Chapter 5

Weaving Complex Patterns — From Weaving Looms to Weaving Machines

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Additional information is available at the end of the chapter

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Abstract

A chronological overview of the historical facts of the art of hand weaving, with an emphasis on the development of large and complex patterns is provided. The development of looms or weaving machines through history for weaving fabric with large patterns is described. Hand weaving complex patterns from primitive weaving on frames to more complex weaving with two weavers operating one loom was especially explored. The beginning of Jacquard weaving and its application even to the electronic Jacquard looms has been emphasized. An analysis of the development of patterned fabrics with multiple effects was carried out. The analysis was conducted according to patterns using the shortened version of drawing a sample. The results show that it is possible to determine the technique of weaving and construction parameters of each fabric pattern that vary in color and/or in a weave used. The most accurate way to highlight the contours of the points of the transition of one effect into another, namely by shifting warp and weft interlacing points on the edges of each pattern (opposing thread float), is described. Based on the obtained results and finding an identical yarn, it is possible to replicate the pattern on the Jacquard loom.

Keywords: Hand weaving, looms, Jacquard weaving machine, complex patterns, fabric analysis

1. Introduction

The term textile is usually associated with a cloth that is produced on a loom or weaving machine as a fabric manufactured by interlacing warp and weft threads. Weaving is one of the oldest crafts and has a long historical development. Studying the history of the production of fabrics is based on archaeological finds, pictorial representations, frescoes, stone monuments, archival documents, etc. One of the valuable records is the Bible, which mentions the intricate network of Solomon's Temple. In Greek myths, Arachne, the weaver is mentioned who was turned into a spider by Athena; Homer describes decorative veils of the Temple of Athena. The beginnings of fabric production date back far into the past and cannot be precisely defined. The oldest sites as evidence of fabric production are certainly records and drawings in China and Egypt, carved in stone or clay pottery, which date back to 12,000 BC. It is assumed that the first interlacing of warp and weft occurred much earlier in making dwellings from brushwood. To create a roof area and better insulation of the space, mud and leaves were used, which were coiled and intertwined with each other in two directions (warp and weft directions). Thus, a solid and long-lasting roof structure was made. After that the manufacture of baskets, bags, and other household and transport articles developed. This interweaving of brushwood was probably the forerunner in the development of fabric making. By hand twisting twigs, leaves, and animal hair, an initially coarse, and afterward a finer thread was made from which fabric was manufactured by interlacing [1]. Despite coarse weaving, these fabrics had a definite advantage when worn compared to fur, especially in the summer. The preserved drawings show that fur was the first to have been used to cover the body. Fabric has gradually assumed the function of the fur and was primarily used to protect the body from bad weather. Sensitivity of textile products, and the tendency to decay, represents a particular difficulty in assessing the beginnings of making fabrics so that drawings of looms carved in stone or clay are more reliable and older evidence of the beginnings of the craft of weaving [2].

2. Production and description of fabrics with large and complex patterns

Weaving has always represented an extremely complex operation that requires not only a certain knowledge of the technological process, but also a way of creating patterns on the fabric. The production of yarns from different fibers and its transformation into a fabric is one of the oldest human crafts and technologies. Various historical textiles and materials, as an invaluable part of cultural material heritage, testify to social background and time of origin [3]. Throughout history more complex fabrics, especially silk fabrics with gold or silver threads, represented a status symbol of high society and were of great value. Most often they were used for garments, church vestments, and furniture decoration. Old simple fabrics without or with smaller patterns made from wool, linen, cotton, or similar fibers, are also greatly appreciated and carefully preserved [4].

The manufacture of closely woven silk fabric with multicolored Jacquard patterns always required a weaver with certain technological knowledge, skill of transferring a pattern on the fabric, and sense of matching colors in the pattern. Woven fabric is formed by interlacing warp and weft threads according to a weave and pattern in order to produce a compact fabric with an appropriate design. In addition, the appearance of the fabric depends on the density of warp and weft threads, composition and fineness of yarn, thread tension, loom type, and the weaver (precision, patience, skill, knowledge of weaves, matching of density and color, etc.), especially when it comes to hand weaving.

It is assumed that wool is the oldest fiber that was used for making fabric. However, the oldest preserved samples are not from wool, although records mention wool processing. Egyptians wrapped mummies mainly in linen, which did not decompose, and in addition, their religion did not allow taking animal fibers into the tomb; this is the main reason why wool fabrics are not the oldest preserved samples. Over time, certain skills and weaving techniques preserved in secrecy in narrower communities were developed. Increasingly more valuable and more beautiful fabrics recognizable by regions and communities of origin began to appear. The value of a fabric was assessed according to the raw materials' complexity of manufacturing and pattern size. The fabric was evaluated according to the raw material (silk), fineness, density, and the complexity of manufacturing, had mostly a high price, and in some regions it was used as currency. Valuable preserved patterns belonged to the higher class, for vestments and appropriate clothing for various ceremonies.

Sensitivity of textile products and tendency to decompose represent a particular difficulty in assessing the beginnings of fabric manufacturing as well as manufacturing complexity. The oldest preserved samples of linen fabrics were taken from Egyptian mummies and date back to 5000 BC, when woven fabrics of certain dimensions were also woven. Most of the preserved fabrics with complex patterns were woven from natural silk. China had a centuries-old monopoly in the production and processing of natural silk. However, this monopoly was threatened as early as in the 12th century by the Italian city of Luca, which was the most famous producer of silk in the West. In the 13th century, the Silk Guild of Paris produced famous green silk fabrics woven with motifs of birds, lilies, and vine leaves. After that, the German city of Regensburg was known for its half-silk fabrics and Venice for samples of brocade with metallic golden threads. The following are some familiar names of fabrics woven on handlooms and their description [5].

Velvet is a fabric produced by weaving weft and warp threads in the form of loops, which are then cut to create the pile effect on the fabric face. It may be warp effect if warp threads are cut or weft effect if weft threads are cut. In hand weaving velvet is mostly made with patterns, and the pattern creates the pile effect which can be cut in different heights and in combination with loops (as terry cloth) depending on the pattern or the weaver's imagination. Fabrics with greater pile densities are called velours.

Brocade is a heavy, Jacquard-type fabric with a raised pattern or floral design. Traditionally, the pattern is produced with gold or silver weft threads. Weft threads are actually made from linen or wool wrapped with thin flat metal which is gold-plated or silver-plated.

