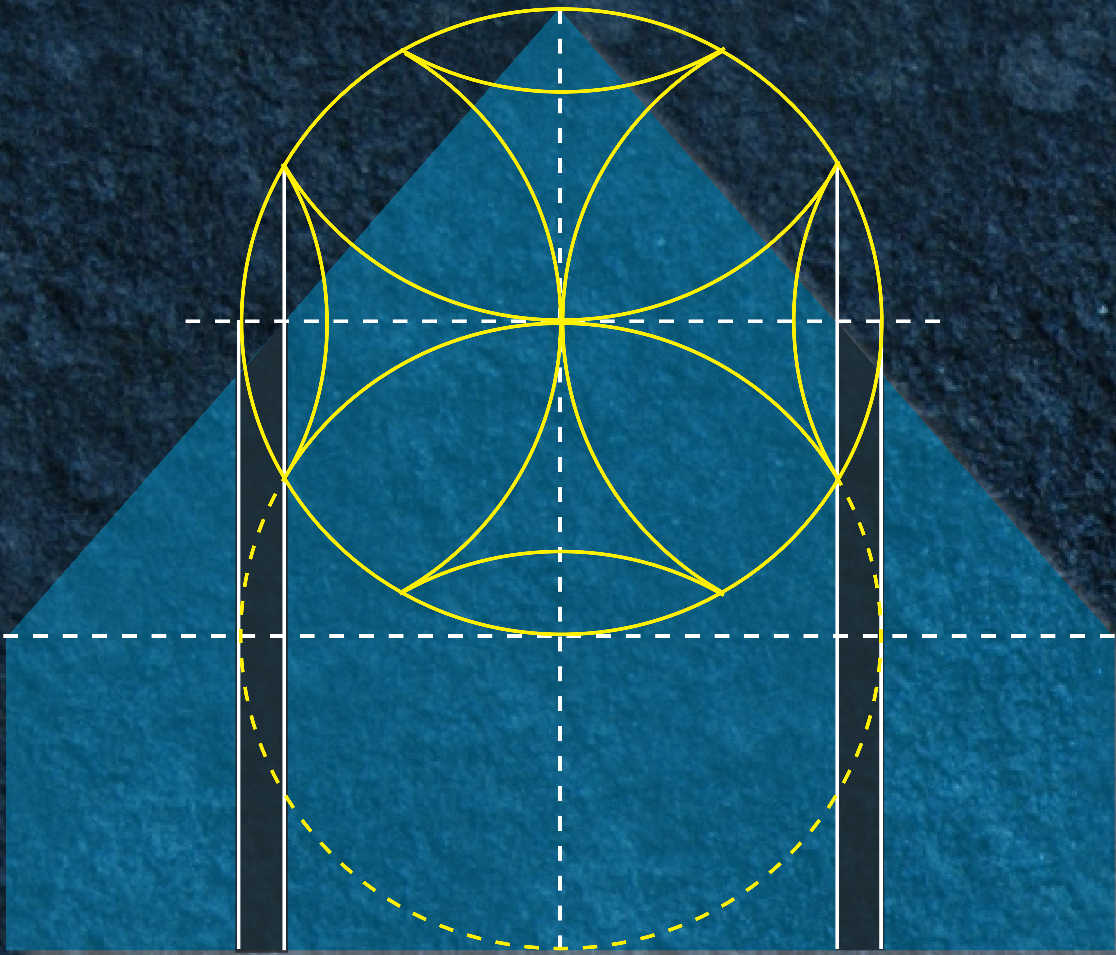
Geometrical Timber Frame Building Design at Tŷ-mawr, Castle Caereinion, Montgomeryshire, Wales, 1460



Laurie SMITH

HISTORICBUILDINGGEOMETRY

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Laurie Smith is an independent early-building design researcher, specialising in geometrical design systems. Because the medieval educational curriculum included geometry he uses geometrical analysis to excavate and recover the design systems of the past, a process he thinks of as design archaeology. He lectures, writes, runs practical workshops and publishes geometrical design articles on his websites –

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Preface

The original version of this article was one of fifteen articles published in The Montgomeryshire Collections, Volume 89 (2001), ISSN 0144-0071, a special Millenium volume focussed solely on Tŷ-mawr, the aisled hall built at Castle Caereinion in Montgomeryshire from timber felled in the spring of 1460.

The original research of this article was abridged in The Montgomeryshire Collections but full copies are maintained for reference in the National Monuments Record at the Royal Commission on the Ancient and Historical Monuments of Wales in Aberystwyth, and the project archive maintained by the Clwyd-Powys Archaeological Trust in Welshpool, Powys.

This new 2018 **e**DITION supercedes the original article. Monochrome geometrical drawings have been redrawn in colour at a larger scale and the text re-written to encompass more recent geometrical design findings. New interior and exterior colour photographs add to an understanding of the house.

Tŷ-mawr is in Wales. The name means Great (mawr) House (tŷ) and the accent above the ŷ is known in Welsh as a *to bach* or little roof. In the immediate surroundings of the house are the poetic place names Allt y Ceiliog, steep hill of the cockerel, and Pant yr Alarch, the hollow of the swan, names that were almost certainly familiar to the builders of Tŷ-mawr.

INTRODUCTION

This paper records the discovery of a systematically applied geometrical design procedure used in the planning of Tŷ-mawr, Castle Caereinion. The discovery is important because it is a breakthrough in our understanding of medieval vernacular buildings of domestic scale. To date there is scant evidence for the design of vernacular timber-framed buildings of the medieval period and it appears that Tŷ-mawr is the first such house in Wales to yield evidence of a clear design programme that flows from concept to construction. The geometrical design system employed at Tŷ-mawr is extremely sophisticated yet, once its principles are understood, logical and sequential in its application. The paper is divided into two sections, the first a review of relevant geometrical examples from surviving written and built records, the second a stage by stage geometrical reconstruction of Tŷ-mawr's design.

Tŷ-mawr was clearly the product of an active school of design and this suggests that other houses of related date, scale and status might also yield evidence of identical or related geometrical design systems. This is an exciting prospect as far as vernacular buildings are concerned for any further design discoveries could be synchronised to recent dendrochronological findings to take their place as the first indicators in a Welsh or wider design chronology. The establishment of a design chronology would, in turn, inform our understanding of the changes in structure and style within the county and beyond. It would reveal whether Tŷ-mawr was part of a local, regional, national or even international movement.

The presence of a sophisticated design system resolves, or at minimum casts light upon, the unproven but persistent notion that much medieval building, particularly in the timber tradition, was erected in a casual, trial and error way. In this context some reminders of Tŷ-mawr's structure are in order.[1] The house has six cross walls, two of which are gables. Four of the walls have sill beams and all have posts, tie beams, collars, braces and studs (the cruck truss stands on the long aisle wall sills and the spere truss posts rise from stone pads on the hall's floor). From the measured drawings, which record the house prior to repair, the six cross walls contain seventy timbers and the locations of further, missing timbers can be seen. The long axis of the house reveals two sill beams, two wall plates, two arcade plates, two purlins and a ridge beam, all running for almost sixty feet in length. There are fifty braces, some connecting the cross walls and purlins and other, larger braces arcing between cross frames and the arcade plates. Without accounting for the missing aisles and common rafters the drawings define over a thousand feet of timber, much of which is very large in section. Some of these timbers have highly defined forms: the spere post sections, for example, are fundamentally octagonal but with alternate concave facets and the cruck truss apex has seven timbers that show cusping. The spere and cruck trusses both exhibit curved arch braces and the spere posts have small crenelated capitals at the point where the braces spring. Planking was required for solar flooring, doors and shutters. Smaller timber was necessary for the staves and wands of wattle infill panels and pegs for locking the frame.

1
Philip Dixon & Patricia Borne, *'Tŷ-mawr, Castle Caereinion: building recording and analysis'* Montgomeryshire Collections 89 (2001), 7-42

Timber scaffolding was essential for construction. It is logical that the selection, felling and conversion of this volume of timber required a highly organised plan of campaign, for the length and section of each individual timber depended entirely upon its specific functional and decorative role within the structure of the building as a whole. Assembly was facilitated by a rigorous system of carpenter's marks that indicated both individual frames and the positions of constituent timbers within them, the place of each timber known and marked from a horizontal test assembly on the framing floor. Finally, after any necessary adjustment, the frames were transported to site for erection. The geometrical design system discovered at Tŷ-mawr gives a clear insight into how such a plan was conceived, developed and resolved.

Discovery of the Tŷ-mawr geometry resulted from the convergence of several lines of inquiry. The measured drawings made by Borne and Dixon provided a primary route towards understanding. Each of the drawings were analysed manually by compass in an initial search for geometrical configurations and proportional relationships, a search complicated by the fact that the original aisles were missing. Conversely, the structure of the nave remained intact and was open to geometrical analysis. Moreover, the structural integrity of the nave raised the possibility of a core geometrical design. If this proved to be the case the aisles would result from subordinate geometrical development.

The single geometrical symbol (see preface) recorded on the south face of the eastern aisle post of Truss I provided a second path. Truss I is Tŷ-mawr's uphill gable and its south face is on the inside of the building. The siting of the symbol in this position was enigmatic. When timber frames were test assembled on the framing floor the assembly, or carpenter's, marks were applied to the frame's upper face. The upper face is, obviously, the side of the frame facing upwards from the framing floor but it is simultaneously the perfect side of the frame, the side where all the joints are set flush in a continuous plane. Paul Price and John Winterbottom, the historic frame carpenters of Woodwrights in Dorset, once told me that

> *A frame carpenter thinks of a wall frame as a perfect plane stretched tight between four points and a gable frame stretched tight between five, the additional point being the ridge. Where wall frames and gable frames meet they have two points in common, at the junction of the sill beams at the foot of the post and at the junction of the wall plates at the head of the corner post.*

The upper face of the frame expresses the tightly stretched perfection of these geometrical planes which always face outwards on external walls for optimum resistance to weather. It follows logically that the lower face, or inside, of such walls show variations in timber section because corner posts, sill beams and wall plates require greater strength than the intervening studs and smaller ties. The geometrical symbol, being on the inside, or lower face of Tŷ-mawr's gable wall, was therefore on the opposite side of the wall to that with the assembly marks. It is obvious from this siting that the symbol was never intended as an assembly mark, as noted by Borne and Dixon.[2]

2
The original symbol was unfortunately removed from the building, was mislaid during the recent repairs and has been replaced by a replica. The relevance of the carving as part of Tŷ-mawr's historic fabric was important in its own right but also had a deeper meaning, as this paper shows.

Geometrical symbols

The measured drawings and the geometrical symbol are both specific to Tŷ-mawr but other important insights can be drawn from different sources. The display of geometrical symbols in or on buildings is not unusual and they can, for example, be found incised into frame timbers on other Montgomeryshire houses, but the earliest and most distinctive are found in East Anglia, accurately cut into stone at Ely cathedral. Analysis of the Ely geometrical symbols reveals a precision design language that can be used to determine harmonic proportions in the floor plans of the buildings. The floor plans of the two great timber-framed barns at Cressing Temple in Essex exhibit bay rhythms[3] that can be derived from the Ely symbols. There is a geometrical path from eleventh-century Ely via thirteenth-century Cressing to fifteenth-century Tŷ-mawr for, despite differences of scale, the buildings share the principle of aisled construction and have related geometrical designs.

A longer route also leads to Tŷ-mawr. The Roman architect Vitruvius wrote authoritatively on symmetry, harmony and proportion in architecture and his precepts were the primary architectural reference work for centuries. His writing, which was well known in the fifteenth century, makes it plain that geometry was central to architectural design.

The writings of Vitruvius

Marcus Vitruvius Pollio, a Roman architect of the first century BC and author of the *Ten Books on Architecture* makes many illuminating comments on all aspects of building design. In Book 1, chapter 1, under the heading 'The Education of the Architect' Vitruvius states:[4]

> *Geometry, also, is of much assistance in architecture, and in particular it teaches us the use of the rule and compasses, by which means we acquire readiness in making plans for buildings in their grounds and rightly apply the square, the level and the plummet.*

He continues,

> *It is true that it is by arithmetic that the total cost of buildings is calculated and measurements are computed, but difficult questions involving symmetry are solved by means of geometrical theories and methods.*

3
Adrian Gibson, *'Further light on the design of the Great Barns at Cressing Temple'*
Essex Archaeology and History 27 (1996), 182-7;
Laurie Smith, *'The geometrical designer at Cressing Temple'*
Essex Archaeology and History 27 (1996),188-92.
4
Morris Hicky Morgan, *Vitruvius, The Ten Books on Architecture* (New York, 1914).

The two statements, in recognising geometry as central to architectural design, also give some further insights. It is quite clear in the first statement that Vitruvius draws a distinction between the rule and compass on the one hand and the square, level and plummet on the other. It is clear from the sense of the passage that the rule and compass are drawing board design equipment and that the square, level and plummet were working tools for the building site. The distinction is important because it makes clear that the drawing board tools have two precise functions – the drawing of straight and curvilinear lines. The second statement is equally revealing for it makes emphatically clear that design is a solely geometrical matter. Measurement, on the contrary, is used to convert the proportional values of the geometrical design into the specific dimensions of, for example, timbers of the correct sections, lengths and numbers for the assembly of a wall frame.

In Book 1, chapter 2, Vitruvius sets out the 'Fundamental Principles of Architecture' which he defines as Order, Arrangement, Eurhythmy, Symmetry, Propriety and Economy. Of these, Propriety and Economy specify the fitness for purpose of a building and site management respectively and do not directly concern us here. In contrast, the definitions of Order, Arrangement, Eurhythmy and Symmetry contain important passages as far as the design and aesthetic resolution of buildings is concerned. Vitruvius writes,

> *Order gives due measure to the members of a work considered separately, and symmetrical agreement to the proportions of the whole.*

The definition that Vitruvius gives for Arrangement confirms this and further suggests that adjustments may be made that are appropriate to the character of the work. This is revealing for it suggests that Vitruvius held a flexible view of the design process and that some fine tuning was considered in order. Arrangement also specifies that the design was attained by means of ground-plan, elevation and perspective drawings. Vitruvius writes,

> *A ground-plan is made by the proper successive use of compasses and ru1e, through which we get outlines for the plane surfaces of buildings.*

This statement reinforces the idea that the compass and rule are the sole drawing board tools and stresses the consecutive nature of their use. The design of a building therefore results from the progressive interplay of the two tools and their opposing yet related characteristics, the curvilinear line and the straight line. Meaningful relationships of curvilinear and straight line construction, attained through the successive use of compass and rule, will become evident in the ground plan and elevations of Tŷ-mawr. In defining Eurthythmy, Vitruvius states that it is

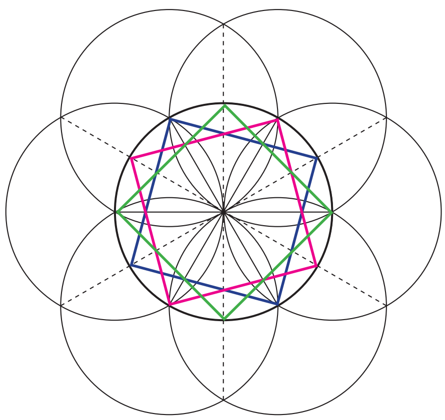
> *. . . beauty and fitness in the adjustments of the members. This is found when the members of a work are of a height suited to their breadth, of a breadth suited to their length, and, in a word, when they all correspond symmetrically.*

Here, emphasis is given not to a harmonic relationship between components and the whole but to the fact that individual components should themselves have a balanced aesthetic resolution. Vitruvius continues, *Symmetry is a proper agreement between members of the work itself, and relation between the different parts and the whole general scheme, in accordance with a certain part selected as standard . . . symmetry may be calculated from the thickness of a column . . . or even from a module.*

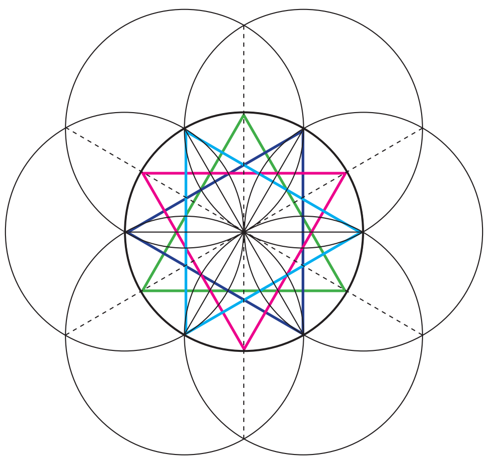
In his definition of Symmetry Vitruvius makes it clear that a standard was used in the design process and that it was derived from the building itself. If the thickness of a column was selected as the standard it became the unit of proportion that would exert influence on every aspect of the design. However, when Vitruvius mentions a module the sense of the text is that he does so in contrast to this concept, inferring that a module can be defined by the architect himself. This is extremely interesting because it heralds the potential for an individual design approach within the parameters of a particular school of architectural thought. The design of a specific module as a prelude to the design of a building itself will be seen to be an influential concept in the design of Tŷ-mawr, though the rules of intimate proportional inter-relationship will still apply.

