Patterns for Skew Mad Weave Polyhedra

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Abstract

Mad weave (anyam gila) is a type of basketry originating in Indonesian area. There is very little literature on the technique, and it is not widely used, but it produces a very pleasing fabric, with a symmetry (p6, or **632** in orbifold notation) that makes it suitable for the construction of polyhedra with triangular and hexagonal faces. Various patterns can be produced if strands of different colours are used, but in practice for any particular polyhedron geometric constraints limit the possibilities to just a few that have reasonably small fundamental regions, and are consistent with its symmetry.

Mad Weave

Mad weave is a basketry technique with weaving elements in three directions (at 60° to each other) woven close together so that an almost continuous surface is produced. Technically it is a twill weave since for any pair of directions the weaving elements in one direction go under 1 over 2 (those in the other direction go over 1 under 2). The weaving pattern is cyclically related: A goes under 1 over 2 Bs (so B goes over 1 under 2 As), B goes under 1 over 2 Cs, C goes under 1 over 2 As (figure 1). The resulting structure has p6 (**632**) symmetry, with small holes occurring at the centres of sixfold and threefold symmetry. It is important to remember the distinction between the two types of hole and the chirality of the weave when trying to understand how it works, especially when trying to create it practically.

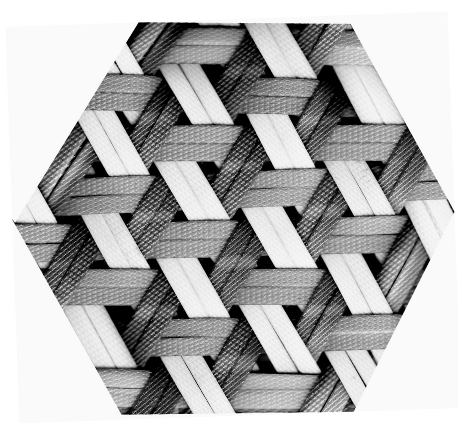

Figure 1: *A sample of mad weave.*

The technique seems to have originated some time before nineteenth century, probably in Eastern Indonesia, and an early account[1] goes into some detail about the preparation of the traditional material (pandanus leaf) and the method of working. The basket starts with six strands around one of the sixfold centres of symmetry, and is built up by working in three directions, braiding, rather than weaving, although modern western basket-makers seem to prefer to weave.

Colour Cycles

Translation along one of the directions of symmetry of the weave will map a strand (with different direction) onto an equivalent one that is three strands away. It follows that any colour pattern (apart from the trivial case, when all strands are the same colour, or when all strands in any direction are the same colour, as in figure 1) must have a fundamental domain that is a multiple of three strands in any direction. With one exception (two alternating colours) only the simple cases when the repeat distance is exactly three strands wide will be considered.

When each direction has strands of three different colours, the strands in each direction must cycle through the same three colours in the same order if rotational symmetry is to be preserved. Even then there are several different possibilities because of the different ways in which the cycles in each direction can relate to each other. The start of the cycle in each direction can be defined by picking an arbitrary six-fold point, and taking one of the two sets of three rhombi at 120° to each other. Figure 2 shows the pattern when the cycles in all three directions start at the same colour.

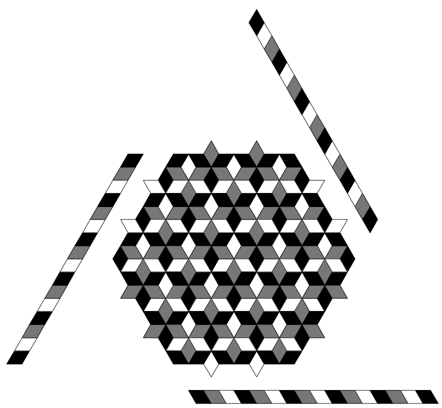

Figure 2: *The cycle in each direction starts with the same colour.*

The only other possibility that will preserve rotational symmetry has each cycle starting with a different colour (figure 3).