Damask fabric is a firm and glossy Jacquard-patterned fabric made of silk, wool, linen, cotton, or synthetic fibers, with a pattern formed by weaving. It is characterized by the combination of satin and sateen weave, made with one warp and one weft in which, generally, the satin warp and the sateen weft weaves interchange. The figures or the designs are in the weft and the background is in the warp. Twill or other binding weaves may sometimes be introduced.

The term originally referred to ornamental silk fabrics, which were elaborately woven in colors, sometimes with the addition of gold and other metallic threads. Damask weaves are commonly produced today in silk, linen, or linen-type fabrics that feature woven patterns featuring flowers, fruit, forms of animal life, and other types of ornament.

Double cloth is a kind of woven fabric woven from two sets of warp threads and two sets of weft threads. Through weaving, two distinct fabrics are made, connected by the binding weft or warp threads. The fabric is very strong and compact and was mostly woven from wool in hand weaving.

Gros de tours fabric is a ribbed silk fabric made with a two- or three-ply warp interlaced with organzine and tram weft. Rep weave creates longitudinal or transversal stripes on the fabric. Stripes can be more or less distinct. This weave type is defined as plain weave with double threads in one thread system (mostly double weft threads) forming a ribbed appearance of the fabric. The fabric is made with a high density so it is necessary to draw into more than two heddle shafts with straight or broken draft. This disburdens shafts and warps are arranged in several shafts although they bind in the same way, so they do not cover in the fabric which is possible, especially if they are drawn into the same dent of the reed. Thus, the fabric appearance is nicer and more uniform because each thread has a certain width within the fabric and they are mutually parallel in spite of a high density. In this manner double threads that bind in the same way create stripes.

Lame is a shimmering fabric that is created by combining metallic threads, often of gold or silver, and natural or synthetic threads into a woven fabric.

Lampas is a figured textile in which a pattern composed of weft floats bound by a binding warp is added to a ground fabric formed by a main warp and a main weft. The ground fabric is mainly woven in plain, twill, or satin weave or their derived weaves with the smallest weave units. The weft, which creates the pattern, may be in the same color as the main weft or the decorative (multicolor) one, binding in plain, twill, or satin or only floats on the fabric face as extra weft-figured and/or brocaded.

Lisere is a fabric with a pattern created by the floating main weft.

Taffeta is a dense plain woven fabric. In hand weaving these fabrics are mainly woven figured with lance (extra) or brocaded wefts.

Extra weft fabric – the weft creating the pattern on the fabric is inserted over the entire fabric width. It is on the fabric face only where the pattern is created.

Brocaded weft fabric – the weft creating the pattern is on the face of the fabric and is seen only where the pattern is, and it is not woven in the other parts of the fabric. For this reason the weft consumption is lower which is especially significant if gold or silver threads are used. During insertion the brocaded weft is not cut for each weft thread, but at the end of the pattern it is returned into the pattern in the next shed, and thus relatively strong edges of the pattern are made. Pattern design of fabrics with brocaded wefts is performed with the fabric face pointing downward which facilitates and accelerates the weaving.

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3. First looms

At the beginning of weaving longitudinal threads (warp threads) were hung next to each other on a bar with hanging weights forming one set of threads which were then interlaced with horizontally arranged threads (weft threads). Wefts were inserted, beaten up from bottom to top. This way a fabric of specific structure, softness, breathability, and comfort was produced.

In the old records weaving frames are described. The warp was taut during weaving, previously dimensioned fabrics were woven and later they were joined laterally and transformed into simple articles of clothing.

The form of the first loom changed through history and it cannot be said for certain whether the first loom was vertical or horizontal (Fig. 1). Vertical looms take up less space and are more suitable for weaving outside dwellings, but their height required prolonged abnormal body posture and standing work, especially in the beginnings of weaving when the warp was hung to weights and the weft was inserted from top to bottom. This made weft beating up more difficult. No higher warp and weft densities could be achieved, warp tension was irregular, and each weft was inserted by interlacing the warp with fingers, until the formation of the shed was invented. Vertical looms were developed mostly for weaving loosely woven fabrics in the warp direction, but with very high strength. The assumption is that the tapestries, rugs and carpets were mainly woven on vertical looms with larger widths where the colored weft conceals the loosely woven warp and creates a pattern. By tightening the warp on both sides of the frames, thereby eliminating the weights for tightening the warp, it is possible to weave from bottom to top, which made weft beating up easier and achieving a higher weft density. Additional bars and strings enabled to form two sheds, specifically for weaving in plain weave; this increased the fabric production and quality of these looms. Vertical looms are more suitable than horizontal ones for weaving larger patterns, according to the picture, which can be easily placed under the warp (no shafts that prevent placing the picture below the warp as on horizontal looms) as well as drawing pictures or drawings on the warp before weaving. This has resulted in unique items of immeasurable values. Despite slower work, and thus lower productivity in relation to the horizontal loom, vertical looms were probably more numerous at the beginning of weaving. Because of their simpler construction, vertical looms allowed achieving the utilization of the whole warp whereby it is possible to weave fabrics with selvedges on all four sides to make one article of clothing without cutting. This fact is confirmed by the preserved samples of fabrics (e.g., oldest woollen fabric woven in Europe with the edges on all four sides found in Bosnia and Herzegovina 1983; fabric age dates back to 3550-3800) [6]. It can be interpreted from the loom drawings carved in stone or clay that they are more reliable and older evidence of the beginnings of the craft of weaving and weaving process than the preserved samples of fabrics [7].

Horizontal looms are more suitable for weaving in dwellings; weavers wove in a sitting or squatting position. With the introduction of shafts and treadles weaving on the horizontal loom became easier because of the use of the feet (to press treadles) and hands (weft beating). Horizontal looms experienced a noticeable development as weaving the most complex patterns. Their productivity rose, with the introduction of the shuttle with a cop, especially in

