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# The Assembly of Roof Structures in the Mediaeval Churches of Finland: The Case of Karjaa Church (1470)

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## Abstract

The last still-standing examples of Finland's mediaeval timber constructions are the roof structures of some 20 stone churches. Karjaa Church — built in 1470 — boasts one of Finland's best-preserved examples of such structures; it is vital in the country's wooden cultural heritage. We present our interpretation of the building process of the Karjaa Church nave's roof structure. Given the lack of written records on church building processes from the Finnish Middle Ages, we have employed a building archaeological approach, also integrating observations from Finland's other mediaeval roof structures. This is complemented by a secondary-sources review to mirror the more general knowledge on Finnish mediaeval society and estimations of the local population, animals, labour tasks and workdays to understand the financing and labour provided by the local community. The fieldwork (2020/2024) involved systematically documenting the nave's roof trusses, focusing on the doweled joints and the rafter feet, as well as the deliberate and incidental marks of craftsmanship, e.g. numberings and drill marks. Our findings indicate the trusses were manufactured on the ground

in stacks before being dismantled and reassembled at wall-plate level. Evidence suggests that the rafter feet remained intact during this process, whilst other elements were reassembled after transport. Observations of the drill marks and notches reveal construction-technique variations, likely attributable to individual craftsmen's methods. By analysing structural details and contextualising them within their historical and societal framework, this research enhances understanding of Finland's mediaeval roof construction, providing foundations for future studies on the material — labour — craftsmanship interplay in historical architecture.

### Keywords

assembly process – Finnish churches – Middle Ages – roof trusses – wooden cultural heritage

## 1 Introduction

Mediaeval timber constructions in Finnish churches have gained attention in new research projects in the 2020s (e.g. Savolainen *et al.* 2023a). Since all of Finland's mediaeval wooden buildings have been dismantled or destroyed in fires across centuries, the only standing examples of mediaeval timber constructions are the roofs of mediaeval stone churches, which constitute an invaluable part of Finland's wooden cultural heritage. One of the best-preserved examples is the roof structure of Karjaa's stone church, built in 1470.

Wooden churches were built in Finland (or, more accurately, in the Diocese of Turku) throughout the Middle Ages.<sup>1</sup> Stone-church construction in mainland Finland only started in the early 15th century. The substitution of the wooden churches with stone churches was obviously led at the episcopal level, and the construction was based on a general church model for the Diocese of Turku with only small local differences and influences of the master builders (Savolainen *et al.* 2020a: p. 26; Hiekkänen 1994, 2006: pp. 20–21). The labour force was local, except for the master builders and the master brickmakers

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1 The medieval period began in Southwest Finland in the mid-12th century and expanded gradually to other territories in tandem with the spread of Swedish rule and Catholic Christianity, reaching Eastern Finland c. 1300. In the Middle Ages, Finland — or more correctly the eastern region of the kingdom of Sweden — formed the Diocese of Turku, which was subordinate to the Archdiocese of Uppsala. The period lasted until the mid-16th century (Haggrén 2015: pp. 373–379).

(Aalto 2018: p. 20), and comprised farmers from the parish, who paid their tax contribution to the Church in the form of day labour and the provision of material (Hiekkanen 2003: p. 11). Current research indicates that 104 stone church projects were started in the Diocese of Turku in the Middle Ages (Hiekkanen 2020: p. 26). In approximately a dozen of those churches, the mediaeval roof structure has been preserved in its entirety.

In Finland, hardly any written sources regarding the building of mediaeval churches, such as documents on construction decisions or drawings, have been preserved. An exception is the accounting records of the Kalliala parish, which show the masons' wages that were paid for the construction of St Olaf's Church in Tyrvää at the beginning of the 16th century (Orrman 1997). Thus, the only way of acquiring further information is through a thorough examination of the structures themselves, including the deliberate or incidental marks of craftsmanship left upon them.

In this article, we present the results of building archaeological fieldwork conducted in Karjaa Church in 2020 and 2024. Our aim was to unveil the assembly process of the roof structure based on our surveys and observations. To achieve this, we searched the structures for any markings and traces left by the builders and combined them with knowledge gained from other Finnish churches, as well as from literature. Additionally, secondary literature was consulted to contextualise the construction into its sociological context to understand what quantities of labour, time and finances the construction required from the local community of the Karjaa parish around the 1460s.

In Finland, interest in mediaeval churches emerged in the late 19th century but, unlike in Scandinavia, early Finnish research largely overlooked roof trusses. In the 1990s, Markus Hiekkanen (1995) made a significant contribution by surveying the potentially preserved roof structures in Finland's mediaeval stone churches. His inventory served as a foundation for further research into Finnish roof structures that started in the early 21st century. In recent years, studies in Finland have considered, for example, the inscriptions and structural innovations of mediaeval roof structures, but the construction process itself has received relatively little attention (Blomqvist 2004; Huttunen 2007, 2008). Contrastingly, in Sweden, the construction of roof structures has been widely investigated (Hallgren & Gullbrandsson 2020; Melin 2020; Gullbrandsson 2023a,b). However, the structures studied there differ in many ways from those in Finland; for instance, they are, in many cases, older, relatively small and often include tie beams or ridge purlins (Gullbrandsson & Hallgren 2021; Gullbrandsson *et al.* 2021: pp. 91–97).

This article is structured as follows: we first give a brief overview of Karjaa Church and the fieldwork carried out in its attic, after which we present, in

detail, our observations and documentation regarding the roof structure, followed by an interpretation of the assembly sequence and the reasoning behind it. Subsequently, the construction project and its required labour will be described from a social perspective. Finally, we conclude with remarks and reflections on the construction process and its organisation.

## 2 Case: Karjaa Church

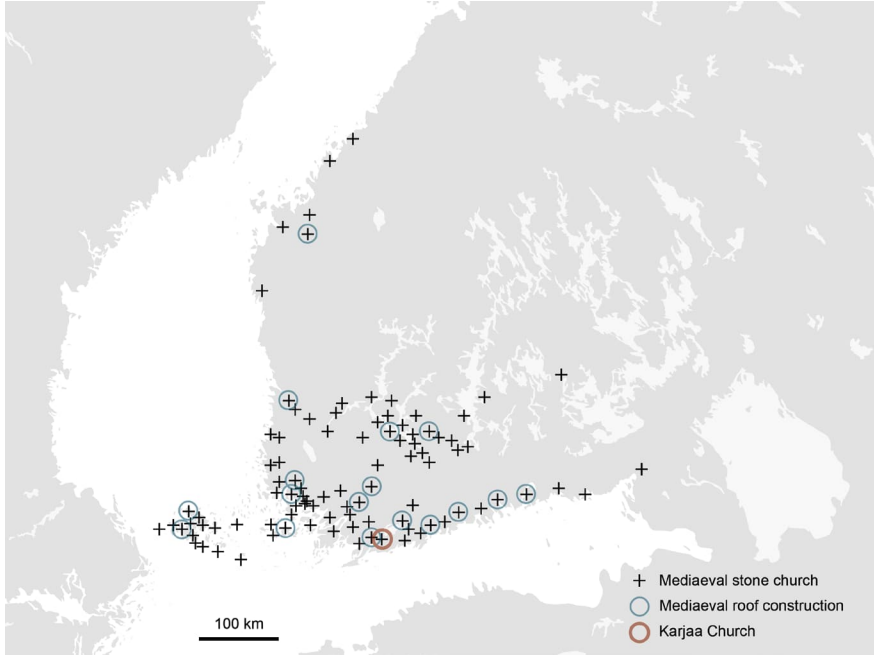
As there are almost no written sources left, the Middle Ages in Finland is, in essence, a prehistoric period when it comes to construction. No documents have survived that could shed light on the building process of the roof of Karjaa Church. To gain information on the subject, we need to combine different methods, such as building archaeology and crafts research, as well as circumstantial evidence, such as historic records on church building in other Nordic countries. Observations made in various mediaeval churches in Finland can also be compared and combined to gain an overall understanding of the local building practices.