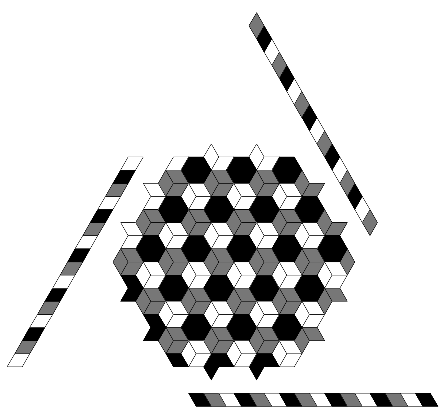

Figure 3: *The cycle in each direction starts with a different colour.*

All the other possibilities have the cycles in exactly two directions starting with the same colour, breaking rotational symmetry (figure 4).

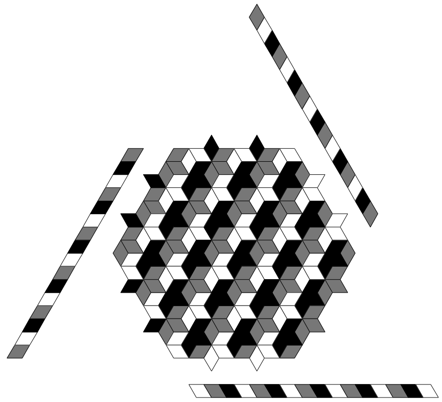

Figure 4: *The cycles in exactly two directions start with the same colour.*

Duplicating Colours

Of course it is possible to duplicate colours (replace a pair of colours with a single colour) to produce different patterns, and some patterns illustrate aspects of the structure of the weave. For example if the start of the cycle is the same colour in all directions, and all the other strands are another colour, the pattern in figure 5 is produced. This pattern is produced naturally if Richard Ahrens's method is used to create a basket[2], and shows that the strands at the same point in the cycle form an open hexagonal weave (figure 6) [3]. Actually figure 3 shows another way in which mad weave can be decomposed into open hexagonal weave structures, and in this case they have a borromean relationship: remove any one and the other two are disconnected.

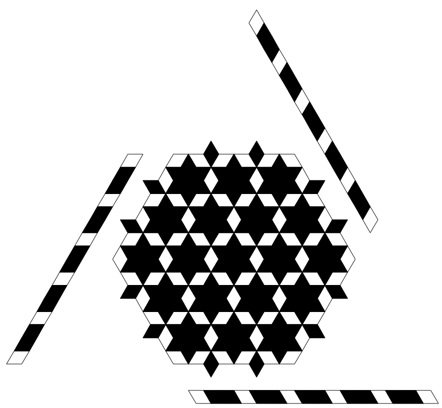

Figure 5: *Duplicating colours can reveal an aspect of the structure.*

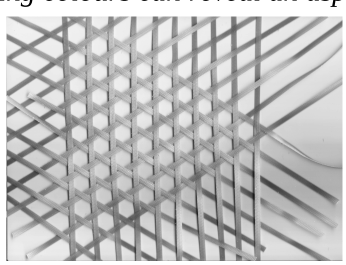

Figure 6: *An open hexagonal weave.*

Figure 7 shows the result of duplicating colours so that each direction has only two of the three colours, but since there is a cyclic relationship rotational colour symmetry is preserved.

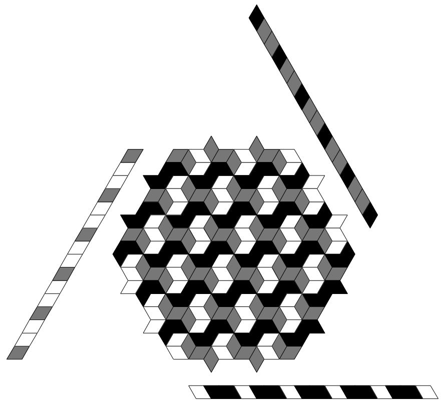

Figure 7: *A cyclic duplication of colours preserves rotational colour symmetry.*

Alternating Colours

Probably the most obvious way to produce patterned mad weave is to alternate the colours of the strands in each direction, but since this gives a cycle of period two, and the structure itself has a cycle of period three, the resulting pattern has a cycle of period six. If three colours are used cyclically, two in each direction as in figure 7, a rather confused pattern results, but if there are only two the resulting pattern has quite large areas of single colour, and is easily apprehended (figure 8).

