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The Peasant Master-Builders' Double Cross-Church

Abstract: The centralized church type called double cross-church was introduced in Sweden in the 17th century and later extensively applied in log built churches in Finland. The study focuses on the churches built by a family of peasant master-builders in southeast Finland 1790–1830. We have reconstructed possible building procedures of these master-builders on the basis of existing churches, documents in congregational archives digitized by the National Records Office (Helsinki), generally known procedures of historic log building and information from measured drawings in the archives of the National Board of Antiquities (Helsinki). The main question was the methods used by the master-builders, who had no formal education, to work out the statics of these rather large wooden buildings. Our premise was that they probably relied mainly on a few basic geometric formulas to achieve a pleasing form and a secure structure for their churches. Design schemes that corresponded with the measured drawing material were found in the treatises of Renaissance architectural writers, Francesco di Giorgio Martini, Sebastiano Serlio and Philibert De l'Orme. The schemes found have been known by builders and technicians since Antiquity, i.e. long before these writers recorded them in their treatises.

Keywords: Log Building, Wooden Church, Vernacular Architecture, Peasant Master-builder, Geometric Mensuration, Geometric Ratio, Centralized Church, Lutheran Church, Finland

Fig. 1. The double cross-church of Valkeala built by master-builder Johan Salonen in 1796. After Klemetti 1927, fig. 470.

The Peasant Master-Builders' Double Cross-Church

Merja Härö & Eeva Maija Viljo

This study deals with a centralized church type that was applied in log building in southeast Finland in the late 18th and early 19th centuries. The object is a group of Lutheran churches built between 1792 and 1830 by a family of farmer master-builders from the parish of Savitaipale in South Carelia. These master-builders had no formal education, and there are scarcely any records of how they built their churches, but on the basis of fragmentary information on building practices found mainly in congregational records and comparisons with rules of geometric mensuration in architectural treatises from the Renaissance period, we want to examine the principles along which these men might have designed the churches they built. We view them as applying primitive techniques and age-old geometric rules on their building sites.

I

THE CENTRALIZED CHURCH IN FINLAND

The centralized church plan was introduced in Sweden in the 17th century. On the eastern side of the Baltic Sea – in what is now Finland – it was to become the dominant plan for parish churches, notably in the eastern regions where from the 1660s onwards it replaced the mediaeval rectangular plan. The cen-

Fig. 2. The double cross-church of Puumala built by master-builder David Rahikainen in 1830. Photo Harri Heinonen 2014.

tralized church was, initially, represented by the type with a Greek cross plan, that gained ground at the same time as government measures consolidated the position of Orthodox Lutheran Protestantism as the only accepted form of Christian worship in Sweden. Enforced attendance at divine services required larger church buildings and in timber block building, where limitations set by the nature of the building material had to be countered by technical means, the cruciform plan proved both structurally and functionally advantageous.[1] The new centralized church type was a challenge for peasant church builders who had to face a number of structural problems, the most difficult being the wide span of the central part of the building, a new element in log-built church architecture.[2]

Lars Pettersson has concluded that the shift to a new type of church was not a spontaneous popular movement, but a change in line with the ecclesiastical policy of the central government in Stockholm, and managed chiefly through the organization of the Church and the fief-holding or landowning upper strata of rural society as well as town administrations. He assumes that at the initial stage of introducing the new church type, local carpenters would have been given designs prepared elsewhere, that they then had to adapt to log building.[3] It is likely that instructions were given on building sites as well.

The population increase, starting in the second half of the 18th century, created a demand for even larger churches, and the answer to this was the so-called double cross-church, which became the dominant type in eastern Finland. These churches could be built with a more unified spatial arrangement than the Greek cross churches. The increase in the number of corner chains from 12 to 20 contributed to the stability of the structure, and shorter logs could be utilized for the walls, which was a great advantage as slash-and-burn farming and early sawmill industry had reduced the amount of heavy timber available at manageable distances from habitations. In the church building boom that began in southeast Finland in the 1790s and lasted for some decades, with only two exceptions, all new churches were built on the double cross plan. (Figs. 1–2)

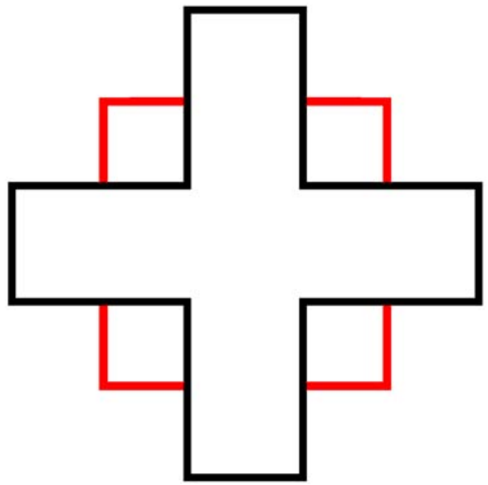


Fig. 3. The double cross-church plan as developed from the Greek-cross plan by adding a structural line on all four sides of the centre square. The corners of the square can be treated as separate volumes or they can merge into the central space of the church to make one large volume. Drawing Merja Härö.

This type of cruciform church was called “dubbelkorskyrka” in some congregational records[4] and the term has since been accepted as denoting this type of church. “Double cross-church” is a literal translation of the Swedish term. It has a floor plan that can be thought of as a square superimposed by a Greek cross with arms extending past the sides of the square (fig. 3).

The double cross-church is one of the centralized church types which, according to Rudolf Wittkower, dominated church architecture and architectural theory in the Italian Renaissance from the 15th century to 1530.[5] The most celebrated example of this centralized type is Bramante’s plan for St. Peter’s in Rome. For the particular double cross-church tradition with which this article deals, Sebastiano Serlio’s (1475–1554) visionary project for “a temple which is truly in the form of a cross”[6] has been a source,[7] but perhaps was not the only model (fig. 4).

The structure of the double cross-church

The overall structure of the double cross-church of southeast Finland is shown in the axonometric projections of the first church of this type, built in 1754,

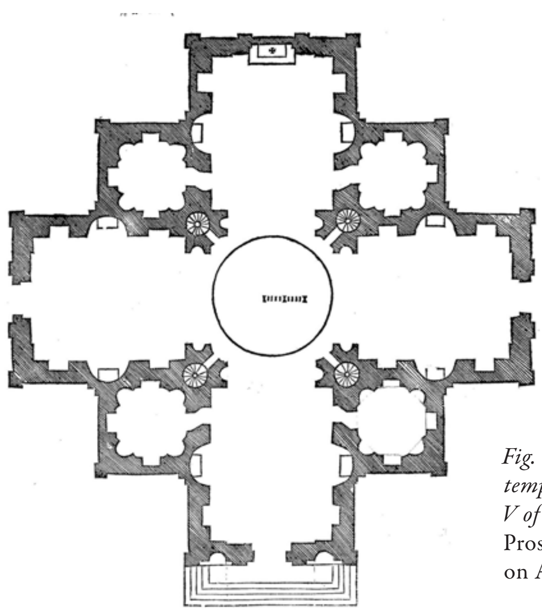


Fig. 4. Sebastiano Serlio’s plan for a temple “quadrato et in croce” in Book V of Tutte l’Opere d’Architettura et Prospettiva. *After* Sebastiano Serlio on Architecture*, p. 417.*

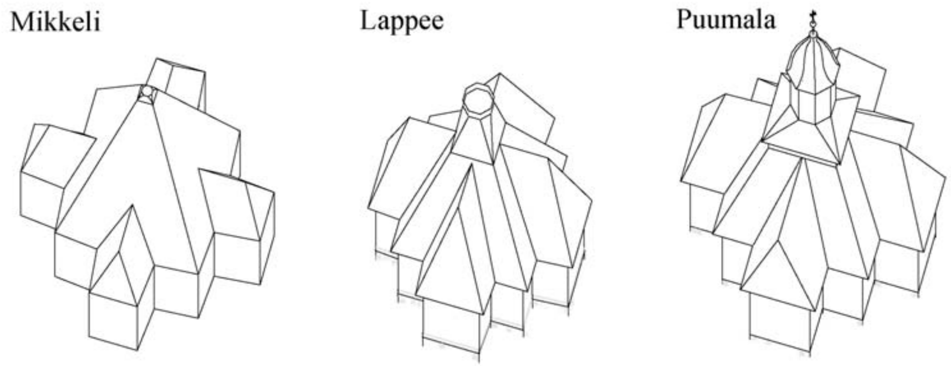


Fig. 5. Axonometric diagrams of three double cross churches: Mikkeli 1754, Lappee 1792 and Puumala 1830. Drawing M. Härö.

and the first and last double cross-churches from the years 1792 and 1830 of the master-builders from Rahikkala, on whose production this article focuses (fig. 5). In the first church a small knoblike “lantern” closes the gap between the rafters of a steep pyramid roof (Mikkeli). It has not been possible to reconstruct the original form of the roof of the church from 1792 (Lappee); its central lantern or tower was rebuilt twice in the 19th century.[8] In later double cross-churches the lantern can function as light source for the interior (Puumala).

The structural system of a double cross-church is based on the floor plan, and forms a unity from the stone foundation to the spire, or lantern, in the centre of the building. Walls, roofs and ceiling vaults are all interdependent parts of this unity. In the simple Greek cross church the sides of the centre square give the width of the cross arms, and tie beams connecting the corners of the building’s centre square secure the wall construction of horizontally laid logs. In the double cross plan type the centre square has expanded beyond the limits set by the cross arms, so that additional construction lines are needed for roofing over the area of the centre square. Tie beams over the void of the centre square are constructed, and these beams cross in the central part of the building where they are hewn into one another to make a rigid grid, which, in addition to the log walls, forms the base for the roof constructions. The term “double

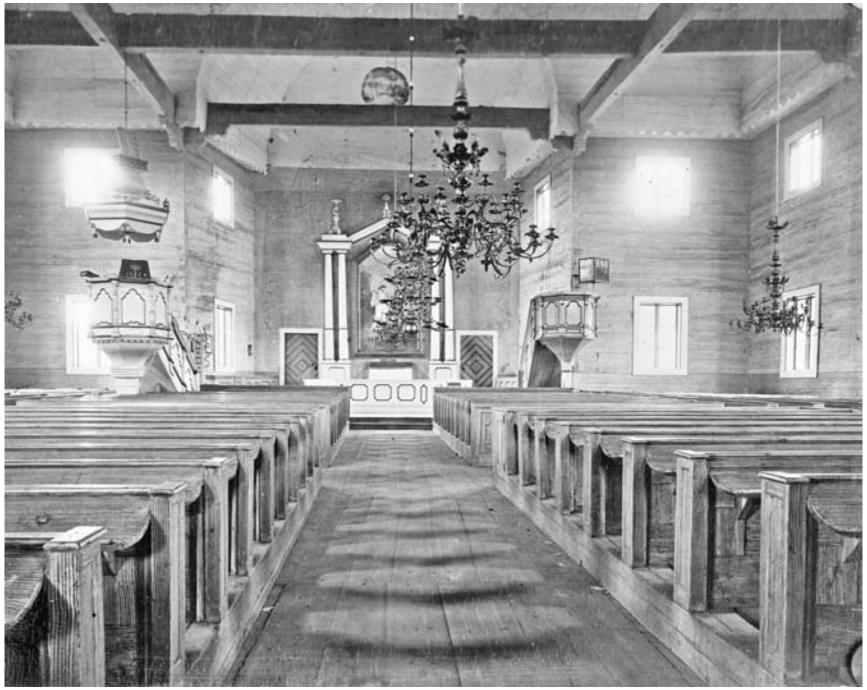


Fig. 6. Interior of Valkeala Church. The tie-beam crossings lack vertical supports. Photo Christian Ganderup 1898. National Board of Antiquities, Picture archives, 3976.

cross-church" may refer to this doubling of the structural lines of the central part of the church, the tie beam grid and the walls (fig. 6).

In the first double cross-churches the tie beam grid has no other vertical support than the walls, which puts a limit to the weight of the roof or "spire". In double cross-churches with heavy central lanterns, the tie beam crossings are supported by pillars (fig. 7).

The farmer master-builders of Rahikkala, their double cross-churches and their relationship to building inspection

The master-builders who constructed the new spacious temples in southeast Finland were three farmers from Rahikkala village on the southwest coast of Lake Saimaa in the South Carelian parish of Savitaipale: Johan Salonen (1739–1807/1811), his son Matthias Salonen (1769–1823) and the Salonens' neighbour

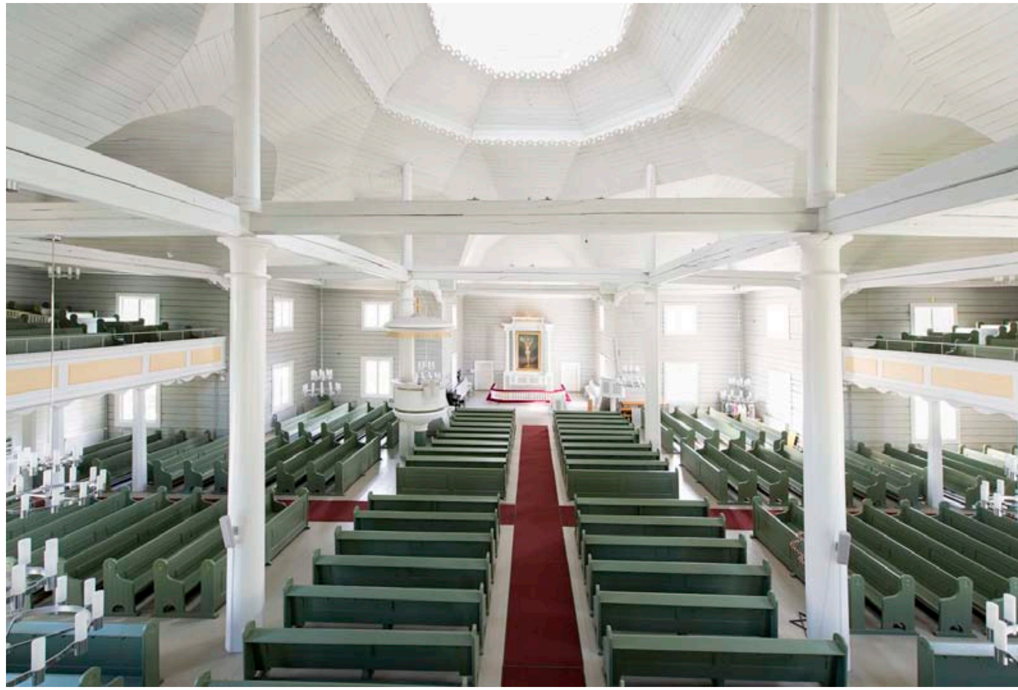


Fig. 7. The tie-beam system supported by pillars in the church of Puumala. Photo Harri Heinonen 2014.