Vitruvius gives two related examples of geometrical design in his comparison of the layout of Greek and Roman theatres that are important to our understanding of geometrical design procedures. In the design of the Greek theatre a circle is host to three squares which overlap each other to generate twelve equidistant points on the circle's circumference, drawing 1. In the Roman theatre design the circle is host to four equilateral triangles which also generate twelve equidistant points around the circle's circumference, drawing 2. The two circles, with their internal angular structures, are modules. The background circles enable the construction of squares and equilaterals within the central, primary circles.

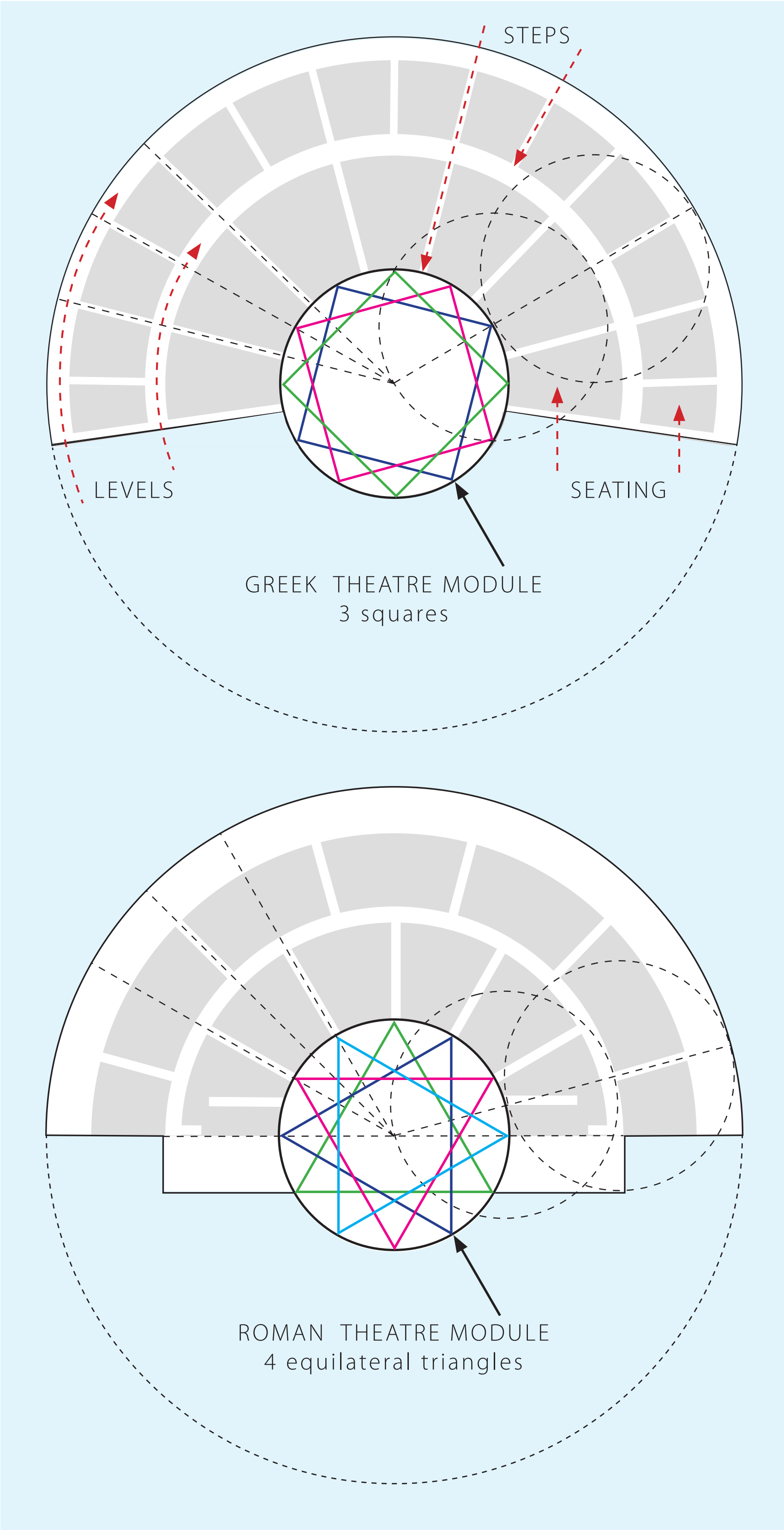
It can be visualised that the squares and triangles each share an identical axis with that of the central primary circle and that they can, therefore, be rotated into their positions. That the circle can host other differing and multi-layered geometrical figures that share its axis is an important concept in geometrical design. Also, in the case of theatres, it is clear that the squares and triangles within the circle influence the design beyond the circle's boundary. Once the design of the auditorium is complete the squares and triangles that gave it form have no further purpose.



1 GREEK THEATRE MODULE
3 squares



2 ROMAN THEATRE MODULE
4 equilateral triangles



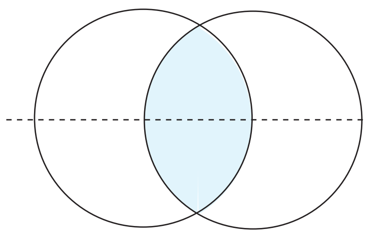
3 MODULES DEVELOPED INTO THEATRE DESIGNS
In each design the module defines radials that pass through points on the central, primary circle's circumference to mark the alignment of steps that ascend through the amphitheatre. Further circles, identical in diameter to the module, determine the extent and upper boundaries of the seating.

Geometrical symbols at Ely Cathedral

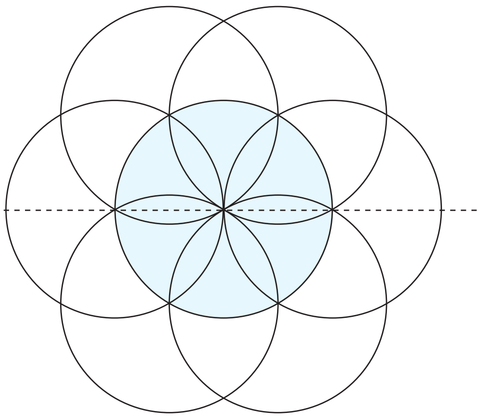
The first significant evidence of geometrical design in British architecture appears in the wake of the Norman conquest. It is found in the cathedrals, abbey churches, great halls and monastic barns which, despite their wide geographical distribution and greater scale, are all precursors of Tŷ-mawr's aisled floor plan.

At Ely, building of the Romanesque cathedral commenced under Abbot Simeon in 1081. Internally, the cathedral's structure is lean and powerful, an austere environment in which two distinctive geometrical symbols stand out in striking contrast. They are significantly placed, either alone or adjacent to sculptural imagery. These symbols, the vesica piscis[5] and the daisy wheel are both formed by compass construction. The vesica piscis results from two circles drawn through each other's centres along a centre line, drawing 4. The daisy wheel, in contrast, is generated by a sequence of six circles drawn around the circumference of an initial circle, which is the boundary of the wheel itself, drawing 5. The vesica piscis and the daisy wheel are both examples of circle sequences and are linear and rotational expressions of the same idea.

They are shown overleaf where a single vesica frames the figure of Christ in Judgement above the Prior's door, photograph 6, two identical vesicas flank the high western entrance arch to the nave, photograph 7, and two daisy wheels mark the cusps in the tripartite tympanum of the Monks' door where they are found adjacent to the carvings of two kneeling monks, intertwined mythical creatures and foliage trails photograph 8. There is no doubt about the importance of these geometrical symbols within the cathedral's grand scheme for they are prominently sited and are given the same aesthetic significance as the cathedral's representational sculptures. Here, the symbols are regarded as modules and as evidence that a geometrical design system was employed at Ely, a view supported by analysis of their characteristics.[6]



4 VESICA PISCIS



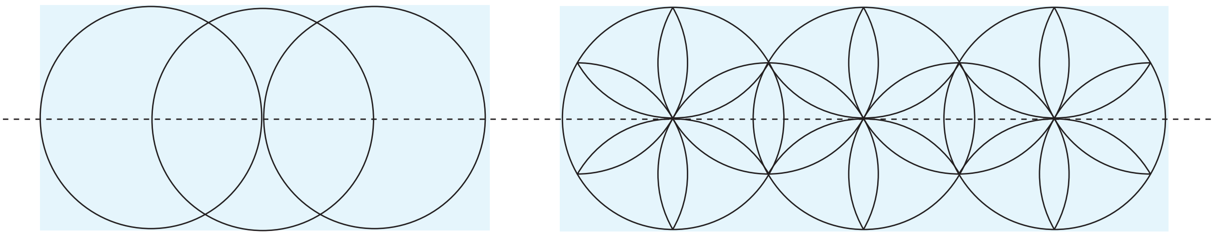
5 DAISY WHEEL

5
The literal translation of vesica plscis, 'fish's bladder'. refers to the fish-like shape caused by the overlap of two circles. The fish was an early Christian symbol prior to the adoption of the cross. The vesica is often represented as a mandorla surrounding the body of Christ. 'Daisy wheel' is the common narne for the six-petalled compass-drawn geometrical flower.

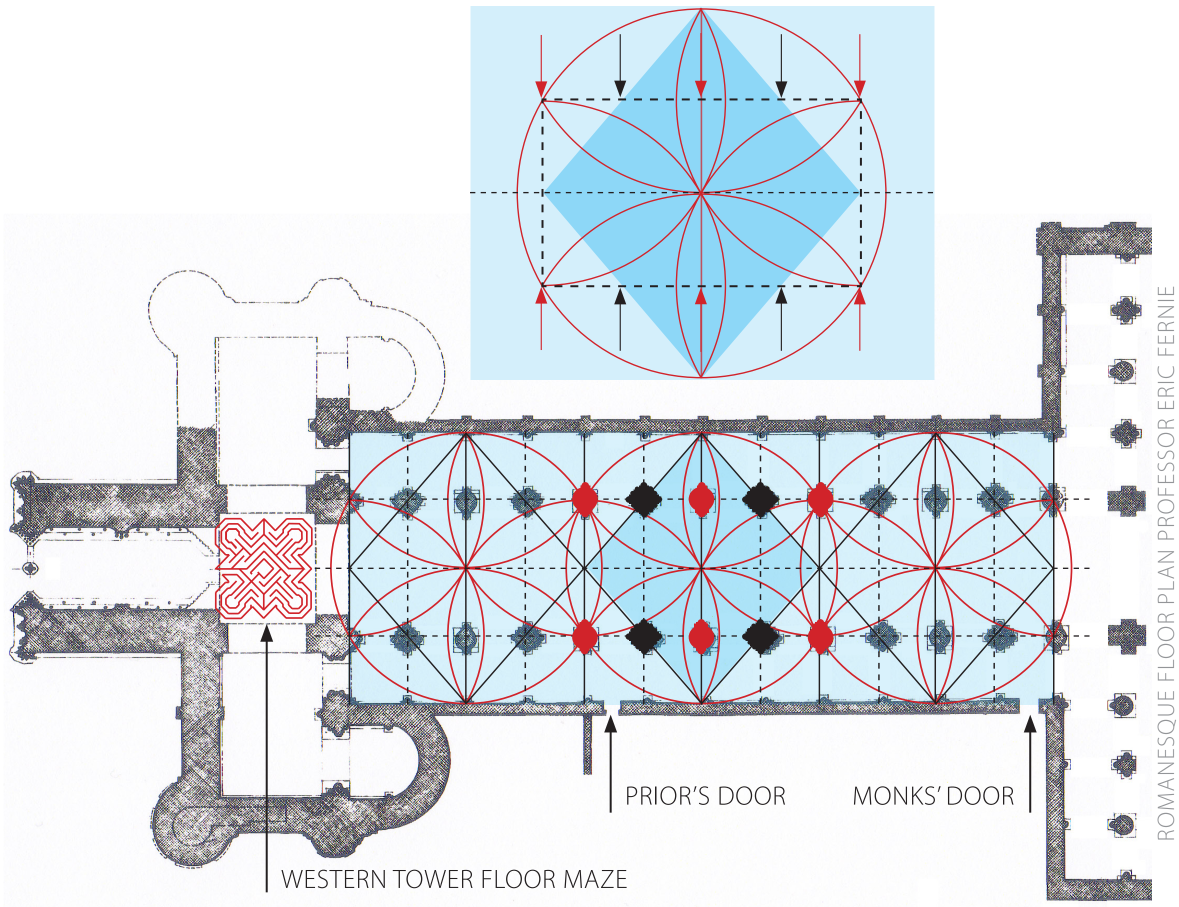
6
Laurie Smith, '*Following the Geometrical Design Path from Ely to Jamestown, Virginia*" pp 11-32 in '*Built from Below: British Architecture and the Vernacular*'. Edited by Peter Guillery. Routledge 2011, ISBN13 978-0-415-56533-2 (pbk).

6 UPPER THE PRIOR'S DOOR VESICA PISCIS
7 CENTRE WESTERN ENTRANCE ARCH VESICAS
8 LOWER MONKS' DOOR DAISY WHEELS

The vesica piscis and daisy wheel geometries can be multiplied along a centre line to generate circle sequences of different lengths. These linear geometrical grids give rise to rectilinear floor plan proportions, drawing 9. The Romanesque nave floor plan at Ely is based upon the triple daisy wheel sequence but has an angular diamond sub-geometry constructed within the wheels, drawing 10. The arcades express circularity and angularity, the two fundamental geometrical opposites, through the alternation of cylindrical and angular piers, their locations determined by the daisy wheel and diamond sub-geometry. It can be seen that the cylindrical piers sit on the compass geometry (the daisy wheel's circumference and vertical diameter) and that the angular piers sit on the diamond geometry (where the diamonds cut the 4 point rectangles). The geometry is shown for a single daisy wheel and for the full nave in drawing 10. The cylindrical and angular piers are highlighted in red and black respectively in the nave's central daisy wheel.



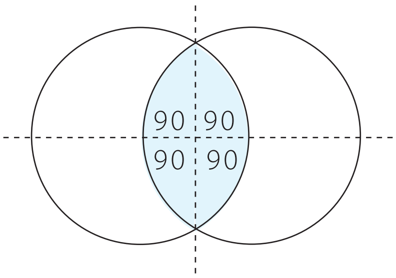
Drawing 9 VESICA PISCIS AND DAISY WHEEL FLOOR PLAN PROPORTIONAL GRIDS



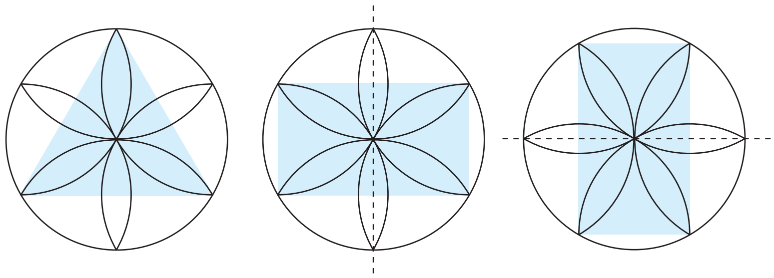
Drawing 10 ELY NAVE FLOOR - DAISY WHEEL AND DIAMOND SUB-GEOMETRY

Vesica piscis and daisy wheel geometries

The vesica piscis and the daisy wheel both embody further geometrical properties that are relevant to the design of buildings. If the vesica piscis is drawn along a centre line and a perpendicular is drawn through its intersections, four right-angles are formed at its centre. It is therefore a tool for generating perpendiculars to a centre line and can be used for this purpose at small scale on a drawing board or at large scale on the ground, drawing 10. The daisy wheel is a primary source of proportional relationships. Connection of three alternate points gives an equilateral triangle, drawing 11, left, the basis of Vitruvius's Roman theatre design. The wheel can be rotated to give either vertical or horizontal orientation where connection of four points forms a horizontal or vertical rectangle, drawing 11, centre and right. This rectangle has an important place in geometrical design and to distinguish it within the remainder of the text it will be referred to as the '4 point rectangle'.

