Savolainen, Panu; Seppänen, Liisa; Laine, Laura; Huttunen, Marko; Aakala, Tuomas

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Revealing the Innovations in Late Medieval Roof Structures of Finland

Panu Savolainen | ORCID: 0000-0002-8473-6255
Department of Architecture, History of Architecture and Architectural Conservation, Aalto University, Otakaari 1, 02150 Espoo (PL31000, 00076 Aalto), Finland
Corresponding author, e-mail: panu.savolainen@aalto.fi

Liisa Seppänen | ORCID: 0000-0002-1337-9764
Department of Cultural Heritage, Archaeology, University of Helsinki, Unioninkatu 35, 00170 Helsinki (PL 4, 00014 University of Helsinki), Finland
liisa.h.seppanen@helsinki.fi, liseppa@utu.fi

Laura Laine | ORCID: 0000-0001-8068-0904
Department of Architecture, History of Architecture and Architectural Conservation, Aalto University, Otakaari 1, 02150 Espoo (PL31000, 00076 Aalto), Finland
laura.laine@aalto.fi

Marko Huttunen | ORCID: 0000-0001-5594-8286
Department of Architecture, History of Architecture and Architectural Conservation, Aalto University, Otakaari 1, 02150 Espoo (PL31000, 00076 Aalto), Finland
marko.huttunen@livady.fi

Tuomas Aakala | ORCID: 0000-0003-0160-6410
School of Forest Sciences, University of Eastern Finland, Yliopistokatu 7, 80101 Joensuu, Finland
tuomas.aakala@uef.fi

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Abstract

In Scandinavia and Finland, nearly all constructions, including monumental and sacral architecture, used only timber until the 11th century. In Finland, timber remained the dominant construction material until the 19th century. Due to many fires, wars, and other catastrophic events, the number of still-standing wooden buildings and constructions erected before industrialization is very limited. Medieval wooden buildings can only be found in archaeological excavations, and the last remaining medieval load-bearing wooden structures are preserved in the medieval stone churches. While medieval roof constructions have been widely researched elsewhere in Europe, a comprehensive understanding of medieval roof constructions in Finland is largely lacking. This article presents an ongoing study of roof structures in Finnish medieval stone churches, focusing on two churches, Pernaja and Hammarland, which provide evidence of the transition from tie beam roof trusses to roof trusses without a tie beam. We examine the typology of the trusses, and present new results based on a comparison of the churches and dendrochronological analyses. Finally, we discuss possible explanations for the structural innovations and the emergence of the roof truss without a tie beam in a wider cultural context.

Keywords

dendrochronology – Gothic roof truss – Middle Ages – roof trusses – tie beam truss – wooden heritage

1 Introduction

In Scandinavia and Finland, there has been a long tradition of wooden architecture since prehistoric times, and wood remained the main building material until the early twentieth century. Numerous wooden buildings from the 18th and 19th centuries survived both in rural and urban environments, but original examples from older time periods are few (e.g., Khodakovsky & Skjold Lexau 2006). These can, however, be frequently discovered in archaeological excavations, but the remains unearthed are often condemned to be disposed after documentation owing to preservation and maintenance costs as well as requirements of land use planning. Interestingly, a vast number of still-functioning medieval wooden structures in Europe, particularly in Scandinavia and Finland, are hidden under the roofs of thousands of stone buildings.

The erection of masonry buildings in the Middle Ages brought along a new kind of architecture with new challenges for materials and constructors. In medieval Europe, Finland was among the latest regions to adopt masonry architecture, and the first stone and brick buildings were erected at the end of the 13th century. These included dozens of churches as well as a few strongholds and castles constructed by the Kingdom of Sweden. In the Middle Ages, Finland formed the Eastern part of the Kingdom of Sweden, and hence, the construction of the churches in Finland was an intimate part of the Swedish church building project and ecclesiastical organization of the Catholic Church in the north-eastern part of Medieval Europe.

The construction of masonry churches was led by the diocese of Turku, which now covers the southwestern part of present-day Finland. The construction period of medieval stone churches extended from the end of the 13th century to the mid-16th century with a clear boom in the mid-15th century (Hiekkanen 1994, 2007, 2020; Ringbom 1994, 2010; Ringbom *et al.* 1996; Uotila 1998; Seppänen & Ihr 2021). Overall, there are 104 identified medieval stone church projects in Finland so far, mainly in the southern part of the country. Some of these churches have been ruined, and over 30 of them were not finished because the Lutheran reformation ceased the construction of churches from the 1520s onwards. Owing to fires and other destructions and renovations, only about 15–20% of the churches contain original medieval roof constructions preserved until the present (Fig. 1).