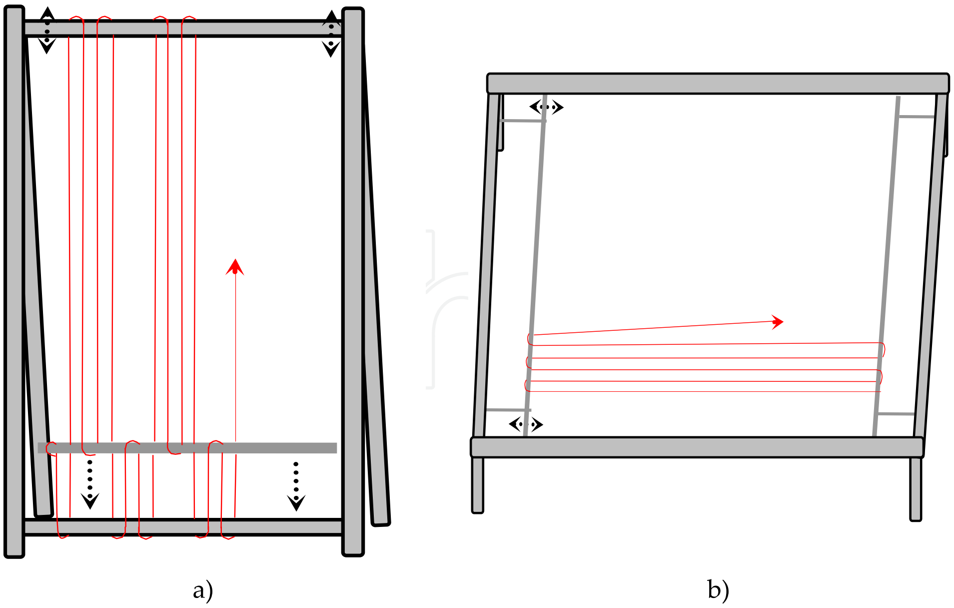

Figure 1. Warping on the loom in the form of a frame to produce a fabric with selvedges on all four sides; a) vertical loom, b) horizontal loom

case of simpler patterns. Their development was in several directions, e.g., with regard to raw materials, weaving processes, and pattern complexity. Over time, the increasing weavers' skills became more apparent in interlacing warp and weft threads creating more complex weaves, using different raw materials, finer yarn counts, and greater thread densities. In weaving greater lengths and widths of fabrics were achieved, and fabrics were later cut and sewn into more complex items of clothing. Larger and more complex patterns requiring an excellent skill and knowledge of weavers were created. The yarn was dyed with natural dyestuffs and woven, or less frequently, the fabric was dyed after weaving. Woollen fabrics were sometimes filled in order to produce warmer and softer articles of clothing. At the same time looms were adapted for weaving more complex patterns and lightweight fabrics. In this regard, horizontal looms were at an advantage: the fabric had regular and uniform dimensions across the width; it was possible to create a shed by pressing the treadles with a variety of connecting shafts and treadles, which made it easier to insert the weft; easier and faster weaving; better quality fabrics; and more possibilities of pattern design. Horizontal looms became increasingly complicated when making larger patterns and larger dimensions with extreme fineness and density of threads, which required a complex and longer warp and weft preparation. For larger fabric widths looms with two pairs of treadles and with two weavers working in pairs were constructed (Fig. 2). Sometimes, weavers were also artists or worked with them closely in weaving large patterns. Art paintings, which corresponded to proportions of drawings and colors, were adapted and woven. This required long training of weavers for weaving such patterns and reading the records of the pattern, but also artistic talent in matching colors according to the model, and skill in using different weaving techniques and knowledge of weaves that were the most suitable for the development of certain patterns and designs. Horizontal looms were specialized in weaving specific raw materials (for lightweight

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silk fabrics, heavy woollen fabrics, etc.), in the technique of weaving (velvet, terry, damask, lampas, etc.), in the complexity of a pattern (with extra floating wefts (lance), with brocaded wefts, with metal (gold-plated or silver-plated wefts etc.). The complexity of making patterns begins with the use of fiber (e.g., natural silk, linen, wool, cotton), yarn count (from the finest silk threads to coarse wool and metallic threads), and warp and weft density amounting to 150 threads/cm.

On the first looms, the warp had a relatively small length which sufficed for making an article of clothing. That the skill of weaving existed in the Stone Age is witnessed by findings of bone needles and dressmaking equipment made of stone. One of the more valuable artifacts are stone weights for the warp, which originate from Troy 2500 years BC, confirming the use of looms at that time [8].

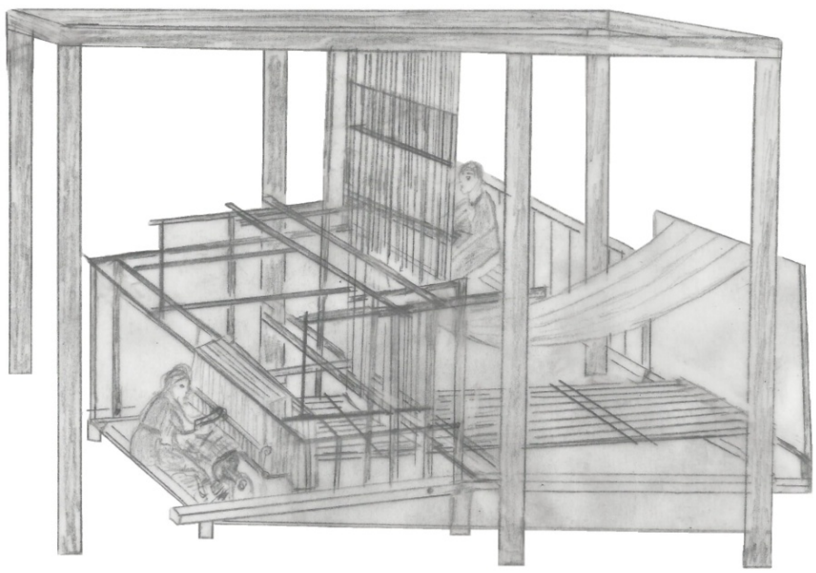
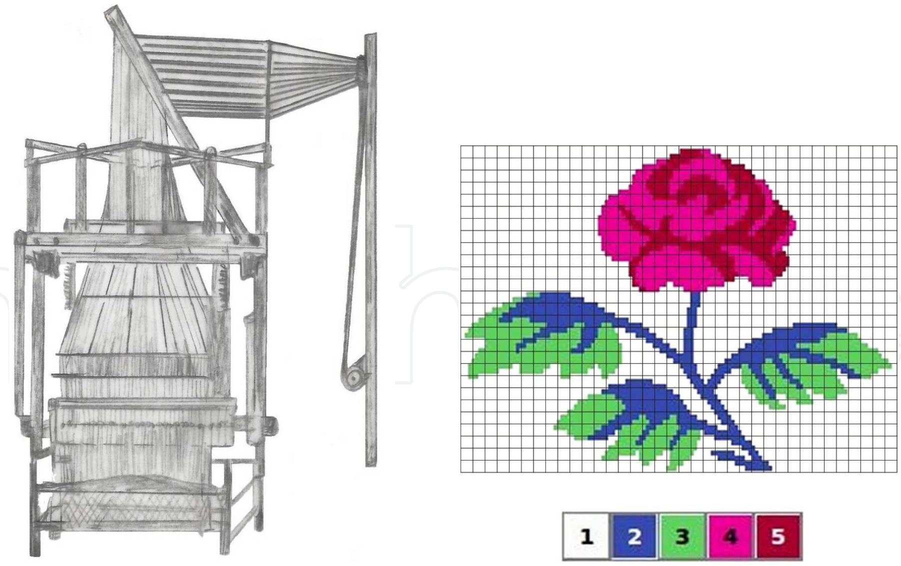


