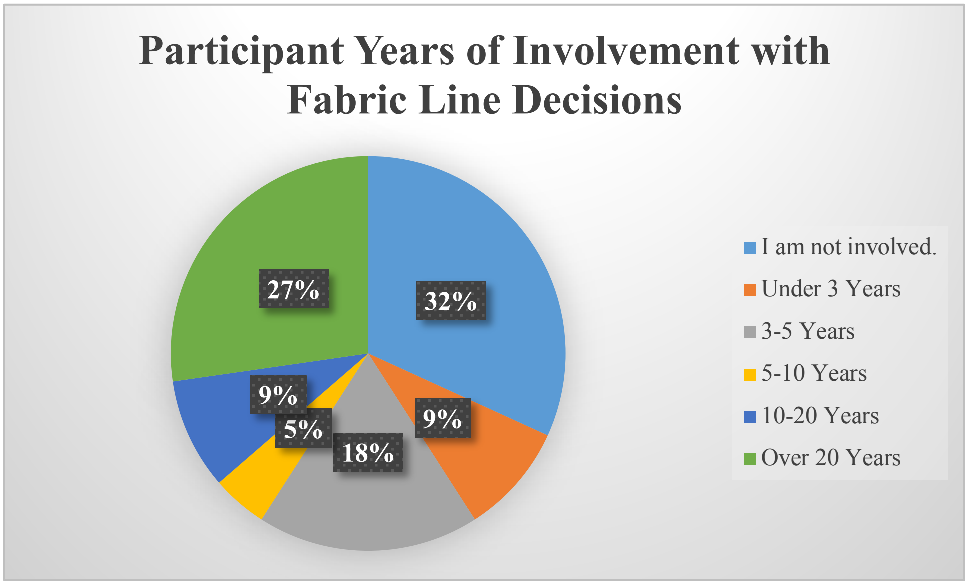


Figure 27. Participant Years of Involvement with Fabric Line Decisions.

The participants' years of involvement with fabric line decisions can be seen above in Figure 27. Similar to Table 12 (on the previous page), the number of respondents who selected "I am not involved" is also shown for consistency. 40% of the involved participants responded that they had been part of fabric line decisions for over 20 years, the other 60% for 20 years or under. If "I am not involved" was selected when asked if involved with fabric line decisions, the question which asked about participant frequency of engagement was also not shown. "I am not involved" was also included in Figure 28 on the following page to include all participants. All values for frequency of engagement can be seen in Figure 28.

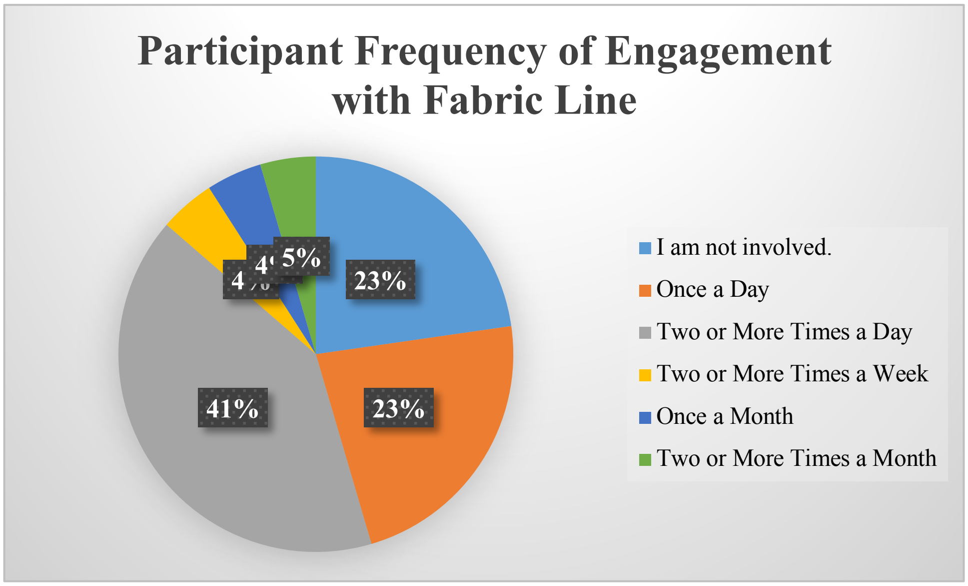


Figure 28. Participant Frequency of Engagement with Fabric Line.

4.3. Research Objective and Research Questions

The research objective was to determine expert response to inkjet digitally printed jacquard woven base cloths. This objective was addressed through three research questions.

4.4. Research Question 1

The first research question was: How do professionals in the textile industry respond to digitally printed jacquard woven fabric samples? Table 13, shown on the following page, details which print was applied to which base cloth. Only the four printed samples (Auden, Loris, Renato, and Zinnia) are included in the table. To understand participants' global response to each fabric and identify any effects for specific treatments, a 2-way analysis of variance (ANOVA) was run for the overall means of each fabric. Assessment responses were also analyzed in terms of each item for each fabric. These results are discussed in relation to the appropriate research questions in the following sections.

Table 13 (below) is provided for clarification of which samples relate to which research questions due to the type of printed design on each sample (photo and painting).

Table 13. *Base Cloths and Prints Integration*

Photo	**Painting**
Photo Base Cloth (Artwork A) **Photo Print (Artwork 2A)** Auden **1**	**Painting Base Cloth (Artwork B)** **Photo Print (Artwork 2A)** Zinnia **2**
3 **Photo Base Cloth (Artwork A)** **Painting Print (Artwork 2B)** Loris	**4** **Painting Base Cloth (Artwork B)** **Painting Print (Artwork 2B)** Renato

The number of responses for each fabric sample ranged from 20 to 22. For Delsie, only 20 participants responded to the overall impression, and utilization questions. For Jovany, 21 participants rated the sample for the item "Potential for Markets Beyond Upholstery" (but 22 for all the other characteristics) and the overall impression question. For Auden, 21 participants completed all questions related to Auden. For Renato, 21 participants rated the sample on the variable "Potential for Markets Beyond Upholstery" (and 22 for the other variables). For Zinnia, 22 participants answered all questions except for only 21 responses on the item "Fabric Hand."

4.4.1. Research Question 1 Survey Item Responses

In the assessment, the participants were shown six different samples. There were two unprinted base cloths, Delsie and Jovany, and four printed fabrics, Auden, Loris, Renato, and Zinnia. Although it was not explained explicitly during the assessment, Delsie and Jovany were the control fabrics and were not included here for comparison. The highest and lowest variable means for Delsie and Jovany can be seen in Table 14 on the following page. For Renato and Zinnia, the printed designs matched the woven designs. For Loris and Auden, the printed designs did not match the design that was used during weaving. Auden and Loris were both printed on the Artwork A substrate. Renato and Zinnia were both printed on the Artwork B substrate.

For the four printed base cloths, the means for each item for each sample were calculated. The 11 variables were able to be ranked from 1-5, with 1.0 referring to perceptions which were "Very Poor" and 5.0 being "Very Good," the samples received means from the 3.0 rating of "Adequate" to 4.5 rating, which was between "Good" and "Very Good" when evaluating each sample for each of the 11 variables.

The grand means and standard deviations for each sample were also calculated from these 11 items. The grand means and standard deviations are also shown in Table 14, along with the variables' means for each of the eight common items. Although the means are relatively similar, Loris received the highest rating with a grand mean of 4.03. The second highest grand mean of a printed sample was Auden with a rating of 3.90. Renato received a rating of 3.73 and Zinnia 3.79, respectively. An interesting notation is that Loris and Auden were both printed on the Artwork A base cloth and Renato and Zinnia printed on Artwork B.

Table 14. *Grand Means and Standard Deviations for Each Sample*

Sample Name	Auden	Delsie	Jovany	Loris	Renato	Zinnia
Aesthetic Appeal	3.76	3.95	4.05	4.14	3.91	3.64
Surface Texture	4.05	4.25	4.27	4.41	4.14	3.91
Weaving Technique	4.00	4.15	4.00	4.05	4.00	4.09
Yarn Choice	4.10	3.95	4.14	4.27	4.00	4.00
Fabric Hand	4.24	4.50	3.77	4.50	3.59	3.62
Fabric Weight	4.33	4.35	4.18	4.32	4.05	3.77
Appropriateness for Upholstery	3.95	4.20	4.27	4.27	3.86	3.77
Potential for Markets Beyond Upholstery	3.48	3.45	3.52	3.59	3.38	3.18
Grand Mean	3.90	4.00	3.99	4.03	3.73	3.79
Standard Deviation	0.87	0.99	0.97	0.91	0.85	1.00

As shown above in Table 14, Auden received the highest mean score of 4.33 for "Fabric Weight" and a lowest score of 3.48 for "Potential for Markets Beyond Upholstery." Loris received the highest mean of 4.50 for "Fabric Hand" and the lowest mean of 3.27 for "Printed Design Clarity." Renato's highest mean score of 4.14 for "Surface Texture" and 3.38 for "Potential for Markets Beyond Upholstery." Zinnia highest mean was for "Weaving

Technique" and received a score of 4.09. The lowest mean was 3.18 for "Potential for Markets Beyond Upholstery." It is an interesting finding that for all of the printed fabrics except Loris, the lowest mean score was for "Potential for Markets Beyond Upholstery." There was not a similar commonality between the printed samples for the highest mean score.

The means for each of the 11 variables for the printed base cloths can be seen below in Figure 29. The means for "Printed Design Clarity," "Printed Color Saturation," and "Integration of Woven and Printed Designs" are shown in Figure 29. An important notation is that three of the variables' names are not completely shown in Figure 29 due to figure scaling limitations. The full names of these variables are "Integration of Woven and Printed Designs," "Appropriateness for Upholstery," and "Potential for Markets Beyond Upholstery."

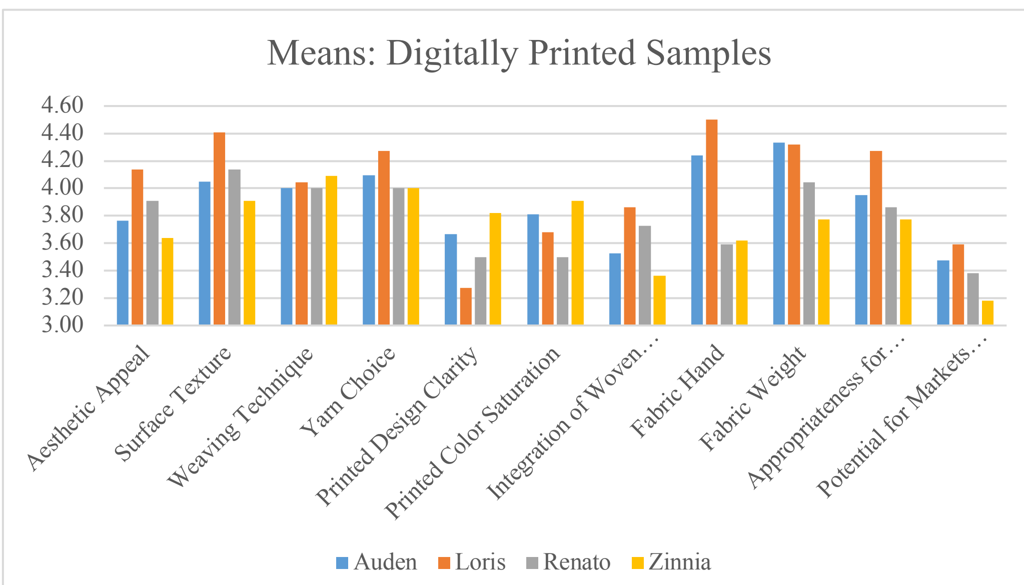


Figure 29. Variable Means for Digitally Printed Samples.

4.4.2. Statistical Analysis Research Question 1

The results from the 2-way ANOVA of the overall means can be seen directly below in Table 15. As seen in Table 15, there were significant differences in expert overall perceptions of the printed fabrics at the $p \leq .05$ level for "Base Cloth Type" [$F(1,20) = 4.342$, $p = 0.05$]. Regardless of print type, participants responded differently to the fabrics with base cloths derived from two different sources.

Table 15: *2-Way ANOVA Tests of Within-Subjects Contrasts*

Measure: Measure_1								
Source	**Print Type**	**Base Cloth Type**	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Print Type	Linear		.483	1	.483	2.769	.112	.122
Error (Print Type)	Linear		3.492	20	.175			
Base Cloth Type		Linear	.838	1	.838	4.342	.050	.178
Error (Base Cloth Type)		Linear	3.861	20	.193			
Print Type* Base Cloth Type	Linear	Linear	.014	1	.014	.152	.701	.008
Error (Print Type* Base Cloth Type)	Linear	Linear	1.832	20	.092			

In Table 16, on the following page, the significant items found during the 1-way ANOVA are shown. Of the 11 items, two were found to be significant at the $p \leq .05$ level.

Significant differences were found in expert perception of “Fabric Hand” at the $p \leq .05$ level [F(3,82) = 7.703, p = 0.001] between base cloths digitally printed with digitally manipulated photographs and digitally manipulated paintings. There were also significant differences in expert perceptions of “Fabric Weight” at the $p \leq .05$ level for the two conditions [F(3,83) = 3.505, p = 0.019].

Table 16. *1-Way ANOVA for Fabric Hand and Fabric Weight*

		Sum of Squares	df	Mean Square	F	Sig.
Fabric Hand	Between Groups	13.408	3	4.469	7.703	.000
	Within Groups	47.580	82	.580		
	Total	60.988	85			
		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Fabric Weight	Between Groups	4.593	3	1.531	3.505	.019
	Within Groups	36.258	83	.437		
	Total	40.851	86			

Before further analysis was conducted, a Test of Homogeneity of Variances was performed to determine if equal variance could be assumed for both significant variables. For “Fabric Hand,” equal variance could not be assumed. For “Fabric Weight,” equal variance could be assumed. The post hoc test for each of these variables can be seen in Table 17 and Table 18 in section 4.5.

4.4.3. Respondent Free Responses per Sample

The participants were provided the opportunity to leave free responses after evaluating each sample. The question prompt was “What are your overall impressions of ____?”, with the blank being filled with the name of the sample the respondent was evaluating at that time. Responses which most closely related to the highest and lowest variable means for each sample are provided in the below sections.

4.4.3.1. Free Responses to Sample Auden

When evaluating Auden, a few participants provided insight which aligned with the highest and lowest variable means. Three of these responses are included. “Nice hand and weight, but print technique not suitable due to color penetration.” “The chenille yarn really helps this print pattern especially in the black/brown areas. I feel like areas left unprinted would add to the appeal. Not a full coverage print.” “Surface texture is not visible. Lighter colors might be more effective. Would also like to see how this looks in repeat. The design would be for a specific market with a narrow appeal.”

4.4.3.2. Free Responses to Sample Loris

Four responses to Loris in terms of the highest and lowest variable mean were included. The majority of these participants considered Loris to have a sufficient fabric hand, but color which lacked clarity. “Great hand,” “Great hand, coverage of print is iffy in some spots (looks sparse),” “Good hand, good use of yarns. Colors are good but muddied some with overlap,” “Would like to see how it is repeated. Also would like to see it at a distance. The print is muddy and dated.”

4.4.3.3. Free Responses to Sample Renato

Similar to Loris, the colors used in Renato were found by two to be insufficient in terms of clarity and vibrancy. “The print on the texture makes it far more appealing. Hand is a bit rough but, in terms of upholstery, that could be ok. Colors lack saturation and smooth transitions. There is a slight lack of clarity in the design when the fabric texture changes,” “Color feels a bit washed out but I like the areas of print on top of the novelty yarn. More visual texture and depth.” Unlike Loris; however, the colors of Renato were also found by two participants to be adequate. “Color and overall pattern are more appropriate for furniture industry- excellent colors. Pattern is more of an all over/chopper, and would be easier to work with on larger pieces,” “Love the color.”

4.4.3.4. Free Responses to Sample Zinnia

Three participants responded to Zinnia with evaluations which were the most similar to the highest and lowest variable means. These respondents had differing views in terms of fabric weight and print quality. “Good weight, but again printing not very good pen[e]tration,” “A little too stiff for some applications.” “Very interesting and unique pattern. Abstract repeat would be difficult for manufacturers to cut for products other than pillows.”

4.4.3.5. Respondent Free Responses to Samples as a Collection

When the respondents had finished evaluating each fabric sample individually, they were given the choice to complete a free response for the set as a whole. The question prompt was, “Do you have any additional comments or thoughts about the samples reviewed today?”

In one of the responses, a participant noted that the Artwork B base cloth was more favorable to them. “Seemed as if similar prints were used. The prints on boucle were more effective than those printed on chenille.”

An additional participant evaluated the collection as a whole and also provided insight into their perceptions of a specific base cloth. “Delsie was a particularly textile [*sic*] for use as a base cloth for digitally printing. I love how the color and texture worked together on the printed options. The collection looks like they could fit right into ROMO’s fabric line today! I also really love the way colorations really utilized the flexibility of digital printing. The samples were uniform in size, and tagged in a professional manner which also elevated the presentation. Beautiful work.”

One participant responded that the digital print added value to the base cloths, but the prints could be improved for dye coverage. “The unprinted fabrics did not appeal to me, but the addition of a print made a substantial difference. The all over abstract prints work well with the abstract nature of the weave. Saturated colors seem to be the biggest difficulty whether that be in saturation in some areas or penetration/coverage in others. The printed samples are beautiful and seem like strong upholstery candidates given they would be durable enough!”

Another respondent noted the research’s limitations and provided some options for future study. “The variations are not broad. It seams [*sic*] that the weft yarns used is limited to one or two. The research should include different yarn types to produce similar produce smoother surface and print same patterns to reveal the surface suitability for digital printing.”

An additional respondent provided insight into further research. “Extremely interesting sample and potential for growth. I would be curious to see the same samples printed on a variety of different platforms using different ink chemistry!”

