The Twelfth Century Church at Værnes, Norway – a geometrical speculation

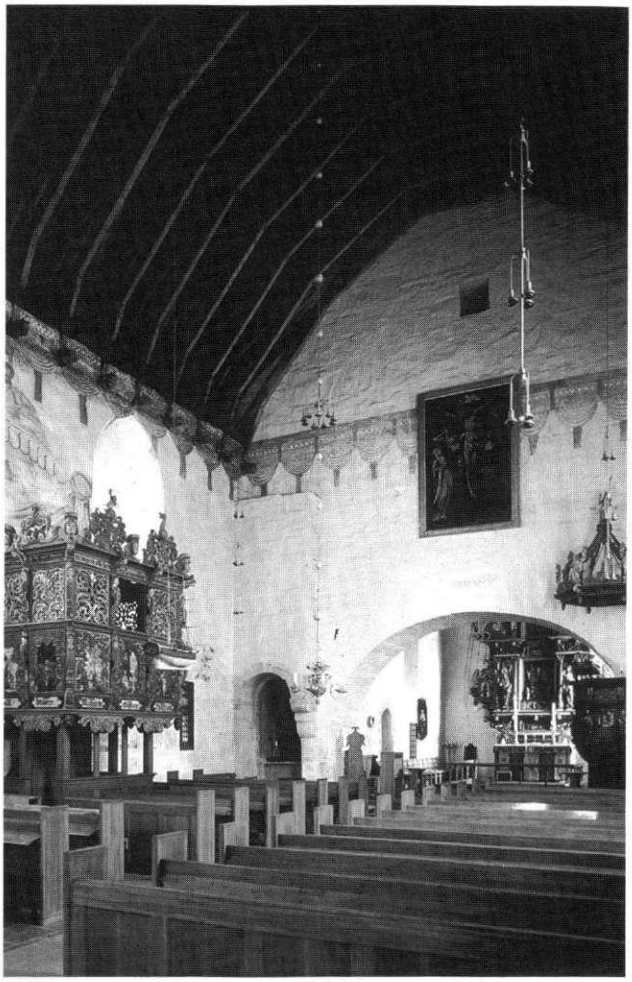
Dag Nilsen

The following is an exercise in what may seem an old-fashioned art, popular among architects in the 19th and early 20th centuries, but later somewhat discredited – the search for geometrical patterns underlying mediaeval church design. However, this activity has in recent years been revived, proof of which is a steadily increasing flow of publications reporting scientifically rigorous studies. My contribution concerns the church at Værnes, near Trondheim, Norway, and its impressive open truss timber roof of the nave. Not content with previous suggestions on how the roof design might have been determined, I compared it to similar structures in the region, and found several cases of the same ratio of width to heigth. I also noted that this ratio corresponded almost excactly to a simple geometrical diagram, and this further led me to make some assumptions on how Værnes church was originally planned.

The early laws for Norway north of the central mountain massif were codified in the first half of the twelft century into a regional law, the *Frostuthingslog*, which contains an act concerning the building of churches. According to this, the principal church of each county should be built of stone; if it was built of timber, a fine was to be paid to the bishop. In the eight counties constituting the mediaeval Trøndelag, at least sixteen stone churches were built before 1200, not counting the churches in the city of Nidaros (now Trondheim), abbey churches, and a few private chapels[1].

Twelve of these are still standing, most of them in a fairly well-preserved state. The churches contain many interesting pieces of decoration that must be ascribed to influence from the episcopal see in Nidaros. When Nidaros was elevated to an archdiocese in 1152, the construction of a new cathedral church approaching European size and standards of the time was started.

Some time earlier, work was begun on the principal church of the then Stjørdala county at Værnes. This is one of the largest and best preserved country churches in Norway. Unlike most of the others, generally younger churches of the region, it has no west door – the nave is entered only by doors in the north and south walls[2]. The foundations of the first cathedral of Trondheim have openings at the centre of each long wall of the nave, that have been interpreted as doors. If it also had a west door, this cannot be ascertained from the remaining foundations.



Værnes church, interior towards east. Photo: E. Gjone.

At Værnes, the south door of the nave is in the western part of the wall, which is the ordinary position of side entrances in the Trøndelag churches. This door is however of late mediaeval character, whereas the north door is early romanesque and strangely situated markedly to the east of the cross axis of the nave. This is the more peculiar when one takes into account the unusual rectangularity of the plan.

The church is very well preserved in its mediaeval state, except for the post-reformation widening of the chancel arch, and enlarged windows. The most interesting feature is perhaps the elegant timber roof of the nave, an open truss construction with no horizontal tie beams at wall-head level, over a free span of almost 11 metres (c. 35 ½ ft.). According to dendrochronological analysis, the timbers were felled in 1191. Allowing for seasoning time for the pine timbers, at least the eastern part of the nave roof may have been completed around 1200.