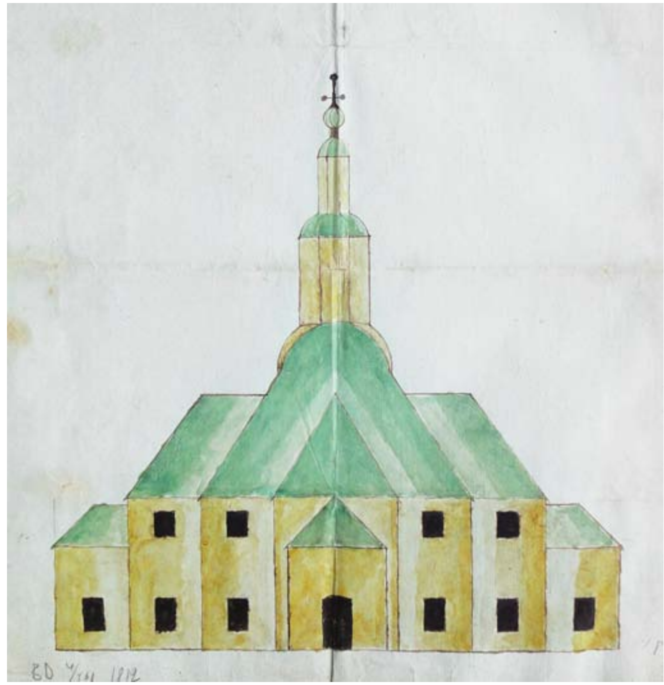
David Rahikainen (1795–1858), who is said to have been trained by Matthias. David's marriage to Matthias's niece sealed his status as family member with the responsibility to carry on the church building tradition of the Salonens.[9]

Savitaipale had come under Russian rule in 1743, when the first of the master-builders, Johan Salonen, was four or five years old. In 1786 he was granted the privilege as builder of (Lutheran) churches in the Russian province of Vyborg. After his death the privilege seems to have been given to Matthias.[10] After the war in 1808–1809, when the autonomous grand duchy of Finland was founded as part of the Russian empire, the province of Vyborg (with a mostly Finnish-speaking population) was incorporated into the grand duchy, which retained Swedish legislation and administrative practices. Matthias's church builder's privilege was probably no longer valid, officially. As an arrangement for recruiting competent master-builders it had lost its *raison d'être*, but the changed situation did not diminish Matthias's trade. He had no serious competitors, neither in Carelia nor in formerly Swedish South Savonia, where he was soon fully employed building churches and belfries.

The Rahikkala master-builders had no formal schooling, except possibly a brief attendance at the parish school, which would not have contributed greatly to their scholarly accomplishments.[11] We know on documentary evidence that Matthias Salonen and David Rahikainen could write, which was unusual for peasants of their time. Of Matthias we have some coloured drawings for churches, and it must be supposed that he had taught his apprentice David Rahikainen to make designs on paper. The only evidence we have of David's drawing ability is a documentary mention;[12] none of his actual drawings have survived. There are no direct sources on Johan's scholarly or artistic abilities, but his standing as church master-builder required more elementary skills than those of the average peasant. Like his son Matthias and David Rahikainen, he too must have mastered enough arithmetic to calculate amounts of building materials.

Peasant master-builders never visualised the structures of their churches with section drawings, but only as plans and elevations. This goes for Matthias Salonen as well. His drawings, preserved in the archive of the grand duchy Senate, are designs for churches attached to building permit applications.[13] They are drawn to a scale of Swedish ells ("alnar"), mostly on coarse low-grade paper; the lines are drawn with pencil using a ruler and reinforced with broad lines of colour, and the building surfaces filled in with watercolours or grey wash (fig. 8).

The beginning of the remarkable church building tradition of Rahikkala is something of a mystery. The village of Rahikkala is isolated, and in the first half of the 18th century it was far from prosperous. There were only two proper farmsteads in the village, those of the Salonens and the Rahikainens, and in 1743 both were deemed barely viable, the Rahikainen household even as downright poor. The change of regime that same year freed the overtaxed farms from serving as supporting "augments" of military fiefs,[14] which had become their lot when Sweden, in the late 17th century, organized the upkeep of its armed forces by tying the military personnel to the land. The economic situation of the Salonens must have improved by the time Johan was old enough to begin as apprentice to some experienced church master-builder. There is no documentation on what he did, where or when he went, nor do we know on what building sites he was trained. But the unknown master-builder or master-builders who



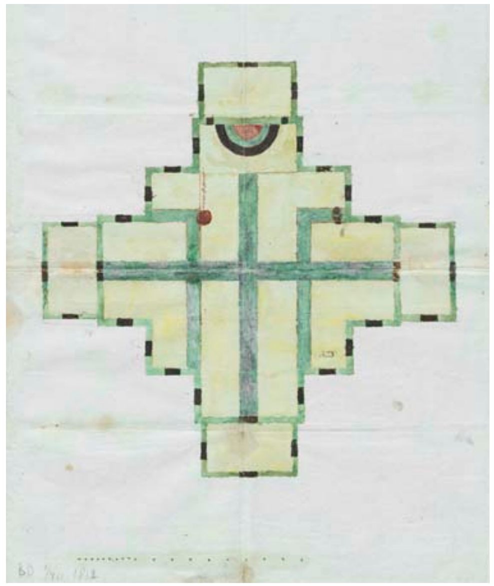


Fig. 8 a–b.. Matthias Salonen's sketches for the church of Parikkala from 1812. Elevation and floor plan. National Records Office, Economic Department of the Senate, 1812 4/461.

taught him the essentials of constructing log churches must have been involved in the church building boom that started around the middle of the 18th century further east in Carelia. Lemi parish church that Johan built on a Greek cross plan in 1786 showed, especially in its original form, similarities with these east Carelian churches.[15]

The church of Lappee, from 1792, in the town of Lappeenranta in the then Russian province of Vyborg was Johan Salonen's first double cross-church. By 1809 Johan and Matthias Salonen had built six double cross-churches in the Vyborg province and at least one in the vicinity of St Petersburg in Ingermania that had a Finnish, Lutheran population.[16]

Russian legislation required architectural designs for churches to be inspected by provincial architects.[17] There never seems to have been any question of inspection in connection with the Salonens' building projects, so that the church master-builder's privilege granted by the provincial government looks like an official acceptance of vernacular church architecture. With no bureaucratic pressure to imitate current academic architectural models, the Salonens developed their own type of double cross-church.

In the Grand Duchy of Finland, an Intendant's Office was founded 1810–1811 to administrate public building and carry out building inspection. It functioned along the lines that had been adopted from its model, the Superintendent's Office in Stockholm. From 1776 onwards the Superintendent's Office had inspected all church building projects in Sweden – the Finnish provinces included – and turned down designs by local master-builders or amateurs and substituted drawings prepared by its own architects.[18] The revising of church designs continued in the Intendant's Office, and all designs for double cross-churches that the Office architects turned out as improvements on the sketches sent in by the congregations were of the pillared type. The church master-builders were required to follow officially approved designs, but these gave only a general outline of the appearance of the church. Arrangements of spaces and windows were often impractical, and construction details were sketchily indicated. The Rahikkala master-builders followed these outlines faithfully, but also introduced their own improvements on the official designs. As far as constructions went, they relied on their own know-how, as indeed the architects of the Intendant's Office must have known them to be capable of doing.

Matthias Salonen, and after him David Rahikainen, met the challenge presented by the designs of the Intendant's Office successfully; between 1813 and 1830 they built nine double cross-churches in different parishes of Savonia and Carelia.[19]

The double cross-church in Sweden

The double cross-church of the Rahikkala master-builders, like the church type with Greek cross plan, goes back to Swedish church architecture of the 17th and early 18th centuries. Lars Pettersson has demonstrated that three double cross-churches built in Sweden were important for the transmission of this type into Finnish vernacular church building: Katarina Church in Stockholm, built from 1656 onward, the Admiralty Church at Karlskrona from about 1685 and Ulrika Eleonora Church in Hamina (Sw. Fredrikshamn), built in 1730 and rebuilt after a fire as Elizabeth Church in 1749.

Katarina Church was to be included in the complex of a new fortified royal palace. But of the grandiose plan, which would have been a display of the close connection between church and state, only the church was built. Its floor plan is modelled on Serlio's drawing for a temple mentioned earlier, and was the first attempt in Sweden to explore the possibilities of the double cross design for Lutheran divine service, combining Protestant emphasis on the sermon with traditional (Roman Catholic) altar service.[20] It may have been an example for master-builders of rural parish churches, but its over-all shape and structure had to be remodelled for construction in timber.

The attempt to create a functioning model for a Lutheran church in the Katarina Church had no immediate following; the simple Greek cross plan prevailed among the later 17th-century cruciform churches in Sweden. An exception is the church of the Admiralty at Karlskrona. Karlskrona was founded as Sweden's chief naval base in the 1680's, and a temporary place of worship for the congregation of the Admiralty was built as a timber-frame structure. The most likely designer of the church is the provincial governor and quartermaster general of the Swedish army, Erik Dahlbergh.[21] A strictly practical approach is evident in the use of timber-frame technique suitable for more or less temporary structures in encampments or military posts as is also the severe rationalism of the building's geometry. The Admiralty Church is still standing and used by the Admiralty congregation – because the project for a permanent church in stone was never carried out (fig. 9).

Fig. 9. The Admiralty Church (Ulrica Pia) in Karlskrona, Sweden. Drawing from the 1690s. After Andersson & Kindström 1946–1959, fig. 92.

The double cross-church at the port town of Hamina was a project for a congregation of townspeople, who commissioned its design from an artillery officer engaged in the town's fortification works. Hamina had been founded on the northern coast of the Gulf of Finland for the defence of Sweden's eastern border after the loss to Russia, in 1721, of easternmost Swedish Carelia with the port town of Vyborg. The church was named Ulrika Eleonora in honour of the queen and was destroyed in the siege of the town in the war between Sweden and Russia in 1741–1743. Another outcome of the war was the ceding of additional land areas, including Hamina, to Russia.

Ulrika Eleonora was rebuilt on the same foundations and according to the original design, as reported by historian Sigurd Nordenstreng. The second church, dedicated to the Russian Empress and thus called Elizabeth Church, was destroyed in a town fire in 1821, but its appearance is known from drawings in a cartographic work of the Russian province of Vyborg (fig. 10). Both the Ulrika Eleonora and Elizabeth churches were block constructions with log

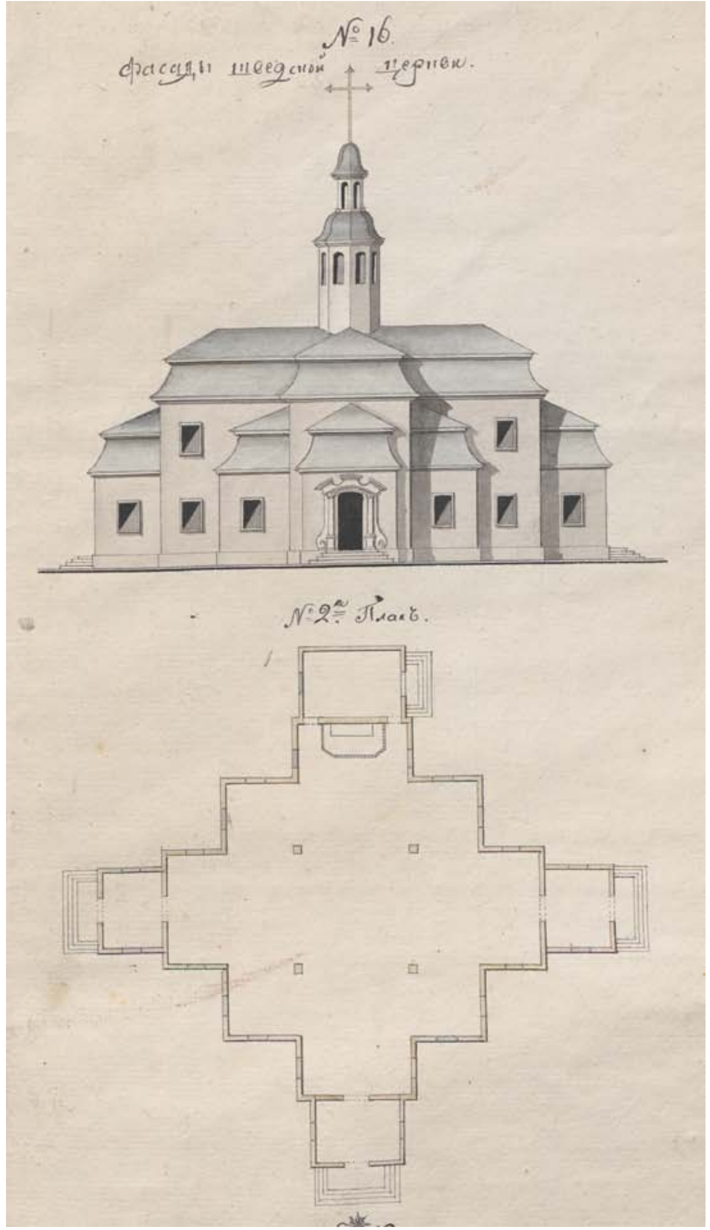


Fig. 10. Floor plan and elevation of Elisabeth Church at Hamina. Detail of plate 16 in Atlas Vyborgskoi Gubernii, *National Records Office, Helsinki.*

walls. The master-builder of Ulrika Eleonora is not known; the peasant master-builder of the Elizabeth Church came from the Swedish province of Savonia in eastern Finland.[22]

Both the Admiralty and Elizabeth churches have lantern towers over the roofs of the centre square and a framework of timber supporting the towers. The base of the framework consists of four pillars standing at the points of intersection of tie beams extending from the inner corners of the cross arms. Another set of pillars continues the vertical construction lines above the intersections.

