Original Article

# Analysis Of Crystallographic Patterns Of Iban Pua Kumbu

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## Abstract

One of the famous traditional textiles in Sarawak is the Iban Pua Kumbu. This paper presents the crystallographic patterns, geometry concept and symmetry analysis present in the Iban Pua Kumbu patterns. This paper will also look at the colour-symmetrical patterns and motifs used in these textiles. The Ibans' weaving technique subtly incorporates geometric concepts using exquisite and precious designs. The Pua Kumbu of the Iban can be similarly classified according to the patterns displayed in the wallpaper and frieze. The current research findings could assist students to learn mathematics. In this study, samples comprising eight (8) repeated patterns were collected from field visits, museums in the Sarawak, and personal collections of scholars. From the findings, it shows that all Pua Kumbu patterns bear at least one of the seventeen crystallographic groups. Most of the Pua Kumbu motifs are symmetrical and those motifs is mathematically identified as a design. The Pua Kumbu contains decorative patterns whose relevance and imaginative portrayal are demonstrated by the intricacy of the creative process. Pua Kumbu weavers appear to have excellent memory skills, strong visual perception, and an innate aptitude for applying mathematics to their work.

**Keywords:** Pua Kumbu, weaving, mathematical concepts, crystallographic patterns, geometry, symmetry analysis

## 1. Introduction

The current study aims to determine the sets of symmetries and metrics in the Iban Pua Kumbu patterns by analysing a sample that represented the concept. In the developing context of today, examinations of culture occur from the standpoints of many fields of learning, from history to mathematics. The talent and selection of motifs, as well as how they express the meaning behind the crafts, contribute to the distinctiveness of traditional Iban Pua Kumbu weaving. Crystallographic patterns were then utilised to analyse the Pua Kumbu motifs. Analytical research has shown that Pua Kumbu designs employ transformational geometrical shapes in the frieze (Truna et al., 2021). This paper examines the geometrical concepts that have been represented as various flora and fauna motifs.

The objective of this study is to examine a collection that was broadly representative of the variety of symmetries seen in Iban Pua Kumbu. Additionally, this study will analyse the colour-symmetrical designs and patterns found in Pua Kumbu textiles. In this study, numerous fundamental mathematical concepts are identified together with the mathematical thought processes of those involved in the Pua Kumbu weaving process.

### *1.1.* Relationship between Art and Mathematics

Mathematical concepts have been used to create a variety of works of art. Art can graphically communicate the phenomena of complicated mathematical concepts to a broad audience, allowing people to comprehend what is around them or even inside them (Nimkulrat & Matthews, 2013). Within the scope of textile art and design, advancements in textile design seem to have mathematical influences. Also, mathematicians have recognised the potential for textiles to represent mathematical concepts. To illustrate proof of mathematical concept, a complicated mathematical idea can be converted into a physical textile design. Mathematicians frequently employ textile techniques, such as crocheting, knitting, and weaving, to explore and express a wide range of mathematical concepts (Nimkulrat & Nurmi, 2019).

The symmetries of a finite design or repetitive pattern in a cultural adornment, such as a textile, are studied mathematically. Symmetries within particular designs and patterns are known as plane isometries (translational, rotational, reflectional, or glide reflectional). The plane transformation preserves the distance and involves the transfer of discrete designs or repeating patterns onto the plane itself (De Las Peñas et al., 2018). As Vasqueza et al. (2020) outlined, the variety of textiles woven in La Paz and San Juan display novel patterns in which the utilisation of symmetry analysis is described, thus causing the patterns to reveal how beautiful they are. Symmetry is a mathematical theory that can be used to analyse a repetitive pattern in a textile or fabric. It also investigates how components of a pattern are repeated to complete the pattern as a whole (Vasqueza et al., 2020).

Osinga and Krauskopf (2014) revealed that the Lorenz Manifold's features are conveyed plainly through a crochet item constructed from its computer-generated graphics. Meanwhile, Taimina (2018) illustrates hyperbolic geometry with crocheted objects. Harris (1988) investigates the mathematical content of several textile activities and shows how learning textile crafts can help students improve their arithmetic skills. In the author's work, textiles were utilised so that visible, touchable, and three-dimensional concepts of mathematics could be illustrated. These included symmetrical shapes, pairings, patterned effects, and tension, as well as the set, lattice, net, and solid. The symmetry of the pattern is also used to classify frieze and plane patterns. Frieze patterns have seven symmetry group types called frieze groups, while plane patterns have 17 symmetry group types called plane groups (De Las Peñas et al., 2018).

### *1.2.* The Iban Ethnic and Pua Kumbu Weaving in Sarawak

The major ethnic groups in the state of Sarawak are the communities of Ibans, Bidayuhs, and Orang Ulus, and they live distinctively in the different types of longhouses. Since the Middle Paleolithic era, the anthropologist and archaeologist findings have demonstrated the existence of human inhabitants in the Borneo Island—the third largest island in the world—which is in Niah Cave, Miri, Sarawak. The tools found in the aforementioned cave were the main evidence, and these indicate the existence of humans in that area (Kanyan & Zainurul, 2015).