We first present the church under scrutiny, then shortly describe the fieldwork and surveys performed in the church roof structures and, finally, we go through the observations of the structures, along with their limitations.

### 2.1 *An Overview of Karjaa Church*

Karjaa Church is located in the Uusimaa region of southern Finland. It is one of approximately 20 mediaeval churches in Finland which have the original roof structure even partially preserved (Fig. 1). The walls and gables of Karjaa Church are mainly built of natural stone, whereas the vaults and the exterior decorations on the gables are made of bricks (Fig. 2). The nave of Karjaa Church was finished in 1470. The exact dating, which is very rare amongst the mediaeval buildings of Finland, is based on a text that was written in fresh plaster by the west window (Fig. 2). Before the stone church, a timber church stood in the same location (Hiekkanen 2007: p. 437).

Karjaa Church closely resembles other Finnish mediaeval churches built between the 1410s and 1550s. The nave has been laid out in an east–west direction with the altar in the east (Fig. 3). The chancel is equal in height and width to the nave and was originally separated from it with a wooden partition which no longer exists. The sacristy is in a separate wing of the building, located on the north side of the nave, close to the chancel, whereas the porch is on the south side, closer to the west end of the nave. The exterior dimensions of Karjaa Church's nave are approximately 33 metres by 17 metres. It is somewhat



**FIGURE 1** A map of the mediaeval stone churches in Finland. Entirely or partially preserved roof constructions are highlighted with a blue circle and Karjaa Church is highlighted with a red circle. Kemimmaa Old Church in Northern Finland is excluded from the map

MAP BY LAURA LAINE (2024)



**FIGURE 2** An exterior view of Karjaa Church (left). Inscription: 'a[nn]o d[omi]ni : m : cd : lxx : ???', painted and carved into the plaster by the west window (right)

PHOTO ON THE LEFT BY LAURA LAINE (2024), PHOTO ON THE RIGHT BY FRANZISKA DAHLHEIMER (2024)

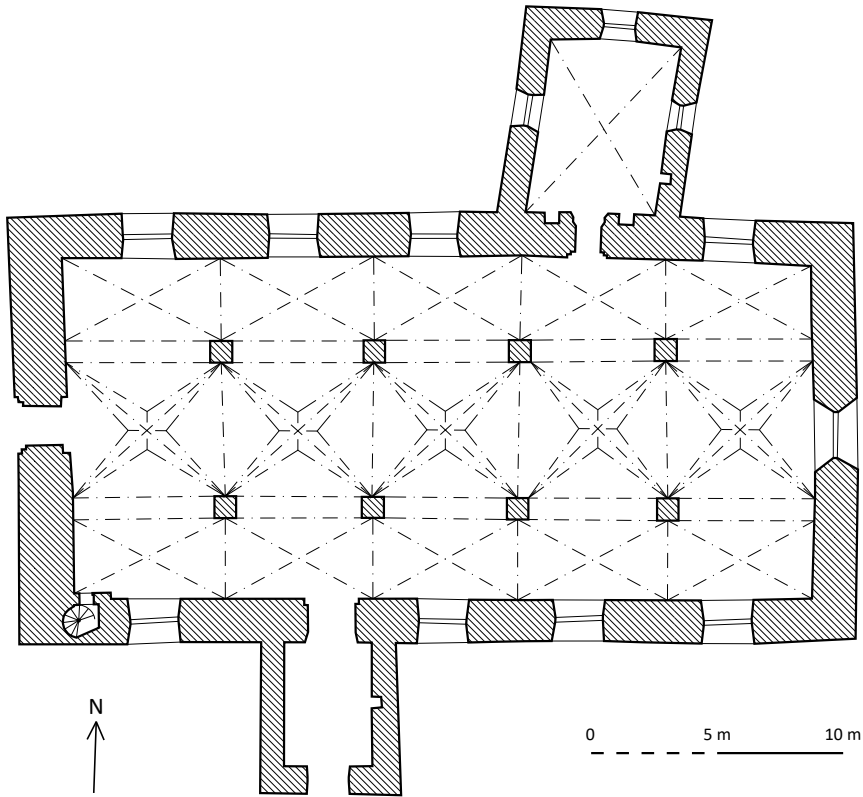


FIGURE 3 The layout of Karjaa Church with the porch on the south side of the nave and the sacristy on the north

DRAWING BY LAURA LAINE (2024), PARTIALLY BASED ON THE MEASUREMENT DRAWING BY ERKKI KARTANO (1936)

larger than the average mediaeval church in mainland Finland but not uncommonly big (Hiekkanen 1994: p. 31).

In his doctoral dissertation, Markus Hiekkanen (1994: p. 218) states that the nave and the sacristy of Karjaa Church were built around the same time based on many common features between them. The sacristy must have preceded the nave somewhat since its original roofing has left a clear mark on the outer wall of the nave. However, according to Hiekkanen (1994), the temporal difference may have been as short as one year. The porch, in contrast, differs from the rest of the building and may not originate from the Middle Ages at all (*ibid.*: p. 219). Observations in the porch attic support the interpretation that the porch was a later addition (Huttunen & Mattila 2010: p. 23). The entire roof structure of the nave is almost intact, whereas the structures of the sacristy

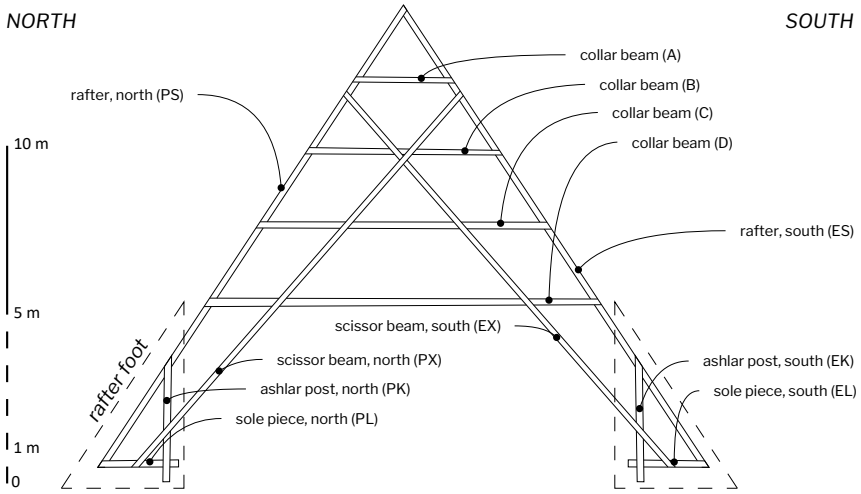


FIGURE 4 The roof trusses of Karjaa Church comprise rafters, rafter feet, scissors and four collar beams. The letter codes are largely based on the Finnish language names of the structural members

DRAWING BY LAURA LAINE (2024)

and porch have been replaced. The only dendrochronological dating of Karjaa Church was carried out in 2020 (Aakala 2020: pp. 2–3), but it did not reveal the age of the roof structure. The nave roof structure is, however, connected to the stone gables in such a way that it is not conceivable that it would ever have been replaced. Therefore, the aforementioned year, 1470, is also presumably the dating of the roof structure.