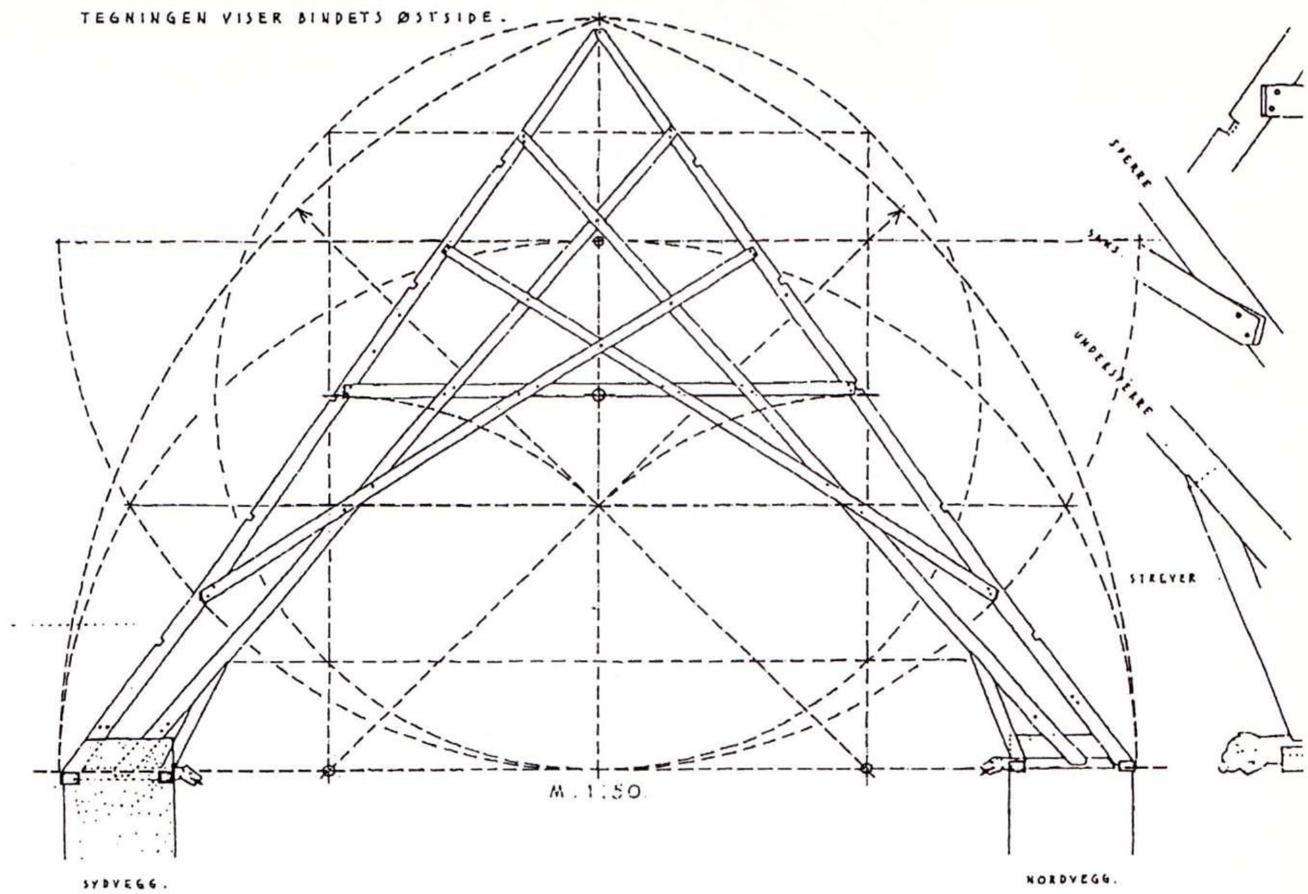
In the 1950s, the roof was meticulously measured and studied by one of Norway's leading experts on historic timber structures, the late architect Professor Erling Gjone of the Norwegian Institute of Technology, who led the restoration works. Although he acknowledged that the trusses had been produced horizontally on the ground, or on a temporary podium on top of the walls, he did not try (or at least did not publish any attempt) to examine any relationship to geometrical ratios.

This is the more peculiar, as he measured the almost identical trusses preserved at Selbu church, with a roof slope of almost excactly the same inclination. The timbers of this roof were felled the same year as those of the nave at Værnes, and it is very likely that the Selbu roof was built by the same team of carpenters. Situated some 20 miles south of Værnes, Selbu was also part of the mediaeval Stjørdala county.

Mr. Gjone made, however, some assumptions about how the different lengths of the truss members could have been determined. He noted that the length of the outer rafters of the nave roof equalled the distance from the inner flight of the north wall to the inside of the outer south wall plate, and that the meeting of the lower and outer rafters were equal to the north wall thickness. As a design method this appears somewhat contrived, even more so as he had to assume for the chancel that the distance from the outside wall flight to the outer side of the inner wall plate of the opposite wall determined the rafter length. The ratio of wall thickness to the narrower nave at Selbu makes it impossible to fit the design methods he envisaged for Værnes.

Whatever method might have been used, Mr. Gjone demonstrated his thorough understanding of the structure when he constructed a new roof from this model for the ruined church at Sakshaug, belonging to the same group of 12th-century churches of the region. This roof was built without any use of modern hoisting equipment.

The nave roof of Værnes has stood the test of 800 years. The construction of a magnificent and daring structure like this must have been the result of a development in technical skill and knowledge, most likely over more than one generation. It seems natural to assume that such a development



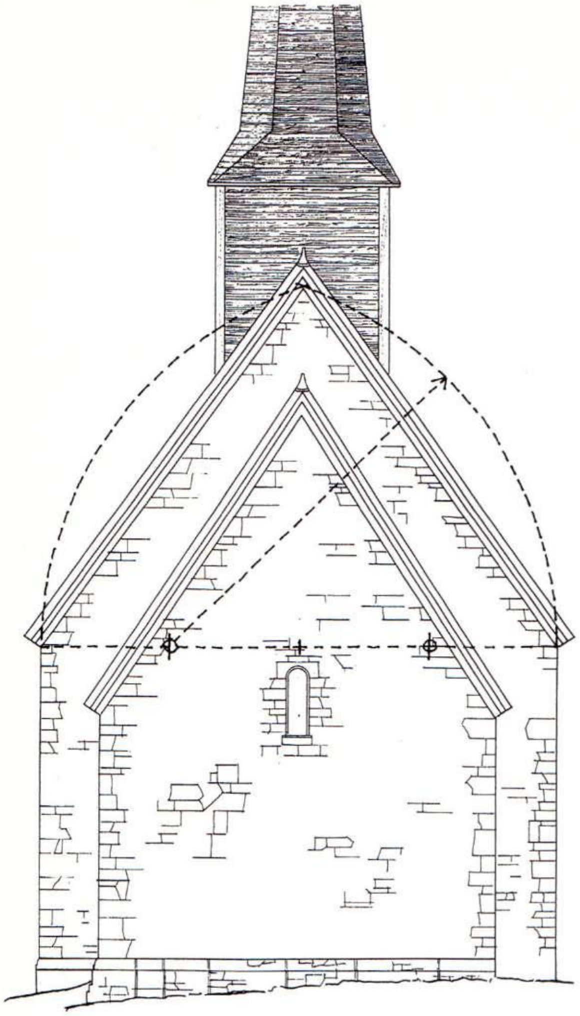
Værnes, nave roof truss, after G. Gjone. Geometrical analysis by the autor. (1:100)