From a historical perspective, Borneo is home to the communities of the Iban or Sea Dayak, who were nomadic and had the reputation of being brave and courageous. This was due to their widespread recognition as fearsome fighting men who engaged in headhunting (Sim & Khan, 2014). 'Borneo Wildman' or 'Headhunter' was the title given to the Iban tribe, and their characteristic as nomads or wanderers was the concept adapted from the activity they do, berjalai (going on a journey).

Kiyai and Tugang (2019) stated that the Iban tribe forms 30% of the state's population of 2.5 million, which is also the largest ethnic group in Sarawak. They are known as Sea Dayak because of their settlement during that time, which was next to rivers and their skills in handling boats. Although the modern Iban community has embraced Christianity, the old belief is still practiced and worshipped until now. For example, Iban people traditionally have beliefs in the spirit of Singalang Burung, which means the bird-god of war (Kiyai & Tugang, 2019).

These people live in the thick jungle to ensure their lifestyle, culture, belief celebration, and social regulation will be sustained to maintain the harmony in the community. Over the years of modernisation and social changes, the Iban community slowly came out from the jungle to the civilised community to be in line with the world development (Ahmad & Ramli, 1997). In Iban society, a collective belief that they are a major tribe and survivors exists; in historical times, they would take any action necessary to safeguard their culture and traditions (Sim & Khan, 2014).

The roles of design motifs applied on the Sarawak Iban's Pua Kumbu to function as a platform in transmitting the knowledge and identity of the Iban community among the locals and the international community are hindered by knowledge gaps. This opinion is supported by Magiman et al. (2018), who asserted that the establishment of documentation is a significant effort to preserve the culture from extinction and to keep the culture alive. The Pua Kumbu represents a non-physical form of this ethnic group's customs that both express their culture and illustrate how valuable knowledge and skills can be passed down inter-generationally. According to Kiyai and Tugang (2019), rather than being the duty of a single individual, everyone is responsible for safeguarding for posterity and transferring the customs and beliefs of every culture.

The majority of Pua Kumbu studies have been produced by bloggers for their own or general use; the topic has received little academic attention. This may be due to the need to tacitly and verbally communicate with Pua Kumbu as a form of knowledge. Observing the practice or having it demonstrated are the only ways to learn how to accomplish it. The basis for the motifs in the Pua Kumbu designs especially is retained in a collectively remembered knowledge domain. Through this, the knowledge and history of the Pua Kumbu are conserved (Jehom, 2016). Traditionally, costumes made of Pua Kumbu are used to create sacred space at ceremonies and festivals. Iban rituals employ Pua Kumbu cloth, which can also be fashioned into ceremonial garments, as shown in Figs. 1 and 2.

**Fig. 1:** Custom-made women cloth from Pua Kumbu

**Fig. 2:** Custom-made men cloth from Pua Kumbu

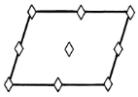
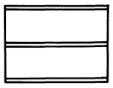
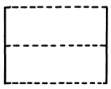
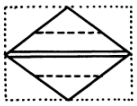
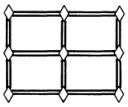
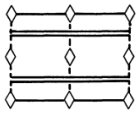
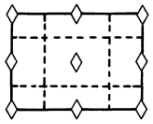
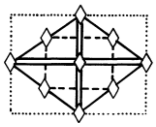
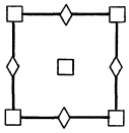
### *1.3.* Crystallographic Patterns

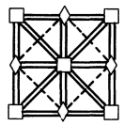
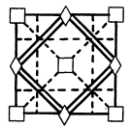
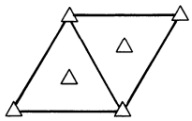
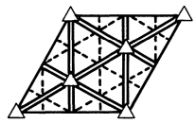
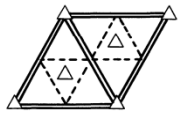
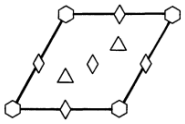
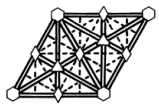
Generally, people usually knew about geometric patterns. For some people, they consider it sufficient enough for a pattern to be constructed from geometric elements, though they don't have to be related geometrically. Crystallographers in the 19$^{th}$ century were the first to study discrete plane symmetry groups, finding 17 of these, which are generally referred to as plane crystallographic groups. It is possible to identify the association between particular periodic patterns and the 17 plane symmetry groups using these groups (Joseph A. Gallian, 2013).

Crystallographic patterns (CPs), which differ greatly from the majority of patterns, are a key aspect of research into crystals. Rigid crystal-containing bodies arrange themselves in three-way recurring patterns. CPs are constructed according to the same principles of crystal formation. It is possible to identify such a pattern through the particular plane crystallographic (wallpaper) group (one of the 17) as an extra type of discrete plane symmetry group that arises from plane designs that repeat infinitely. Therefore, these patterns do not vary, with a linear connection being found between two translations that have linear independence (Kartika et al., 2022).

