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Mathematical and Anthropological Analysis of Northern Luzon Funeral Textile

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The study presents a mathematical analysis and provides an anthropological perspective of the funeral textile of the indigenous communities in northern Luzon, Philippines. In particular, a symmetry analysis is performed, based on principles of group theory and transformation geometry, on the various repeating patterns found in funeral garments and blankets. Results show that particular frieze groups and plane crystallographic groups are favored due to choice of motifs which are reflective of cultural beliefs and funeral traditions, as well as weaving style and methodology. The results of the analysis point to the depth of mathematics present in the work of the weaver, who is able to arrive at meaningful geometric designs without formal training in mathematics. This study contributes directly to the branch of mathematics pertaining to mathematical crystallography in art and cultural heritage which deals, among others, with the use of group theoretic methods and tools in mathematical crystallography to understand the mathematics in artworks arising from various cultures all over the world. It provides further data and analysis to the growing body of literature that uses symmetry to enhance interpretation of culture from the artistic style of its artifacts.

Key words: frieze group, funeral textile, mathematical symmetry, northern Luzon indigenous communities, plane crystallographic group, symmetry group

INTRODUCTION

The Cordillera region of northern Luzon is home to distinct ethnolinguistic groups who have a long history of producing textiles used in varied ways for clothing, rituals, and trade. These are the Kalinga, Ifugao, Bontoc, Ga'dang, Kankana-ey, Ibaloy, and Itneg among others (Figure 1a). The Itneg have been given the archaic exonym Tingguian, which the Spaniards used to refer to the "mountain people" found in the interiors of Abra, Ilocos Sur, and Ilocos Norte.

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Throughout the Cordillera region, the different ethnolinguistic groups use textiles for funerary rituals. A common practice requires a fabric to wrap the deceased. As Ellis (1981) suggests, "textiles permeate all stages of the life cycle, from conception to death". Specifically, cloth plays a significant role in Bontoc funerals (Labrador 1998): "not being properly attired would provoke the ire of the anitos, making their souls' journey more uncomfortable than the Bontok can imagine". As such, the selection of funerary textiles are done with great care so as not to offend the spirit of the deceased. Elaborate preparations of rituals including the choice of funerary clothing are made to signify the status of the deceased.

Figure 1. (a) Map of the Cordillera region, north Luzon Philippines where representative samples of funerary garments and textiles are derived from anthropological fieldwork; b) a local weaver with her backstrap loom, weaving the central panel of *pinagpagan.*

Custom also decrees that the body of the deceased is surrounded and buried with as many blankets as the family can accumulate (Jenks 1905; Cole 1922; Barton 1946; Respicio 1997) in the belief that this will facilitate immediate recognition of the deceased by the ancestral spirits in the afterlife. It is a symbol of the social status of the deceased and his ancestors.

A funeral is always complete with garments and textiles that are sacrificed, wrapped and buried with the deceased. Perhaps the most lavish display of textiles occurs at death. In the 20th century, early accounts documented the wealth of loincloths and blankets that bedeck the deceased's displayed body, envelop the corpse before burial, and then wrap the bones for secondary burials; the more cloth, the wealthier and more prestigious the person (Jenks 1905; Moss 1920; Barton 1946; Dozier 1966). At present, some areas in the Cordillera region still practice the traditional ways of burying the dead, as observed through the funerary rituals in different communities during the course of anthropological fieldwork from 2013-2015. Modernization of society, conversion to Christianity, intermarriages, and trade have brought changes to other funeral practices. For instance, there are cases where the funeral blankets are now folded and placed inside the coffin of the deceased particularly observed among the Ibaloy, Bontoc, Kalinga, and Ifugao.

In this study, we present a mathematical analysis of funeral textiles, using symmetry, an ordering principle with specific geometric considerations. In previous studies, it has been employed as a mathematical yardstick to classify and compare patterns in cultural material. (Washburn 1986; Washburn & Crowe 1988, 2004). In the Philippines, traditional textile abound from our different indigenous communities. The textile tradition dictated by various elements: weaving technique, forms and decorations, religious, socio-political, and artistic significance, as they behave in each culture. Not much has been studied mathematically in terms of the symmetry structure present in a particular Philippine textile, and how this relates to its anthropological aspects. Earlier studies on Philippine indigenous textiles examined the anthropological relevance of designs, as well as the technology of producing various patterns (Ellis 1981; Respicio 1997, 2003, 2014; Pastor-Roces 1991) and the significance of numbers in motif analysis of textiles from southern Philippines (Quizon 1998). This paper is a mathematical and anthropological analysis of the textile from northern Luzon and focused primarily on sacred textile used by the indigenous communities for one of their important rituals, the burial ceremony. This work picks up from previous initial studies on mathematical symmetries of Kankana-ey textile (The Faculty of the Discipline of Mathematics 1996; De Las Peñas et al. 2012).

The selected funerary garments (woven skirt, upper garments, belt or sash, loincloth and headcloth), and funerary blankets that were examined are representative examples acquired from the weaving communities in the Cordillera region from anthropological fieldwork in 2013-2015. The funerary garments used by the Bontoc,

and representative funeral blankets used by the Kalinga, Itneg, Kankana-ey, and the Ibaloy-speaking communities in Benguet have been made within the last 20-30 years. Some blankets are heirlooms inherited from their predecessors; photographed and analyzed for the purposes of this paper. During the course of fieldwork, the authors observed first hand, the funerary rituals among the Bontoc and Kalinga and how funeral textile are used during these occasions. This is further corroborated through the method of photo-elicitation (Banks 2008) where photographs of funerals taken by the respondents in the last ten years, and photographs of textiles from secondary sources (see Rubinstein 1989) are brought to the field to elicit responses from weavers and cultural bearers to generate further understanding on the funerary textiles.

Maxwell (2003) posits that textiles have numerous designs and motifs that convey important messages significant to a particular and religious principles of the people who produced them. In addition, textiles highlight the unconscious spatial and cognitive composition of graphic designs and patterns, localized technique, skill and dexterity in weaving, and more so, the indigenous peoples' mathematical ingenuity.

The Weaving Process

In northern Luzon communities, weavers are usually women who learned how to weave from their mothers. Most weave at home, where weaving is a part-time endeavor balanced with other responsibilities such as child caring, household duties, and work in the rice fields.

All Bontoc garments and most textiles in northern Luzon are produced with backstrap or back-tension loom by plain weave and supplementary weft, locally called *impaod* or *impagod* which means "strapped". Other parts in northern Luzon also employ the use of foot looms. In backstrap weaving, weavers fasten a backstrap loom with warp of threads around their waist (Figure 1b). The designs in the textile are achieved by varying the ways the horizontal (weft) threads are inserted across the vertical (warp) threads. The technique called supplementary weft is common, evident in the funeral blankets of the Bontoc and the Itneg. Unlike the basic weft, that is woven with the warp threads, the supplementary weft floats over several warp threads, creating a contrast in color and the resulting pattern.

The weaving technique is a contributory factor to the algebraic and geometric structure of the patterns in a given textile.

METHODOLOGY

Mathematical Principles

Symmetry is an underlying mathematical principle for the analysis of a repeated pattern in a textile or fabric. A *symmetry* is an isometry which sends a pattern to itself. *Isometries* are geometric transformations that keep the distance between points unchanged or *invariant*. There are exactly four types of isometries in the plane: translations, rotations, reflections, and glide reflections (Figure 2a-d). A *translation* moves every point of the plane through a fixed distance in a particular direction specified by a given vector. A *reflection* moves every point of the plane to its mirror image about a fixed line called an axis of reflection. A *rotation*, on the other hand, moves every point of the plane through a fixed angle about a fixed point called the center of rotation. A *glide reflection* is a combination of a translation and a reflection, defined by specifying a reflection axis and a translation vector parallel to the axis of reflection.