Figure 2. Horizontal loom for larger fabric widths

4. Development of looms and weaving machines for more complex weaving patterns

The first looms for making larger patterned fabrics with larger repeats that were predecessors to the Jacquard loom had a very complex construction (Fig. 3a). Before making a Jacquard loom with programming cards, making patterns with a great weave unit in combination of different weaves required a very complex weaving preparation and weaving itself [9]. A stencil plate (Fig. 3b) was prepared according to a painting, which was usually an artist's work of art. A copy of the painting and sometimes the original work was divided into squares that were 1 cm wide and 1 cm long.



a) b)

Figure 3. a) Weaving loom for making old complex patterns before the Jacquard weaving loom, b) picture prepared for weaving with number of effects in the picture

First, it was necessary to determine the density of ends/1 cm and to calculate the total number of warp threads (density of ends/1 cm multiplied by the fabric width to be woven with the addition of threads for selvedges). According to the painting, the number of effects on the fabric pattern, which were distinguished by color and / or weave, were determined. One thread system was single-colored (or hidden) and another multicolored (creating the fabric face). In such patterns, the warp is usually single-colored, and the weft is in different colors, which creates a pattern on the fabric face. In this way, the preparation of single-colored warp is simpler and faster. According to this weaving technique, the warp threads were hidden within the fabric by beating up the weft, whereas the multicolored weft created versatile effects on the fabric. In order to hide the warp threads on the fabric face, the warp threads should be loosely warped, tauter, stronger, twisted, and preferably thinner than the weft threads. This relationship is mostly based on experience, now known as double weft, triple weft, or multiweft fabrics. In multiwarp fabrics the weft is invisible, the warp threads create a pattern, and they are finer and denser than the weft threads. Warp threads were dyed before warping, so warp preparation and warping lasted longer, but weaving was faster because the weft was mostly single-colored. A group of cords for drawing warp threads for the corresponding effect is assigned to each effect on the picture or the fabric. One of the weavers pulled the cords (weaving with two weavers) according to the corresponding effect over the whole warp width. The other weaver had to watch out for the effect in the direction of the fabric width and insert the corresponding weft color. In order to insert the warp thread over the whole fabric width, the cords for each effect in the fabric fell had to be drawn. The weft color corresponding to the effect was inserted in that fabric segment where this effect was drawn according to the pattern and the program for raising the cords for this effect depended on the weave. After the weft thread had been inserted over the whole fabric width for all effects being woven at that moment, the weft threads were beaten up, and the process was repeated for the next weft

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insertion. The pattern was woven face downward for easier weft insertion, and a mirror was used to control the fabric pattern. The number of picks/cm depended on weft thickness and beat-up force. The thinner the weft thread and the stronger the beat up force of the weft, the more beautiful the pattern, with more distinct and accurate pattern contours created, but weaving time was longer or more weft threads had to be inserted per 1 cm. Similarly, the density of warp threads affected the quality and appearance of the fabric pattern. The greater the warp density and the finer the warp threads, the more distinct were the contours and the fabric pattern was more beautiful and more faithful. Fabric patterns made by hand weaving large patterns from natural silk, especially in combination with gold-plated and silver-plated threads (brocades) are of exceptional value [10].

The first weaving loom on which punched cards raised and lowered warp threads according to a program was invented by Joseph Marie Jacquard [9] in 1805 (Fig. 4). This loom raised warp threads with the help of a program card. This eliminated pulling cords according to effects. One cord was pulled attached to the prism and moved the card for one weft thread. By pressing the treadle the needles would come into contact with the card. The card is read for each weft and usage of hooks and the harness raises warp threads (punched hole in the card) or remains in the lower shed (unpatched hole in the card) over the whole width.

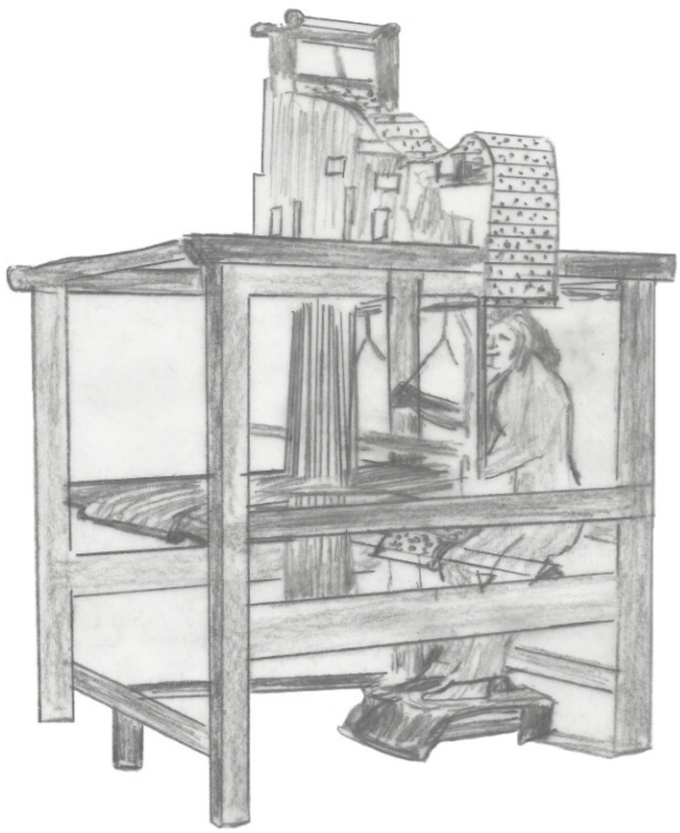

Figure 4. Jacquard loom (1805)

A punched hole in the card means that the needle passes through it and pulls the hook because it is engaged with the knife and will raise all the cords fastened to this hook and the heddles hung on the corresponding cords, and thus the threads drawn into the corresponding heddles. If there is no hole in the card, the needle remains on the card surface and does not pull the hook, it is not in contact with the knife and will not pull it, as cords or heddles and warp threads will remain in the lower shed position. One or more weft threads are inserted by colors and fineness, depending on fabric effects in this fabric segment. The technique of weft insertion by effects is the same as on the previous loom without punched card, only the shed is inactive until all weft threads are inserted as required by the pattern. This weaving technique using punched card (Jacquard punched card loom) achieves higher production, enables easier operation, and machine operation is built for one weaver and there are fewer possible faults [11].

