Drawing an Islamic Pattern

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1 Introduction

In considering methods of constructing Islamic star patterns, whether by hand or by computer, we might distinguish two main approaches. One is to try and investigate the methods used by the original craftsmen; the other is to attempt to deduce the underlying geometry by examination of the surviving examples of authentic patterns.

If we choose the first approach we immediately encounter two major difficulties. In the first place, no detailed instruction manuals seem to have been produced at any time for the use of the early craftsmen; and secondly, the few surviving collections of master craftsmen's working drawings are of limited help, and mostly confirm practices which can be deduced from an examination of finished authentic patterns from a variety of artefacts.

The second approach is by far the most rewarding. It does not necessarily seek to discover the methods adopted by medieval craftsmen, nor to inquire into their understanding of the geometry which may or may not have underlain their creations. Instead, this approach can look at the patterns from a modern, purely geometrical point of view, and thereby determine which patterns can be interpreted as configurations with an exact geometry that includes precisely regular motifs, or which patterns necessarily involve some degree of geometrical incompatibility, leading inevitably to approximations, with at least some motifs having to be constructed in some non-regular manner.

Patterns in the first category, with exact geometry, may be termed determinate, in that their exact geometry enables us to express or define their structure in precise mathematical terms, and, if we wish, using precise trigonometrical formulae at all stages of their construction.

Patterns in the second category may be termed indeterminate, in that the approximations inherent in their structure necessarily entail ambiguity or uncertainty in the interpretations we wish to place on them. It is not that a mathematical analysis in this case is essentially difficult or impossible, but rather that the decision as to which specific analytical solution to adopt among many, perhaps infinitely many, possible solutions can become extremely tedious and time consuming. In addition, the presence of approximately-regular motifs will increase the often already large numbers of angles and lengths in use, and can also lead to modifications in the geometry of areas outside the approximate motifs, and therefore to further complications over and above those caused by the non-regular motifs.

The final arbiter and guide to the choice of proportions in our computer graphical renditions of Islamic star patterns should of course be the authentic patterns themselves (colour is a separate issue, and may be dealt with later, together with other forms of authentic treatments). However, even this admirable requirement presents its own difficulties. Given that it is often difficult to decide whether two similar patterns should be regarded as varieties of one and the same pattern, or whether they constitute separate and distinct patterns, we frequently find a great variability in the way in which authentic patterns are drawn, either in different regions or at different times.

Investigating Islamic star patterns in terms of pure geometry can sometimes reveal certain "ideal" configurations which clearly reflect an underlying network in its purest and most symmetrical form; such an ideal configuration then becomes a "standard" construction, and the relationship between underlying net and the pattern itself is expressible in precise mathematical terms. Unfortunately these standard constructions are not always widely distributed as authentic patterns, but unless examples are found we cannot claim authenticity for the standard constructions we illustrate.

The ideal configurations of the "standard" constructions represent modern interpretations of determinate patterns in terms of precise mathematical formulae; there is no suggestion that the original artisans understood such patterns in these terms, or that their constructional methods mirrored the underlying networks used in our trigonometrical analyses. Consideration of original methods of drawing out authentic star patterns is not our primary concern, which is to copy the original Islamic patterns as accurately as possible, using precise mathematical tools, insofar as this is appropriate. These high aims can, however, begin to fail when we attempt to copy patterns in which a great many arbitrary or freehand adjustments have evidently been made in order to smooth over some unavoidable geometrical incompatibility. Such arbitrary arrangements are tedious to mimic with precise mathematical formulae, and may necessitate so many preliminary trials that certain patterns of this type are deemed to be hardly worth the effort. Luckily, there are relatively few patterns which fall into this category, although even in those which have been attempted, we may in certain cases have to make do with a provisional graphic, which does not quite capture the artistic subtleties of the authentic original.

† We have a subsidiary aim in producing our computer graphic — to provide geometric properties of the pattern which can be input to a search engine to locate specific patterns.