There are three classes of symmetrical patterns (assuming containing more than the trivial symmetry, an identity isometry) that may be found in textile. A *finite pattern*, for instance, is a repeated pattern that does not admit any translational symmetries. There are two types of finite symmetrical patterns. One that admits only rotational symmetries or one that has both rotation and reflectional symmetries (e.g. see Figure 2e or f, respectively). Symmetric patterns along a strip that have translational symmetries in one direction are called *frieze* patterns. Frieze patterns are usually found in the borders of a cloth. *Plane crystallographic patterns* or *planar patterns* are repeated patterns that have translational symmetries

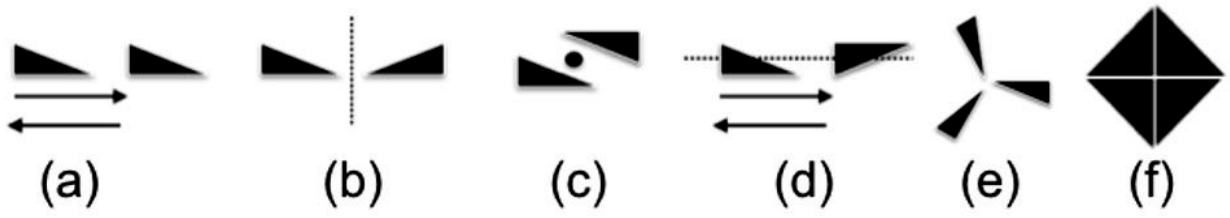

Figure 2. A right triangle with its image/s under: (a) translation (translation vector is shown); (b) vertical reflection (with reflection axis shown); (c) 180° rotation (center is given); (d) a glide reflection (reflection axis and translation vector is shown); (e) 120° and 240° rotations; and (f) 90° rotation and a horizontal reflection.

in two directions. The set consisting of all symmetries of a finite pattern, frieze pattern or a plane crystallographic pattern, form an algebraic structure called a *group* under the operation composition of isometries. This is called the *symmetry group* of the respective pattern. There are seven types of frieze patterns and seventeen types of plane crystallographic patterns known; each is classified based on its symmetry group or the symmetries the pattern admits.

A labeling method to determine the symmetry group of a frieze pattern (called a frieze group) is as follows (Schattschneider 2008). For the first symbol, *m* is assigned if there exists a vertical reflection symmetry, otherwise it is 1. The second symbol is: i) *m*, if there exists a horizontal reflection symmetry; ii) *g*, if there is no horizontal reflection symmetry, but has a glide reflection symmetry; iii) 2, if there is no horizontal reflection symmetry but has a 180° rotational symmetry; or iv) 1, if a horizontal reflection, glide or 180° rotation is not a symmetry. Hence, the seven labels to determine the symmetry group or type of a repeating frieze pattern are *mm*, 1*m*, *mg*, 1*g*, 12, *m*1 and 11. The presence of a horizontal and vertical reflection, with axes that intersect, yields a 180° rotation whose center is the point of intersection of the axes. In which case *mm* is the same as *m*2. Table 1 presents the 7 frieze patterns with their corresponding symmetry groups.

For the symmetry group of a plane crystallographic pattern (called a plane crystallographic group), a naming method is as follows, from left to right (Schattschneider 1978): (1) *p* or *c* to denote a primitive or centered lattice unit; (2) integer *n* to denote the highest order of rotational symmetry present; (3) denotes presence of a symmetry axis normal to the *x*-axis: *m* indicates there is a reflection axis, *g* means a glide reflection axis only, *l* indicates no symmetry axis; (4) denotes there is a symmetry axis at an angle *a* to the *x*-axis: $a = 180^{o}$ for $n = 1$,or 2; $a=45^{o}$ for n=4; $a= 60^{o}$ for n=3 or 6. The symbols *m*,*g*,*l* are interpreted as in (3). For a list of the seventeen types of plane crystallographic patterns along with their symmetry groups, Schattschneider 1978. The reader may also consult Washburn & Crowe (1988), Gallian (2017) for flowcharts and identification algorithms of symmetry groups of frieze and planar patterns.

In this study we classify the repeated patterns appearing in a given funerary textile, whether it is a finite, frieze, or a plane crystallographic/planar pattern based on its respective symmetry group, and the symmetries present. A garment or blanket may contain a finite, frieze or a planar pattern, or a combination of these patterns. Although a frieze pattern technically repeats indefinitely along a line in one direction; or a planar pattern indefinitely in both directions, it is assumed that in a given textile or fabric, only a portion of the pattern is exhibited.

Frieze Pattern	Symmetry group
	mm
	1m
	mg
	1g
	12
	m1
	11

Table 1. The seven frieze patterns.

RESULTS

Common Motifs on a Funerary Textile

Each repeating pattern has a basic unit or *motif*. An application of an isometry, or a combination of the four planar isometries to a motif, gives rise to the repeating pattern. The motif, for example, in each of the frieze patterns in Table 1, is a right triangle.

According to Respicio (1997, 2000) the motifs that appear commonly on a funerary garment from Northern Luzon are the *matmata*, *tiktiko*, *shukyong* (arrowhead or spear) *tinagtagu* (human), *uweg* (snake), and *bituwon* (star). The *tiktiko* and *matmata* (Figure 3) suggest abundance, reverence, and high regard to whatever these stand for. Rice gives the body nourishment and is usually given

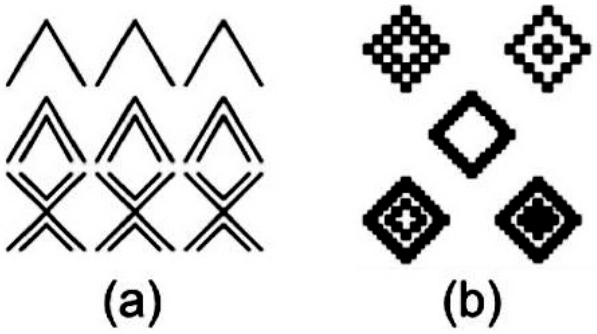

Figure 3. Common motifs on a funerary textile: (a) *tiktiko* and (b) *matmata*.

reverence. As such, the *tiktiko* X is used to represent rice mortars and the double-lined ◊'s *matmata* are perceived to represent rice grains. In certain instances, the *matmata* represent the eyes of the ancestors, who are given utmost respect. The combination of X's *tiktiko* and ◊'s *matmata* are expressive of wealth and abundance; hence, these are designs used exclusively for the clothing material of a deceased belonging to the upper rank or class, referred to as *kachangyan* in the Bontoc community. *Tinagtagu* and *uweg* motifs may be employed in the design to generate good omen on the deceased and his kin. The arrowhead or spear denotes protection from evil.

The use of the motifs and how these are detailed in a garment contribute to a pattern's symmetry group structure as shown in the succeeding discussion.

Our analysis first pertains to funerary garments, followed by funeral blankets or burial shrouds. Under each garment or blanket, a specfic textile is listed by ethnolinguistic group.