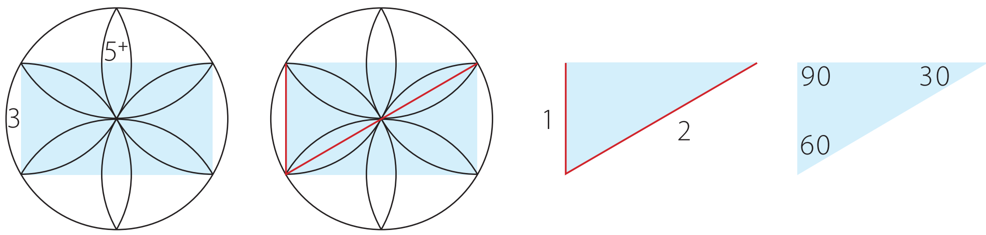


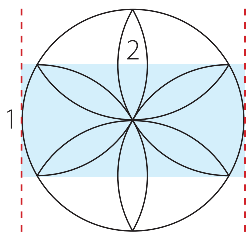
10 VESICA PISCIS RIGHT ANGLES



11 DAISY WHEEL PROPORTIONS

The external proportions of the 4 point rectangle are, at 3:5+, not quite exact in dimensional terms but it has the perfect internal geometrical ratio of 1:2 between its short side and diagonal. The diagonal also halves the 4 point rectangle to generate angles of 30, 60 and 90 degrees, drawing 12. If the 4 point rectangle's long sides are extended to meet tangents to its parent circle a double square is produced, with the perfect external ratio of l:2, drawing 13. Sharing a common construction and ratio, the 4 point rectangle and the double square are harmonically related. The 4 point rectangle's internal ratio of l:2 is central to the design of the Cressing Temple barns (see below).



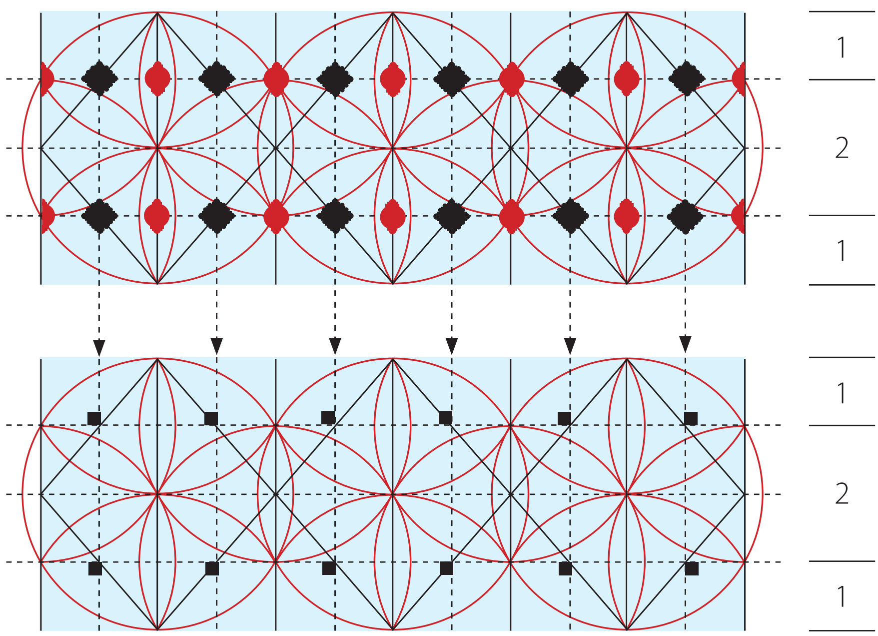


Drawing 12 DAISY WHEEL PROPORTIONS AND ANGLES
Drawing 13 DAISY WHEEL DOUBLE SQUARE

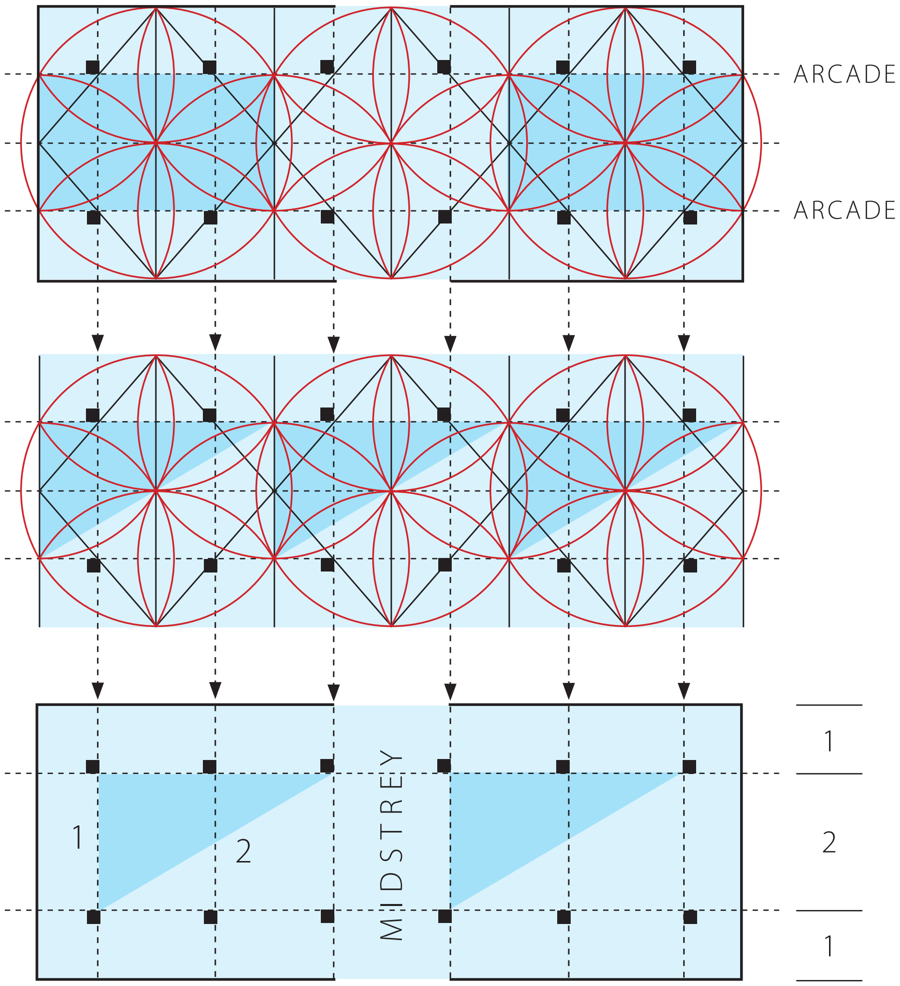
Geometrical evidence at Cressing Temple

Similar geometries to those employed at Ely can be found 150 years later at Cressing Temple in Essex where, in c. 1220 and 1250, the Knights Templars built two massive barns, the Barley Barn and the Wheat Barn.

The two barns, halfway in time and scale between the cathedral at Ely and the house at Tŷ-mawr, are closer to the latter in conception and construction. They are of aisled, timber-framed construction, have low long walls relative to their overall length and hipped roofs, though these differ slightly in having gablets at their transition from hip to ridge. It was once thought that the Barley Barn had its gable walls rebuilt closer to the end aisle posts, a concept based on the fact that the two end bays were narrower than the five central bays, the presumption of the time being that all seven bays should be of equal length. However, since the publication of the original article, later research has shown that the Barley Barn retains its original structure. While the earlier analysis presented a solely daisy wheel based plan (including the 1:2 ratios shown in drawing 12), the later research introduces the same diamond sub-geometry that generates the angular piers in the Ely nave and it is the sub-geometry that defines the aisle post positions in the Barley Barn (while preserving the 1:2 ratios). The Ely nave and the Barley Barn have identical floor proportions and aisle to nave width ratios of 1:2:1but differ in the number of piers in their arcades. Ely, being a heavy masonry structure, has eleven freestanding piers in each arcade while the Barley Barn, being a relatively light timber framed structure, has six. The interesting aspect of the new research is that Ely's six angular piers and the Barley Barns six arcade posts occupy identical geometrical positions on the diamond sub-geometry. The two floors are shown below at identical scale for geometrical comparison but, in reality, the Ely nave is 250 feet and the Barley Barn just under half that at118 feet in length. Geometry, however, can exist at any size and retains its proportional integrity at any scale.



14 DAISY WHEEL AND DIAMOND SUB-GEOMETRY PROPORTIONS IN THE ELY NAVE, ABOVE, AND BARLEY BARN, BELOW.



15 DAISY WHEEL, 4 POINT RECTANGLE AND DIAMOND GEOMETRY
16 DAISY WHEEL AND 1:2 TRIANGULATION
17 1:2 TRIANGULATION BETWEEN AISLE POSTS

The Barley Barn's long walls are tangential to the triple daisy wheel sequence and its gable walls are defined by the short sides of the 4 point rectangles in the outer wheels of the sequence, drawing 15. The 1:2 ratios generated by cutting the 4 point rectangles along their diagonals are shown in drawing 16 and the location of the ratios that were discovered between the aisle posts by Adrian Gibson[7] can be seen in drawing 17. My contribution was to recognise that Adrian's ratios could be constructed within the daisy wheel, a discovery from analysis of the Ely nave that was also applicable in the design of the Barley Barn. Adrian and I collaborated on further research into the design of the barn and published two further short papers on our findings.[8] Sadly, Adrian died in 2006 and never lived to see the development of the diamond sub-geometry and its impact on the barn's floor plan.

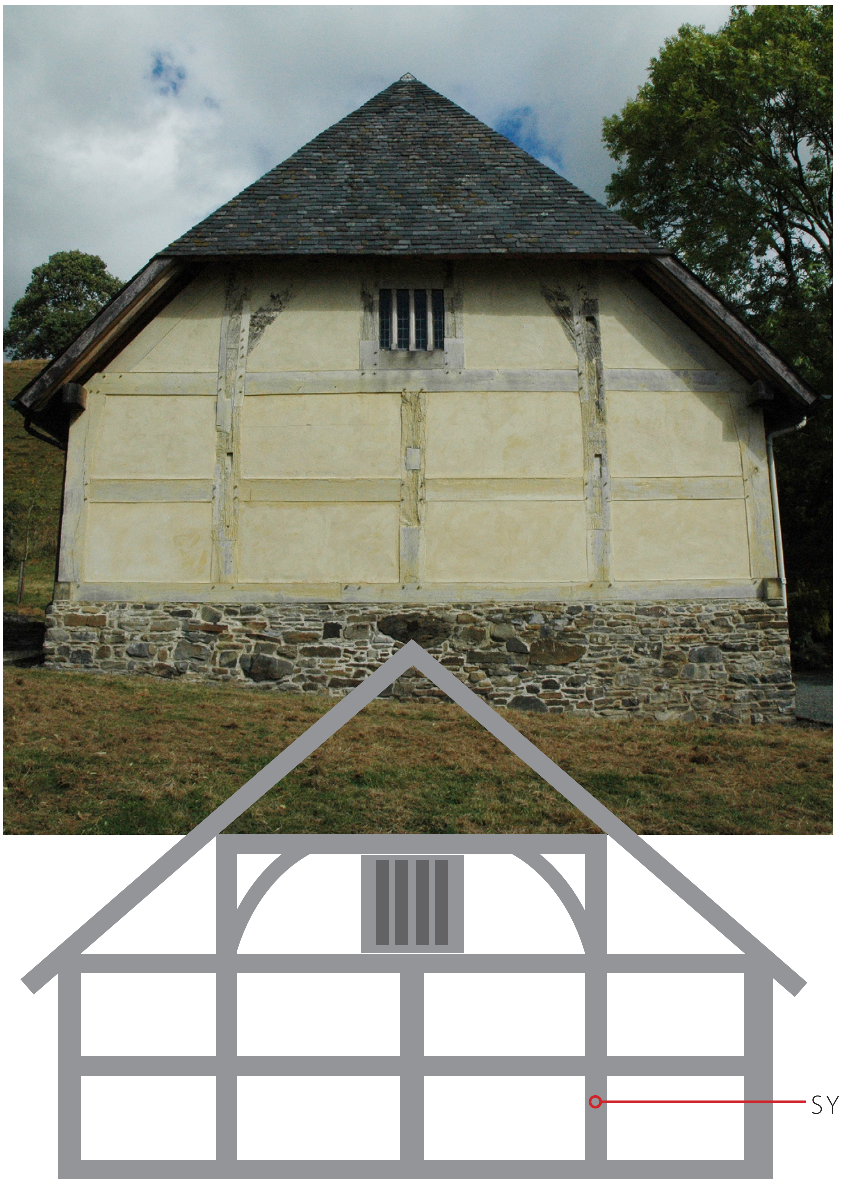
7
The discovery of the ratio 1:2 between transverse and diagonal alignments of the aisle posts in the Barley Barn at Cressing Temple is given in Adrian Gibson, *'The constructive geometry in the design of the thirteenth century barns at Cressing Temple'* Essex Archaeology and History 25 (1994).
8
Adrian Gibson, *Further light on the design of the Great Barns at Cressing Temple.* Laurie Smith, *A geometrical designer at Cressing Temple.* Essex Archaeology and History 27 (1996).

Geometrical Timber Frame Building Design at **Tŷ-mawr**, Castle Caereinion, Montgomeryshire, 1460

The foregoing pages demonstrate the historical flow of geometrical design over almost two thousand years. A geometrical analysis of Tŷ -mawr would reveal whether a parallel system to that found in East Anglia had reached Montgomeryshire and, as such design systems might only be found in buildings of high social standing, Tŷ-mawr was a potential source of evidence.

The geometrical analysis followed a clearly defined procedure under three primary headings. Firstly, *the building itself*. In this context, the structural integrity of the nave provided an opportunity for full-scale analysis in situ, particularly at floor level. Secondly, *the measured drawings*. The drawings, by Philip Dixon and Patricia Borne[9], were scanned onto computer where evidence of erosion, subsidence and racking of the building's frame could all be brought back into perpendicular alignment to facilitate a series of individual geometrical searches. These included the nave floor, long section and cross section proportions including the roof pitch, the spere truss, posts and capitals, the cruck truss and its cusping, the arch braces and the race-knife circles employed in the carpenter's marks. Thirdly, *the geometrical symbol*. The unique geometrical symbol at Tŷ-mawr, recorded as a measured drawing and captured in a video still, above, raised the exciting possibility that there might be some correlation between its own geometrical configuration and the design of the house itself. There was insufficient space to reproduce all of the above listed analyses in the original article but the symbol's geometrical construction and design application, which has been so pivotal to an understanding of Tŷ-mawr's design, follows below.

9
Geometrical analysis of Tŷ-mawr was undertaken from copies of drawings from the initial survey report: Patricia Borne & Philip Dixon, *Tŷ-mawr, Castell Caereinion: a Report on the Survey and Excavations*, (unpublished, 1981), Department of Archaeology, University of Nottingham.

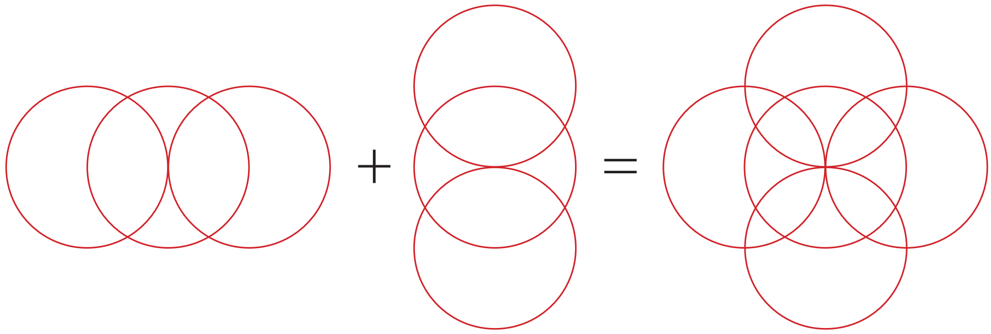


18 PHOTOGRAPH OF TŶ-MAWR SOUTH GABLE EXTERIOR
19 DRAWING OF TŶ-MAWR NORTH GABLE (TRUSS 1) INTERIOR
20 GEOMETRICAL SYMBOL AND ITS LOCATION ON TRUSS 1

10
Geometrical symbol carved on the south face of the north truss eastern aisle post of Truss I at Tŷ-mawr: measured drawing left (after Dixon & Borne 2001) and video still (CPAT) right,

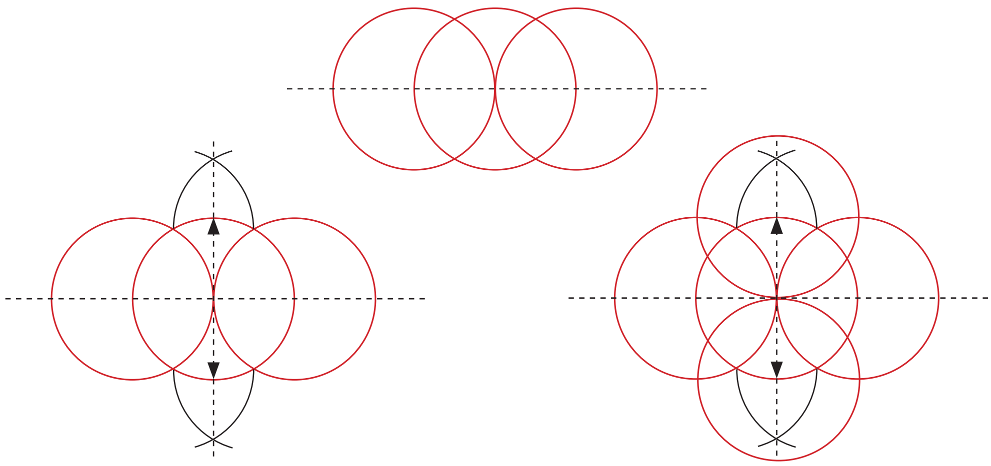
The geometrical symbol

Before attempting to find any correlation between the symbol's measured drawing, video still and the structure of Tŷ-mawr it is first necessary to analyse the symbol itself, to understand its geometrical structure and any potentials that might arise from it. The symbol is composed of a primary circle enclosing eight arcs of secondary circles: four long arcs that cross the whole face of the symbol through its axis and four further short arcs that connect the long arcs at the circle's circumference. If the four arcs at the circumference are temporarily removed it can be seen that the symbol is formed from two perpendicular triple circle sequences that have their central circle in common, drawing 21.