When evaluating the samples as a collection, a participant provided both concepts for additional research and important concepts to consider. “Very interesting project and beautiful samples. Breadth of project could be improved by varying the type of pattern and scale. What does this look like with mid-scale or small patterns? What about geometrics or stripes? Could expand to a wider market audience with more types of patterns. Important to keep in mind final cost, end customer and use. If very expensive, could you sell to high end editors/jobbers? What are they willing to pay, and what do they see worth in? Consider trying some [v]ery high end, super textural plains that combine weaving and printing.”

4.5. Research Question 2

The second research question was: Are there differences in expert perceptions of a digitally manipulated photograph and a digitally manipulated painting as digital prints for jacquard woven base cloths? A 2-way ANOVA was used to compare the overall mean assessments for all fabrics, regardless of base cloth, printed with the digitally manipulated photograph and printed with the digitally manipulated painting. The ANOVA revealed no main effect for print type on the overall mean assessment score. As mentioned above significance was only found for the item “Base Cloth Type” the $p \leq .05$ level. Table 15 (shown in section 4.4.2.) shows the values obtained during the 2-way ANOVA when conducting Tests of Within-Subjects Contrasts. Further analysis looked at responses recorded on individual assessment items as discussed in the following section.

A one-way between subjects ANOVA was conducted to compare the expert perceptions of base cloths digitally printed with digitally manipulated photographs and digitally manipulated paintings on “Aesthetic Appeal;” “Surface Texture;” “Weaving Technique;” “Yarn Choice;” “Printed Design Clarity;” “Printed Color Saturation;” “Integration of Woven and Printed Designs;” “Fabric Hand;” “Fabric Weight;” “Appropriateness for Upholstery,” and “Potential for Markets Beyond Upholstery” items. Table 16 (seen above in section 4.4.2.), shows the means scores for the significant variables “Fabric Hand” and “Fabric Weight.” When evaluating the variable “Fabric Hand,” a Games-Howell Post Hoc test was conducted since a significance of .024 at the $p \leq .05$ level was found during a Test of Homogeneity of Variances. A significant p value indicated that equal variance could not be assumed. The Games-Howell results can be seen in Table 17 on the following page.

Table 17. *Multiple Comparisons using Games-Howell for Fabric Hand*

Dependent Variable: Fabric Hand						
Post Hoc Test: Games-Howell						
					95% Confidence Interval	
(I) Print Type	(J) Print Type	Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
AUDEN	LORIS	-.26190	.19897	.558	-.7956	.2718
	RENATO	.64719	.27171	.099	-.0839	1.3783
	ZINNIA	.61905*	.19977	.018	.0829	1.1552
LORIS	AUDEN	.26190	.19897	.558	-.2718	.7956
	RENATO	.90909*	.25828	.007	.2107	1.6074
	ZINNIA	.88095*	.18107	.000	.3961	1.3658
RENATO	AUDEN	-.64719	.27171	.099	-1.3783	.0839
	LORIS	-.90909*	.25828	.007	-1.6074	-.2107
	ZINNIA	-.02814	.25889	1.000	-.7281	.6719
ZINNIA	AUDEN	-.61905*	.19977	.018	-1.1552	-.0829
	LORIS	-.88095*	.18107	.000	-1.3658	-.3961
	RENATO	.02814	.25889	1.000	-.6719	.7281

*. The mean difference is significant at the 0.05 level.

Table 17 (seen above) contains the results from the Post Hoc comparisons which were conducted using the Games-Howell test for the variable "Fabric Hand." This test indicated significant differences for Auden and Zinnia at the $p \leq .05$ level (MD = .619, SE = .200, p = .018). The mean score for the “Fabric Hand” condition was also significantly different for Loris and Renato at the $p \leq .05$ level (MD = .909, SE = .258, p = .007), and Loris and Zinnia at the $p \leq .05$ level (MD = .881, SE = .181, p = .001). When evaluated for two pairs, Auden and Zinnia and Loris and Renato, the print was the same in each pair, but the base cloth was different. The third pair, Loris and Zinnia, had different prints and also different base cloths. Three of the four pairs of fabrics that were printed on different base cloths were perceived as different in terms of "Fabric Hand," which would indicate the assessment of "Fabric Hand" was being driven largely by the base cloth. However, the print used could be a contributing factor as shown in the case of Loris and Zinnia, but this is difficult to conclude because the base cloths were also different. Interestingly, Auden and Renato have both different base cloths and different prints but were not perceived differently in terms of "Fabric Hand."

Table 18. *Multiple Comparisons Using Bonferroni for Fabric Weight*

Dependent Variable: Fabric Weight						
Post Hoc Test: Bonferroni						
					95% Confidence Interval	
(I) Print Type	(J) Print Type	Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
AUDEN	LORIS	.01515	.20164	1.00	-.5299	.5602
	RENATO	.28788	.20164	.943	-.2571	.8329
	ZINNIA	.56061*	.20164	.040	.0156	1.1056
LORIS	AUDEN	-.01515	.20164	1.00	-.5602	.5299
	RENATO	.27273	.19928	1.00	-.2659	.8114
	ZINNIA	.54545*	.19928	.045	.0068	1.0841

Table 18. *Continued*

RENATO	AUDEN	-.28788	.20164	.943	-.8329	.2571
	LORIS	-.27273	.19928	1.00	-.8114	.2659
	ZINNIA	.27273	.19928	1.00	-.2659	.8114
ZINNIA	AUDEN	-.56061*	.20164	.040	-1.1056	-.0156
	LORIS	-.54545*	.19928	.045	-1.0841	-.0068
	RENATO	-.27273	.19928	1.00	-.8114	.2659

*. The mean difference is significant at the 0.05 level.

When evaluating the item "Fabric Weight," a Bonferroni Post Hoc test was conducted since no significance was found at the $p \leq .05$ level ($p = .878$) during the Test of Homogeneity of Variances and equal variance could be assumed. The Bonferroni results can be seen above and on the previous page in Table 18. Results indicated the mean score for the "Fabric Weight" variable to be significant at the $p \leq .05$ level for Auden and Zinnia (MD = .561, SE = .202, p = 0.40) and Loris and Zinnia (MD = .545, SE = .199, p = 0.45).

Similar to the variable "Fabric Hand" which was discussed above, the pair Auden and Zinnia were printed with the same print but on different base cloths. The pair Loris and Zinnia were printed with both different prints and different base cloths. Two of the four pairs of fabrics that were printed on different base cloths were perceived as different in terms of "Fabric Weight," which would indicate the assessment of the item "Fabric Weight" can be driven by the base cloth. However, in terms of Loris and Zinnia, the print can be a contributing factor, but this is difficult to conclude due to differences in base cloth. Also similar to "Fabric Weight," it is interesting that Auden and Renato were both printed with different designs and on different base cloths but were not perceived differently in terms of "Fabric Weight."

4.6. Research Question 3

The third research question was: Are there differences in expert perceptions of digitally printed jacquard woven samples based on whether the designs for weaving and printing were based on the same imagery or different imagery? When evaluating using the 2-way ANOVA, no main effect in the overall means was found for the interaction of print type and base cloth type. This indicated that respondents did not perceive overall differences in the samples based on whether the printed design matched the pattern of the substrate or did not match. (See Table 15 in section 4.4.2. for the 2-way ANOVA results.).

An Independent-Samples T-Test was conducted to compare expert impressions of base cloths digitally printed with imagery that matched the woven or imagery that did not match for Aesthetic Appeal; Surface Texture; Weaving Technique; Yarn Choice; Printed Design Clarity; Printed Color Saturation; Integration of Woven and Printed Designs; Fabric Hand; Fabric Weight; Appropriateness for Upholstery, and Potential for Markets Beyond Upholstery conditions. The Independent-Samples T-Test for Weave Match, (beginning on the following page in Table 19), was conducted to determine whether participants perceived a difference between base cloths printed with matching prints or prints which did not match.

An independent-samples t-test allowed the two independent groups to be created for analysis. To evaluate whether the samples with both the woven and printed designs matching were perceived differently than the samples where the designs were different, the samples were coded into two categories. Auden and Renato were assigned the group for "Matches."

Loris and Zinnia were assigned the group which corresponded with “Does not Match.” Auden and Renato were added to the matching group since each had woven and printed designs which were based on the same imagery. Loris and Zinnia were grouped in the other category since the woven and printed designs were based on different imagery. In this test, the categories were based solely on whether the print and woven designs matched or not, and not whether the painting or photo print was being used. No significance was found during the independent-samples t-test in any of the 11 variables at the $p \leq .05$ level, which indicated that the respondents did not perceive a difference between imagery which matched the woven design or did not match.

Table 19. *Independent-Samples T-Test for Weave Match*

		Levene's Test for Equality of Variances		**t-test for Equality of Means**				
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Aesthetic Appeal	Equal variances assumed	2.582	.112	-.260	85	.796	-.049	.189

Table 19. *Continued*

Surface Texture	Equal variances assumed	.313	.578	-.346	85	.730	-.066	.191
Weaving Technique	Equal variances assumed	.234	.630	-.497	85	.621	-.068	.137
Yarn Choice	Equal variances assumed	.083	.773	-.652	85	.516	-.090	.138
Printed Design Clarity	Equal variances assumed	.053	.818	.162	85	.872	.036	.222
Printed Color Saturation	Equal variances assumed	.100	.753	-.600	85	.550	-.144	.241
Integration of Woven and Printed Designs	Equal variances assumed	1.150	.287	.076	85	.939	.0143	.187
Fabric Hand	Equal variances assumed	1.917	.170	-.890	84	.376	-.163	.183
Fabric Weight	Equal variances assumed	.281	.598	.951	85	.344	.141	.148

Table 19. *Continued*

Appropriateness for Upholstery	Equal variances assumed	.018	.895	-.561	85	.576	-.116	.206
Potential for Markets Beyond Upholstery	Equal variances assumed	.205	.652	.179	84	.859	.0422	.236

4.6.1. Respondent Free Response to Samples as a Collection

As with the free responses included in the analysis of Research Question 1, the question prompt was, "Do you have any additional comments or thoughts about the samples reviewed today?" A participant responded to this question in terms of the print being based on the same or different imagery as the base cloth.

In one of the free responses, a participant did not find the registration between woven and printed design completely successful. This participant also offered input on which base cloth was more preferable to them when used for printing. "When experimenting with digital prints on jacquard base cloths, try integrating the print pattern with the jacquard pattern more intentionally. They should interact with each other more to create visual interest and make the 2 step process worth the extra expense. Overall the prints on [J]ovany turned out better than the prints on Delsie. Colors of Loris and Renato were great!"

CHAPTER 5: CONCLUSION

Digital printing has become an innovative way to add coloration to a previously woven fabric. This process could be applied to jacquard woven fabric to increase both the salability and the level of aesthetic interest. While the combination of these two textile production methods is a process which is not widely used in the textile industry to color home furnishings fabric, it has many potential applications in the fabrics industry for a variety of markets.

The primary research question was to determine expert response to inkjet digitally printed jacquard woven base cloths. Twenty-two textile industry experts from areas of work such as woven fabric design; woven fabric product development; woven fabric research and development; textile screen printing; digital inkjet textile printing; yarn design; textile consultation, color matching, and additional fields were involved in the assessment and completed the accompanying survey. The participants had either worked in the textile industry or were faculty members. Among the fifteen participants who were involved in fabric line decisions, six participants had been evaluating fabric samples for over 20 years. Sixty-four percent of the participants were involved in fabric line decisions at least once week. The expert participants responded to questions from the survey which included both predetermined variables and free response sections. Having both types of responses allowed the participants to add insight to both the predetermined variables and additional concepts which may have not been covered. Due to both types of responses, valuable insight was gained.

The first research question developed to assess the research objective was, how do professionals in the textile industry respond to digitally printed jacquard woven fabric samples?" When evaluated using the 2-way ANOVA, significance was found for the item "Base Cloth Type," which indicated that participants responded with different perceptions of the substrate used for printing, but not on whether the printed design originated from photograph or a painting. As seen in Table 14 in section 4.4.1., the grand means and the means for each of the eight common variables ranged from 3.73 for Renato to 4.03 for Loris, which corresponded to views that ranged from the higher side of the "Adequate" range to the beginning of the "Good" range. Free responses were also garnered which indicated that the samples had attributes which were found to be favorable such as fabric weight, hand, design, and yarn usage. Some of the respondents noted that dye penetration could have been more even, especially when printing on the chenille yarns used in weaving Artwork A.

The second research objective was, are there differences in expert perceptions of a digitally manipulated photograph and a digitally manipulated painting as digital prints for jacquard woven base cloths? The 2-way ANOVA revealed no significant differences in the overall mean ratings for print type. For most of the fabric properties, when evaluating with the 1-way ANOVA, the print type made no difference in the assessment. However, print type may have been a contributing factor in differences in the assessment of the items "Fabric Hand" and Fabric Weight." A possible explanation to the significance found for the items "Fabric Weight" and "Fabric Hand" was that Artwork B was woven at too high a pick density. Reducing the number of picks per inch may have improved the substrate's hand and weight, which might have removed the significant differences between Artwork A and B.

The third research question was, are there differences in expert perceptions of digitally printed jacquard woven samples based on whether the designs for weaving and printing were based on the same imagery or different imagery? The 2-way ANOVA revealed no significant differences in the overall mean ratings for whether prints and base cloth designs matched. This test indicated that participants responded with different perceptions of the substrate used for printing but did not perceive differences when the printed design either matched with the woven design or did not match. No significance was found during the independent-samples t-test which compared the sets of prints which matched the design of base cloths or did not match, either. These results further indicated that the respondents found no significant differences between the two groups. One of the respondents recommended that the printed designs could have been registered more effectively. Perhaps a different artwork with more definitive compositional elements would have provided a more obvious matching aesthetic than the abstracted patterns used.

While this research did not uncover significant results when evaluating for specific types of prints or whether the printed designs matched the pattern of the base cloth or was based on different imagery, the fabric samples were generally well received. When evaluating the grand means of each sample and the free responses, the samples were viewed quite favorably and indicated the potential for growth.

CHAPTER 6: LIMITATIONS AND FUTURE RESEARCH

This research established some valuable insights for the textile industry but could be furthered through additional studies. A single abstracted pattern in a single colorway was used during the pilot work. While only one design was needed to test color fixation, experimentation with additional colorways and designs to measure the color and design clarity when using additional artwork or variegated fabric constructions with alternative yarns could have yielded different results when using the original pretreatment developed for knitted textiles.

A tapestry warp rotation which included ivory, red, green, and in indigo yarns was used when weaving the fabric samples for the assessment. Since undyed or bleached yarns were not available, the samples needed to be stripped of color before printing. The color stripping process did not create fully achromatic base cloths; some of the color remained on the warp yarns, which could be seen after printing as pink and blue yarns. The color reduction process may have also affected the fabric hand.

The color of the woven substrate affected the color of the printed image, which resulted in the Artwork A and Artwork B sample fabrics being color stripped. Additional research could have been conducted to see how the design would have appeared if the pilot trials fabrics had been color stripped before printing.

Another interesting area of study would have been to use the same abstracted design that was printed and print it on different scales. The size of the repeat could affect the interaction between print and woven designs.

Another factor which was not tested in this study was the concept of putting one or more synthetic filling yarns in different places in the filling rotation to study how that yarn would impact the printed design when printed with certain pigments of dyes.

While this study was a valuable foray into the concept of providing coloration to jacquard woven base cloths through digital inkjet printing, there are still areas of research to be conducted before it could be determined if their combination could be a viable option for fabric coloration in the textile industry on a commercial scale.

As research develops into this topic, it would be important to study whether digital printing is also a feasible coloration method for other natural, synthetic, or blended jacquard woven base cloths. Since markets such as contract or marine require fabrics other than cotton due to different performance capabilities than interior upholstery, fabrics with different or variegated fiber contents are used.

All of the samples were created from full cotton fabrics since fiber reactive dye-based inks were used in the Shima Seiki SIP-160F3L flatbed digital printer. Experimentation with other types of inks on other fibers would broaden the application of this research.

On the Shima Seiki SIP-160F3L flatbed printer, the ink droplet size (color booster) can be changed to produce designs which are more or less saturated. This will affect both the crispness of the printed design and the appearance of the print. If less ink is used, more of the woven construction can be seen. When it is desired to hide the construction or color of the original fabric, a larger ink droplet is required. Understanding the capabilities of the printer is important in pushing the boundaries of overprinted textile design. A simple change in factors such as droplet size and print head distance could drastically alter the final surface design.

The construction of the weaves used in producing the cloth will have an impact on the printed design. Some weave constructions will absorb more of the ink due to the openness of the structure. Dyes will be taken in differently on the yarns/weave structures. Having more or less color saturation has the potential to yield additional interest in the surface of the fabric. A trial specifically meant to study weave structures and color saturation would be of interest and could yield surprising results. Through the careful calculation of fabric shrinkage, coloration could be controlled and limited to areas of the fabric with more or less constriction. It would also be noteworthy to utilize the experiments conducted on other types of woven fabrics such as dobby. Knitted and nonwoven fabrics also allow for potential expansion into other textile markets such as apparel. Since this research was focused on woven fabrics for use in the home furnishings industry, exploration was not conducted on other methods of fabric formation than jacquard weaving.

Another potential area of research is that, due to photographic effects which can be achieved through digital printing, virtually any image can be printed onto the surface of the fabric. Since this research did not deal with traditional, geometric, and other genres, these styles of textile designs would be interesting to study to determine expert response. In addition to the established genres included in commercial textile design, research could also be performed to determine ideal artwork for the creation of novelty yarns such as space dyed and slub styles on the fabric surface.

Additional colorways of Artwork A and B were also not tested to determine if expert response would change with additional or different color ways. While coloration was an important component of this study, color was not specifically tested during the experiment. The samples could also be evaluated using industry testing methods for colorfastness and quality of color when compared to the original digitally manipulated painting and photograph. As mentioned by a respondent, another potential research area would be to weave Artwork A and B with different filling yarns, or even on a solid warp, to determine if expert impressions change when the yarns used during weaving are substituted.