5. Development of automatic Jacquard looms

Some inventors attempted to build a mechanically driven machine back in the eighteenth century. Cartwright applied steam power to drive the loom. Mechanical machines increasingly dominated in weaving mills of that time. Industrial production began in the second half of the eighteenth century. In 1894, Northrop invented a pirn changer, a mechanical device that provides automatic supply of weft in looms by changing the contents of the shuttle without stopping the loom. Large-patterned fabrics became possible because of weft pattern forming (two shuttle boxes on each side of the machine or 3 multicolored weft threads) and the use of the Jacquard power loom (Fig. 5).

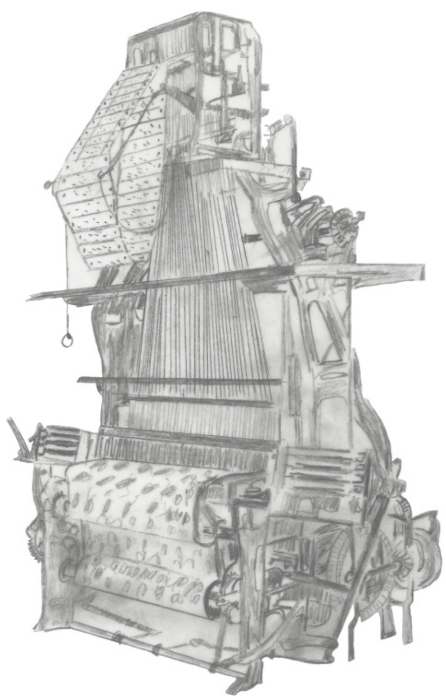

Figure 5. Mechanical Jacquard shuttle loom with weave design

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The production increased a number of times; the machines were improved dramatically and new manufacturers appeared. Weft pattern forming was made possible by adding four shuttle boxes on each side of the machine, which allowed up to 7 multicolored weft threads. Automatic shuttle looms were improved and used for nearly one century and played a predominant role in the historical development of weaving. Shuttle-less weaving machines appeared in the mid-twentieth century (Fig. 6) [12].

The advantage of shuttle-less weaving machines is their high productivity, higher product quality, and easier and more comfortable machine operation. On shuttle-less weaving machines, weft threads are inserted into the shed only from one side; they are unwound from the supply package outside the machine which causes problems for making strong and quality selvedges on the fabric. These machines run at high speeds because the weft inserter picks up each weft individually and it is lighter than the shuttle. On shuttle looms, the shuttle inserts the weft on the weft cop; they are slow and cannot achieve the speed of shuttle-less looms. The basic construction of shuttle-less looms does not differ significantly from the construction of shuttle looms; the only exception is the weft inserter. All devices on the loom can be classified into four basic groups: warp-unwinding devices, shed forming devices, weft inserters, and fabric winding devices.

The looms are divided into the following according to shed formation: cam loom, dobby loom, and Jacquard loom, and according to weft insertion: projectile, rapier (rigid and flexible), air jet, and water jet looms. Besides single-phase weft insertion (one weaving cycle is one weft thread), there are multiphase weaving looms. The weaving machine being developed in this direction is serial shed weaving machine which inserts 4 weft threads at each moment over the fabric width, and its productivity amounts to 6.000 m of weft/min. The other devices are weft patterning devices, warp and weft stop motions, weft accumulators, control devices, etc. [13].

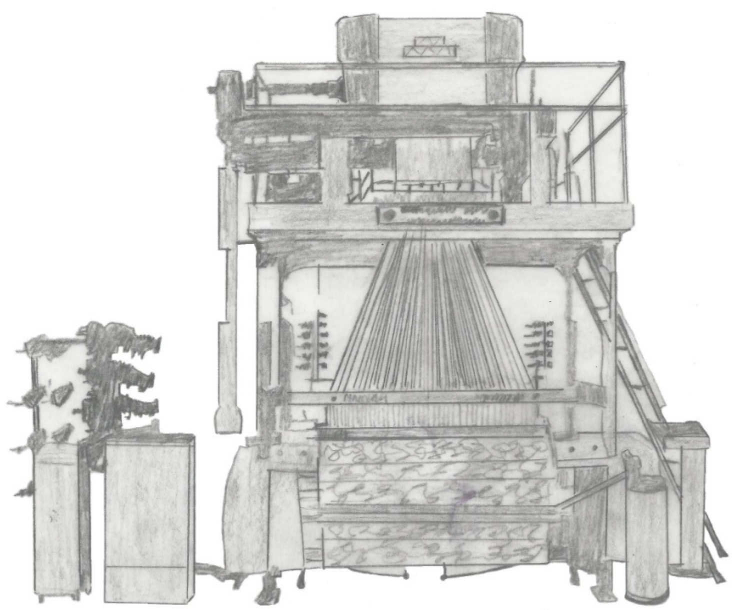

Figure 6. Electronic Jacquard shuttle-less weaving machine

Electronic Jacquard shuttle-less weaving machines have several advantages over looms with weave design. Electronic Jacquard allows better and more productive weaving. Using CAD/CAM systems in weaving shortens the pattern preparation for weaving by several times. The CAD (Computer Aided Design) system processes fabric design parameters and adapts the pattern (figure) for weaving. The CAM (Computer Aided Manufacturing) system for weaving allows controlling the production process of the loom and contains the data required for the process of weaving. CIM (Computer Integrated Manufacturing) for the process control of the whole weaving mill allows complete overview of the production, Internet contact with each loom allowing remote control, service, correction, and repair of the program.

The latest developments in Jacquard weaving are harness-less looms (Fig. 7). The upper part of the Jacquard loom (Jacquard) is "lowered" directly above the bottom machine performing the weaving process. In this way, the machine height has been considerably reduced and no harness is necessary that has to be replaced after a certain time period. These weaving machines have certain drawbacks compared with Jacquard looms with harness, but their development goes on indicating a new, more cost-effective way of weaving fabrics with large patterns.