2 Principles

A number of guiding principles for the design and construction of Islamic star patterns may be noted from observation of a variety of authentic examples.

These principles are important, both for manual drawing and for the production of computer graphics. However, since we are dealing with what is essentially an art form, rather than an edifice of mathematical propositions (however "geometrical" the patterns may appear to the uninitiated viewer), these principles were not always rigorously adhered to by the original artisans. Consequently, the "principles" revealed below are our ideal interpretations rather than truths transmitted across the centuries by written sources.

1. A regular n-fold star motif is based on n equally spaced points round the circumference of one or more concentric circles. Each star motif has an n-fold star, or n-star, at its centre, although usually the n-fold local rotational symmetry of this star extends to additional systems of polygons surrounding the central n-star, forming a compound n-fold motif round its central star. A number of such compound star-motifs are characteristic and unique to Islamic decorative art, for example the ubiquitous geometrical rosette.

2. Two adjacent star motifs are usually (but not invariably) orientated so that their centres and a radius from each motif lie on a single straight line. This forms what we may term a collinear link between two star motifs. The collection of all collinear links in a pattern forms an underlying network of polygons — usually rhombs or squares, but triangles or pentagons, etc., may appear — the edges of which are the collinear links, and the vertices of which are the centres of the star motifs. Noting the form of this network of collinear links may help in grasping the overall design and symmetry of a pattern.

3. Most patterns are in the form of true interlacing patterns, in that they are edge-to-edge tilings with 4-way nodes or vertices, in which adjacent angles at each node add up to 180°. In other words, opposite angles at each node are equal, so that pattern lines through a node can be regarded as two straight lines intersecting at that node. The term "interlacing" thus refers to the fact that pattern lines can be represented as interlacing bands which run alternately over and under one another throughout the pattern. Interlacing patterns can be coloured with just two colours (e.g., black and white, or in general, in two colour modes, e.g., light and dark), so that no two pattern areas sharing an edge have the same colour. The same two-mode colouring can be achieved if an even number of polygons meet at every node, although in this case pattern lines cannot be represented as interlacing bands. A number of authentic patterns contain some nodes with interlacing discontinuities, in which opposite lines through the node are no longer collinear, i.e. certain bands would be bent if the interlacing style were attempted. The geometric reasons for interlacing discontinuities differ from pattern to pattern, but once understood they can be easily emulated as computer graphics.

4. In essence every Islamic pattern is a tiling of the plane, in which the edges (pattern lines) of its constituent polygons (tiles) are shared between pairs

of adjacent polygons. The simplest realisation of this basic form as an actual artefact treats the patterns polygons as cut ceramic tiles, and the pattern lines then become merely the juxtaposed edges of pairs of adjacent tiles. This style of pattern is usually easy to copy accurately as a computer graphic. The pattern lines themselves are frequently widened as bands, which may or may not be represented as interlacing bands, and the bands themselves may be elaborated or decorated in various ways, not all of which are easy to copy by computer. In general our computer graphics attempt to depict the original style of a pattern fairly faithfully, but the number of ways in which the multiplicity of banding styles can be drawn is limited. If the basic pattern lines are widened as non-interlacing bands, these can be represented by thickened graphic lines, which can be drawn in any available colour. Interlacing bands, of variable width, are usually only available as white interlacing. A number of Islamic patterns employ differently coloured interlacing bands in a single pattern. This is a possible graphic option, but requires special programming, currently under review. We can, however, choose to regard the different sections of interlacing bands as pattern polygons in their own right, which, though tedious, allows any combination of band or edging colour. On many wooden doors or minbars, and in wooden lattice, widened bands are frequently represented by short lengths of beading, which may have a three-dimensional structure. In computer graphics it is usual to depict this style by an "embossed" or "mullion" type of banding, emphasized by shading as though lit from a hypothetical light source.