Funerary Garments

Bontoc funerary attire. The traditional funeral attire of the Bontoc is dictated by what their predecessors wore in the past. The funeral garments as well as funeral blankets are still produced by elderly weavers, with the traditional designs and colors intact, woven with commercially produced materials available from the local market. As observed in the Omfeg and Samoki villages in Bontoc province during the course of the anthropological fieldwork, the deceased elder from the *kachangyan* class are garbed in complete and elaborate funeral regalia (as opposed to the *pusi* (lower class), who are clothed in plain garments). Women wear a *facho et lamma* (upper garment), a *lufid ay kinain* (skirt), and a *wakes ay inandulo* (belt) (Figures 4a, b & d respectively). While there are many kinds of colorful skirts used by the Bontoc women, for the deceased, the main color is indigo (bluish-black) or black representing darkness or death. For the same reason, black is also the color of the thread used for the friezes and planar pattern adorning the *lamma*. A plain white *wakes* is usually worn above the *lamma*, with no designs. The men, on the other hand, wear an upper garment that is also predominantly black or dark colored (Figure 5a & b). The design of the gauze upper garment is referred to as *finungalawan*, which is symbolic of the wearer's social status and usually depicts a row of human figures alternating with boat-like motifs (Labrador 2013). The *inewes* (e.g. Figure 5b) is draped on the shoulders for a deceased male or female *kachangyan*, or alternatively hanged on the background if the deceased is on a *sangachil* (death chair). A plain wide white *wanes ay inawing* or *chinangta* (loin cloth) (Figure 5c) is usually paired with the upper garment. They would only regard a male *kachangyan* corpse as appropriately attired for the journey to the afterlife when dressed with the *wanes ay inawing* and adorned with the *finungalawan* design. The textile for the lower class is replete of designs, usually with white plain gauze-like cloth.

Figure 4. A representative funeral attire of a Bontoc woman: (a) upper garment; (b) skirt; (c) detail of skirt and; (d) belt.

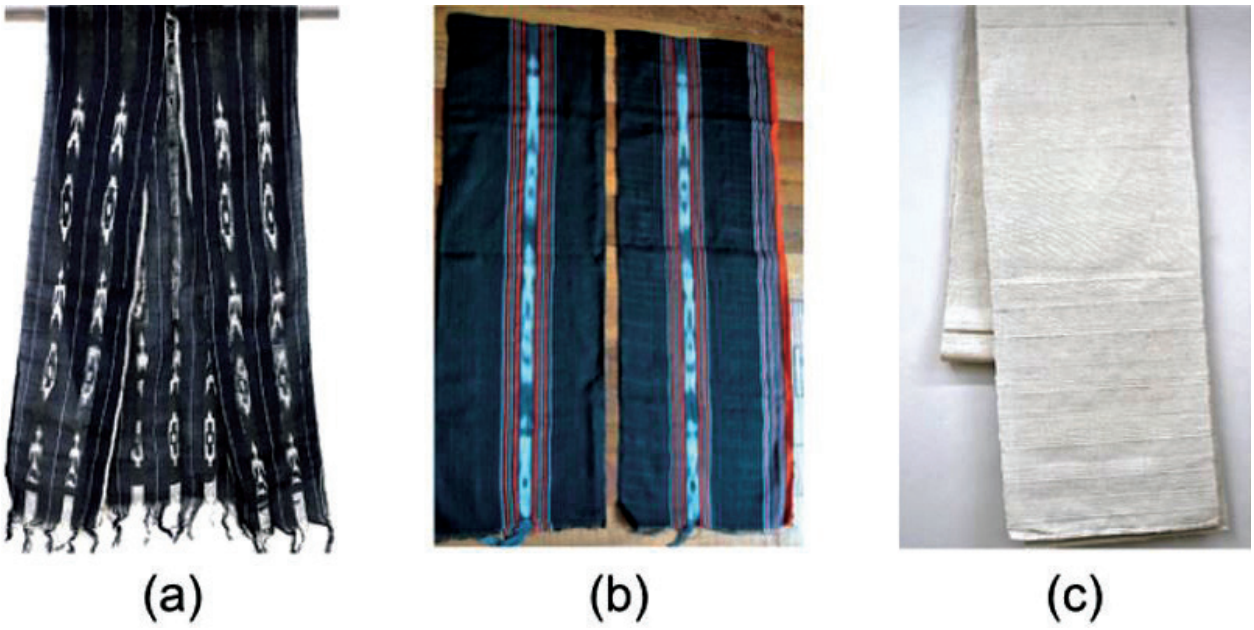

Figure 5. (a)-(b) Upper garments worn by a kachangyan male; (c) loincloth.

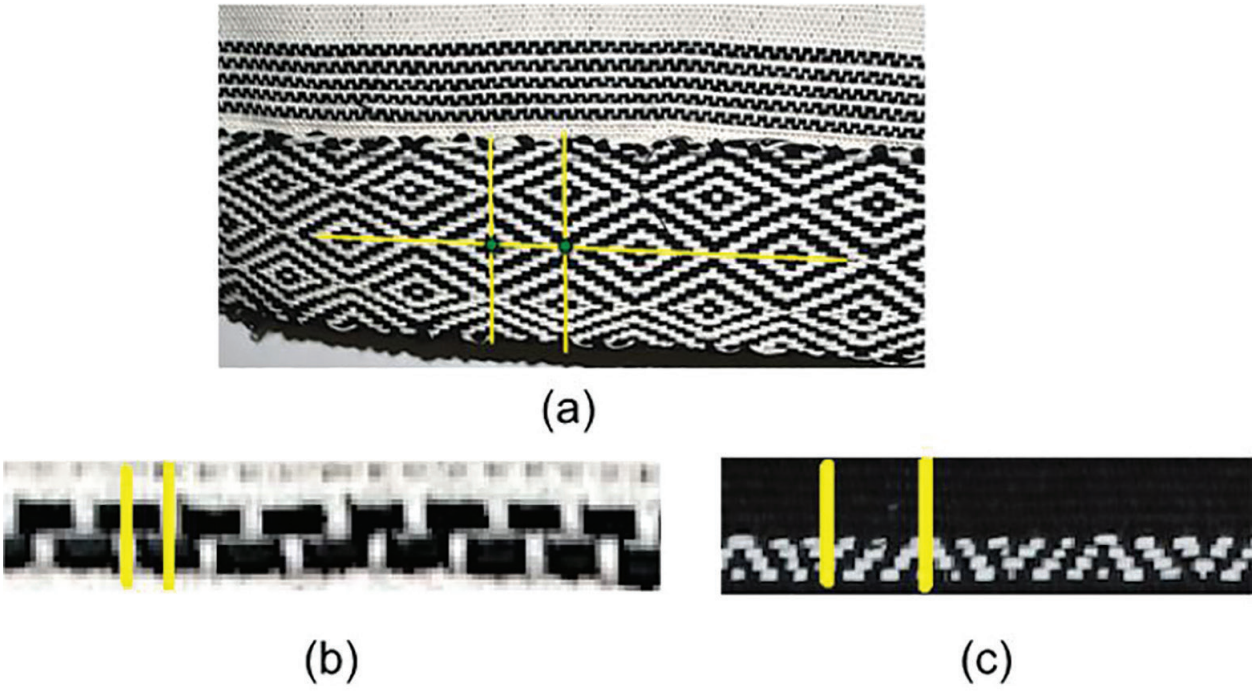

Figure 6. (a) Axes and centers of distinct reflectional and rotational symmetries, respectively of the planar pattern; (b)-(c) axes of distinct reflections of the given frieze.