In the exterior, the centre square of the Admiralty Church is indicated as a comprehensive volume by the cornice and a cupola on an octagonal plan. The cross arms are lower than the centre square, which marks them as separate compartments in relation to the central space. The structure and arrangement of the volumes in the Elizabeth Church go back to Serlio's model. The cross arms meeting at the centre of the building form the highest volume of the interior. The corners of the centre square, which Serlio conceived as chapels, are treated as low-pitch pavilions that enlarge only the floor space.

The appearance of double cross-churches in Finland is at first sporadic, with decades between their occurrences. The start came with the Ulrika Eleonora and Elizabeth churches, but almost a quarter of a century elapsed before the next successful attempt to adapt the double cross model for log construction was launched. In 1754, peasant master-builder August Sorsa (1710s–1756/1766) built the double cross-church of the Savonian rural parish of Mikkeli. Sorsa came from Swedish North Carelia and had been active as church master-builder in the interior of Finland since the 1740s.[23] This first double cross-church in Mikkeli burned down in 1806, and nothing is known of its planning stage or who had introduced the church type to the congregation.[24] It was certainly a novelty. Sorsa may have heard of the Admiralty Church in Karlskrona, and he could have acquainted himself with the double cross-church at Hamina, but his concept for the Mikkeli Church was altogether different, and much closer to the vernacular log-timbering tradition. It had no pillar support for the roof construction, and the appearance of the high pyramid roof comes close to that of a Gothic spire.[25] As to size, the Elizabeth Church in Hamina was tiny in comparison to the Mikkeli double cross-church.

The floor plan and elevation of the Mikkeli Church are known from measured drawings made by land surveyor Johan Heinricius (†1807), fig. 11.[26]

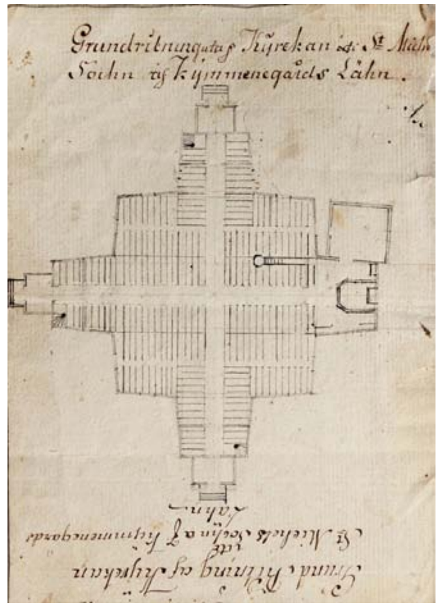


Fig. 11 a–b. Johan Heinricius's measured drawings of the church of Mikkeli parish. Elevation and floor plan. National Records Office, Provincial Archives of Mikkeli, Records of Mikkeli country parish.

In 1784 Johan Salonen was called to Mikkeli on the Swedish side of the border to participate in an inspection of the roof of Sorsa's church, and he was engaged forthwith to carry out its repair.[27] Six years later he built his first double cross-church in the parish of Lappee on the Russian side of the border. This church, still standing, is like that of Mikkeli (1754) built without pillar support for the roof structure. The exact appearance of the original roof of Salonen's Lappee Church is not known. The present roof from 1929 is a reconstruction based on the type of roof that Johan and his son Matthias built in their double cross-churches before 1810. Except for the church of Lappee these double cross-churches have been lost, but photographic documents show the same high pyramid roofs as that of Mikkeli (fig. 11).[28]

The cross arms of the Mikkeli Church (1754) taper outwards, and the corners of the centre square have been fashioned in keeping with the obtuseness of the angles of the tapering cross arms. This feature is found in many Carelian churches of the 18th century, and it was also used by Johan Salonen in his Lemi Church. It could have been a device intended to create a more unified "baroque" space, and it became definitely old-fashioned in the late 18th century. The cross arms of Lappee are very slightly tapered, but the corners of the centre square are right-angled. In the later double cross-churches, Matthias Salonen discarded the tapering cross arms and obtuse-angled corners in favour of right angles.

The only double cross-church in western Finland, that of Lohtaja (Sw. Lochteå) in Ostrobothnia, built in 1768, must be mentioned. Except for the floor plan, it cannot be connected to the double cross-churches of southeast Finland, and we prefer not to widen the scope of this report with its very special construction.

The double cross-church type never became mainstream in Swedish church building, but the tradition was not entirely forgotten. The first architects of the Intendant's Office were trained in Sweden, and they seem to have been familiar with the double cross-church type.[29] At least they kept to the form favoured by congregations in eastern Finland when improving the designs that were sent to them by the congregations.

II
THE MASTER-BUILDERS ON SITE

In trying to reconstruct how the Rahikkala master-builders could have worked out the structural systems of their church buildings, we go by what can be read from the still existing churches and measured drawings, comparing the data with studies of historical building practices and generally known techniques of log building. Our description of a typical church building project of the Rahikkala master-builders is based on information found mostly in the minutes of congregational meetings in several parishes of southeast Finland.

The role of a master-builder on a church building site in the time of the Rahikkala master-builders was that of foreman commissioned or hired on contract by the congregation. The parish authorities, lead by the vicar, took care of the organization and direction of the building project. Farmers delivered timber, fieldstone and hemp for rope from their lands, and money was raised in the parish for buying materials that the farms could not provide, such as window glass and iron for the building smithy, or other objects too onerous for individual farmers to produce in large quantities, for example nails and boards. No administrative tasks fell on the master-builder, who only supervised the building works. The carpenters, also working on contract, and the day labourers stood under his command.

The master-builder took part in choosing the site for the church. He came in the autumn to stake out the ground plan and lay the foundations. Timber was felled and transported to the building site during the winter months; the aim was to get an early start on the log walls the following spring.

Staking out the ground plan

The master-builder had to have a mental image of the church he was going to build. He formed a conception of its general appearance, dimensions and building masses, relationship of the parts to one another, and to the building as a whole. Did he conceive the floor plans of the churches as integrated geometric configurations, as we see them now, and as academically trained architects did at the time? Probably not. In his mind, mensuration, which could be varied in accordance with the intended dimensions of the churches, might have been primarily a series of systematically performed physical operations. We base this assumption on the fact that peasant master-builders, like the Rahikkala church builders, simply lacked the means to draw accurate designs on paper. Their relationship to a church "design" was more likely expressed as the physical act of staking it out on the building lot, and their conception of the design would have drawn on the tacit guide of "body knowledge" in the performative operations of the building program. Whatever the method guiding the mensuration process, the crucial condition, as in any building project, was that the main construction lines had to be known when the stone foundation was laid.

In order to stand out in a landscape of low-rise rural habitations, ecclesiastical architecture required that log building be developed technically to produce buildings of monumental size and shape – the striving for monumentality, which we see in still standing churches, being formed mainly in the 17th and 18th centuries.[30] In what follows, we shall briefly describe the steps that were taken when erecting a double cross-church, i.e. how general rules for log building were applied to a church.

In preparing the building lot, the first step is to locate its highest point and to mark its level on a post. Starting from this point, the terrain is then worked to achieve a more or less even surface level with this mark.[31] The main axis of a church, as determined by the location of the altar in the east, is placed by staking the east-west axis. It is drawn through three posts brought into a straight line by sighting, and the north-south axis is constructed perpendicular to it. The main structural points of the building can be determined from this cross figure.[32] The outline of the floor plan of a double cross-church requires that 20 corner points of the building be staked, as well as the four points where the construction lines cross in the middle of the floor plan. A line representing the building's base level is marked on posts by sighting.

In staking out the church building, the master-builders could avail themselves of simple geometric methods used in topographic surveys, such as using the distance between two points, the locations of which are known, to locate a third unknown point.

Building a log church

A log church was erected on a foundation of field stone. A carefully laid foundation could consist of ashlar blocks about 1 (one) metre square and having a depth of approximately 1,5 metres. The blocks placed under the corners of the

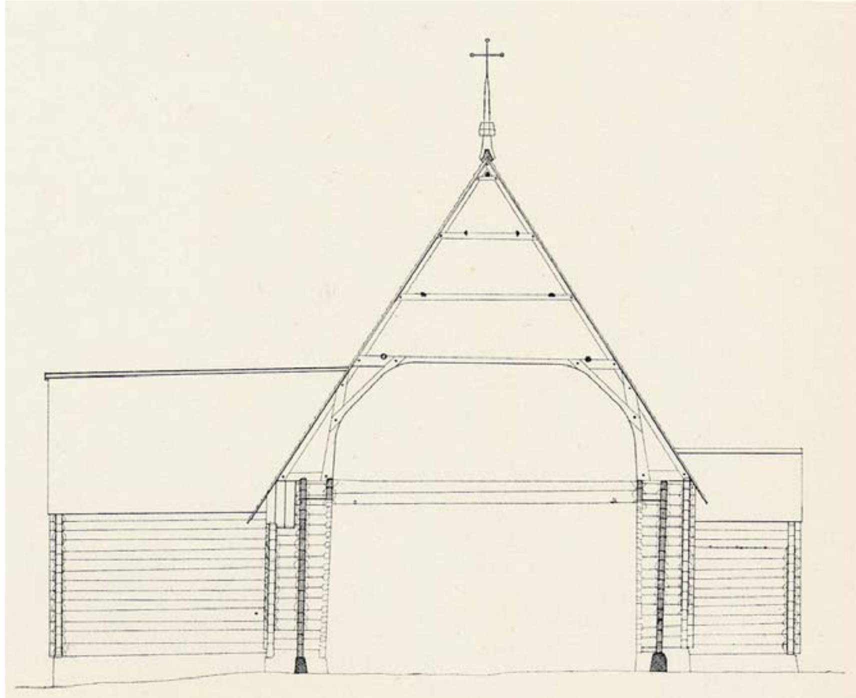


Fig. 12. Reconstructed cross-section of the nave of the church of Hailuoto, built in 1620. Measured drawing showing the doubling of the uppermost log courses of the walls with the solepieces of the roof trusses hewn into them and the tie beam spanning the nave. After Pettersson 1971, fig. 50.

building were larger, as were the blocks placed under the mid-points of the wall stretches to prevent the logs from bending under the weight of the wall.[33]

The log courses of the walls are put together so that the surface of the uppermost course is level, and when this has been controlled by sighting, the next step is to make the woodwork to stiffen the walls and make a firm support for the roof constructions. Two doubled log courses are added all around the building with the doubling on the interior side, and also the tie beams, as part of the log frame, are put in place. The solepieces of the roof trusses are hewed into the uppermost log course (cf. fig. 12).

Doubling the uppermost log courses is a device that antedates the introduction of the cruciform floor plan in church architecture and it was used in

Finnish log churches before the middle of the 19th century (fig. 12).[34] Together with the tie beams, the pillars – if pillars are included in the design – are raised into position. The roof constructions are formed to accommodate the ceiling of board vaults, and the placing of the recess, or "cupola", which rises in the middle of the centre square vault is determined by projection from the plane of the upper surface of the uppermost log course (fig. 27). Constructing the roof of the square central part of the building involves a shift to an octagon, and the octagonal recess in the middle of the central vault marks the completion of this shift.

The structural framework of the roofs in the Mikkeli and Lappee churches depends on the walls and the tie beams of the log frame for its support. The large and heavy lantern of Puumala church stands on a framework reinforced by a system of pillars, from the foundation and up through the interior space of the building. Here, the board vaulting of the ceiling hides the upper part of the framework, and in the exterior the woodwork of the structural base of the octagonal lantern is concealed behind the boards of a square "attic" (figs. 7, 2).

As true levels needed for marking measurements, the building itself offers suitable horizontal surfaces: the foundation, the log frame (walls), the tie beams, roof ridges and eventually also the floor. Checked with levels or by sighting they ascertain the stability of the structure. Among the simple implements that the master-builders would have used for checking lengths and angles is the 12-knot rope, which is useful when fitting together building parts that must be at right angles to one another. It is based on the ratio of the relative lengths of the sides and hypotenuse of a right-angled triangle, *3:4:5*, as expressed in the Pythagorean theorem. The Rahikkala master-builders would certainly have known of the 12 knot-rope and used it (fig. 13).[35] Among other simple and necessary equipment that they would have had are plumb levels, plumb lines, peg and rope for marking distances, boards on which measurements could be marked for comparison and reference, etc. These tools could be easily transported to or made up of materials on the site.