For crystallographic groups or wallpaper groups, the numerous translation directions force the pattern to cover the entire infinite plane compared to the frieze groups. Multiple parts of a wallpaper group are important to represent the translation symmetry, which is used to broaden the entire plane. Generally, sufficient patterns must be drawn to obtain clear translation symmetries in crystallographic groups. The lattice of translations is the collection of all translated images of a point in crystallographic groups. A point in the figure is chosen to mark the point of the lattice of translations. Then, all translations of that point will be marked and unmarked reflected or rotated versions of the point (Schattschneider, 1978). Connecting points adjacent with edges result in a grid or lattice structure, depending on which

points, will be chosen to be connected and but it is not usually shown. The Pua Kumbu's embedded patterns can be identified by the various patterns on crystallographic wallpaper, short forms, and notations, which are presented in Fig. 3.

| Figure | Short Form and Notation | Description (Lattice/Rotation/Reflection) |
|---|---|---|
|  | p1<br>p1 | Parallelogram/None/None |
|  | p2<br>p211 | Parallelogram/2/None |
|  | pm<br>p1m1 | Rectangle/None/Parallel |
|  | pg<br>p1g1 | Rectangle/None/None |
|  | cm<br>c1m1 | Rhombus/None/Parallel |
|  | pmm<br>p2mm | Rectangle/2/90 degree |
|  | pmg<br>p2mg | Rectangle/2/Parallel |
|  | pgg<br>p2gg | Rectangle/2/None |
|  | cmm<br>c2mm | Rhombus/2/90 degree |
|  | p4<br>p4 | Square/4/None |

| | | |
|---|---|---|
|  | p4m<br>p4mm | Square/4 +/None |
|  | p4g<br>p4gm | Square/4 */45 degrees |
|  | p3<br>p3 | Hexagon/3/None |
|  | p3m1<br>p3m1 | Hexagon/3 +/30 degrees |
|  | p31m<br>p31m | Hexagon/3 */60 degrees |
|  | p6<br>p6 | Hexagon/6/none |
|  | p6m<br>p6m | Hexagon/6/30 degrees |

**Centers of Rotation:**

2-fold

3-fold

4-fold

6-fold

Axis of reflection

Axis of glide-reflection

Outline of lattice unit

Outline of 'centered cell'

**Fig. 3:** Figure, short form, and notation for seventeen (17) crystallographic groups (Schattschneider, 1978)

Fig. 4 shows the flowchart to classify particular plane periodic patterns based on 17 types of crystallographic groups. To achieve this, the rotational symmetry needs to be determined, as well as the type of symmetry found in the pattern, which could be nontrivial glide-reflection or reflection.

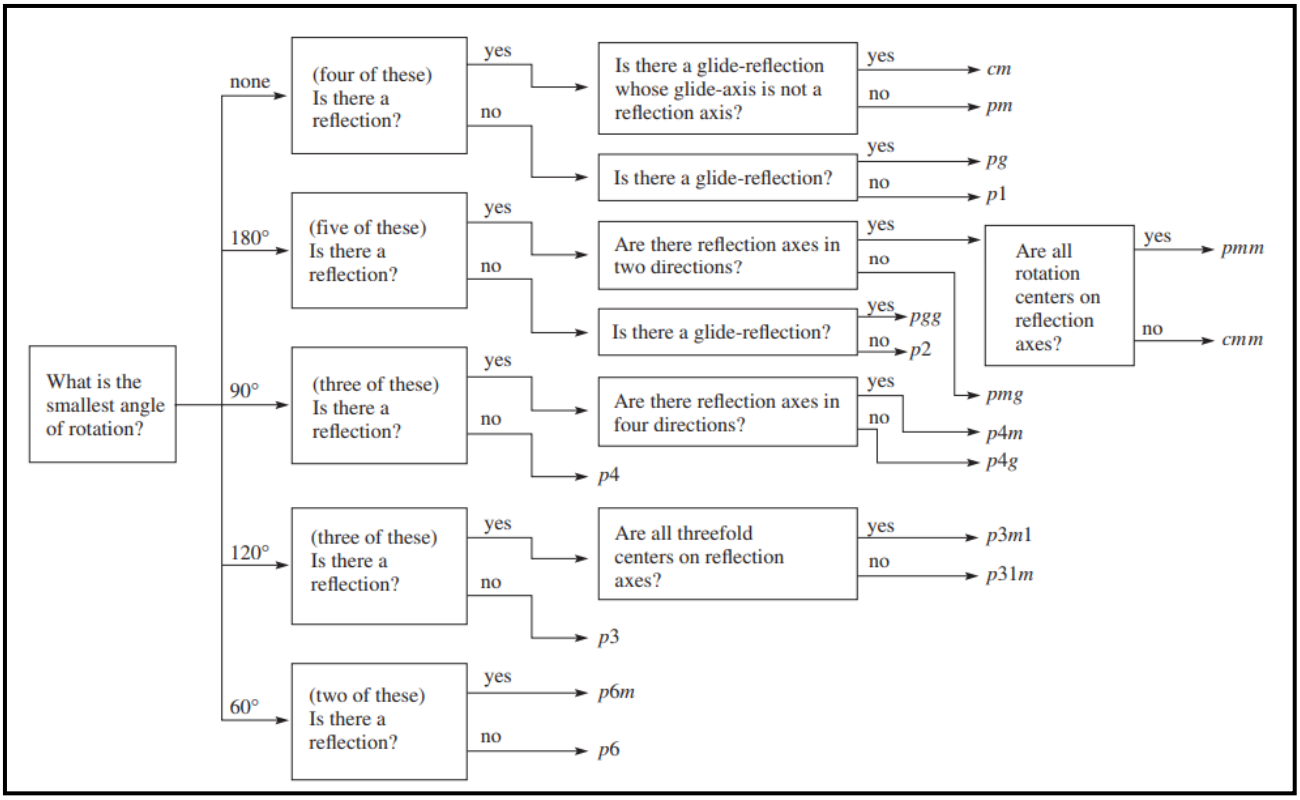



**Fig. 4:** Flow chart information to classify the patterns based on seventeen (17) crystallographic groups (Joseph A. Gallian, 2013).