Churches with original roof trusses have attracted scholarly interest since the mid-19th century in Central Europe and Nordic Countries, notably Denmark (Müller 1887; Janse 1902; Ambrosiani 1904; Curman 1937; Møller 1953; Ullén & Lagerlöf 1983–1985; Sjömar 1992, 1995, 1999; Madsen 2007, 2014). However, Finland is underrepresented in the field of medieval archaeology. Medieval churches in Finland have been considered important cultural heritage sites since the 1870s, and churches have been investigated frequently in recent decades. Research has been labelled by research trends of the time, including ideas about national history and identity, approaches from art history, and methods from natural sciences (e.g., Hiekkanen 1994, 2007; Valkeapää 2000; Ringbom 1994, 2010, 2011). However, little focus has been directed to wooden constructions in the attics that constitute the last and only testimony of still-standing and functioning wooden constructions from the Middle Ages in Finland (Hiekkanen 1995; Seppänen 2012). The survey of medieval roof structures (see Table 1 for an overview) began in the early 2000s and was linked to the architectural conservation of the churches in Porvoo and Sipoo (Huttunen & Saarinen 2009; Huttunen 2016).

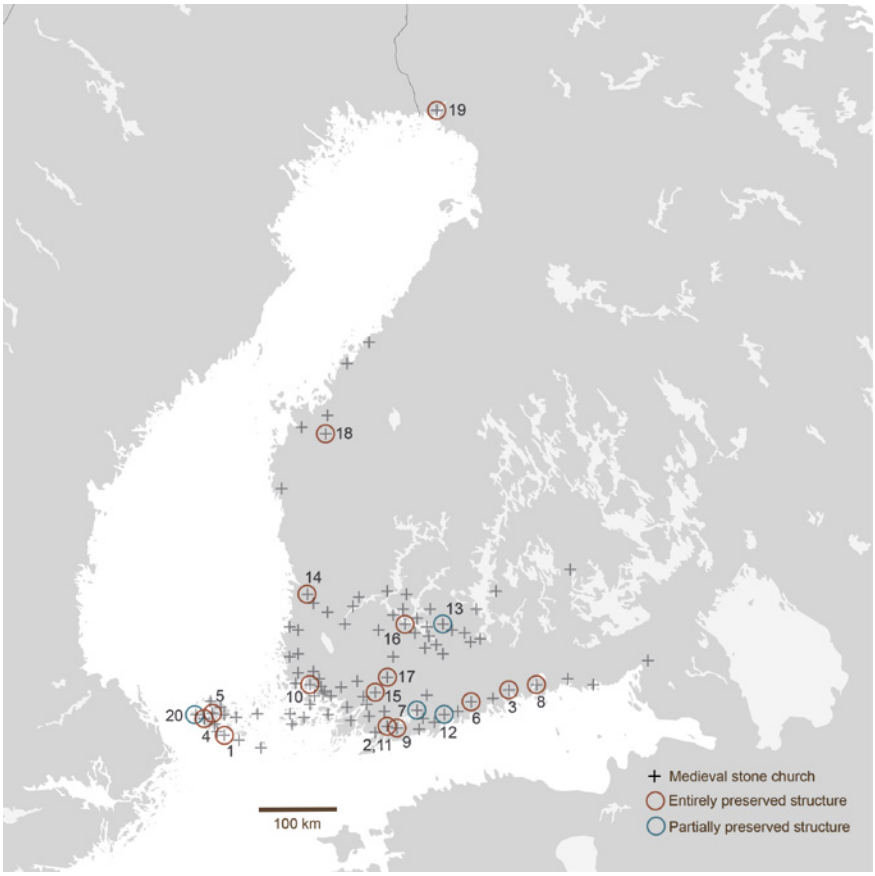

FIGURE 1 Medieval stone churches of Finland with entirely and partially preserved original roof structures. The numbers refer to Table 1
MAP: LAURA LAINE & PANU SAVOLAINEN