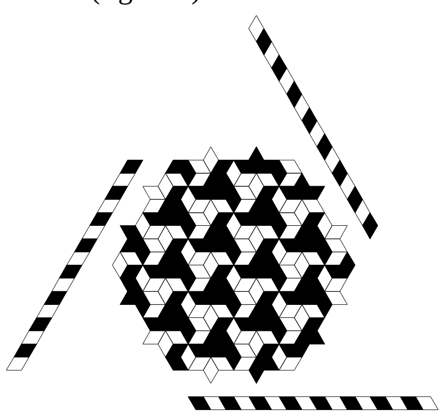

Figure 8: *The pattern produced by alternating colours in each direction.*

Corners

The structure must be modified to produce corners if anything more than a flat piece of basketry is required, but strands change direction at a corner, so that in general colour sequences are not preserved, and a regular pattern would be disrupted. Basket-makers seem to accept this, but it is avoidable in certain cases. The most obvious example is when the pattern in figure 5 is used, and the corners are arranged to coincide with the centres of the “stars”. At such points any permutation leaves the pattern unchanged since all the strands have the same colour. It is quite easy to make baskets with this pattern: first make an open hexagonal basket (using the white strands), and then fill in the rest of the mad weave. (It is not quite so obvious at first, but with practice this method is very convenient.) Obviously it can be used for any structure, but those with five-fold corners, or a mixture of corner types, can have no other regular pattern with a repeat distance of three. Actually there are larger scale patterns, with a repeat distance of six, for example, that include single colour “stars”, but they would only work on very large baskets.

In general corners are made by bending the strands so that a six-fold centre in the weave has fewer strands. Sequences are preserved when the order is reduced to four if colours alternate around the centre, such as in figure 2. Such centres also occur in figure 8, and in figure 5 (which is the pattern of figure 2 with a pair of colours identified).

Colour sequences are preserved in three-fold corners when strands in the original centre with the same direction have the same colour. This is clearly the case when all the strands in any direction have the same colour (figure 1), and in figure 7. Of course the pattern in figure 5 will work, but it is also possible to modify the “stars” so that they have three colours in the correct arrangement (figure 9).

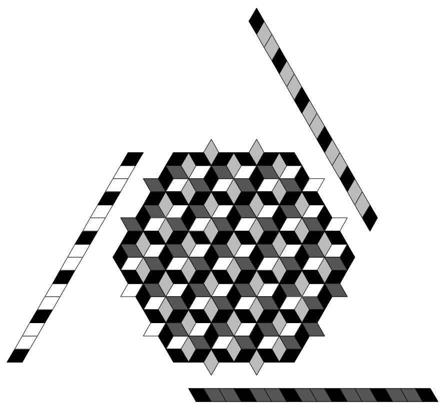

Figure 9: *A modified pattern that will allow three-fold corners.*

Applying the same modification to get alternating colours, suitable for four-fold corners, simply produces the pattern in figure 2. Alternatively the pattern in figure 5 can be produced by replacing any pair of colours in figure 2 with a single one, demonstrating that only one third of its six-fold centres lie at the centres of “stars”.

Skew Mad Weave Polyhedra

Triangles and hexagons are the most natural polygons produced with mad weave although 60° rhombi and rectangles built from modules with √3 proportions are also possible. There are only five possibilities if all corners are to be of the same order: three Platonic polyhedra (tetrahedron, octahedron and icosahedron) along with two Archimedeans (truncated tetrahedron and hexagonal antiprism), and the Archimedeans have five-fold corners so only the Platonics will be considered. .

