A Timber-framed Encyclopaedia of Geometrical Carpentry Design

Laurie SMITH

HISTORICBUILDINGGEOMETRY

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Figure 1

Introduction

The doorhead of the two storey timber framed porch at Old Impton, built at Norton in Radnorshire in 1542, is carved with a virtuoso array of geometrical symbols and foliage panels, figure 1. The two prominent and visually striking geometrical constructions, the interlaced squares on the left and circle of interlaced arcs on the right, are key to understanding the design of the porch for both are constructed on underlying, compass drawn geometrical modules that function as proportional guides at every stage of the design. This paper commences with the geometrical construction of the modules and then demonstrates how the three dimensional framework of the porch and its two dimensional surface patterns were all designed geometrically using them as reference. Because geometrical design is a practical, hands on process the developments are shown in step by step geometrical drawings.

Modules

An early documentary reference to modules used as proportional guides in architectural design can be found in the writing of Vitruvius, the 1st century BC Roman architect and author of *The Ten Books on Architecture*. Vitruvius states that buildings can be proportioned . . . *in accordance with a certain part selected as standard . . . to the diameter of a column . . . or even to a module*. Describing the design of classical amphitheatres, Vitruvius shows that the Greek design, figure 2, evolves from a core geometrical construction of three superimposed squares within a circle and the Roman design, figure 3, from four superimposed equilateral triangles within a circle, both constructions generating twelve equidistant points around the circle's circumference. Radii expanding through these points outside the circle determine the alignments of steps within each auditorium.

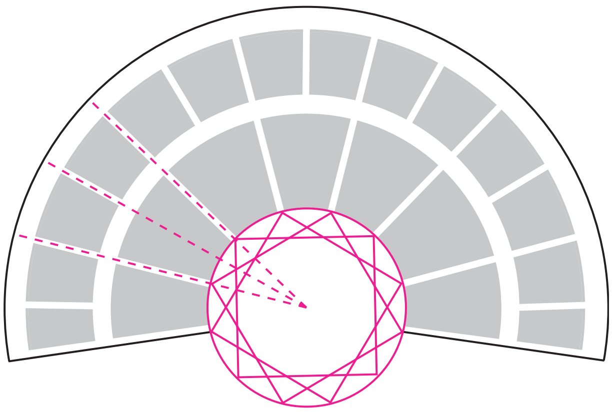

Figure 2 The Greek amphitheatre

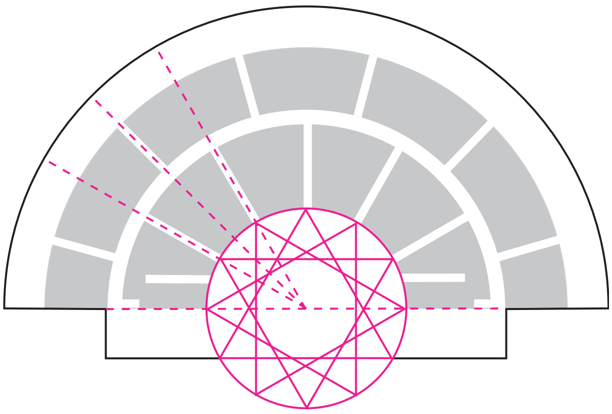

Figure 3 The Roman amphitheatre

The two amphitheatre geometries are clearly neither *a certain part selected as standard* nor *the diameter of a column* but are unmistakeably examples of modules. The module was a conceptual breakthrough, a recognition that the circle could act as a vessel carrying geometrical instructions that could be used to design two dimensional patterns and three dimensional structures, or both. This idea was second nature to the Old Impton carpenter.

Two related compass-drawn modules are used at Old Impton, each underlying one of the doorhead's two dominant geometrical constructions. The interlaced squares on the left of the doorhead are developed, perhaps unexpectedly, from a five circle geometry, figure 3. The circle of interlaced arcs on the right is developed from the seven circle daisy wheel, figure 4.

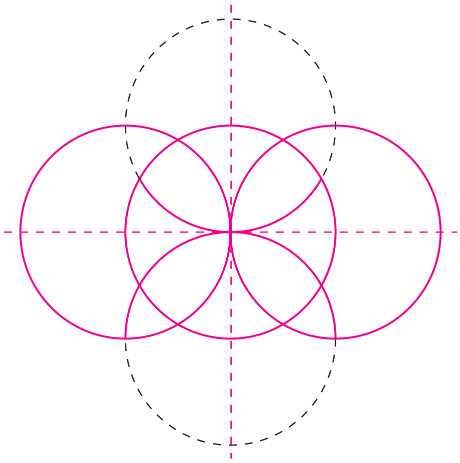

Figure 3 Five Circle Module

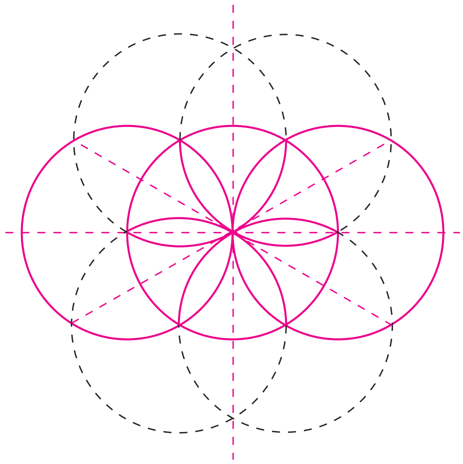

Figure 4 Daisy Wheel Module

The five circle module is an example of two *linear* circle sequences that cross at right angles and therefore share a common circle at the module's centre, hence the five circles. The daisy wheel module is an example of *rotational* circle development where six circles are drawn around the circumference of a central circle. In the first stage of drawing, the five circle and daisy wheel modules share the common characteristic of three circles drawn along a centre line. Because the modules have all their circles drawn to an identical radius their structures embody an intrinsic proportional symmetry that is the bedrock of the Old Impton design.

Both modules have a number of points of intersection. The five circle module has eight on the central circle's circumference and four more where the outer circles cross. The daisy wheel has six on the central circle's circumference and another six where the outer circles cross that can be connected to the circle's axis. There are twelve intersections in each module's central circle and these are the same twelve points found in the Greek and Roman modules.

Designing the porch facade with the five circle module

Figure 5 shows Old Impton's two-storey porch with later *panic posts* inserted under the front jetty to prevent its imaginary collapse.

Figure 6, at the head of page 5, shows the construction of a large square from the intersections of the module's four outer circles and a small square and diamond from the central circle's twelve points of intersection. From these constructions a finer grid of diagonals can be drawn to provide a graph for the design of the porch facade.

Figure 7, at the foot of page 5, shows, on the left, the three proportionally related stages of the porch facade design, the ground level entrance, upper floor and gable. Each stage is shown here on a separate grid for clarity but, in reality, there is only one drawing. On the right, following the magenta arrows, the three elements are brought together to form the facade.

The design logic is crystal clear: that the gable, upper floor and ground level entrance are constructed in the upper, middle and lower parts of the grid in accord with their intended positions.

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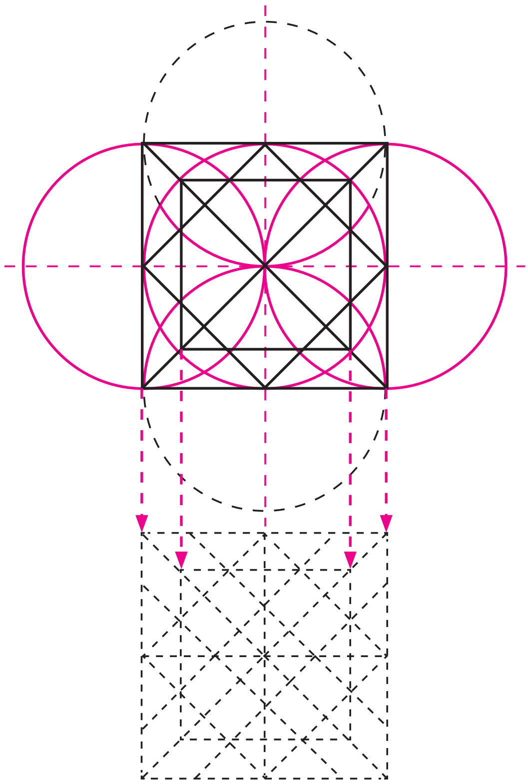

Figure 6 Developing a grid from the module.