## 2. Literature Review

### *2.1.* The Birth of Crystallography

Crystallography is a scientific discipline of the properties and structure of crystals. Since the earliest days of crystallography until its most recent developments, scientists from many disciplines have been involved, including physicists, chemists, materials scientists, geologists, biologists, pharmacists, and medical experts. Thus, a prospective crystallographer could have been trained in one of numerous disciplines. Crystallography is also seen as a basis of reference used in the field of art and architecture. Atomic structural knowledge and research undertaken on crystals indicates that atoms have common internal components. Crystals can appear to contain natural artistry due to the substantial complexity with which the atom and molecule order is arranged in the crystals. Artistically minded individuals can become inspired to create pieces with a natural appearance. The cognitive foundation from which the descriptive morphological characteristics and structural categorisation of natural objects are obtained can be provided by crystallisation and crystal physics. Artists and archaeologists can portray natural objects through actual or imagined analogies. Numerous artists have been, and continue to be, deeply inspired by the ways crystal shapes, recurring patterns, groups of symmetry groups, and the rules of crystallography lead to two- or three-dimensional space being divided (Dooryhee, 2007).

Since crystallographers also study how crystals can be described geometrically and internally arranged, the field also has a mathematical element. The frieze and the wallpaper are two patterns of symmetry into which crystallography can be grouped (Vasquez et al., 2020). Crystallographic patterns (CPs) are patterns produced with the elements of the images of living matter. It can be identified based on the characteristics of the pattern, which are the internal arrangement of the patterns that is represented in two-dimensional crystals and the projection of the patterns. Furthermore, elements of such CPs may be geometric figures (Mamedov, 1986). Therefore, since the analysis of symmetry, rotations, reflections, glide reflections, and translations are aspects of crystallography, the field can be seen as a sub-field of geometry.

Wherever humans attempt to articulate creativity, it is possible to find symmetry. Hence, hard scientists, artists, and humans may encounter it, as it may also be evident in nature. Since antiquity, a primary scientific principle has been the presence or absence of symmetry, which can be identified in many artistic fields. Therefore, symmetry may be a consideration for painters, sculptors, potters, architects, musicians, dancers, and poets, while it may be found in various crafts such as carpet- and rug-making, ceramics, and calligraphy (Abiddin & Nawawi, 2015). Varied symmetrical forms could be exposed by art and architecture. For instance, translational symmetry may be seen in patterns that repeat infinitely. The patterns could be in one dimension, such as friezes, or two dimensions (Vasquez et al., 2020). Where images to the left and right mirror each other, this is a form of bilateral symmetry, which can be found naturally in butterflies, for example. Architectural projects throughout history have often utilised bilateral symmetry, such as in India with the Taj Mahal, in China with the Forbidden City, and in Mexico with the Chichen Itza of the Maya. While painting rarely features bilateral symmetry, this concept is frequently used in art (Norris, 2014).

The intersection between the formal qualities of artworks and their crystallographic foundation can be demonstrated using many examples and depictions. Frequent assimilations are formed between the concepts of symmetry and harmony, which has its basis in ordered and organised ideas involving clarity and rationality. Charming outcomes are often conveyed by the theme of symmetry, which artists occasionally use to create suitable solutions.

### 2.2. Pattern and Motifs of Pua Kumbu

While Iban motifs play a key role as components of visual communication for the tribes, the motifs are becoming less prominent. Their aesthetic value continues to be appreciated by the younger generation, although their intrinsic meaning as a form of identifying a culture is neglected (Kanyan & Zainurul, 2015). It is observed that the design motifs applied were inspired from nature: flora and fauna and the animism belief. The embedded gold and silver threads portray the wealth and uniqueness of the community itself. The Malay community also possesses the Songket cloth as part of the culture, where it has the same technique of weaving but different selection of design motifs, in which the focused motif is only on flora, excluding the fauna motifs (due to the belief factor). The majority of Malay people embrace the concept of oneness of God, Allah SWT.

Many of the younger generation fail to understand the meanings of the motifs and appear to be less interested in the design motifs employed within the Pua Kumbu, perhaps because the symbolic representations of the latter are highly complex (Magiman et al., 2018). Therefore, the weavers' hands hold in secrecy the information about this form of intangible cultural heritage. If this form of knowledge is not disseminated, it will be deemed to be permanently lost.

The way each person appreciates something is different from each other, depending on how we see things and reacts towards it. Kiyai and Tugang (2019) reported the same thoughts on people demonstrating differences emotional appraisal of art, which makes art interesting. Trained and untrained viewers are distinct in the ways they evaluate and criticise works of art, thus, the levels of artistic appreciation vary.