The planar pattern that appears in the lower portion of the *lamma* shown in Figure 6a is woven with *matmata* designs. It has symmetries consisting of reflections with vertical and horizontal axes and 180° rotations with centers where the reflection axes meet. Its symmetry group is a plane crystallographic group of type *p*2*mm.* A frieze appearing above the planar pattern, and bordering the *lamma* on its sides and sleeves, has symmetry group *m*1. Two distinct reflection axes are shown in Figure 6b. The frieze has no horizontal reflection, glide, or 180° rotational symmetries.

The *kain* has three panels that are joined together. Figure 4c (detail photo) shows there are three frieze patterns woven in white with a *tiktiko* motif, which is assumed to repeat in one direction across the three panels. A frieze pattern has symmetry group *m*1 with reflections and translations as symmetries (Figure 6c). Also evident in the *kain* is a finite design in each panel, made up of a combination of eight yellow *tiktiko* x and seven red *matmata* motifs (Figure 7a). Its symmetries are a 180° rotation about the center of the design, and two reflections with axes that are perpendicular to each other, passing through this center. The other finite design in a panel is made up of fifteen *tiktiko* V motifs (Figure 7b) and has symmetry a reflection with vertical axis cutting through the center of the design.

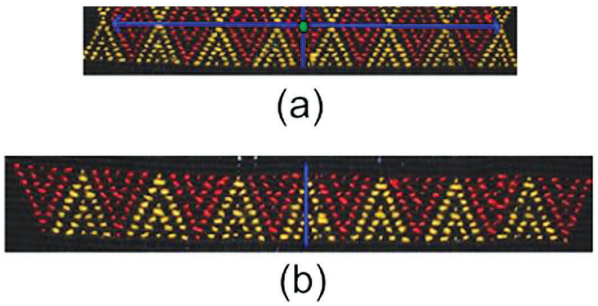

Figure 7. (a) A finite pattern with axes of reflectional symmetries and a center of 180° rotation; (b) a vertical axis of reflection that divides the finite pattern into two.

The *finangulawan* design is a frieze which has a reflectional symmetry, with axis that splits the design into two congruent parts, and translational symmetries. The symmetry group of the frieze is the frieze group 1*m*.

Odd numbers have significance for the Bontoc people. The odd number of *matmata* designs in the skirt (Figure 4c) refers to the number of days accorded to the funeral wake of the deceased, and also indicates the status of the wearer. The *kachangyan* is usually accorded 7 days; the middle class 3-5-days; and the *pusi* or lowest class, one day (Personal communication with Julia Bete, a Bontoc elder). The *chinangta* (Figure 5c) likewise, will have horizontal rows of supplementary warp that number 9, 7, or 5 to indicate, respectively, the status of the wearer: *kachangyan*, middle class, or *pusi*.

Ibaloy headcloth. In death, an *Ibaloy* male is wrapped in a blanket and a headcloth called *salibobo* is worn around the head like a turban. A red and white *salibobo* is shown in Figure 8a with frieze patterns. The symmetry group of a frieze is *mm*. The reflection axes and centers of rotations are shown in Figure 8b, of distinct symmetries.

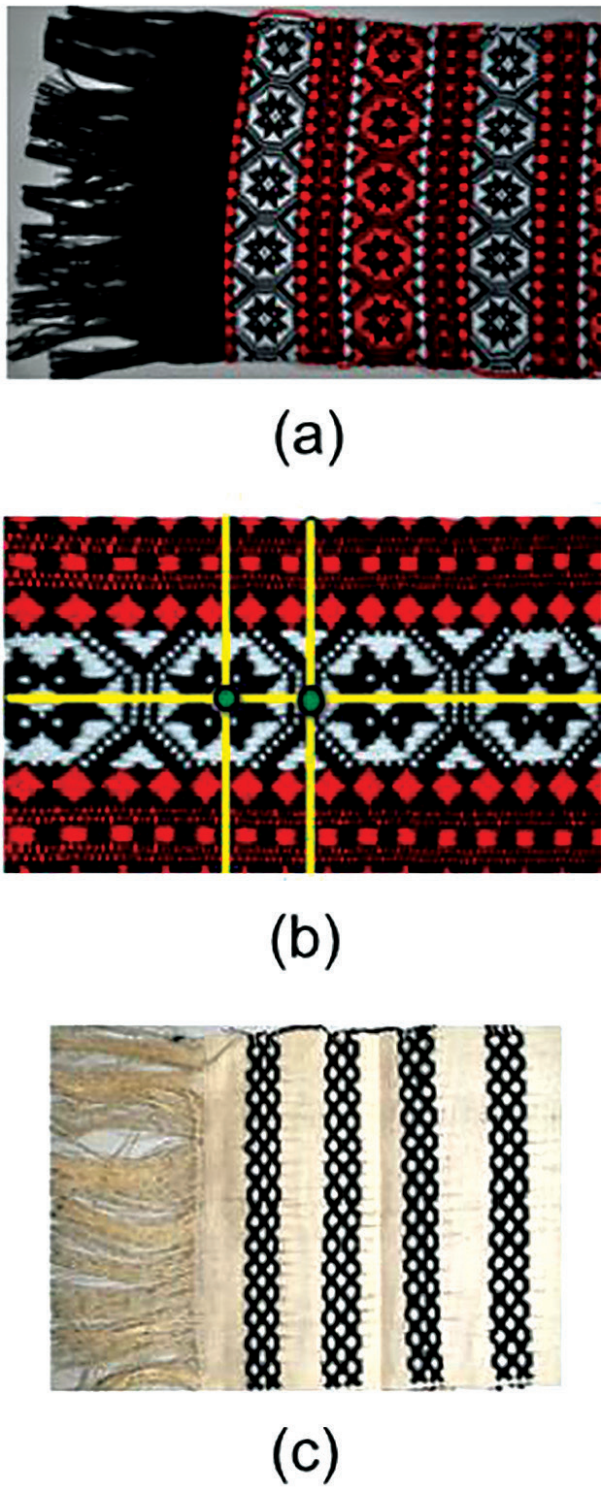

Figure 8. (a) *salibobo*; (b) axes/ centers of distinct reflectional/180° rotational symmetries; (c) bagket.

Ibaloy belt. A belt or sash called the *bagket* is worn by a female Ibaloy and the Kankana-ey speaking communities in Benguet. The belt's design consists of friezes (Figure 8c). A frieze pattern shown has the same type of symmetry group *mm*, as the frieze appearing in Figure 8b. The *bagket*

is also worn with a *lamma*, a blouse that is similar to that of the Bontoc, but with a colorful band of red, green and yellow on the friezes. The *bagket* is woven in Guinzadan, Mt. Province. The proximity of the place and the weaving traditions might have influenced the funerary attire of a particular group.

Funeral Blankets or Burial Shrouds

Blankets are important elements of northern Luzon culture. These are not just used to keep the body warm at night but these are also important artifacts in a funeral rite. It is interesting to note that "cotton textiles on the Cordillera have always been highly prized and have clearly established values based on type, rarity and complexity of designs" (Milgram 1992). As such, the complexity of the designs is given premium to indicate the status and identity of the wearer. If an ancestor had used a particular blanket in the past, the same blanket will be used in death by a descendant. This practice is based on the belief that the deceased is recognized by the spirits of his ancestors when he journeys to the afterlife.

Below are samples of blankets used by the different indigenous communities in Northern Luzon, each highlighting various patterns.

Bontoc

Uwes pinakawha. This elaborately designed blanket used to be wrapped around the deceased. But with the advent of Christianity, this is now usually folded and placed inside the coffin of a deceased *kachangyan.* An example of this blanket, here shown in Figure 9a, has three panels that are stitched together: the *pa-ikid* (side panels), which occupy the upper and lower portions of the blanket and the *pakhawa* (center field) . The blanket as a whole has reflectional symmetries across vertical and horizontal axes, such that its upper and lower halves, as well as its right and left halves, are images of each other.