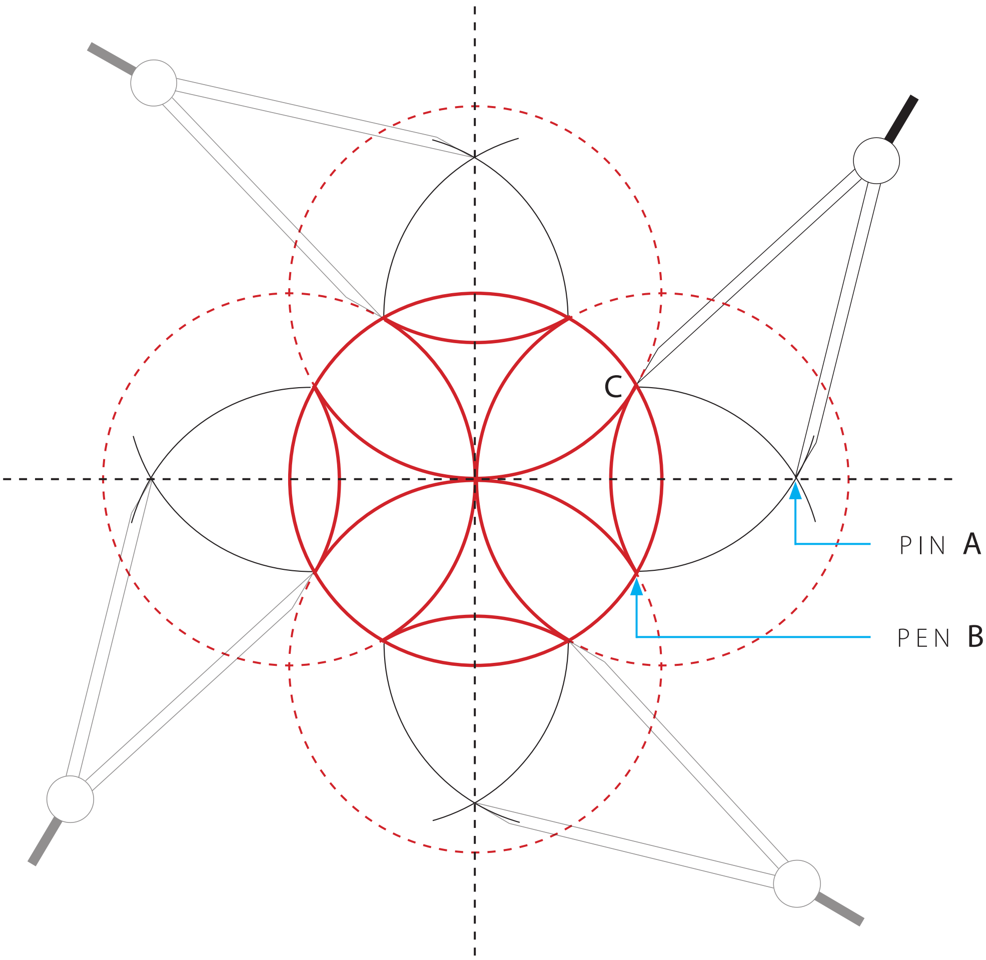


21 COMPOSITION OF THE SYMBOL

Remembering Vitruvius's proper successive use of compasses and rule, the symbol can be drawn as follows. A horizontal centre line is drawn first and three circles of equal radius are drawn along it so that the circumference of each passes through the axis of its neighbour, drawing 22A. A vertical perpendicular to the horizontal line is constructed next. Four arcs (shown in black line) are drawn from the intersections of the horizontal circles, two above and two below the horizontal centre line, so that two new points of intersection are formed. A vertical perpendicular,drawn through the new points, cuts the arrowed north and south poles of the central circle, drawing 22B. Two further circles of identical radius are drawn from the north and south poles to complete the five circle configuration at the heart of Tŷ-mawr's symbol, drawing 22C.

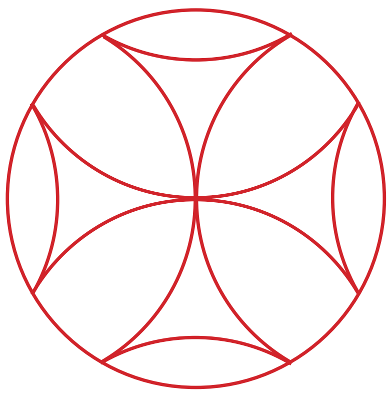


22 DRAWING THE SYMBOL A (TOP), B (LEFT) AND C (RIGHT)



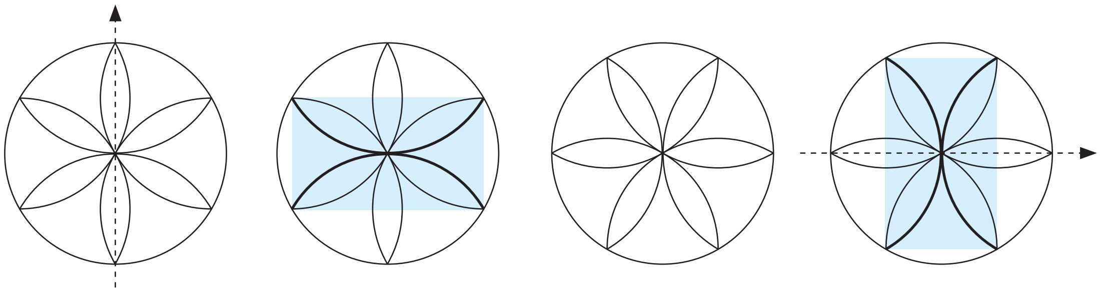
23 DRAWING THE SYMBOL'S SMALL ARCS

The final stage of the symbol's construction is to draw the four arcs of circle that link the long arcs where they meet the symbol's circumference. The arcs are drawn from the same points of intersection used for the construction of the horizontal and vertical perpendiculars. Historically, the arcs would be drawn with dividers (a compass with a pin on each arm) but their construction is easier to describe using a modern compass (with a pin on one arm and pen on the other). In drawing the arcs, the PIN remains static and the PEN revolves. The PIN is placed on the horizontal perpendicular, exactly on the intersection of the two arcs at **A** and the PEN is placed at the end of a long arc at PEN **B**. An arc is drawn upwards until it meets the symbol's circumference at **C**. This is repeated for the remaining three arcs, drawing 23. The radius of the small arcs is identical to every other circle in the symbol (so that the dividers use a single setting for the whole construction). Drawing 24 shows the complete symbol.



24 THE SYMBOL

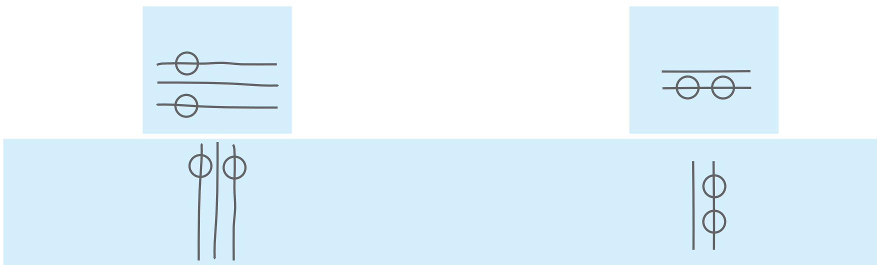
It is important to recognise that the curvilinear construction of the symbol generates a symmetrical matrix from which 4 point rectangles can be constructed. The four large arcs that span the symbol's face are, in fact, constituent arcs of horizontal and vertical daisy wheels and it follows that connection of the arcs will generate horizontal and vertical 4 point rectangles, drawing 25. It is a quirk of geometry that the daisy wheel with vertical orientation, left, generates a horizontal 4 point rectangle and the wheel with horizontal orientation, right, generates a vertical rectangle. The two rectangles are crucial elements in the application of the symbol in Tŷ-mawr's design.



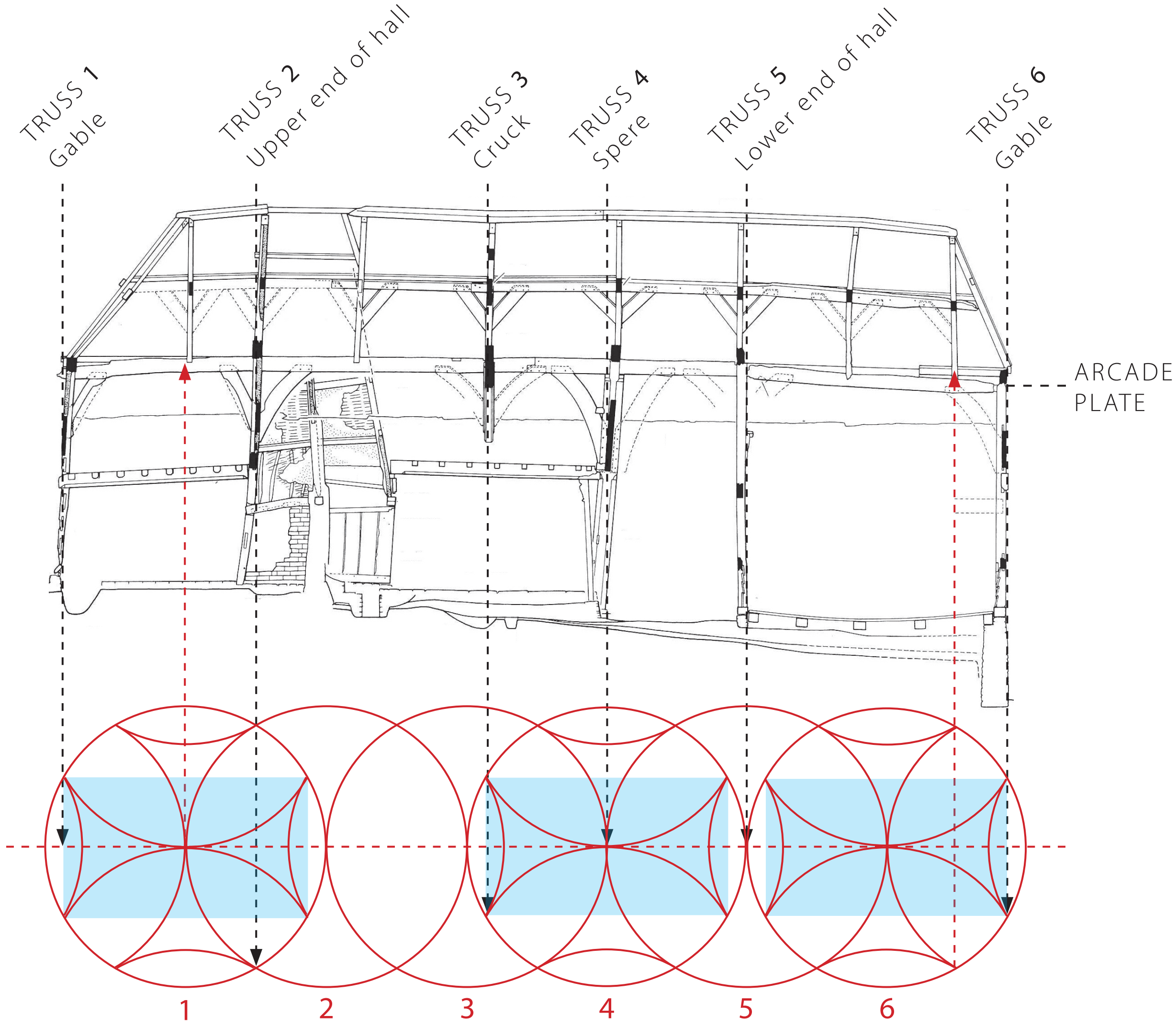
25 ORIENTATION OF 4 POINT RECTANGLES IN THE SYMBOL

26 VIDEO STILL OF THE SYMBOL

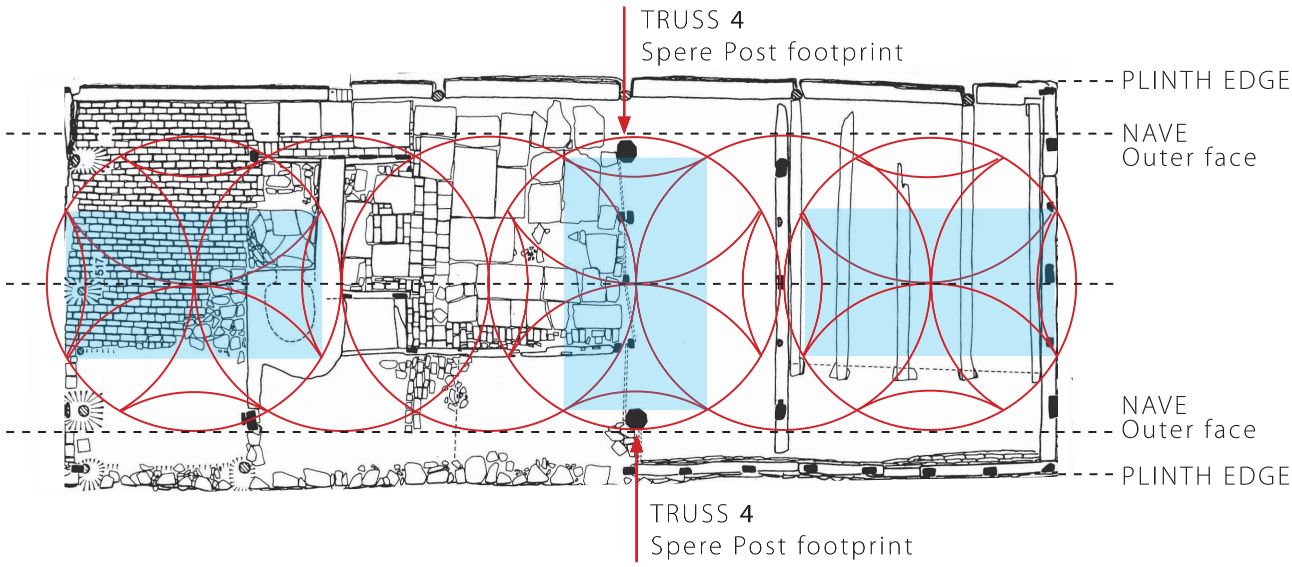
The video still, 26, records the symbol which, as Dixon and Borne noted in their measured drawings, was not a carpenter's assembly mark. Carpenter's assembly marks are of two kinds and are drawn with either dividers or a compass race knife, the former giving a fine linear mark and the latter a small but distinctive trench. The circle and arcs of the symbol video still are significantly wider and deeper than divider-scribed lines and show that a race knife was used. The race knife can also be dragged across timbers to give straight lines. The carpenter's race knife marks in drawing 27 are from the second and third joints on the mid-rail of Tŷ-mawr's truss number 5, at the lower end of the hall cross passage, and show how each joint was marked from right to left with the wall code circles and the joint number in Roman scratches (II and III).