The multi-layered associations between the generation of opinions, visual stimuli, and individual comprehension result in diverse forms of aesthetic perceptions. The complexity of a visual work can induce positive or negative perceptions (Xenakis & Arnellos, 2014). There are two main categories of the aesthetic: firstly, the sensible qualities people display when confronted with objects and, secondly, the pleasant feelings or otherwise that may arise, depending on one's aesthetic judgements and reflective movements (Kant,1987: Harris, 1988). Some have argued that 'reflective' reactions refer to personal experiences when addressing visual objects (Harris, 1988).

Moreover, Berlyne (1974) stated that 'aesthetic' may refer to any activity involving the senses being collected through the ears, body, eyes, or nose. The foundations of the art-aesthetics connection are embodied awareness, as well as relationships that respond to emotions and communicative expressively.

One must display a vulnerability to remaining open and attentive if one is to gain a full appreciation of aesthetic experiences. Genuine aesthetic experiences can only be attained through the profundity gained when one employs a certain manner of looking, hearing, feeling, and possibly imagining objects or processes (Berlyne, 1974). The perceptions of perceivers are key determinants of whether an experience obtained via one's surroundings or environment is pleasing or otherwise. Furthermore, such perceptions may vary according to the time-specific situations in which people find themselves.

Feelings aroused due to aesthetic perceptions are termed 'art receptions'; these cognitive processes are highly complex. According to Vandenabeele (2011), they involve communicative procedures that connect, among others, those who consume art, creative activities, the artist and his or her artwork. Simply taking a look at artwork is not analysing it; the only way to comprehend the works is by appreciating them intrinsically. The term 'collative variable' refers to

how complex a work of art is (Berlyne, 1974), and the work becomes a singular entity through the inclusion of the different aspects it includes. Complexity, according to one definition refers to the extent at which reconstructing an image from its description becomes difficult. This can be linked to various elements, which include the colour, texture, edges, curves, number, and size of objects, as well as the regularity and composition of patterns (Thumfart, 2008).

The model produced by Tinio illustrated how the making and appreciation of artwork have a clear connection. When the art is just beginning to be made, the artist receives an aesthetic perception that has a parallel in the latter stages of this perception (Tinio, 2013).

This model aims to justify the factors contributes to the individual aesthetic experience towards visual artwork in this model (Redies, 2015). It is proposed that the perceptions are derived from the combination of both formalist and contextual aspects. The most significant element in this model is perceptual and positive evaluation channel in production of emotion and aesthetic experience (Dijkstra et al., 2017).

Hierarchical "Feed-Forward" Mode

By using the first of such mathematical approach, Thumfart et al. (2008) have developed a model that combines the statistical and emotional characteristics of aesthetics generated by visual textures.

The Neuropsychological Model

This model is a "feed-forward" system proposed by Chatterjee (2014) which engaged with processing a variety of attributes and provides a neurophysiological framework for visual aesthetics. It is guided by visual neuroscience, which explains the visual information processing is related to initial features extraction and image identification is accomplished at the early stage. The aim of neuroaesthetics is to obtain the scientific review of aesthetics from a neurobiological angle.

The Information-Processing Model

Leder et al. (2004) proposed a cognitive model of information processing which contributes to aesthetic experiences and aesthetic judgement. The flow of data through separate circuits, which similar the flows of the signal in the brain. The neural for the data processing cover at least by three functionally distinct sets of the brain; cortical, subcortical and the regulators of the reward (circuit, amygdala, thalamus, and hippocampus).

Visual Complexity

Assessments of aesthetics are generally indicated by complexity, but there is ongoing debate over the ways complexity and aesthetic attraction are related, so the topic needs to be discussed. Any experiment involving psychology faces a major problem in terms of sample size limitations, which make it difficult to obtain a sufficient range of complexity (Sun et al., 2015). On the other hand, a researcher would find an empirical experiment too expensive if thousands of samples are employed. Consequently, overall guidelines for aesthetic assessments are unavailable if an empirical experiment is to be conducted. Moreover, there is a lack of clarity over how theories of psychology should be applied in terms of their scope because intra and extra-category images may differ considerably in complexity (Sun et al., 2015). One definition of complexity is the extent at which reconstructing an image from its description becomes difficult. This can be linked to various elements, which include the colour, texture, edges, curves, number, and size of objects, as well as the regularity and composition of patterns (Sun et al., 2015).

The Aesthetic Features Motifs of the Pua Kumbu

Koelsch (2015) suggested that 7% of emotions that are experienced daily stemmed from dealing with cultural artifacts. According to Kaufmann (2003), an aesthetic stimulus leads to the existence of visual art and the subsequent evocation of an emotional reaction. Any aspects of art might become motivations triggering perceptions if there is a compromise between the ways to perceive and receive aesthetics. Among the indigenous Iban tribe, a primary form of their physical culture is the Iban Pua Kumbu. The older generations, in particular, and the Iban community as a whole protect considered this tangible element of their traditional heritage sacred. The Iban society has a collective belief that they are a major tribe and survivors; in historical times, they would take any action necessary to safeguard their culture and traditions (Sim & Khan, 2014).