An old ell rod worn by use in the Church Builders' Museum at Savitaipale is said to have belonged to Matthias Salonen, and surely a master-builder would have had such a measuring stick in his tool bag. It was for checking that correct measures were followed down to details.

Constructing the log walls of the church is common basic carpentry. To experienced carpenters – who knew how to hew the corner locks and trim the logs to be fitted into a wall structure, taking care that corners and log courses were in plumb – the walls presented no great structural problems. If the carpenters had worked on church building sites before, they were able to erect the log frame even without the direction of a master-builder – as happened on the building site of Rautu Church in 1823, where the master-builder Matthias Salonen died when work on the church had barely begun.[36] He must have completed the staking out before his death since the team of carpenters could proceed on their own with the log frame. A new master-builder was not needed until it was time to start with the roof.

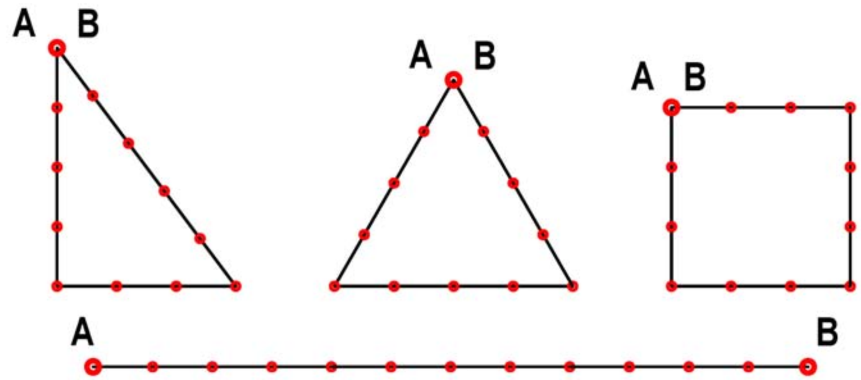


Fig. 13. The 12-knot rope is handy for checking right angles with the prime Pythagorean triangle, but it can also be folded into other figures. Drawing M. Härö.

The master-builder planned the building taking into account the subsidence of the walls of horizontally laid tree trunks. The undersides of the logs are fashioned to fit over the curved upper sides of the lower log course, and over time the weight of the logs presses down the courses tightening their fit as the walls subside. The rate of subsidence is at its greatest immediately after the wall construction is completed. In vernacular building, finishing work like hewing out window openings was not undertaken until approximately one year had elapsed from the completion of the building. The proportions of the height of walls and roof structure had to be planned with this subsidence in mind. The roof structures of the large double cross-churches were designed and executed to withstand wind forces and counteract structural tensions that could cause deformations of the fabric.

The designs for double cross-churches built after 1810 invariably included pillars to support the central part of the roof. This often included a heavy lantern, and master-builders who worked exclusively with wood as building material would make the pillars of solid tree trunks (fig. 7). As these vertical elements retained their original height while the walls of horizontal logs subsided, it was necessary to correct for the resulting difference in height in order to ensure an even subsidence over the whole building and prevent loosening of the corner locks of the walls. Accordingly, the pillars were made only as high as the walls were estimated to be after subsidence, and wedges were put under the tie beam crossings to even out the difference. As the walls subsided, the wedges were removed.[37] This is an example of the technical obstacles that a peasant master-builder had to overcome in adapting architectural designs to log building.

Geometric and arithmetic methods of mensuration

Rudolf Wittkower maintains that the geometric method of determining proportionate construction systems and the arithmetical method of finding commensurable systems existed side by side in Mediaeval and Renaissance building practices. The geometric method avoided the difficulty of expressing ratios involving irrational numbers and also had other practical advantages in an age when standards of measurements varied according to locality. Consequently, Renaissance architects did not reject geometric mensuration although – following Vitruvius whose *Ten Books on Architecture* (*De architectura*) was their frame of "theoretic" reference – their primary interest was to develop a rational aesthetic where the ratios of symmetry in a building could be expressed numerically with small integers like the ideal, harmonic ratios of Alberti, 1:2, 2:3, 3:4. Renaissance architectural treatise writers integrated geometric procedures with the arithmetic method of mensuration, but gave numerical values the preferred position as a basis for developing a rational architectural design method. In Mediaeval building arithmetic had been applied less systematically, more as a complement to geometric calculations.[38]

Does the question of geometric vs arithmetical systems of mensuration have relevance for the work of the Rahikkala master-builders? Considering the conditions of the church building sites of their time, it is likely that if they used

both systems the stress would have been on the geometric method. We have consulted three architectural writers of the Renaissance period, Francesco di Giorgio Martini (1439–1501), Sebastiano Serlio (1475–1554) and Philibert De l'Orme (1514–1570), and compared the geometry of the double cross-churches with the directions on architectural design that these authors give to architects and builders.[39]

The writings of Francesco di Giorgio Martini are preserved as manuscripts and they have been edited and published in 1967. The editor describes Francesco as a technician more than an artist, and notes that his wide experience of practical building is reflected in the discussions of theoretical problems in the texts.[40] A more recent study of Francesco's treatise, or treatises, concurs with this view, and stresses the fact that his *Trattato di architettura* became immensely popular precisely because it treats architecture from the point of view of on-site practice. A great many manuscript copies of it circulated among the building professionals, and it also served as a text-book for those learning the craft.[41] Francesco is to be regarded as a compiler of the heritage of the collectively achieved knowhow in engineering, architecture and military science in 15th-century Siena.[42]

One of the 16th-century architects who profited from Martini's architectural heritage was Philibert De l'Orme, who in the 1530s became acquainted with current Italian architectural practice and humanist discourse.[43] Practical problems of building sites and presentations taken from his own production are prominent in his treatise. Serlio's treatise with its systematic treatment of the basics of Euclidian geometry and perspective as applied to architecture was disseminated widely in Europe. All three writers demonstrate geometry as the fundament of design.

The example of combining arithmetic in the form of an even grid with geometric mensuration illustrates Francesco's problem of finding a ratio for the division of a church into a central nave and two aisles. The same exercise is presented in De l'Orme's treatise, here shown as the division of a town gate into the three gateways of the tripartite triumphal arch type. The widths are in both cases expressed in terms of the units of the grid, but height values are arrived at geometrically.[44] Serlio introduces the even grid in his geometry "course" and demonstrates its use in connection with perspective.

The grid as an instrument for the design of various objects has been used since antiquity, and the master-builders of log churches must have known about this method whether they used it themselves or not. In the material presented below, we have included two churches where planning has started from a grid, but they seem to be exceptions, and the grid as the starting point for the design possibly belongs to a different tradition than the one generally followed by the Rahikkala master-builders.

In a diagram Francesco di Giorgio Martini demonstrates how the same geometrically derived proportions apply to an ideal human (male) body and the plan of a church: it shows how the head and torso of the figure fit the plan of a double cross-church (fig. 14).[45] The proportions of the double cross-churches of the Rahikkala master-builders are closer to the plan in Francesco's diagram than to that of Serlio's project for a temple; the latter we have already mentioned as a source for Katarina Church in Stockholm (fig. 4). The many editions of Serlio's treatise on architecture spread throughout Europe and found

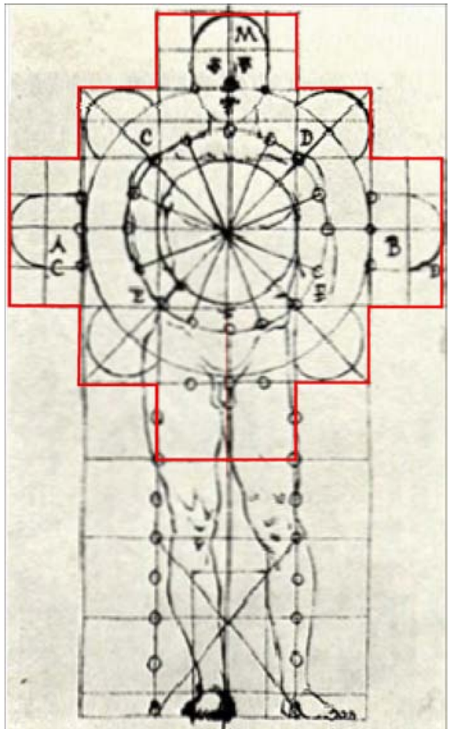


Fig. 14. Francesco di Giorgio Martini's ideal human (male) figure consonant with the ratios of a proportional floor plan of a church. After Francesco di Giorgio Martini*, pl. 236.*
The outline in red: M. Härö.

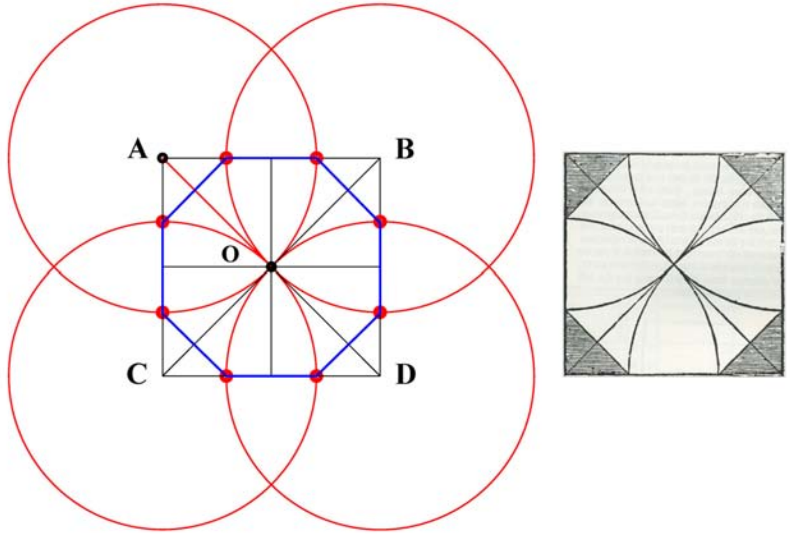


Fig. 15. To the right: The correct proportionate method of constructing an octagon from a square according to Sebastiano Serlio in Book I of Tutte l'Opere d'Architettura et Prospettiva *(after* Sebastiano Serlio on Architecture*, p. 28). To the left: analysis of Serlio's construction. M. Härö.*

their way to architects, land surveyors and military engineers in Sweden at least by the 17th century.[46] The treatise is not much concerned with architectural practice, but the demonstrations of the application of Euclidian geometry and perspective would have been of interest as well as the presentations of ancient Roman architecture.

Serlio demonstrates the use of a horizontally placed grid to derive height values. The elevation is as it were raised from the plane into vertical position. If the grid values are set arithmetically, the details of the elevation – such as doorways – can be measured from the grid and the ratios of measurements on the vertical plane are thus arithmetically defined.[47] Serlio discusses polygons as approximations of a circle and shows the correct geometric method of deriving an octagon from the measurements of a square (fig. 15).[48]

We are not suggesting that the Rahikkala master-builders were themselves familiar with Renaissance architectural writings, but much of the basic geometry of architectural design that these treatises contain would have trickled down to

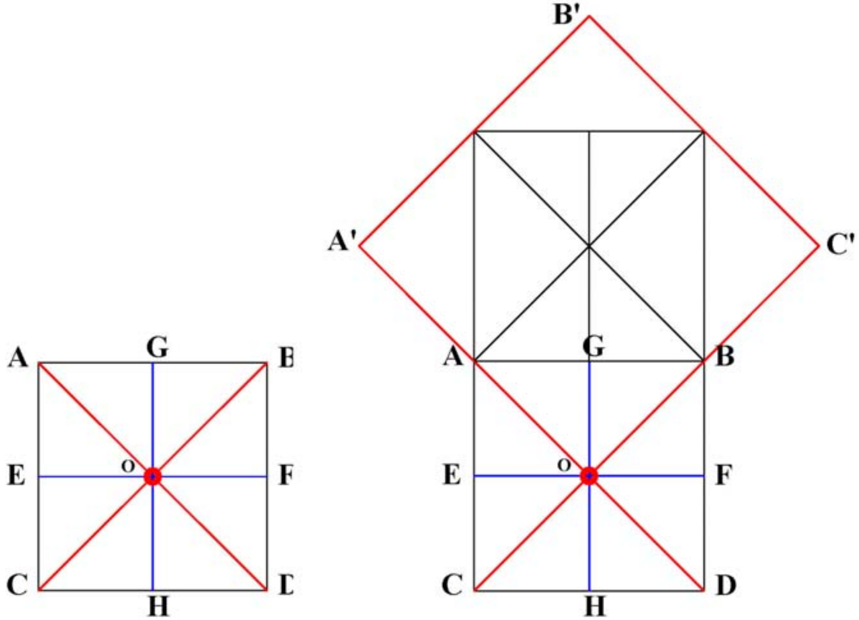


Fig. 16. The basic square to the left and the geometric method of enlarging it proportionally. Drawing M. Härö, after Francesco di Giorgio Martini*, pl. 234.*

the practical level of building sites. Here, presumably, educated members of the building trade met with locally recruited carpenters to whom they introduced new ideas and techniques. The treatises are compilations of architectural know-how and important in disseminating information. Practical building activities where instruction was part and parcel of the work were not, however, necessarily dependent on printed forms of knowledge.

The basic square

We call the middle part of a cruciform church plan *centre square*, and designate it ABCD. With another term, *basic square*, we shall demonstrate how the structure of a double cross-church is developed from a given length value, the side of the basic square, indicated with small letters, *abcd* (see figs. 20–25).