3 Colour Choices

Authentic Islamic patterns vary widely in their use of colour as a decorative element. The greatest use of colour occurs in those patterns executed in glazed ceramic tiles, whether as cut shapes in ceramic mosaics or inlay, or as whole tiles, usually square, produced by the dry-cord technique, in which the colours are often less intense. In addition, patterns in latticework windows often have inlaid pieces of coloured glass. In other cases any visible colour usually depends on the colour of the medium in which the pattern is executed: wood, stone, marble, stucco or terracotta, etc.. The part played by colour in ceramic or glass patterns is taken over by variations in texture, or by the interplay of lighting and shadow effects in those media which have no inherent colour differentiation of their own.

Our computer graphics can accurately render the original colours of ceramic tile patterns, given good, clear source images, but in those cases where the original pattern has no colour other than that of the medium from which it is made, we think it best to invent colour combinations of our own to emphasis the geometric structure. In some patterns, based on inlaid wooden panels, as in doors or the sides of wooden minbars, inspiration may come from the colours in the wood itself, or from the use of various inlay materials, for example ivory. In general, however, when the authentic source material has no colour other than its medium, the colours used in our computer graphics have been arbitrarily chosen.

Ideally, if a pattern allows a two-mode colouring, the best effects will be produced if these are differentiated as light versus dark, so that only colours of contrasting modes occur on opposite sides of each edge of the constituent pattern polygons. The vast majority of authentic coloured patterns adhere to this "rule". For example, in traditional Moroccan zellij compositions the "light" mode contains the colours white and canary-yellow, while the "dark" mode contains black, green, blue, red and honey-brown. The distribution of colours in two-mode colourings in other regions can be different.

4 Determinate Patterns

We refer to these as patterns with "exact geometry", that is to say, whether or not the original artisans understood them in these terms, they can be easily analysed mathematically and their proportions expressed as, for example, trigonometrical formulae, which can then be solved to any desired level of accuracy. Sometimes the proportions and angles are fully determined, and allow no variation, as in Shah-i-Zinda complex, Mausoleum No 15, Samarkand, or Cairo, Zawiyat al-Abbar. In other cases, proportions become fixed only after some arbitrary parameter has been decided upon, e.g. Bourgoin, Plate 120 — in this particular case, expressed by choosing parallel-sided 12-fold rosettes. If, alternatively, the 9-fold rosettes of this same configuration are chosen to be parallel-sided, we obtain Bourgoin plate 120, standard construction. It is possible to have both 9-fold and 12-fold rosettes parallel-sided, e.g. Alhambra, Mirador de Lindaraja, but in this case the pattern is no longer fully determinate, although some of its proportions can be based on those of the determinate case, for example, the precise ratio between the radii of the 9- and 12-fold rosettes, as here. Fully determinate patterns are not common among all kinds of Islamic geometric patterns, but most depend on setting a particular value of some parameter, where the parameter may involve a certain angle, or a certain property of some element in a pattern, as in the choice of parallel-sided rosettes (other choices may be convergent-sided, or divergent-sided rosettes). Once the value of the parameter has been set, this determines the proportions throughout the rest of the pattern.

There are certain special classes of determinate patterns, each based on a few relatively simple designs, in which the pattern shapes, as free standing cut tiles in either glazed ceramic or some other material, can be rearranged in virtually endless ways, to create large numbers of new patterns. In the process of attempting to join together already existing tiles into new, and more complex patterns, it may happen that gaps or spaces will be enclosed, for which a tile shape does not yet exist. These can then form the basis for new tile shapes, to be added to the set of shapes already existing. Additional patterns based on the new, enlarged set of shapes can then generate further new tile shapes in the same way, which can then in their turn form even more new arrangements. Such sets of tiles may be thought of as “self-generating”, in the sense that new arrangements are continually allowing the formation of new shapes which then enlarge the existing set of shapes, and the larger set can subsequently be used to form even more new patterns, and so on. Two major open-ended classes of such determinate patterns, based on “self-generating” sets of tile shapes, may be loosely referred to as “octagonal” and “decagonal”, based on 8-pointed and 10-pointed stars, respectively. These important classes of patterns, characteristic of western Islam and Central Asia, respectively, are described separately below.