depended on methods for storing and conveying the accumulated experience, and that these methods may well have involved the use of easily remembered geometrical diagrams that could be set out on the building site.

The root two connection

An analysis of the measured drawings of the roof trusses in Værnes[3] and Selbu naves reveals that in both cases the ratio of the height of the roof ridge above the wall plates to the external width is very close to the ratio of the side of a square to its diagonal, or $\frac{1}{2}\sqrt{2}$. This relationship can be determined in a simple way by dividing the external width (W) into four parts, and using the outer division points as centres for circular arcs of ¾W staring at the outer ends and meeting at the ridge. On further elaboration of this diagram, several of the joints seem to correspond to significant points in the geometry. As the truss members were dressed and joined in a horizontal position, it would be a simple matter to produce a full scale model in accordance with this geometry by using a cord[4] or a lath.

The 50 years older trusses of the Værnes chancel are of a somewhat different design, which may represent an earlier stage of the design developement. The narrower span obviously also required fewer members, but the slope angle is the same. Structures similar to the Værnes chancel roof can be found in the neighbouring county of Jämtland (Sweden)[5]; of these the roof of Norderö church is especially interesting in this context, as it has the same slope angle. At least one of the other examples seems to fit into an equally simple, but different geometrical diagram[6]. Could it be that different carpenters (or



Mære church, Trøndelag, east elevation, after T. Bentsrud. Gemetrical analysis by the author. (1:200)

teams of carpenters) used their own methods of design, and the roofs of Norderö nave and Værnes chancel were built by the same team; or might they have had command of a *repertoire* of methods to adjust to different design requirements of the master masons responsible for the general layout?

If the roof trusses at Værnes were designed with the use of geometrical methods, it is tempting to look for similar patterns that might have been employed in the design of the entire building. Starting with the chancel, the outside length of the east wall is 8,91 m, and the south wall is 8,94 m from the east wall of the nave to the east end of the chancel externally. The chancel extension in the horizontal plane thus forms a square as accurate as one can expect with the roughly dressed stones of the masonry.

Inside, the east wall of the chancel is 6,30 m wide. The ratio of 8,91 to 6,30 is 1,4143, which is very close to root two – really too excact to be believable, considering the character of the masonry. This should mean that a circle inscribed in the square formed by the three outer wall flights of the chancel and its inner wall to the west will touch the internal eastern corners where it intersects the diagonals – that is, if all the walls were of equal thickness. In that case, this should fit the roof geometry.

The north wall, however, is slightly thicker than the south wall, and the east wall is even more so – about the same dimension as the average of the long walls of the nave. The chancel is also slightly wider at the west end. Concerning the nave, it seems impossible to find any ratios corresponding to this method, other than the ratio of the nave's internal width to the chancel's external width and length, as we shall see later.

A free-standing west tower?

The Danish architect Mogens Koch (1898–1992) commented in an article of 1963 upon observations concerning several Danish mediaeval parish churches. In these the internal width of the nave is half its external length, which also often equals the internal diagonal of the nave. Koch suggested that this might mean that the geometry of the typical consecration crosses found in many mediaeval churches had been used to determine the plan. As argument for this he proposed that this geometrical diagram makes it easy to establish a square angle horizontally, and thus determine the east-west direction when the north-south direction has been found by the position of the mid-day sun[7]. Using his architect's imagination, Koch writes about the geometry of the consecration cross:

> It was a well known geometrical diagram, and it was not kept secret; it was also a cross. If some of the parish churches of Denmark were set out this way – a rectangle could not be set out easier – then one had at the same time, for all to see, consecrated the ground upon which the church was built to Christianity[8]. The first churches were often built on sites formerly dedicated to pagan gods. The simple geometry on the ground could be both practical and sacred; we will never know whether it also had an aesthetic significance.