### 2.3. Weaving Techniques of Pua Kumbu

A brief explanation was provided by Jehom (2016) of Iban ladies' production of the Pua Kumbu. This involved the method of dyed resist, while a backstrap loom was used to weave the products. These ceremonial blankets contain patterns of many colours and are accorded considerable appreciation. Before dying, the untreated cotton yarn, as shown in Fig. 5, is given a mordant treatment to create varied shades of browns, reds, and yellows; where the vivid dyes are made from natural components derived from plants such as engkudu, tatum, and engkerbai plants, as shown in Fig. 6. The Pua Kumbu contains design motifs that are characterised by their complexity and abstraction. The inspiration for them may be derived from plants, animals, or traditional concepts of animism, in addition to the regular life of the Iban people themselves (Jehom, 2016).

The woven cotton textiles of the Pua Kumbu are the most well-known textiles for Sarawak's Iban people. Custom and belief are connected in many groups, not least in the Pua Kumbu, which demonstrates the crafting and matching of this understanding. Women in many societies are generally associated with weaving activities, and their standing in their respective communities may be ascertained by the motif forms used in their weaving. Historically, only chiefs' wives or daughters were permitted to weave motifs featuring humanoids or anthropomorphic shapes (engkaramba). Such a figure, which typically had raised its arms and turned out its legs, would represent an Iban religious deity. It could also have a talismanic role, protecting whoever wore it from harm and ensuring the harvest season would be advantageous. While interpreting the various images is problematic, an environmental feature is often the inspiration for a motif or colour, revealing numerous details about Iban practices and values. Whereas fauna, flora and daily life are the most common elements represented visually in the motifs, others may have a greater degree of complexity and abstraction. Tradition and heredity generally influence the Pua Kumbu's intricacy.

It is understood, the art of designing the motifs of Pua Kumbu is passed from generation to generation; from a mother to her daughter and remains preserved to this day. The ikat, also known as the tie-and-die approach, is used most frequently. Longitudinal threads are dyed selectively to create warp patterns prior to weaving, as illustrated in Fig. 7. Having used a plain weft to weave the dyed yarns, fuzzy and indistinct warped patterns are created, as shown in Fig. 8. A weaver may choose types of motif enhancement by introducing embroidery, tapestry, or brocade weaving, as well as additional weft embroidery. Weavers have tended to retain the long-standing weaving motifs and approaches due to the customary view that they would encounter misfortune or death if they adopted new ways. More recently, Iban motifs have been regarded less frequently as vital aspects of a tribe's visual communication. Meanwhile, they continue to be appreciated by the younger generations for their aesthetics rather than their inherent cultural meanings (Kanyan & Zainurul, 2015).

As UNESCO 2017 outlined, the term 'cultural heritage' has undergone significant alterations in recent decades. While it incorporates landmarks and collections of objects, it also covers oral tradition, performing arts, social and ritual practices, festivals, natural and global features, as well as traditional knowledge. As a whole, these shape traditional or real expressions of the ancestral inheritances in which older people would pass on to their children. Therefore, there is a need to increase awareness, especially among the younger generations, on the importance and protection of intangible cultural heritage.

**Fig. 5:** The cotton yarn

**Fig. 6:** Natural plants such as engkudu is used to create dyes for the cotton yarn

**Fig. 7:** Mounting the folded yarn onto the tying frame

**Fig. 8:** Ikat or tie-and-die method

## 3. Results and Discussion

### 3.1. Crystallographic pattern of Iban Pua Kumbu patterns

Using the patterns in the crystallography, it is only possible to analyse six Pua Kumbu motifs. Flowcharts in Figs. 3 and 4 outline the approaches used to collect the findings after analysing the Iban Pua Kumbu designs' crystallographic patterns. From the findings, we realised that all Pua Kumbu patterns bear at least one of the seventeen crystallographic groups. Most of the Pua Kumbu motifs are symmetrical and those motifs is mathematically identified as a design. The current researchers focused on conducting a symmetry analysis of those patterns in the Pua Kumbu that revealed limited designs or repeating patterns originating from fundamental units or motifs. According to Truna et al. (2021), the basic structure of Pua Kumbu consists of buah pua (the main part of the Pua Kumbu), punggang ujong (the proceeding accompaniment), punggang pun (the preceding accompaniment), kelemebai or sengkalan (the fencing of the Pua Kumbu), anak pua (the side borders of the Pua Kumbu), and ara and tisi (the selvedge of the Pua Kumbu).

The reflections were bidirectional, whereas every rotation centre design was on the reflection axis with two directional translations, as shown in Fig. 9. Therefore, the buah pua pattern of Pua Kumbu falls under the p2mm crystallographic group. Fig. 9 shows the fern motif with all its 90-degree rotations centre and reflection axes.