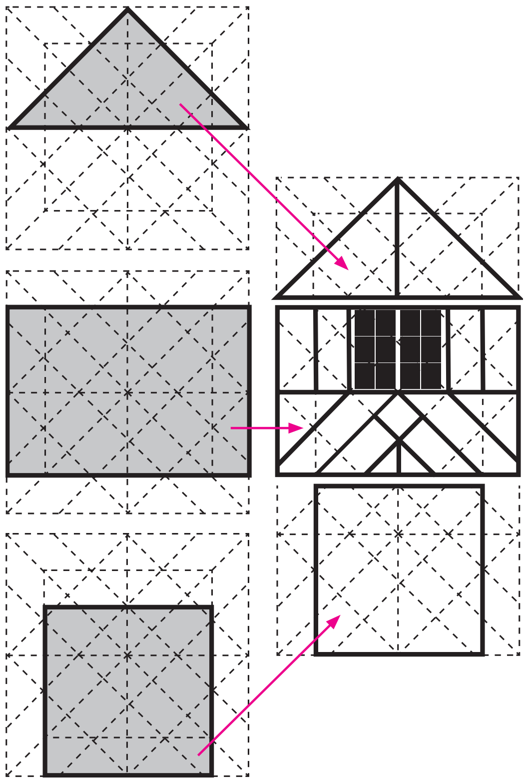

Figure 7 Porch proportions, left, and assembly, right.

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Designing the jettied first floor

The grid also provides a platform, literally, for the design of the jettied first floor, which simultaneously acts as the ceiling of the ground floor entrance. The jetty oversails the ground floor by the distance between the large and small squares of the grid.

Figure 8 shows the grid and the diagonals selected to frame the floor. The large square's full diagonals cross at the centre of the floor and project outwards beyond the small square as dragon beams at the corners of the porch. The intermediate diagonals combine to form chevrons that are triangulated from the large square inwards across the small square.

Figure 9 shows the ceiling within the porch where the left quadrant's original chevron has been lost and replaced by conventional joists.

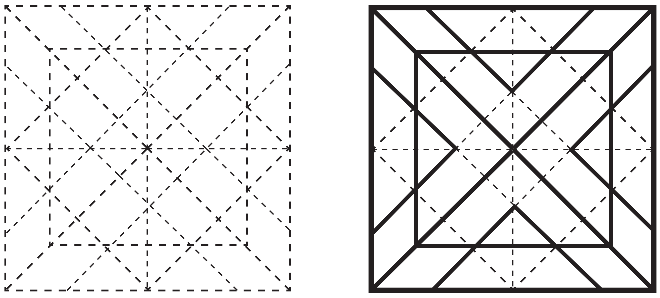

Figure 8 Dragon beams and chevrons in the grid


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Figure 9 Dragon beams and chevrons

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Designing the doorhead

The deep profile of the doorhead is also generated from the five circles module. Figure 10 shows how two squares (or a square and diamond) are drawn from the perpendiculars and diagonal intersections of the central circle to overlap in the form of an eight point star.

Figure 11 shows how compass bisection of the star's stellations establishes a second star and how the distance between the two stars forms a parallel bandwidth. The geometrical construction is shown on one stellation for clarity but would, in reality, be constructed on all the stellations to enable accurate construction of the bandwidth. The bandwidth is used as the construction for the doorhead's interlaced squares, shown on the left in the photograph above.

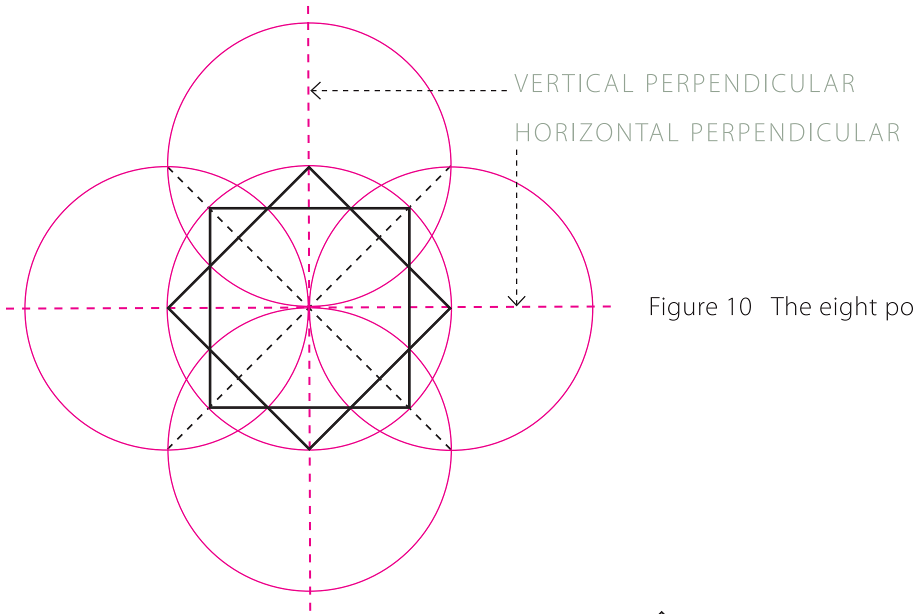
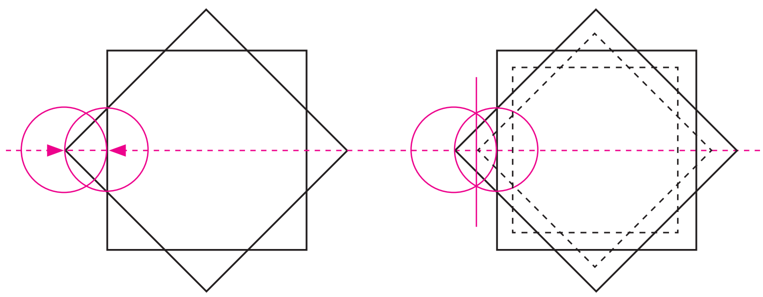