The *pakhawa* is adorned with a planar pattern consisting of *matmata* motifs and friezes with *tiktiko* $\wedge$ motifs (Figure 9c). The *matmata* done in supplementary weft, are colored white, yellow and green; the white and yellow threads are used to highlight the *bituwon* (stars). The effect is an elaborate star design that appears on both ends of the *pakhawa*, joined together by red woven parallel lines that run through the center. The planar pattern with *matmata* motifs has symmetry group *p*2*mm*. It has reflectional symmetries with axes that intersect at a point which is a center of a 180° rotational symmetry (Figure 10a). The frieze patterns consisting of *tiktiko* $\nearrow$ motifs (Figure 9c) has symmetry group *m*1. Its symmetries consist of reflections with vertical axes passing through the center of each *tiktiko* $\wedge$ and translations. As one can observe from Figure 10c, one of the friezes combine a *tiktiko* $\wedge$ and a double lined *matmata* ◆'s to denote figures of arrowheads or spears, referred to as *shukyong* by the Bontoc, to symbolize protection. However, in some northern Luzon communities these represent the ancestors in the afterlife.

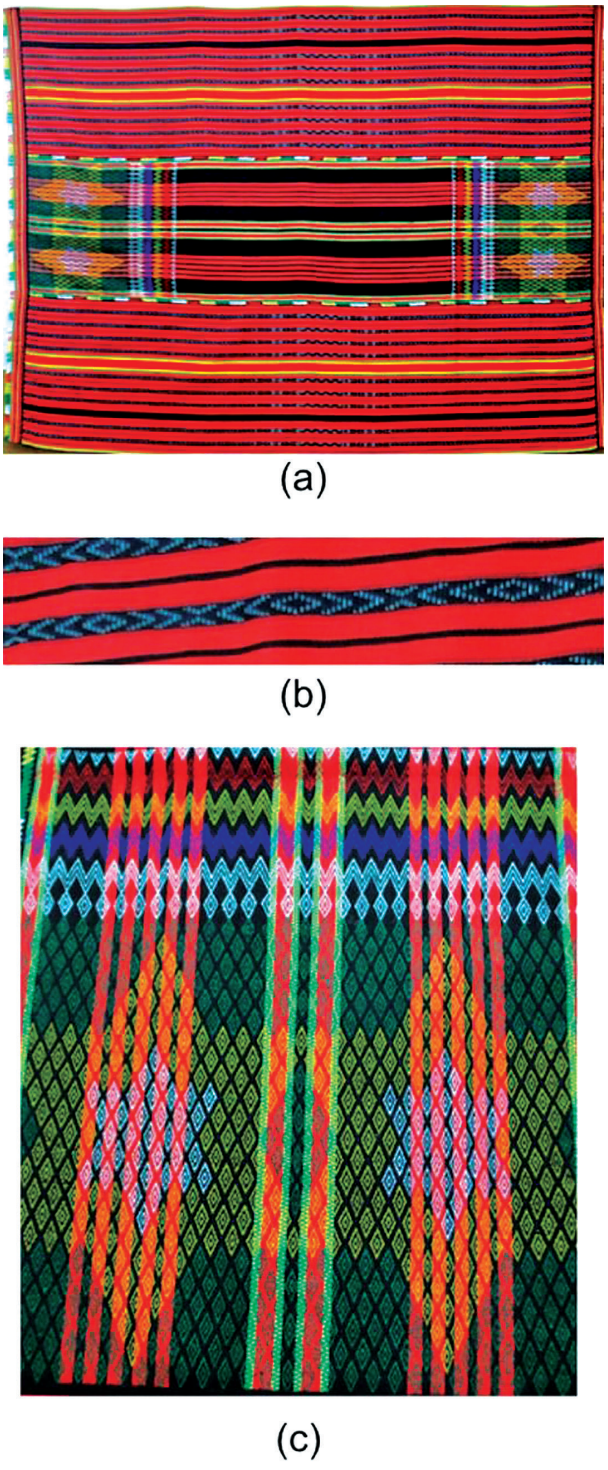

Figure 9. (a) The *uwes pinakawha*;(b) detail of a frieze found in the top and bottom panel; and (c) the *matmata*, tiktiko motifs, and the bituwons, highlighted in yellow and white, appearing in the center field.

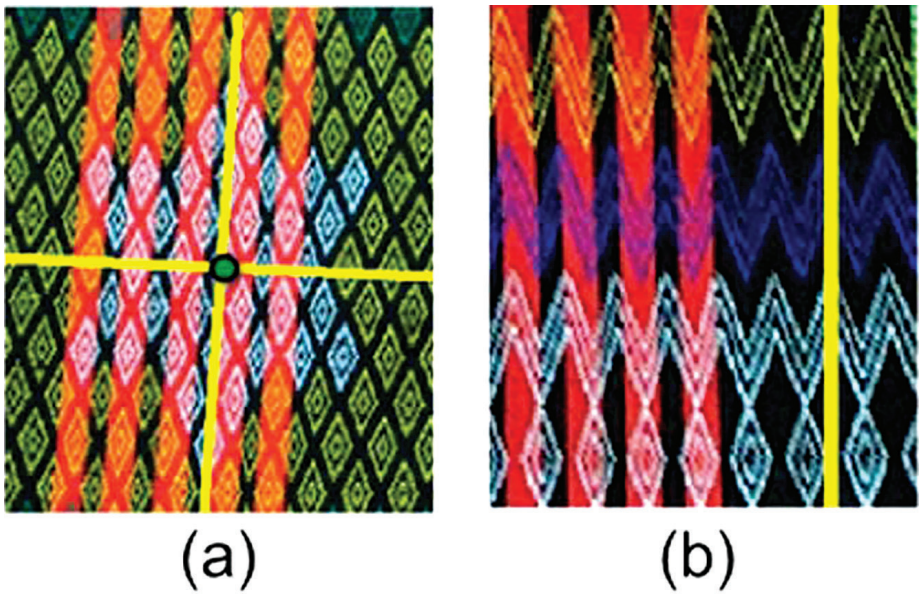

Figure 10. Patterns from the *pakhawa*: (a) planar pattern exhibiting axes of reflections and a center of 180° rotation; (b) friezes with an axis of reflection.

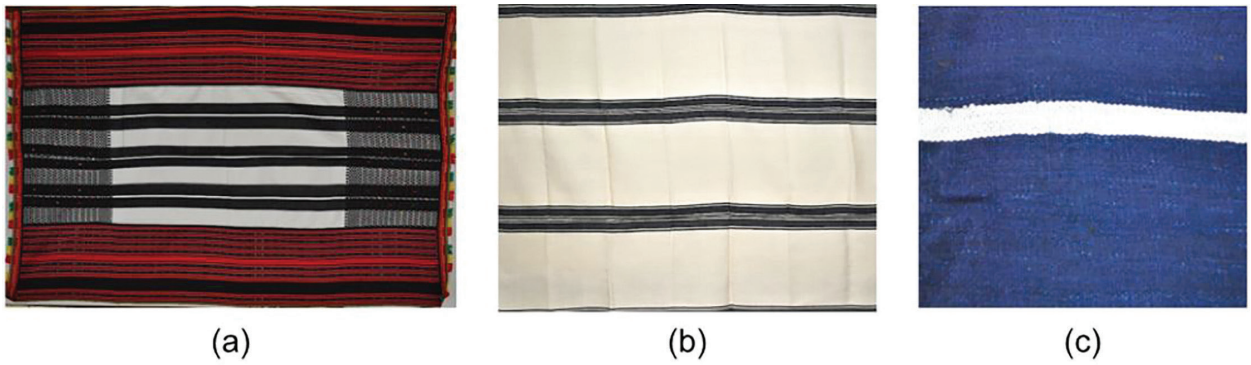

Figure 11.(a) *pinagpagan*; (b) *fanchala* and (c) *fayaong*.