The ratio of the side *s* of a square and its diagonal, $s{:}s\sqrt{2}$, has been applied in

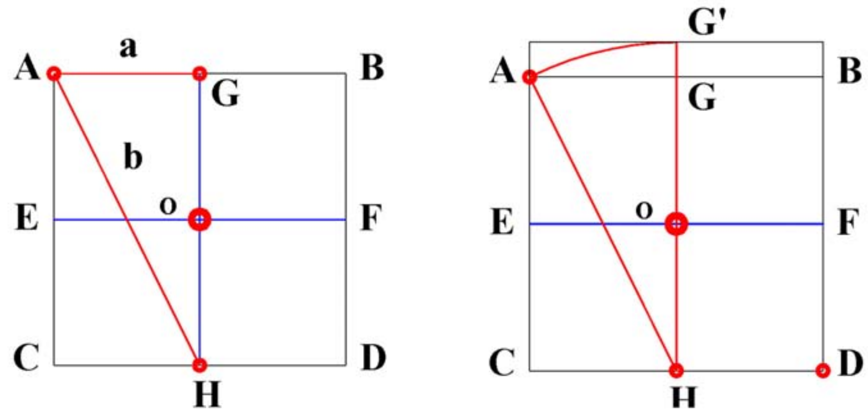


Fig. 17. The geometric construction for proceeding to a new ratio ($b=\sqrt{5}a$) using the basic square. Drawing M. Härö, after Francesco di Giorgio Martini*, pl. 203.*

building and land surveying since ancient times, and its use in mediaeval building has been established in studies of Gothic architecture.[49] The Renaissance architectural treatise writers also recognised its usefulness.

Construction of the basic square starts by determining the length value of its side. The area of the square is divided equally into four small squares by connecting the midpoints of the sides. The diagonals *AD* and *BC* of the basic square are drawn. The resulting figure offers possibilities for mensuration by both small integers or their multiples and geometric constructions. Francesco di Giorgio Martini demonstrates the geometric application of $s{:}s\sqrt{2}$ in an exercise on calculating different ways to establish proportionate relationships within a building, including calculations of height values proportionate to given widths (fig. 16).[50]

Francesco also demonstrates the geometric ratio arrived at by halving the square, the side of which is known, and drawing a diagonal of the rectangle so produced (fig. 17).[51] All of the main proportions and figures can be derived from the two crosses: the cross that divides the basic square into two equal rectangular halves, and that which is formed by its two diagonals.[52]

Serlio declares the square to be the most perfect figure of all rectangular forms. He finishes his first book on geometry with a diagram that is a key to two useful geometric constructions based on the square, *s:s*$\sqrt{2}$ and the diagonal of the rectangle that is half of the square. In this particular demonstration these geometric ratios have been used to find the measurements of a temple doorway (fig. 18).[53]

The basic square can be enlarged or diminished by applying the ratio *s:s*$\sqrt{2}$. Using the diagonals as parts of the sides of the square and/or placing them into the square and constructing circles with the corner points as midpoints, gives length values that are proportional to the given length, the side of the basic square (fig. 16). Francesco di Giorgio Martini, Sebastiano Serlio and Philibert De l'Orme include different examples of this geometric calculation in their treatises.[54]

Geometric mensuration on the building site

Rope was an important commodity in historic building techniques. There are always large amounts of rope included in the written estimates of required building material made by the Rahikkala master-builders. Almost all of their specifications include rope of two different thicknesses expressed in terms of the circumference of the rope. The circumference of the thicker rope is 5 Swedish inches (*tum*), and that of the thinner one 3 Swedish inches (approximately 12.4 cm and 7.4 cm). It is never indicated for what purpose the rope is to be used, but the smaller amounts of the heavier rope suggest that it could have been used for hoisting heavy building material or parts of building elements. These would have been "prefabricated" into shape on the floor, taken apart and reassembled in the upper regions of the building. The thinner rope, of which much larger quantities are required, could have been intended for staking out the church, measuring, plumb lines and various other, even occasional, uses. There is great variation in the total amount of requisitioned 3-inch rope, which is hard to explain as the churches are much the same size. The amounts indicated diminish steadily in time from site to site, from almost 570 metres in 1795 (Valkeala church) to almost 107 metres in 1812 (Parikkala church) as if the master-builders were finding increasingly economical ways, perhaps shortcuts, to carry out their staking and measuring operations.[55]

The Swiss archaeologist Rudolf Moosbrugger-Leu has in excavated buildings explored signs of uses of rope for staking out floor plans. These show markings, such as peg holes, and ratios of lengths and angles, that point to a non-numerical "design method" not based on measurements but on an order having

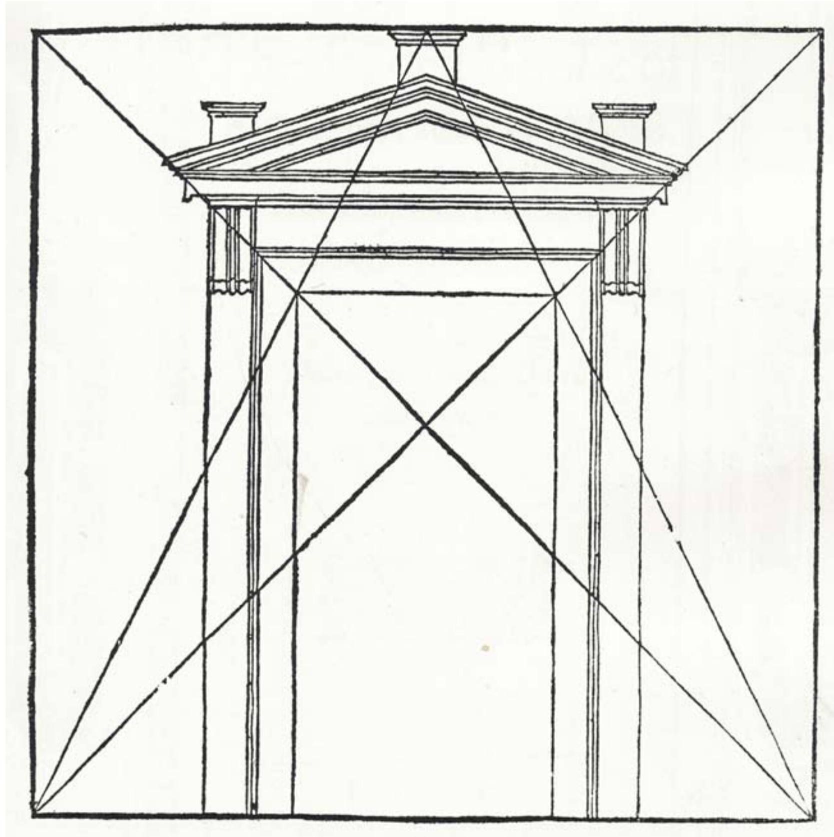


Fig. 18. Serlio's demonstration of the geometrically expressed ratios s:s$\sqrt{2}$ *and the diagonal of the rectangle that is half of this square as applied to the design of a temple doorway. The "key" to these geometric ratios ends the first book of* Tutte l'Opere d'Architettura et Prospettiva. Sebastiano Serlio on Architecture*, pp. 32–33.*

a self-emergent, inherent symmetry (in the Vitruvian sense). The operation of establishing this order in a building plan requires a fair amount of rope. The procedure starts with a basic length or baseline or *canon*. Its value is set as the given of the problem of finding construction lines and points.[56]

Among the building projects that Moosbrugger-Leu has researched, we find the enlargement of the chancel of Chrischona Church in Bettingen, Switzerland, in 1509.[57] The triangle method (triangulation) of staking out the Chrischona chancel enlargement, that he reconstructs, can also be applied to a church with cruciform plan. The given, or canon, in the Chrischona case is the new width of the chancel; for a church of cruciform plan, the given is the length of the side of the basic square.

This method of staking out buildings could still have been in use in the early 19th century. As the material to which Moosbrugger-Leu refers shows, his geometric – or *ordometric*, as he prefers to call it – method of constructing is rooted in prehistoric building practices and antedates ancient Greek geometric theory, and it was still current in the early sixteenth century (as the chancel of Chrischona Church shows). He discusses an early 18th-century Portuguese pictorial representation of the founding of Alcobaça monastery in the 12th century. In the painting, made on ceramic tiles, three men stake out a monastic building by triangulation with ropes. He comments on the artist's clear idea of an operation that had taken place several centuries earlier.[58] It is obvious that the artist is depicting the historical event on the basis of contemporary experience; the drawing reads like a documentation of a work scene of which he has first-hand knowledge.[59] If the technique of triangulation with rope was still a commonplace in the early 18th century, it is quite reasonable to assume that the Rahikkala master-builders staked their churches with this method. At least it is easier to believe that they did, than try to imagine them as operating with technically more advanced equipment.

In the churches under discussion, it is evident that the length of the canon, or the side of the basic square, is determined at the planning stage to accord with the intended size of the church. The master-builder would have been the person who estimated this length value on the basis of the size of the congregation. To find the right value for the canon he must have relied on his experience of different-size churches and possibly also on some general rule of thumb. The length of the side could have been expressed in ells, a common unit of measure that all concerned with the building project would have understood, but its numeric value had, of course, no bearing on the staking procedure.

How the dimensions of the several parts of the church were arrived at may have varied according to the circumstances of the site. When the parish of Sulkava, in 1753, built a simple Greek cross church, the final decision as to its size was made at a parish meeting when the building project was already well under way. Timbering of the walls was to start, and the dimensions of the log frame had to be set. Actually, the only measurements still open were those of

the lengths of the cross arms.[60] The dimensions of the central part of the church must have been set at an earlier stage of the project. The reason for leaving the lengths of the cross arms for a later decision was probably that it was only after the timber had been transported to the site that one could know for certain the trunk lengths available. Log length rather than design determined the length of the cross arms.

Geometric analysis of some double cross-churches

We present here a geometrical analysis of some of the double cross-churches of which we have been able to find measured drawings drafted to scale.[61] Most of this drawing material has been in digital form. The digitization has been done from original drawings, photographs of measured drawings and architectural drawings based on measured drawings and in one case on measured drawings printed in a book. The quality of the digitized material varies according to the quality of the originals on which it is based and on the resolution of the digitization. The accuracy of the photographic copies of drawings in the archives of the National Board of Antiquities in Helsinki cannot be assessed as the original drawings are lost or have not been accessible. It remains a possible source of error, but large distortions would have shown up and made the analysis impossible.

Practical reasons have prevented us from searching for drawing material in the archives of some of the congregations where the double cross-churches are still extant. The church of Puumala is included on the strength of observations and rough measurements made *in situ,* and additional information from drawing material in the congregation's archive.

We have excluded the Elizabeth Church in Hamina from this comparative analysis mainly because the small size of the drawing makes the accuracy of the engraving in *Atlas Vyborgskoy Gubernii* questionable.[62] On the other hand, we have included the church of Lemi, which is not a double cross-church, but it does represent a link to the earlier history of the design tradition of the later double cross-churches.

In order to get a uniform base for the analyses, the plans, cross sections and elevations have been redrawn with the program AutoCad. The main measurements have been checked by comparing with the scales in the drawings and other available information. The measurements have been taken from approximately the middle of the construction lines in order to reduce the effect of inaccuracies in the drawings, and the revised drawings have been brought to the same scale for easier examination and comparison.

The geometrical analysis has been limited to the main body of the churches, that is, the area of the double cross figure. Vestibules narrower than the cross arms have not been included as some of them have been built later than the church itself or been subjected to later modifications. For the same reason, lanterns or towers are also left out of the analysis.

The following churches have been analysed:

1. Admiralty Church, Karlskrona, consecrated in 1685. Design by Erik Dahlbergh? Master-builder Olof Hylting. Measured drawings by J. Söderberg, 1940's. Floor plan, section east-west.[63] Interior measurements approximately 36 m in both directions; height from floor level to top of lantern approximately 31 m; area 655 m2. Extant. (Fig.19)
2. Church of Mikkeli rural parish, built in 1754. Master-builder August Sorsa. Undated measured drawings by land surveyor Johan Heinricius (†1807). Floor plan, elevation.[64] Interior dimensions of plan 30.2 m. Height from floor level to top of lantern minus spire 29.29 m; area 910 m2. Destroyed in fire 1806. (Fig. 21)
3. Church of Lemi parish, built in 1786. Master-builder Johan Salonen. Measured drawings by T. Hirvonen and A. Valo, 2002. Floor plan, elevation, section.[65] Length and width without porches approximatively 27.5 m; height from floor level to roof ridges approximatively 15.20 m; area 455 m2. Extant. (Fig. 22)
4. Church of Lappee parish and Lappeenranta Lutheran congregation, built in 1792. Master-builder Johan Salonen. Measured drawings by Väinö Häkkinen, 1927. Photographs of floor plan, section and elevation.[66] Length and width without porches approximately 32.5 m; height from floor level to roof ridge approximately 17.5 m; area 680 m2. Extant but heavily rebuilt in 1929. (Fig. 23)
5. Church of Kivennapa parish, built in 1806–1808. Master-builder Matthias (and Johan?) Salonen.[67] Drawings made for rebuilding the galleries. Architect Leander Ikonen, 1901. Photographs of floor plan, section, elevation.[68] Floor plan 40.4–40.5 m in both directions; total height 47–48 m; area 680 m2. Destroyed in WW2? (Fig. 24)
6. Church of Parikkala built in 1813–1814. Design by the Intendant's Office, 1812. Master-builder Matthias Salonen. Measured drawings architect Alarik Tavaststjerna, 1911.[69] Length and width 17.8 m; height from floor level to top of lantern approximately 10 m; area 850 m2. Extant, but partly rebuilt 1859 and 1912. (Fig. 20)
7. Church of Puumala parish, built in 1830. Design by the Intendant's Office, 1823. Master-builder David Rahikainen. Documentation and measurements architect Merja Härö, 2016–2017;[70] area 890 m2. Extant. (Fig. 25)

Floor plans

In the double cross-church plan the basic square, the side of which is the given, is in this sample most often the square formed by the beam crossings or centrally placed pillars, that is, the main construction points of the central part of the church. However, in the Admiralty Church at Karlskrona and the church of Parikkala – built by Matthias Salonen not after his own sketch, but according to the design of the Intendant's Office[71] – the staking began by setting an evenly spaced grid and then marking the location of the four pillars supporting the roof constructions at suitable grid crossings in the centre of the floor plan (figs. 19–20). The east-west and south-north axes divide this square of four grid units in half. The grid is extended and construction lines and points are placed according to the structure of the grid. When this is the case, the geometric method does not apply as all proportions can be stated as ratios of small integers.