Nordic medieval roof trusses exhibit a great variety of structural solutions (Storsletten 2002; Thelin & Linscott 2008; Courtenay & Alcock 2015; Seim et al. 2015; Gullbrandsson & Hallgren 2021). However, the most important typological difference is observed between trusses with and without tie beams. Trusses with tie beams (Romanesque roof truss) form an integral triangular structural entity, where the forces and loads of the roof are conveyed mainly vertically to the side-walls. When stone or brick vaulting became widespread, the so-called Gothic roof truss emerged in Sweden in the mid-15th century, in which there is no tie beam. This completely changed the structural principle of the trusses that made up the roof construction and the masonry components of the entire

structure. In the Gothic truss, there is a rafter foot on top of the wall plates and scissor beams (Fig. 2). This typological differentiation from "Romanesque" and "Gothic" trusses is entirely based on structural features, and was first introduced by Elna Møller (1953). The grouping does not follow a strict chronology, since tie beam trusses still existed in the late Middle Ages, but the overall picture of the structural shift in the late Middle Ages is relatively clear in Scandinavia.

Compared to Sweden, Finland's medieval churches are relatively young. While in Sweden, ecclesiastical stone construction had begun in the 12th century in the eastern part of the Kingdom, 85% of the stone churches in present-day Finland were built between 1410 and 1550. Therefore, the typology of roof construction differs largely from Sweden. In Sweden, tie beam roof trusses are common. However, in Finland, preserved or partially preserved tie beam trusses can be found in only four churches. Compared to Finland, the number of medieval churches in Sweden is much higher, with more than 250 churches having original roof constructions (Linscott 2007, 2017; Gullbrandsson 2021). However, many Finnish constructions date to the transition point from trusses with tie beams to trusses without tie beams, which makes Finnish material particularly interesting in the entire medieval Baltic Sea Region.

In this study, we present new research on the transition from tie beam trusses to Gothic trusses without a tie beam, based on Finnish material and new building archaeological and dendrochronological results. We focus particularly on the Pernaja and Hammarland churches, which have both tie beams and Gothic trusses in different parts of the church, thus providing evidence of the transition and structural innovation. The results presented in this study shed

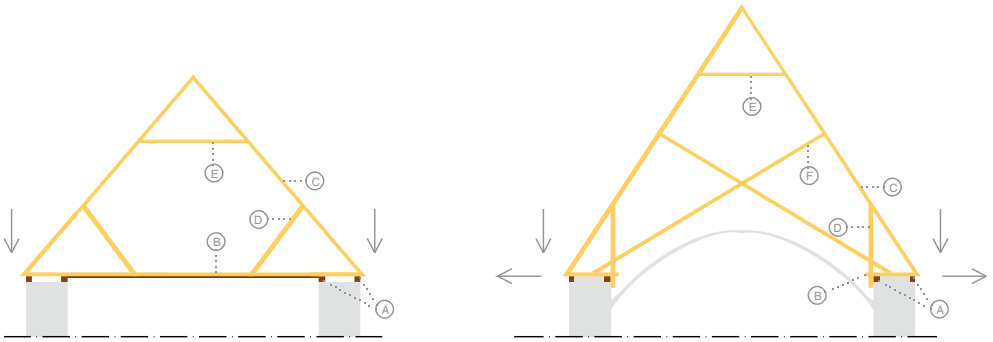

FIGURE 2 The structural principle of a tie beam (or Romanesque) roof truss and a rafter foot roof (Gothic) truss without tie beams. (a) Wall plates; (b) tie beam/sole piece; (c) rafter; (d) strut/ashlar post; (e) collar beam; (f) scissor beam
DRAWING: PAULIINA SAARINEN

light on a similar transition in mainland Sweden, where research has mainly focused on the oldest Romanesque roofs, and the late medieval churches have attracted less scholarly interest until recently (Gullbrandsson 2021).

2 Materials and Methods

In Finland, archival sources and documentary evidence from the Middle Ages are limited; therefore, archaeological and material evidence plays a significant role in architectural-historical research. Combining archaeology and dendrochronology with comparative typological analysis reveals new information about the transition from tie-beam trusses to Gothic roof trusses.