A *pa-ikid* in the blanket is covered with frieze patterns of the same design, consisting of *matmata* and *tiktiko* × motifs (Figure 9b). A frieze has symmetries that include reflections with vertical axes that pass through the center of each × motif and the center of each *matmata*; and a reflection with horizontal axis also passing through the same centers. There are also 180° rotations with centers located at points of intersection of the reflection axes. The symmetry group of the frieze pattern is *mm*.

Pinagpagan. As in the *uwes pinakawha* discussed previously, the *pinagpagan* (Figure 11a) has three panels: an upper and lower panel covered with frieze patterns, and a central panel occupied with three bands. The identifying feature of the *pinagpagan* is the white and black colors at the center. The upper and lower panels are usually a combination of red and black. The dominant design of a frieze pattern (Figure 12a) consists of *matmata* and *tiktiko* × motifs. The frieze has reflectional symmetries with vertical axes that pass through the center of each × motif and the center of each *matmata*; and a horizontal axis also passing through these centers. There are also 180° rotational symmetries about these centers. In this case, the weaver introduces what is referred to as a "symmetry breaking" when she breaks the translational symmetry of the *matmata* and *tiktiko* motifs, by introducing images of a snake and a human figure. The depiction of a snake following a human is common to denote good omen or luck both for the living relations of the deceased. As Labrador (1998) elaborates, the manifestation of the deceased ancestor is a snake that brings good providence to the family of the deceased: good fortune, well-being and smooth interpersonal relations within the kin. This representation appears in other blankets around the northern Luzon community, see for instance the blanket from the Ibaloy shown in Figure 16.

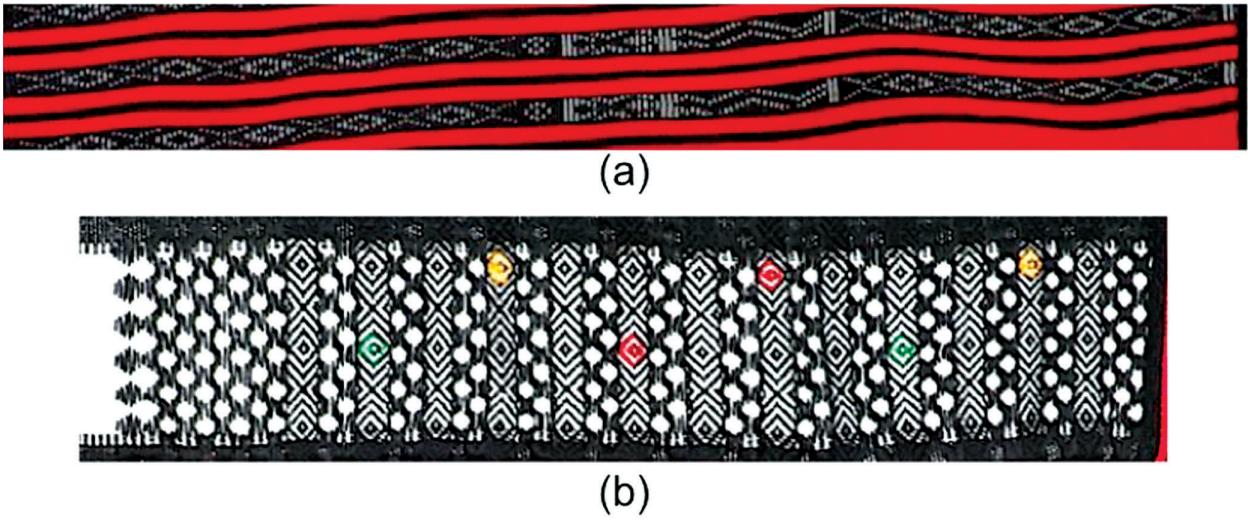

Figure 12. (a) Detail of a frieze pattern on the pinagpagan with matmata and tiktiko motifs; and a snake following a human figure; (b) thirteen frieze patterns on both sides of the central panel of the pinagpagan.

The middle part of the *pinagpagan* has a white background with three pairs of black bands. On both ends of the black panels are adorned thirteen frieze patterns, aligned vertically, (Figure 12 b), consisting of *matmata* and *tiktiko* × motifs. Each frieze pattern has reflections and 180° rotational symmetries with axes and centers positioned in the same manner as the horizontal frieze patterns described earlier. The symmetry group of each frieze pattern is *mm*. The intentional use of colored thread for the *matmata*, called *pud-ok*, found in a given frieze, signifies light, "a guiding light" or the "eyes of the ancestors" as one journeys to the afterlife. To the left of the vertical frieze patterns are figures of arrowheads or spears, also found in the *uwes pinakawha* presented earlier.

Fanchala. These blankets do not have repeating patterns; instead, black bands/lines run in parallel across the blankets (e.g Figure 11b). These black lines indicate the number of days for the funeral wake and the rank. There are blankets with five, three, or one band. Although a *fanchala* with one band is used by the *pusi*, a *kachangyan* may be wrapped with this blanket as an outer covering alongside other blankets.

Fayaong. The *fayaong* is usually blue with a white band running across the blanket, and with no repeating patterns or designs (Figure 11c). In Ibaloy communities, this blanket with similar pattern is also known as *kinteg*. Along with layered blankets, and the *fanchala,* the *fayaong* is also wrapped as the final layer for the *kachangyan* in some instances. Respicio (1997) has noted the variety of funerary textiles used for the different social classes in Bontoc society.

Itneg

Binakul. There are features of funerary blankets whose designs or patterns are meant to confuse the malevolent spirits in exacting misfortune to the deceased and their families. One such example is the *kusikus* or whirlwind design, a common feature in the blankets among the Itneg (Figure 13b). This results from a special kind of weaving technique called the *binakul*, where the arrangement of negative and positive colored threads in the form of graduated rectangles emanating from a central rectangle (Figure 13a) provide the illusion of movement, as of a whirlwind. These motifs are repeated horizontally and vertically at the same distance and fill up the plane. The result is an illusion of swirling circles or ripples. The *kusikus* pattern has 180 rotational symmetries about the center of each central rectangle. Reflectional symmetries have axes that are perpendicular to each other and that also intersect at a center of 180° rotation (Figure 13a). The symmetry group of the planar pattern is of type *p2mm.*

Dinapat. The term *dinapat* denotes "full or total", referring to the design that fills up the whole blanket. The *dinapat* blanket in Figure 13c has motifs that include human figures horses, carabao calves, and large deer. Symbolically, all these are taken by the deceased to the afterlife. This blanket is reserved for the upper class and used in ceremonies to cover the dead. The top and lower halves of the blanket are images of each other under a reflection, with horizontal axis passing through the center of the blanket. In similar fashion, the left and right halves of the blanket go to each other under a reflectional symmetry with vertical axis also passing through the center.

