Roof structures in Swedish churches: preservation challenges and solutions

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Roof trusses - an unexplored treasure

In 2014, the Vasa Museum had over a million visitors. More than 21 million visitors have until today seen the ship in its current museum. People are fascinated by the exciting story of the magnificent ship that sank on its maiden voyage in August, 1628. At the museum exhibitions and guided tours will provide you with knowledge about Sweden in the 17th century, about shipbuilding and life onboard a war ship. To be on site and see the real actual ship, almost four hundred years old, gives you a sense of contact with the 17th century society. When Vasa sailed out, the roof structure of Forshem Church had carried its roofing and kept the building dry for nearly five hundred years. It continues to do so today. Nine hundred years after it was built, it still carries its load. It represents an equally exciting peephole into our history as the Vasa ship, but is completely unknown to most people. In many of our oldest church attics, there are timber structures that are unique, often beautiful and exceptionally old.

Our knowledge of historic Swedish church roofs and their structural behaviour is limited. Congregations responsible for the maintenance and management of churches are often not aware of the values of roof structures, many of which are early medieaval. The lack of published knowledge is an obstacle for high ambitions in preservation work as it prevents simple things as comparing structures and determining if an object is unique or common. Furthermore, there is a gap in our common understanding on how our oldest timber structures are best restored.

This article summarises experiences from the field of practical preservation. Methods used are all the everyday methods of a practitioner in the field of building conservation. Examples from ongoing work at Marka medieaval church and the spire of Skörstorp round church are presented.

Values

Old timber structures can be said to have a large number of different cultural-historical values. But I would like to simplify and hightlight three values (or properties) that are important to bear in mind.

Historic church roofs:

- create rooms (attics) that are unique as historic settings. In (a decreasing number of) church attics, it is still possible to experience an environment that has been unchanged for centuries.
- are historic documents, sources for historical research.
- are load carrying structures - of exceptional sustainability. Their presence prove that load bearing structures built from renewable materials can function for at least 900 years.

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Figure 1 Threats to historic church roof trusses. a) Insidous, successive changes that transform the attic as a historic setting. b) Structural problems (the picture shows a material failure in a rafter). The dominating problem is the one where the trusses have lost their horizontal support. This leads to large stresses in rafters. c) Rot. d) Trusses are covered in insulation and become difficult to inspect.

Threats

The most important threats to the preservation of these values/properties are simple in theory, but continue to have major implications in practice:

- Successive, insidious transformations of the attics as historical settings. Gangways, lighting equipment, cables and alarm installations are frequently insensibly installed.
- Design-related structural problems. These are unusual but can have large consequences.
- Moisture and its extreme consequence rot. Rot often leads to structural problems. Choosing repair measures typically means that one have to choose between preserving the historic setting and the structural behavior and preserving the historic material.
- Insulation: structures are covered in a way that makes inspection impossible.

Solutions

"Museum-like" management

It seems reasonable that the care given to our very oldest timber heritage should have similarities with the care that objects obtain in museums. A strive for control is desirable. The following might seem basic but is crucial in the management:

- Control and awareness over what's there. Most congregations have a "care and maintenance plan" in which this information could be included. Inventories should be carried out by professionals (historians/antiquarians).
- Control over what happens in the attic. It might be a good idea to put up a sign: "You are entering a thousand year old building. Please consult the responsible manager before carrying out any arrangements."
- Control over the climate in the attic.
- Control of the state of the structure by regular inspections.

Skara diocese has set an example and taken several steps towards this kind of controlled management. A handbook has been developed on how to take care of medieval roof trusses, historical research on medieval churches and their trusses has been sponsored and an inventory of all medieval roofs in the diocese has been carried out.

Minimized damage in restoration

As preventive care is not always perfect historic roof trusses are often subjected to restoration measures. When it comes to restoration, the following should be considered:

- Professionals with expertise in the field of historic timber structures should be hired.
- All relevant professionals should be involved at an early stage.
- Craftsmen should document their work.
- Repair measures should be chosen with respect for the values of:
  - the attics as unique *historic settings*
  - roof constructions as *sources for historical research*
  - roof trusses as *load carrying structures – with exceptional sustainability.*

Repair measures: two case studies

Two on-going cases will illustrate decisions that have to be taken when dealing with damage by rot.

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Figure 2 a) Skörstorp church, exterior. b) The attic above the round nave and the 17th century spire. Photos: Carl Thelin.

Skörstorp is a Swedish round church built in the end of the 12th century or beginning of the 12th century with vaults from the 15th or 16th century and a spire from the 17th century. The spire over the round nave has three structural parts/systems. Firstly and lowermost, there is a system of beams stretching across the nave. Secondly and above, there is a central system of vertical posts. Thirdly, there is the system of radially placed rafters, with their lower ends standing on the system of beams and the other end meeting the central post system.

When inspecting the roof tiles, the property manager at the Swedish church became aware of the existence of damage by rot. Some of the beam ends and wall plates were entirely destroyed by real-rot fungus as well as some of the lower rafter ends. The central beam in the beam system was rotten in the middle and was leaning against the vault. There was a system of partially inefficient repair measures. These were at least a few decades old, suggesting that some of the damages had been there for a long time

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Figure 3 Skörstorp church. a) Rot damages. b) Some of the old repair measures. c) Wall plates were found to be more damaged than first assumed. d) Part of the beam system damaged by rot. Photo a, b and d: Carl Thelin. Photo c: author.