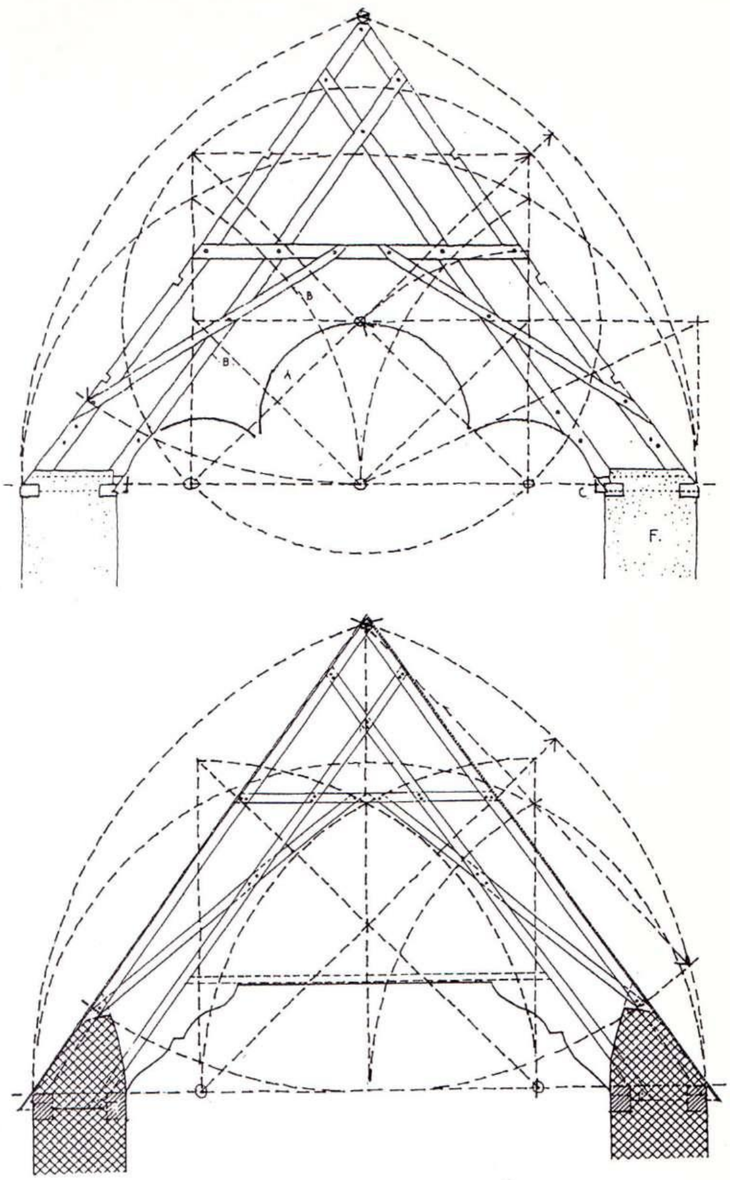
When applied to the Værnes nave, this diagram will at first sight not fit very well, unless one presupposes that the nave was planned c. 2,50 m (c. 8 ft. 4 in.) shorter than actually built. The eastern wall of the nave is however substantially thicker than the long walls, to give room for side altar recesses in the wall thickness, and probably also to carry the weight of the tall gable. But the thickness seems not to have been arbitrarily determined. If the chancel quadrangle is circumscribed by a circle, the perimeter of this will pass within 5 cm (2 in.) from the inner flight of the east nave wall.

What is more, if one squares the supposedly planned external length of the nave (supposed to be twice the internal width) and marks half its diagonal from each corner of the east side of this square ("the sacred cut", not to be confused with "the golden section"[9]), these define the external width of the chancel. The distance from the inner wall flight of the east wall of the nave to the outer flight of the east wall of the chancel equals then the internal width of the nave. Furthermore, the inner flight of the east chancel wall seems to have been determined by an equilateral triangle with the inner east wall flight of the nave as basis.

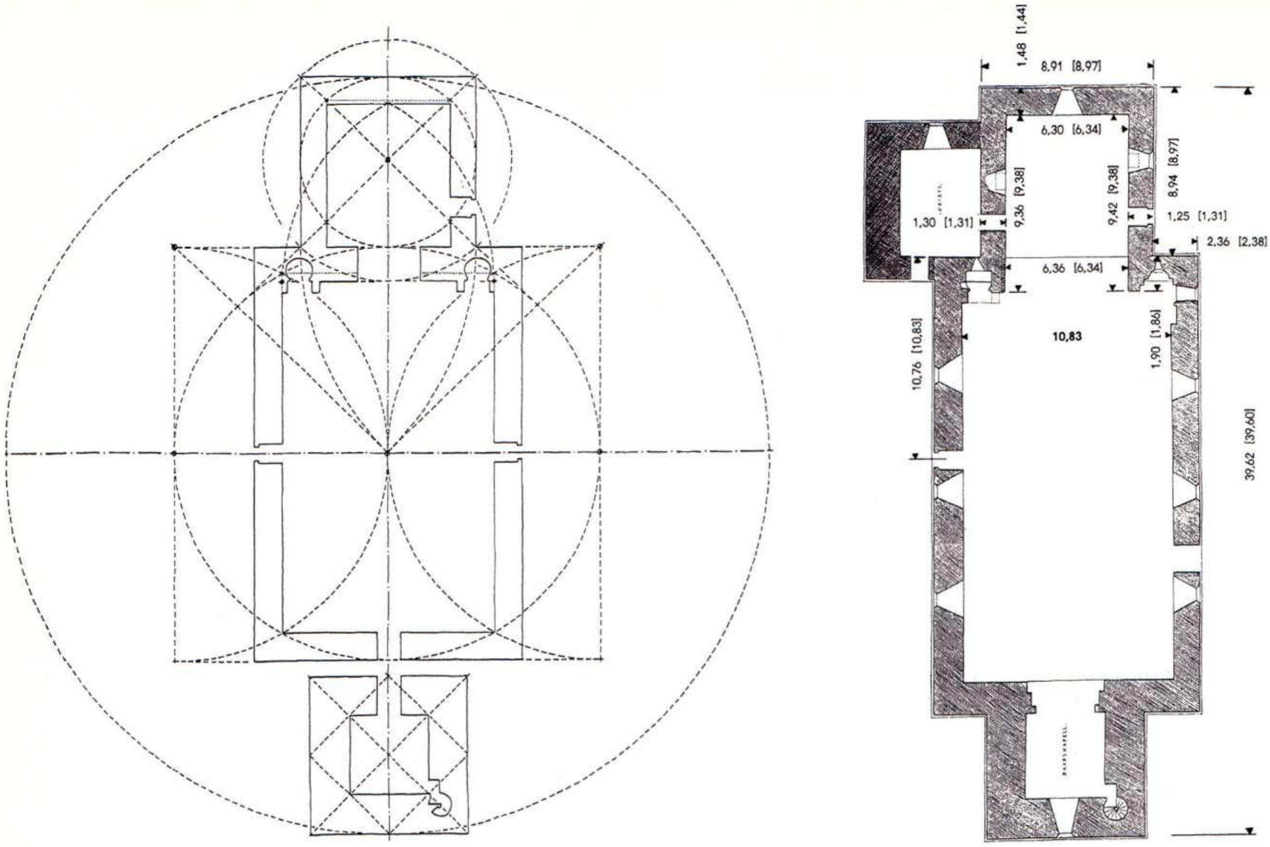
But this hypothesis also carries some further implications that seem quite suggestive. The cross axis of this shorter nave divides the total length of the church, including the west tower, almost excactly in two halves. This hypothetical cross axis will then run almost straight through the centre of the north door of the nave.