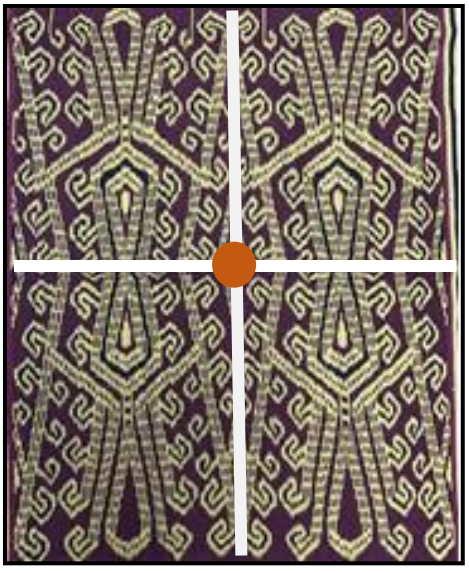


**Fig. 9:** Buah pua pattern in Pua Kumbu showing a similar pattern with symmetry group p2mm (orange center of rotation and white axes of reflection).

On the other hand, Fig. 10 illustrates the inspiration for buah pua patterns that derived from parts of plants, for instance, flowers, tendrils, stalks, and leaves. Based on the crystallographic pattern, the arrangement for the design is a p1m1-type symmetry group, whereby each motif was set out using horizontal reflection and no rotation angle.

Decorative weaving and dyeing techniques are used on many of the fabrics that one may have seen, where these patterns and designs frequently have colour. The same-coloured motifs of the same kind are a defining property of all the ikat repeated designs examined in this work, which can be related to the dying process.

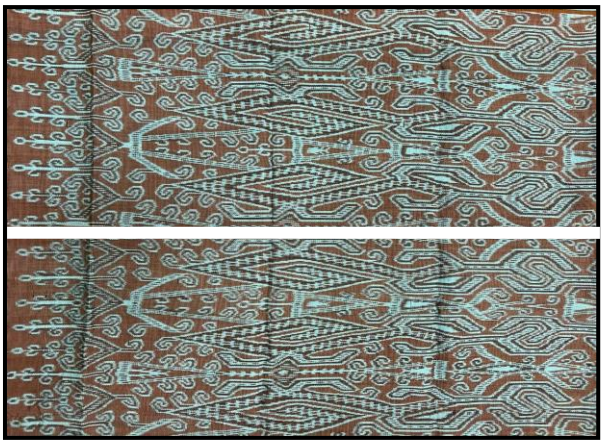


**Fig. 10:** Buah pua pattern in Pua Kumbu showing same pattern with p1m1 symmetry group (white axes of reflection).

Fig. 11 illustrates a repeated pattern motif, much like the one shown in Fig. 12, which is created by inserting weft threads. This produced a recurring sequence of two distinct configurations of vertical wefts. Fig. 13 shows that the threads are pulled, stretched, and knotted horizontally prior to the application of the dye, which consequently produces vertical reflection symmetry. Local flora and fauna are the motifs of the Pua Kumbu, with the human motif being the most expensive. The Ibans also take cues from animals, plants, and other items that are significant to their daily lives when creating their Pua Kumbu designs and patterns. Crocodiles, tigers, birds, deer, lizards, frogs, and snakes are animals that are most frequently represented in Pua Kumbu. In fact, the nature is quite geometric and has continued to inspire weavers. In Fig. 12, the Pua Kumbu pattern was designed using frog motif and falls under the p1m1 in crystallographic group; however, no angle of rotation was detected except only a vertical reflection.

**Fig. 11:** To produce a motif of the repetitive design, weft threads are added.

**Fig. 12:** Buah pua pattern with frog motif in Pua Kumbu showing same pattern with p1m1 symmetry group.

**Fig. 13:** Ngirit technique where a thread is horizontally pulled, stretched, and knotted before the dye is applied**.**

As shown in Fig. 14, a plane pattern may be arrested by a crystallographic pattern at the cloth ends, or the punggang ujong pattern. For example, Fig. 14 depicts a plane pattern with a p1m1 symmetry group at the Pua Kumbu border. Meanwhile, Fig. 15 shows the crystallographic patterns at the buah pua of the Pua Kumbu.

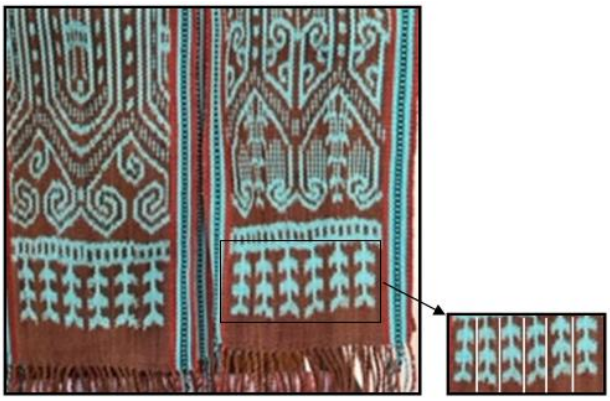


**Fig. 14:** Punggang ujong pattern in Pua Kumbu showing same pattern with p1m1 symmetry group.

Fig. 15 illustrates the one-directional vertical reflection of the p1m1 group of crystallographic patterns. It belongs to the p1m1 group because the pattern reveals no rotation. The reflection axes are perpendicular to one of the axes of translation and parallel to the other, whereas glide reflections and rotations are absent.