The roof trusses in the nave of Karjaa Church represent a type specifically designed to function without tie beams, adapted to accommodate masonry vaults that rise above the wall-plate level. This so-called Gothic roof truss type prevailed in Finland from the mid-15th century onwards (Fig. 4). The roof trusses are likely to be mostly made of Scots pine (*Pinus sylvestris*). The roof structure of the nave comprises 29 trusses which are spaced approximately 1.2 metres apart. Joints in the roof trusses are simple doweled lap joints, without notches or dovetail. The dowels are made of coniferous timber, whilst the roof trusses are connected by longitudinal beams and oblique ties. Sturdy planks serve as the underlay of the shingle roof. Simultaneously, the planks bind the trusses together to form a structural whole. At both ends of the nave, the outermost roof trusses are part of the church's gable facades. The second trusses from both ends stand at the inner edge of the end walls and are visible in the attic.

## 2.2 *Karjaa Church Surveys*

Since at least the 1990s (Hiekkanen 1995), it has been known that the original mediaeval roof structure of Karjaa Church has been preserved, which led Marko Huttunen to make a short research visit in 2009 (Huttunen & Mattila 2010). In the spring of 2020, more extensive field studies were conducted in the attic of Karjaa Church for six days as part of the project 'Historic Timber Structures and Architectural Innovations in Late Medieval Northern Europe'.<sup>2</sup> The multi-disciplinary project group comprised specialists in archaeology, history, architecture, conservation, osteology, dendrochronology and engineering. During the field studies, nine researchers studied the roof structures through systematically surveying them by sight. Trusses and their structural parts were documented as archaeological units and field observations were recorded on unit sheets. Additionally, some total station measurements and photogrammetric measurements of the structure were realised, but they proved to be irrelevant compared to the on-site observations of the structures, where even small and weak traces in the structures could be observed.

For the purpose of documentation, the trusses were numbered, starting from the east, and the structural members of the trusses were given symbols consisting of letters (Fig. 4). In this way, each part and joint of the roof structure could be assigned a unique code consisting of letters and numbers. Hundreds of these codes were printed on pieces of cardboard and pinned to the structures, which was crucial for the accuracy of documentation. As the researchers conducted a comprehensive photographic documentation, the printed structural codes were included in the photographs, which was known to be vital for later identifying the contents of the pictures.

The goal of the 2020 field study was to obtain an overall understanding of the roof structure of Karjaa Church. Researchers strived to grasp how the roof had been built and its parts manufactured. They also remained critical of the originality of the structure and tried to establish whether later additions or alterations had been made. Possible signs of reused timber parts were also considered of interest. Throughout all the investigations, particular attention was paid to any markings, intentional or not, that might shed light on the building process. A research group of several people, including research assistants, and the relatively long time reserved for the documentation presented many advantages. For example, the first field day could be used for illuminating the

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2 See <https://www.aalto.fi/en/research-art/historic-timber-structures-and-architectural-innovations-in-late-medieval-northern-europe>, funded by Kone Foundation and the Finnish Cultural Foundation.

attic, setting up the coding system and removing much of the dust that had gathered on the surfaces.

In 2024 the authors continued field studies in Karjaa Church on three separate days. This time, the focus was strictly on the manufacture and assembly of the trusses and the process of raising the roof structure. We systematically collected data on specific forms printed out beforehand. After each field day we processed the collected data and planned the following stages of fieldwork accordingly. In this way we were able to develop our hypothesis and specifically look for evidence that would either corroborate or contradict it.

Based on the earlier 2020 field study and wider experience of other mediæval churches in Finland, we presumed that most informative observations would be found in the joints of the trusses. We especially looked for and documented incidental drill marks that form on the joints during the manufacture of the trusses. We also considered the direction, type and length of dowels important.

The lighting conditions were far inferior to those in 2020, and dust had again settled on all surfaces. This made the fieldwork significantly slower and more dangerous. Due to safety issues, we were forced to limit our studies to parts of the trusses that we could safely reach. This meant that most of our efforts went into investigating the rafter feet, as well as the joints closest to the ridge of the roof. Other areas of the attic would require a safety harness which we did not have at our disposal.

### 2.3 *Karjaa Church: Observations*

In this chapter, we present our findings from Karjaa Church, starting from the timbers that are used in the roof structure. Documentation of numberings, reused timbers and the incidental drill marks in doweled joints is exhibited in table format. We also show our observations regarding the scissor beams and the diagonal wind braces. In the following chapter, we combine these findings and give our interpretation of the assembly sequence of the roof structure of Karjaa Church.

#### 2.3.1 Timbers

Typical local wooden resources, such as Scots pine and Norway spruce, were used for the construction of the roof structure (Savolainen *et al.* 2023a: p. 70). The roof trusses were mostly made of whole timbers with the pith at the centre. However, some of the timbers used for the scissor beams were cleaved along the middle. Cleaved timber was also employed for the roof boards and wind braces. The largest dimensions can be found in the wall plates and the rafter feet, and the diameter of the timbers reduces towards the top of the roof

structure. The weight of Karjaa Church's 29 trusses is estimated to be more than 10 000 kg per truss (including collar beams and scissor beams), as this was the estimated weight of the trusses in two similar Finnish mediaeval stone churches (Dalheimer & Aakala 2024: p. 46).

Alongside the timbers produced for this construction project, reused timbers were also found in the roof structure of Karjaa Church at several locations. The said timbers were identified both through notches, which are the remains of previous joints, and their difference in size. Reused timbers were especially placed as collar beams in the western part of the structure (Table 1), and as

TABLE 1 The numbers and signs of reuse found on various parts of the roof trusses

Roof trusses from east to west	Numbered members*	Numbering	Members with signs of reuse*
1			
2			
3	PL, PX, EX, D	I (1)	
4	PL, PX, EX, D	II (2)	
5	PX, EX, D	III (3)	
6	PL, PX, EX, D	IIII (4)	
7	PL, PX, EX, D	IIIII (5)	
8	PX, EX, D	IIIII (6)	
9	PX, EX, D	IIIIII (7)	
10	PL, PX, EX, D	IIIIIII (8)	
11			
12			
13	PL, PX, EX	I (1)	
14	PX, EX	II (2)	
15	PL, PX, EX	III (3)	
16	PL, PX, EX	IIII (4)	
17	PL, PX, EX	IIIII (5)	
18			B, C
19			B
20			B, C
21	PL	IIIIII (7)	B
22			B
23			B, C
24			C
25			

TABLE 1 The numbers and signs of reuse (*cont.*)

Roof trusses from east to west	Numbered members*	Numbering	Members with signs of reuse*
26	B	IIIIII (7)	B, C
27			B
28			
29			

\* The codes for all roof truss members are shown in Figure 4.

oblique ties connected to the rafter feet. One of the oblique tie beams was dendrochronologically dated (Aakala 2020: pp. 2–3). The exact year of felling could not be determined, since too much of the outer surface had been removed when the timbers were shaped with an axe. In terms of current research, it is not known whether the reused timbers originated from the wooden predecessor church or were leftovers of the construction process described in this article.

There are no signs of sawing in the roof structure of Karjaa Church, which corresponds to all known cases of mediaeval roof structures in Finland. Instead, the timbers were manufactured through the use of an axe, as evidenced by the hewing marks on the timber's surface (Fig. 5). In a few cases, mainly found in the scissor beams towards the west gable, the timber seemed to have been cleaved with an axe and wedges, and then additionally hewn in some places (Fig. 5).