In August Sorsa's church at Mikkeli the measurements of the floor plan (fig. 21) seem to follow, more or less, the same principle as that of Hamina Elizabeth Church (fig. 10; not included in this analysis). The given in Mikkeli is the side of the square formed by the crossing tie beams. Call the square *abcd* and place it so that the intersection of the main axes is its centre point *O*. Draw the lines of the tie beams and the diagonals of *abcd*. The point *O'* on the south-north axis divides *cd* in half. With *aO'* as radius and *a, b, c*, and *d* as centre points mark the extended diagonals of *abcd*. Call the points of intersection *ABCD*. The larger square thus formed is the centre square of the double cross design. Extend the sides of *abcd*. These are the lines of the tie beams, which determine

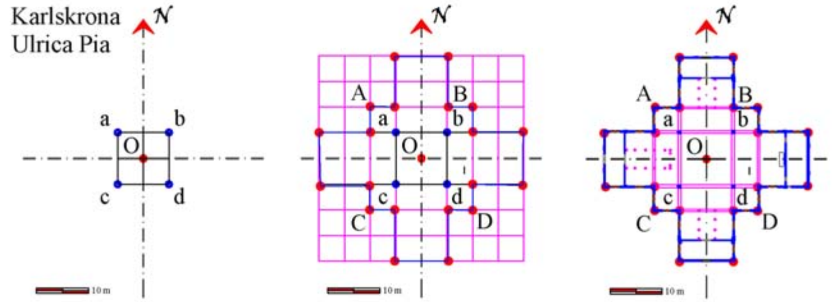


Fig. 19. Geometric analysis of the Admiralty Church in Karlskrona, Sweden. M. Härö.

the width of the cross arms. Using the formula given by Francesco di Giorgio Martini,[72] enlarge *ABCD* by constructing perpendicular lines to its diagonals at the points *A, B, C* and *D*. The length of the diagonal of *ABCD* is the length of the side of the larger square so formed. The intersections of the sides of the larger square and the extended sides of the tie beam square *abcd* determine the length of the cross arms.

The Elizabeth Church had pillars supporting the tie beam crossings. In Mikkeli the crossings had no vertical supports; the rigidity of the tie beam square was achieved by locking the crossing beams to one another. The obliqueness of the walls in Mikkeli was probably accomplished by simply moving the corner points of the cross arm ends towards the central axes and adjusting the corners of the central square to conform to the desired degree of obtuseness of

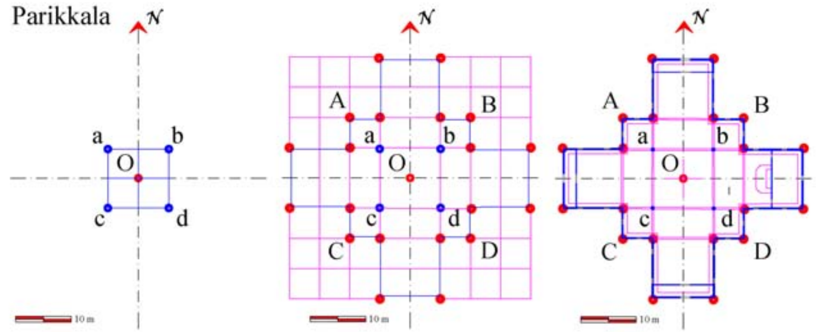


Fig. 20. Geometric analysis of the church of Parikkala. M. Härö.

the corners. In the drawings, the side walls of the cross arms deviate from the perpendicular by 2 ells, that is, the width of the cross arms decreases by 4 ells (about 2.4 m). The occurrence of the same structural scheme in the floor plans of the Elizabeth Church and Mikkeli parish church may be a coincidence, but more likely it is a sign of Elizabeth Church being an operational model for the Mikkeli Church. The basic geometry of the plan is the same, but in other respects the two churches are quite different.

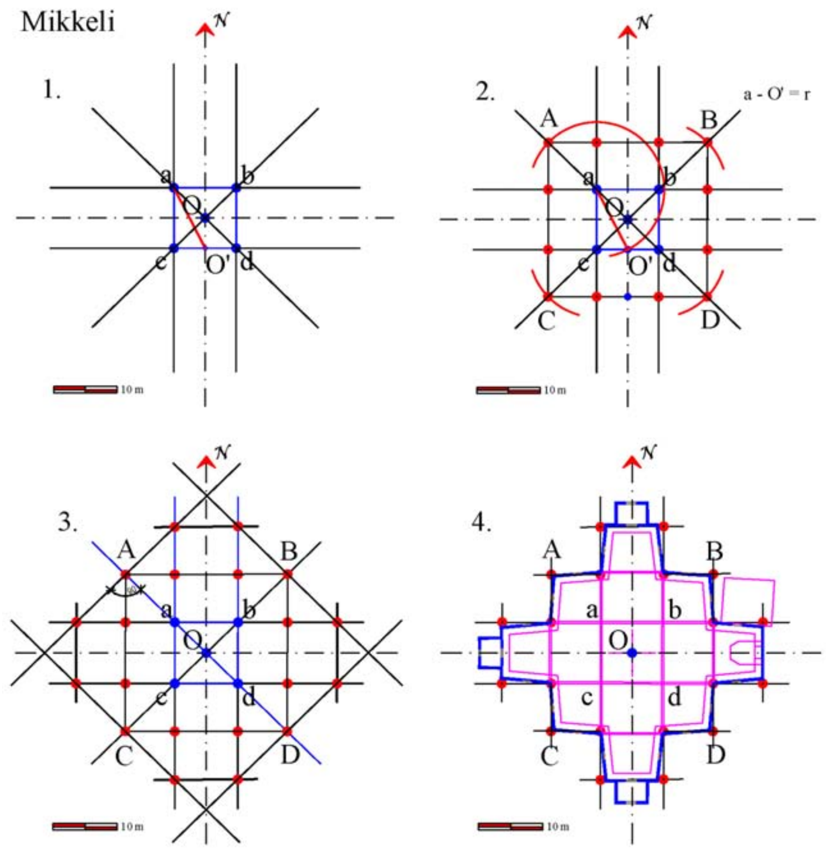


Fig. 21. Geometric analysis of the first double cross-church at Mikkeli from 1754. M. Härö.

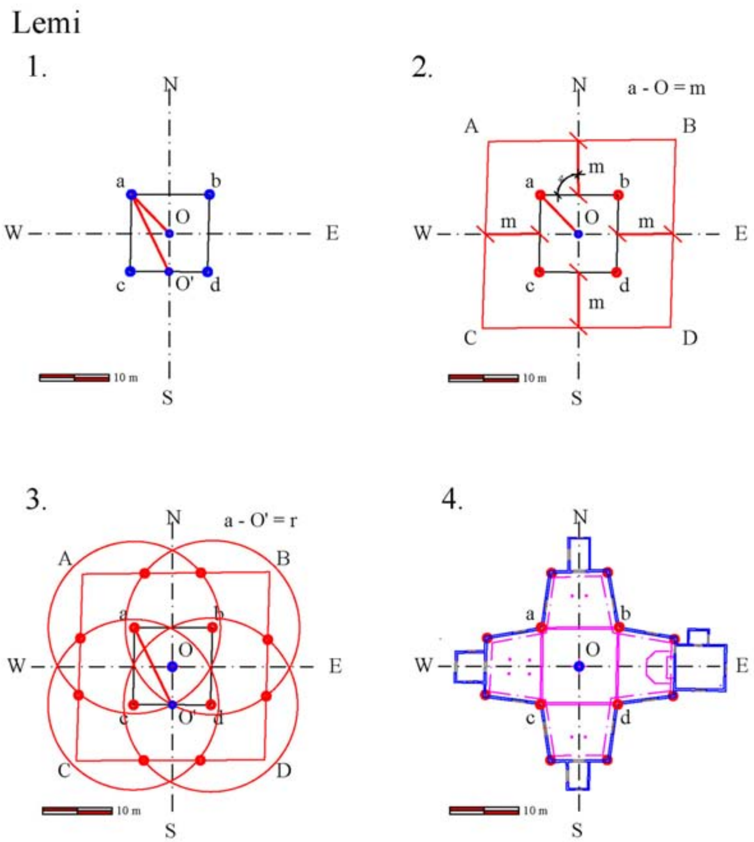


Fig. 22. Geometric analysis of the church of Lemi. M. Härö.

The geometry of the church of Lemi, on a Greek cross plan, shows that the double cross design method is rooted in an earlier practice of geometric mensuration (fig. 22). In the Greek cross plan the centre square and the basic square coincide. The centre square, the side of which is the given, is *abcd*. The east-west and south-north axes, intersecting at *O*, divide the square into four equal small squares. The length of the cross arms is equal to the diagonal of a small square, *aO* or *m*. It would have been quite simple to measure off this length with rope and peg technique placing the peg on the midpoints of the sides of *abcd* and transferring the length of the diagonal to the main axes, and then constructing square *ABCD*, which circumscribes the whole floor plan.

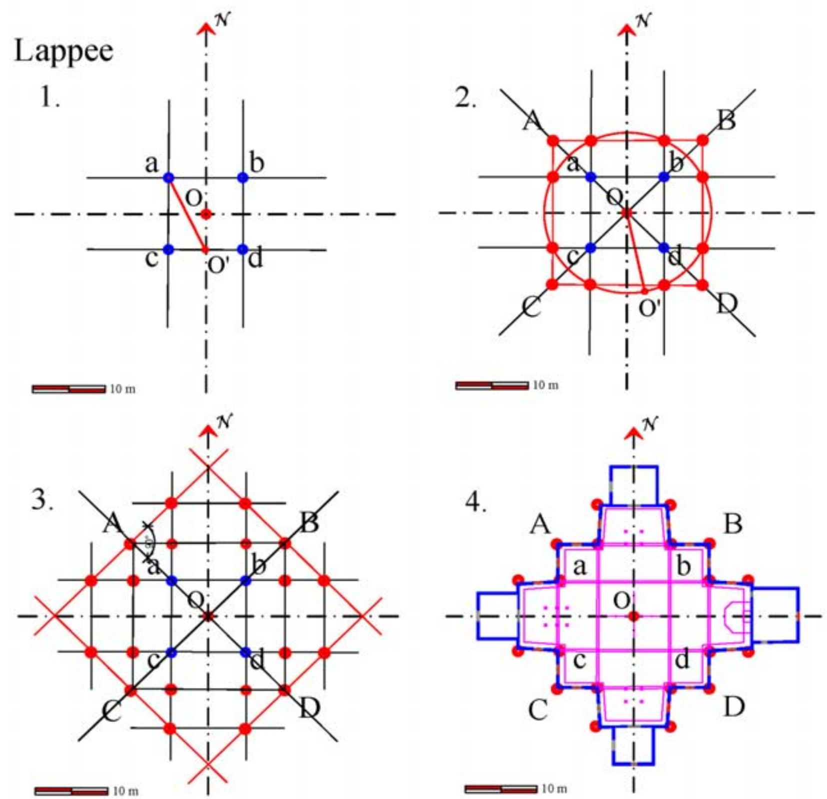


Fig. 23. Geometric analysis of the church of Lappee. M. Härö.

Serlio's demonstration of constructing an octagon inscribed in a square can be used for finding the lengths of the cross arm endings. A main axis divides *abcd* in two rectangles. The centre point of *cd* is designated *O'*, and *aO'* is the diagonal of one of the rectangles. With *aO'* as radius four circles are constructed using the corner points of *abcd* as midpoints. The circles intersect the sides of *ABCD*, and the points of intersection are connected to the corners of the centre square giving the lines of the oblique sides of the cross arms.