27 CARPENTER'S RACE KNIFE MARKS



28 GEOMETRICAL FLOOR, TŶ-MAWR'S LONG SECTION AND TRUSS LOCATIONS



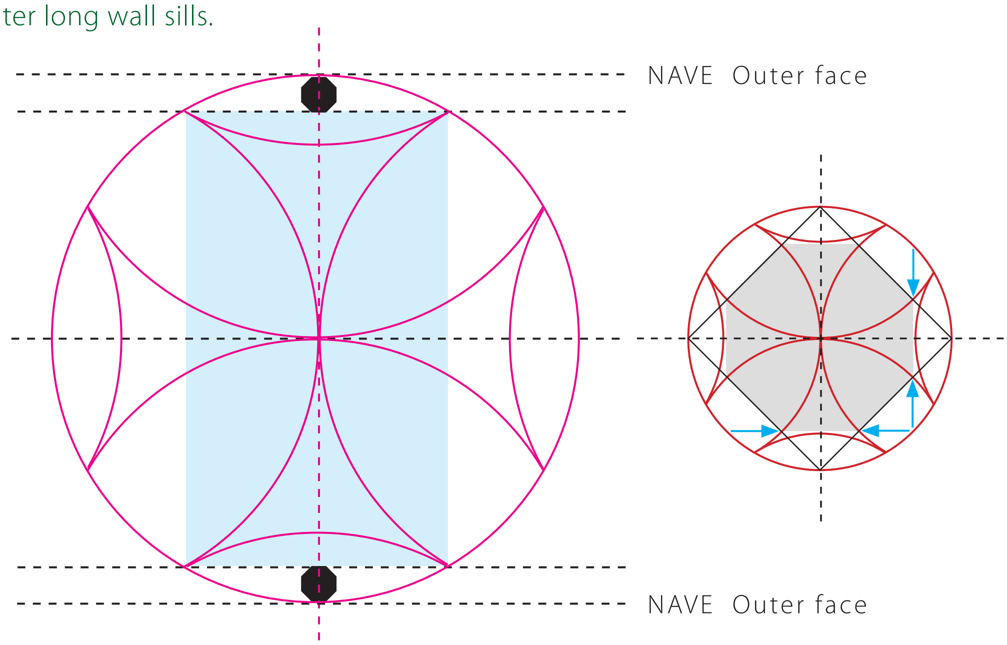
29 GEOMETRICAL FLOOR SUPERIMPOSED ON TŶ-MAWR ACTUAL FLOOR

Tŷ-mawr's floor, as recorded in the measured drawing above, is narrower than the original floor and was rebuilt closer to the building's nave when the cruck truss failed above the aisles. This is also why the cruck truss is only shown above the arcade plate in drawing 28, above.

Summary of analysis

In commencing the geometrical analysis of Tŷ-mawr, the measured drawings were subjected to simple compass drawn tests to see whether a circle-based design system was present. A six-circle sequence drawn on a centre line, where each circle passed through the axis of its neighbours, immediately generated some of the symbol's arcs, drwaing 28. On computer the full symbol geometry, including horizontal 4 point rectangles drawn in the end circles, was overlaid on the nave measured drawing floor plan and synchronised to the nave's width, drawing 29. Correlations between the plan and the geometry revealed that in three circles the symbol was critical to the design. These were the circles at each end of the sequence, where horizontal 4 point rectangles defined the positions of the gable sills in truss 1 and truss 6, and the fourth circle from the north, where a vertical 4 point rectangle defined the location of the spere truss, truss 4 (on the rectangle's left side in drawing 28) and the exact positions and scale of the spere post bases (between the symbol's outer circlumference and the short sides of the 4 point rectangle in drawing 29).

The survival of the spere posts in situ meant that it was possible to measure the distance between their outer faces (the latter simultaneously the outer face of the nave) and therefore to translate the diameter of the geometrical symbol and the length of the 4 point rectangle within it into full-scale measurements on the nave floor. These measurements, which cast light on the transition from the design of Tŷ-mawr to its full-scale construction, are discussed in detail in the conclusion. In all, the six-circle sequence confirmed the positions of seven walls, the nave's four outer faces and three internal cross walls. The hall lower end was defined at the intersection of circles I and 2, the spere truss by the diameter of circle 4 and the hall upper end by the diameter of circle 5 (and the meeting of circles 4 and 6 at the centre line). The only truss missing was the cruck truss, which rose originally outside the nave from positions on the aisle outer long wall sills.

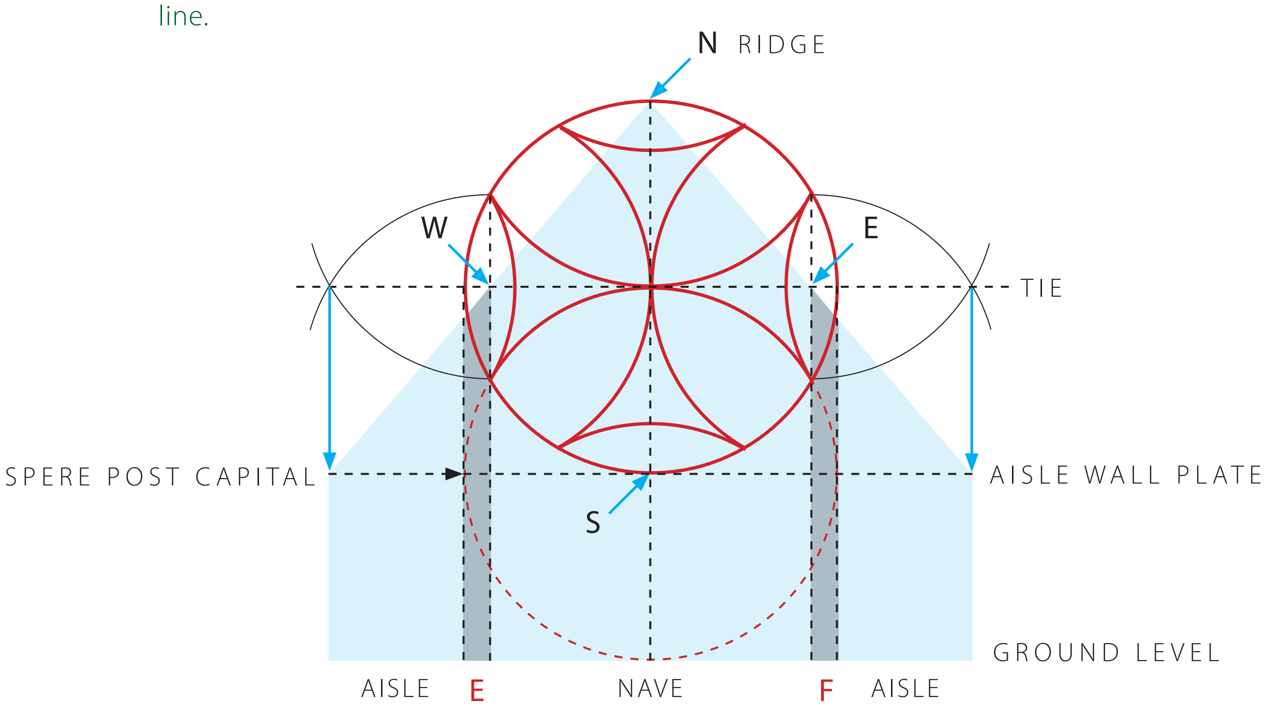


30 SYMBOL SPERE POST GEOMETRY, LEFT, SPERE POST SECTION, RIGHT

Tŷ-mawr's spere posts occupy the space between the symbol's circumference and the 4 point rectangle, left. The spere post's octagonal section is also derived from the symbol. A square, drawn between the symbol's poles cuts the symbol's long arcs at the octagon's angles.

The synchronisation of the six-circle sequence to the measured floor plan confirmed the presence of a circle-based design system and, more importantly, the symbol's role as a precision locational mechanism within selected individual circles. Further, the presence of the symbol in the floor design and its function in the precision location of trusses suggested that it might also be used in the cross sectional design of the gables and internal cross walls. Further trials on computer proved this to be the case.

The cross-section from floor to ridge was equal to two circles of the six-circle sequence which, allowing for the circles' overlap, made the house exactly one and a half circles in height, drawing 31. Further, it became clear that the small vesicas on the north, south, east and west sides of the symbol were critical to the design of the roof pitch, which in turn defined the precise location of the missing aisles. Cardinal geometrical points are used to esablish the roof pitch for both nave and aisles. The logic is very clear, that the circumference of the upper symbol circle defines both the roof's apex at **N** and the base line of the pitch at **S** on the vertical centre line, while the angle of pitch runs precisely through the centres of the two small vesicas at **W** and **E** on the symbol's centre line.

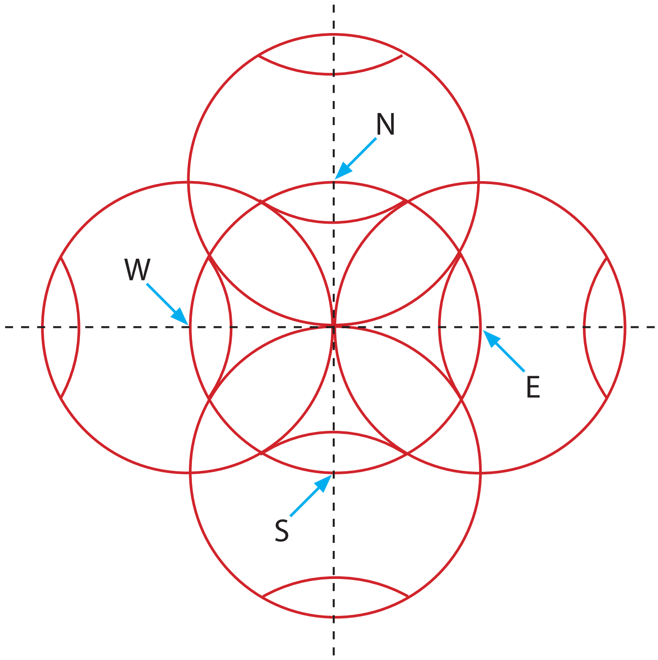


31 TŶ-MAWR'S SECTION GEOMETRY

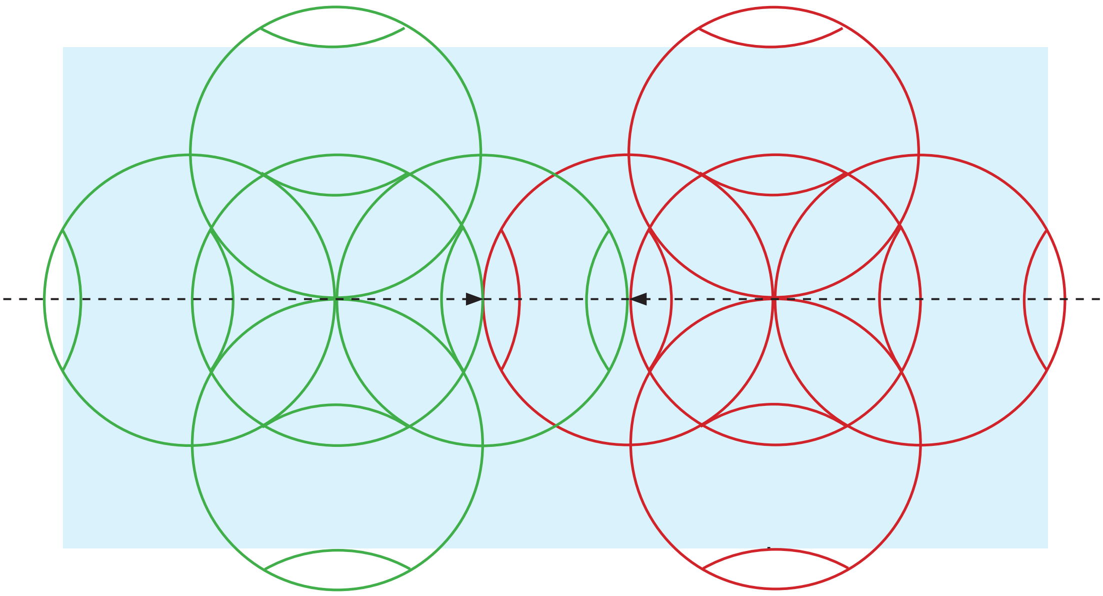
The base of the lower dashed circle, which continues the symbol's lower long arc, defines the nave floor at ground level. Vertical tangents to the circles define the outer faces of the nave in general, and spere posts in parlicular, at **E** and **F**. It can be seen that the small black arced points of intersection, which gave centres for drawing the symbol's short arcs adjacent to **W** and **E** are also locations for plumbing the building's outer aisle wall alignments (by the vertical blue arrows).

A unified geometrical scheme

Drawing 31 shows how the symbol's internal long and short arcs are used to determine the building's roof pitch and ridge height above ground level.



32 FIVE CIRCLE GEOMETRY



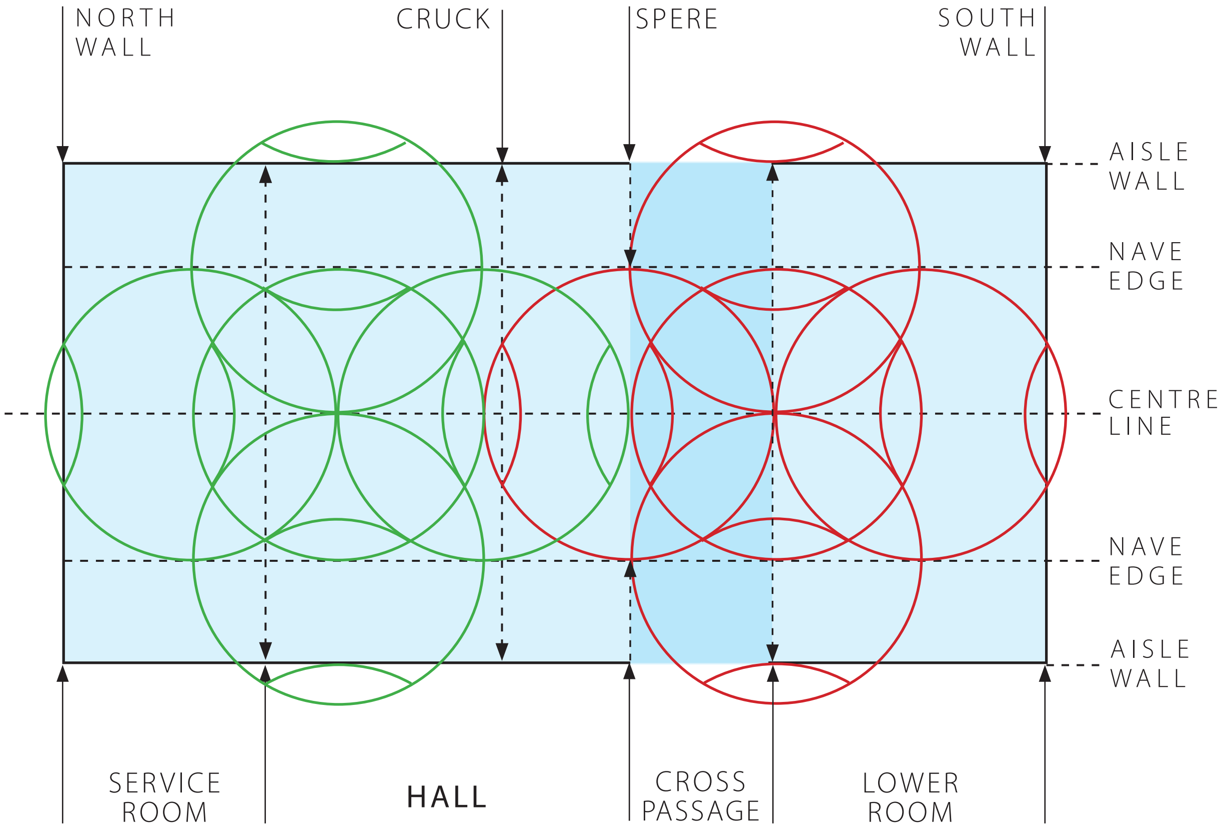
33 TŶ-MAWR'S FLOOR GEOMETRY

Drawing 32 demonstrates how the arcs within the symbol are developed outside its circumference to generate a five circle geometry comprising a central circle and four additional circles at the central circle's north, east, south and west poles. The four small arcs linking the central circle's long arcs at the circumference are reproduced in the four polar circles. All five circles, long arcs and short arcs are drawn to identical radii.

Drawing 33 shows how the full five circle geometry is duplicated, in green and red, along a horizontal centre line so that each five circle symbol kisses the central circle of its neighbour (at the black arrows). It can be seen that the green and red polar vesicas define the boundary of the building's floor, as tangents to the vesicas on the long walls and as bisections of the vesicas on the short walls. The green and red five circle geometries coalesce to form a six circle sequence along the centre line.