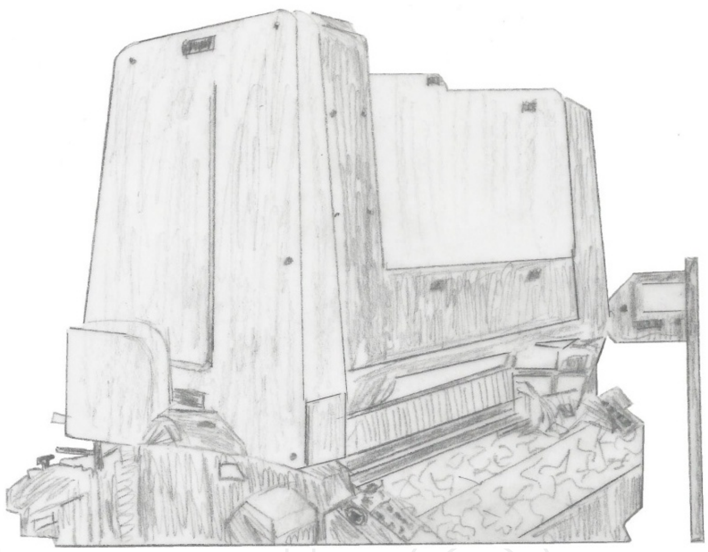

Figure 7. Electronic Jacquard loom without harness (Grosse's Unished Jacquard)

Despite the rapid development of the textile industry in the twentieth century, hand weaving has remained in handcraft industry, even in factories for manufacturing carpets having high value and quality. Today, Mexican and Persian carpets made on vertical hand looms are famous for their long life and beauty throughout the world.

6. Experimental part

The silk fabric, which will be analyzed here as an example, was woven on the Jacquard loom (Table 1, Fig. 8). The ground warp is black and has an even density across the fabric width.

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The ground warp (black) and the ground weft (black) are woven in plan weave across the whole fabric surface, regardless of whether it is the ground fabric or the pattern. Various weaves and color combinations of the warp and weft compose fabric effects. The weaving machine is equipped with two warp beams: one warp beam is intended for the ground warp, and the other warp beam is intended for the pattern warp.

Warp density (ends/cm)	Ground warp (black)	92
	Pattern warp (in 7 colors)	50
Weft density (picks/cm)	Ground weft (black)	35
	Pattern warp (blue and red)	36
Fineness of warp threads (dtex)	Ground warp (black)	44
	Pattern warp (in 7 colors)	94
Fineness of weft threads (dtex)	Ground weft (black)	82
	Pattern warp (blue and red)	242

Table 1. Basic parameters of the tested fabric

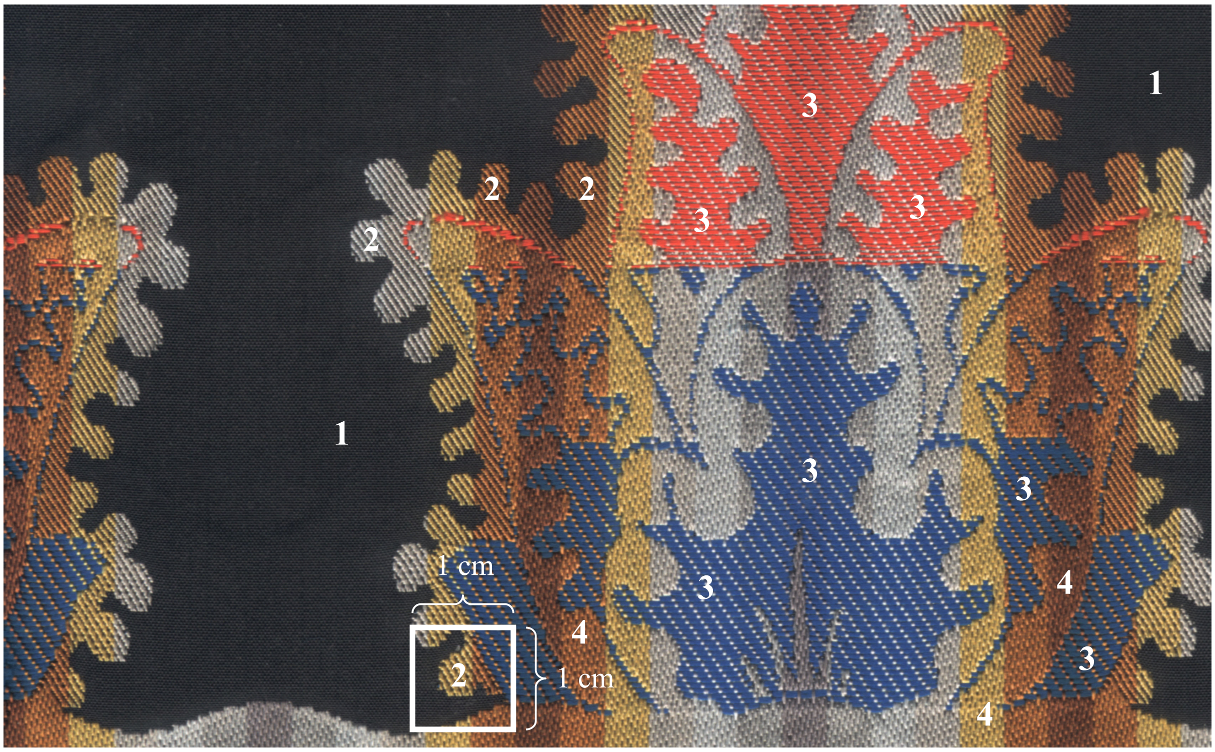

Figure 8. Fabric pattern with a multicolored warp (ground: black, pattern: cream-colored, pale gray, gray, dark gray, yellow, brown, and dark brown) and multicolored wefts (ground: black, extra floating weft: blue and red) 1-4 effects created by the pattern