Figure 10 The eight point star

Figure 11 The parallel star



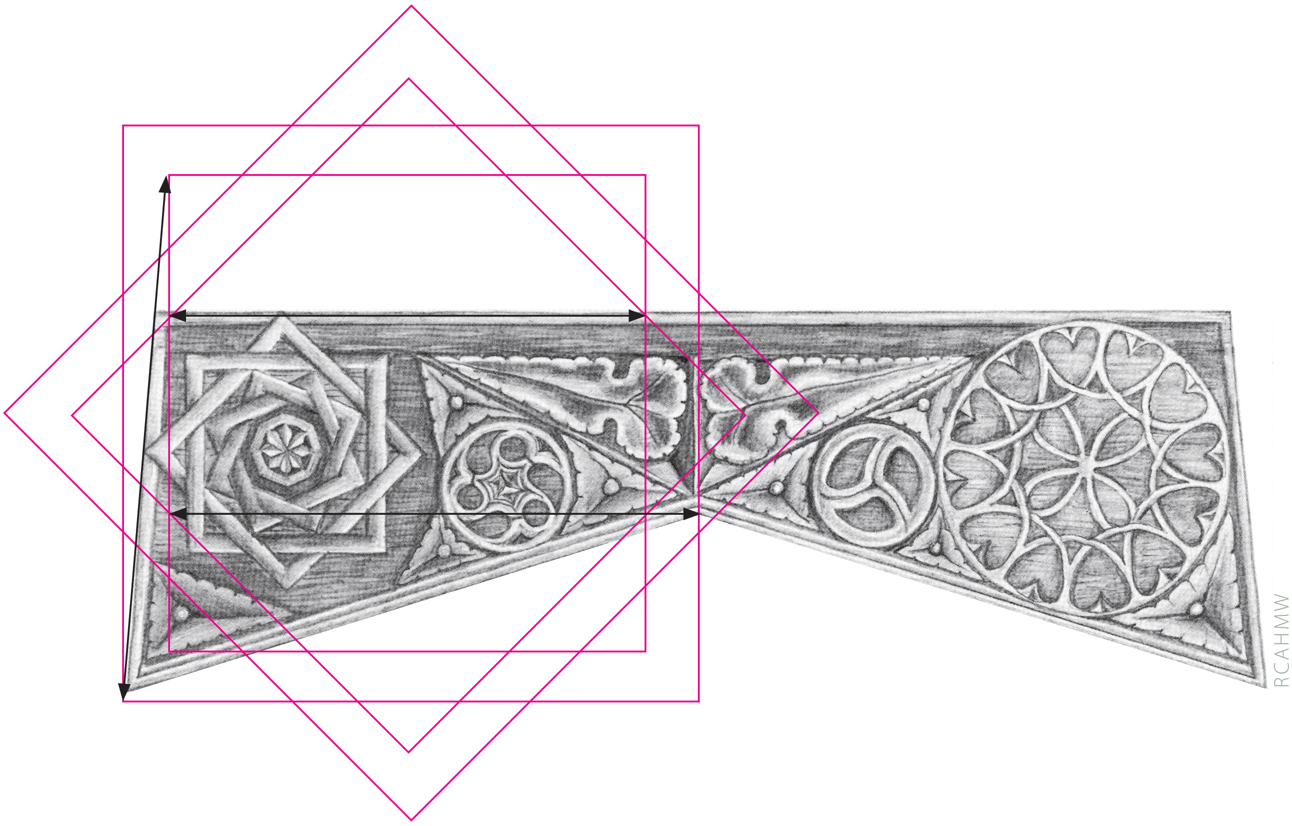


Figure 12 The eight point star doorhead design

Once the parallel stars are constructed the profile of half the doorhead can be designed by connecting points of intersection within the stars. Figure 12 shows how the left half of the doorhead is designed using cardinal points of intersection, indicated by magenta arrows, within the parallel eight point stars. The design is replicated in mirror image for the doorhead's right half.

Figure 13 continues the construction of the doorhead's interlaced squares. It follows logically that because the eight point star has eight angles between the stellations it also has eight angles on its internal face. The eight internal angles are the points of connection for the two smaller, internal interlaced squares. The left drawing shows the outline of one square and the right drawing completes the doorhead image. If the bandwidth of the outer star is also used for the inner star the small triangles that form the stellations are diminished on the internal star, exactly like the Old Impton doorhead.

The small octagonal space at the centre of the interlaced squares is filled, appropriately, with an eight petal rosette. The rosette can also be designed using radials drawn between the five circle module's eight points of intersection.

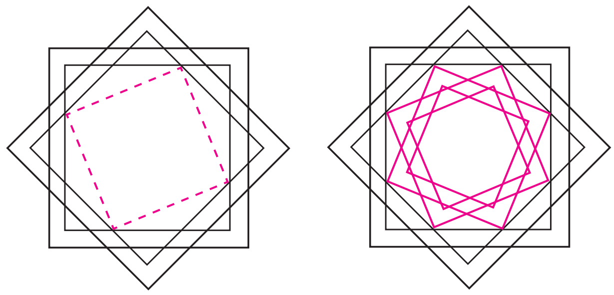


Figure 13 The interlaced squares

Designing the jetty bressummer

The final stage of five circle design is marking out the jetty bressummer in a continuous strip of alternating triangles, diamonds and parallelograms between plain roll mouldings. Everything is based on two whirling squares, drawn in black line in the five circle module. The geometry and a photograph of the bressummer are shown together in figure 14.

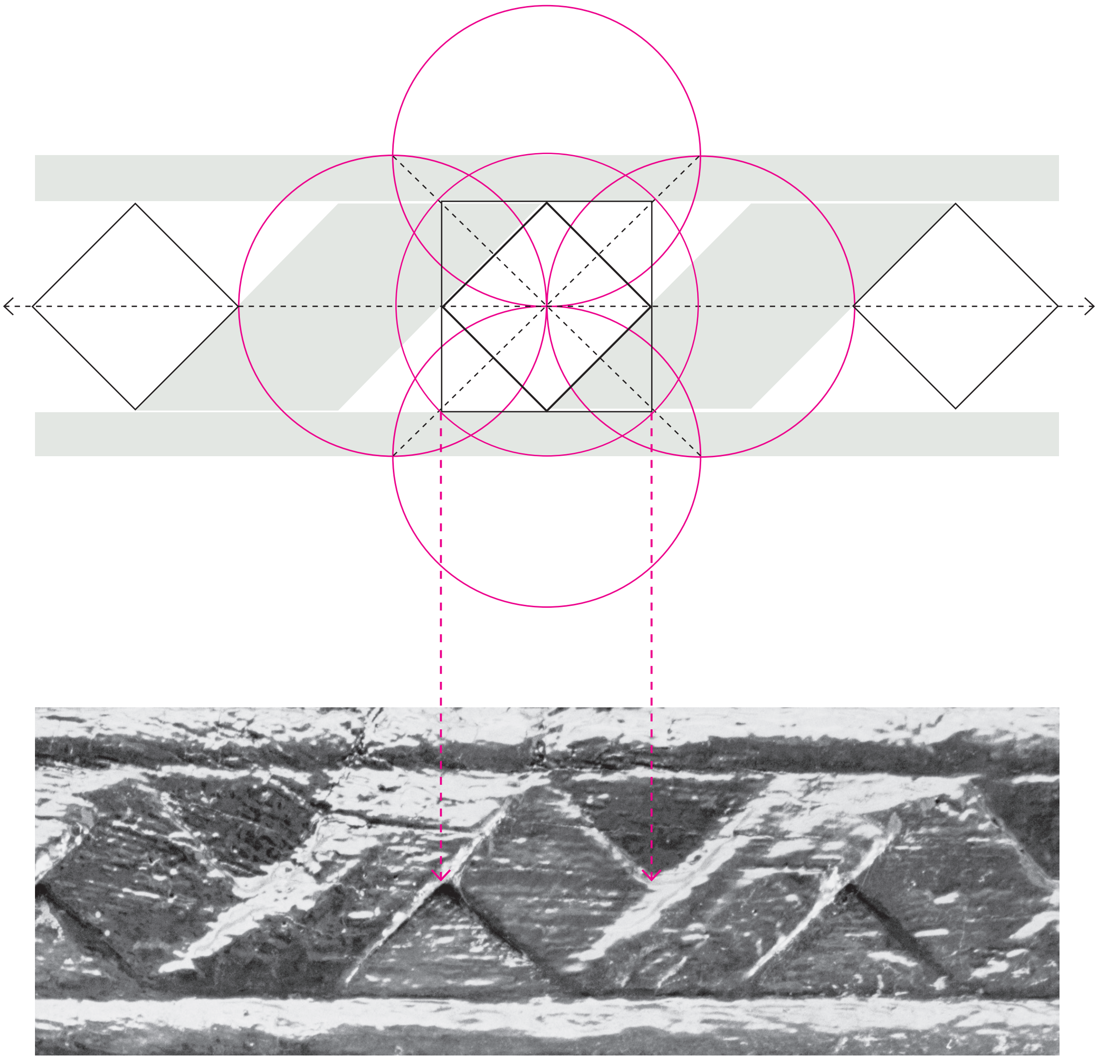


Figure 14 The bressummer moulding

Designing the doorhead surface pattern with the daisy wheel module

As well as the major image of interlaced squares on the left, the doorhead displays three circular images, two smaller circles that are centrally placed and the major circle of interlaced arcs on the right, that counterbalance the interlaced squares. The three circular images are designed using the daisy wheel module or, to be precise, from the module's central circle and its internal configuration of arcs, figure 15.

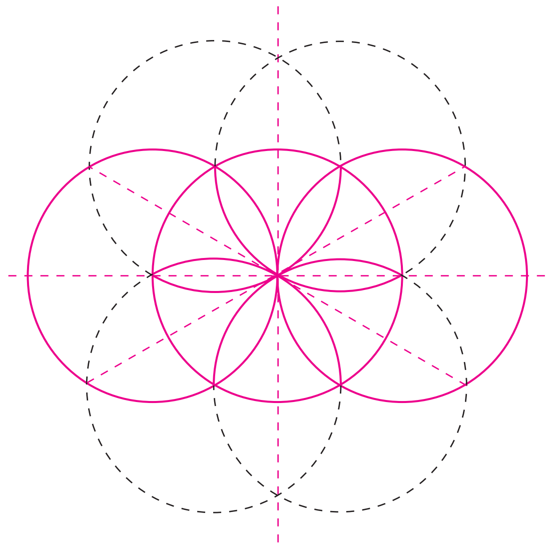


Figure 15 The daisy wheel module

Drawing the interlaced arcs

The petal tips of the daisy wheel mark six equidistant points around the circle and these can be connected to form two equilateral triangles which, in combination, form the star of David. Figure 16 shows the construction is drawn on the same axis as the interlaced circles on the doorhead.