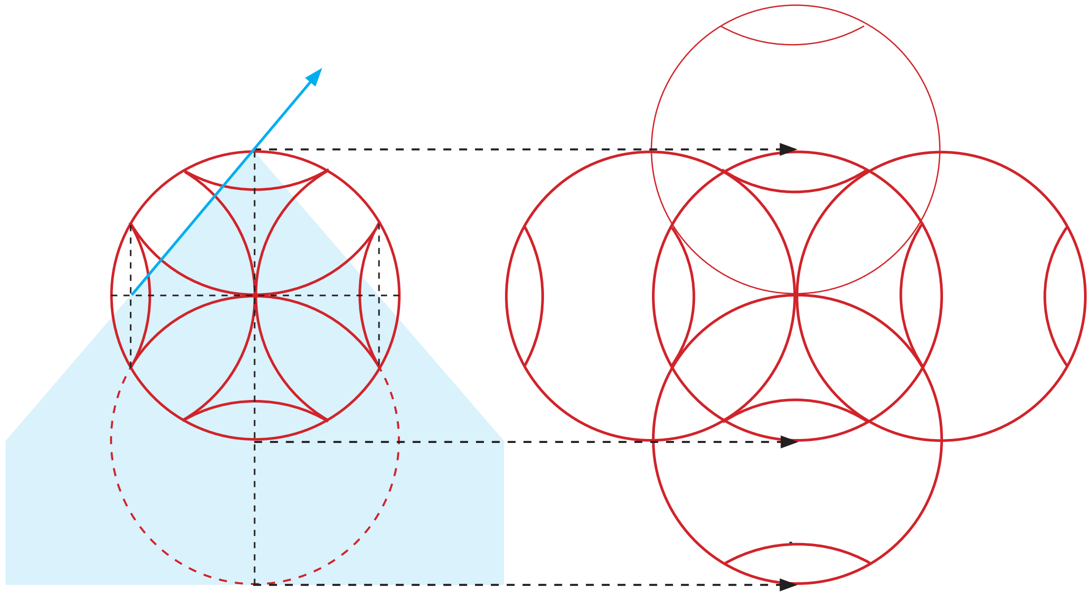
Drawing 33 shows how the symbol's five circle configuration can be duplicated to form a longer geometry suitable for the development of a linear building's floor plan, in blue tone.

Drawing 34 shows how linking selected points of intersection converts the geometry into cross wall alignments. The floor plan boundary is determined by bisection of vesicas and tangents to vesicas, and the cross walls follow the same principle. The four internal cross walls are the upper and lower ends of the hall and the cruck and spere trusses within it. The hall upper end alignment bisects the large vesica formed by the green symbol's central and western circles, the cruck alignment bisects the small vesica on the red symbol' s western circle circumference, the spere truss alignment is formed by a tangent to the red symbol's central circle western vesica and the hall lower end bisects the red symbol at its vertical diameter. A cross passage, defined between the spere truss and the hall lower end, is shown in darker blue tone. The speres span just the width of the aisles from the outer walls to the building's nave.

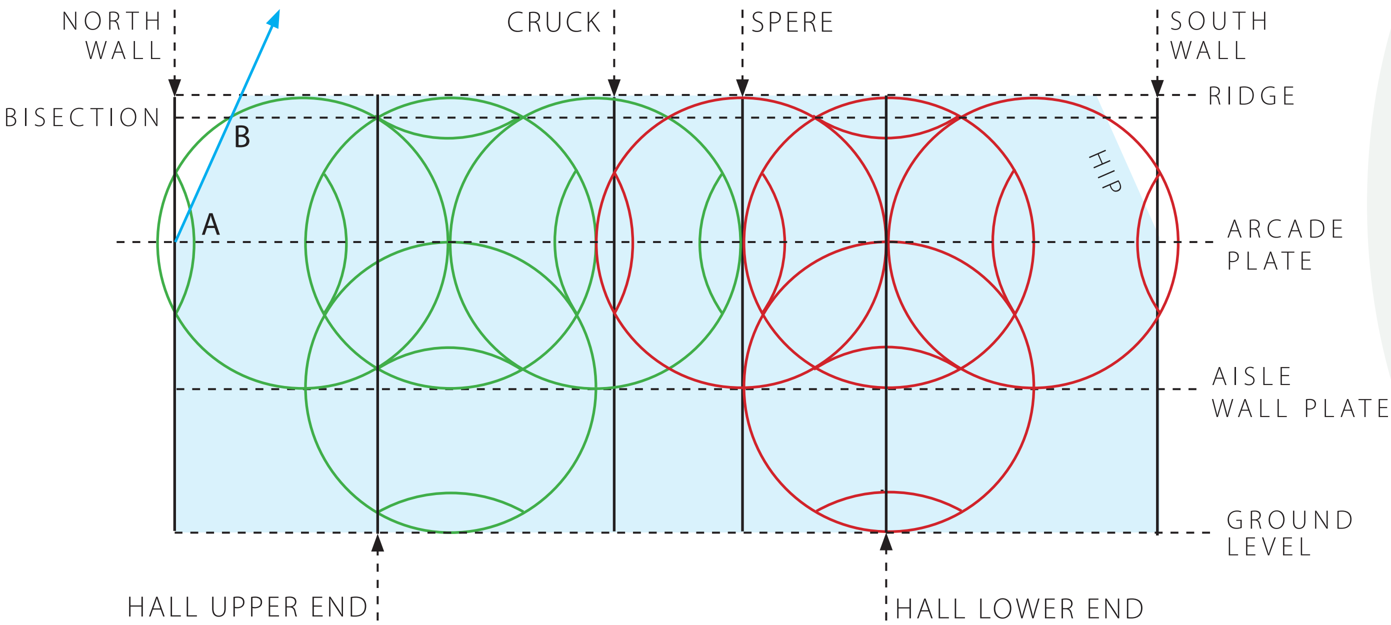


34 TŶ-MAWR'S FLOOR PLAN

Drawing 35 shows the relationship between the symbol's sectional proportions, left, and the full five circle symbol, right, and shows that the building is 1½ circles in height from ground level to ridge. It follows logically that the building's long elevation will be the same and that, in the full double green and red symbol geometry, one row of circles is redundant. Drawing 36 shows the long elevation within the double symbol geometry, with the upper half circles omitted and the roof ridge running as a tangent along the central circles' upper circumferences. The building's ground level runs as a tangent along the lower circles' lower circumferences.



35 TŶ-MAWR'S 1½ CIRCLE HEIGHT AGAINST THE FULL SYMBOL



36 TŶ-MAWR'S LONG ELEVATION

Drawing 36 shows the building's long elevation within the double green and red symbol geometry. On the left, the drawing shows the development of the north wall hip angle, rising as a blue arrow from the axis of the upper end circle's left vertical vesica at **A** and passing through the point of intersection between the upper end circle and the upper circles' horizontal vesica bisection line at **B**. This is repeated in mirror image for the south wall hip angle.

The development of the long elevation hip angle in drawing 36 is identical in principle to the building section's roof pitch angle shown in blue line on the left in drawing 35. Both angles rise from a vesica centre, revealing considered geometrical consistency in the building's design.

CONCLUSION

Analysis of the measured drawings taken from Tŷ-mawr prior to its repair has yielded clear and consistent evidence that a geometrical system was used in the design of the house and has revealed the crucial importance of the geometrical symbol on Truss I for a full understanding of Tŷ-mawr's design. The symbol is pivotal to a complete reconstruction of the design method, but only when applied to the circle matrix. So, the design can be seen to be dependent upon the inter-relationship of two critical components, the six by three circle matrix and the symbol, itself circular, which can occupy any circle within the matrix. The matrix and symbol in conjunction provide an integrated and harmonic network from which primary proportional decisions such as the extent of the floor plan or the long and cross-sections of the building can be made while the symbol simultaneously introduces the potential for finer resolution of the design. The three by six circle matrix exhibits a number of important characteristics. It uses neither numerical dimensions nor calculations, it is fast to draw, simple to develop designs from, easy to scale up to full size and harmonic in the proportions that it generates.

The use of the circle matrix requires no measurement beyond the initial choice of circle radius and the number of circles to be used in sequence. The matrix provides a sophisticated, multi-directional web of predetermined geometrical relationships that do not require to be expressed as numbers or dimensions. Indeed, it is the very absence of numbers, dimensions and calculations that makes the system so fast and easy to use. The circle matrix is a *spatial* system concerned with the proportions of individual planes and their relationship to one another within the transcendent form of a building. Each two-dimensional plane, at full scale, is simultaneously the upper face of a three-dimensional frame resting upon the framing floor. In erection on site the frames are raised and pegged together to form the three-dimensional structure of the building, which expresses in space all of the geometrical harmony inherent in the flat matrix from which its design was taken.

The drawing technique is rapid. Using only the compass, rule and scribe as instructed by Vitruvius, it takes under five minutes to construct a six by three circle matrix with circles of 8¼ inches in diameter, a scale discussed below. The construction of the symbol, including its intemal arcs and vesicas, can be drawn in two minutes and the aisle post sections in one. In less than flfteen minutes the matrix, symbol, floor plan and section can all be drawn. However, beyond this basic stage, which establishes the fundamental boundaries of the design, the drawing would take longer in order to allow time for consideration.

Initially, the deliberations of the designer are constrained by the limited choices of intersection evident within the matrix, but as each new linkage is drawn it generates further intersections. As the design evolves it therefore multiplies the number of choices available to the designer, but it does so in a natural progression from the initial matrix. This means that as the design moves towards its culmination the potential for resolution grows ever finer, yet is at all times in harmonic resonance with the earlier stages of the design. There is a wonderful sense of clarity and logic in this process for imagination is not required to pluck architectural concepts from the air but is focused firmly upon the actuality of the matrix, upon tangible rather than abstract potentials. The chosen floorplan defines the house at ground level and the section defines the form of the outer walls, roof pitch and ridge. Within these boundaries further choices of interconnection can be made until each truss is resolved, those of the gables remaining simple in deference to weather and their humbler function, those of the hall developing the elaboration appropriate to the status of a principal room in an important house.

The design process outlined throughout this paper implies not only a system of planned building but the production of a master drawing from which a full-scale chalk line layout could be transferred to the framing floor. The writings of Vitruvius describe the means by which the master drawing was made. It is useful at this point, to add weight to the idea that medieval designers derived elevations from their plans, to quote from a document that was drawn up at the time that Tŷ-mawr was being designed and built. In 1495 , master masons from Strasbourg, Vienna and other European cities met at Regensburg in Germany to standardise the statutes of their lodges. The resulting rules included the explicit edict:[11]

> *No workman no master, no journeyman will tell anyone who is not of the craft and who has never been a mason how to take an elevation from a plan.*

It is obvious from this directive that the knowledge of how to develop elevations from plans was widespread amongst masons at all levels ofthe craft. In all probability it was also common knowledge among the frame carpenters of the time. It seems unlikely that the protectionist aims of the Regensburg statutes had much effect in Montgomeryshire and the assumption here is that the designer of Tŷ-mawr knew exactly how to take elevations from plans. The issue here is the scale of the master drawing itself and the means by which it was converted to full scale on the framing floor. Tŷ-mawr offers some critical clues: in the scale of the race knife circle assembly marks, in the recorded scale of the geometrical symbol itself and, most importantly, in the full-scale symbol circle, shown in drawing 31, that defines Tŷ-mawr's nave width at the outer faces of the spere posts as 16 feet 6 inches or 1 medieval Rod, the dimension used for the diameter of the symbol at ground level when Tŷ-mawr's frame was laid out.

There is evidence from both sides of the country for the use of the rod in medieval buildings. At Cressing Temple, Adrian Gibson discovered that both the Barley Barn and Wheat Barn were built to dimensions based on the Rod. To be specific, they were built to circle sequence designs and the circles were based

11
Nicola Coldstrearn, Masons and Sculptors (British Museum, 1991), 38.

on the dimensions of the rod, the Barley Bam circles to a diameter of three rods and the Wheat Bam, using a slightly different geometry, to a circle drawn through the corners of a two rod square.[12] Closer to hand, in Shropshire, Madge Moran mentions evidence of the rod in medieval buildings in Whitchurch and the double rod of 33 feet as the width of burgage plots in Ludlow.[13] The double Rod has some interesting numerical properties for all of its subdivisions, including the Rod, are either fractions or numbers that include fractions. The double rod is the first whole number in a long sequence of dimensions in which every one results from either division or multiplication by 33, the number of feet in the double Rod. These characteristics, which are relevant to Tŷ-mawr, are shown in the table below

÷ 33 x 33	inches	feet	Rods	Tŷ-mawr
33 ÷ 32	$1\frac{1}{32}$	-	$1\frac{1}{192}$	race knife circle diameter
33 ÷ 16	$2\frac{1}{16}$	-	$\frac{1}{96}$	symbol carving diameter
33 ÷ 8	$4\frac{1}{8}$	-	$\frac{1}{48}$	nave circle design radius
33 ÷ 4	8¼	-	$\frac{1}{24}$	nave circle design diameter (1)
33 ÷ 2	16½	-	$\frac{1}{12}$	-
33 x 1	33	-	$\frac{1}{6}$	-
33 x 2	66	-	$\frac{1}{3}$	-
33 x 3	99	8¼	½	nave circle actual radius
33 x 6	198	16½	1	nave circle actual diameter (2)
33 x 12	396	33	2	full scale circle matrix width (3)

Note. A design drawing with circles of 8¼ inches in diameter (1) is in 1:24 scale to the full scale nave circle of 16½ feet in diameter (2) that passes through the outer faces of the spere posts. It should be noted that Tŷ-mawr is narrower than the full two rod width of the circle matrix (3). The repaired width of the house is 29 feet 2½ inches but the geometrical width, scaled up from the matrix, is 8½ inches less at 28 feet 6 inches.

Several things are clear from the table: that the doubling of dimensions evident in the inches column is replicated in the feet column to establish a I:12 relationship, and that the actual dimensions of the race knife circle assembly marks and the carved symbol occupy accurate places in the dimensional sequence. If the symbol diameter is doubled to give a design drawing radius of $4\frac{1}{8}$ inches, the resulting six by three circle matrix would have circles of 8¼ inches in diameter. This, in turn, is in 1:24 scale to Tŷ-mawr's built size. A drawing of the six by three circle matrix based on circles of 8¼ inch circles would be 2 feet 5 inches long by I foot 4½ inches wide, a standard drawing board drawing. Scaling up from such a drawing to full scale is simple for any distance taken from the circle matrix can be multiplied by 24 to attain full scale. An even simpler process is to double the dimension of any distance taken from the circle matrix and to scale up on a I:12 ratio, the difference between inches and feet. Any distance taken

12
The geometrical floor plans of the Barley and Wheat Barns and their relationship to the rod is demonstrated by Adrian Gibson *op. cit*. (note 3), 183, 184.
13
M, Moran, *The Vernacular Archtecture of Whitchurch and Area* (Logaston Press, 1999), 93.

from the matrix in inches is, if doubled, automatically in feet. The 8¼ inch plan circles, for example, if doubled to l6½ inches are automatically l6½ feet, or one statute rod at full scale. The arithmetic is simple and minimal. Marking up for full scale is also an easy process with the large, waist high compasses or dividers seen in many medieval illustrations of building construction work,[14] the tool doubling the plan dimension and stepping out twelve 'paces' along a chalk line on the framing floor or along actual timbers during cutting and assembly. Two independent yet interdependent characteristics dominate the six by three circle matrix. The first is the repetitive occurrence of the circle's radius and diameter which, identical in all directions, give regularly spaced and predetermined points of intersection across the whole grid. The matrix therefore has predictability and is a known quantity. The second characteristic is the unpredictable potential for linkage between the points of intersection for these increasingly depend upon the choices taken as the design proceeds. The six by three circle matrix is therefore simultaneously a stable foundation and a dynamic platform upon which the activity of designing can take place. Because all design decisions emanate from the matrix they all embody its underlying structure and symmetry and because every timber, from the least to the most significant, arises from the circle matrix, the system establishes the '*perfection of individual elements and harmony in the whole*' described so authoritatively by Vitruvius.
It should be remembered, however, that design systems are useless without an understanding of the materials being used to execute the design. It is well recorded that medieval master masons and carpenters started life in the quarry or the forest and worked their way up through the ranks. In consequence, the master carpenter had a sound working knowledge of timber selection, felling and conversion, and of the strength and behaviour of timber, as well as the prevailing construction techniques and aesthetic vogues of the time. The aisled hall, essentially a house with two linear outshuts, demonstrates both an awareness of the limits of timber's structural potential and the means to circumvent this through an imaginative design approach. The design was not a design in isolation but an aggregate of theoretical and practical expertise, the choices from the circle matrix were all made, simultaneously, under the guiding mind of a skilled geometer and the guiding hand of a skilled carpenter.