But then the tower must have been planned to stand outside the west wall of the nave, at a distance of about 0,85 m (c. 2 ft. 10 in.), which would seem rather strange. However, at the aforementioned Selbu church, built about the same time, this is actually the case. And the Selbu west tower has no west door either, but only the tower and western parts of the nave have been preserved. That church was substantially rebuilt and enlarged eastwards in the early 19th century, and it is now impossible to ascertain the original length of the nave and size of the chancel for any assumptions on possible mathematically generated ratios.

Because of the unfortunate consequences of misguided maintenance work in the 1980s, when plastic paint was applied to the walls, the external wash of Værnes church was partly removed in 1996. I had then the opportunity to examine the nave walls and their connection to the west tower.



Roof truss from the chanel, Værnes, after E. Gjone (top) and Norderö, Jämtland, after O. Storsletten (bottom). The curved line in the lower part of the Værnes truss is the contour of the board ceiling, probably a later addition. Geometrical analysis by the author. (1:100)



Værnes church. Left, "ideal" plan with detached west tower (author). Right, plan as executed with late 13th C. vestry after E. Gjone. Measures accordig to the "ideal" geometry in brackets. (1:400)

There was, however, no indication that the tower had been built before the west wall of the nave. On the contrary, tower and nave walls are connected in solid bond. An almost vertical crack in the north nave wall some 3 m (10 ft.) from the west end has obviously been caused by the settlement of the tower, having pulled the west part of the nave with it[10].

However, if the original plan included a free-standing west tower, the plan may have been changed before the western parts were built. Of the 20 roof trusses, the 9 western ones differ slightly from those of the eastern part. On the west side of the 11th truss from the east there are traces of a temporary, board-clad gable wall, indicating a halt in the building campaign.

What started as speculations on possible geometrical design methods has thus led to raising the question whether there has existed in the region – or elsewhere – an early tradition of churches with a disconnected west tower standing only a couple of feet outside the gable wall of the nave[11], from which follows the question of what functional or other meaning this arrangement might have had.

Considering the thick walls – more than 2 m (almost 7 ft.) – the idea that immediately springs to mind is that it was meant as a stronghold. The narrow gap between the tower and the west wall of the nave would make attack on the entrance door difficult, while at the same time it could be reached without entering the church. Two singular, square fortified towers are known from Jämtland, both standing within churchyards, but not this close, and seemingly without any axial relationship to the church.

From the top of the tower one would have an unobstructed view above the vegetation of the river plain, commanding the wide central basin of the Trondheim fjord, as well as far up

Værnes church	"ideal" measures (metres)	actual measures (metres)		difference (metres)	(percent)
Nave:					
Internal width at east end	**10,83**	10,83		**0**	0
Thickness of north wall	1,45	1,52		0,07	4,83
Thickness of south wall	1,45	1,38		-0,07	-4,83
External width at west end	13,73	13,79		0,06	0,44
Axis through north door to outside east corner	10,83	10,76		-0,07	-0,65
Thickness of east wall	1,86	1,9		0,04	2,15
Chancel:					
East wall, exterior	8,97	8,91		-0,06	-0,67
South wall, exterior	8,97	8,94		-0,03	-0,33
Thickness of north wall	1,31	1,3		-0,01	-0,76
Thickness of south wall	1,31	1,25		-0,06	4,59
Thickness of east wall	1,44	1,48		0,04	2,78
East wall, interior	6,34	6,29		-0,05	-0,79
Internal width at west end	6,34	6,36		0,02	0,32
Total length from western flight of nave's east wall	10,83	10,86	(north)	0,03	0,28
		10,89	(south)	0,06	0,55
Internal length from western flight of nave's east wall	9,38	9,36	(north)	-0,02	-0,21
		9,42	(south)	0,04	0,43
Total length of the church	39,6	39,69	(north)	0,09	0,23
		39,62	(south)	0,02	0,05

the valley along which the route to Jämtland and Sweden runs. In addition, the tower could of course serve as a belfry for the church.