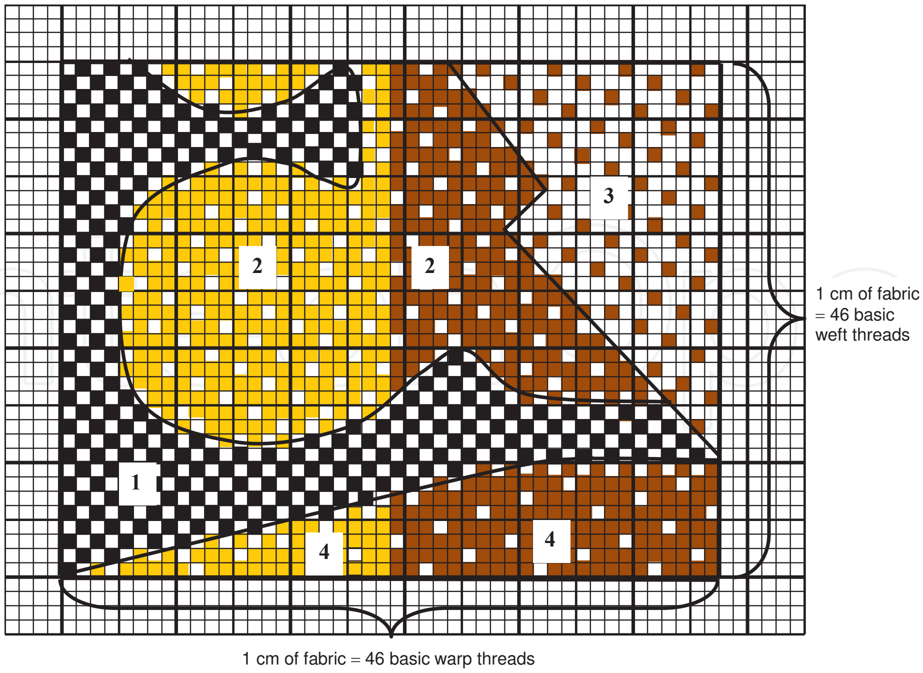

Figure 9. Weave design for 1x1 cm fabric (pronounced square on the fabric pattern, Fig. 8)

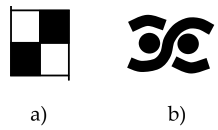

Figure 10. The first effect or ground fabric is created by the warp (black) and weft (black) in plain weave; a) weave unit; b) cross section in the weft direction

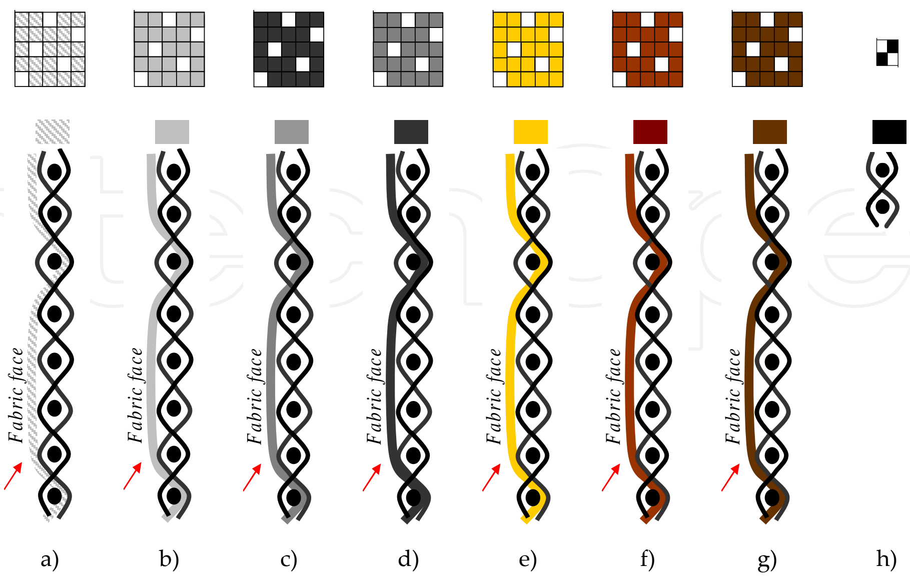

Figure 11. The third effect is created by different colors of warp threads; a) cream-colored, b) pale gray, c) gray, d) dark gray, d) yellow, f) brown, g) dark brown; they interlace with the ground in 5-end warp satin; on the back side, ground warp (black) and ground weft (black) interlace in plain weave

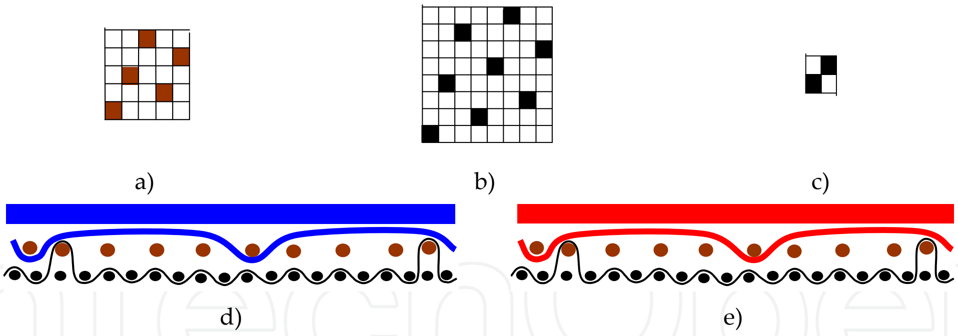

Figure 12. The third effect is created by the red and blue weft threads which interlace with pattern warp threads in 5-end weft satin; on the back side, the ground warp (black) and ground weft (black) interlace in plain weave, in the middle section of the fabric the pattern warp threads interlace with the ground warp threads in 8-end warp satin; a) 5-end weft satin, b) 8-end weft satin; c) plain weave, d) cross section with blue weft on the fabric face, e) cross section with red warp thread on the fabric face

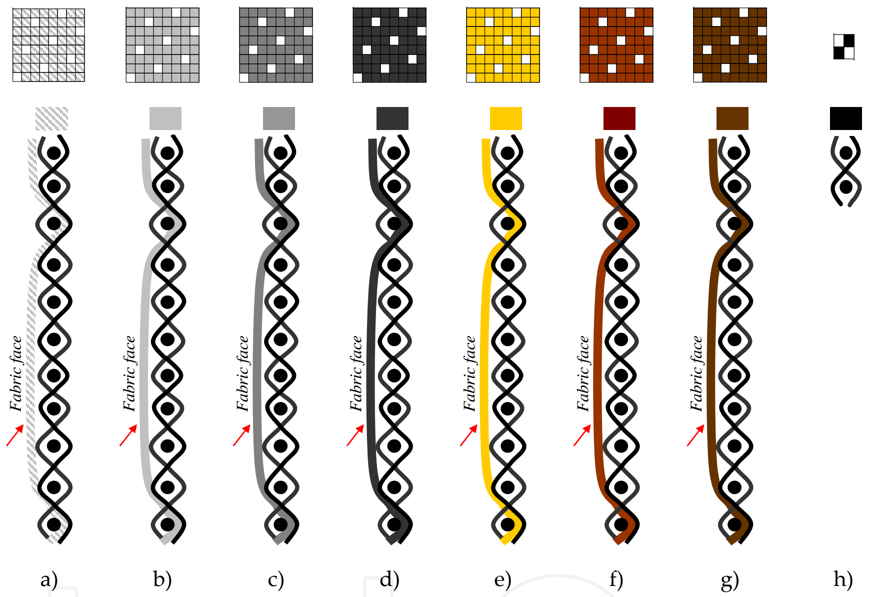

Figure 13. The fourth effect is created by different colors of the warp threads: a) cream-colored, b) pale gray, c) gray, d) dark gray, e) yellow, f) brown, g) dark brown interlace with the ground weft in 8-end warp satin; on the fabric face, the ground warp (black) and ground weft (black) interlace in plain weave