Determinate patterns contain a greater degree of regularity than other patterns. For example, star motifs in determinate patterns are always regularly formed, and are therefore easily searched for. Their geometry can be used to provide information for an SQL search engine, so that the patterns can then be found by entering their geometrical properties in an HTML form.

5 Indeterminate Patterns

Members of this group do not have a set of parameters which once set determine the proportions and angles throughout the pattern. This category includes most Islamic geometric patterns, but the degree of indeterminacy in their construction varies widely. Indeterminate patterns can often be analysed mathematically, and may have regularly formed star motifs, but they always contain some elements whose metrical properties have to be arbitrarily chosen. These properties may include the relative sizes of different motifs in a single pattern, or the precise way in which a motif or subelement may be constructed. If the star motifs are regularly formed then patterns containing them can be found using the search facilities, but many indeterminate patterns contain at least some motifs which, for geometrical reasons, cannot be regular, and therefore cannot be searched for. From the point of view of the original artisans drawing out an Islamic design by hand (i.e. not using mathematical calculations), it is immaterial whether the pattern is determinate or indeterminate in the present sense, since the slight errors inherent in a manual construction will mask all but the most careful and accurate layout. This might suggest that the Muslim artisans had no reason to distinguish between what we might refer to as “exact” and “non-exact” patterns, since on the whole they would have experienced them only at the practical level of manual constructions, not at the level of theoretical geometry or of mathematical calculations.

A good example of an indeterminate pattern is Great Mosque, Damascus. Here, the relative positions of the centres of the main motifs are fixed by the underlying basis of this particular pattern type, but the manner in which both the 8-fold and the 12-fold rosettes are drawn is quite arbitrary. The 8-star has a vertex angle of 90° and the 12-rosette is parallel-sided, but these are both the results of arbitrary decisions, and neither property is dependent on anything else in the rest of the pattern. The centres of the small pentagons may be regarded as determined by the intersection of radii from neighbouring 8-star and 12-rosette, while the size of the pentagons, if they are circle-inscribed (by no means obvious), depends on a simple parameter. However, if the pentagon radii have to align with radii from adjacent 8-star and 12-rosette, it is obvious that they cannot be regular, therefore a decision has to made as to the best way of drawing the pentagons so that they look as nearly regular as possible. Arbitrary rules of thumb can be formulated to allow the construction of nearly-regular pentagons, and such rules may be adapted to a mathematical analysis, but again, they are not dependent on the geometry in the rest of the pattern, so this must be the result of another arbitrary decision. Since these decisions are not decided or determined by the inherent structure of the rest of the pattern, we refer to this as an indeterminate pattern.

A rather less indeterminate version on this same basis is Bourgoin, Plate 116A, in which the forms of the 8- and 12-rosettes depend on the precise angles at the pentagon vertices where they contact the rosettes. Again, the pentagon centres are located in the same way as in the last pattern, but the size of the pentagons has to be decided, and whether we want them to be circle-inscribed, and also how we wish to construct them so they appear as regular as possible. So the arbitrary decisions made as to the size and shape of the non-regular pentagons determine the shapes of the two kinds of rosette. If the pattern designer wishes to avoid the interstitial pentagons altogether, yet retains 8- and 12-rosettes in contact, centred on the two tetrads of a *p4m* pattern, then a fully determinate realisation is possible, as in Bourgoin, Plate 118, standard construction. Unfortunately, this ideal situation was rarely achieved for this particular configuration in authentic Islamic ornament, mainly due to ignorance on the part of the artisans concerned.