These patterns exhaust the possibilities that are suitable for making reasonably sized skew mad weave polyhedra.[4]. That is not to say that there are no other symmetrically decorated mad weave polyhedra (the reference gives an example), but if the polyhedron is skew (its edges are not aligned with the principal directions of the weave) such decoration is disrupted.

The characteristics of each pattern determine the possibilities for the underlying weave to align across the polyhedral edges since not all six-fold centres are potential corners, in general. There is considerable freedom over the precise size of the polyhedron, although if it is too small there is a tendency for the strands to be quite strained because of the small radii of curvature where they cross the edges, and this produces a weave that tends to creep apart. Larger polyhedra obviously use more material, and take longer to make, so there is an incentive to keep them reasonably small, unless there is a particular reason to make them big.

If there were no constraints because of pattern an edge of the polyhedron would cross a single strand in the direction more or less aligned with it. It is possible to calculate the minimum number of strands needed to weave a polyhedron from this observation. Symmetry requires that each edge is crossed by a strand at its mid-point, and, whatever path it takes, the same strand must cross the opposite edge at its mid-point, since there is an axis of two-fold symmetry through the two mid-points. Although there can be paths that cross more than two edges at their mid-points (for example there are four hexagonal paths, each passing through six mid-points of the edges of an octahedron, defining a cuboctahedron) they do not occur in skew mad weave structures. So the minimum number of strands is half the number of edges, three for a tetrahedron, six for an octahedron and fifteen for an icosahedron.

Any of the polyhedra with patterns based on the “star” pattern (figure 5) will have three times the minimum number strands: the open hexagonal form, which is one third of the complete mad weave, has the minimum number. This group of patterns includes figure 7 since the odd colours in each direction form an open hexagonal weave.

Figure 2 provides a particularly pleasing octahedron since the choice of corners that uses the minimum number of strands (six) creates corners of all three types, with opposite vertices having the same type. The octahedron based on the pattern in figure 8 needs at least twelve strands.

Figure 10 shows the full range of patterns that can be used to weave minimum polyhedra (in terms of the number of strands), apart from the three strand tetrahedron that uses the pattern in figure 1.

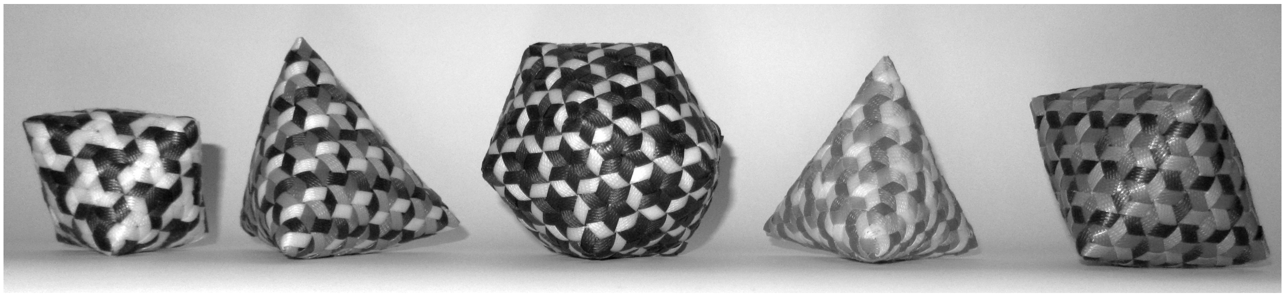

Figure 10: *The patterned polyhedra with the minimum number of strands.*

References

[1] Mason OT, *Anyam Gila (Mad Weave): A Malaysian Type of Basket Work*, Proceedings of the United States National Museum, **36** (1909), Smithsonian Institution, Washington, pp.385-390.

[2] http://www.bridgesmathart.org/art-exhibits/bridges06/ahrens.html

[3] Bamford J, *Hexagonal Open Plaiting*, the Basketmakers’ Association, http://www.basketassoc.org, 2003.

[4] Gailiunas P, *A Mad Weave Tetrahedron*, Bridges Coimbra Proceedings, 2011.