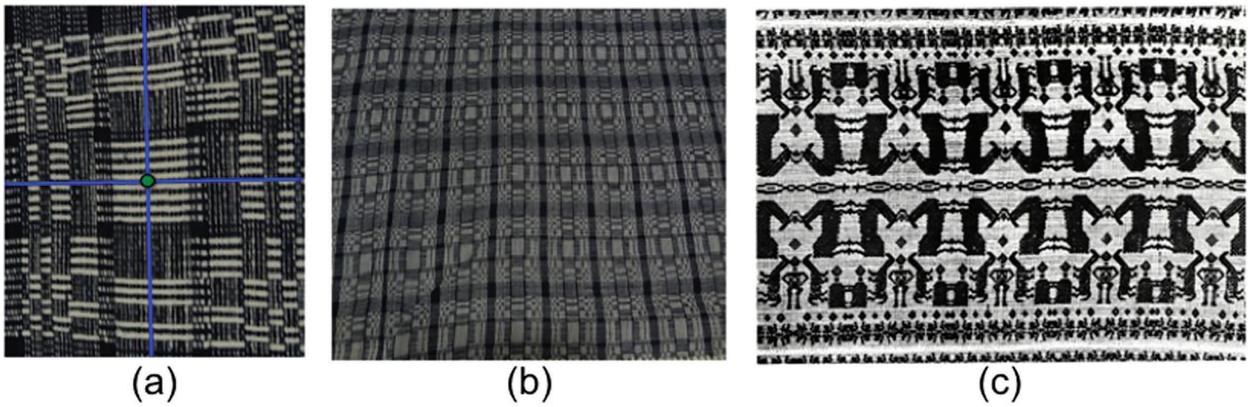

Figure 13. (a) Reflection axes, center of 180° rotation positioned at a central rectangle;(b) blanket with a *kusikus* pattern, from the Floy Quintos collection and (c) *dinapat* blanket (photo courtesy of Rubinstein).

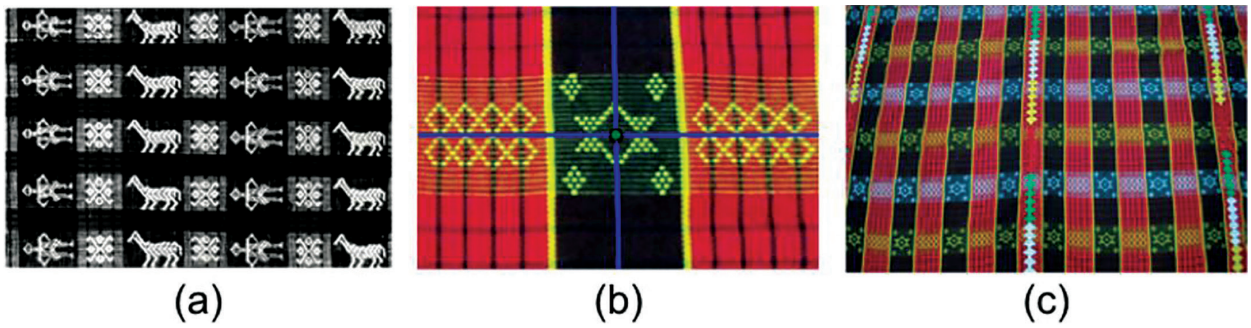

Figure 14. (a) *Pinilian*; (b) Reflection axes and center of 180° rotation positioned at a *bituwon*; (c) a *sinanbituwon* blanket.

Pinilian. The Itneg blanket shown in Figure 14a, displaying figures of human forms, horses and warp-frame designs is a sample of what was used in the olden times to announce deaths. Notice that the human form is lying down while the horse is upright. Whenever one dies, his blanket is mounted on his horse, and his horse was set loose to gallop around the neighboring village to announce that the horse's owner passed away (Cole 1922). The design in this blanket, woven using the *pinilian* technique, is achieved by varying the ways the horizontal (weft) threads are inserted across the vertical (warp) threads. Each weft pattern "floats" from left to right at repeated intervals. The result is a planar pattern with translational symmetries in two directions. Its symmetry group is a plane crystallographic group of type *p*1. There are no rotations, reflections, or glide reflection symmetries.

Kalinga

Sinanbituwon. This funerary blanket is intended for the most affluent in northern and southern Kalinga. A *bituwon* or star is its dominant motif. Stars are believed to be the guide for the deceased elderly as he journeys into the afterlife. It is only the upper class that can wear the *sinanbituwon*. The plane crystallographic pattern that makes up a panel in the *sinanbituwon* blanket shown in Figure 14b has symmetry group *p*2*mm*. The reflection axes meet at the center of a *bituwon*, which coincides with a center of 180° rotation (Figure 14a).

Binaliwon. The *binaliwon* is the customary blanket used to wrap the dead in southern Kalinga, used by the middle and poor classes. Alternatively, it is folded and used as a pillow inside the coffin. It has a deep connection with the spirit of the *achogwa* or spirit of the dead (Shedden 2009). Aside from the blanket being used to wrap the deceased, the widow or the widower during the funeral sits or lies in a corner of the room, hiding under the blanket to keep out of sight of the *achogwa*. Alternatively, a *binaliwon* could be strung up partitioning off a corner of the room where the surviving spouse would remain concealed from their partner's *achogwa* until the coffin is taken outside for entombment.

The *binaliwon*'s design is not as elaborate as the *sinabituwon* blanket. A typical *binaliwon* blanket is presented in Figure 15b and shows parallel lines with bright colors red, green, and yellow, alternating with frieze patterns of black and white. A closer view of the frieze pattern (Figure 15a) shows the presence of reflection symmetries with axes shown. The frieze pattern is of symmetry type *mm*.

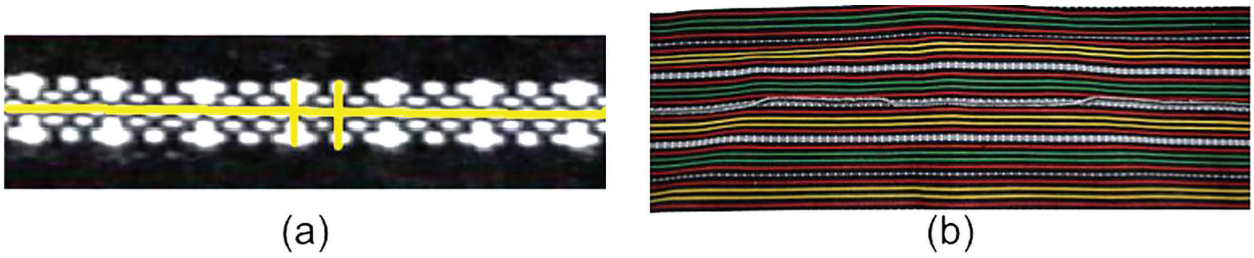

Figure 15. (a) vertical and horizontal reflection axes on a frieze pattern; (b) a *binaliwon* blanket.