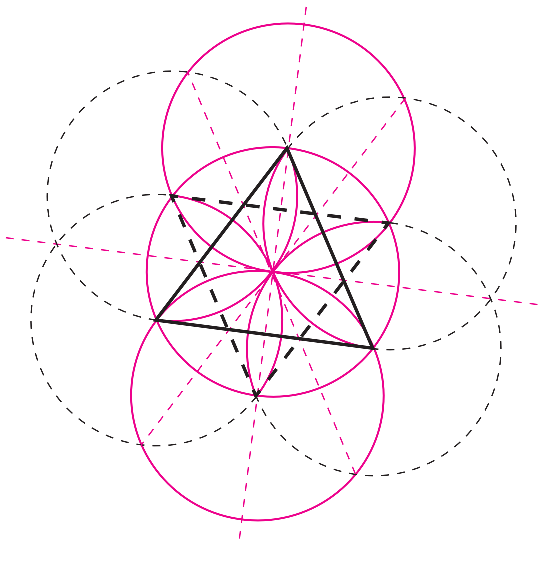


Figure 16 The star of David

The interlaced arcs are drawn in two stages, the first six arcs with their axes on the six points of the Star and their arcs touching the equilateral triangles, figure 17.

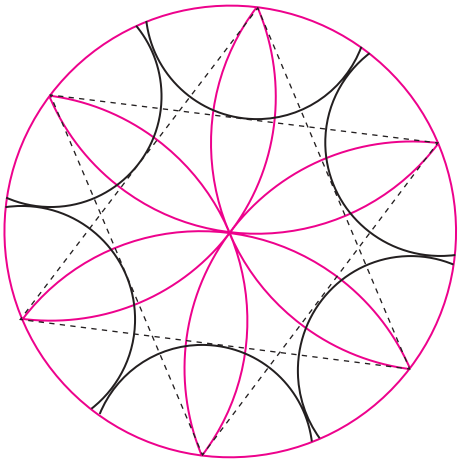


Figure 17 The first six arcs

The first six arcs meet just inside the main circle so that they reach the circumference slightly apart and the second six interlacing arcs are drawn with their axes in these small gaps. The gaps also define the bandwidth of the interlaced arcs by defining the origins and terminations of twelve further, parallel arcs, of which just two are shown at the top of the circle in figure 18.

With twelve interlaced arcs the circle can be divided into four quadrants (12 ÷ 3 = 4), by drawing perpendicular diameters. Where the two diameters intersect the interlaced arcs, at the arrows, they define the four axes from which the central arced cross is drawn. This is also shown in figure 18 where, for clarity, the daisy wheel petals and the star of David are omitted.

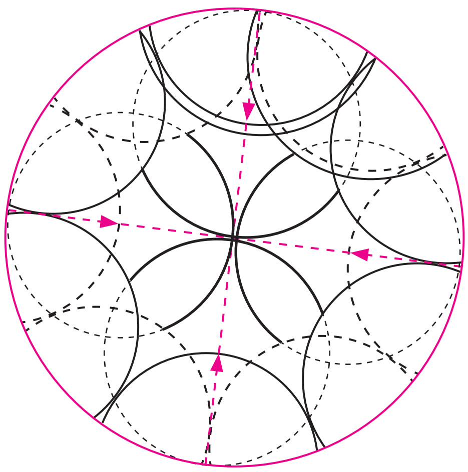


Figure 18 The second six arcs and central cross

Drawing the small central circles

The small circle to the left of the doorhead's centre uses the same background geometry as the large interlaced circle. The daisy wheel generates the star of David and where its two equilateral triangles intersect they give the axes of six small circles which meet at lines bisecting the daisy wheel's petals. This is the only way possible to draw this circle of circles.

The circle of circles is refined as a ring of interconnected double circles with diminishing tails by removing sectors of the circumferences and drawing a larger, surrounding circle. The double circles are also connected by a link exactly where the sides of the equilateral triangles pass through their circumferences. A small triangle is drawn at the centre.

The small circle on the right of the doorhead's centre is a simple triskel that follows the curves of the daisy wheel petals, figure 19.

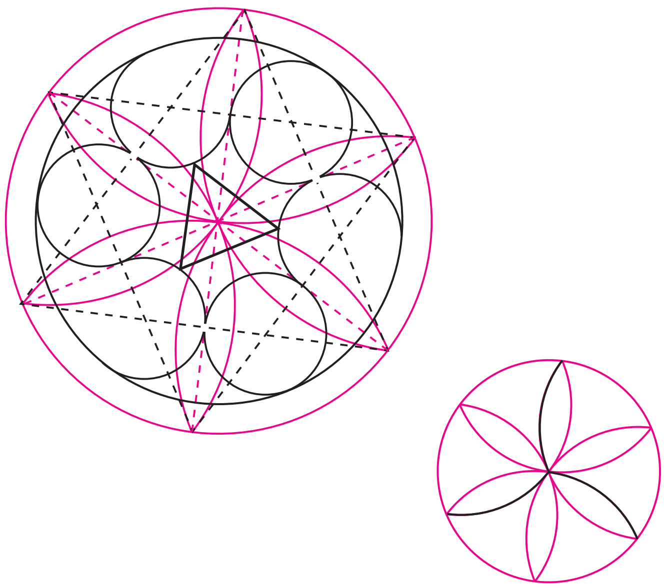


Figure 19 Ring of circles and the triskel

Placing the interlaced squares and circles

The five circle and daisy wheel modules underpin every aspect of the doorhead's visible geometrical constructions. In some cases, such as the triskel, the link with the daisy wheel is easy to detect but in others, such as the interlaced squares, almost impossible without a knowledge of geometry. In each case the geometry of the modules can be seen as temporary design scaffolding which is removed after use, in the same way that a builder's scaffolding is dismantled after it has served its purpose.

However, there are even deeper geometrical relationships in the layout of the doorhead for, although different in scale to the eye, the interlaced squares and circle of interlaced arcs that dominate the doorhead share their diagonal and diameter as a common dimension. This is shown in figure 20 where the diagonals, diameters and primary elements of each module are superimposed upon the other at identical scale.

Further, as well as occupying opposite ends of the doorhead, the two major geometrical constructions occupy precision locations in relation to the doorhead's boundary moulding. The interlaced squares extend to the upper and left hand *outer* edges of the doorhead's perimeter moulding while the circle of interlaced arcs rests against its *inner* edges at the upper, lower and right hand sides. These placings, which are assymetrical to the modern eye, are both considered and precise in expressing the two locational choices open to the carpenter, either to extend across the boundary to its outer extremity or to remain constrained within it. There is a visual logic in the sharp angles of the interlaced squares piercing the boundary while the soft form of the interlaced circles is contained by it.

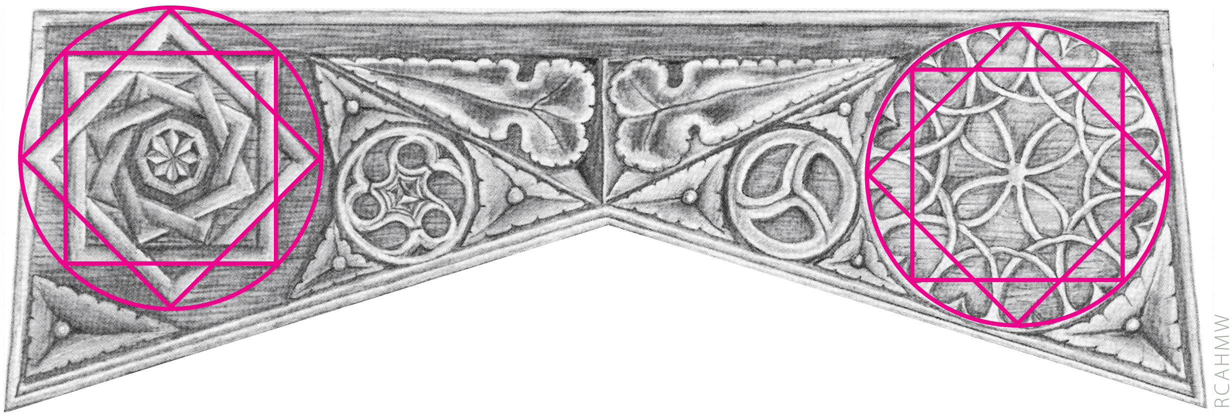


Figure 20 The doorhead's integrated geometry and asymetrical symmetry

Designing the jetty brackets

The four brackets supporting the upper floor and gable jetties of the porch are carved on the side facing the entrance. Three display further geometrical and foliage carvings and the fourth a full set of carpenter's tools, to all intents and purposes a portrait of the Old Impton carpenter's personal tool kit. The brackets are designed using the daisy wheel module. Figure 22 shows how connection of four of the wheel's petal tips forms a rectangle that determines the bracket's straight vertical and horizontal sides. The rectangle has the harmonic ratio 1:2 between its short side and diagonal.