2.1 *Medieval Roof Structures in Finland*

The research is based on surveyed roof structures in Finnish Medieval churches. In this study, however, we focus on two churches, which elucidate the research question of the article, that is, the shift from the tie-beam truss to the Gothic roof truss. The known medieval roof structures in Finland are listed in Table 1, with information based on the current state of research and survey. All structures are according to dendrochronological studies from 1290 to 1560, covering almost 300 years and the era of stone church construction in Finland, including the Åland islands (Table 1). In this article we use 'd', for example 1465d, to indicate dating to a certain year/s based on dendrochronological studies.

The majority of roof trusses in Finland are Gothic trusses with a rafter foot and without a tie beam. The trusses were linked to each other in different ways, for example, by nailing oblique ties to the underside of the rafters, boarding on top of the rafters, and placing longitudinal beams that stretch from one gable end to the other on top of the collar beams (e. g. Huttunen et al. 2009; Huttunen 2016). The Finnish Gothic trusses are very similar to each other, consisting of rafter foot trusses, scissor beams, and 3–5 collar beams. An exception is the roof construction in Sipoo church, which has no scissors but vertical struts between the collar beams (Figs 3–6). There is sparing use of timber in the structures that were built. Thick and dense timber was needed only for the wall plates and rafters, but relatively young trunks could have been used in other parts. According to dendrochronological and visual analyses, the medieval roof trusses are composed of Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*).

TABLE 1 Roof Trusses in Medieval Stone Churches of Finland According to Our Present Knowledge

No.	Church	State of preservation	Dating	T (tie beam), G (gothic), TG (both)	Reference
1	Lemland	Complete	ca. 1290d, 1311–1316d (tower)	T	Ringbom & Remmer (2000)
2	Pohja wooden church	Recycled to the structures of the stone church	14th century	T	Wallenius (2020)
3	Pernaja	Complete	1410d, 1440d, 1453d	TG	Zetterberg (1991b), Aakala (2020)
4	Hammarland	Complete	ca. 1440d, 1465d	TG	Ringbom & Remmer (1995)
5	Finström	Partial	ca. 1450d	G	Ringbom 1994
6	Sipoo	Complete	ca. 1450d (nave and sacristy), 1454d (porch)	G, no scissor beams, vertical posts	Zetterberg & Hiekkanen (1991)
7	Lohja	Complete, later additions	ca. 1470–1490d	G	Zetterberg (2004b)
8	Pyhtää	Complete	1461–1462d	G	Zetterberg (1991c)
9	Karjaa	Complete	ca. 1470 (dating based on inscription)	G	Aakala (2020)
10	Lemu	Complete, later additions	1473d	G	Aakala (2023a) (forthcoming)
11	Pohja	Complete, later additions	1475–1480d	G	Zetterberg (2004a)
12	Espoo	Partial, later additions	1485–1490d	G	Zetterberg (1989, 1997)
13	Hauho	Complete, later additions	ca. 1500	G	–
14	Ulvila	Complete	1495–1510d	G	Zetterberg (2003)
15	Pertteli	Complete	ca. 1506d	G	Aakala (2023b) (forthcoming)
16	Akaa	Only sacristy	1510d	G	Zetterberg (1999)

TABLE 1 Roof Trusses in Medieval Stone Churches of Finland (*cont.*)

No.	Church	State of preservation	Dating	T (tie beam), G (gothic), TG (both)	Reference
17	Somero	Only sacristy	ca. 1500	G	–
18	Isokyrö	Complete, later additions	1513–1514d	G	Hiekkanen (2004)
19	Keminmaa	Complete	1550–1551d, 1560d	G	Zetterberg (2004c), Aakala (2020b)
20	Eckerö	Partial, later additions	no data, medieval rafters not dated	T	Ringbom & Remmer (1995)