Since the Artwork A and B samples for this study were created on a small scale when compared to industry production, further research into how much this process would cost on a production-level scale would need to be conducted to produce a costing model. Once a model is developed, commercial viability could be evaluated. An analysis of the supply chain would also be a factor when research application for industry. A study into the length of production time of jacquard woven fabrics versus the production time for printed fabrics would need to be explored before attempting to compare with the time to combine weaving and printing.

This thesis studied expert response to digitally printed jacquard woven base cloths. Further research into consumer or student response would create an interesting study to compare if the assessments would be similar or not. The samples used in this research could be used to determine the response of other demographics.

Only abstract artworks were used with one originating from a hand painting and the other from a digitally manipulated photograph. Additional colorways, other artwork created from these techniques, or additional artwork genres would need to be researched in another study. Another factor which could be researched is the effect of using mercerized yarns. The yarns used in creating the samples for the assessment were not mercerized. Mercerization would have allowed the fabrics to have a better luster and receive more dye during printing.

The fabrics were printed on a flatbed printing machine in piece form and not roll to roll. When produced in the piece method used, there were opportunities for changes in fabric dimension and printed design quality from piece to piece. Due to the nature of printing small runs of individual samples at a time, minor printing defects occurred when printing some pieces of the sample Zinnia. Printing in roll form could have produced samples which were printed at the same time and looked identical when perceived visually. Due to limitations in ink supply and printer usage, there was no opportunity to reprint.

The survey was administered on iPad devices which may have impacted some participants' inclination to type responses in the free response sections. A participant mentioned during an assessment that the iPad did make typing longer responses difficult since it mitigated the ability to see what was previously written in the text box. An additional factor could have been that the participants did not want to type anything additional on the iPad due to the typing process and not being able to write with a pen. If any of the participants were unfamiliar with an iPad, this could also have had an impact in desire to leave a response when optional.

There are multiple options for further research along the focus of digital printing on jacquard woven fabrics, either through aspects studied in this thesis or from related focuses. Types of printers, inks, fibers, yarns, finishing methods, and pattern designs all present exciting avenues of discovery. Due to the innovative nature of digital printing, especially when used as a colorant for jacquard woven fabrics, this field offers many exciting areas of growth in the textile industry.

REFERENCES

Bae, J., Hong. K., & Lamar, T. (2015). Effect of Texture on Color Variation in Inkjet-Printed Woven Textiles. *Color Research and Application*, 40.3, 297-303. Retrieved from http://onlinelibrary.wiley.com.prox.lib.ncsu.edu/doi/10.1002/col.21865/abstract

Ballard, J. (2016). Desizing; Overview of Textile Wet Processing; Mercerization; Pigments; Printing. [Presentation]. *Lectures presented in Fall 2016 PCC 302: Technology of Textile Wet Processing at North Carolina State University*. Raleigh, NC.

Becker, J., & Wagner, D. (2014). *Pattern and Loom: A Practical Study of the Development of Weaving Techniques in China, Western Asia, and Europe*. (2nd ed.). Copenhagen, Denmark: Nordic Institute of Asian Studies Press.

Cahill, V. (2006). The Evolution and Progression of Digital Printing of Textiles. In Ujiie, H. (Ed.). *Digital Printing of Textiles*. (pp. 1-15). Cambridge, UK: The Textile Institute, Woodhead Publishing Series in Textiles.

Carden, S. (2016). *Digital Textile Printing*. London, UK: Bloomsbury Academic. Retrieved from https://catalog.lib.ncsu.edu/record/NCSU3564941

Chamberlin, C. (2013, March 6). Phoenix Art Museum Embraces New Technology with 'Digital Print Fashion' Exhibit. [Online Image]. *Elle.* Retrieved from http://www.elle.com/culture/tech/news/a22800/digital-print-fashion-exhibit/

Cie, C. (2015). *Ink Jet Textile Printing*. Cambridge, UK: Woodhead Publishing in Textiles. Retrieved from http://www.sciencedirect.com.prox.lib.ncsu.edu/science/article/pii/B9780857092304000078

The Editors of Encyclopedia Britannica. (n.d.). Pointillism. *Encyclopedia Britannica.* Retrieved from https://www.britannica.com/art/pointillism

Fabric Link. (n.d.). Sweater Knit & Yarn Resource. *Fabric Link*. Retrieved from *http*://www.fabriclink.com/university/knit/Spaced.cfm

Fashion Snoops. (2017, July 11). Fashion Snoops Home, Fall/Winter 18/19, Forecast, Pattern + Graphics, Terra, Nordic Lights. [Online Image]. *Fashion Snoops*. Retrieved from http://www.fashionsnoops.com.prox.lib.ncsu.edu/ReportPage/home/Forecast/Main/item/F-W%2018-19-75/75-44429-item

Fashion Translated. (n.d.). [Mary Katrantzou Line "Mary Katrantzou + Adidas"]. [Online Image]. *Fashion Translated*. Retrieved from http://www.fashiontranslated.com/mary-katrantzou-adidas-collaboration/

FESPA Staff (a). (2017, September 3). Canon Launches Océ Colorado 1640. *FESPA*. Retrieved from https://www.fespa.com/news/industry-news/canon-launches-oce-colorado-1640.html

FESPA Staff (b). (2017, October 2). Kornit Digital President Praises Introduction of FESPA Asia. *FESPA*. Retrieved from https://www.fespa.com/news/industry-news/kornit-digital-president-praises-introduction-of-fespa-asia.html

Freire, E. Mariano (2006). Ink Jet Printing Technology (CIJ/DOD). In Ujiie, H. (Ed.). *Digital Printing of Textiles*. (pp. 29-53). Cambridge, UK: The Textile Institute, Woodhead Publishing Series in Textiles.

Geselowitz, M. (2016, July 18). The Jacquard Loom: A Driver of the Industrial Revolution. *The Institute.* Retrieved from http://theinstitute.ieee.org/tech-history/technology-history/the-jacquard-loom-a-driver-of-the-industrial-revolution

Gong, R.H., & Wright, R.M. (2002). *Fancy Yarns, Their Manufacture and Application.* Cambridge, UK: The Textile Institute, Woodhead Publishing.

Gorgani, A. S., & Shakib, N. (2013). Single-Phase Ink-Jet Printing onto Cotton Fabric. *Color Technology*, 129.2, 109-113. Retrieved from http://onlinelibrary.wiley.com.prox.lib.ncsu.edu/doi/10.1111/cote.12011/abstract

Hawkyard, C. (2006). Substrate Preparation for Ink-jet Printing. In Ujiie, H. (Ed.). *Digital Printing of Textiles*. (pp. 201-215). Cambridge, UK: The Textile Institute, Woodhead Publishing Series in Textiles.

Kan, C., & Yuen, C. (2012). Digital Ink-Jet Printing on Textiles. *Research Journal of Textile and Apparel*, 16.2, 1-24. Retrieved from http://search.proquest.com.prox.lib.ncsu.edu/docview/1015352534?accountid=12725

Konica Minolta. (n.d.). Technology Overview. [Online Image]. *Konica Minolta*. Retrieved from https://www.konicaminolta.com/inkjet/technology/technology.html

Laxmi. (n.d.). Rotary Textile Screen Printing Machine. [Online Image]. *Laxmi*. Retrieved from http://laxmi-printingmachines.com/index.php/products/rotary-textile-screen-printing-machine

Liao, S., & Chen, H. (2011). Ink-jet Printing of Nylon Fabric Using Reactive Dyestuff. *Coloration Technology*, 127.1, 390-395. Retrieved from http://onlinelibrary.wiley.com.prox.lib.ncsu.edu/doi/10.1111/j.1478-4408.2011.00335.x/epdf

Mathur, K., Hinks, D., Seyam, A. F. M., & Donaldson, R. A. (2008). Prediction of Color Attributes Through Geometrical Modeling. *Research Journal of Textile and Apparel*, 12.1, 19-31. Retrieved from http://www.emeraldinsight.com/doi/pdfplus/10.1108/RJTA-12-01-2008-B003

Mathur, K., Hinks, D., Seyam, A. F. M., & Donaldson, R. A. (2009). Towards Automation of Color/Weave Selection in Jacquard Design: Model Verification. *Color Research & Application*, 34.3, 225–232. Retrieved from http://onlinelibrary.wiley.com.prox.lib.ncsu.edu/doi/10.1002/col.20494/abstract;jsessionid=0754C380602626BC9C739A7CC5A15428.f02t04

Mathur K. & Seyam A.F. (2011a, July 27). Color and Woven Relationship in Woven Fabrics. [Adapted Online Image]. *Intech*. Retrieved from https://www.intechopen.com/books/advances-in-modern-woven-fabrics-technology/color-and-weave-relationship-in-woven-fabrics

Mathur K. & Seyam A.F. (2011b, July 27). Color and Woven Relationship in Woven Fabrics. [Online Image]. *Intech*. Retrieved from https://www.intechopen.com/books/advances-in-modern-woven-fabrics-technology/color-and-weave-relationship-in-woven-fabrics

Merriam-Webster. (n.d.a.). Aesthetic. *Merriam-Webster*. Retrieved from https://www.merriam-webster.com/dictionary/aesthetic

Merriam-Webster. (n.d.b.). Appearance. *Merriam-Webster*. Retrieved from https://www.merriam-webster.com/dictionary/appearance

Mimaki USA. (n.d.a.). Mimaki CJV150 Series: High Quality Cut and Print. *Mimaki USA*. Retrieved from http://www.mimakiusa.com/products/solvent/cjv150-series/

Mimaki USA. (n.d.b.). Mimaki CJV 150-160 Digital Printer. [Online Image]. *Mimaki USA*. Retrieved from http://www.mimakiusa.com/wp-content/uploads/2014/10/CJV150-160-NEW-v3.jpg

MJ Styling. (2013, March 18). Let's Get Digital, Digital! [Web log post]. *MJ Styling*. [Online Image]. Retrieved from https://mjstyling.wordpress.com/tag/top/

Ng, F., Kim, K., Hu, J., & Zhou, J. (2014). Patterning Technique for Expanding Color Variety of Jacquard Fabrics in Alignment with Shaded Weave Structures. *Textile Research Journal*, 84.17, 1820-1828. Retrieved from http://search.proquest.com.prox.lib.ncsu.edu/docview/1567029847?accountid=12725

Ng, M., & Zhou, J. (2010). Full-Colour Compound Structure for Digital Jacquard Fabric Design. *Journal of the Textile Institute*, 101.1, 52-57. Retrieved from https://doi.org/10.1080/00405000802231291

Ng, M., & Zhou, J. (2013). *Innovative Jacquard Textile Design Using Digital Technologies*. Cambridge UK: The Textile Institute, Woodhead Publishing Series in Textiles.

Parrillo-Chapman, L. (2016, 23 May). ITMA Technology: Digital Printing. *Textile World.* Retrieved from http://www.textileworld.com/textile-world/features/2016/05/itma-technology-digital-printing/

Phipps, E. (2011). *Looking at Textiles, A Guide to Technical Terms*. Los Angeles, California: The John Paul Getty Museum.

Pluck, C. (2017). The Road to Digital Printing. *Impressions*, 40.7, 54-56. Retrieved from http://search.proquest.com.prox.lib.ncsu.edu/docview/1853272368?accountid=12725

Polston, K., Parrillo-Chapman, L. & Moore, M. (2015). Print-On-Demand Inkjet Digital Textile Printing Technology: An Initial Understanding of User Types and Skill Levels. *International Journal of Fashion Design, Technology & Education*, 8.2, 87-96. Retrieved from http://web.b.ebscohost.com.prox.lib.ncsu.edu/ehost/detail/detail?sid=cfc1ee55-a294-4df0-bf2d-598e4f71000c%40sessionmgr101&vid=0&hid=125&bdata=JnNpdGU9ZWhvc3QtbGl2ZSZzY29wZT1zaXRl#AN=103265626&db=tdh

Seyam, A. F. M. (2011). *Specialist Yarn and Fabric Structures, Development and Application*. In Gong, R.H. (Ed.). Cambridge, UK: The Textile Institute, Woodhead Publishing Series in Textiles.

Seyam, A. F. M. (2016). Backed Weaves; Double Cloth; Intro to Weaving; Pile Fabrics; Ply Cloth. [Presentation]. *Lectures presented in Fall 2016 TT 551: Advanced Woven Structure and Design. North Carolina State University*. Raleigh, NC.

Shima Seiki. (n.d.a.) Shima Seiki SIP-160F3L. *Shima Seiki*. Retrieved from http://www.shimaseiki.com/product/print/sip160f3/

Shima Seiki. (n.d.b.). Shima Seiki 160-F3 Flatbed Digital Printer. [Online Image]. *Shima Seiki*. Retrieved from http://www.shimaseiki.com/product/print/sip160f3/images/fig_01.jpg

Stäubli. (n.d.). Our Innovation- Your Success: Stäubli's Jacquard Range. Stäubli. Retrieved from http://www.staubli.com/en/textile/textile-machinery-solutions/jacquard-weaving/

Stearns, P. (n.d.). Fragmented Memory. [Online Images]. *Phillip Stearns*. Retrieved from https://phillipstearns.wordpress.com/fragmented-memory/

Threadbird. (n.d.). Everything You've Always Wanted to Ask About Screen Printing but Were Too Afraid to Ask. [Online Image]. *Threadbird*. Retrieved from https://www.threadbird.com/the-screen-printing-process

Treadway, C. (2004). Digital Imagination: The Impact of Digital Imaging on Printed Textiles. *Textile*, *The Journal of Cloth and Culture*, 2:3, 256-273. Retrieved from http://www-tandfonline-com.prox.lib.ncsu.edu/doi/abs/10.2752/147597504778052720

Watt, M. (2003). Textile Production in Europe: Printed, 1600-1800. *The Metropolitan Museum of Art*. Retrieved from http://www.metmuseum.org/toah/hd/txt_p/hd_txt_p.htm

Weeks-Atkin, J. (2015) Additive vs. Subtractive Color Models. *X-Rite.* Retrieved from https://www.xrite.com/blog/additive-subtractive-color-models

Williams, A. (2016, June 30). Valdese Weavers line by Valdese weavers "Weaving History." [Online Image]. *Business North Carolina*. Retrieved from http://businessnc.com/weaving-history/

Yuen, C., Kan, C. Jiang, S., Ku, K. Choi. P., & Wong, K. (2009). Optimum Condition of Ink-jet Printing for Wool Fabric. *Fibers and Polymers*, 11.2, 229-233. Retrieved from http://link.springer.com.prox.lib.ncsu.edu/article/10.1007%2Fs12221-010-0229-z

Yuen, C. W. M., Ku, S. K. A., Choi, P. S. R., & Kan, C. W. (2005). Factors Affecting the Color Yield of an Ink-Jet Printed Cotton Fabric. *Institute of Textiles and Clothing*, 319-325). Retrieved from http://journals.sagepub.com.prox.lib.ncsu.edu/doi/abs/10.1177/0040517505054733

APPENDICES

Appendix A: IRB Approval

Dear Traci Lamar:

Date: November 17, 2017
IRB Protocol 12277 has been assigned Exempt status
Title: Assessment of Digital Inkjet Printing on Jacquard Woven Base Cloths
PI: Lamar, Traci Ann May

The research proposal named above has received administrative review and has been approved as exempt from the policy as outlined in the Code of Federal Regulations (Exemption: 46.101. Exempt b.2). Provided that the only participation of the subjects is as described in the proposal narrative, this project is exempt from further review. This approval does not expire, but any changes must be approved by the IRB prior to implementation.

1. This committee complies with requirements found in Title 45 part 46 of The Code of Federal Regulations. For NCSU projects, the Assurance Number is: FWA00003429.
2. Any changes to the protocol and supporting documents must be submitted and approved by the IRB prior to implementation.
3. If any unanticipated problems or adverse events occur, they must be reported to the IRB office within 5 business days by completing and submitting the unanticipated problem form on the IRB website: http://research.ncsu.edu/sparcs/compliance/irb/submission-guidance/.
4. Any unapproved departure from your approved IRB protocol results in non-compliance. Please find information regarding non-compliance here: http://research.ncsu.edu/sparcs-docs/irb/non-compliance_faq_sheet.pdf.

Please let us know if you have any questions.

Sincerely,

Deb Paxton
919.515.4514
IRB Administrator
dapaxton@ncsu.edu
NC State IRB Office

Jennie Ofstein
919.515.8754
IRB Coordinator
irb-coordinator@ncsu.edu
NC State IRB Office

Showing 1 to 1 of 1 entries

Protocol No.	Title	Department	PI	Status	Submission Date	Last Status Change	
12277	Assessment of Digital Inkjet Printing on Jacquard Woven Base Cloths	Textile & Apparel, Technology & Management	Lamar, Traci Ann May	Exempt	11/01/2017	11/17/2017	Select View PDF
Filter Protocol	Filter Title	Filter Department	Filter PI	Filter Status			

Return to Main Menu

Appendix B: IRB Invitation Email to Participants

Email to Participants
Purpose: To gain permission to survey participants.

North Carolina State University
Study: Assessment of Digital Inkjet Printing on Jacquard Woven Base Cloths

Principal Investigator: Claire Hider   Faculty Sponsor: Dr. Traci A.M. Lamar

Dear (Name of Respondent),

My name is Claire Hider and I am in the process of conducting my thesis research at North Carolina State University. The purpose of my research is to determine expert response to digitally printed jacquard base cloths. This research study will consist of participants who are knowledgeable in the areas of woven fabric design, woven fabric product development, woven fabric research and development, digital inkjet textile printing, textile screen printing, yarn design, textile consultation, and color matching.

The assessment will be conducted in the College of Textiles at NC State. During the assessment, the participants will evaluate one set of fabric samples created in the College of Textiles by the Principal Investigator (PI) by completing a survey which has been created by the PI and Faculty Sponsor.