7. Discussion

Marked effects on the fabric are only those created by different weaves. Effects by the colors of warp and weft threads are not specifically identified, but they are visible on the fabric and in the weave development. In addition to the ground weft, two extra floating wefts (lance) (red and blue) creating the pattern with the pattern warp run in the weft direction. The pattern warp and lance weft threads are on the back side of the fabric and do not interlace in the ground fabric part. The fabric was woven on the Jacquard weaving machine, and the pattern does not include the weave unit. The weave is drawn on the appropriate graph paper which corresponds to the ratio of warp-to-weft density. Since the weave unit is relatively large, the total number of warp and weft threads is not covered by the analysis of drawing the weave. That is why the weave of only one fabric part has been drawn, covering all the effects. It is important that in the transition from one into another effect there is opposing thread (warp or weft) float. In that case, a certain displacement of interlacing points in favor opposing thread float is allowed which was done in the figure representing the weave development (Fig. 9).

The looms, which were used to weave pattern fabrics before Jacquard weaving, had to be adjusted for this kind of interlacement which required a specific skill and knowledge of the weaver. In transition areas of effects the weave is disrupted, meaning that the weft interlacing point is applied in one effect opposite the warp interlacing point in the other effect and vice versa in order to point out the boundary between two effects. In hand weaving, the weaver had to pull weft threads past the shed in transition areas of effects in order to create opposing thread float. Pulling the weft thread through in these areas was difficult and resulted in faults in the weave, breaks of warp threads and longer weaving. This problem disappeared when Jacquard looms were introduced because cards were punched according to the prepared weaving pattern where opposing thread float had been drawn. In this way, the shed was opened for each warp with opposing thread float in areas between effects, resulting in a great increase of productivity and fabric quality. Punching cards for each warp thread allowed forming one shed for all effects and weft colors to be inserted into the corresponding shed. Thus, it was unnecessary that the other weaver raised warp threads according to the effects because the card was punched for all warp threads over the whole fabric width or all effects across the fabric width at this moment.

Each effect is explained in detail below:

- The first effect is the ground part of the fabric, where the ground warp (black) and the ground weft (black) are interlaced in plain weave (Fig. 10).
- The pattern warp in different colors (cream-colored, pale gray, gray, dark gray, yellow, brown, and dark brown) and the ground weft makes the second effect (black). The weave on the fabric face (pattern warp and ground weft) is 5-end warp satin (A 4/1 with a leap to the right), and plain weave on the backside (ground black warp and ground black weft) (Fig. 11).
- The third effect is made by the lance weft (black or red) and the pattern warp in different colors (cream-colored, pale gray, gray, dark gray, yellow, brown, or dark brown) which interlace in weft 5-end satin (A ¼ with a leap 3 to the right), and the weft is visible on the fabric face. In one fabric segment the red weft and the blue weft interchange, and the logic rule of their interchange in the pattern is not visible. In the second effect, the ground weft and the pattern warp in different colors interlace in 8-end warp satin (A 7/1 with a leap 3 to the right) which is the middle layer of the fabric, while the ground warp and the ground weft interlace in plain weave on the backside of the fabric (Fig. 12).

- The fourth effect is made by the pattern warps in different colors (cream-colored, pale gray, gray, dark gray, yellow, brown, and dark brown) and the ground weft (black) in 8-end warp satin (A 7/1 with a leap 3 to the right) (Fig. 13).

8. Conclusion

The historical development of weaving dates back before the Neolithic period. Interweaving brushwood in building dwellings is the forerunner of interlacing warp and weft threads in fabric making. At first, a coarse textile fabric with low-density simple weaves was made; by increasing yarn fineness and improving weaving procedures, the fabric became finer and more comfortable. Gradually, weaving skills and techniques kept in secrecy in the narrower community were developed. Larger and more complex patterns were introduced. Weaving looms changed throughout history and were adapted to types of fabrics woven on the loom. The manufacture of fabrics with larger and more complex patterns, before Jacquard looms had been constructed, was performed on more complex designed Jacquard looms operated by two weavers according to a drawing or a picture. Productivity was very low regardless of the skill and training of weavers. Yarn preparation (spinning, dyeing, warping, drawing in) required an operator's knowledge and skills. With the advent of the Jacquard loom in the early nineteenth century, productivity rose several times as well as the quality of weaving; one weaver operated the loom.

The principle of the shed formation using a card with punched and unpunched holes did not change for decades. Only the Jacquard gauge changed and the possibility of weaving with several differently interlacing warp threads increased. With the advent of shuttle weft insertion power looms productivity increased several times. Machine operation was simpler, because of the automatic pirn change in the shuttle, one weaver could operate several looms, and the fabric became better and cheaper. The electronic Jacquard loom with CAD/CAM weaving system increased the pattern preparation for weaving as well as the possibility of making larger patterns or greater weave units. Moreover, the consumption of cards was eliminated as well as trial weaving, and greater faults in weaving were not possible.

In order to analyze the pattern of the fabric, it is necessary to define the face of the fabric, the warp and weft direction, and the size of the weaving unit if the fabric pattern involves the weave unit. The analysis of the large pattern fabric involves analyzing the fabric construction parameters for each design or the development of each fabric effect. Due to the complexity of making the weave in the pattern, the analysis is often conducted only on a small area of fabric (1×1cm), preferably that it encompasses all designs or analyzes each design separately. The implementation of such an analysis is important because in order to prepare a certain amount of yarn by color, warp length, and the method of winding on one or two warp beams. Besides, it is important to define the density, contraction, and yarn fineness. According to warp thread density, fabric width, and arrangement of colors in the fabric width it is possible to calculate the total number of warp threads as well as the number of threads by colors. According to the weaves per designs, it is necessary to draw in warp threads into the harness according to the weave, design program, and lowering warp threads (manual pulling the hooks before the Jacquard, punching the cards after the Jacquard or pattern preparation using the CAD/CAM weaving system). In order for the fabric pattern to have precise contours (or boundaries) between individual designs, it is necessary to subsequently move the warp and weft interlacing points (to achieve opposing thread float as much as possible) on the edges of the design.

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