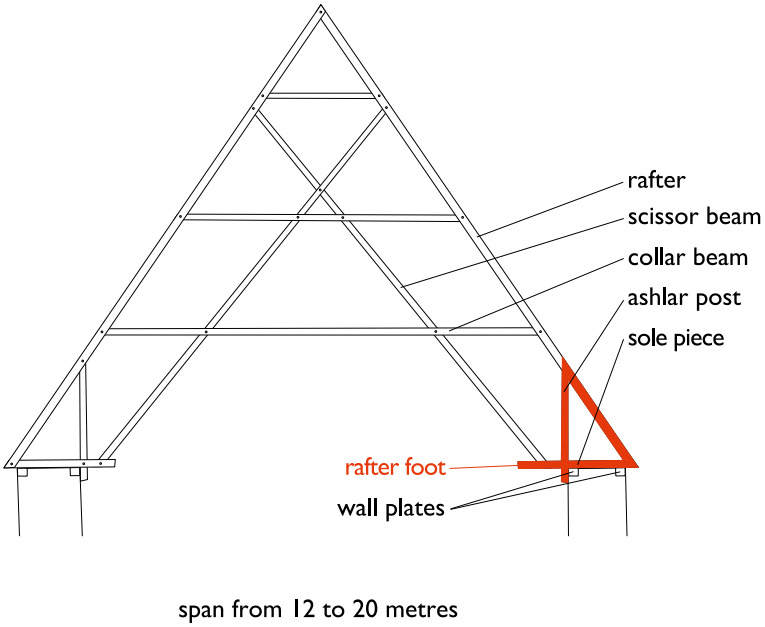

FIGURE 3 The typical form of a rafter foot (Gothic) roof truss in the Finnish medieval stone churches
DRAWING: LIVADY

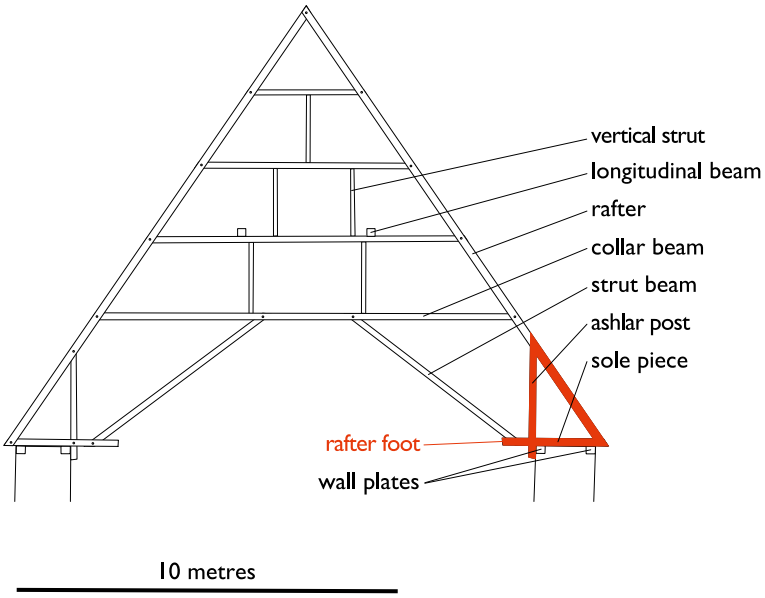

FIGURE 4 The roof structure of Sipoo church, cross-section (ca. 1454d)
DRAWING: LIVADY

FIGURE 5 The roof structure of Pyhtää church (1461–1462d)
PHOTO: PANU SAVOLAINEN

FIGURE 6 The roof structure of Pernaja church (1440d, 1452–1453d)
PHOTO: LIVADY

2.2 *Documentation of the Roof Trusses*

The principal method is to build an archaeological survey in which each structural member is assigned a unit code based on the number of trusses and the function and location of the member. This enables the creation of an evolutionary chronological model to identify any changes and alterations made to a structure. Drawings of structures are made afterwards by combining total station and handmade measurements with photographic documentation. The data produced enables the identification of separate construction phases and helps to make decisions about dendrochronological sampling. Unit-based documentation forms a database that allows the addition of information to any member of a structure when needed.

2.3 *Pernaja and Hammarland Churches*

The Pernaja Church in Southern Finland and Hammarland Church on Åland islands are the key to understanding the shift from tie beam trusses to Gothic trusses, since both types of trusses exist in these churches because of their complex construction histories. The roof structures in both churches are from 1410–1465d. The data presented in this article were gathered from 2016 to 2018 (Pernaja Church) and 2020 (Hammarland Church).

FIGURE 7 Hammarland church with both tie beam truss and rafter foot truss visible in the gables
PHOTO: LIVADY

The Hammarland Church on Åland islands is exceptional because the preserved roof constructions from the 15th century comprise both tie beam trusses and rafter foot trusses without tie beams. The nave of the church was built in the beginning of the 14th century (Hiekkanen 2014), but after the fire, the roof construction was rebuilt around 1440d according to dendrochronological data (Ringbom & Renner 1995). The construction of the nave in the 1440s is a tie beam structure (Figs 7–8). For some reason, the roof of the chancel was erected only later, in the 1460s. The roof of the chancel is a rafter-foot structure without a tie beam. Dendrochronological dating (Ringbom & Renner 1995) indicates that the timber was felled in 1465d.