Writing on aisle-truss halls in *Houses of the Welsh Countryside*, Peter Smith makes the interesting point that the aisle-truss halls in north east Wales are a Welsh expression of English social and architectural trends and that they are '*not so much an invading race as an invading idea*'.[15] The statement refers to the social status of such houses in the minds of their owners but it also seems likely that these buildings expressed the rising aesthetic acumen of a sophisticated breed of designer craftsmen who were well versed in geometry and used geometrical systems for designing and for full-scale layout. The use of such systems can be traced from the geometrical epicentre of classical Greece, through the Roman world of Vitruvius and from there, over time, across the Arabic and European countries, the geometrical ripples spreading ever wider until they reached here. The idea was less an invading idea than a *pervading idea* and, like

14
The most well-known drawing is by the thirteenth-century Benedictine rnonk, Matthew Paris of St Albans. It shows a king, a courtier and a master mason with waist-high compasses, adjacent to a building site where workers are erecting an arcade (British Library, Cotton MS Nero D1, fo.23v).
15
Peter Smith, *Houses of the Welsh Countryside* (HMSO, 2nd edn, 1988), 93.

all good ideas, it travelled far and wide. Ideas are light baggage on long journeys, they carry their own passports and their survival is entirely dependent upon their utility. The worldwide spread of the computer is a modern example. When Tŷ-mawr was built in the fifteenth century, geometry was the state of the art design system across Europe and it was inevitable that it would be found in Wales. What is interesting is the sophistication of Tŷ-mawr's geometrical design and the illuminating and stimulating insight it gives into the working of a fifteenth-century master carpenter's mind.

Finally, it is necessary to say a word regarding the timing of this paper for the opportunity to undertake the research only arose after repair work at Tŷ-mawr was well under way and was only concluded after the repairs were complete. This is a matter for deep regret because the findings were consequently not available as another area of understanding in the service of historic building repair. The geometrical findings in this paper that suggest slightly different aesthetic solutions to those applied in the repair of the cruck and spere trusses, if available at the right time, might have given pause for thought. At minimum they would have offered another choice, a new angle of view, and an additional perspective on medieval building design.

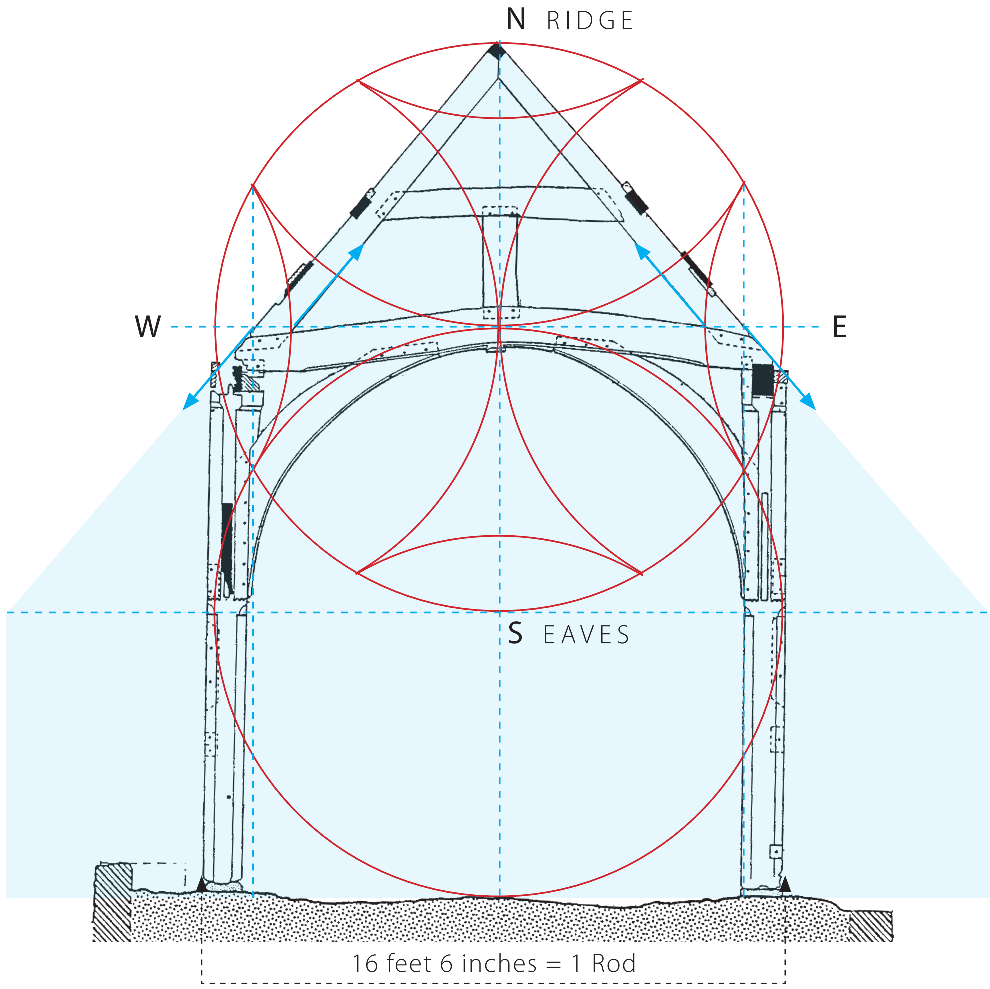
The geometrical symbol at Tŷ-mawr has been the key to unlocking the building's highly sophisticated geometrical design code and this, in turn, has made possible the findings presented here. The lesson is loud and clear, that we have much to learn from the recording and analysis of all geometrical carvings or images found in historic buildings and that they should be carefully preserved in situ where their meaning is greatest.

Acknowledgements 2000

I am grateful for having access to the measured drawings of Tŷ-mawr made by Patricia Borne and Philip Dixon, for without them the geometrical analysis of the house could not have been undertaken. I am also grateful to Bill Britnell for tracking down the video of the repair work and for making a still of the carved symbol available to me, for without the symbol it would have been difficult to reach a full understanding of Tŷ-mawr's design. I must also record my indebtedness to my friend David Goodman of Llanfyllin who meticulously metamorphosed my typescripts, manual drawings and verbal instructions for the Montgomeryshire Collections millenium edition into crystal clear computer text and diagrams, more often than not late into the night. (This edition is my own work). I would like thank Dave Oakley, the current resident at Tŷ-mawr, for kindly allowing me access to the house and especially for helping me to measure the primary circle that passes across the floor of the hall and through the outer faces of the spere posts. I am grateful to the Royal Commission on Ancient and Historic Monuments in Wales for permission to use the drawings of Tŷ-mawr and Pen-y-bryn from *Houses of the Welsh Countryside* in the full report and to Peter Smith, the author, whose writing on the aisle-truss halls, in particular, has been a critical source of understanding.

Acknowledgements 2018

In revising this article I must acknowledge with gratitude the warm welcome of Anna Ingram, Tŷ-mawr's current resident, whose coffee, cakes, stimulating conversation and, above all, appreciation of the house made each visit a pleasure.

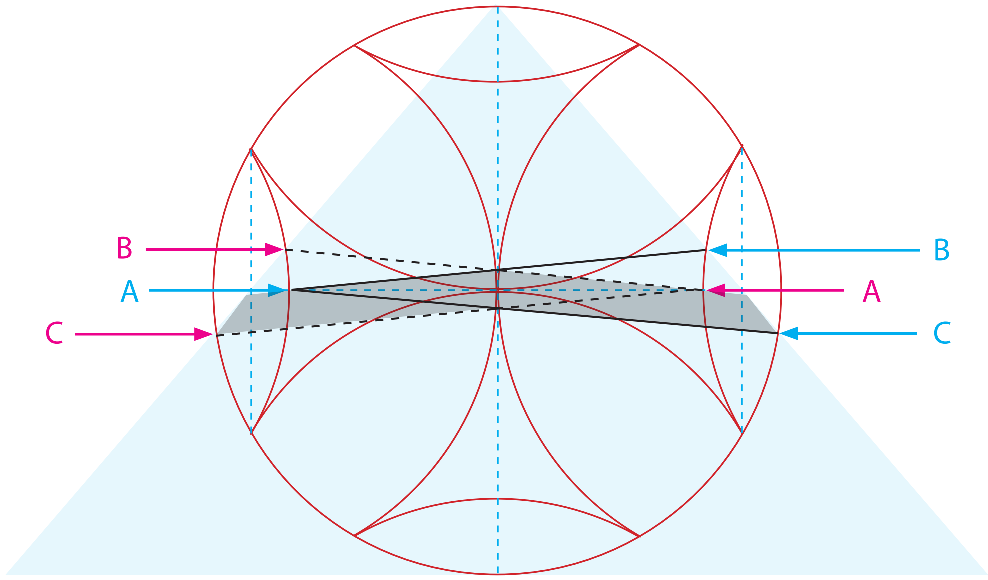


Appendix 1 The spere truss

Tŷ-mawr's spere truss, forming an arched entrance into the hall from the cross passage, and cruck truss, which spanned the centre of the hall and had cusped bracing in its apex, are the two central and most elaborate trusses of six. The remaining four trusses are the upper and lower ends of the hall and the north and south gables.

The drawing above shows Patricia Borne and Philip Dixon's measured drawing of Tŷ-mawr's spere truss, chosen for testing the viability of the symbol's geometry because, apart from its lost aisles, it stood at the protected centre of the house and had suffered the least damage and racking. The drawing has been cleared (on computer) of later studs and boarding to reveal the original truss and restored by a few degrees to its original vertical stance.

The building's ridge is one and a half circles above ground level with the symbol drawn in the upper circle. The radius of both circles is 8 feet 3 inches, giving the measured diameter of 16 feet 6 inches (1 Rod) at the outer faces of the spere posts. Triangulation between the symbols upper and lower circumference, at the ridge and eaves levels, defines the roof pitch by passing through the centres of the vesica cross hairs at **E** and **W**. The downward blue arrows emphasise the pitch and the upward blue arrows define the alignment of the principal rafters.

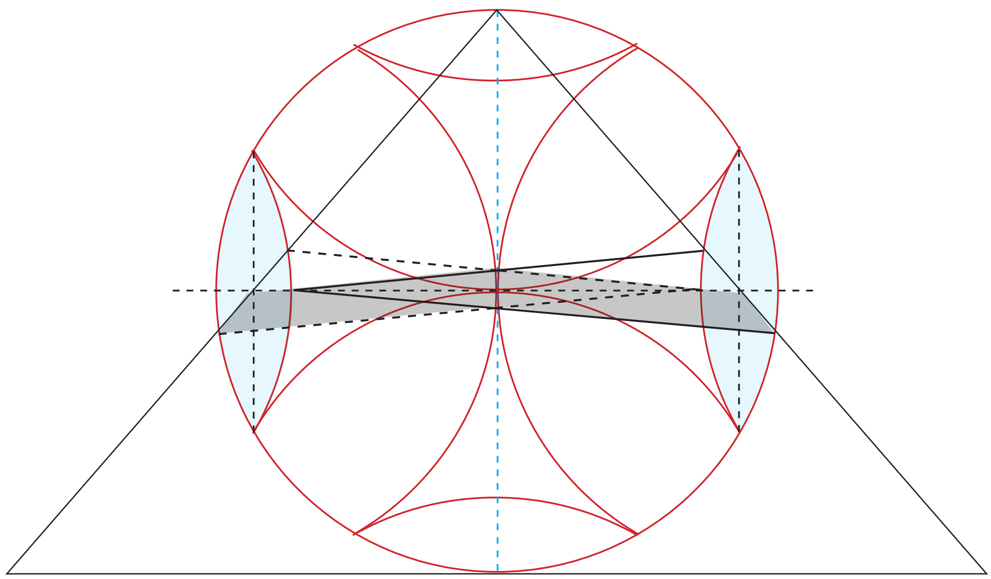


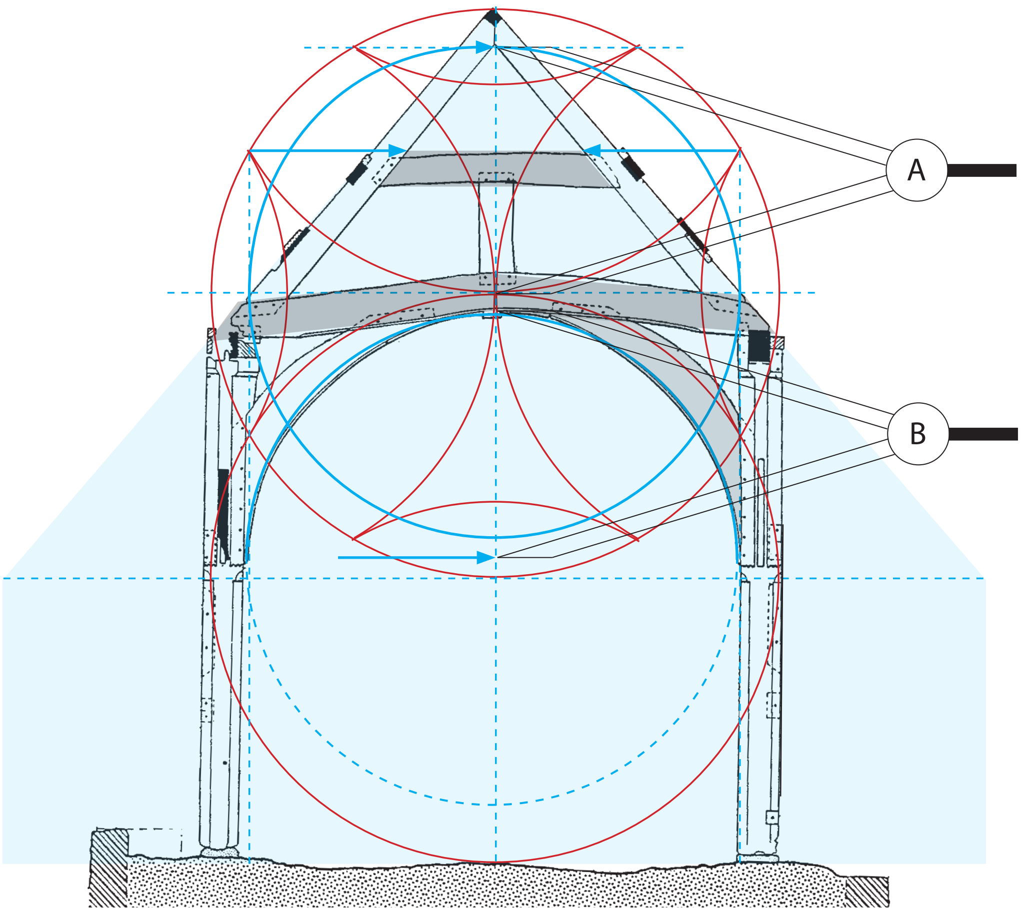
Appendix 2 The spere truss cambered tie beam

The spere truss has a cambered tie beam. The angles of the camber are determined by linkage of cardinal points in the symbol's vesicas. Linking **A** to **B** and **C,** at the blue arrow tips, gives the angle of the camber either side of the truss centre, specifically the lower face of the tie beam to the right of the symbol's vertical centre line to **C** and the upper face from **A** to the symbol's vertical centre line. These alignments are shown in black line.

The other half of the tie beam is drawn in mirror image between the magenta arrows in dashed black line. The form of the cambered tie beam is defined between these lines and is shown as a grey tone.

It can be seen that the vertical vesicas are crucial to the whole roof design and that the design principles utilise the linkage of the points of intersection found within them. The drawing below shows the crucial links within the grid and the aesthetic certainty that arises from their use.