All participants will fill out an informed consent form prior to completing the survey and the results of the survey will remain anonymous. After analysis of the results, I will gladly discuss the findings with all the participants. Please let me know if you would be able to participate in my experiment. The survey should take no longer than a half-hour of your time. Since the visual assessment and survey will be conducted with three participants at a time, a tour of the College of Textiles will be provided should there be a wait. Thank you very much.

Sincerely,

Claire Hider

Appendix C: Survey Instrument

You are being asked to take part in a research study. Your participation in this study is voluntary. You have the right to be a part of this study, to choose not to participate, or to stop participating at any time. The purpose of this research study is to gain a better understanding of expert impressions to digitally printed jacquard woven base cloths. If you do not understand something in this form, it is your right to ask the researcher for clarification or more information. If at any time you have questions about your participation, do not hesitate to ask the researcher Claire Hider or faculty sponsor, Dr. Traci Lamar.

The purpose of this study is to measure expert response to fabric samples created through the combination of jacquard weaving and digital printing. The survey results will become part of the published thesis research conducted by Claire Hider.

The information in the study records will be kept strictly confidential. Data will be stored securely in password protected documents accessible only by the principle investigators. No reference will be made in the thesis which could link you to the study. If you are an NC State employee, participation in this study is not required as part of your job.

There is no monetary compensation awarded for participation in this study. However, one benefit in participating in this study is the knowledge that you will have contributed your expertise and experience to a greater body of work. There are no foreseeable risks associated with completing this survey.

If you have questions at any time about the study of the procedures, you may contact the researchers, Claire Hider or Dr. Traci Lamar, (919-513-4196), at the College of Textiles, NC State, and Raleigh, NC 27606. If you feel you have not been treated according to the descriptions in this project, you may contact Deb Paxton, Regulatory Compliance Administrator, by phone at (919) 515-4514 or by email at dapaxton@ncsu.edu.

By selecting “I accept” below, I acknowledge I have read and understood the above information and am over the age of 18. I may obtain a printed a copy of this agreement for my records. I agree to participate in the study with the understanding that I may withdraw at any time.

If you select "I do not accept" below, the survey will close.

- ○ I accept.
- ○ I do not accept.

Please select which sample you are currently reviewing form the below list. The sample's name can be found in the lower right-hand corner of the fabric face.

- ○ Delsie
- ○ Jovany
- ○ Loris
- ○ Auden
- ○ Zinnia
- ○ Renato

Please rate the sample, Delsie, using the characteristics below considering potential end use in home furnishings.

	1: Very Poor	2: Poor	3: Adequate	4: Good	5: Very Good
Aesthetic Appeal	○	○	○	○	○
Surface Texture	○	○	○	○	○
Weaving Technique	○	○	○	○	○
Yarn Choice	○	○	○	○	○
Woven Design Clarity	○	○	○	○	○
Appropriateness for Printing Substrate	○	○	○	○	○
Integration of Fancy Yarn Types	○	○	○	○	○
Fabric Hand	○	○	○	○	○
Fabric Weight	○	○	○	○	○
Appropriateness for Upholstery	○	○	○	○	○
Potential for Markets Beyond Upholstery	○	○	○	○	○

What are your overall impressions of Delsie?

- ○ Please add in the box provided.
- ○ I do not wish to leave additional impressions.

Do you consider the utilization of jacquard weaving technique in this sample to create an effective base cloth for digital printing?

- ○ Yes
- ○ Maybe
- ○ No
- ○ Unsure

Please select which sample you are currently reviewing form the below list. The sample's name can be found in the lower right-hand corner of the fabric face.

- ○ Delsie
- ○ Jovany
- ○ Loris
- ○ Auden
- ○ Zinnia
- ○ Renato

Please rate the sample, Jovany, using the characteristics below considering potential end use in home furnishings.

	1: Very Poor	2: Poor	3: Adequate	4: Good	5: Very Good
Aesthetic Appeal	○	○	○	○	○
Surface Texture	○	○	○	○	○
Weaving Technique	○	○	○	○	○
Yarn Choice	○	○	○	○	○
Woven Design Clarity	○	○	○	○	○
Appropriateness for Printing Substrate	○	○	○	○	○
Integration of Fancy Yarn Types	○	○	○	○	○
Fabric Hand	○	○	○	○	○
Fabric Weight	○	○	○	○	○
Appropriateness for Upholstery	○	○	○	○	○
Potential for Markets Beyond Upholstery	○	○	○	○	○

What are your overall impressions of Jovany?

- ○ Please add in the box provided.
- ○ I do not wish to leave additional impressions.

Do you consider the utilization of jacquard weaving technique in this sample to create an effective base cloth for digital printing?

- ○ Yes
- ○ Maybe
- ○ No
- ○ Unsure

Please select which sample you are currently reviewing form the below list. The sample's name can be found in the lower right-hand corner of the fabric face.

- ○ Delsie
- ○ Jovany
- ○ Loris
- ○ Auden
- ○ Zinnia
- ○ Renato

Please rate the sample, Loris, using the characteristics below considering potential end use in home furnishings.

	1: Very Poor	2: Poor	3: Adequate	4: Good	5: Very Good
Aesthetic Appeal	○	○	○	○	○
Surface Texture	○	○	○	○	○
Weaving Technique	○	○	○	○	○
Yarn Choice	○	○	○	○	○
Printed Design Clarity	○	○	○	○	○
Printed Color Saturation	○	○	○	○	○
Integration Of Woven and Printed Designs	○	○	○	○	○
Fabric Hand	○	○	○	○	○
Fabric Weight	○	○	○	○	○
Appropriateness for Upholstery	○	○	○	○	○
Potential for Markets Beyond Upholstery	○	○	○	○	○

What are your overall impressions of Loris?

○ Please add in the box provided.

○ I do not wish to leave additional impressions.

Do you consider the utilization of digital printing technique in this sample to be an effective coloration method for jacquard woven base cloths?

○ Yes

○ Maybe (Please Specify)

○ No

○ Unsure (Please Specify)

Please select which sample you are currently reviewing form the below list. The sample's name can be found in the lower right-hand corner of the fabric face.

○ Delsie

○ Jovany

○ Loris

○ Auden

○ Zinnia

○ Renato

Please rate the sample, Auden, using the characteristics below.

	1: Very Poor	2: Poor	3: Adequate	4: Good	5: Very Good
Aesthetic Appeal	◯	◯	◯	◯	◯
Surface Texture	◯	◯	◯	◯	◯
Weaving Technique	◯	◯	◯	◯	◯
Yarn Choice	◯	◯	◯	◯	◯
Printed Design Clarity	◯	◯	◯	◯	◯
Printed Color Saturation	◯	◯	◯	◯	◯
Integration Of Woven and Printed Designs	◯	◯	◯	◯	◯
Fabric Hand	◯	◯	◯	◯	◯
Fabric Weight	◯	◯	◯	◯	◯
Appropriateness for Upholstery	◯	◯	◯	◯	◯
Potential for Markets Beyond Upholstery	◯	◯	◯	◯	◯

What are your overall impressions of Auden?

◯ Please add in the box provided.

◯ I do not wish to leave additional impressions.

Do you consider this utilization of digital printing technique to be an effective coloration method for jacquard woven base cloths?

◯ Yes

◯ Maybe (Please Specify)

◯ No

◯ Unsure (Please Specify)

Please select which sample you are currently reviewing form the below list. The sample's name can be found in the lower right-hand corner of the fabric face.

◯ Delsie

◯ Jovany

◯ Loris

◯ Auden

◯ Zinnia

◯ Renato

Please rate the sample, Zinnia, using the characteristics below.

	1: Very Poor	2: Poor	3: Adequate	4: Good	5: Very Good
Aesthetic Appeal	○	○	○	○	○
Surface Texture	○	○	○	○	○
Weaving Technique	○	○	○	○	○
Yarn Choice	○	○	○	○	○
Printed Design Clarity	○	○	○	○	○
Printed Color Saturation	○	○	○	○	○
Integration Of Woven and Printed Designs	○	○	○	○	○
Fabric Hand	○	○	○	○	○
Fabric Weight	○	○	○	○	○
Appropriateness for Upholstery	○	○	○	○	○
Potential for Markets Beyond Upholstery	○	○	○	○	○

What are your overall impressions of Zinnia?

- ○ Please add in the box provided.
- ○ I do not wish to leave additional impressions.

Do you consider this utilization of digital printing technique to be an effective coloration method for jacquard woven base cloths?

- ○ Yes
- ○ Maybe (Please Specify)
- ○ No
- ○ Unsure (Please Specify)

Please select which sample you are currently reviewing form the below list. The sample's name can be found in the lower right-hand corner of the fabric face.

- ○ Delsie
- ○ Jovany
- ○ Loris
- ○ Auden
- ○ Zinnia
- ○ Renato

Please rate the sample, Renato, using the characteristics below.

	1: Very Poor	2: Poor	3: Adequate	4: Good	5: Very Good
Aesthetic Appeal	○	○	○	○	○
Surface Texture	○	○	○	○	○
Weaving Technique	○	○	○	○	○
Yarn Choice	○	○	○	○	○
Printed Design Clarity	○	○	○	○	○
Printed Color Saturation	○	○	○	○	○
Integration Of Woven and Printed Designs	○	○	○	○	○
Fabric Hand	○	○	○	○	○
Fabric Weight	○	○	○	○	○
Appropriateness for Upholstery	○	○	○	○	○
Potential for Markets Beyond Upholstery	○	○	○	○	○

What are your overall impressions of Renato?

- ○ Please add in the box provided.
- ○ I do not wish to leave additional impressions.

Do you consider this utilization of digital printing technique to be an effective coloration method for jacquard woven base cloths?

- ○ Yes
- ○ Maybe (Please Specify)
- ○ No
- ○ Unsure (Please Specify)

Please select which sample you are currently reviewing form the below list. The sample's name can be found in the lower right-hand corner of the fabric face.

- ○ Delsie
- ○ Jovany
- ○ Loris
- ○ Auden
- ○ Zinnia
- ○ Renato

Do you have any additional comments or thoughts about the samples reviewed today?

- ◯ Please type in the box provided.
- ◯ I do not have any additional impressions.

Thank you for your responses to the samples you have reviewed today. The following section is used to collect demographic information.

Please select the range in which your birth year falls.

- ◯ 1940-1949
- ◯ 1950-1959
- ◯ 1960-1969
- ◯ 1970-1979
- ◯ 1980-1989
- ◯ 1990-1999
- ◯ 2000-2009
- ◯ Other (Please Specify)

Please write the name and address of your company.

- ☐ Company
- ☐ Address of Company

What is your current area of work (check all that apply)?

- ☐ Woven Fabric Design
- ☐ Woven Fabric Product Development
- ☐ Woven Fabric Research and Development
- ☐ Textile Screen Printing
- ☐ Digital Inkjet Textile Printing
- ☐ Yarn Design
- ☐ Textile Consultation
- ☐ Color Matching
- ☐ Other (Please Specify)

Are you directly involved in fabric line decisions?

- ○ Yes
- ○ No

Condition: No Is Selected. Skip To: In which aspect of the fabric line ar....

How long have you been involved in fabric line decisions?

- ○ Under 3 Years
- ○ 3-5 Years
- ○ 5-10 Years
- ○ 10-20 Years
- ○ Over 20 Years
- ○ Other (Please Specify)

In which aspect of the fabric line are you involved (check all that apply)?

- ☐ Color
- ☐ Pattern Design
- ☐ Line Development
- ☐ Construction
- ☐ Quality Control
- ☐ Production
- ☐ Sales
- ☐ Marketing
- ☐ Other (Please Specify)
- ☐ I am not involved.

Condition: I am not involved. Is Selected. Skip To: End of Block.

What is your frequency of engagement with fabric line?

- Once a Day
- Two or More Times a Day
- Once a Week
- Two or More Times a Week
- Once a Month
- Two or More Times a Month
- Once a Quarter
- Two or More Times a Quarter
- Once a Year
- Rarely (Less Than Once a Year)
- Other (Please Specify)
- Never

Thank you for your participation in this survey. By clicking "I consent" or "I do not consent" below, your responses will be recorded. If you do not consent, you may also leave the survey without submitting your responses.

- I consent.
- I do not consent.

Appendix D: Preparing Artwork A for Jacquard Weaving

Artwork Creation (Photography and Adobe Photoshop)

In this Appendix, Artwork A is being used to illustrate the digital printing process. Artwork B was created in a similar fashion. The differences between A and B will be noted. For Artwork 0A, a photograph was taken using an iPhone 5 and then edited it using Photoshop filters. The original image was made in Shanghai, China, in a botanical garden featuring water lilies. The selected image was chosen because it had a range of colors, but the botanical nature of the composition was not intended to be manifest in the artwork developed for this thesis. Artwork 0A can be seen on the following page. The image resolution was set to 72 PPI.

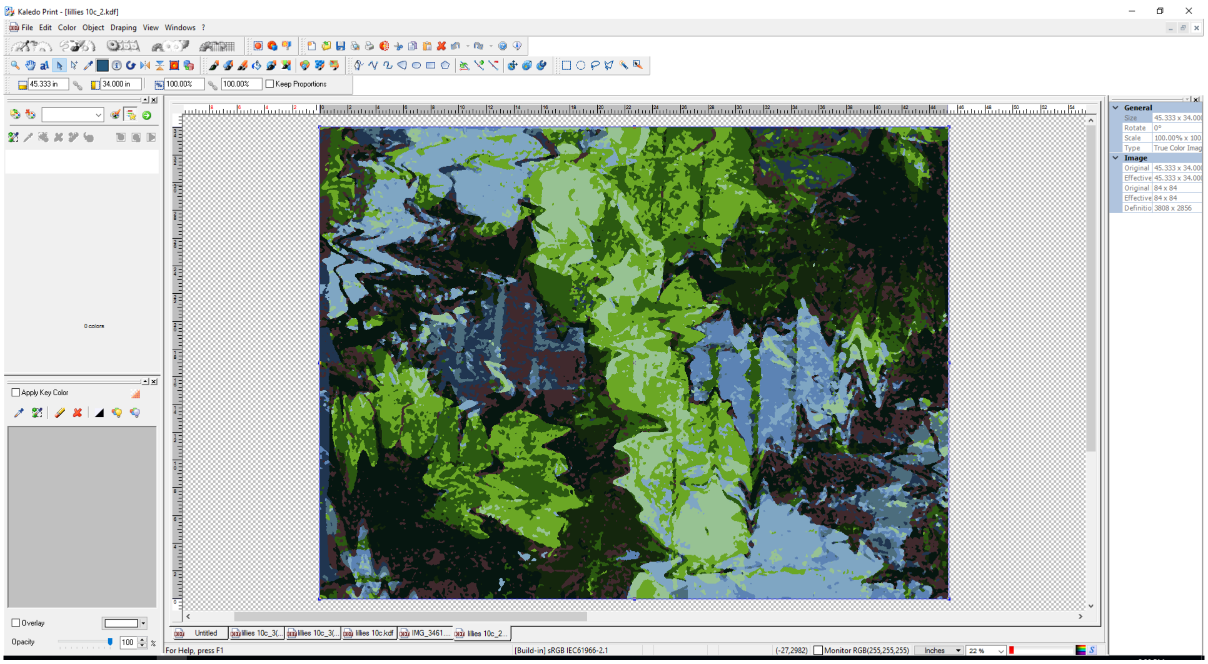
(For Artwork B, the painting was photographed by a Nikon 3300 digital camera with an 18mm-55mm lens in RAW image mode at 300 dpi).

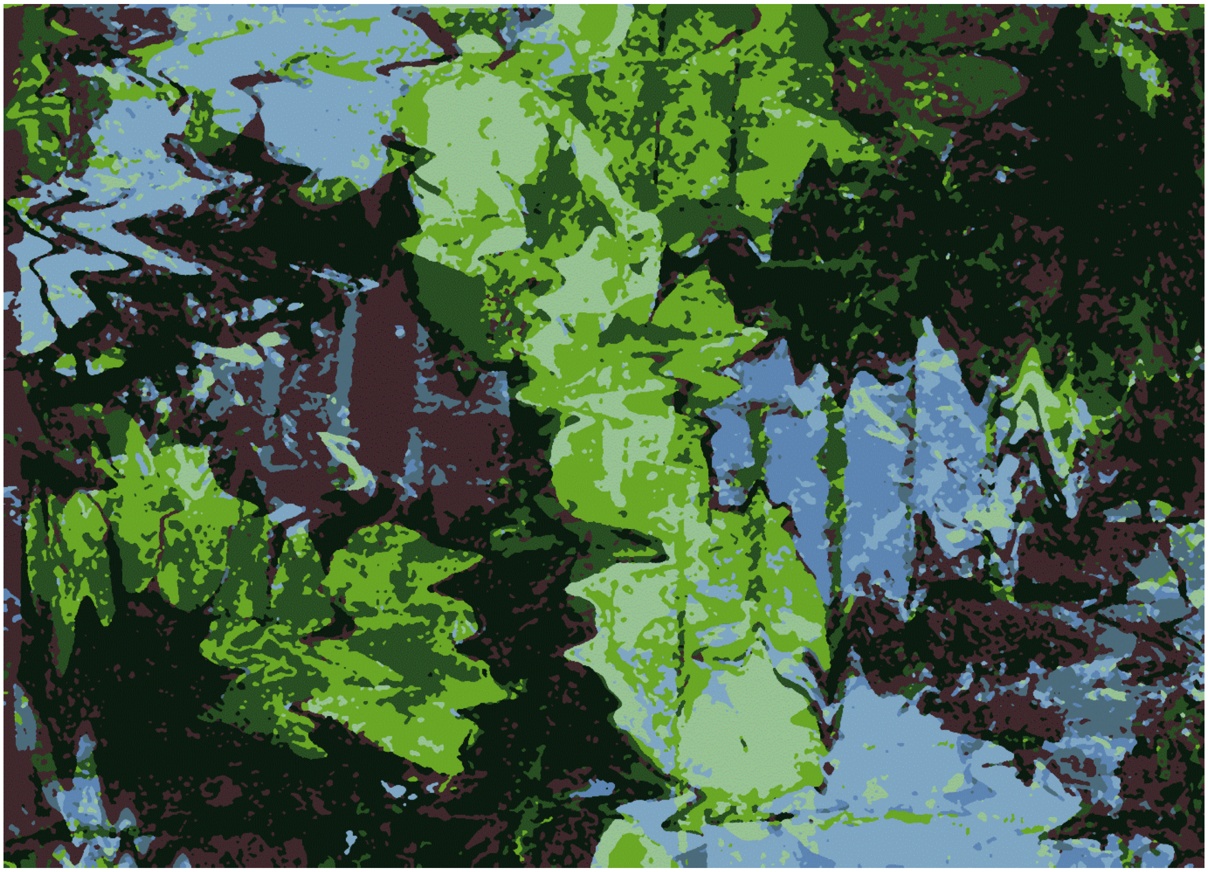
Color Reduction (Adobe Photoshop and Lectra's Kaledo Print)

Artwork 0A was reopened in Photoshop and saved as Artwork A. After renaming, the file was color reduced to 20 colors. After saving, the artwork was transferred from Photoshop to Kaledo Print and color reduced from 20 colors to 10. The 20-color image can be seen on the following page. (The 10-color image after cleaning can be seen below under the Image Cleaning section). Note: Artwork B was reduced to two colors in Photoshop.