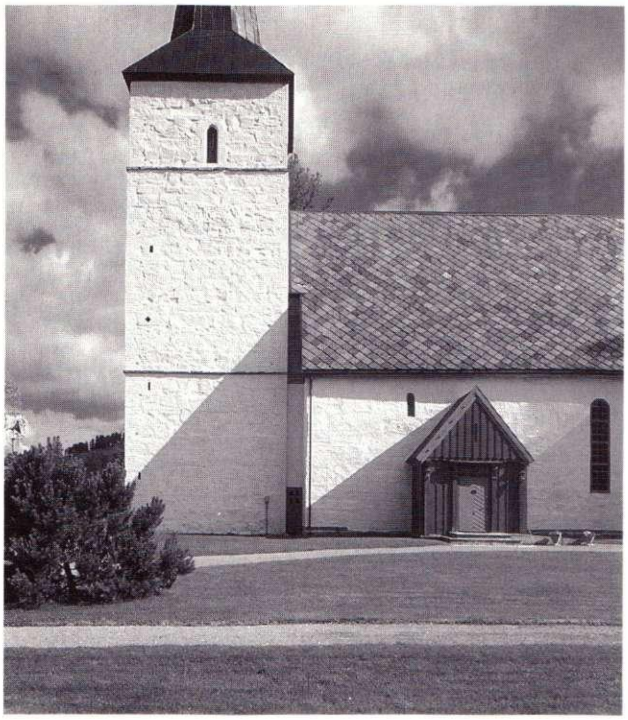
Erling Gjone suggested that the ground floor chamber of the tower was intended as a baptistry. With the present plan, this would not be an ideal solution, as the cathecumens would have to be brought some way through the church before receiving the sacrament. However, if the tower was free-standing, the baptistry could be entered directly from outside the church. Through a west door adjacent to the tower entrance the new members of the Christian community could then be brought directly into the church. One thinks immediately of the baptistries in front of the west doors of several Italian cathedrals, e.g. Florence, Parma, Pisa and Torcello.

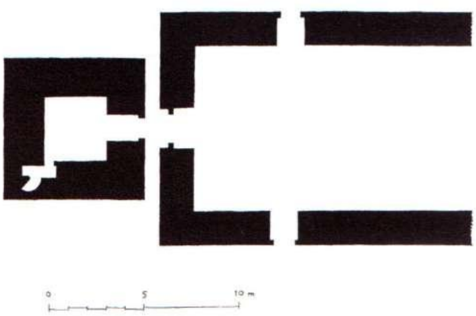
When Værnes church was planned, only 100 years had passed since the martyrdom of St. Olav at Stiklestad, about 35 miles to the north-east. One must presume that unchristened adults were still around, and it would then be wise to have a baptistry that could be entered without going through the church. Later, when virtually all small children were brought to baptism, this may have been considered less of a problem. The reason that the south door of the nave is not adjacent to the north door may be that, when nave and tower were connected, the south door was moved westwards to minimize the route of the unbaptized through the church, and keep them at a safe distance from the altar. However, the most obvious place for the font would rather be immediately inside this door.

Mathematically based design methods, or "proportioning systems"

My own curiosity concerning speculations on "forgotten" design methods employing simple mathematics was aroused when working with vernacular architecture of the 19th century. I was then intrigued by the occurrence in many of the buildings of certain ratios of one-digit numbers, or corresponding to elementary geometrical constructions[12]. It occurred to me that this may have been the outcome of methods, or "rules-of-thumb", to help making design decisions by builders not aware of the modern notion of architectural form as an expression of its author's feeling and intuitive sense.

Their aim would have been to comply with cultural norms and current ideals which, of course, also may have carried





Selby church, Trøndelag. Tower and western part of the nave, south side.
Photo: author, 1997.

symbolic meanings. As is well known, there exists a host of more or less speculative theories on the meaning and validity of such proportioning systems. Equally well known is the body of classical proportioning prescriptions, developed from Renaissance theories on harmony and discussed in numerous architectural manuals.

The significance of proportions in architecture is recognized, but there is no general agreement on the aesthetic value of one system over the other, or in the use of mathematically based methods at all. The question of such systems for proportioning in architecture is generally – and not without good reason – treated with scepticism, if not amusement.

In Norway, the reerection of the nave vaults and west front of Trondheim Cathedral raised a debate that eventually came to render the question of proportion systems unworthy of any serious attention for a long time. In 1915 J.F. Macody Lund launched his theory on a comprehensive system of geometrical diagrams governing the total design of the mediaeval church, in opposition to the Cathedral architect's design. In his polemical treatise on his system, *Ad Quadratum* (1919), he maintained that he had discovered the very system underlying all sacred building of the Western civilization from the ancient Greeks on, and that the Cathedral of Trondheim was the most illustrious and magnificent example of its application.

Begun 50 years earlier, the restoration of the cathedral was a popular symbol of the restoration of Norway as an independent nation, and the controversy became a matter of national significance. The Norwegian Parliament appointed a commission of international experts to review Mr. Macody Lund's work, and funded the translation of his voluminous treatise into English and French[13]. It thus came to make some influence on the international debate on the subject, which was a theme widely discussed among architects in the 1920s.

Eventually the commission concluded in 1923 that no scientifically valid proof for the application of Macody Lund's system on the design of Trondheim Cathedral had been provided. The restoration works had, however, been halted for several years while waiting for the verdict, and the architectural profession was divided in two camps.

If one avoids being distracted by popular conceptions of the issue – the question whether proportions according to ratios of certain numbers, or generated by geometrical diagrams, *per se* are more beautiful or pleasant than other, arbitrarily conceived forms – one may focus on other perspectives on the use of mathemathics in the design process.

The mainly numerically based classical systems certainly had aesthetic implications, inasmuch as aesthetics also had to do with the expression of symbolic meanings ascribed to certain ratios of numbers. Fragmentary documentation concerning mathematically based design of earlier periods indicates however a more wide-spread use of geometrical diagrams, which in the late mediaeval case of Rodrigo Gil de Hontañon was a means to store experiential knowledge of the structural capacity of masonry[14]. However, Eric Fernie doubts that such considerations played any part in the use of geometry he has deduced from his measurements of some large Norman churches in England[15].