### 2.3.2 Numberings

The roof structure of Karjaa Church is one of five mediaeval church roof structures in Finland where a numbering system of some kind has been found (Savolainen *et al.* 2023b). The numberings in Karjaa consist of small dashes measuring approximately 5 centimetres in length (Fig. 6). The markings are all made with a similar tool, probably a small axe with a narrow, thin blade. This axe would have differed from that used for hewing the timbers. Instead, it may have been the same tool employed to create starting notches for drilling the dowel holes. The numberings on the timbers had already been recorded in 2020, but, nevertheless, in 2024 we were able to find some new ones. It is also possible that some numbers still remain undiscovered. Clearly, some markings on sole pieces (PL5, PL8, PL9, PL14) had been destroyed when the sole pieces were hewn shorter in order to make room for vaults.



FIGURE 5 Hewing marks on an ashlar post indicate manufacturing by axe (left). The cleaved surface of a scissor beam, in some places, additionally hewn (right)  
PHOTOS BY FRANZISKA DALHEIMER (2024)



FIGURE 6 Numberings on a sole piece (left) and on a scissor beam (right). Both photographs are taken from below  
PHOTO ON THE LEFT BY LAURA LAINE (2024), PHOTO ON THE RIGHT BY MIINA TOLONEN (2020)

Around half of the trusses in Karjaa Church are numbered, but only numbers between one and eight have been found (Table 1). In the eastern and middle part of the attic, the numberings are more coherent, but some trusses lack numbering. From Truss 18 onwards, only two numbered timbers have been found (Fig. 7). The locations of the numbers in question appear to be random,

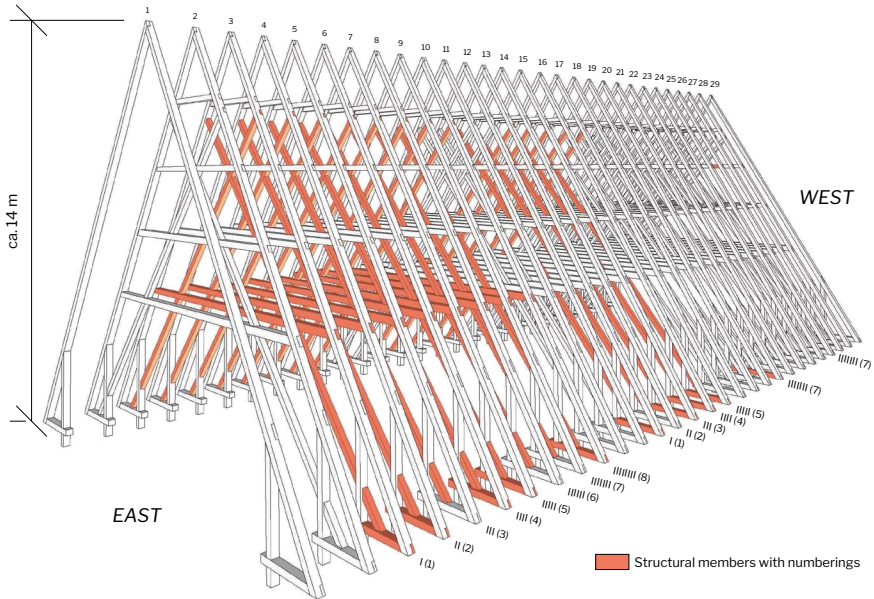


FIGURE 7 The location of the numbered roof truss members in the roof structure of the Karjaa Church nave  
DRAWING BY LAURA LAINE (2024)

and one is even on a member with apparent signs of reuse. All the numberings are located on the lower side of the members, some in the middle and some on the western edge (Fig. 6). On the reused collar beam (B26) the marking is, however, on the eastern edge.

### 2.3.3 Dowels and Dowel Holes

All the joints of the Karjaa Church roof trusses are doweled lap joints. Iron nails have only been used to attach wind braces, roof boards and shingles. This corresponds to almost all preserved mediaeval roof structures in Finland. In Karjaa Church, dowels are not merely found in the joints, but are also scattered across other parts of the roof trusses. Some have served as ladders during the construction, but, for the most part, the purpose of these abundant dowels is so far unknown. In this study, we only consider the doweled joints. However, the roof structure of Karjaa Church contains more than 700 doweled joints, and, therefore, comprehensively documenting individual dowels was not feasible. That being said, the dowels generally appear to be made of pine (*Pinus sylvestris*) and to have been first cleaved and then hewn with an axe.

All the dowels in the trusses have been inserted from the west side. The length of the dowels varies. In joints between rafters, sole pieces and ashlar



FIGURE 8 The different starting notches made before drilling the dowel holes: a square-shaped starting notch (left), a round-shaped starting notch with rather undefined edges (middle) and a triangle-shaped starting notch (right)  
PHOTOS BY FRANZISKA DALHEIMER (2024)

posts, the dowels are short, but in joints between the scissor beams and other members in rafter feet, the dowels usually protrude a few centimetres on the back side of the joint. Higher up in the roof structure, the dowels are often considerably longer, protruding as much as 10 or even 20 centimetres. No clear difference in dowel lengths between scissor beam joints and collar beam joints could be detected.

The holes for dowels have also been drilled from the west side. In most cases, there is a shallow notch that has likely been created to make drilling easier to start. These drilling notches have been made with a small axe, probably similar to the tool used for the numberings. The drilling notches vary in depth and in shape. They are rarely triangular and are mostly square shaped or have round, rather undefined edges (Fig. 8). The drilling notches and their shapes were documented in the rafter feet, but no clear patterns were observed. There are almost twice the number of square-shaped notches on the south side compared to the north, whilst both of the triangular notches are on the north side. However, it does not appear that any of these techniques were used for specific joints.

#### 2.3.4 Drill Marks

In almost all of Finland's mediaeval church roof structures there are incidental drill marks that have been formed during the original building process when the trusses were manufactured on top of one another, with the underlying truss being used as a template for the next one. When a hole was drilled for a doweled joint and the drill penetrated the timbers, it often left a mark on the underlying truss. On the one hand, the presence of drill marks indicates that the aforementioned procedure was utilised. On the other hand, the shapes of the drill marks relay information on the types of drills that were used. In Karjaa



FIGURE 9 Traces of three different types of drill. The trace of a comparatively larger diameter drill (left), the drill mark of a spoon-shaped drill (middle) and the drill mark of a drill with an edge (right)

PHOTOS BY FRANZISKA DALHEIMER (2024)

Church, incidental drill marks of different shapes were found throughout the roof structure, examples of which are shown in Figure 9. The shapes of the drill marks were documented in the rafter feet, but they formed no discernible pattern. On the south side, most marks appeared to have been made with a spoon drill, but other drill types appear to have also been used in places. On the north side, different types of drills have been used more evenly.

The drill marks are most interesting when the drill has happened to fall partly on the dowel in the underlying truss. In those cases, the drill has left a mark on the dowel as well as the truss. If the drill mark can no longer be seen on the dowel, it indicates that the dowel has been added or changed later in the construction process. Examples of different cases and the codes used for them are presented in Figure 10.

In our fieldwork in Karjaa Church we were only able to systematically document drill marks in the rafter feet (Tables 2 and 3). A drill mark has fallen on a dowel in 40 of the joints, although in a few cases interpretation was uncertain. Nevertheless, a rather clear pattern can be observed. Joints between rafters, sole pieces and ashlar posts present type-b drill marks, whereas type-a marks prevail in other joints. Admittedly, there are a handful of exceptions to this rule and sometimes interpretation of the marks proved to be challenging. A systematic inventory above the rafter feet was not feasible due to safety issues, but still sporadic findings of type-a drill marks were uncovered in collar beam joints, whereas no type-b drill marks were observed.