Image Cleaning (Lectra's Kaledo Print)

The artwork needed to be cleaned to remove some of the digital noise and rough edges created during the color reduction process. Since each pixel approximately translated to a yarn intersection during weaving, some of the small sections in the design were removed to create a more smooth and unobstructed image for weaving and to help ensure that the chenille yarn did not create unwanted random fuzzy dots on the surface. The file before cleaning (but reduced to 10 colors) can be seen in the image on the following page. The image also shows the Kaledo Print workspace.

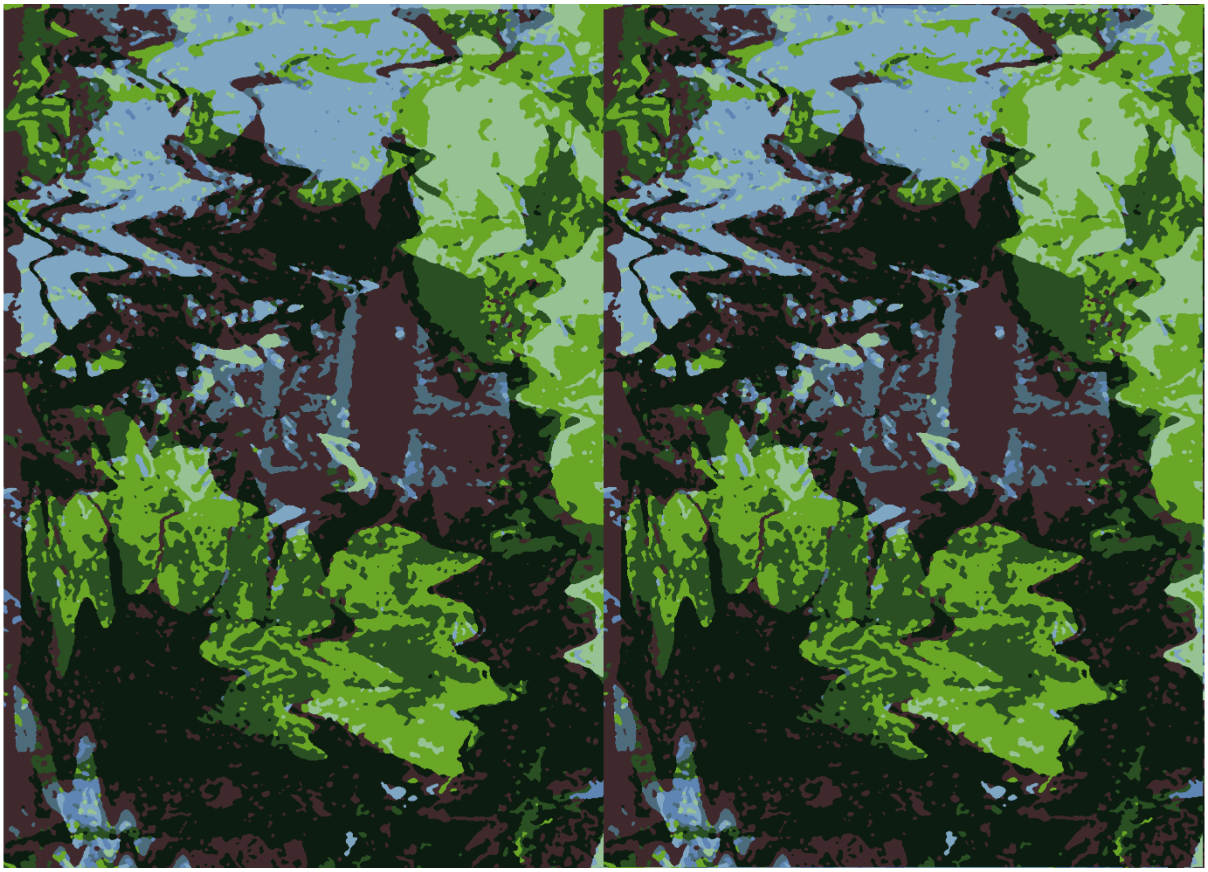

Kaledo Print - [lillies 10c_2.kdf]
File Edit Color Object Draping View Windows ?
Keep Proportions
Apply Key Color
Overlay
Opacity
For Help, press F1
[Build-in] sRGB IEC61966-2.1
Monitor RGB(255,255,255)
Inches
General
Image



In the image directly above, the full image after cleaning in Kaledo Print can be seen.

Image Editing (Lectra's Kaledo Print)

Since the whole width would be used to weave the entire image at the file size, the file was cut in half to get two samples across the full width. Cutting the image in half made each sample 27-inches wide, which made a sample which would be easier to handle during the assessments. The version with two samples side by side can be seen in the image on the following page.



Yarn Selection

An organic 1400 YPP cotton chenille yarn was chosen to experiment with how well the digital print would look on a textured base cloth. Cotton rich yarns were needed to be successfully printed using the fiber-reactive dye-based inks used during the sample development.

Resolution Correction and JC5 File Creation (EAT DesignScope Victor)

Once the artwork was cleaned, color reduced, and transferred to TIFF format (to be readable by the weaving software), it was opened in EAT DesignScope Victor. For Artwork A, the “54-inch Scan Single Filling” template was opened. This scan chain (an EAT template created at NC State) allows the artwork to be resized and color reduced. For Artwork B, a 27-inch template was used and the template automatically put two side-by-side to weave at the same time along the fabric width.

After converting to the correct resolution needed to weave the file on the NC State loom setup and to maintain the scale of Artwork A without size distortion, the new resolution was 54 x 39.85 inches or 4800 x 3542 pixels. The pixel count corresponds to an end and pick density of 84. Although the file was created in 72 dpi in Photoshop, the resolution was changed to 84 EPI and PPI in EAT and to make the fabric a little more dense.

In the table below, the calculations used for resolution can be seen. 88.889 is the weave multiple for an 84-pick density.

Resolution Calculation	
4800 Hooks(Ends) / 54 Inches = 88.889	3452 Picks / 88.889 = 38.835 Inches

Scan Single Filling Icon List:

SCAN III / TRUE COLOR CORRECTION

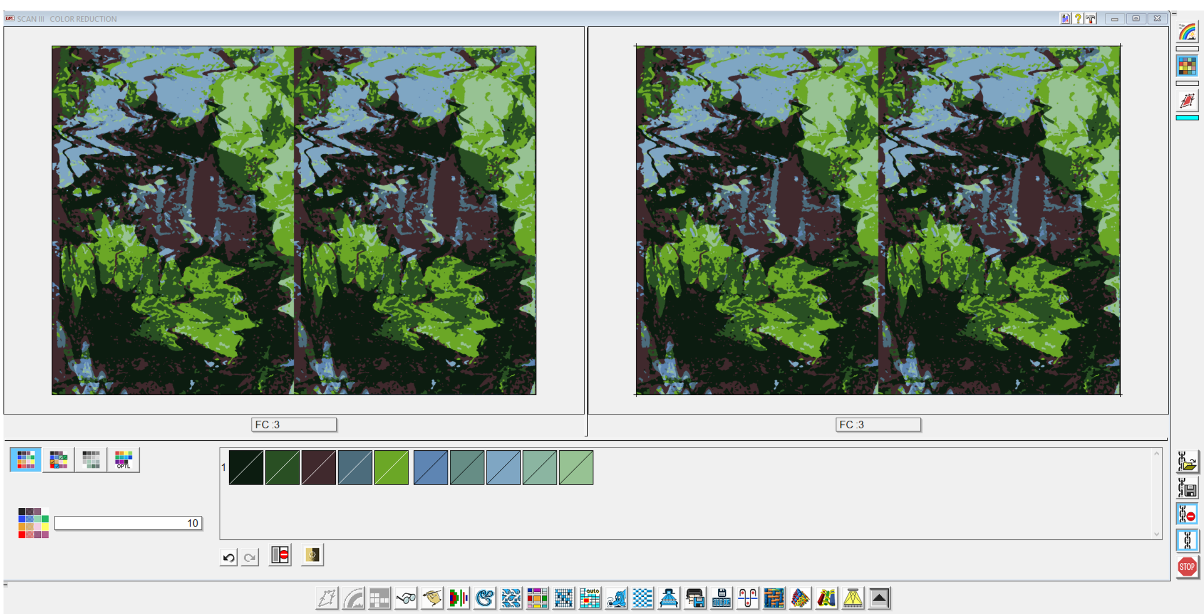
SCAN III / TRUE COLOR CORRECTION

SCAN III / ALIGN

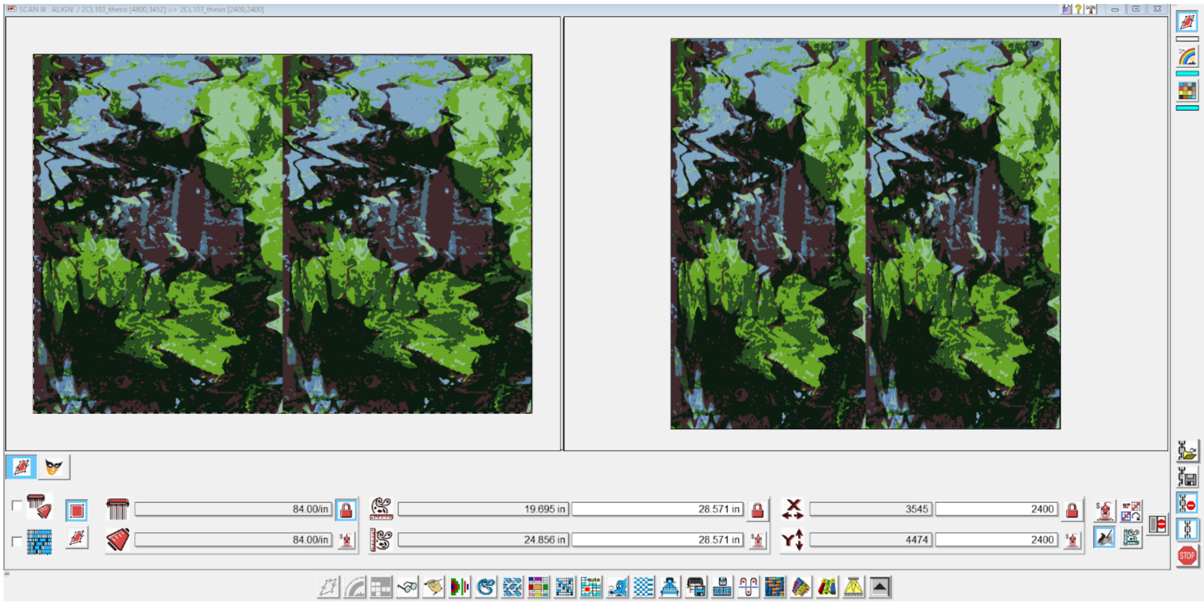
On the bottom of the previous page, the Scan Single Filling Chain Icon List is shown. The rainbow icon above on the Filling Icon List was named the “SCAN III / TRUE COLOR CORRECTION” and allowed the designer to edit the artwork to make it brighter, darker, or shift the colors. This function was not used in either Artwork.

The second icon that resembles a square inlaid with smaller squares was named “SCAN III / COLOR REDUCTION” and allows a designer to color reduced the artwork. The template automatically defaults to a 20-color palette. Since Artwork A contained 10 colors (as it was color reduced in previous steps), the 10 was typed into the box and entered.

An example of the file during color reduction can be seen. The EAT workspace is also shown in the below image.



In the third icon that resembled a shifted rectangle named “SCAN III / ALIGN,” the artwork is resized to fit onto predetermined weaving templates. The templates allow for fixed measurements in the weft direction (or X direction) of a fabric but are not fixed in the warp direction (or Y direction). The image below shows the file before converting to the correct resolution.



Once the file was ready for the next stage of JC5 file creation, the "54- inch Template Single Filling" template (also created at NC State) was opened. This template includes the running chain which further allows the file to be transferred into a JC5 file, the file that the jacquard head reads to weave the pattern into the fabric. The Template Single Filling Chain Icon List can be seen on the following page.