According to dendrochronological studies, the sacristy of the Pernaja Church was built in ca. 1410d as the first part of the stone church project. The

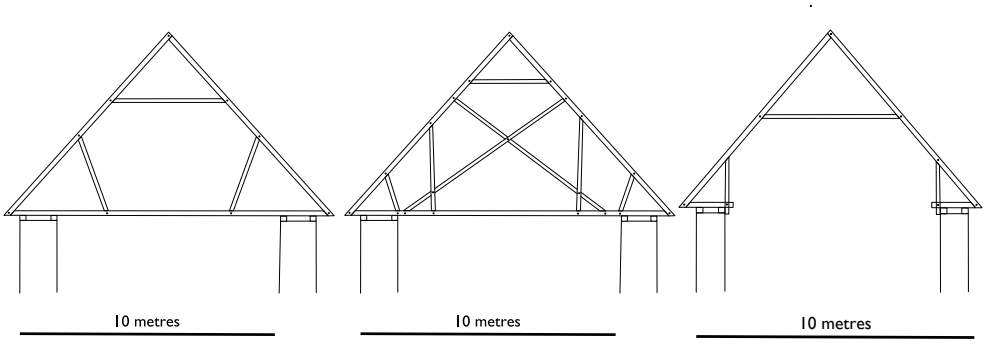

FIGURE 8 Cross-section of Hammarland church roof trusses. (a) The original Romanesque nave truss reconstruction from the early 14th century. (b) The tie beam trusses of the nave from ca. 1440d. (c) The rafter foot roof trusses of the chancel from 1465d
DRAWINGS: PANU SAVOLAINEN

nave was added around 1439–1440d (Knapas 1994; Zetterberg 1991a). Previous researchers have demonstrated that the brick vaulting of the nave is a secondary structure, and there were no plans for brick vaults initially. However, there was no dating done for the vaulting. In our study from 2016 to 2020, we focused on the major alterations in the roof structure when the brick vaulting was realized.

The construction of the vaults required major alterations to the original tie beam roof structure because the tie beams were removed, and newly raised ones were added to the structure. The structure is an amalgamation of tie beam and rafter foot trusses with scissor beams, and perhaps a testimony to the transition from tie beam trusses to rafter foot trusses (Fig. 9).

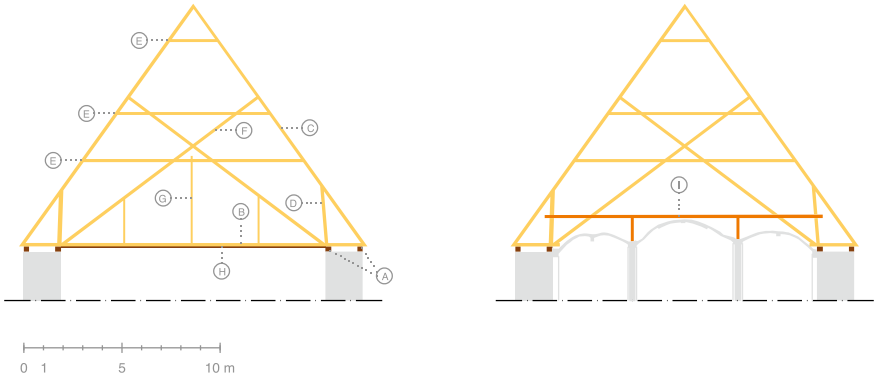

FIGURE 9 The alteration made to the roof structure of Pernaja church when the wooden ceiling was replaced with a brick vault (1440d, 1452–1453d)
DRAWING: PAULIINA SAARINEN

Based on the documentation, we were able to identify members of trusses that were added when the structure was modified to provide the space needed for the construction of brick vaults (Fig. 9). Dendrochronological samples were taken from this previously unidentified phase of construction related to brick vaults, which replaced an earlier wooden ceiling.