In the church of Lappee, the basic square *abcd* is also constructed and divided in half to make two rectangles (fig. 23). As in Mikkeli, the diagonal of one of these rectangles *aO'* as radius and the corners of the basic square as centre

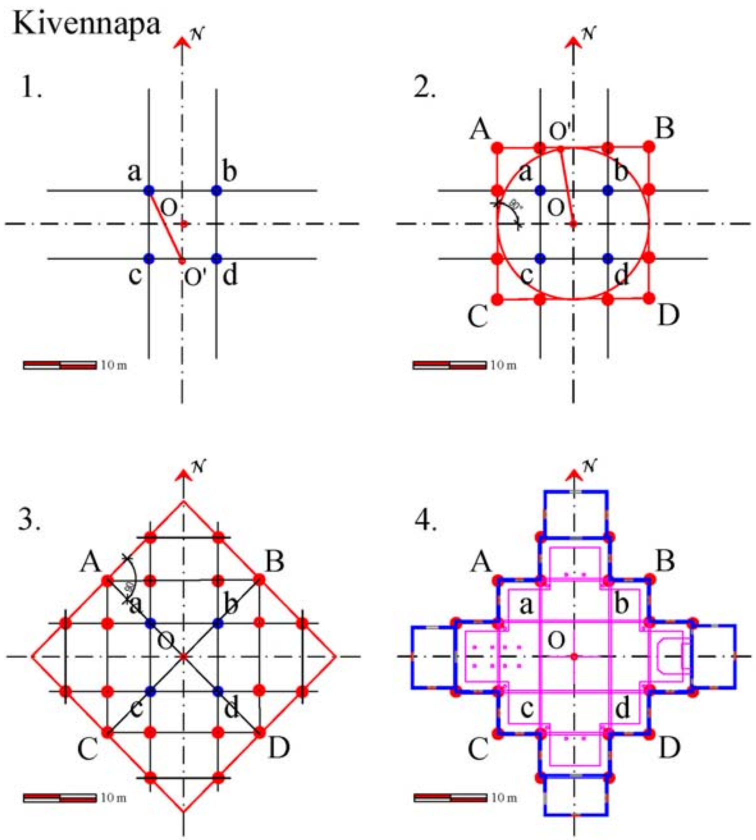


Fig. 24. Geometric analysis of the church of Kivennapa. M. Härö.

points give the corners of the centre square *ABCD*. The next step is a little different. With the diagonal *aO'* as radius, but with the intersection of the east-west and south-north axes as centre point, a circle is drawn which intersects the extended sides of the basic square, i.e. the tie beam square. These intersections give the width of the cross arms on the sides *AB, BD, CD* and *AC*. The ends of the cross arms are found in the same way as in Mikkeli by drawing a square with the length of the diagonal of *ABCD* as the length of its side by constructing perpendiculars on the diagonals of the squares at the points *A, B, C* and *D*. The cross arms narrow down slightly towards the ends. Here, too, the obliqueness

has been achieved by moving the end corners of the cross arms 1½ ells towards the central axes shortening the end wall 3 ells (about 1.8 m). The narrowing down can be experienced as a feeling of "intensification" of space, but the deviation from right-angles at the corners is not large enough to be detected as an actual narrowing of the cross arm. The chancel cross arm is 1 (one) ell longer than the other three cross arms, another deviation from regularity which is impossible to detect as such. One can only guess whether these deviations are intended modifications or shifts come about by chance. The mensuration method used in Lappee church has resulted in a remarkably wide interior, which is all the more impressive because there are no vertical obstructions (pillars).

The staking of Kivennapa church was started, as in the churches already mentioned, from the tie beam square *abcd* as basic square and continued by drawing the diagonal *aO'* of the rectangle that is one half of the square (fig. 24). A circle is drawn with this diagonal as radius and the intersection *O* of the east-west and south-north axes as centre point. This circle is inscribed in square *ABCD*, the sides of which are found by constructing perpendiculars from the points where the circle intersects the axes. The diagonals *AD* and *BC* are drawn, and the diagonal length is the length of the sides of the square drawn by constructing perpendiculars to the diagonals at the points *A, B, C* and *D*. All construction lines and points, including the end corners of the cross arms, can be found from the intersections of the tie beam lines and the enlarged square.

The staking out of the church of Puumala starts not from the square determined by the tie beams, but from the centre square *ABCD* itself, i.e. basic square and centre square coincide (fig. 25). The diagonals of *ABCD* are drawn. With half the length of the diagonal of the centre square as radius, and its corner points as centre points, circles are drawn, and the points of intersection of these circles and the sides of the centre square marked as if the intention were to construct an octagon by the geometric method demonstrated by Serlio. This procedure gives the lines of the tie beams and their points of intersection where the pillars supporting the tie beam crossings are to be placed. By enlarging the centre square so that the length of its diagonals becomes the length of the side of the larger square the intersections of the side of the larger square with the tie beam lines gives the location of the ends of the cross arms.

The staking out procedures of the ground plans of the double cross-churches analysed in this study show a definite preference for the geometric method of

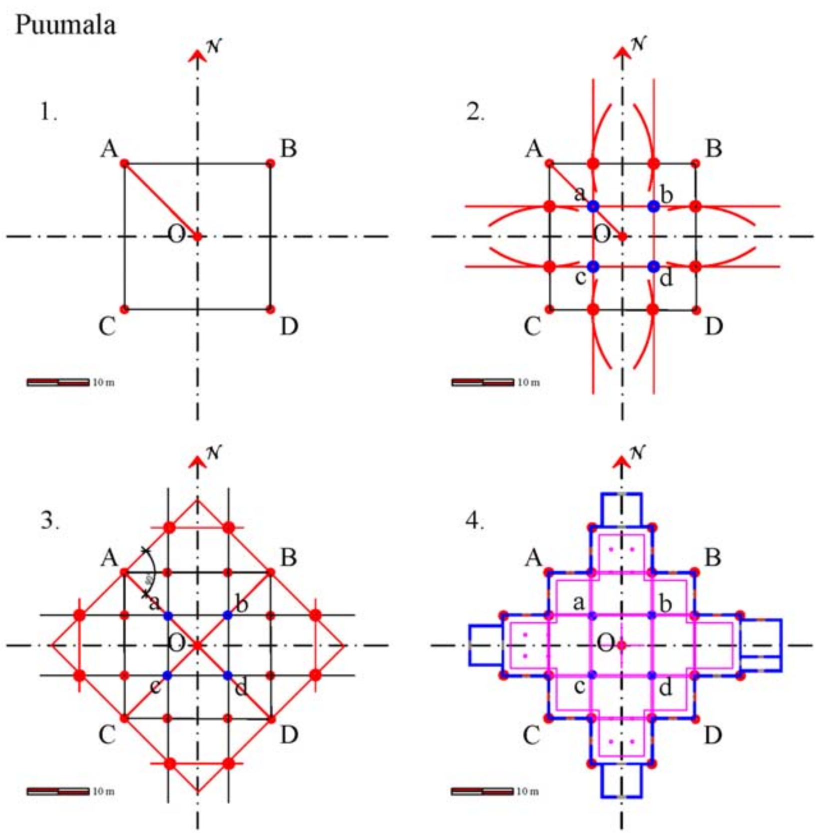


Fig. 25. Geometric analysis of the church of Puumala. M. Härö.

construction design, but the even grid that gives the plans the ratios of small integers, 2:1:2:1:2, in both directions is also used (Karlskrona, Parikkala). Geometrically derived ratios are a resource for varying the proportional structure of the churches. The Rahikkala master-builders aimed for this variety by utilizing the diagonal of a square, the side of which is known, or the diagonal of the rectangle that is half of this square. On the basis of the material in this study, the common method to find the length of the cross arms is to enlarge the centre square proportionally using the length of the diagonal as the length of the side of the enlarged square. This method is, like all the other geometric procedures described here, older than its codification in the Renaissance treatises. It was

used, for instance, in the Middle Ages for constructing a proportionate cloister quadrangle, but also for detail work like forming a pinnacle.[73]

Not surprisingly, this study shows that fixing construction points starts at the centre of the building, where the heaviest loads and the structures involving the greatest risk are located and staking out the floor plan can begin with manageable spans. There seems to be a certain freedom about the placing of peripheral construction points, but that may have applied only to churches built on a Greek cross plan. The double cross-churches are more likely to have been built on more comprehensive designs. For instance, the elevation of the church of Puumala is designed with continuous oblique construction lines from the ends of the cross arms to the central lantern tower. The importance of the principle that the main lines and points of construction are considered simultaneously, regardless of at what height in the edifice they are positioned, is evident.

Proportionate height values

The following part of our study is very superficial as these double cross-churches have never been researched systematically. There are no archaeological data nor accurate measured drawings for an analysis of the structure and the pro-

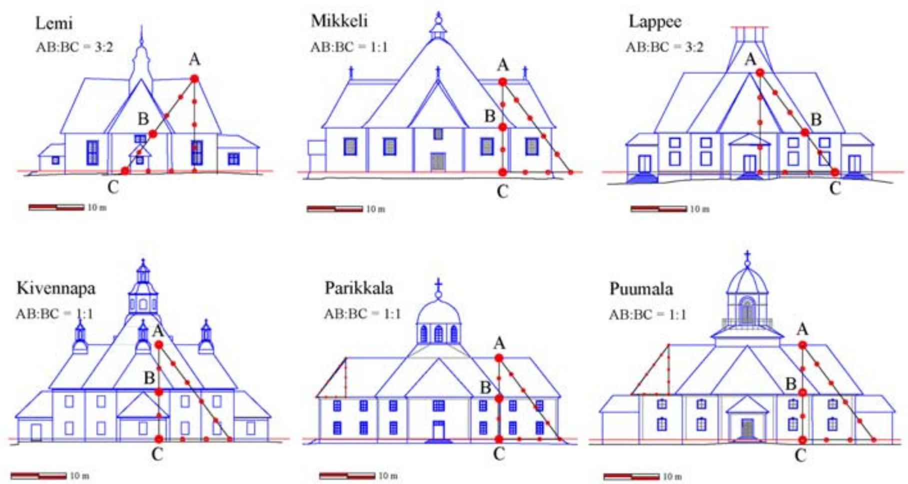


Fig. 26. Proportionate height values of Lemi, Mikkeli (1754), Lappee, Kivennapa, Parikkala, and Puumala churches as demonstrated with the prime Pythagorean triangle. M. Härö.

portions involved in the elevations. We give the proportional heights of the churches as measured from the cross arms because original height values of the central part cannot be obtained from all the churches presented in the sample.

Measured from the socle or floor level to the eaves and from the eaves to the roof ridge, the ratio of wall and roof height is 1:1 in Mikkeli, Kivennapa, Parikkala and Puumala and 2:3 in Lappee (fig. 26). The height values of wall and roof in Lemi Church are, like those of Lappee Church, in the ratio of 2:3 as the prime Pythagorean triangle in the diagram demonstrates. It is interesting that the ratio in Mikkeli, built in 1754, is the same as that of the churches built in the neoclassical period of the early 19th century. Parikkala and Puumala are both based on drawings by architects at the Intendant's Office, whereas Matthias Salonen probably built Kivennapa after his own design or that of his father Johan Salonen. Johan's Lappee Church, the Rahikkala master-builders' first double cross church, has – like his earlier church of Lemi – the archaic steep roof of the mid-18th century Carelian church building tradition, a mediaeval or "Gothic survival" element in these churches.

The section drawings in our sample reveal that the same scheme was used repeatedly in building the board vaulting of the church ceilings. The cross arms have "barrel vaults" of varying form, and the corners of the centre square are made into "squinches" when the square shifts to the octagon of the roof. At the crossing, a tiered, octagonal recess represents a cupola, but looks like a canopy, especially when decorated with carved wooden lambrequins in imitation of textile ornaments (fig. 27). It is possible that the geometric pattern of the tiers was calculated as ratios of small integers. The "cupolas" have no connection to an above light source. Puumala Church is unique in that its cupola has an opening into the lantern that lets in daylight into the church interior.

Conclusions

Our article can be characterised as a pilot study of architectural design in vernacular timbered church building. It concerns the rise of a specific type of centralized church, the monumental double cross-church, which came to dominate ecclesiastical architecture in southeast Finland for a few decades before and after the year 1800. Our focus has been on a series of churches that were built by three farmer master-builders, who belonged to the same family or "school" based in a remote South Carelian village. The sample that we have been able to

Fig. 27. The ceiling in the church of Lemi. The octagonal recess marks the crossing. The trefoil section of the cross-arm ceilings, which is seen in the background, is a sign of Gothic survival. The lambrequins and the decoration in red are original ornaments, but painting the surfaces of the vaults white may date from 1874 when the entire interior was painted, possibly for the first time. Photo E. M. Viljo 2016.

gather for a geometric analysis of their design methods is not representative of their entire production. It is possible, for instance, to find more material from the first years of the grand duchy when Matthias Salonen started his building activities in Savonia. A topic for further research is the relationship of the master-builders to the Intendant's Office, on which we have touched only briefly.

In this summary of the results of our study, we can speak only of the churches in our sample, but we think that our method, which focuses on geometric design of the buildings, could be useful as a complement to the historic data on wooden churches of the preindustrial period in general. The fundaments of the study of old buildings are archaeological data and measured drawings, but as we hope to have demonstrated in this article, geometric analysis also gives information about the builders of these churches, about their capacities as architectural designers.

Much of what we could call results of our study remains conjectural, but our analyses show that the master-builders with whom this study deals depended mainly on geometric mensuration in constructing their churches. Their training in architecture and building made no distinction between the two, and it took place primarily, if not entirely, on the building site. This limited their practice of design to a few basic operations that could be mastered chiefly as a routine physical performance. The geometry that it involved was sufficient to give scope to variation within the general scheme of the double cross-church type. In their preference for the geometric method of mensuration the master-builders resemble their mediaeval forerunners, which is natural as the conditions and the equipment on the building site were much the same as in the Middle Ages. Nevertheless, the double cross-church was a Renaissance innovation, and somehow the geometry of its design came to be adopted by farmer master-builders working in southeast Finland, who took on the technical challenge that it represented.

We have touched on questions of construction only in a general way trying to sketch the essential elements of log building technique at the time of the master-builders that we study. We take it for granted that an absolute prerequisite for constructing the large double cross-churches was a thorough knowledge of their material, wood, and familiarity with working it.

The exact relationship of geometric and arithmetic methods of mensuration on the building site of a wooden double cross-church is a question perhaps never to be clarified as there is no data to be found on building practises and procedures from the period in question here. We have, however, discovered an alternative, arithmetical method to stake out structural points and lines of a double cross-church on an even-spaced grid, which is, apparently, a method used by military engineers. It is also apparent that peasant master-builders preferred a more imaginative, geometric method of staking out the structures of their churches. This method was based on ratios and geometric operations that

had been used in building since antiquity and that Renaissance writers of architectural treatises had codified. Obviously, this geometric system was introduced with the centralized church in the 17th century and became part of the knowledge applied and disseminated on the building sites where the master-builders acquired it.