Template Single Filling Icon List

BOX MOTION II

COM III / ASSIGN WEAVES TO COLORS

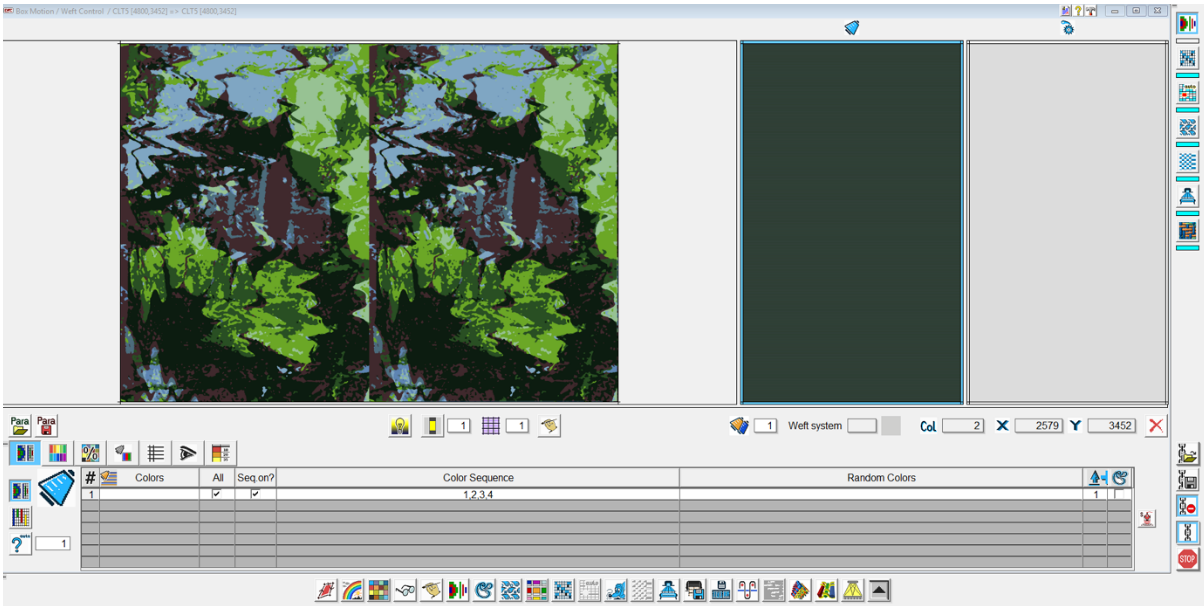
FLOAT WIZARD

REPEATS

COM III / SELVEDGE

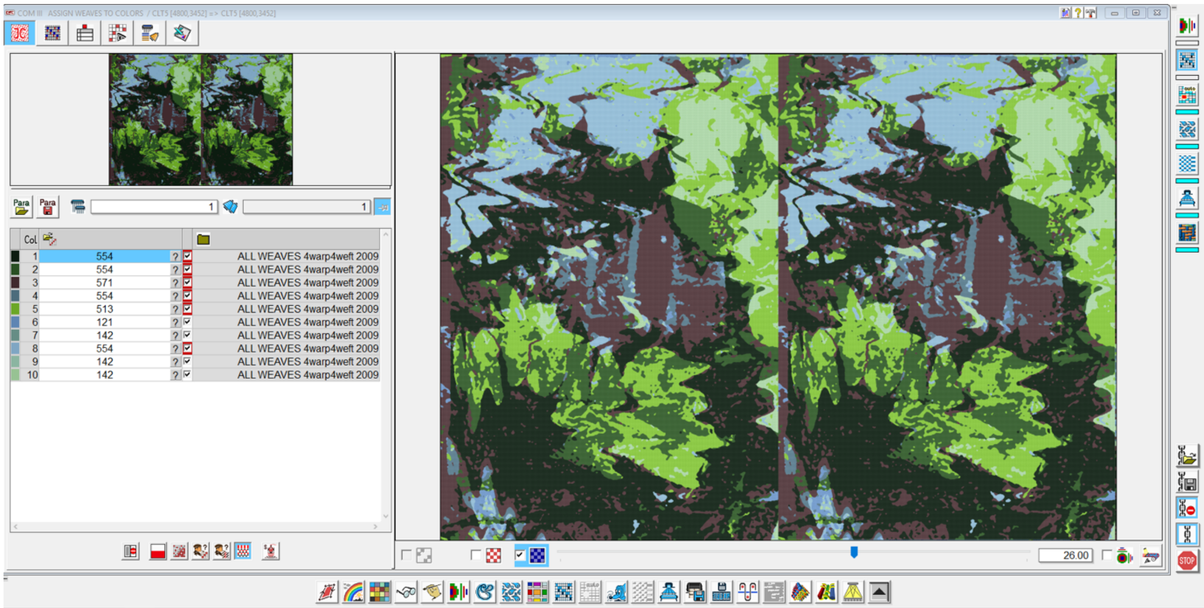
COM III / MACHINE DEFINITION

2D-DEFINITION

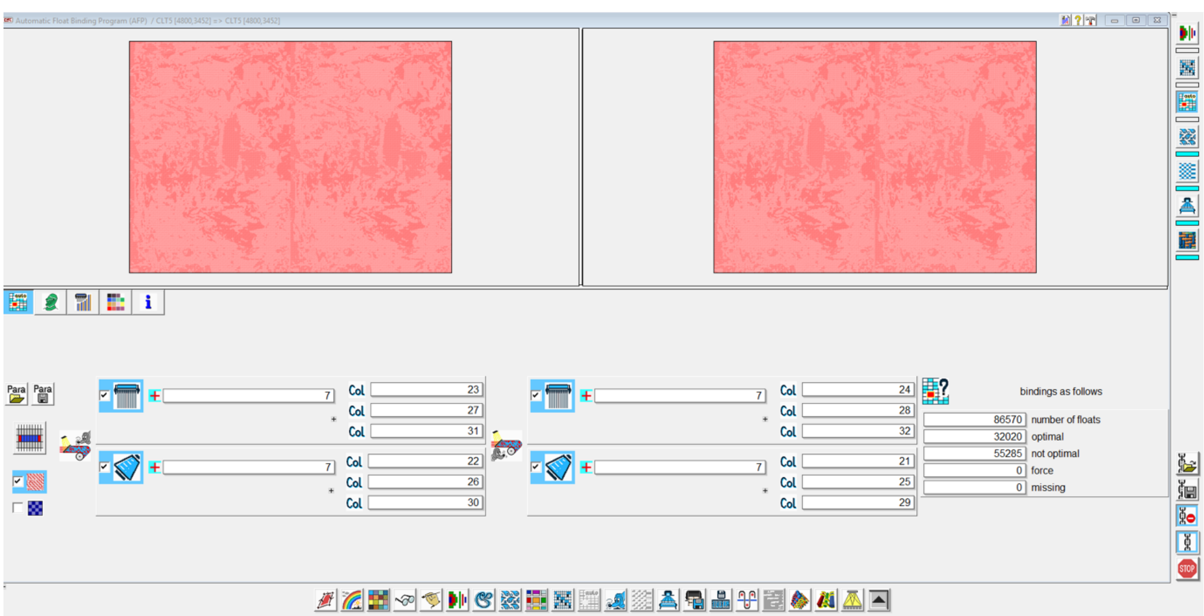


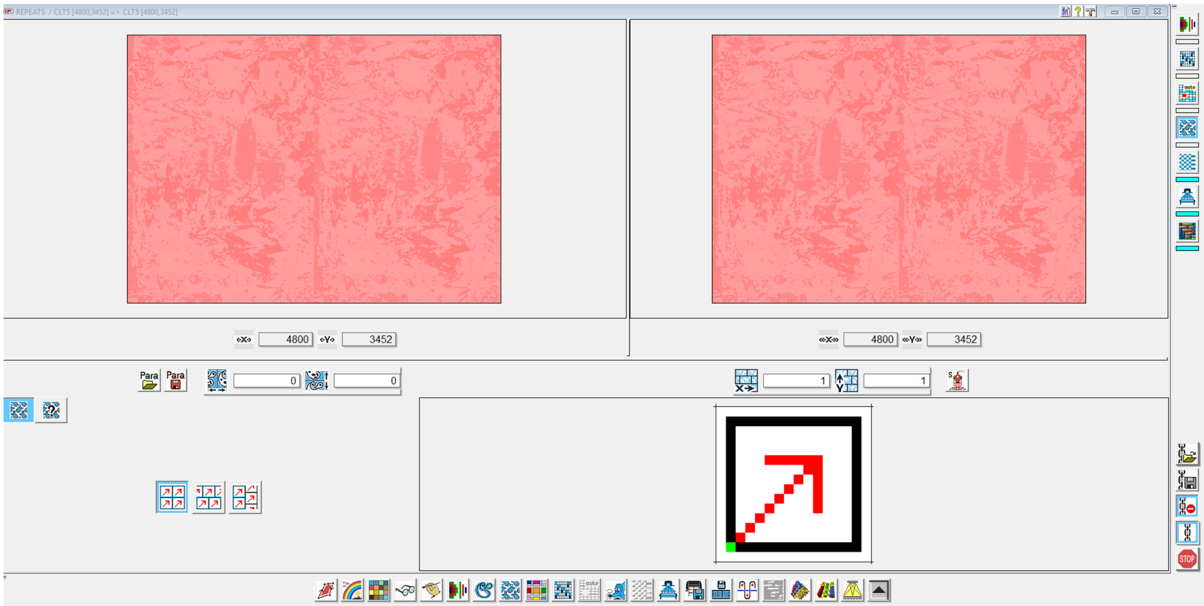
The first icon shown in the table on the previous page is named “BOX MOTION II,” and represents the box motion, or the number and filling order of yarns that will be inserted into the shed through different selectors, or loom attachments which hold the yarns. For both Artwork A and B, 4 filling yarns were inserted into the shed (Shown in the image directly above as “color sequence” 1,2,3,4).

The second icon (going down the list) named “COM III / ASSIGN WEAVES TO COLORS,” allows the designer to input the weaves which have been saved in a separate folder. Some of the weaves shown in the image on the following page were used twice to make the overall design simpler. A previous test by the PI found the woven fabric looked too messy with 10 weaves. By reducing the number of weaves, the fabric surface appeared smoother and allowed larger areas of each weave to be used.

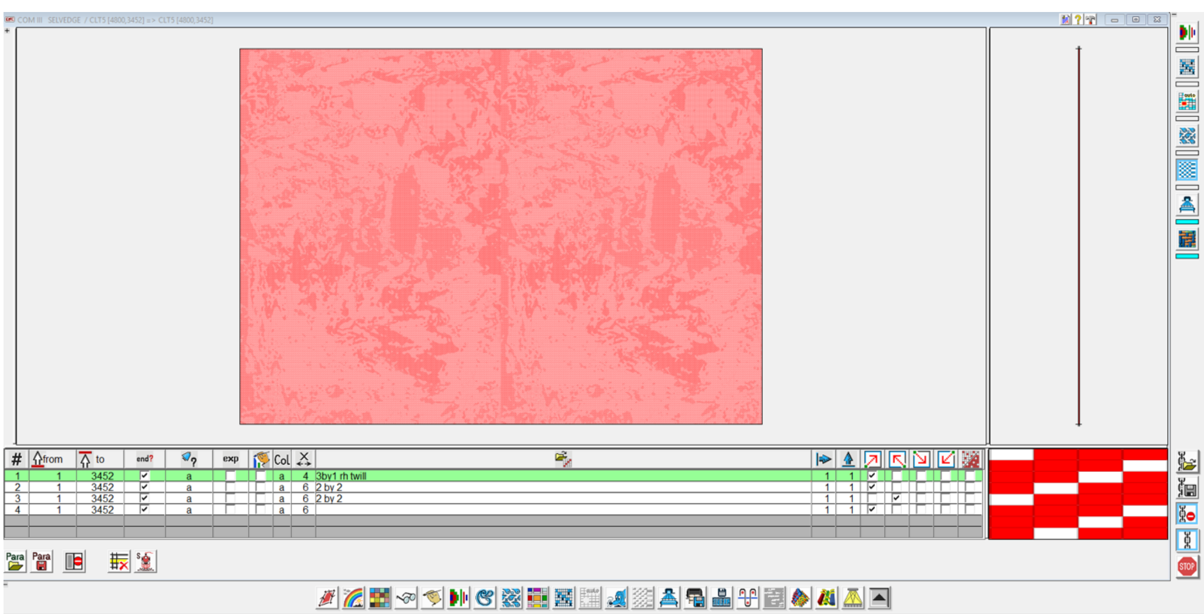


Third icon “FLOAT WIZARD” automatically checked the number of floats in the design. The default used was 7 (on the top and bottom of the warp and weft – for the four boxes which have a 7) and was not changed in either artwork. This stage can be seen in the image directly below.

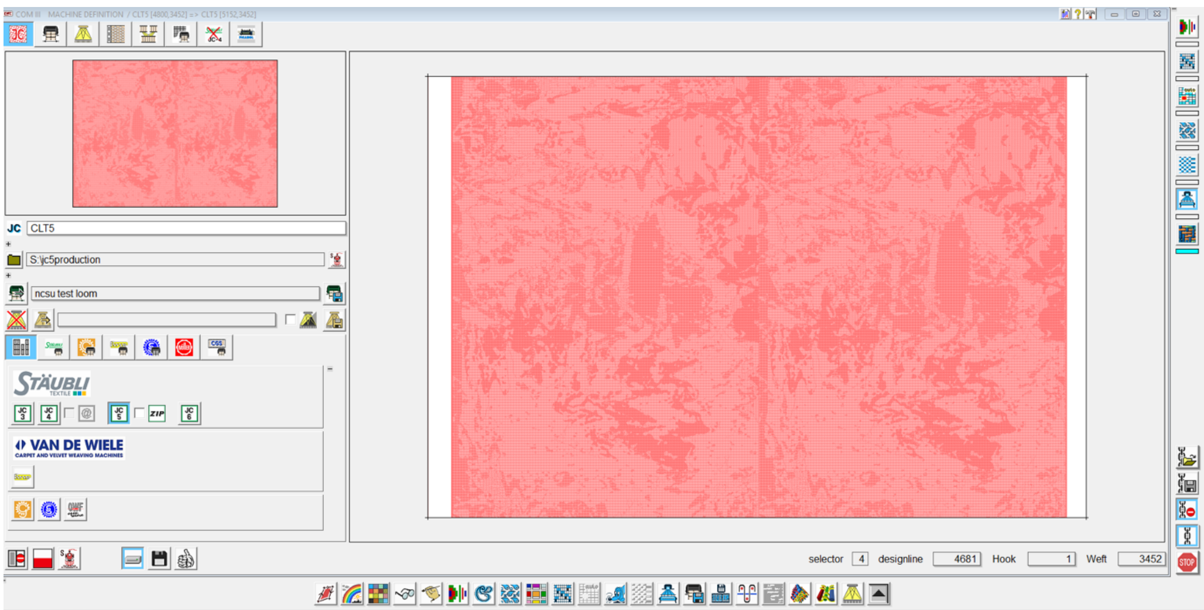




The fourth icon in the chain, “REPEATS,” allows the type of repeat to be changed; for example, if the designer wants to change the style of repeat used in weaving. For Artwork A, the same design was needed twice, so a straight repeat was used during weaving. This type of layout can be seen in the image directly above.



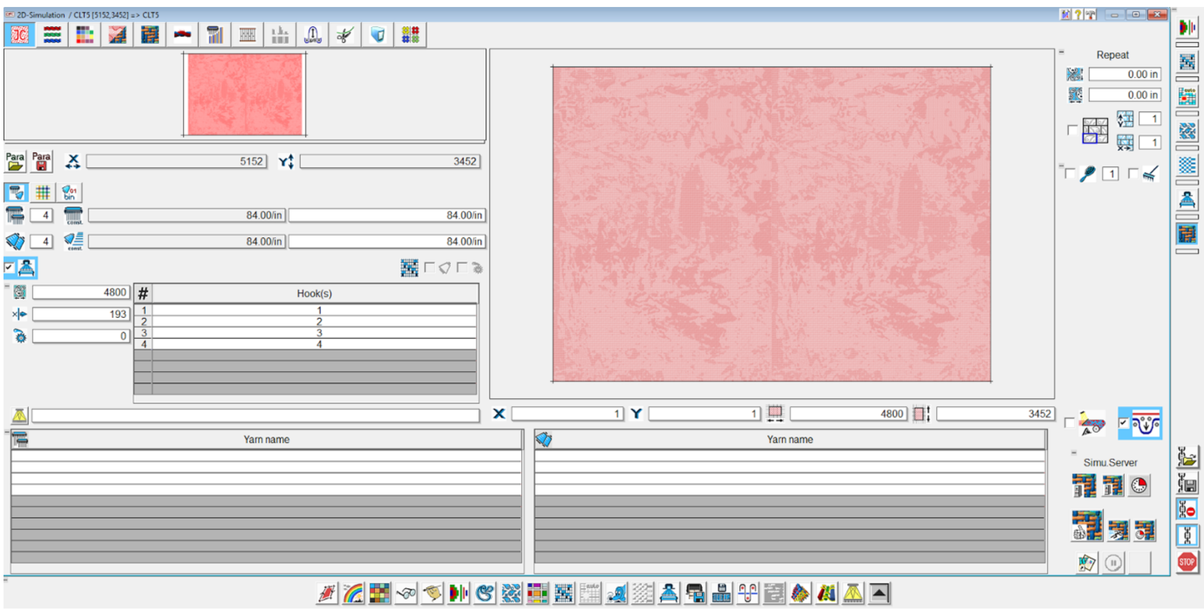
The fifth icon, “COM III / SELVEDGE,” allows the weaves that make up the selvage of the cloth to be altered. For each of the files, the first selvage was changed from a 2 by 2 plain weave to a 3 by 1 right hand twill since a twill is a looser weave structure. The looser structure is needed when inserting larger yarns into the shed such as the 1400 YPP organic cotton chenille. This image is shown above on the previous page.



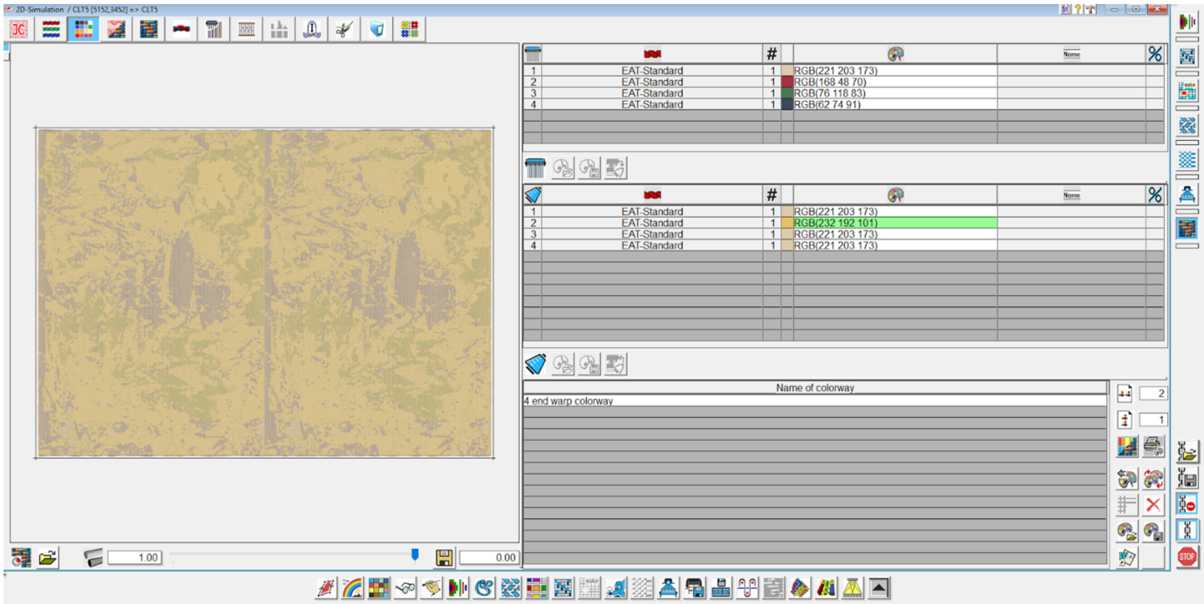
The sixth icon “COM III / MACHINE DEFINITION,” allows the file to be sent to the loom. There are a variety of loom options, depending on the needs of the designer. For this research, a Stäubli JC5 electronic jacquard head was used on the “ncsu test loom,” so the JC5 file type was chosen. Also, at this stage the files were named for weaving (CLT5 and CA2). This step is shown in the image directly above.

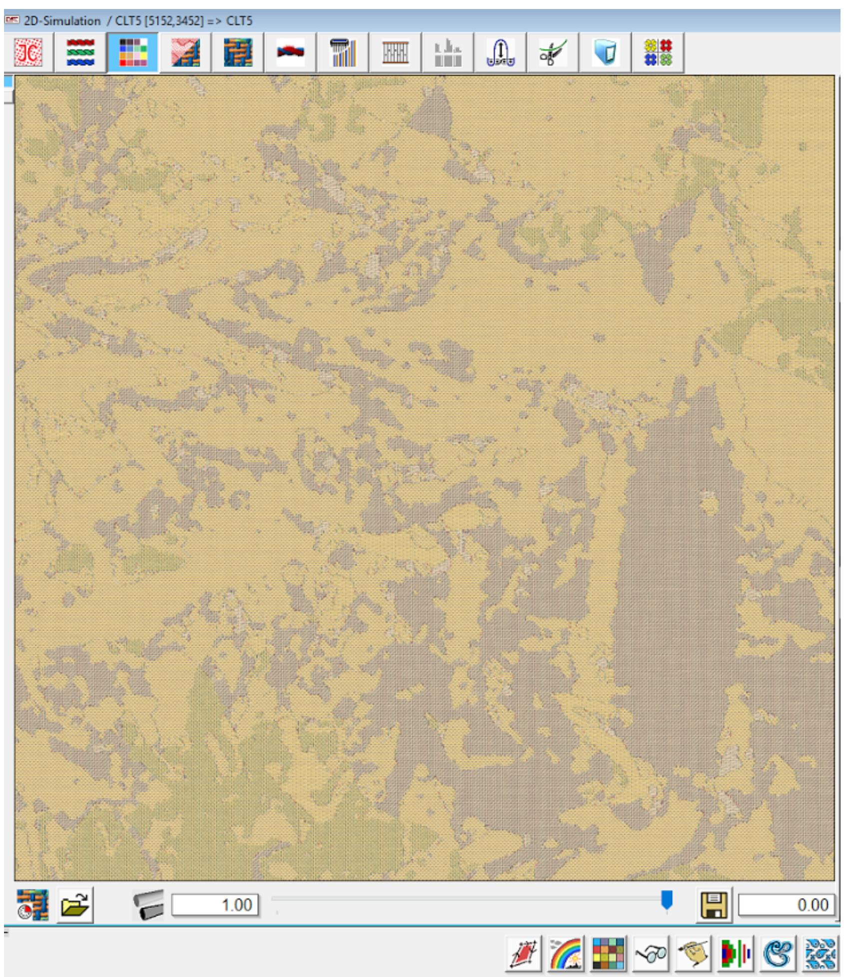
The seventh and final icon in the single filling template, “2D-SIMULATION,” allowed for simulations of the weaves and yarns chosen for weaving. Although a chenille yarn was used during weaving, a chenille was not simulated in EAT so the detail of the design could be more clearly seen. When the detail of the design is intended to be seen, finer yarns were best to use for simulation.