2.4 *Dendrochronological Samples*

A subset of the structures was selected for dendrochronological dating. We took five samples with a standard 5.15 mm diameter increment borer. Four of the samples were taken from structures that were related to the alterations of the roof structures, and one was extracted from a structure that had earlier been dated to 1440 (Zetterberg 1991b). At each structure, the sampling points were chosen such that the original surface of the log was still visible to ensure that the date of the last ring coincided with the year of felling. However, the original surface of two samples were not clearly detected (Table 2), but we estimated that a maximum of 1–2 rings may have been missing.

Each sample was treated using standard dendrochronological methods. In short, the samples were mounted on channeled wood and sanded with progressively finer grit until the tree ring structure was clearly visible. Samples were then scanned to 1200 dpi resolution, and tree rings were measured using CooRecorder software (Coorecorder 9.4. Cybis Elektronik & Data, Saltsjöbaden, Sweden). The tree species were identified from the wood anatomy of the cross

TABLE 2 Dendrochronological Results for the Norway Spruce (*Picea abies*) Samples

Sample	Structure	Rings	Last year	Surface	Felling date
EX9	Scissor beam nr. 9, south	65	1439	Intact	Dormant season 1439–1440
21PÖ	Added strut in truss nr. 21	45	–	Intact	–
22EÖ	Added strut in truss nr. 22	54	1448	Unclear	ca. 1448
23–24V	Raised tie beam (added when vaulted)	77	1451	Unclear	ca. 1451
7V	Raised tie beam (added when vaulted)	60	1452	Intact	Dormant season 1452–1453

sections. The obtained tree-ring sequences were then statistically dated using CDendro software (Cdendro 9.4. Cybis Elektronik & Data).

3 Results

The following results show that we can date a transition from tie beam roof construction to Gothic roof trusses with a tie beam to the 1450s. After the 1450s, all known medieval roof structures in Finland are Gothic roof trusses. This indicates that the transition identified in Swedish roof constructions (e.g., Gullbrandsson 2021) can be identified precisely in Finnish material. In Finland, this shift to Gothic roof trusses was probably connected to the intense stone church construction, where the wooden parish churches were replaced with stone and brick churches (e.g., Hiekkanen 1994).

3.1 *Dendrochronological Results*

The new samples from the Pernaja Church were all identified as Norway spruce (*Picea abies*) and had between 45 and 77 tree rings. Both the species and series length are problematic for dating; the available Norway spruce chronologies did not go sufficiently far back in time, and the number of rings are quite short for data based purely on statistics, as spurious dating may occur simply by chance with shorter tree ring sequences.

However, in the boreal zone, ring widths of both Norway spruce and Scots pine (*Pinus sylvestris*) display similar variability in response to weather and growing season temperatures in particular (Aakala et al. 2018). Consequently, we first dated the individual Norway spruce sample from the structure with a known construction date to 1440 (Zetterberg 1991b), using a southern Finnish Scots pine chronology. We specifically tested whether the last ring of the Norway spruce sample was from 1440. This analysis resulted in plausible dating (t = 4.7) to the dormant season of 1439–1440, supporting this expectation.

Thereafter, we used this dated sample to date the rest of the Norway spruce samples belonging to the alteration phase. Three out of four samples received statistically plausible dates between 1448 and 1452, with t-values ranging between 4.5 and 4.7 (Table 2). These dates were further supported by the presence of the 1408 ring that is a well-known particularly narrow ring (i.e., a marker ring) for Scots pine in southern Finland (Zetterberg 1991a). The remaining sample contained only 45 rings and could not be reliably dated.

Based on previous knowledge of the construction dates, statistical analysis, and the marker ring of 1408, we consider 1452–1453 as a plausible dating for the alterations of structures when the church was vaulted. In this alteration, the

principle of the structure was changed to resemble the structural performance of a Gothic roof truss (Fig. 9).

3.2 *Unveiling the Transition to Gothic Roof Trusses*

The original tie-beam trusses in the Pernaja Church from 1439 to 1440d and the alterations made for the vaulting in 1452–1453 testify for the transition to constructions without tie beams made for vaulting. The Pernaja and Hammarland churches demonstrate this transition, where the homogenous Gothic-type truss became dominant and completely replaced the tie beam trusses.

From 1450 onwards, a more intense and systematic building period of medieval churches began in Southern Finland (Savolainen et al. 2020b). This change is also visible in the typology of roof trusses, where the Gothic common roof truss became the standard model for timber construction in Finnish churches in the 1450s.