Figure 23 shows how the rectangle's diagonal is modified to give the the bracket's curvature, the radius of the daisy wheel being tripled to give the larger radius necessary for drawing the curve. This is simple to attain by taking the radius and stepping it out three steps along a line, upper drawing. A string double the length of this line can be placed manually at opposite ends of the bracket's curve, pulled taut, and it's centre marks the arc's axis, lower drawing. From the axis a stick and nail trammel can be used to scribe the curve and once the first bracket is cut to shape it can be used as a template to scribe the remainder.

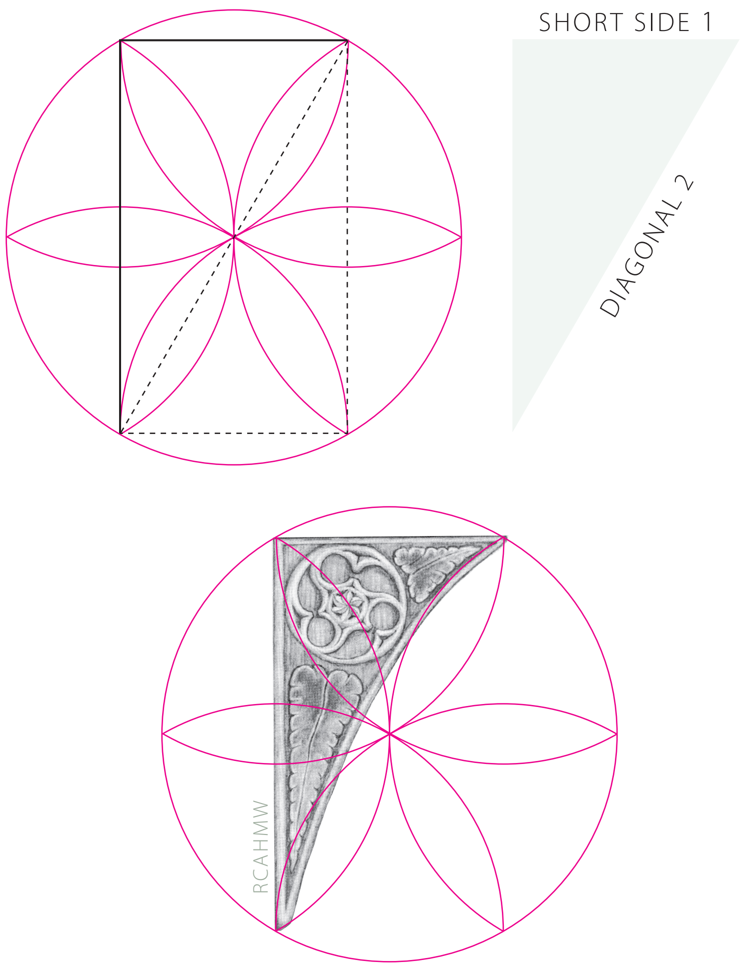


Figure 22 A jetty bracket

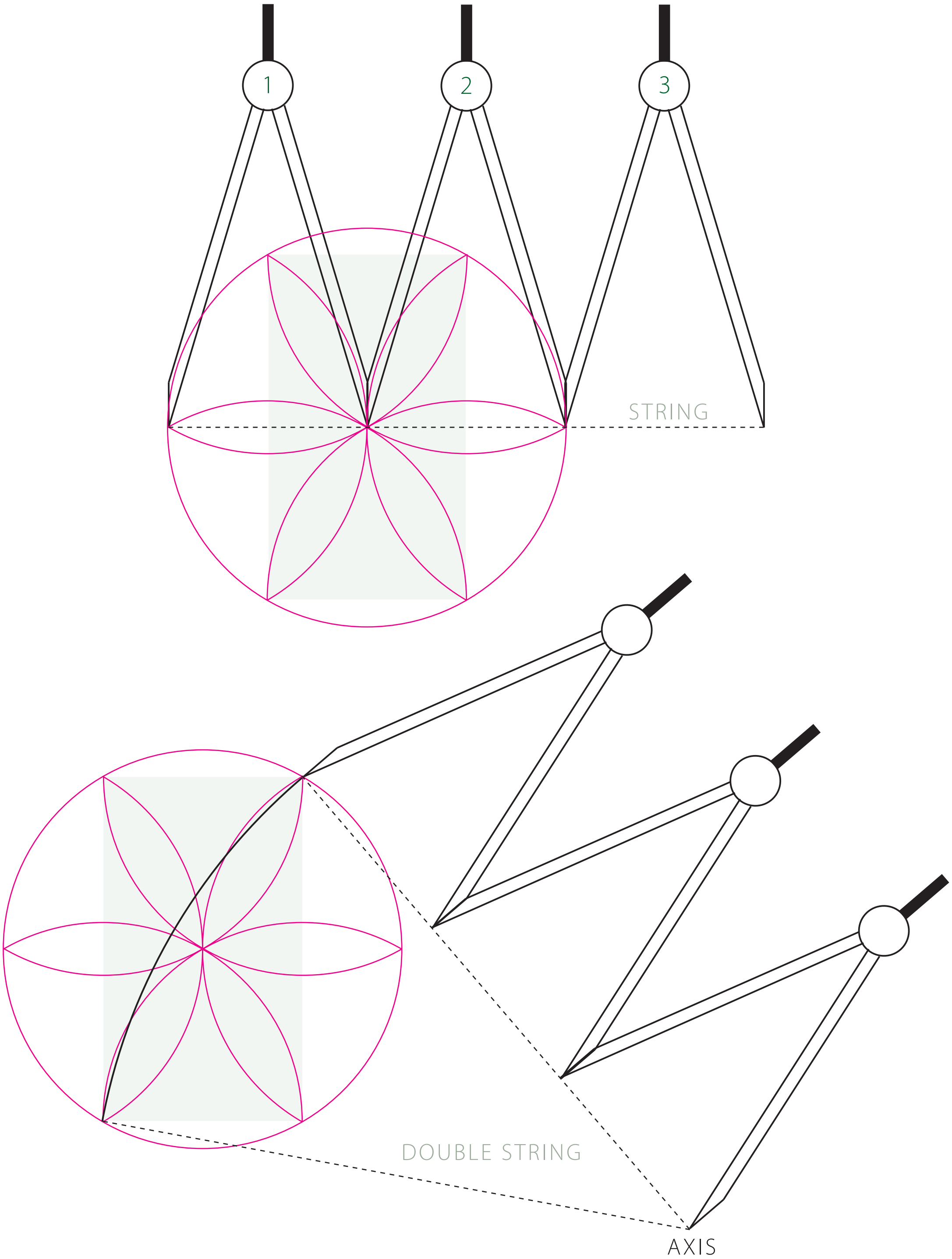


Figure 23 The bracket's curvature

The main circle geometry on the bracket shown in figure 22 is identical to that on the doorhead shown in figure 19 but, at the very centre, there is a further, highly intricate construction that is, once again, drawn from the daisy wheel module.

The design uses the triangulation between three daisy wheel petal tips so that each arc has its axis at point 1 and passes through points 2 and 3. This construction is made from all six petal tips so that the arcs intersect each other between the daisy wheel petals.

A second set of arcs are drawn from the intersections of the first (at the magenta arrow tip) to form radial arcs between the daisy wheel's petals. Both stages are shown in figure 24.