The inclusion of non-regular motifs, whether stars or polygons, usually ensures that a pattern is indeterminate. All such non-regular motifs are typically drawn to look as though they were regular, but emulating this appearance in computer graphics is not always easy. This is because there is no single logical procedure for drawing them which is inherent in the geometry of the rest of the pattern. There may in fact be many possible routes to achieving a non-regular motif, perhaps in some cases infinitely many, and it becomes extremely tedious attempting to choose the mathematically most parsimonious sequence of arbitrary formulae which will produce a satisfactory result. We frequently have to erect the most elaborate underlying scaffolding of triangles in order to derive a suitable sequence of trigonometrical formulae. The inclusion of a single type of non-regular polygon in the interstitial area between the main motifs is usually fairly straightforward, e.g. pentagons (Bourgoin, Plate 168 — the 7s and 14s are regular) or heptagons (e.g. Sultan Shah mosque — the main rosettes are regular). However, these non-regular elements cannot be searched for.

We have not so far attempted to include non-regular main stars or rosettes (for a rare exception, see Imam Mosque, Kerman). In the first place, as stated already, the SQL search engine cannot recognize non-regular stars. In the second place, there is no simple computational procedure for satisfactorily including such approximate motifs within the structure of a pattern, even though in some cases their centres may be determined easily by the intersection of radii from regular motifs within the same pattern. In contrast to the second point, however, manual constructions (and some other computer graphical methods) present no such difficulty, since in general the manual artist is not concerned with the difference between "exact" and "non-exact" drawing methods.

6 Western Islam and the Octagonal Class of Patterns

It is curious that different regions of Islam have over the centuries shown preferences for families of patterns with particular symmetries. Thus, western Islam — mainly Spain and Morocco — has shown a predilection for eight-fold symmetries, or motifs in multiples of four, whereas eastern Islam — mainly Central Asia, and Iran especially — has chosen to work out the possibilities of ten-fold symmetries involving motifs with ten points.

The basic motifs in patterns with eight-fold local symmetries are two types of 8-pointed stars, seen for example in Samarra, Mosque of Gawhar, Mashhad, Bourgoin, Plate 42 and Alcazar, Seville. One, called khatem, has a vertex angle of 90°, while the other has a vertex angle of 45°. The second is geometrically a "stellated" variety of the first, so the two are frequently found combined in one motif. On the basis of these two simple stars various elaborated arrangements of increasing complexity may be built up, as in Alhambra, Sala de la Barca, Fez motif, Granada museum, Bou Inaniya Medersa/Mosque, Meknes, Meknes, Manezeh Fountain, Sefferine Medersa, Fez and Tomb of Moulay Ishmael, Meknes.

Patterns with 16-pointed rosettes occur in the Alhambra in Spain — Alhambra, Sala del Mexuar, and even, rarely, with 24 points — Alhambra, Sala de la Barca (although this last has a 12-fold, rather than an 8-fold background). However, it is to Morocco that we must turn for the most elaborate compositions with 8-fold motifs featuring a central motif of 24 points or higher, see Medersa Ben Youssef, Marrakesh, Fez. At present the 24-fold motif is the highest we have attempted, owing to difficulties in representing the incompatibilities between the large motif and its 8-fold background mathematically. These difficulties may be summarised by stating that the 8-fold local symmetries in the background allow for a rectilinear octagonal hole for the insertion of a large central motif, whereas the central motif itself necessarily has a circular boundary. In practice a mosaicist has a number of tricks up his sleeve to overcome these problems, but trying to emulate these in mathematical terms for computer graphical representations is not easy.

We have informally designated the set of shapes generated by increasingly elaborate patterns based on the two 8-pointed stars as the "8-matrix" series of shapes. This, however, is strictly a theoretical concept, and refers to polygonal shapes whose side lengths belong to a specified sequence of vectors, and whose internal angles are multiples of 45°. In practice, the Moroccan craftsmen include many other categories of shapes in their 8-fold backgrounds, which fill an ad hoc artistic need, but which do not properly belong to the 8-matrix set.

7 Persian Decagonal Compositions

Although western Islam has dabbled in 10-fold symmetries, and even has some quite complex compositions to its credit — e.g. Bu 'Inaniya Medersa, Fez, Bou Inaniya Medersa, Fez — these early forays never seem to have been followed up to the extent that 10-fold symmetries have been taken over by eastern Islam, particularly in Iran.