### 2.3.5 Scissor Beams

Scissor beams (X) are the second largest structural members of the roof trusses after the rafters. The function of scissor beams is to stabilise the trusses, especially in windy conditions. In Karjaa Church, the scissor beams are attached,

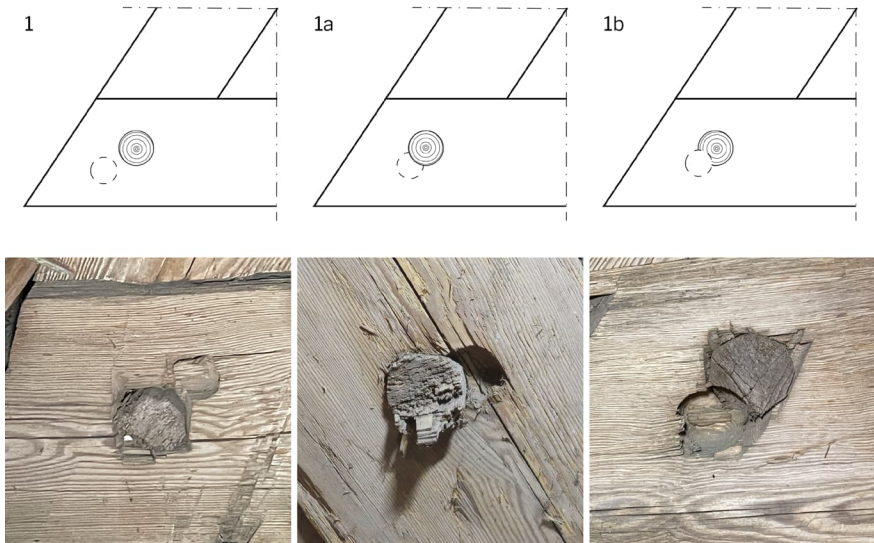


FIGURE 10 The different ways in which a drill mark can coincide with a dowel, as found in the rafter feet, and the codes that are used in the inventory. The number in the code indicates the number of drill marks — in these cases, one. The drill marks do not coincide with dowels (left). Type-a drill mark where the dowel is intact, which means that the dowel has been added or changed after the drill mark has been made (middle). Type-b drill mark where the drill has left a mark on the dowel, i.e. the dowel has been in place already before the mark was formed (right)  
 PHOTOS BY LAURA LAINE (2024)

TABLE 2 Documentation of the incidental drill marks in the joints of the northern rafter feet and how those drill marks coincide with the dowels

Roof trusses from east to west	Joint PS – PL (rafter, sole piece)	Joint PS – PK (rafter, ashlar post)	Joint PK – PL (ashlar post, sole piece)	Joint PX – PL (scissor, sole piece)	Joint PX – PK (scissor, ashlar post)
1	*	*	*	*	*
2	1a		–	–	–
3	1b?	–	–	1	–
4	1	–	1b	–	–
5	1	1	1	–	1
6	1	1	–	1	–
7	1	–	1b	1	1
8	1	1	1	1	–

TABLE 2 Documentation of the incidental drill marks (*cont.*)

Roof trusses from east to west	Joint PS – PL (rafter, sole piece)	Joint PS – PK (rafter, ashlar post)	Joint PK – PL (ashlar post, sole piece)	Joint PX – PL (scissor, sole piece)	Joint PX – PK (scissor, ashlar post)
9	1	1	–	1	1
10	*	1	–	1	1
11	1	1	–	–	–
12	–	*	1	1	–
13	–	1	1	1	–
14	1	1	1b	1	1a
15	1	–	1	1	–
16	–	1	1	1	–
17	–	–	1b	–	–
18	–	1	1b	–	1a
19	–	1	–	1a	1a
20	–	1	–	–	–
21	1b ?	1b	–	1a	–
22	–	1	–	–	1a
23	1 ?	–	1 ?	–	–
24	–	1	–	–	–
25	–	1b	1b	–	–
26	–	1	–	–	–
27	*	2 ?	–	–	1
28	*	*	*	*	*
29	*	*	*	*	*

The codes for different types of drill marks are explained in Figure 10.

\* Some joints could not be inspected because those are embedded in the gables or otherwise obstructed.

with doveled lap joints, to the west-facing surfaces of rafters, collar beams, ashlar posts and sole pieces. As can be seen in Figure 4, the two scissor beams cross very close to Collar Beam B, creating an assembly of joints labelled xxv. In Karjaa Church, there are five different versions of this joint which are found in various trusses, as shown in Table 4. The incidental drill marks of these joints were not documented consistently, but they can be found (Fig. 11).

TABLE 3 Documentation of the incidental drill marks in the joints of the southern rafter feet and how those drill marks coincide with the dowels

Roof trusses from east to west	Joint ES – EL (rafter, sole piece)	Joint ES – EK (rafter, ashlar post)	Joint EK – EL (ashlar post, sole piece)	Joint EX – EL (scissor, sole piece)	Joint EX – EK (scissor, ashlar post)
1	*	*	*	*	*
2		1b			
3	1b	1b?	1b		
4	1b	1			
5	2			1a	
6	1			1	*
7	1	1/1b	1		
8					1
9	1			1a	1
10		1	1	1	
11	1?				
12			1	1	
13	1	1?		1?	1
14	1		1b	1	
15					1a
16		1	1a		1
17			1b		1
18		1?	1	*	1
19	1	1	1	1a	1
20	*	1b	*	1	1a
21	1	1a/1b	1b		
22		1b	1?		
23		1		1b	1
24			1a		
25		2	1a		1
26	1a	*	1b	1a	1
27					
28	*	*	*	*	*
29	*	*	*	*	*

The codes for different types of drill marks are explained in Figure 10.

\* Some joints could not be inspected because those are embedded in the gables or otherwise obstructed.

TABLE 4 Different types of joints between the scissor beams (PX and EX) and the second highest collar beam (B)

Roof trusses from east to west	XXB joint type	Key
1	*	
2	A	
3	A	
4	A	
5	A	
6	A	
7	A	
8	B	
9	C	
10	D	
11	D	
12	C	
13	C	
14	B	
15	B	
16	C	
17	C	
18	B	
19	C	
20	C	
21	C	
22	C	
23	B	
24	B	
25	B	
26	B	
27	E	
28	B	
29	*	

Different joint types are illustrated schematically from western side. Figure by Laura Laine (2024).

\* Trusses 1 and 29 are in the facades of the gables and do not have collar or scissor beams.



FIGURE 11 Different types of joints between scissor beams and the Collar Beam B. On the left it can be seen that there is an incidental drill mark which coincides with the dowel, but the dowel is intact  
PHOTO BY LAURA LAINE (2024)

Roof Trusses 1 and 29, located in the facades of the east and west gables, respectively, have neither scissor beams nor collar beams. However, the easternmost truss at least has notches for collar beams (but not for scissor beams).

#### 2.3.6 Wind Braces

The wind braces are made from cleaved timbers of varying dimensions which are attached to the inside of the rafters with iron nails. Their purpose is to join the trusses together and stiffen the structure. The roof boards also serve the same purpose, but, presumably, the wind braces had particular importance during the construction before the roof boards were installed.