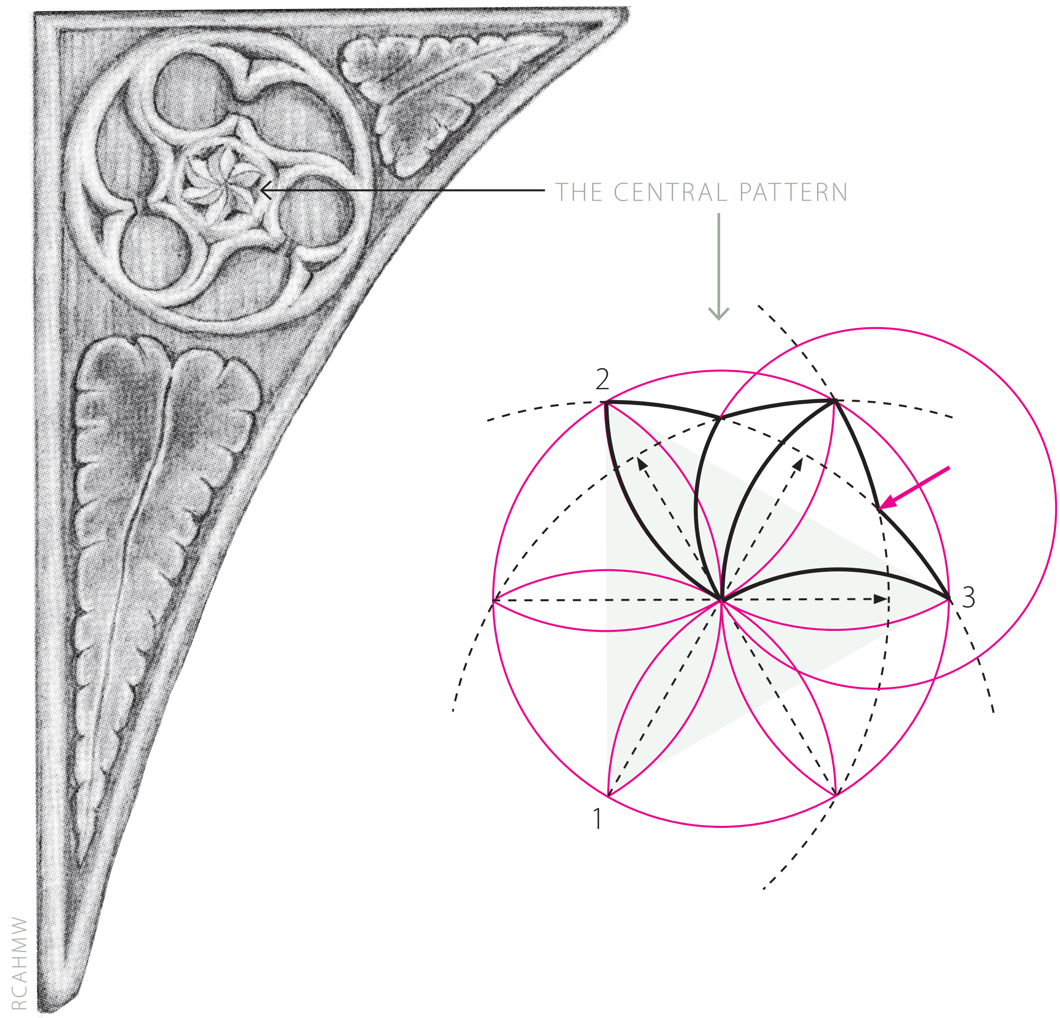
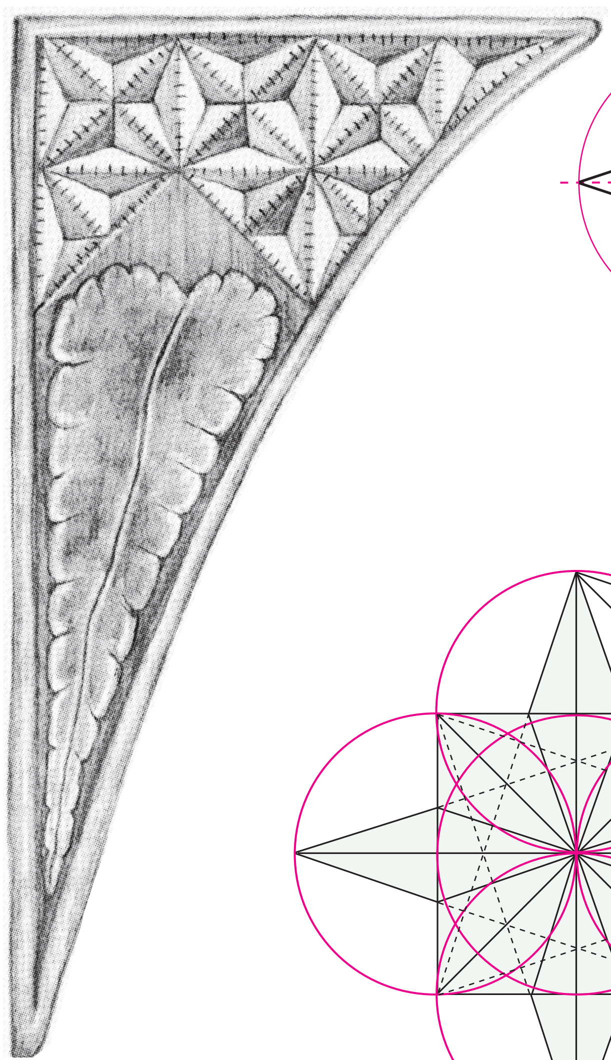


Figure 24 The intricate central pattern

There is a further pattern of note on the brackets, drawn using the five circle module to generate an angular linear grid of interlocking stellated squares.

First, a square is drawn from the intersections of the four outer circles and then each corner of the square is triangulated to the apex of the opposite circle. This generates four small triangles outside the square (in the four outer circles) which are then connected diagonally to form four further triangles inside the square. The eight triangles combine in mirror image to form four diamonds or stellated square, figure 25.

The pattern can be developed manually by extending the lines and repeating lengths using a straight edge and dividers, the method almost certainly used by the Old Impton carpenter. In figure 26 two of the pattern's angular stars are emphasised in tone but the pattern can be read visually in many other ways.



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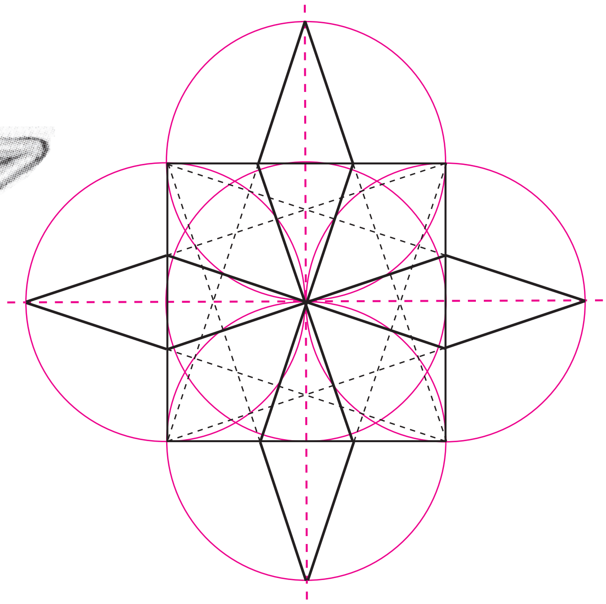