Again, the later elaborations had simple beginnings, e.g. Bourgoin, Plate 175, Qom, Atabeki Court, which gave rise to increasingly complex designs — Qom Atabeki courtyard, David Collection door panel, Fatima's Haram, Qom (and similar compositions further east, in India — Mausoleum of I'timad al-Daula).

The problem with increasingly complex compositions, containing many hundreds, or even thousands of individual shapes or cut tiles is that the overall structure of the whole can quickly become lost in a confusion of multicoloured chaos, unless some larger scale order is imposed on the perception of its grand design. In Morocco order is achieved through the use of smaller modular shapes which can be fitted together in many different ways to create a larger composition, e.g. Tomb of Moulay Ishmael, Meknes. In the case of Central Asian decagonal patterns, however, large scale order is usually brought about by means of two-level patterns.

8 Two-Level Patterns

Two-level patterns exist principally as subsets of those formed from the octagonal and decagonal "self-generating" series of tiles, and are characteristic of western Islam and Central Asia (especially Iran), respectively. In each case there is a large scale upper-level pattern, with a lower-level, smaller scale pattern filling the polygons of the larger pattern. See Masjid-i-Sayyed, Isfahan, Imamzeda Darbi Islam, Isfahan, Imamzeda Darbi Islam, Isfahan and Fatima's Haram, Qom. There are many different methods for achieving the interlocking between the two levels, but by no means all of them satisfy the criteria for self similarity that many recent authors have been at pains to establish. Nevertheless, it is a remarkable fact that many, if not all, shapes in certain series, say, the octagonal or decagonal, may be dissected into smaller shapes from the same series, and often in many different ways. It is uncertain to what extent this property may extend to other families of patterns, say, those based on 12-fold or 14-fold motifs.

If upper and lower levels of a two-level pattern employ shapes from the same geometrical series then the resulting composition is an example of true self similarity, see, for example Masjid-i-Jami, Isfahan. Many similar examples occur in Iran, but there are some equally complex patterns in which the lower level pattern uses the same series of shapes as in the previous example, but the upper level, while still a decagonal pattern, has shapes derived from the corresponding "rosette" type of decagonal pattern, e.g. that shown in Bourgoin, Plate 171. In this case, since the two levels use different series of shapes, the overall pattern cannot strictly be regarded as an example of self similarity. The same argument could be applied to many of the large, complex tile mosaic compositions characteristic of Moroccan zellij. Here, the overall pattern is built up from a number of standard modular shapes, traditionally outlined in black, such as octagons, squares, diamonds and other shapes, each filled with tile shapes derived from the octagonal series of patterns. Examples are Palace of the Bahia, Marrakech, Tomb of Moulay Ishmael, Meknes and Sultan's Palace, Tangier. Occasionally the modular shapes are outlined in blue, e.g. Moulay Ishmael Mosque, Fez.

The outlines of the upper level patterns from Morocco and Moorish Spain are not simple lines, but are normally composed of shapes from the lower level pattern. In contrast, in two-level patterns from Iran the outlines of the upper level pattern consist of lines made from elongate pieces of cut glazed tiles, usually blue or black in colour, and of an appreciable thickness relative to the scale of the small lower level elements. If the high quality image of Masjid-i-Jami, Isfahan is magnified it will be noticed that the blue outlines of the upper level pattern, while following local mirror axes through the lower level pattern, actually overlap and very slightly obscure those parts of the lower level shapes which are close to the mirror lines. This is the result of the lower level pattern having been drawn first, then simply overlaid with the thickened lines of the large scale pattern. This is not, however, the way authentic two-level patterns are constructed in Iran. Here, the local mirror lines of the lower level pattern become applied to the edges on each side of the thickened lines of the upper level pattern, not to the middle axis of those lines. Thus, the local mirror axes of the lower level pattern now coincide with the edges of the polygonal spaces enclosed by the thickened bands of the upper level pattern, and lower level pattern elements are still mirrored across the now thicker bands of the upper level pattern, into adjacent upper level polygons. Two important points follow from this. First, it often happens that the scale of the lower level elements each side of the upper level bands necessarily changes, because the lengths of two corresponding edges no longer exactly match. In practice, if the upper level bands are not too wide, this difference in scale can be ignored, and the same size of mosaic pieces can be used throughout the composition, but a precise mathematical treatment would find such scale changes awkward. Secondly, in calculating the overall dimensions of the whole two-level pattern, the thickness of the upper level bands has to be taken in account.