In the image directly below, the file technical specifications are shown. This way the designer can check that all the dimensions are correct. From this page, the simulation can be activated.



The simulation shown on the top of the following page was programmed to follow the actual yarns used during weaving. The warp colors were used from Table 2 in Chapter 3, section 3.3.1. and the ivory color value was also used in the same filling positions as during weaving. The second image on the following page shows a close up view of the simulation. This way, the warp and weft interlaces can be seen more clearly.


2D-Simulation / CLT5 [5152,3452] => CLT5
EAT-Standard
RGB(221 203 173)
RGB(168 48 70)
RGB(76 118 83)
RGB(62 74 91)
RGB(232 192 101)
Name of colorway
4 end warp colorway
1.00
0.00


2D-Simulation / CLT5 [5152,3452] => CLT5
1.00
0.00

Jacquard Weaving

Once the JC5 files was developed, the samples were created through jacquard weaving. The samples were woven at the same time to keep the Artwork A fabrics as consistent as possible. Each file was woven six times to create 12 samples of each artwork, or 24 in total. Additional samples were woven to allow for potential errors in the printing process and experimentation of the ideal artwork file, ink level during printing (color booster), and printer head height (distance the ink had to travel from printer to fabric). The samples – once removed from the loom and overlocked into individual pieces – are shown in the image seen directly below.

Appendix E: Preparing Artwork for Inkjet Digital Textile Printing

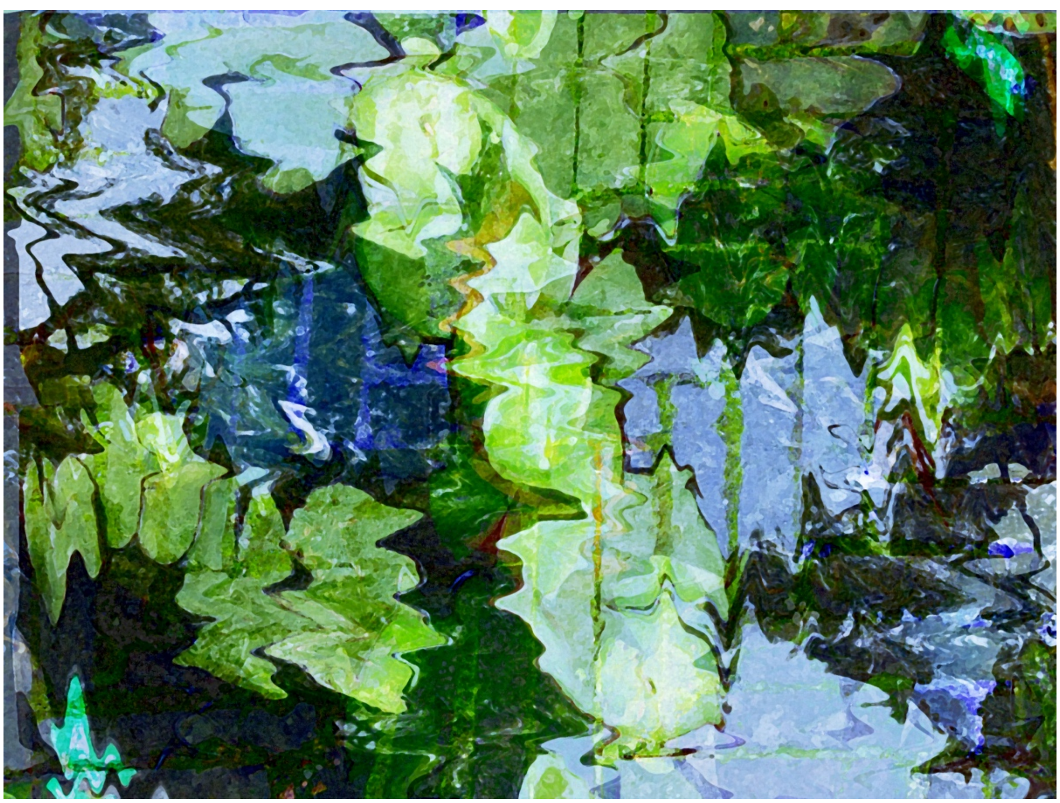
The following steps were used to create Artwork 2A. Artwork 2B had a similar workflow. The color changes from Artwork B to 2B can be seen in the text in Table 1 in section 3.3.

Artwork Creation

The digital files used for inkjet digital textile printing started with the same files as for jacquard weaving. The difference is that these versions of the original files were not color reduced. Color reduction would be an unnecessary stage when preparing files with as many colors as possible. The next stage of the design process is also different from the weaving file preparation process and should be saved as a separate file. In all, there are three files needed in the creation of both printing and weaving the same design. The additional versions were saved as separate files to document any changes needed to develop successful fabrics.

Artwork Color Editing

Unlike the jacquard weaving files, there was a need to make sure the colors were variegated in levels of lightness or darkness. When color reduced, there are a set number of colors which are read by the system monitoring the color process. In printing, however, a range of hues are needed to make sure the colors do not appear muddy. Artwork 0A and Artwork 2A can be seen in the image below. Artwork 2A is the bottom image, and the changes in color lightness and darkness are evident.



Resolution and Sizing

To achieve as accurate printing alignment as possible, the printing files were resized after jacquard weaving, scouring, and pretreatment to accommodate for fabric shrinkage. On the Shima Seki SIP-160F3 printer used to make the samples during this research, the files were scaled to fit the samples once taped down to the printing bed.

Artwork 2A was saved at 72 dpi and Artwork 2B at 300 dpi in Adobe Photoshop to be prepared for printing. The flatbed printer used could print files with a resolution of up to 300dpi, and this capability was utilized for Artwork 2B. For Artwork 2A, the original photograph was taken at 72 dpi and was not scaled up to maintain clarity.

File Type

To print on the Shima Seki SIP-160F3, the artwork images were saved in Adobe Photoshop as JPEG files.

Digital Printing

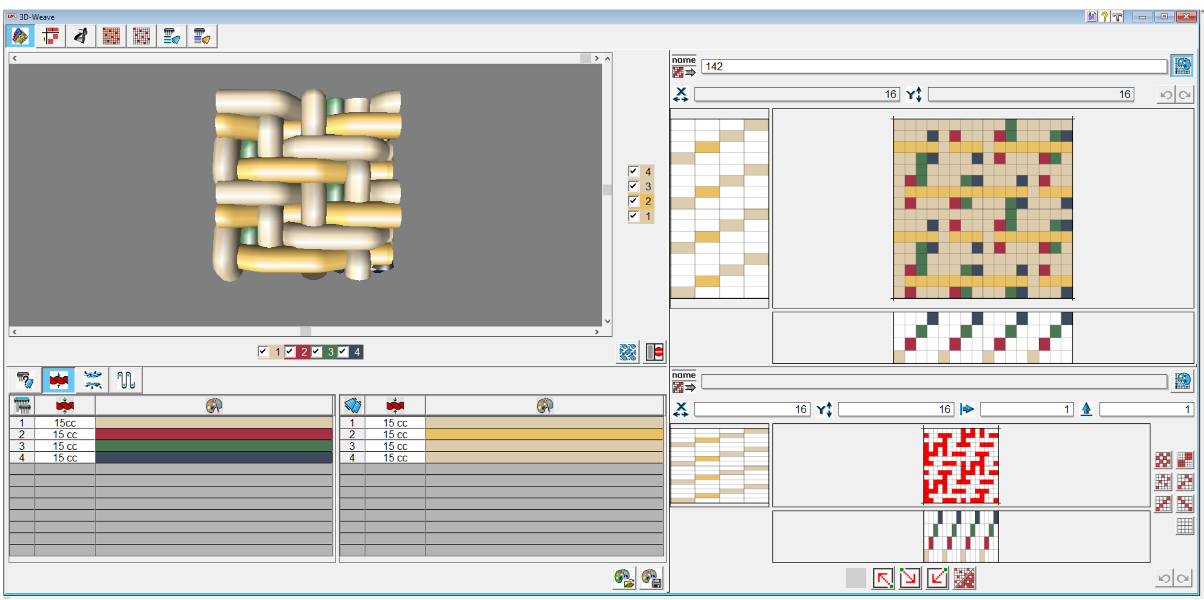
To prepare for printing, the fabrics were taped down to the print bed. After this step was completed, the print bed was scanned to aid with alignment of the printed designs with the woven designs. Once the print bed was scanned, the files were loaded into the printing software and lined up. All fabrics were printed with a head height of 7.0mm and a color booster of 300. To achieve the 300-color booster level, the fabrics were first printed with a color booster of 200 and then printed a second time with a color booster of 100. In the images below, the fabrics can be seen during printing. The colors are darker than the finished fabric since the steaming process had not yet occurred. The fabrics after printing, but before being removed from the printed bed can be seen in the below image.

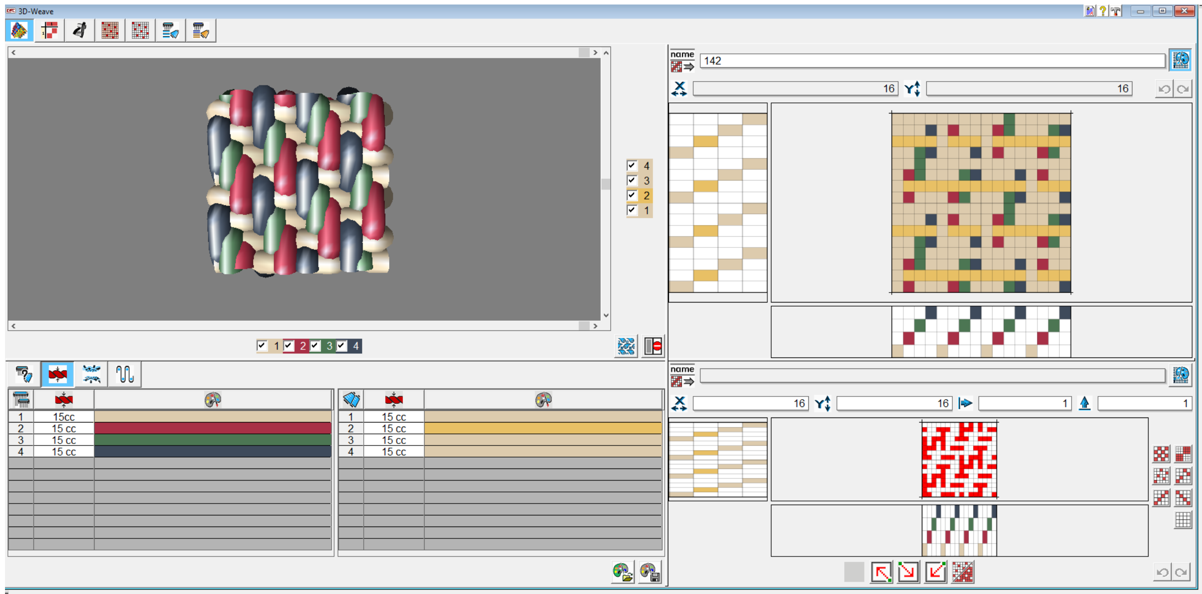
Appendix F: Weave Structures Used from Weave Blankets

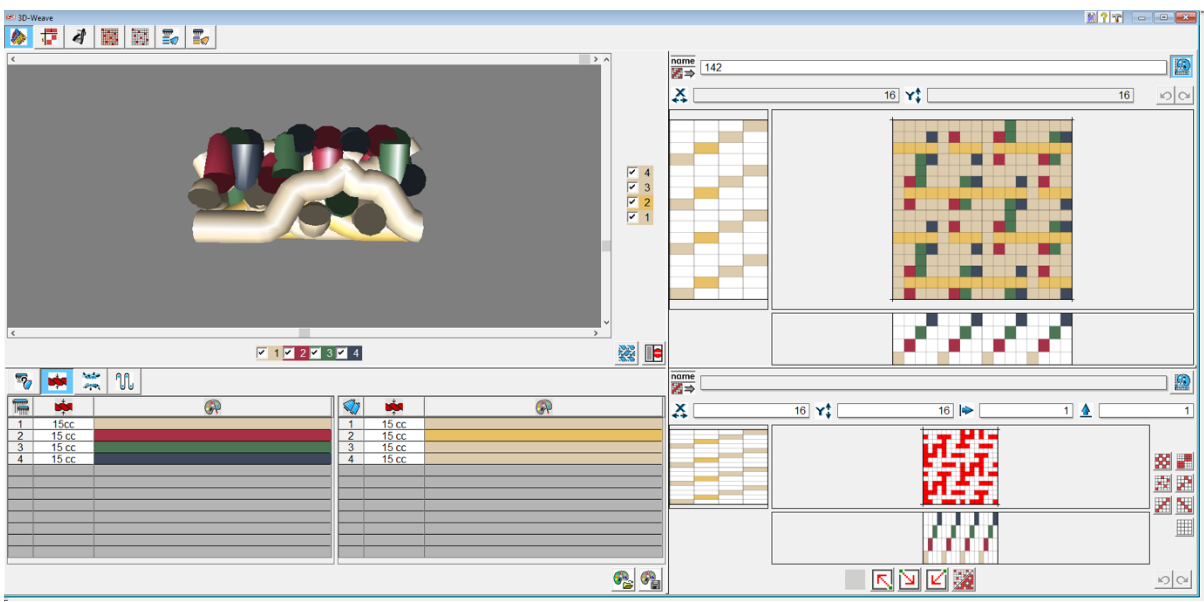
Artwork A: 5 Weaves (10 Colors in Design)

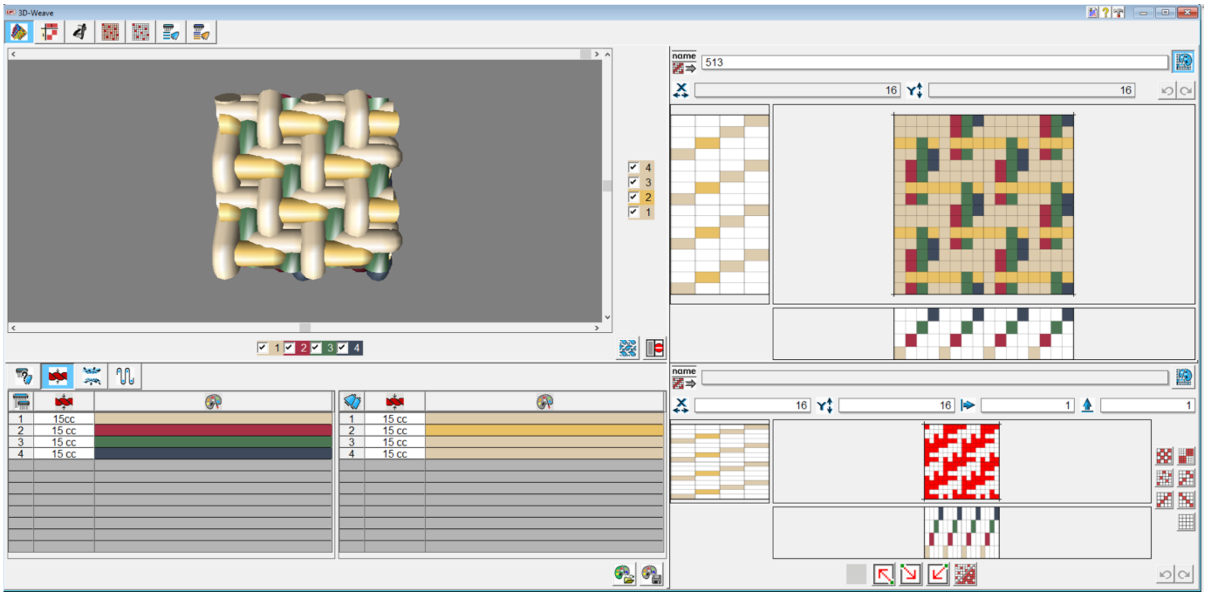
Five weaves from the 4 -color NC State filling blanket - 121, 142, 513, 554, 571 - were used to create Artwork A.