The northern roof plane comprises five wind braces, whereas the south plane comprises seven (Fig. 12). The lengths of the braces vary between approximately 8 and 13 metres. The wind braces criss-cross diagonally so that each overlaps with at least one other. In all the crossings, the wind brace which is located farther west lies beneath the other brace. At both ends of the attic, the wind braces are embedded in the masonry of the gables.

#### 2.4 *Interpretation of the Assembly Sequence*

As mentioned in the introduction, there are no documents left from the Finnish Middle Ages describing the building process of a church roof. However, earlier research and historic records from the Kingdom of Sweden, of which Finland was part, point to trusses being prefabricated on the ground before the final assembly (Almevik & Melin 2022: p. 13). Surveys in various mediaeval churches in Finland have arrived at the same conclusion. Because of the large size of the roof trusses in the naves of Finland's mediaeval churches, lifting a roof truss to the wall-plate level as a whole would have been unfeasible. Instead, the trusses

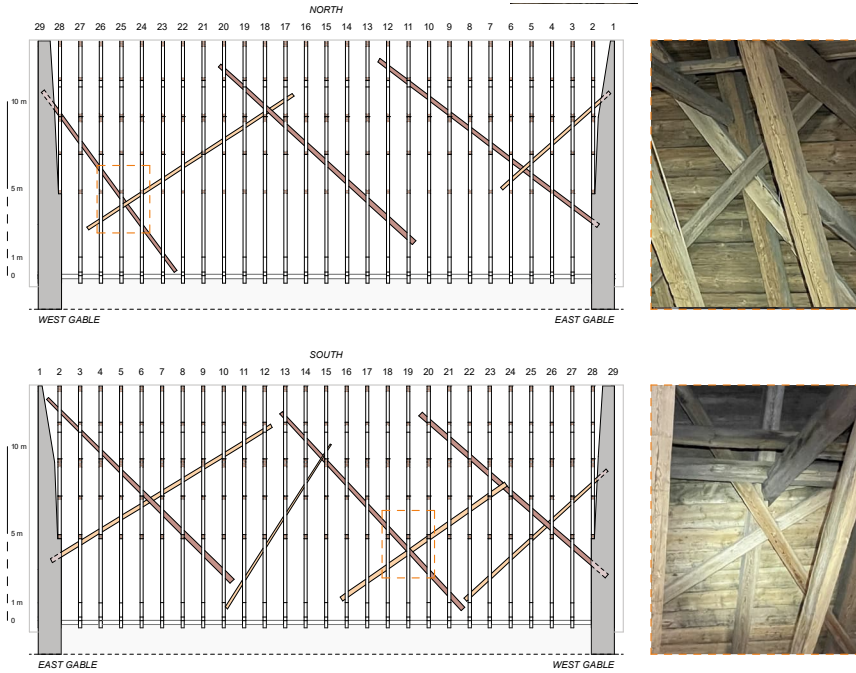


FIGURE 12 The location of the wind braces attached from the inside to the rafters on the north and south side of the nave. The widths of the braces are not to scale. The locations of photographs are marked with a dashed line  
ILLUSTRATIONS BY FRANZISKA DALHEIMER, PHOTOS BY LAURA LAINE (2024)

were dismantled, lifted piece by piece to some kind of scaffolding on top of the walls, and then reassembled there (Huttunen 2008: p. 49; Savolainen *et al.* 2020b: p. 59). Observations made in Karjaa Church are consistent with the aforementioned procedure.

The roof trusses of Karjaa Church have evidently been manufactured whilst lying flat, with the west-facing surface upwards, since all members of the trusses have been added from that side. Simply, the trusses have been assembled with an upper face, which has been typical of mediaeval roof trusses in Central Europe (Binding 1991: e.g. Fig. 101; Épaud 2011: p. 83) and in Sweden ever since the High Middle Ages (Gullbrandsson 2023a, 2023b), and of the preserved mediaeval roof trusses in mainland Finland. In Karjaa Church's trusses, all the incidental drill marks and the drilling notches are on the west-facing surface and all dowels are also inserted from the west. The order in which the structural members of the trusses were joined together is presented in Figure 13, and a Harris matrix of the assembly process is shown in Figure 14.

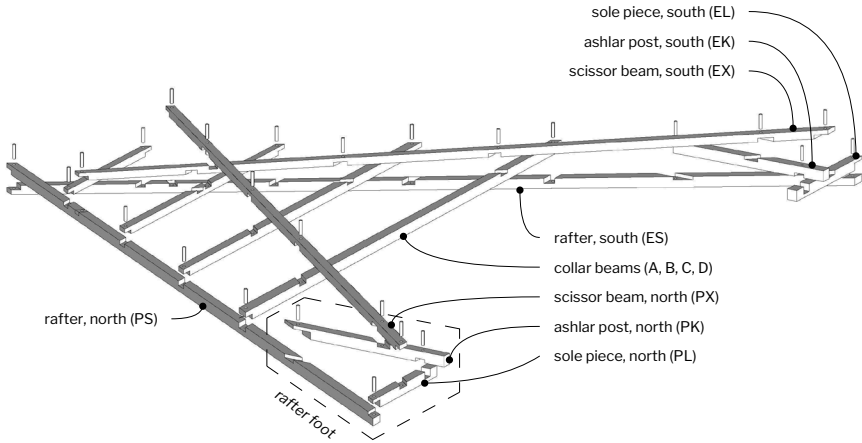


FIGURE 13 A schematic presentation of how the members in a Karjaa Church roof truss are joined together. Roof truss is laying with its west-facing side up. All the trusses in the Karjaa Church nave follow this structure, except those in the outer facades of the gables which lack collar beams as well as scissor beams  
DRAWING BY LAURA LAINE (2024)

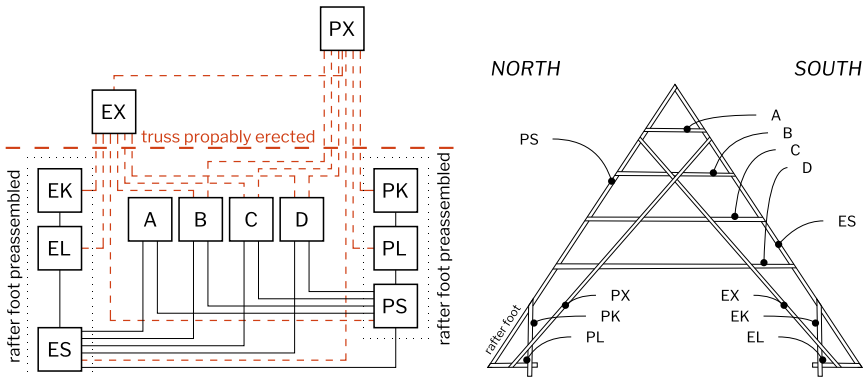


FIGURE 14 A Harris matrix of a Karjaa Church roof truss  
DRAWING BY LAURA LAINE (2024)

The formation of the incidental drill marks, as well as their variations, was described in the previous section. Joints usually have only one incidental drill mark (in rare cases, two), and drill marks are found all across the roof structure and in all the types of roof truss joints. These findings indicate that each truss was used as a template for the next one, which was manufactured on top of it, as opposed to any truss functioning as a template for several others, which would result in many drill marks in specific trusses. Two series of

numberings — 1 to 5 and 1 to 8 — imply that manufacturing might have been carried out in stacks of varying numbers of trusses. The placements of numberings on trusses, on the undersides of the sole pieces for example, are such that they could very easily have been created whilst the trusses were stacked.