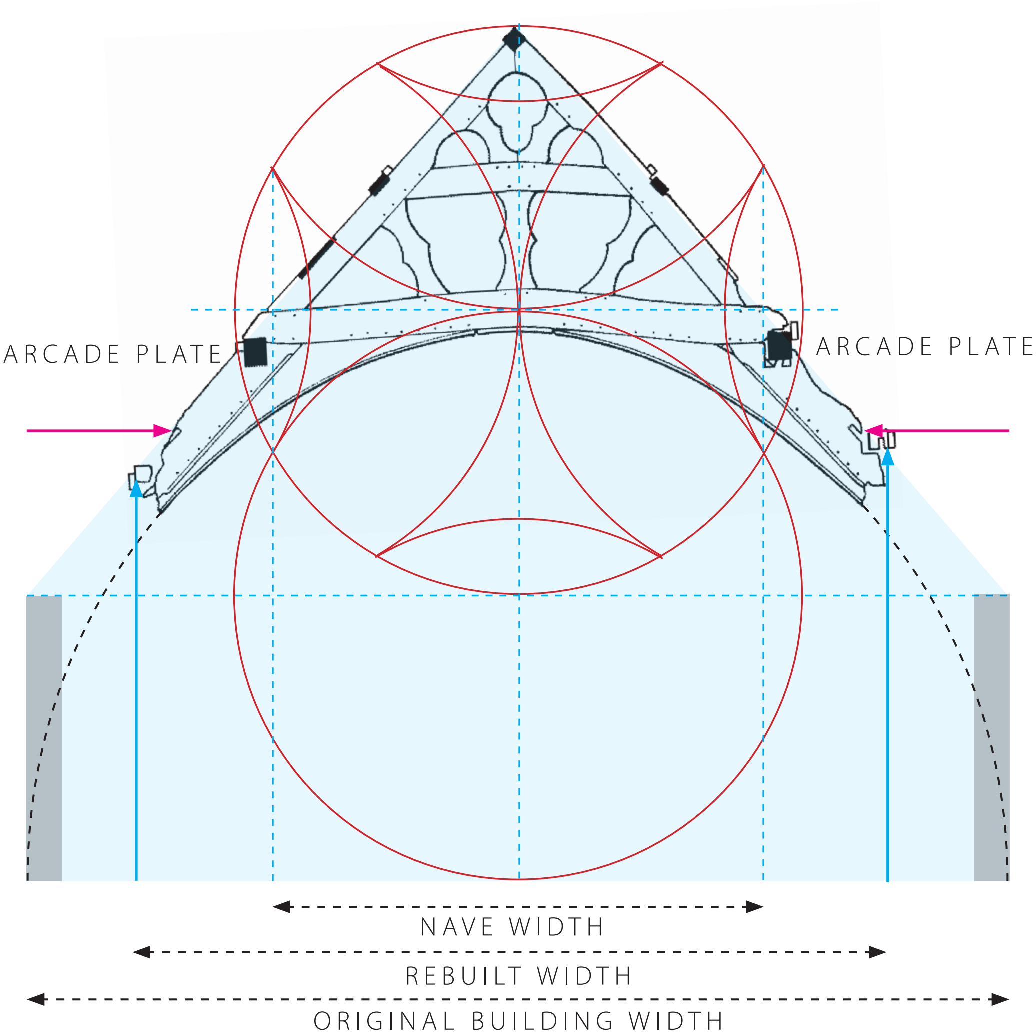




Appendix 3 The spere truss arch and collar

The spere truss cambered tie beam is supported by a semi-circular arch and this needs further geometrical construction. The first stage is to draw a circle with dividers A from the symbol's axis so that the circumference passes through the ridge vesica's centre. The circle is drawn in blue line and indicates the ridge vesica's centre at the blue arrow. Once circle A is drawn, the dividers can transmit the circle to position B which is found by placing the upper divider pin exactly at the centre of the cambered tie beam lower face. The lower divider pin is then at the vertical centre line axis of the arch, shown in blue line. The right blade of the arch is shown as a grey tone.

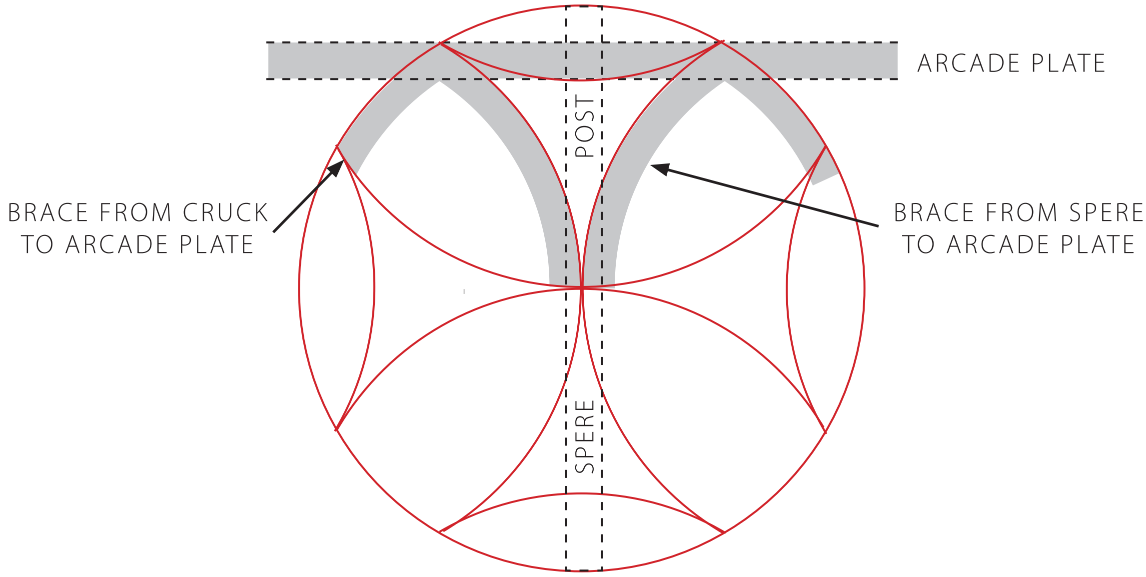
The top point of the vertical vesicas, level with dividers A, are linked by a horizontal line to give the upper face of the collar, at the blue arrows. The collar is shown in grey tone.

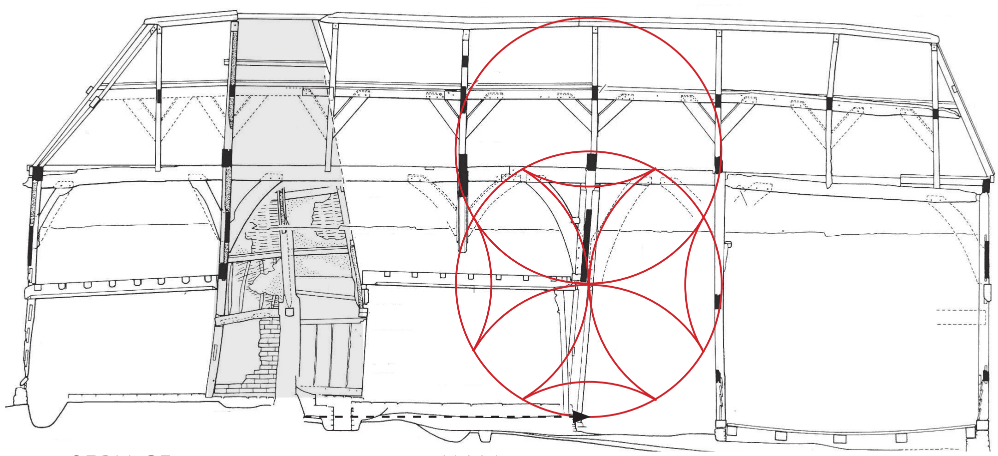


Appendix 4 The base cruck truss failure

When Tŷ-mawr was discovered by Peter Smith it was derelict, clad in corrugated iron and serving as a farm building. The lower halves of both base cruck blades were lost but the crown of the cruck survived intact above the arcade plates. Patricia Borne and Philip Dixon's measured drawing is shown scaled to fit the symbol's geometry where the cruck blades' failure is clearly identical on either side of the hall. The horizontal magenta arrows mark the remnant upper ends of mortices that held the tenons of the braces that ran from cruck to arcade plate. Reconstructing the demise of the house it is clear that, once roofing flags were damaged or missing, rainfall was chanelled down the cruck blade and brace upper faces directly into the mortices in the cruck blades.

With the house descending the social ladder and maintenance neglected it was only a matter of time before the ingress of water eroded the cruck blades at their weakest structural point. And when this happened the solution was to rebuild the aisle walls on a narrower alignment dictated by the remaining ends of the cruck. The vertical blue arrows indicate the new alignment for the aisle walls, a decision that meant demolishing the building's long wall stone plinth and rebuilding it to generate a narrower building but also a decision that ignored and destroyed the symmetrical aesthetic of the building's original design. Clearly there was neither capital, carpentry expertise nor will to repair the house properly at the time.





Appendix 5 The spere and cruck truss bracing

The upper drawing shows how the symbol also governs the curvatures of braces from the cruck blade and spere post to the arcade plate. The braces between the cruck and arcade plate follow the symbol's circumference and are in the roof plane. The braces between the spere post and the arcade plate follow the vertical arcs upwards from the symbol's axis and rise vertically to the arcade.

The lower drawing shows how one and a half circles determine the building's height and how the symbol can be drawn in the lower circle to define the curvatures of the braces. It can be seen that the spere post and braces have racked to the right but the design principle is clear.

The lower drawing also shows the timber framed chimney, in grey tone, opening left into the service room and right into the hall. Two inserted ceilings are also recorded.

Appendix 6 The symbol

In 1460, during Tŷ-mawr's construction, a carpenter using a compass race knife scribed a symbol into the interior face of the north gable's eastern aisle post. The symbol was a design icon, cypher or module, a visual seed at the heart of a geometrical design language. Within the seed's circumference, four long arcs passed in cruciform symmetry through its axis and were linked by four short arcs at the poles of the symbol's circumference. Every element was drawn to the same radius. Extending the arcs beyond the symbol's circumference allowed the seed to germinate, grow and flower into the three dimensional form of an aisled hall. It was a cypher recognisable by fifteenth century craftsmen in the same way that £ or $ signs are recognisable throughout the world today.

The symbol survived where it was scribed for over 500 years until, after years of gradual decline, the house was rediscovered and the decision was made to repair it. Although the symbol was recorded in Patricia Borne and Philip Dixon's survey report[16] and was captured on video (see video still above) it's significance was not recognised during the repair phase. The aisle post on which it was scribed was removed from the frame and a modern aisle post took its place. With the repairs nearing completion and with Prince Charles expected to officiate at the re-opening ceremony a clean up of the house, site and site hut took place. A pile of scrap timber was burned and the symbol was never seen again.

The loss of the symbol was a catastrophe for architectural history because Tŷ-mawr was the first house in Wales to yield a symbol that could be analysed, opened and developed to a full house plan, floor, section and long elevation, timber profiles and sections. The subsequent provision of a poorly executed replica, albeit in the right location, merely emphasised the loss. That the loss occurred during a programme of restoration under the guidance of an architect beggars belief.

Something should be learned from such a sorry story. The first lesson is that sometimes things that seem insignificant or which are not understood need protecting until their significance is recognised. The second lesson is that such findings should be clearly marked and brought to the notice of everyone working on a project. The third lesson is to leave such findings in situ where they retain their original meaning. The fourth lesson is to learn some basic geometry so that geometrical symbols can be replicated on paper or computer and analysed with a view to understanding. The fifth lesson is that the symbol holds the key to a sophisticated spatial design language that, once unlocked, is the genesis and evolution of Tŷ-mawr's simple yet sophisticated design.

16
Patricia Borne & Philip Dixon, *Tŷ-mawr, Castell Caereinion: a Report on the Survey and Excavations*, (unpublished, 1981), Department of Archaeology, University of Nottingham.

Appendix 7 Exterior from the North, East, South and West

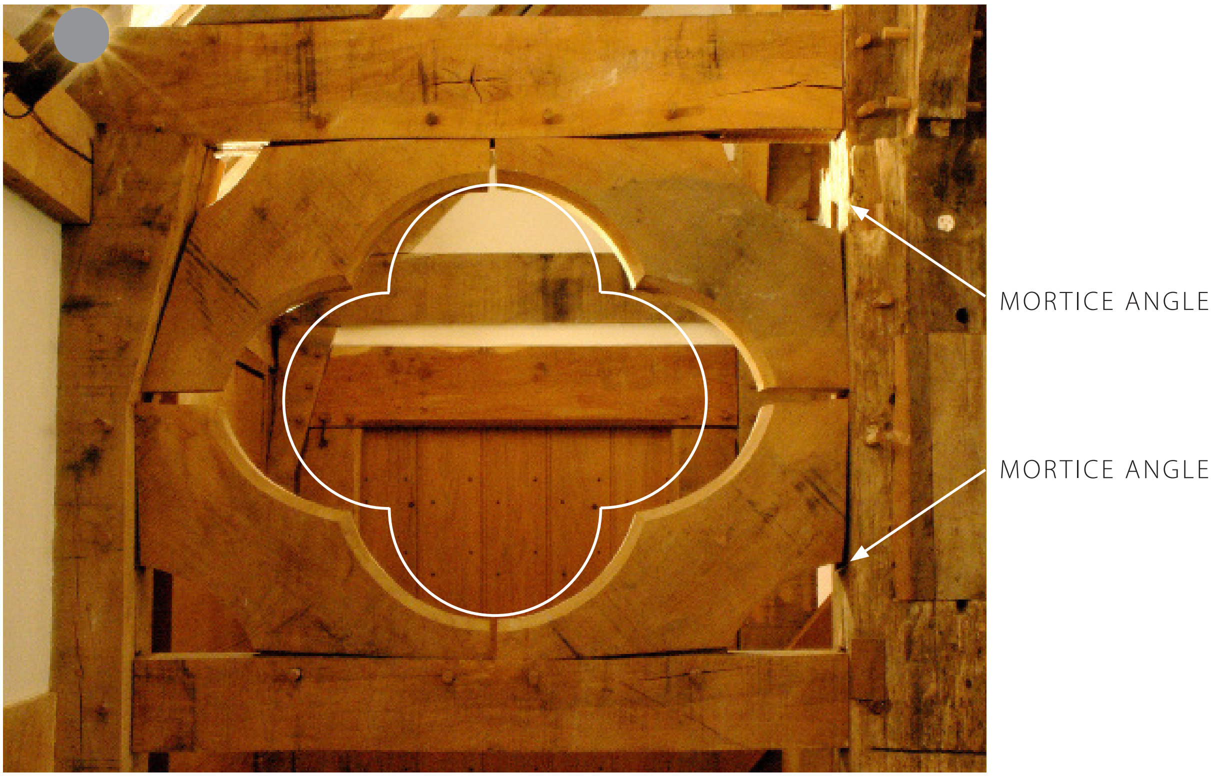
Appendix 8 Hall interior

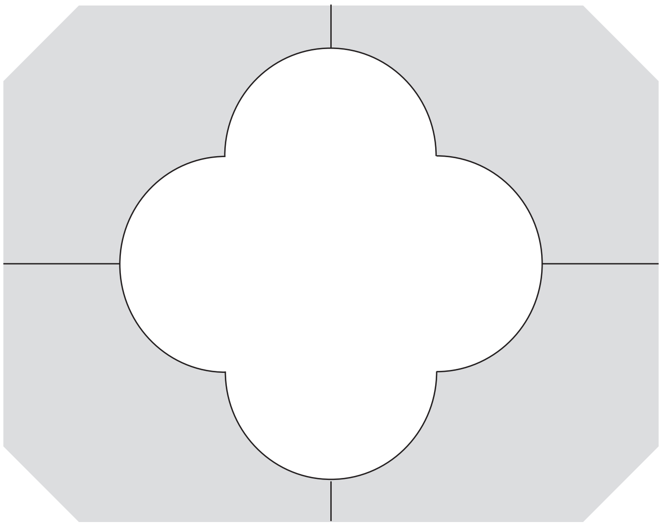
Timber framed chimney beyond cruck arch.
Upper end of hall. Stairs to solar above service rooms and chimney hearth.
Lower end of hall beyond cruck and spere. Stairs in cross passage to storage.

Appendix 9 Interior Original and modern timbers
Spere post, left, and cruck, right, bracing to arcade plate
Spere post, left, arcade bracing and hall arch (arrowed)

RACE KNIFE
CARPENTER'S
MARK

Appendix 10 Interior Original timbers
Cusped cruck head
Spere post crenelated capital
Compass race knife circle carpenter's assembly mark





Appendix 11 **Interior** Spere post to aisle wall quatrefoil bracing

The nave timbers, having dried naturally, had survived for over 500 years. The reconstructed aisles and quatrefoil bracing were framed in green oak. Incompatible from the start, the green oak's shrinkage was accelerated by underfloor heating installed during the building's repair with disastrous results, as the photograph shows. Because the repairs were carried out without the symbol's guidance some poor aesthetic judgements were made. Stretching the quatrefoil horizontally (because the aisles were framed too wide) and cutting curves at the corners of the braces when the existing spere post mortices suggested angled corners destroyed the aesthetic symmetry between the spere posts and aisle walls. The drawing shows the quatrefoil with corners angled to fit the existing spere post mortices and fitted to the symbol's geometrical aisle width.

How needful and necessary
the most secret Arte of Geometrie is
for every Artificer and Workman,
as those that for a long time
have studied and wrought without the same
can sufficiently witness, who since that time have
attained unto any knowledge of the said Arte,
do not onely laugh and smile
at their own former simplicities,
but in trueth may very well acknowledge
that all whatever had bene formerly done by them,
was not worth the looking on.

Sebastiano Serlio, Venice 1584
English translation 1611

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