9 Newly Invented Patterns

Once we understand the basis for the construction of Islamic geometric patterns, it is tempting to invent new ones which as far as we know have never appeared as authentic examples. We have ourselves made a number of earlier forays into this area, see for example In Islamic Style (data175/AJL1), In Islamic Style (data186/IS1), both involving 18-point stars. A pattern with 14-pointed stars, In Islamic Style (data175/AJL2), was composed by analogy with Shah-i-Zinda complex, Mausoleum No 15, Samarkand and Cairo, Zawiyat al-Abbar, which are both authentic and embody similar geometries. The same 14-pointed star occurs in a different arrangement in Mosque of Gawhar Shad, Iran, which is from Iran, but our invented In Islamic Style (data175/AJL2) has not so far been seen as an authentic pattern. Patterns with 7- and 14-pointed motifs are relatively uncommon among all types of Islamic geometric patterns. About 3% of Bourgoin's collection contains examples of "heptagonal" patterns, and this proportion seems representative of Islamic patterns in general. A number of further patterns "in Islamic style" have been added to the web site recently, and more may be added in future versions.

10 † Some technical issues

This web site has been developed over some years. As our understanding has grown and the supporting software developed, some problems have been overcome, while others remain. Here, we consider some of the remaining issues:

Base pattern. Consider the patterns Alhambra, Sala de las dos Hermanas and Alhambra, Sala del Mexuar. These two patterns are essentially the same: the first being a zellij construction the second using interlacing. Strictly, the second one does not support the symmetry of reflection. (Reflection inverts the up/down sense.) Our decision is to ignore the influence of the interlacing on reflections and regard both patterns as having *p4m* symmetry. In other words, we regard the symmetry as being determined by the base pattern (disregarding interlacing and colour).

We have further problems with coloured interlacing or banding which appears in only part of a pattern, since the identification of the base pattern is perhaps less obvious. Since coloured interlacing is handled by drawing the interlace using extra polygons, we need a different approach in order for the description of the geometry to reflect the properties of the base pattern. We achieve this by using the base pattern to derive the geometric properties, but the full pattern for drawing the graphic.

Text searching. A record has been made recently of the usages of the search facilities. It has been found that the text search is used substantially, but text searches have several problems:

1. Spelling is taken from the source documents which are often inconsistent.
2. The country in which a pattern appears is often not given explicitly.
3. The text used for searching was not specifically written with searching in mind.

Due the amount of text within the system, it will take sometime to overcome these problems.

Approximate polygons. The design of the system does not lend itself to allowing a search, for say, a pentagon which is not quite regular. In principle, it would be possible to search for a pentagon whose vertices lie of a circle. The difficulty with such a proposal is that the search facilities become more complex. Usage seems to indicate that the current search facilities are complex enough.

Irregular tiles. An index to almost all of the irregular tiles has been produced, but it is not clear how such information could be used. One possibility would be add a step into the tree search for the presence of a specific irregular tile.

"Difficult" patterns. As noted above, producing a pattern using the mathematical methods defined here, it becomes increasingly difficult if the pattern has underlying complexity. Examples are TRA 0601 and TRA 0218. It is not clear if we should list such examples, since it is always possible that such patterns are produced in a mathematical form in spite of the inherent difficulty.

A related issue are the patterns for which no high-quality image (ie, PDF) is available. This patterns were originally provided so that the Bourgoin plates could be all included in the system. However, they are only partly integrated into the system implying that the design of this part of the system should be reconsidered.