**Fig. 15:** Buah pua pattern in Pua Kumbu showing same pattern with p1m1 symmetry group.

Fig. 16 shows the basic pattern of Pua Kumbu. Every Pua Kumbu weaving community frequently uses this basic weave. There is no glide reflection the shapes of the motifs are not similar in Fig. 16. Therefore, the punggang ujong pattern of Pua Kumbu falls under the p1 of crystallographic group. All Pua Kumbu weaving societies use the same basic weave.

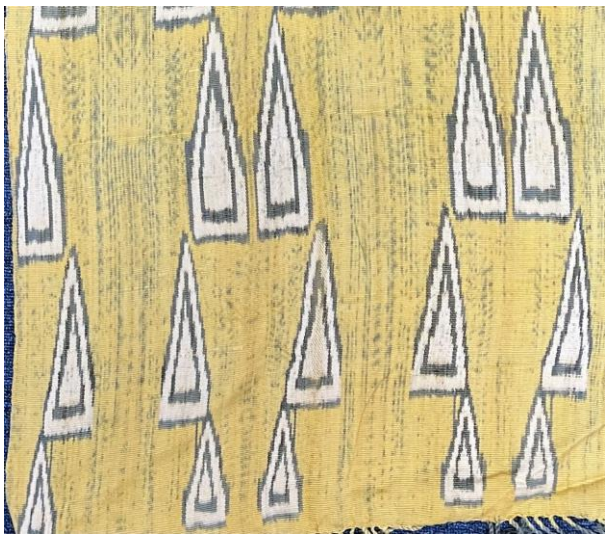


**Fig. 16:** Punggang ujong pattern in Pua Kumbu showing same pattern with p1 symmetry group.

The pattern in Fig. 17 reveals one-directional reflections and that each rotation centre is on the reflection axis. Thus, the Pua Kumbu buah pua pattern can be classified into the p2mg crystallographic group. This is because the horizontal and vertical white lines towards the right of the buah pua pattern display vertical and horizontal reflections, respectively.

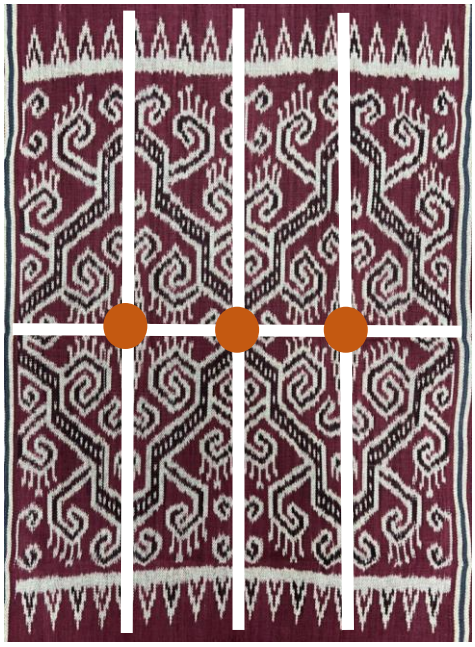


**Fig. 17:** Buah pua pattern in Pua Kumbu showing same pattern with p2mg symmetry group (orange center of rotation and white axes of reflection).

The pattern shown in Fig. 18 can be classified into the p2mg group of crystallographic patterns because it is possible to rotate the diamond-shaped patterns at 90 degrees, and they are vertically and horizontally reflected. Fig. 18 also reveals glide reflection, the pattern of which can be classified as p2mg. The white stripes pattern reveal horizontal and vertical reflections while the rotation is at 180 degrees.

**Fig. 18:** Buah pua pattern in Pua Kumbu showing same pattern with p2mg symmetry group (white axes of reflection).

The results show that p1m1 pattern in crystallographic patterns is widely used, followed by p2mm pattern. The p1m1 pattern is the easiest and simple to weave. In terms of the plane's types of crystallographic groups, p2mm, p1m1, p1, and p2mg were the patterns identified, in which vertical reflections were also visible.

## 4. Conclusion and Recommendation

The analysis of the results revealed that the Pua Kumbu designs contain a wealth of mathematical patterns, shapes, and ideas. The seventeen crystallographic groups can be used to identify the mathematical ideas found in the Pua Kumbu. Most of the motifs on these parts of the Pua Kumbu are type p2mm, p1m1, p1, and p2mg of the crystallographic pattern. Based on the motifs of the Pua Kumbu pattern, each Pua Kumbu design has a unique type of pattern. Despite the Iban weavers' lack of mathematical training and familiarity with mathematical concepts and patterns, this research

demonstrates that mathematical ideas are actually present in the designs of Pua Kumbu.

It was found that symmetry analyses, geometric concepts and crystallographic patterns are applied in Pua Kumbu weaving. Nevertheless, the types of symmetries and colour symmetries generated seem to be connected to the weaving methods and the cultures that developed them, according to the sample in this stduy. The idea of transformation is crucial to the craft of Pua Kumbu weaving. Weavers design the Iban Pua Kumbu with great creativity, using designs of elegance and beauty that display the best of the Iban civilisation. The Pua Kumbu contains decorative patterns whose relevance and imaginative portrayal are demonstrated by the intricacy of the creative process. It appears that Pua Kumbu weavers have excellent memory skills, strong visual perception, and an innate aptitude for applying mathematics to their work. Hence, a thorough investigation and research on symmetry analysis of Iban arts should be conducted in the future.

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