In Norway, Jørgen Jensenius has through his accurate measurements of several stave churches found series of ratios indicating a systematic and comprehensive use of simple numerical relationships and geometrical diagrams. These can be produced with simple tools on a building site, and would be part of the mathematical knowledge one must expect was known to those responsible for the planning[16]. He stresses, however, that his material is too limited to suggest any theological significance for these relationships.

It would be unproductive to speculate on whether such methods evolved in order to satisfy technical needs, or whether they originally served ritual or symbolic purposes. Let us just assume that factors of both kinds have played a part, and formed practices governing both production and perception of built form. It should also be noted that the handling of numbers belongs to a literary culture, while geometry can be performed by illiterates.

Aesthetics is in many repects a matter concerning what is meaningful, and in this sense mathematics may be significant as a symbol of an underlying order governing the perceived forms of a seemingly chaotic world – the laws of mathematics represent an absolute "truth". Ratios possessing mathematically "beautiful" and fascinating properties may contain no asthetic value in themselves, but can be seen as means to achieve an aesthetic goal. The experience of the pleasantness of an object or a building designed with the use of such methods could be ascribed to a more or less conscious impression that everything is in a fixed and determined position, and that form and composition are not the outcome of chance.

To determine proportions is not only a question of satisfying the prospective beholder's personal appreciation, but has also to do with the practical production of built form. The need to develop, maintain, and convey the technical skills essential in handling constructional work of a certain complexity requires ways to store the knowledge. In societies with little or no access to a written language, the storage of information is dependent on memory. Systems of proportion may well have originated in mnemonics utilizing geometric diagrams or combinations of numbers of peculiar and fascinating properties, passing on empirical knowledge of structural limitations and possibilities. In cultures where the capacity to deal with abstract science was confined to a few, a mystical status, or even magical powers, have often been attributed to particular diagrams and numbers.

Technical and magical aspects apart, the erection of a building will necessarily involve decisions concerning the physical form, and design methods of this kind may have been useful tools in communicating the meaning contained in concepts like "visual coherence" and "harmony" between the component parts as well as between the parts and the whole. The now widely accepted view of mathematically based systems of proportions as a straitjacket for creative work is of fairly recent date, and it is based on the romantic approach to design theory. The justification of mathematically based methods is however dependent on their expedience for the purpose of actual building.

Furthermore, as the handling of building projects of some complexity requires at least a rudimentary knowledge of geometry, one may well assume that craftsmen with some ability for drawing and a certain conversance with the use of compass and ruler have found pleasure and fascination in playing with these tools, exploring some of their possibilities. As for the "secrecy" and exclusiveness connected with these methods, it should be borne in mind that barring specific information to outsiders has always been an important means of protecting a profession or craft against competition and unauthorised involvement. A person with only fragmentary knowledge of this information might, when attempting at difficult construction work, soon find himself in a situation as embarrassing as the Magician's Apprentice.

It is a trivial fact that lack of documentation of a phenomenon cannot be taken as evidence that it never existed. Design methods of this kind may have sunk into oblivion together with other skills of crafts no longer practiced. One should furthermore not leave out of account the influence from the architectural ideology, where methods of proportioning have been held in rather low esteem for the best part of the last 200 years – with the exception of the renewed interest in mathematics as a tool for arcitectural design in the formative years of the modern movement[17].

In an unpublised lecture of 1951, the art historian Rudolf Wittkower observed that

> our psycho-physical make-up demands the concept of order and, in paricular, of a mathematical order. [...] In fact, it would not be difficult to show that all higher civilizations believed in an order based on numbers; that they sought and established a harmony – perhaps a fanciful and mystical one – between universal and cosmic concepts and the life of man, and that art was expressive of this order and harmony.

He continues by stating that,

> the procedure of nineteenth and twentieth-century artists would seem almost contrary to nature. [...] In any case, never before in history has there been a constellation in the arts when proportion – or the principle of order – was left exclusively to the discretion of the individual artist. Once we realize this, our position appears quite extraordinary[18].

Værnes was the centre of a wealthy agricultural community, only 25 miles from the ecclesiastical centre formed around the shrine of St. Olav in Nidaros. It would not seem unlikely that a master builder conversant with elementary mathematical knowledge of the time might have been employed for the planning and erection of the church.

But, one might object, how would he feel about his beautiful system being distorted by extending the nave westwards, as no apparent ratio of simple geometrical or numerical deduction seems to fit the present plan of the nave? To this objection can be said, that if the man responsible for the original layout was still alive, he would probably long since have moved on to other tasks. A reference can also be made to the modern architect's not too rare experience of deviations from the original design during the building process, due to economy or changed needs of the customer.

Dag Nilsen, architect private practice,
associate professor.
Dept. of Architectural History, NTNU,
Trondheim, Norway