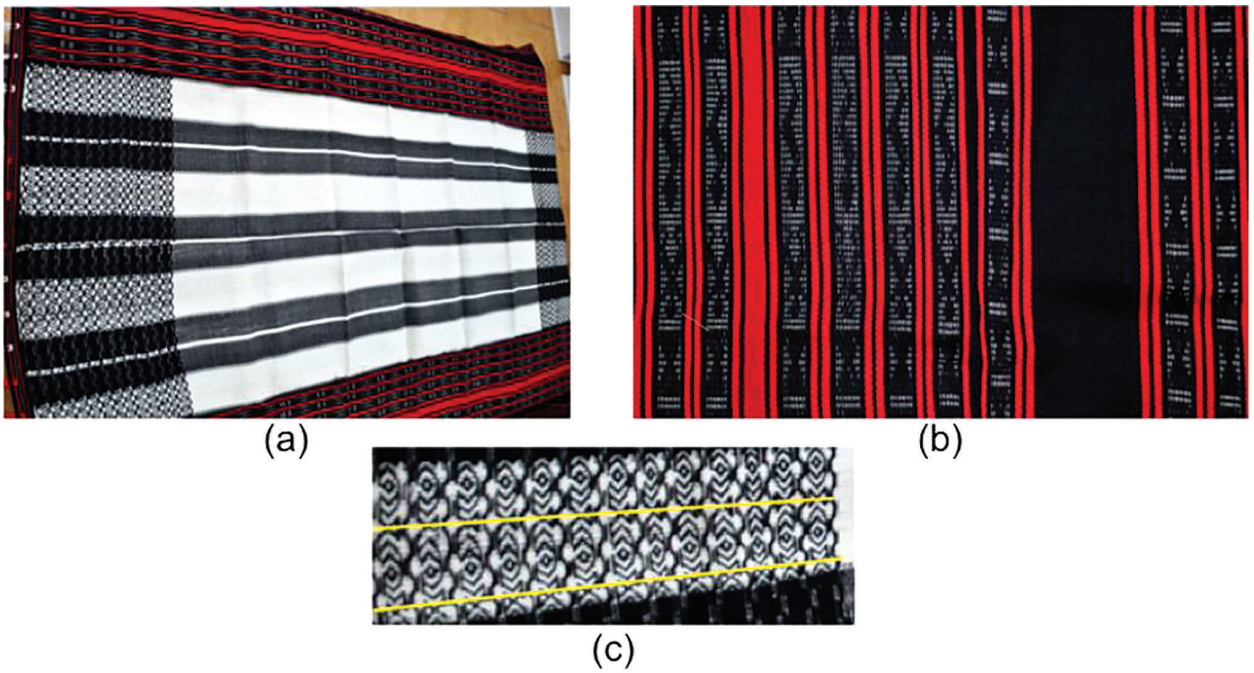

Figure 16. (a) *Dil-e* blanket; (b) frieze patterns on a *kuabaw* and (c) planar pattern on the *Dil-e* with axes of reflectional symmetry.

Ibaloy

Kuabaw. This blanket is used by the *baknang* (upper rank) among the Ibaloy. This is decorated with designs that represent men, snakes, mortar, or shields. An example is the blanket colored red, grey, and black presented in Figure 16b adorned with frieze patterns. A frieze pattern has mortars (X) as motifs and has symmetry group *mm* with vertical and horizontal reflectional symmetries. A "symmetry breaking" of the translational symmetries occur in some friezes with the introduction of the snake following a human, again, to suggest good omen.

Dil-e. A representative blanket, shown in Figure 16a, resembles a *pinagpagan* of the Bontoc. It has an upper and lower panel consisting of frieze patterns. The central panel exhibits three pairs of black bands that run across a white background with a planar pattern on the weft consisting of a variant of the *matmata* (Figure 16c). This blanket, however, does not have the *pud-ok* (eyes) of varying colors found in the *pinagpagan.* A frieze pattern, with human motifs, has symmetry group *mm*. Meanwhile, the symmetry group of the planar pattern is of type *pm*. Reflection axes are shown in Figure 16c. There is no rotational symmetry, nor a glide symmetry for the planar pattern.

Aladdang. Among the Ibaloy and Kankana-ey speaking communities of Benguet, the highest funerary blanket accorded to the affluent deceased is the ikat-dyed *aladdang* (Ibaloy) and also called as *adashang,* (Kankana-ey) previously woven by the Isinays in Dupax del Sur, Nueva Vizcaya. The blanket in Figure 17 is called *aladdang sinikwit.* It is a woven blanket made in Guinzadan, Mt. Province, a prominent northern Kankana-ey town. This is made of four panels with woven red and white vertical stripes with geometric patterns, and with discontinuous supplementary weft "float" design elements, interestingly spaced over a dark background on both faces of the fabric (Conklin 1998). The overall pattern is modeled from the warp-ikat shrouds of the Isinay called the *uwes pinutuan* (Galang 1935; Kron-Steinhart 1991; Salvador-Amores

Figure 17. The highest funerary blanket among the Ibaloy

2015). There are two reflection symmetries with vertical and horizontal axes that intersect at the center of the pattern, which is a center of a 180° rotational symmetry.

CONCLUSION AND RECOMMENDATION

In this paper, a representative sample of funerary textiles from Northern Luzon has been examined. These textiles embody social relations among family, community and the ancestral spirits. It is understood that the weavers involve an enormous amount of energy in the preparation of the funerary blankets, and so do the family of the deceased in wrapping the dead.

Symmetry analysis of the patterns in each textile showed that the patterns almost always contain reflection symmetries. The finite patterns have reflections about a horizontal or vertical axis, or both. In almost all the funeral blankets, the horizontal and vertical axes divide the blanket respectively into an upper and a lower half or a left and right side, that are images of each other. For a given frieze pattern in a cloth, three symmetry groups frequently occurred, the groups 1*m*, *m*1, or *mm*. Moreover, for a plane crystallographic pattern, the symmetry group is either *p*2*mm* or *pm*. A primary reason is due to the motifs present in the pattern. Each motif was chosen by the weaver to satisfy particular custom and beliefs related to death and burial rituals. The combination of the various motifs, and how these are laid out in the textile obeying laws of mathematical symmetry and order, contribute largely to the symmetry structure of each repeating pattern.

The geometric quality of the patterns in the textile is evidence of the clarity and exactness of the weaver's mind. It takes mathematical calculation to weave cloth on a backstrap loom and mathematical ingenuity to create complex geometric patterns. Each design demonstrates the weaver's ability to fuse horizontal and vertical elements of the warp and the weft to arrive at a pattern illustrating various concepts of mathematical symmetry. In the *pinagpagan* blankets, the weaver incorporated the notion of a "symmetry breaking" where there is a change in the design element by introducing new motifs. This highlights the weaver's skill in bringing non-symmetric elements to the design by incorporating abrupt changes in the warp and weft configuration. Weavers themselves recognize that the production of these textiles requires specialized knowledge and that possessing the skill brings honor to the artisan.

This paper presents a model on how mathematics, particularly group theory, mathematical crystallography, and symmetry analysis, can be used as a framework to systematically describe and compare discrete material cultural phenomena (textile motifs), which can be challenging to analyze. It contributes to the growing

body of literature that uses mathematics to enhance interpretation of a culture from its artwork.

The next step of the study would be to do a symmetry analysis of textile from other indigenous communities in the Philippines such as the Bagobo, Mandaya, T'boli, and Bilaan in Southeastern Mindanao and the Muslim peoples of Southern Mindanao and the Sulu Archipelago. The end goal is to be able to classify and characterize the patterns coming from each indigenous community by their corresponding symmetry structures. The question as to which of the 17 plane crystallographic groups and 7 frieze groups are present in textile coming from a particular community is interesting to consider. A comparison of the textile by the presence or absence of these groups, or by the frequency of their occurrence, might give information about relations between cultures. For the same purpose, the study can be extended to textile coming from our Southeast Asian neighbors, such as Malaysia, Indonesia, among others.

A significance of this work for a mathematician is that the patterns in the textile serve as a realization of the existence of abstract symmetry groups. Moreover, an important implication of understanding the mathematical principles behind the creation of these patterns in textile is to use these works of art as stimulating starting points for interdisciplinary investigations. This can lead students to the exploration and the reinforcement of geometric concepts alongside their study of history, social studies, and Philippine culture. Students will appreciate that many underlying geometric principles have corollaries in the real world.

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