Figure 25   The four diamonds

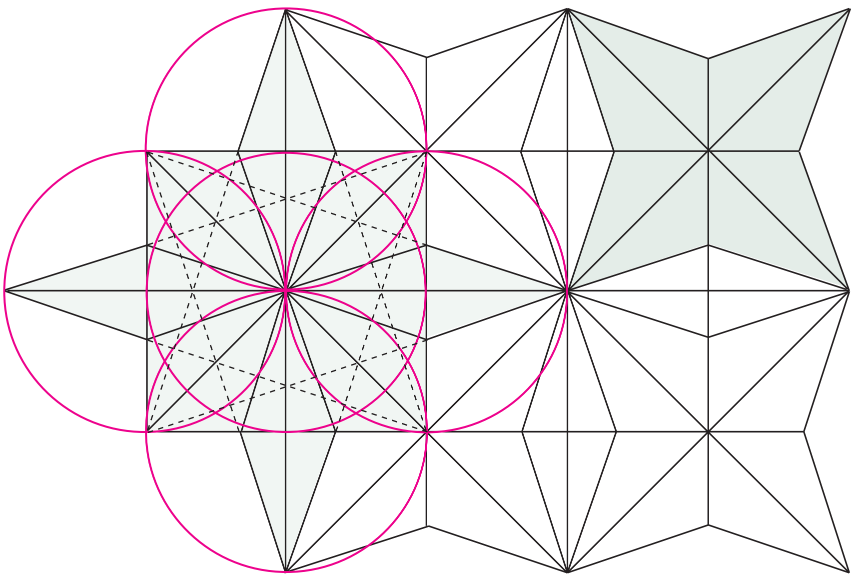

Figure 26   Angular stars developed in the grid


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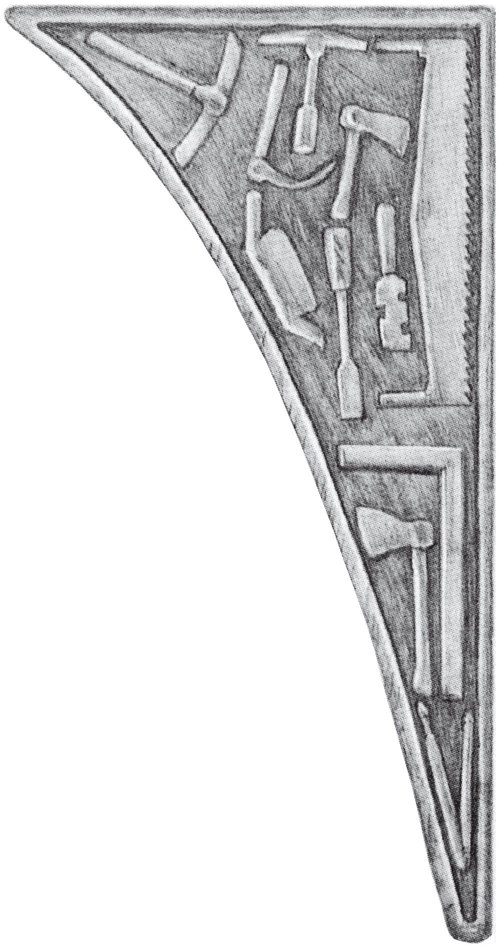
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Figure 27 The carpenter's tool kit

The carpenter's tool kit

The last face of the jetty brackets is carved representationally with a full carpenter's tool kit, figure 27, a forceful reminder of the practical and physically demanding realities of converting living trees into the scribed, cut, jointed and assembled timbers of a standing frame. But it is clearly also an emphatic badge of pride in the practical skills of carpentry.

Placing the square and proportioning the tools

The carpenter's tool kit, though representational, follows the same geometrical scheme applied to the whole design. For example, the carved square hangs exactly on the daisy wheel's horizontal diameter just as it would in use if hung from a horizontal timber for marking a right angle on the timber's vertical face, confirming the fact that the square's location on the bracket is considered rather than accidental, figure 28.

Three major tools are proportioned using the rectangle defined between four of the daisy wheel's six petal points. The double-handed saw occupies half a rectangle, the square a full rectangle and the dividers, appropriately, an angle formed from the diagonal and edge of half a rectangle. It is interesting that these tools each have related functions, the square and dividers for marking out timbers for cutting and the saw for carrying out the work. The proportional relationships of the tools to the daisy wheel are shown in figure 29.

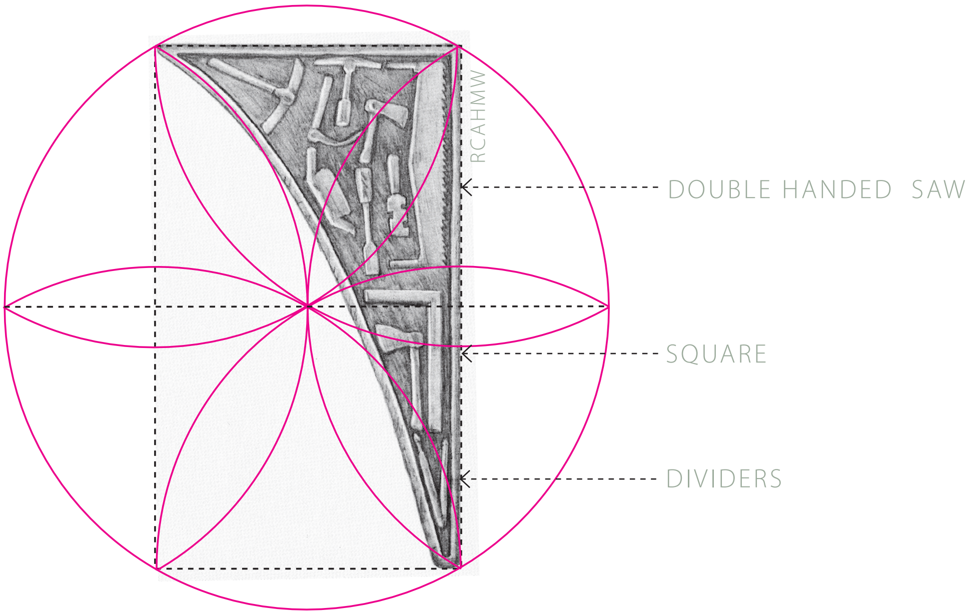


Figure 28 The square's position

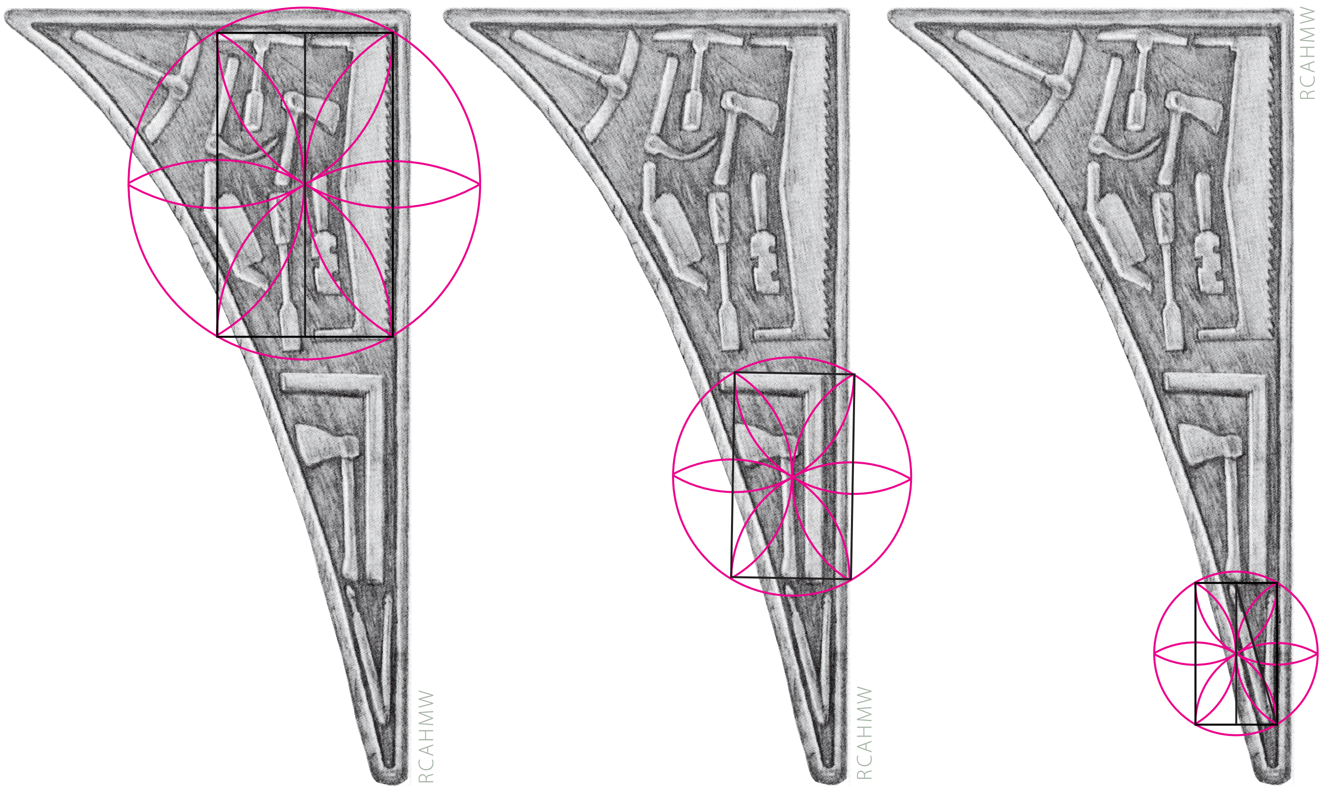


Figure 29 The proportions of the double-handed saw, square and dividers

Ommissions

There are a few ommissions from the description. Of the four jetty brackets, the two supporting the upper floor are angled to follow the alignment of the dragon beams while the two supporting the gable are conventionally placed at right angles to the wall. The upper floor of the facade projects forward in the form of an oriel as is evident in figure 27. There is a further carving, in the form of a concentric, three layered, six petalled rosette, on one of the brackets. These elements are all derived from the geometries described above, the rosette from the daisy wheel module, the brackets and oriel from the five circle module.