The exact number of incidental drill marks and their relation to dowels was documented for the rafter feet, and the results were presented in the previous section (Tables 2 and 3). When the drill mark coincides with a dowel but the dowel is intact (type-a), we can infer that the joint in question has been taken apart after manufacture and later reassembled with a new dowel. Contrastingly, when the drill mark is also seen in the dowel (type-b), this indicates that the joint was assembled only once. The joints where scissor beams (X) connect with sole pieces (L) or ashlar posts (K) belong quite consistently to the former type of mark (type-a), whereas joints between rafters, sole pieces and ashlar posts mostly belong to the latter type of mark (type-b). These observations indicate that the rafter feet were kept intact after the initial assembly on the ground, whilst scissor beams were removed and lifted to the wall-plate level separately. The large size of the roof trusses makes it highly probable that the collar beams were also dismantled for transport and that the rafters were detached from each other. This assumption is supported by the presence of the type-a drill marks in the top parts of the trusses, although the survey was not comprehensive. Our conclusion, therefore, is that the trusses were manufactured in stacks on the ground, and once a stack had been completed, the next step in the process was to dismantle the trusses one by one into eight pieces (Fig. 15).

After the roof trusses were manufactured and disassembled, they had to be transported to wall-plate level — to some type of scaffolding. Ropes would have been required to hoist the heavy timbers up, but we were unable to find any preserved signs of them. The only lifting device found in the attic was a winch (Fig. 16) near the pitch of the roof, but its purpose is not known for certain. Once the pieces of a truss had been transported up, the truss would need to be reassembled. This could have been done in two different ways. On the one hand, the rafters with rafter feet already attached could have been separately lifted to an upright position and joined from the top, after which the collar beams and finally the scissor beams could be added. However, in this case the weight of the rafters would have caused them to sag,<sup>3</sup> and fitting the collar beams to their places would have become difficult. On the other hand, the truss could have been assembled in a horizontal position and then erected,

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3 Sagging like this can clearly be seen, for example, in Sipoo and Ulvila Churches where the outermost trusses have been erected without collar beams (Huttunen 2008: pp. 16, 53).

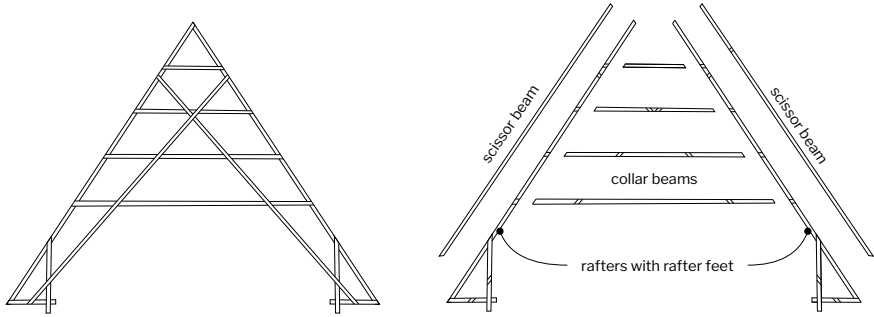


FIGURE 15 The schematic of a roof truss of Karjaa Church (left). After manufacturing the truss was dismantled into eight parts (right)  
DRAWING BY LAURA LAINE (2024)



FIGURE 16 The winch found in the attic of Karjaa Church  
PHOTO BY MIINA TOLONEN (2020)

which seems far more likely. Nevertheless, it is possible that a combination of the two aforementioned methods was used, and some members could have been added when the truss was already upright. The procedure might have even changed over the course of construction. If the trusses were assembled

horizontally, at least some collar beams would have been necessary to stabilise the rafters during lifting. The scissor beams, too, could have been added whilst the truss was lying down, which would have simplified assembly but increased the weight and made erection more difficult. In the nearby Pohja Church, it appears that the scissor beams were added only after the trusses had been erected, despite the challenges this may have entailed (Savolainen *et al.* 2020b: p. 59).

Trusses would have been assembled and erected one by one. Towards the end of the process, there would not have been enough space on the internal scaffolding built at wall-plate level within the church walls to assemble the final trusses. Therefore, additional scaffolding may have been constructed outside the walls to support the assembly of the last trusses, which would then have been dismantled once all the trusses were in place. As soon as a truss was erected, it would need to be joined to the others to stabilise it. This was achieved via the use of wind braces, oblique ties and, finally, roof boards. There might also have been some temporary structures attached to the outside of the rafters which were then removed before installing the roof boards. After the trusses were in place, gables were constructed with masonry. At both ends of the attic, gables have been built between the two outermost trusses. Wind braces and oblique ties are embedded in the gables, which means that the said braces and ties were also in place before the gables were laid.

The roof structure was assembled from west to east, beginning with the westernmost truss, which was the first to be erected. This sequence can be inferred from the way the wind braces intersect, as shown in Figure 12. At each crossing point, the eastern wind brace overlaps the western one, indicating that the braces, and thus the construction, progressed consistently from west to east. When the roof of the nave was built, the sacristy and its roof were already in place at the eastern end. Resultantly, the nave roof structure would have needed to be adapted where it connected with the sacristy. In contrast, the porch at the western end had not yet been constructed. This may have made it more practical to begin assembling the nave roof from the west, as that end would have presented fewer structural challenges.

### 3 The Assembly from a Social Perspective

The physical appearance of Karjaa Church's roof structure revealed a wealth of information regarding the assembly and the whole construction process, which we would like to complement in this section with estimations of the financing, schedule, workforce and labour required for the construction. For

this, an indirect approach will be used, which consists of gathering secondary literature data to reconstruct, compare and discuss aspects that are no longer directly traceable in the case of Karjaa Church. This mirrors the more general knowledge of Finnish mediaeval society and estimations of the local population, animals, labour tasks and workdays in order to understand what quantities of labour the construction required from the local community.

Finnish folklore tales tell how giants built the mediaeval stone churches of St Mary in Hollola and St Martin in Raisio (Kuusi 1980: p. 104; Ruohonen 2010: p. 148). In reality, it was common in mediaeval Finland for the needed material and labour, and thus most of the financing, to be provided by the local farmers as a tax contribution, paid in day labour to the Church (Hiekkänen 2003: p. 11; Savolainen *et al.* 2018: p. 55). Non-local master builders and master brickmakers were additionally hired for their expertise (Aalto 2018: p. 20).

In the case of Karjaa Church, additional donations made by the tax-exempt nobility (in Finnish, *rälssi*) — a social class exempted from the taxes in exchange for military service on horseback (Salminen 2013: p. 277) — are certain. However, the donations rather concerned the land for the vicarage in 1412, assumed to be given by Klaus and Gertrud Fleming (Gardberg 1970: pp. 48–49), which might have even included the church land (Hiekkänen 2007: p. 436). Additionally, at least two saint statues with reredos and a possible side-altar were donated by the *rälssi* couple Lars Axelsson Tott and his second wife Karin (Katarina?) Eriksdotter Nipertz around 1470 (af Hällström 1957: pp. 12–13; Hiekkänen 2007: p. 439). Other, no-longer-traceable donations of the *rälssi* might have presumably included other items, such as liturgical books, candles and interior decorations.

As far as the roof structure is concerned, it is no longer known as to what extent the financing of the day labour and material procurement was taken over by the *rälssi* and how much of the labour was part of the tithes. The preserved Crown tax accounts and land registers, which merged the Church and Crown taxes after the tax reform, from the beginning of the 1540s onwards (Orrman 1981: p. 131), show that 144 farmsteads with assumably more than 1120 individuals in 1540 and 0.72 oxen per farmstead in 1571 were taxed in the current area of Karjaa. The war of 1495–1523 certainly impacted the population numbers, but it is likely that the parish's population during the construction of Karjaa Church in the 1460s was of similar size to its size before the war (Gardberg 1970: pp. 57, 67; Blomqvist 2004: p. 9). It can also be assumed that the number of day-labour days to be done as tax contributions to the Church depended on the size of the farmstead.