Notes

1. Øystein Ekroll: *Med Kleber og Kalk* (an introduction to, and catalogue of mediaeval stone buildings in Norway), Oslo 1997, pp. 275–293).
2. Most of the Trøndelag churches have west doors as well as doors in the north and south walls of the nave near its western end. It is however uncertain if all of these originally had west doors, as in some cases the nave has been extended westwards, or an original west tower collapsed or was pulled down during the Middle Ages. The cathedral of Stavanger in south-western Norway was built about the same time as Værnes church, and has richly adorned north and south doors immediately to the west of the centre pillars of the aisled nave. It has been believed to originally have had no west door; this is however uncertain, as only the foundations below ground of the original west tower remain.
3. There are some discrepancies in the measured drawings of Værnes. In Erling Gjone's project drawings for the restoration, the pitch of the nave roof is somewhat higher than in his later drawing of a roof truss for publication, which I have used here. It seems that in preparing the project drawings he used measured sketches made by students in the inter-war period, and during the restoration works had the opportunity to make more accurate measurements.
4. Paul Booz has commented upon some problems of accuracy when using a cord for setting out measures, discussing the properties of mediaeval cord material. Precision would be affected by material weight, tension and moisture (P. Booz, *Der Baumeister der Gotik*, Berlin/München 1956). However, this should not be much of a problem with the relatively modest dimensions of the Værnes roof trusses. The cord would here, in my hypothesis, be used to divide a given length (the truss width) in half and in half again, and then for setting out arcs with radius three quarters of the width to establish a full scale model diagram on a level surface, from which the trusses could be produced.
5. Jämtland held for a long time a relatively independent position between Norway and Sweden. It was under Norwegian rule from 1178 until 1645, when it became a Swedish county. Except for the period 1570–1645, Jämtland was however always part of the Swedish church province of Uppsala. Although the oldest roof structures in Jämtland churches are similar to those preserved in Trøndelag, the church plans and the generally unadorned stonework show little resemblance to the churches of Trøndelag.
6. Ola Storsletten och Peter Sjömar: "Där Norge och Sverige mötas", in ed. A. Berg & al.: *Kirkearkeologi og kirkekunst* (Studies dedicated to Sigrid and Håkon Christie), Øvre Ervik 1993. The trusses of the chancel at Hackås church has a slightly steeper roof, which pitch may have been determined by a circle with a radius of $\frac{1}{4}\sqrt{5}W$ (the diagonal of a rectangle $\frac{1}{2}W \times \frac{1}{4}W$), where W is the external width of the chancel, with a centre point above the central axis, at a height a quarter of the width above the top of the wall plates. The external roof ridge then (coincidentally?) is at the top point of an equilateral triangle on the wall plates with sides the external width of the chancel.
7. Mogens Koch: "Geometri og bygningskunst", in *Arkitekten* (DK), Copenhagen 1963, reprinted in ed. A. Karlsen: *Geometri og bygningskunst*, Copenhagen 1993, pp. 79-95.
8. This assumption should be modified with an "as it were", as the site would not be consecrated by merely constructing a diagram like this. Consecration involves a specific ritual, which was not performed until the building was ready for use as a church. However, if the master builder's layout of the guidelines for the plan was done in this way, it might well have been perceived as a symbolic way to take the site into possession for the new faith.
9. Unlike the "golden section", which probably had no significance in art and architecture until the first half of the 19th century, the "sacred cut" seems to have been used in Roman antiquity (see Watts, C.M. and D.J.: "Geometrical Ordering of the Garden Houses at Ostia", in *Journal of the Society of Architectural Historians*, vol. XLVI 1987, pp. 265–276). To avoid loading the diagram with any mystic or religious meaning it may never have carried, it should be noted that the term "sacred cut" is of fairly recent origin; to my knowledge it was coined by Tons Brunés in his *The Secret of Ancient Geometry*, Copenhagen 1967.
10. Erling Gjone suggested that the reason for building the Selbu west tower detached from the nave was a recent experience of settlement problems at Værnes (ed. A. Berg, E. Sinding-Larsen: *Tegninger samlet eller utført av Gerhard Schøning*, Oslo 1968, p.23). As the timbers for the nave roofs of both churches by dendrochronological evidence were felled in the same year, it seems probable that the erection of the walls in both places then were well under way. At this stage only the lower parts of the tower at Værnes had been built, and without the weight of the upper parts it is unlikely that settlement of any significance had occurred yet. Anyway, it seems that the church-builders of that time had a fairly light-hearted attitude towards the problem of settlement. An extreme case of building on unsafe ground can be seen in the enormous buttresses propping up the south wall of Sakshaug church, some 40 miles north of Værnes, and the west tower of Mære collapsed less than 100 years after it was erected.
11. Selbu is the only preserved Norwegian church with a west tower in this peculiar position. Is it a unique invention due to specific circumstances or an original mind, or had the master builder seen a similar solution abroad? As the churches of Selbu and Værnes both were situated in the same county, and the roof timbers were felled in the same year, it does not seem unlikely that they were planned by the same master.
12. Dag Nilsen: "Har proporsjonering ved hjelp av geometri eller tallforhold vært anvendt i norsk anonymbebyggelse?", i *Fortidsminneforeningens årbok* (The yearbook of The Norwegian

Society for the Preservation of Ancient monuments) 1991, pp. 273–300.

13. Even a German translation in part was produced from Macody Lund's preliminary work by a German citizen interned in Norway during the last years of World War I, from personal interest in the matter.
14. S. L. Sanabria: "The Mechanisation of Design in the 16th century: The structural formulae of Rodrigo Gil de Hontañon", in *The Journal of Architectural Historians*, vol. XLI 1982, pp 281–293.
15. Eric Fernie: *An Architectural History of Norwich Cathedral*, Oxford 1993.
16. Mr. Jensenius' studies on the stave churches of Lomen, Uvdal and Torpo, and the archaeological evidence of an early churh at Bø, are printed in various publications 1988–1993. His analysis of Torpo stave church can be found in ed.: A. Berg & al. (op.cit.), pp. 69–79.
17. Dag Nilsen: "Geometrien er menneskets språk!" in *Fortidsminneforeningens årbok* (The yearbook of The Norwegian Society for the Preservation of Ancient monuments) 1992, pp. 263–300. For the persistence of the mathematical approach to the question of proportions, see *RIBA Journal*, September 1957 for N. Pevsner's introduction to, and a review of the discussion concerning a motion that "systems of proportions make good design easy and bad design difficult", an almost verbatim qoutation of the physicist Albert Einstein's endorsement of Le Corbusier's *Modulor*.
18. Rudolf Wittkower: *Architectural principles in the Age of Humanism*, 4th edition, London 1988, Appendix IV (quotations from pp. 145–146).