The description of the gable geometry from the five circle module defines the principal rafters. The common rafters are additional to this.

Scaling up

The geometrical design process is high on spatial proportion and low on numerical calculation. The design of the modules is based on a single radius and, if this is used for both modules, their proportional values are entirely interchangeable.

The modules, and any development from them, can be scaled up by using dividers. For example, if the diameter of a module circle is 6 inches long and a required full size circle diameter is 6 feet (72 inches) then the diameters of the modules are in 1 : 12 scale to full size. It follows that any inter-point distance taken by dividers is in the same 1 : 12 ratio to full size. The divider reading is then marked out in twelve steps along a chalk line snapped onto the required timber, a technique that modern frame carpenters refer to as *stepping out*. To limit the chance of error in counting the steps

Proportions and dimensions

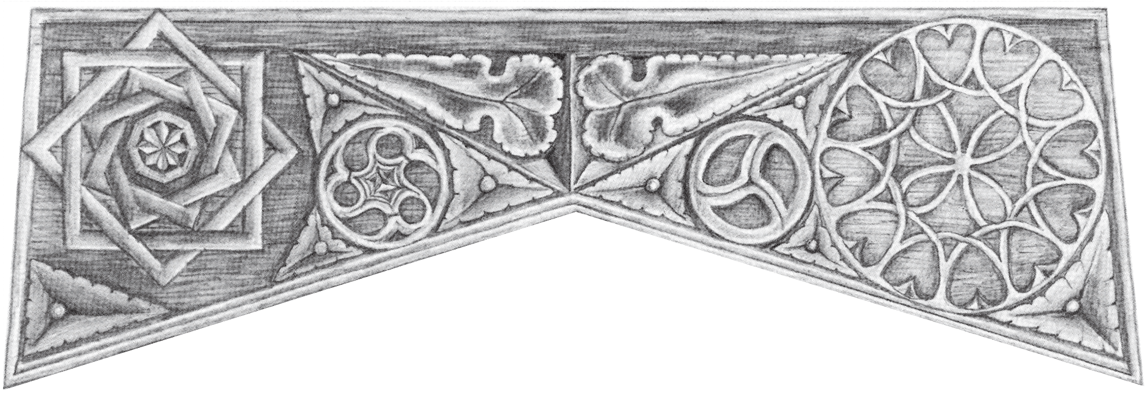
The framing at Old Impton is superb whether or not its geometrical basis is understood. If it *is* understood the framing becomes a geometrical tour de force, an encyclopaedic demonstration of the two primary geometrical modular design systems and how they can be used to determine both the building's three dimensional structure and the two dimensional patterns that enrich it.

A lesson to be learnt from Old Impton is that because the design is geometrical its genesis and development can only be fully comprehended through geometrical analysis. No amount of linear measurement would reveal its true nature because the geometrical language spoken at Old Impton was entirely spatial in concept. To be precise, flat geometries developed in the two dimensional plane were converted into timber frames and then raised, in the manner of flat stage sets, to combine in the assembled form of the building's full three dimensional structure.

A further lesson is that, though the building's geometrical surface decoration was the signal leading to a recognition of the underlying structural design, if the carpenter had left his frame plain the structural design would still be there. The three important recognitions are first, that geometrical design systems were the state of the art design system of the time, second, that where buildings survive substantially intact it is possible to recover the original design through geometrical analysis and third, through doing so we can wind the clock back and enter the design mindset of the time.

Cypher, symbol, module

The most important aspect of the Old Impton porch is the presence of display geometries that can be unlocked to reveal the building's design. These prominently placed and visually arresting geometries are demonstrably cyphers, symbols or modules that speak a spatial language to those who understand them. The carpenter's pride in his craftsmanship, expressed in the jetty bracket's tool kit, was equalled by an identical pride in his geometrical design acumen which he emblazoned, in pride of place, across the doorhead. This was his design manual, there like a Rosetta Stone, for anyone to read.



Acknowledgements

I wish to acknowledge the support and encouragement of Richard Suggett of The Royal Commission on the Ancient and Historical Monuments of Wales, Aberystwyth who first brought the Old Impton porch to my notice, gave generously of his time to discuss the findings and actively encouraged their publication. My thanks also go to the staff of the National Monuments Record in Aberystwyth who gave access to their file on Old Impton and provided copies of drawings and photographs. The photographs, plans and representational drawings of Old Impton that illustrate the text are used by permission of The Royal Commission on the Ancient and Historical Monuments of Wales (RCAHMW). All geometrical drawings are by the author.

The drawing above, which shows the doorhead of the two storey porch at Old Impton in Radnorshire, is from Richard Suggett's book *Houses and History in the March of Wales*, published by the Royal Commission on the Ancient and Historical Monuments of Wales, Aberystwyth and was used with permission in a review of the book by this author in the Mortice and Tenon, the Carpenters' Fellowship Journal of Traditional Timber Framing, M&T 26, Winter 2006.

Old Impton Porch : Some further thoughts

First, from the perspective of practical carpentry, it is important to recognise that the geometrical constructions relate to those elements of the framing that are visible after assembly. It should be remembered that the geometrical design does not account, for example, for the tenons at either end of the doorhead that fit within mortices in the door jambs. After assembly the mortices and tenons would be invisible, except for the pegs that hold them together. However, the mortices and tenons would conform to the carpenter's general marking out code for timber joints and would be additions to the visible doorhead. The mortices and tenons have not been shown here.

Secondly, the framing is superb whether or not its geometrical basis is understood. If the geometry ***is*** understood the framing becomes a geometrical tour de force, an encyclopaedic demonstration of the two primary geometrical design systems, how they can be used to determine three dimensional structure and how they can also generate the two dimensional patterns that are applied to it. The two systems, the daisy wheel and five circles are the basis of all triangle, square and rectangle based geometrical design in the medieval period and both commence from a sequence of three circles drawn along a centre line. The difference is that the daisy wheel has four further circles drawn from the intersections of the first three while the five circles has two further circles drawn on a perpendicular to the first three. Because both systems originate in a sequence of three circles on a centre line it follows that they are harmonically related so that, whichever is used by the carpenter, the resulting configurations will exist in aesthetic harmony, even when circular and square imagery exists side by side.

The most important lesson to be learnt from Old Impton is that because the design is geometrical its underlying concept and subsequent development can only be fully comprehended through geometrical analysis. No amount of analysis by linear measurement would reveal its true nature. It is geometrical and therefore entirely spatial in concept, it is not dimensional and measurement based in the way that we think and design now. To be precise, its geometrical development occurs in a sequence of geometries in the two dimensional plane that are raised, in the manner of flat stage set scenes, to combine in the building's three dimensional structure. The decoration is carved in the same flat planes. All this accords with the modern carpenter's mindset where buildings are still conceived as a series of flat wall planes that are assembled into the whole.

The fundamental geometries that underly the Old Impton design can be found throughout the UK in both the timber and stone traditions but their combination and development to such a high order in such a small frame is exceptional. So where did the idea for such an exquisitely virtuoso timber frame arise from? The answer might be found as little as a day's walk or half a day's horse ride away. The villages of Bredwardine, Letton and Willersley are in Herefordshire, just 15 miles south of Norton as the crow flies and five miles east of Hay on Wye in the river's curving valley. The churches in all three villages have extraordinarily intricate geometrical carvings in their doorheads. That at Willersley is the simplest and is partly obscured today by the tie beam of a later protective porch but it shows both square and circle geometries in its composition, with square on the left and circle on the right as at Old Impton. The doorheads at Letton and Bredwardine both have large central daisy wheels flanked by smaller geometrical compositions and at Bredwardine the doorhead's underside is also carved with a central daisy wheel between fields of smaller geometrical pattern. All this work is Norman. Is it unreasonable to suppose that the Old Impton carpenter came from one of these villages, passed beneath a church doorhead every Sunday and came under its geometrical spell? Or was he one of the highly skilled carpenters responsible for the geometrical precision of rood screens throughout the Marches? It would be good to know the answer and even better to have a name but what we can be certain of is that the anonymous carpenter's 16th century mind was razor sharp and running on pure, undiluted geometry. And, in the iconic symbols of the porch doorhead's interlaced squares and circles, he recorded a medieval geometrical design manual for posterity.

UPPER PHOTOGRAPH The underside of Bredwardine Church doorhead
LOWER PHOTOGRAPH Letton Church doorhead

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