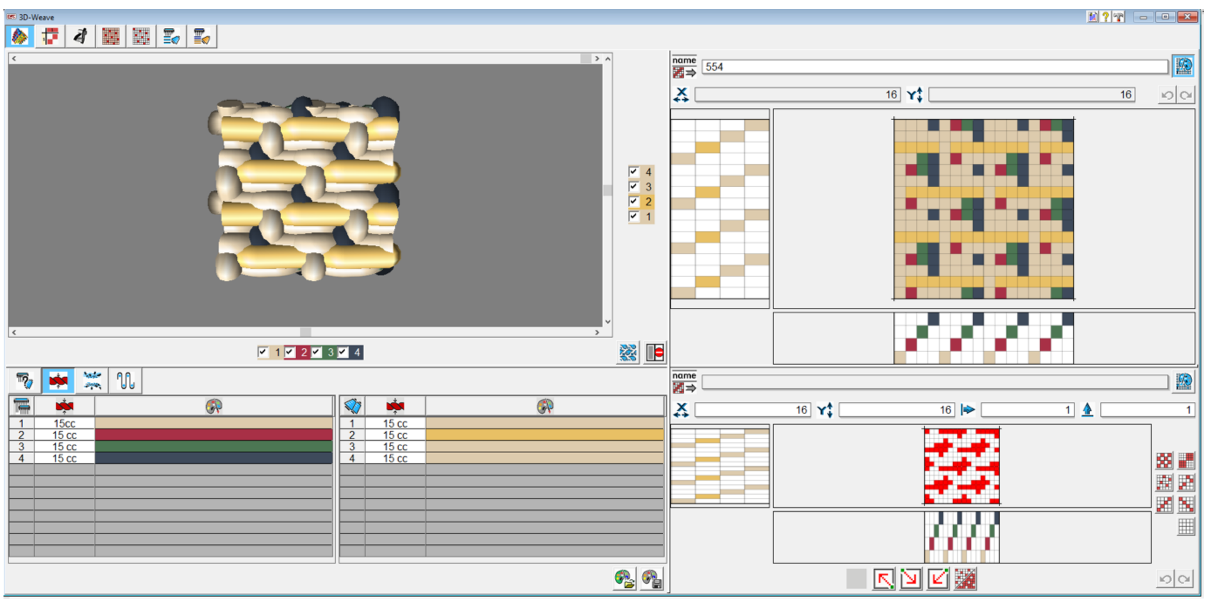
The *3D Weave* function allows the designer to see how a weave will look with different yarns and different interlacing sequences. Shown below in the next three images is how an example weave (142) can be seen on the face, back, and side views. The colors used in the weave simulations are the same RGB values for the yarns used in the weaving simulations. The additional images to follow, beginning with weave number 513, show the simulations for the other four weaves used in Artwork A, for a total of five weaves.

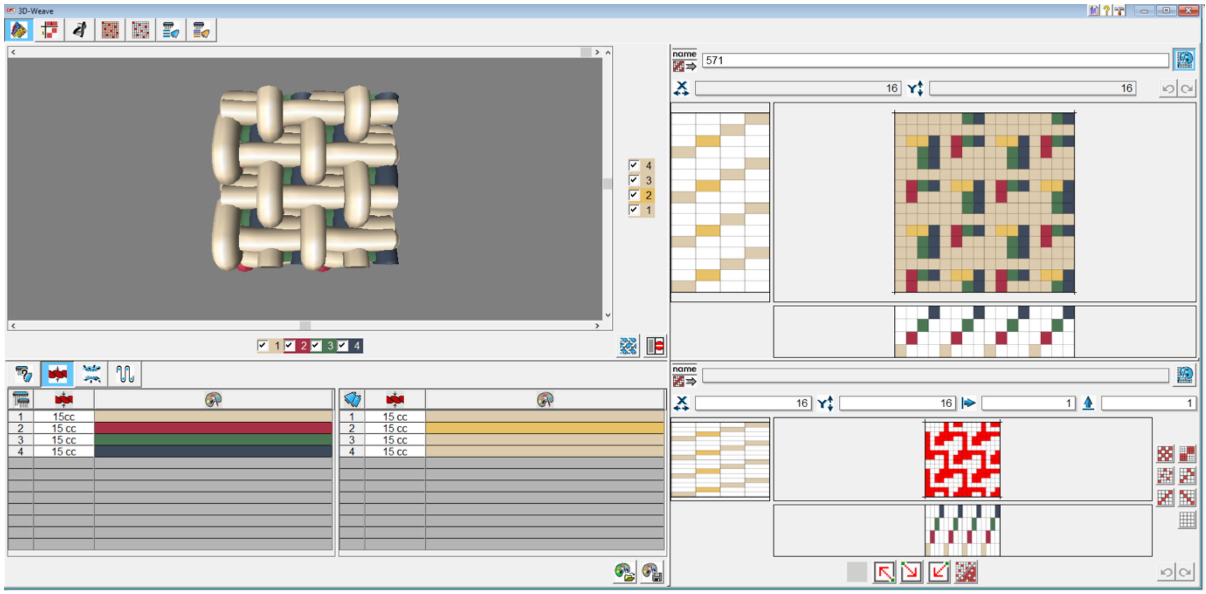


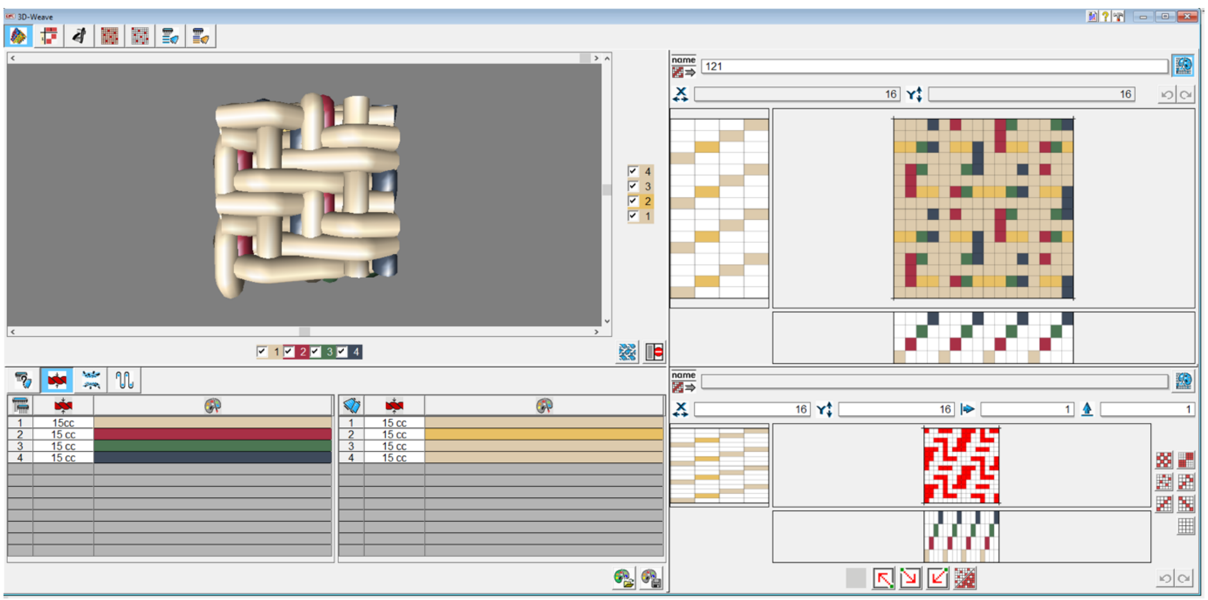








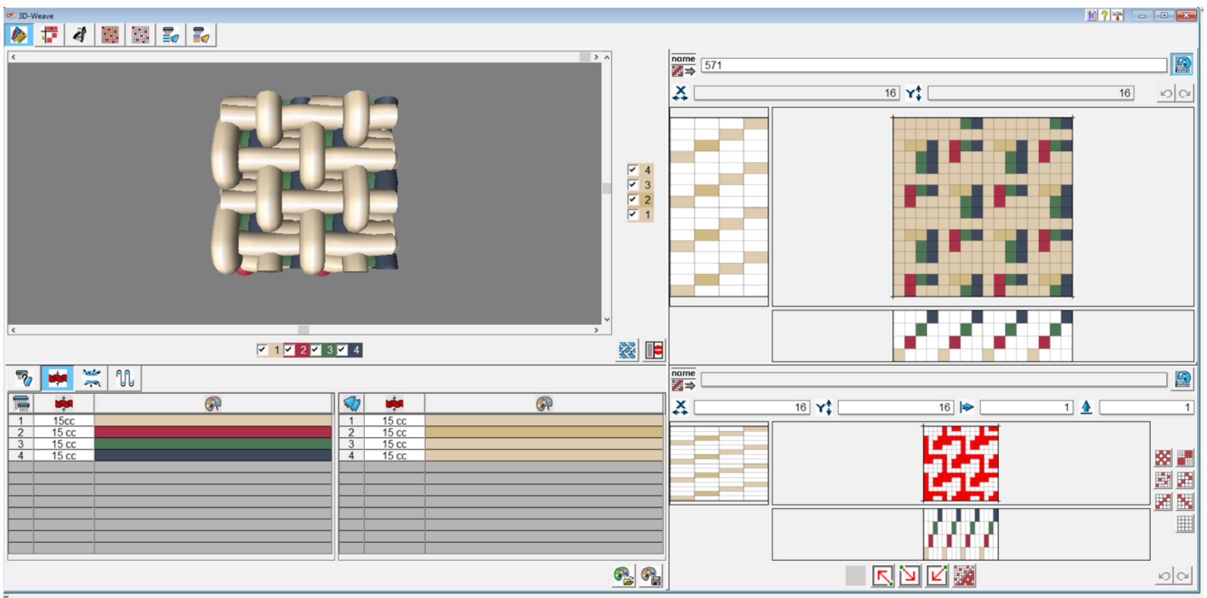


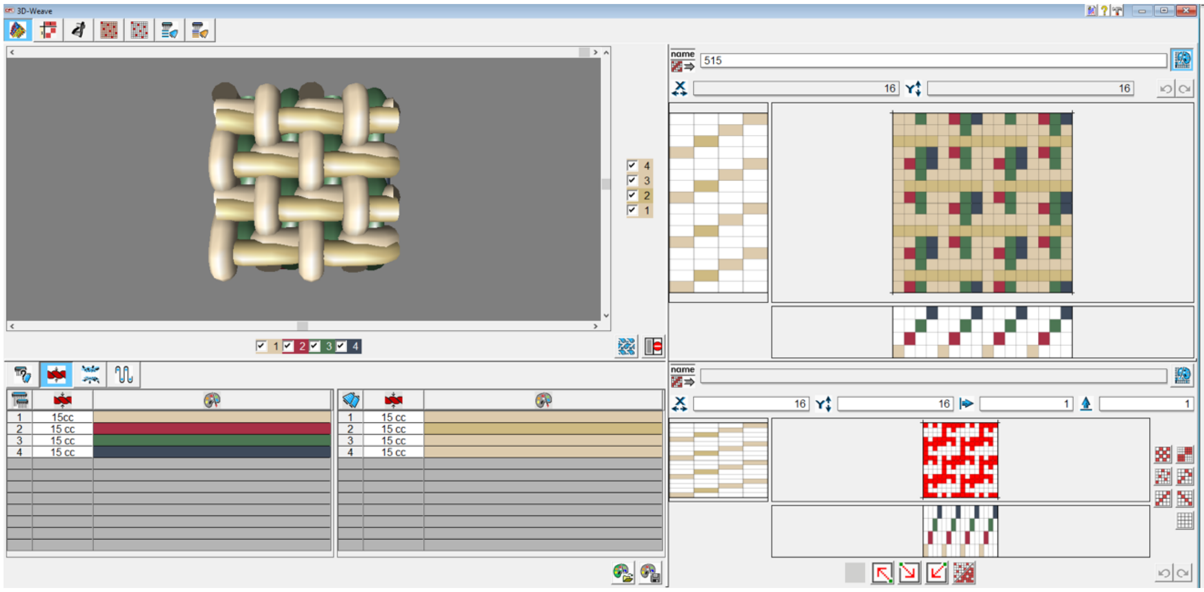


Artwork B: 2 Weaves (2 Colors in the Design)

Two weaves from the 4 -color NC State filling blanket - 571, 515 - were used to create Artwork B.

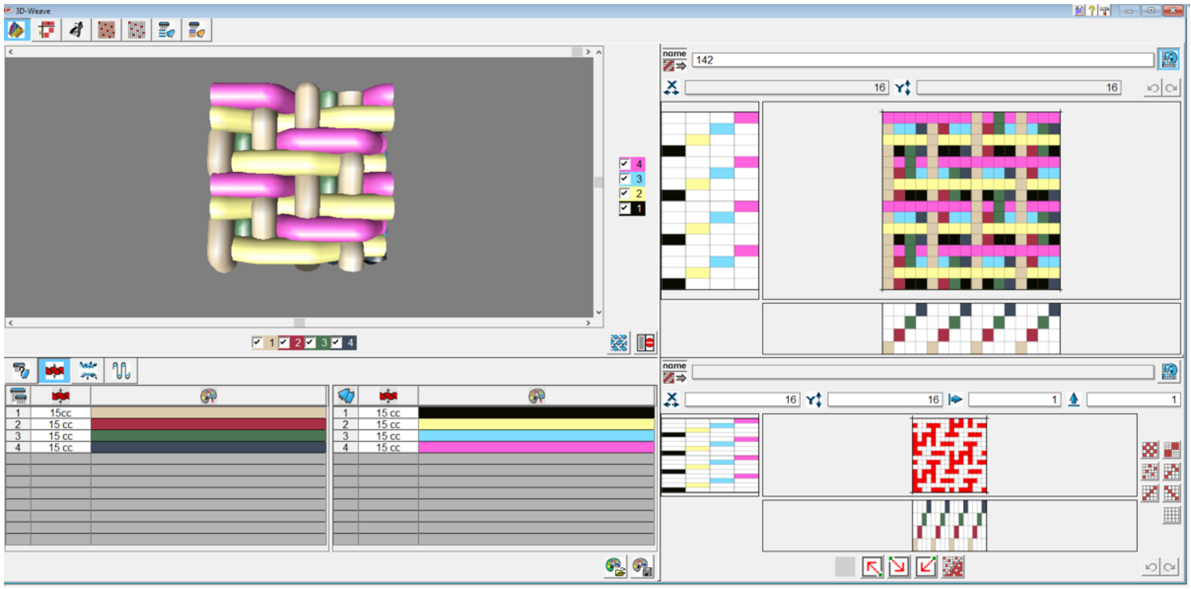
The filling sequence was the same for A and B (with only the second yarn being altered between each sample). The colors shown below were the same RGB values as the yarns used during weaving. Weave 515 is shown on the following page.

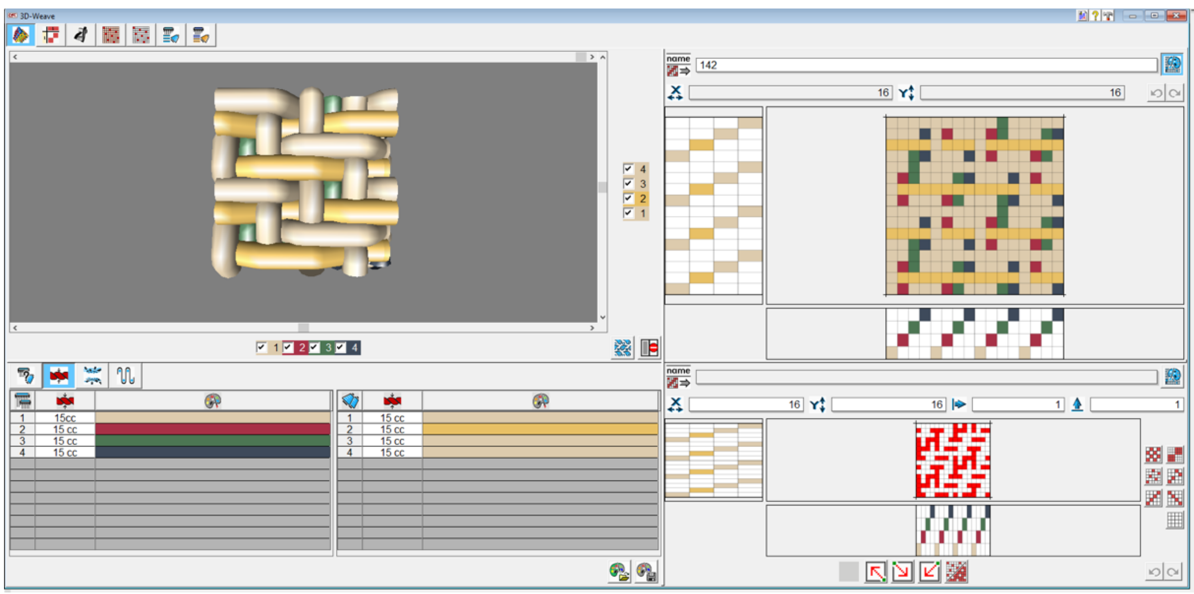



3D-Weave
515
16
16
15cc
15 cc
15 cc
15 cc
15 cc
15 cc
15 cc
15 cc
16
16
1
1

Appendix G: Weaving Filling Color Alterations

The 4-color filling rotation used by NC State is black, yellow, blue, pink in an a,b,c,d,a,b,c,d style rotation. The same rotation was used for weaving Artwork A and Artwork B, but the yarns used in the yellow spot were altered between each Artwork. The original set-up is shown on the following page in the top image. The bottom image (also on the following page) shows a weave used for Artwork A, weave 142 (the golden color represents the chenille). The other three ivory yarns were the same yarn as the ivory yarn in the first position of the warp sequence.





Appendix H: Sample Order Randomization

Twenty-two of the random sample orders included below were utilized during the assessment, one for each respondent.

Sample Number Assignment					
1 – Auden	**2** – Delsie	**3** – Jovany	**4** – Loris	**5** – Renato	**6** – Zinnia

Ramdomizer.Org Sample Order						
1	2	3	6	5	4	1
2	6	5	1	4	3	2
3	6	3	1	2	5	4
4	5	1	6	4	3	2
5	2	6	3	5	4	1
6	4	5	2	6	1	3
7	5	6	4	2	3	1
8	4	3	5	6	2	1
9	1	3	4	6	5	2
10	5	2	3	6	4	1
11	6	4	5	1	3	2
12	1	6	5	2	4	3
13	4	6	1	5	2	3
14	6	2	4	5	1	3
15	6	1	3	5	2	4
16	3	4	2	6	1	5
17	1	4	6	5	3	2
18	6	5	1	4	2	3
19	6	3	2	5	4	1
20	6	3	2	4	5	1
21	5	6	1	3	2	4
22	1	3	5	2	4	6
23	5	2	1	4	6	3
24	6	3	4	5	2	1
25	1	5	4	2	6	3