This relatively rapid turn is also supported by the constructions in other medieval stone churches of Finland. It is evident that this rapid turn can be connected with the construction of brick vaults, which were included in the initial design of stone churches from the 1450s onwards. In Finström church, the vaults were added to the church around 1450, at the same time when the roof structure was almost completely renewed with Gothic rafter foot roof trusses with scissor beams (Ringbom & Renner 1995).

The Lohja Church in Western Finland elucidates the history of the dominance of the Gothic roof truss in the latter part of the 15th century. According to art-historical analysis based on typological comparisons, the church had been dated to 1460–1480. The initial and realized construction plan included brick vaults, similar to all churches of the latter half of the 15th century. As an exception, in the Lohja Church, the walls rise above the top of the vaults, which would have enabled the use of a tie-beam truss. The church is also the largest medieval parish church in Finland with a span of 20 m. Despite the possibility of using a tie beam structure, the roof construction was realized as a common rafter roof truss without intermediate support and with exceptionally long rafters of 26 m required for the construction. The large size of the structure caused structural failures in the rafter foot trusses, perhaps already during construction. The trusses were supported by a large number of additional members, possibly in the Middle Ages. In the 19th century, longitudinal trusses were added to support the medieval structure.

It is difficult to compare the transition phase in Finland and elsewhere in medieval Sweden, because most of the late medieval rafter foot roof trusses are still undated. The earliest dated rafter foot roof truss in Sweden is from the Norra Fågelås Church sacristy from 1432d and the earliest rafter foot truss structure

with scissor beams in Spelvik from ca. 1445d. The remaining 11 dendrochronologically dated Gothic structures are from 1464 to 1560 (Gullbrandsson 2013, 2021). Even though the material for comparison in Sweden is still scarce owing to the limited amount of dating, the roofs with the dating indicate that the transition from tie beam trusses might have taken place in mainland Sweden and Finland simultaneously in the mid-15th century. However, in Sweden, the late medieval timber construction was more varied and there were also tie-beam trusses from the post-1450s period.

Based on the Finnish material, it seems that the booming period of the construction of stone churches, and particularly the adoption of brick vaulting to the initial design of all churches from the 1450s onwards, led to the complete adoption of Gothic roof trusses in a relatively rapid transition.

4 Conclusion

The material from the medieval churches of Finland shows that the transition from tie beam roof trusses to Gothic roof trusses occurred in the mid-15th century in different churches in Finland and was possibly accompanied by the same development elsewhere in the Swedish realm as well. The two examples from Finland provide a testimony of the shift in the structural engineering and roof structures between 1440 and 1465d. The Hammarland Churches, with its tie beam trusses in the nave from the 1440s and Gothic trusses in the chancel since 1465, exhibits this shift in construction. The Pernaja Church offers an even more concrete example with the original tie beam trusses from 1440d, which were altered in 1452–1453d with the removal of tie beams because of the vaulting of the church.

The transition to continental types of Gothic roof structures has previously been explained in Swedish literature as resulting from the increased presence of German merchants and craftsmen in Sweden, and growing importance of craftsmen from town guilds in the construction of parish churches. Additionally, the carpenter guilds emerged for the first time during this period in Stockholm in 1454. In Finland, the shift between 1450 and 1460 might be also explained by the beginning of high construction activity from 1450 onwards in south-eastern Finland and activity of new masters and craftsmen, probably from Tallinn. It is also possible that the fires of the Turku cathedral in 1443 and 1445, which completely destroyed the roofs, brought new expertise on roof construction and introduced Gothic roof trusses in Finland.

The roofing techniques for stone churches and other masonry buildings were introduced in Finland after a long structural evolution and refinement in

continental Europe and, more locally, in Sweden. Our study demonstrates the introduction of one of the most important late medieval innovations in timber structures in the Baltic Sea region. Furthermore, we want to highlight that the logs, joints, and wooden structures not only reveal information about wood working practices, techniques, and adoption of innovation, but the structures preserved in church attics provide an important source material when the organization of the construction of the entire church is studied. Timber structures constitute a carved archive that can reveal new information about wooden structures as well as the construction of churches, medieval society, and mobility of innovations within larger areas.

Acknowledgements

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