The project schedule had to fit into the farmers' annual rhythm of agriculture and animal husbandry, as well as fitting in with the ecclesiastical calendar

and church holidays. In the Diocese of Turku, to which the parish of Karjaa belonged, there were 39 mandatory religious holiday days in the 15th century, and it was, in addition, forbidden to work on Sundays. Furthermore, the Church required days or even longer periods of fasting before Easter and Christmas (Aalto & Helkala 2023: pp. 29–32), which might have had an additional influence on the energy management of the workers and construction times. Most of the farmers' work took place between March and September: the farmers fertilised arable land in March, tilled and sowed in spring (Aalto & Helkala 2023: p. 61; Jutikkala 1946: p. 69), harvested and dried the crop before the first frost in late August and possibly undertook winter sowing in September (Säihke 1963: p. 22). The construction and assembly of the roof structure most likely took place in autumn, when the farmers had completed the majority of the agricultural tasks. This also applies to the making and laying of the bricks, which is only possible in frost-free weather, from May to early September (Stige 2016: p. 150). Before that, in the autumn or winter, the trees would have been felled. They were manufactured into the required timbers in spring or summer as green wood or when at least semi-dry (Sjömar 1988: pp. 250, 253–255; Binding 1991: p. 13; Dalheimer & Aakala 2024: p. 49). Transportation of the stone and timber material would have most likely taken advantage of the snow, transporting the material using oxen as draft animals (af Hällström 1957: p. 15; Stige 2016: p. 150).

Theoretical and practical approaches to estimating the work time for either a whole church or specifically for a church's roof structure were employed for case studies in Sweden, Norway and Finland. Two cases that can be compared to Karjaa Church in terms of age, size, location and background are the late mediaeval Finnish stone churches of St Lawrence in Vantaa (in the Helsinki Parish) and St Mary's Church in Pohja. It is estimated — without any surviving information on the construction and transporting costs — that the approximate 400 farmsteads around the Helsinki church must have contributed more than 10,000 days of labour in total (Orrman 1994: p. 30), whereas a detailed reconstruction for the church in Pohja (including all possible steps of manufacturing of different building products, construction and transport time) estimated that around 62 600 days of day labour were required (Blomqvist 2004: p. 67). Only around half of this estimated number of days of day labour for the church in Pohja was estimated to be required for the 12th century Norwegian stone church of Værnes (36 500 days of day labour), which is smaller than Finnish stone churches, although also here, all possible work steps (such as foundation work, quarrying and lime burning) were included in the estimation (Stige 2016: pp. 185, 190). The experimental archaeology tested on the reconstruction of the Swedish wooden church of Södra Råda showed that trained workers require a large share of the work time for manufacturing the

roof elements, including boards and shingles (Almevik & Melin 2015: p. 89), whereas the assembly of the roof trusses, which were comparatively smaller than those of Karjaa Church, was possible in a relatively short time (Almevik & Melin 2022: p. 16). This seems consistent with the estimates for the church of Værnes, where it is estimated that four day labourers could assemble and raise one nave roof truss in one day (Stige 2016: p. 172). However, the wider nave of Karjaa Church, with its bigger roof trusses that are of larger span, might have required more time (but not necessarily more day labourers), since it is estimated that, regarding the construction of Pohja Church, it took six to eight days for four to five day labourers to assemble and erect one truss (Blomqvist 2004: p. 42: pp. 65–66). Based on those estimations, the assembly and erection of the 29 roof trusses at Karjaa Church would have required from 116 (four day labourers erect one truss in one day) to up to 1,160 (five day labourers erect one truss in eight days) completed days of day labour. However, a comparison with the roof construction time in Central Europe, such as the transcripts of the comparable larger German Regensburg Cathedral (1459), reveals that the crafting, assembly and erecting of the roof trusses took a total 240 day-labour days (48 days by an average of five people) (Schuegraf 1855: pp. 108–126, 174). It is very likely that the construction time for Karjaa Church's roof structure is rather comparable to this.

The labour required to build the whole church was a joint effort over the course of several years or even a whole decade, and the labour was divided throughout the year since the sunlight hours and day labour hours — next to the agricultural work, ecclesiastical calendar, the additional tax payments in kind and labour to the Crown (Skrubbeltrang 1964: p. 166) — were limited. Nevertheless, the economic conditions of the farmers in the late 1460s appeared to be stable and were not marked by protests regarding payments to the Church nor Crown (Katajala 2004: pp. 32–33, 37).

#### 4 Conclusions

The aim of this article was to ascertain how much knowledge we could acquire concerning the manufacture and assembly process of the Karjaa Church roof structure by thoroughly investigating and documenting the marks and traces left by the builders. The 2020 survey had already given a clear indication that the trusses had been manufactured on the ground in some kind of stack before being taken apart and transported to wall-plate level to be reassembled (Savolainen *et al.* 2023b: p. 137). Our observations in 2024 were consistent with the aforementioned findings, but, in addition, we were able to find a clear and

consistent indication that, after the preliminary manufacture on the ground, the rafter feet were not disassembled, even though other members of the trusses were taken apart.

We tried to uncover how the trusses of Karjaa Church had been erected but were unable to find sufficient evidence. We were, however, able to deduce that the process of putting up the trusses had started from the west and advanced towards the east. In light of this context, some of our other observations take on new significance. Firstly, there are no consistent numberings in the western part of the roof structure, whereas, in the middle part of the attic, five trusses are numbered and, in the east, seven. Starting from the west where the assembly began, the first set of numbered trusses has numberings on three truss members and the second set has numberings on four truss members. The numberings in the trusses have a descending order in relation to the direction of assembly (Table 1). Secondly, there are five different types of joints between the scissor beams and the second collar beam; they alternate in the western and middle part but are consistently the same in the seven easternmost trusses (Table 4). The most viable explanation for the numberings is that two final stacks of trusses were numbered, starting from the bottom of the stack, and then erected, starting from the uppermost truss. The introduction of a numbering system, along with its modification, may reflect a reorganisation of the construction process or a change in the way the trusses were stacked. The variation in the joints of the scissor beams probably results from some small change in the geometry of the trusses. Both these findings show that the details of roof assembly were not completely predetermined. The general method of working appears to have been decided in advance and the geometry of the trusses, as well as the overall design of the roof structure, must have been meticulously planned, but, nevertheless, there was still room for adjustments. Small alterations were made as the construction advanced and the builders became familiar with the process and adapted to challenges they faced.

Different shapes of drilling notches, as well as drill marks, were found throughout the structure. These findings probably correspond to different builders who were working with their own specific technique and possibly also with their own tools. We did not find any patterns that would point to specific drills or techniques having been used for particular tasks. The impression conveyed is less one of assembly-line work and more of people collaborating freely, all with their own slightly personal techniques. The traces of craftsmanship left by different builders in different parts of the roof construction could be a fruitful subject for further studies.

The research presented here faced difficulties, especially due to the vast size of the structure and the challenging fieldwork environment. We were

forced to largely limit our documentation to the markings on rafter feet and observations that could be undertaken from wall-plate level, but this research shows that even such a limited area of the roof and the narrow scope of study yielded interesting results. Expanding similar work to other churches could provide material for the comparison of both the construction methods and decision-making involved in the building processes of mediaeval roof structures all over Finland.

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