The relationship of the southeast Finnish double cross-church to the grand tradition of the church architecture of the Italian Renaissance has been discussed and established in the studies of Lars Pettersson. Our research shows a specific aspect of this relationship: the geometric base of the statics of these buildings and how it could have been managed on the building site. To trace the road of influence, following the routes of travelling architects and itinerant builders, from Italy to Finland over three centuries and innumerable building sites spread across Europe would be a real challenge for architectural history.

Notes

1 Pettersson 1989a, 256.
2 Rønningen 2000, 147; see also Sjömar 2000, 125–131, on the relationship of church forms and timbering technique.
3 Pettersson 1989a, 256.
4 National Records Office, Digital archive: Records of Mikkeli country parish, Minutes of church council meeting 1806-9-28; Records of Puumala parish, Minutes of parish meeting 1821-10-27 §1; Records of Valkjärvi parish, Minutes of parish meeting 1822-12-16.
5 Wittkower 1965, 19–20, 30.
6 *Sebastiano Serlio on Architecture*, 416–417.
7 Cf. Pettersson 1989a, 245–246.
8 National Records Office, Digital archive, Records of Lappee parish, Minutes of parish meetings, 1837-6-4 §1, 1839-5-26 §1; Rinno 2015, 68–72.
9 Pettersson 1989b, 301; Viljo 2014, 1–2; National Records Office, Digital archive, Census registers of the province of Viipuri 1818–1859, District of Lappee, Parish of Savitaipale.
10 Pettersson 1989b, 301; National Records Office, Digital archive, Records of Kangasniemi parish, Minutes of parish meeting 1811-3-17.
11 Cf. Kaukiainen 2013, 194–195.
12 National Records Office, Digital archive, Records of Sulkava parish, Minutes of parish meeting 1847-1-24.
13 National Records Office, Economic Department of the Senate, 1812 4/461 (Parikkala), 1812 82/523 (Kirvu), 1820 68/177 (Kesälahti), 1822 30/183 (Valkjärvi).
14 National Records Office, Digital archive, Land registers of the provinces of Savonlinna and Kyminkartano 1722–1739; ibidem 1739, Report on the Inquiry and Land Revision in the Commandantship of Lappeenranta, 1743.
15 Pettersson 1988, 348. See for instance the church of Kuolemajärvi. Rinno 1997, 118–120, fig. 19; Viljo, 2021, Lemin kirkon rakennushistoria, manuscript, 9–10.
16 The churches were built for the following parishes: Lappee (Lappeenranta) 1792, Valkjärvi 1793–1794?, Valkeala 1796, Uusikirkko 1800, Sortavala 1801, Venjoki in Ingermania 1803, Kivennapa 1804–1806. Pettersson 1989b, 302–303; National Records Office, Digital archive, Records of Valkjärvi parish, Pastor Johan Stråhlman's chronicle of the Valkjärvi congregation, #8.
17 Knapas, Rainer 2013, 373–374.
18 Swedlund 1969, 37. Cf. Heikki Klemetti's studies of drawings in the archive of the Swedish National Board of Building in Stockholm. Klemetti 1927. Viljo 2008, 15–23. For background information on the founding of the Intendant's Office and its earliest years see Viljo 2008, 15–23; Suhonen 1981, 29–39; Kydén 1998, 23–42.
19 Kangasniemi 1812, Parikkala 1814, Kirvu 1815, second double cross-church of Mikkeli 1816, Sulkava 1822, Rautu 1823, second double cross-church of Valkjärvi 1826, Savitaipale 1827, Puumala 1830. Pettersson 1989b, 302–303; Viljo 2015, 48–50; National Records Office, Digital archive, Records of the following parishes and minutes of parish meetings: Kangasniemi 1812-7-19, 1812-10.11; Parikkala 1814-2-13, 1814-8-7; Sulkava 1822-1-20, 1822-7-6 §1; Rautu 1823-8-10 §2, 1824-1-25 §2; Valkjärvi 1826-6-11, 1827-11-18.
20 Pettersson 1989a, 245–246.
21 Andersson & Kindström 1946–1959, 135, 158–159, 163–164; Pettersson 1989a, 251. At about the same time, Vor Frelsers Kirke for the settlement of Christianshavn was being built in Copenhagen. This church was designed on a double cross-plan by the master-builder general of King Kristian V of Denmark. Hamberg 1955, 169 ff.
22 Pettersson 1989b, 295–298; Pettersson 1960, 148–154; Nordenstreng 1908–1909, 228–230, 532–534, 536; National Records Office, Map collections, *Atlas Vyborgskoy Gubernii*, Pl. 16 (122/2D 17/11).
23 Pettersson 1989b, 299–300; Manninen 1953, 279; Knapas, Marja Terttu, 2013, 8–9.
24 Cf. Pettersson 1989b, 300.
25 National Records Office (Helsinki), Digital archive, Records of Mikkeli parish, Minutes of parish meeting 1784-6-1, copy of inspection report of Johan Robsahm (1726–1809), manager of Koskenkylä (Sw. Forsby) ironworks. Viljo 2014, note 21.
26 National Records Office, Mikkeli provincial archive, Records of Mikkeli parish, undated sketches of Mikkeli church, probably from the 1780s, by land surveyor Johan Heinricius, (III.J.14–15). Cf. Wirilander 1982, 307–308.
27 National Records Office, Digital archive, Records of Mikkeli parish, Minutes of parish meeting 1784-6-1.
28 Rinno 2014, 73–76; Klemetti 1927, p. 241, fig. 470 (exterior of Valkeala Church), p. 243, fig. 473 (exterior of Sortavala Church), p. 245, fig. 480 (exterior of Uusikirkko church); Viljo 2014, figs. 3, 6, 8, 11 (interiors of Valkeala and Kivennapa churches). The church of Sortavala, now in Russia, was overhauled in Gothic revival style in the latter part of the 19th century and converted into a library in the Soviet Union.
29 Anton Wilhelm Arppe (1789–1862) of the Intendant's Office had been employed at the Superintendent's Office in Stockholm. Klemetti 1936, 9–10. Territorial losses lessened the importance of the Fortifications Office of the Swedish army. Officers of the fortification were often engaged in civilian building projects and could shift from the military to *architecture civile*. Some found employment in the Superintendent's Office and may have brought with them traditions from the Fortifications Office. One such tradition could have been the double cross-church, which from its earliest ap-

pearance in Sweden had been linked to town planning, often the planning of fortified towns. Cf. Pettersson 1989a, 244–245, 251.

30 Peter Sjömar remarks that rules and models for church buildings have always originated outside the sphere of the northern log-building tradition, but erecting them has always depended on local craftsmanship. Sjömar 2000, 125–126.

31 This information, as well as other procedures in log building have been discussed with Timo Sopanen, a carpenter who specializes in log construction and who has been trained in this tradition by his father. Interview with Timo Sopanen 2018-8-30.

32 Philibert De l'Orme recommends this procedure for marking out a grid on a building site. De l'Orme 1648/1981, 32–34. The construction of grids and their application is prominent also in Serlio's work. *Sebastiano Serlio on Architecture*, 1996, 19, 70–73.

33 National Records Office, Digital archive, Records of Mikkeli parish, Minutes of church council meetings 1815-10-12 §3, 1816-5-? §5.

34 Cf. Sjömar 2000, 138–142.

35 Timo Sopanen uses a 12-knot rope for checking details. He does not use it on a large scale, but asked if his father (born 1917) or anybody else he might know of did or does, he vaguely recalled the number series 60–80–100, but could connect it to no particular case or circumstance. Information by Timo Sopanen 2020-8-26. The series suggests a one metre measuring tape folded into a prime Pythagorean triangle. Moosbrugger-Leu (2000/2013, 5–7) demonstrates the possible uses of this versatile implement as well as those of other knot-ropes specially made for certain ratios, such as the one called the golden ratio.

36 National Records Office, Digital archive, Records of Rautu parish, Minutes of parish meeting 1824-1-25 §2.

37 In the church of Puumala the master-builder performed this risky operation on two occasions. The capitals of the pillars that concealed the wedges are joined together from pieces that can be picked apart when the wedges are removed. Viljo 2015, 51–52, fig. 28. See also National Records Office, Digital archive, Records of Mikkeli parish, Minutes of parish meeting 1817-8-24 §1 and Records of Rautu parish, Minutes of parish meeting 1830-8-1.

38 Wittkower 1965, 7–8, 158–161; see for instance Frankl 1960, 51, 66–67.

39 *Francesco di Giorgio Martini*; De l'Orme 1648/1981; *Sebastiano Serlio on Architecture*, 1996. De l'Orme's year of birth, see www.en.wikipedia.org, Philibert de L'Orme.

40 Maltese 1967, xvi–xvii.

41 Merrill 2013, 1–3, 6–11.

42 Merrill 2020, 37–39, 79–80.

43 Bekaert 1981, viii; www.en.wikipedia.org, Philibert de L'Orme; www.fr.wikipedia.org, Philibert Delorme.

44 *Francesco di Giorgio Martini*, 399–401, Pl. 233; De l'Orme 1648/1981, 235–236.

45 *Francesco di Giorgio Martini*, 403, Pl. 236.

46 Börje Magnusson mentions that Erik Dahlberg, the probable designer of the Admiralty Church in Karlskrona, owned a copy of Serlio's work, printed in Basel 1609. Magnusson 1986, 227.

47 *Sebastiano Serlio on Architecture*, 68–69.

48 *Sebastiano Serlio on Architecture*, 28, 70.

49 Cf. for instance Frankl 1960, 35 ff.

50 *Francesco di Giorgio Martini*, 345, Pl. 194, 349, Pl. 203 (upper diagram).

51 *Francesco di Giorgio Martini*, 349, Pl. 203 (lower diagram), Pl. 204.

52 When the basic square is divided into four equal smaller squares and the sides of the latter are bisected, a prime Pythagorean triangle can be constructed by drawing its hypotenuse from a corner of the basic square to either of the bisection points on the outer sides of the opposite small square leaving three units for the shorter side of the triangle. There is, however, no indication in our material that the Rahikkala master-builders used this proportionate measurement.

53 *Sebastiano Serlio on Architecture*, 19, 33.

54 *Francesco di Giorgio Martini*, 401, Pl. 234 (diagram on the right-hand side); *Sebastiano Serlio on Architecture*, 9; De l'Orme 1648/1981, 112–113. Francesco is using this operation not as an enlargement of a two-dimensional figure on a plane, but to find a module to be used in establishing a height value proportional to the width of a church. Philibert is applying it to the proportionate diminishing of a vault towards its apex.

55 Total amounts of 3-inch rope requisitioned for the following churches: Valkeala 569.6 metres (8 lengths of 40 fathoms), Kangasniemi 302.6 metres (2 lengths of 25 fathoms and 4 lengths of 30 fathoms and Parikkala 106.8 metres (60 fathoms). National Records Office, Digital archive, Records of Valkeala parish, Minutes of parish meeting 9.9.1795; Records of Kangasniemi parish, Minutes of parish meeting 12.12.1811; Economy Department of the Senate, 4/461 1812.

56 "…die Selbstentfaltung einer inneren Ordnung", Moosbrugger-Leu 2000/2013, 3–5, 7ff.

57 Moosbrugger-Leu 2000/2013, 10–11, figs 17, 21.

58 Moosbrugger-Leu 2000/2013, 17.

59 Google Search, "Re: sala dos reis alcobaça".

60 The master-builder was the same August Sorsa who built the double cross-church for Mikkeli parish the following year. National Records Office, Digital archive, Records of Sulkava parish, Minutes of parish meetings 1752-7-7 and 1753-May. There was enough material for three cross arms 12 ells (about 7.13 m) in length and for a chancel arm of 14 ells (about 8.32 m).

61 Merja Härö has carried out the structural geometry analyses.
62 The floor plan of Lappee church in the *Atlas* is faulty. National Records Office, Map collections, 122/2D 17/11. There is now no way to detect possible inaccuracies that may have arisen in transferring the drawing to the printing plate; as a primarily cartographic work, the *Atlas* is not necessarily focused on accuracy in the presentation of buildings.
63 Andersson and Kindström 1946–1959, 146–147, figs. 99–100.
64 National Records Office, Provincial Archive of Mikkeli, Records of Mikkeli country parish, III: J a 14–15.
65 National Board of Antiquities, Picture and drawing collections, 416.1–3.
66 National Board of Antiquities, Picture and drawing collections, HK 10000_767. Photographs of measured drawings.
67 Maunu 1912, 4, 8–9; Pettersson 1989b, 303.
68 National Board of Antiquities, Picture and drawing collections, Kivennapa church 1.5–1.6/792–793, negatives 203216–203217.
69 National Board of Antiquities, Picture and drawing collections, MV 580_1_10.
70 Puumala congregation, Records, Measurement of floor plan by master-builder F. E. Ojala, 1927 (III Ja:2), west-east section and lantern tower measurements by master-builder Kalevi Pastila, 1962. Among the material that Merja Härö has used for her analysis are photos of constructions of the church taken by Pekka Huttunen, sexton of the congregation of Puumala. We give our warmest thanks to Mr. Huttunen for also assisting Merja Härö in recording the constructions of the church for this study. We are also very grateful to Helena Castrén, vicar of Puumala congregation (until 2021), for her generous and understanding support of our research.
71 National Records Office, Digital archive, Drawings of the National Board of Building (RakH II), Iaa.187:1
72 See p. 114, fig. 16.
73 See for instance Frankl 1960, 50–51, 149–150, figs. 12, 19.

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