The system of beams have an important role in keeping the lower ends of rafters in place and preventing their slipping. When beams are severely damaged there is a risk that (larger) horizontal forces come to act on the walls of the church. The walls of Skörstorp church are cracked in a way that suggest that they might have been pushed outwards by the roof structure - or by the vault. The question was raised whether the spire had come to lean on vault.

A study of structural behavior showed that the central post structure is not standing on the vault, but hanging in the rafters. The beams are important as ties, but carries only their own weight in bending.

Repair measures were chosen with the ambition to leave the attic with high values as a historic room and high values as a load bearing structure of exceptional age.

Rafter ends were repaired with new timber of the same dimension as the original, using scarf joints. Two beams in the horizontal beam system were changed for new ones. The entire spire had to be carefully raised with a large number of jacks and lifting bags in order for the middle beam to be changed.

To obstruct the rot fungus from re-establishing, the detailed design of the top of the wall was changed. The wall plates were to have little or no contact with the masonry. As a consequence, the masonry between the wall plates was not restored in its original shape. The stones have been cleaned and treated with a fungicide and will be put back on the wall between wall plates without mortar.

Figure 4 a) Repair measures: a new part (in the foreground) and a spliced rafter. b) New wall plates and new rafter ends. The picture was taken when the whole structure was lifted by jacks in order for one of the beams to be replaced.

This change of design means that a possible load path for outward thrust from the rafters has been removed. To compensate for this, a new load path was created. It was made sure that the outer wall plate can function as a ring able to carry permanent tensile forces. This means using metal fasteners in the joints, as timber fasteners can slip when subjected to permanent tensile forces in combination with seasonal changes in humidity.

A follow-up study of crack widths in the walls has been initiated.

It is not known how the original roof was constructed. The beams in the system existing in the church today have empty notches that imply that they have been part of an older roof construction. These notches seem to be the only clues to the design of a former roof. These clues risked being destroyed as beams were replaced. In order to somewhat compensate for this, measures were taken. Firstly, it was decided that the craftsmen were to make a report on the process of the work. Removed (damaged) parts are now documented with sketches and photos and decisions taken during the work are documented and explained. Secondly, new beams have been marked with outlines of notches. Thirdly, healthy parts of removed beams will be stored in the attic.

The medieval church of *Marka* still has a large number of original roof trusses. Dendrochronological analysis has shown that the timbers in the roof trusses above the nave were felled in 1155/1156.[1] The roof trusses were originally visible from the church room but are now hidden by vaults. When these vaults were built (probably in the 15th century) some of the tie beams in the roof trusses above the nave, as well as all of the tie beams in the roof trusses above the chancel, were cut off. Additional parts have been built in at some point to compensate for the removed ones.

Figure 5 Marka church, roof trusses above the nave. Photo: Carl Thelin.

[1] Andrea Seim, Kristina Linscott, Karl-Uwe Heussner, Niels Bonde, Claudia Baittinger, Jan Michael Stornes, Thomas S. Bartholin, Hans W. Linderholm (2015): "Diverse construction types and local timber sources characterize early medieval church roofs in southwestern Sweden" Dendrochronologia, Volume 35.

Early medieval roof trusses of this type with tie beams and crossed struts are rare in Europe.[2] It seems like a large part of the preserved ones are found in Sweden. But the history of roof trusses is insufficiently explored. We do not know where all medieval roof trusses are and how they look. Not even the oldest early medieval ones have been systematically invented, yet less interpreted. Researcher Kristina Linscott believes that there might be as many as 250 medieval roof structures in Sweden.[3] Several inventory surveys have recently been started by dioceses around Sweden, so that we can soon expect to have better knowledge on this topic. The roofs of Marka church have, to some extent, been studied by scientists. They were included in an inventory of medieval roof structures carried out in 2015 in the diocese of Skara. Researchers Kristina Linscott, carpenter Mattias Hallgren and curator Robin Gullbrandsson have pointed out important characteristics in the attic in Marka church that can give clues as to how the trusses were constructed and assembled and how they looked originally. Among other things, there are traces of color, special markings, and uncommon types of joints, burn marks and high quality workmanship.

Today, a number of damages weaken the structures. Many of the roof trusses are partially damaged by rot. Large parts of the wall plates are rotten. A sample has shown that in at least one position there is real-rot fungus. Additional parts, tie beams and others, have been built in in order to strengthen the structure.

The scattered rot and the cut off parts have changed the load paths in the structure so that the structural behaviour is not the original one. Some of the trusses now carry a large amound of load and others only a small part. It is unclear where the largest stresses occur and how high they are.

Restoration measures have been discussed for several years and different actors have been involved. No decision has yet been reached.

Measures like the ones in Skörstorp could be prescribed, where rotted parts are cut off and the remaining parts repaired with new timber. As damages in Marka church are spread over the attic, repairs will probably be visible from almost every part of the room. Also, a large amount of medieaval material will be removed.

Some stakeholders have expressed a wish to keep the structure as it is – with rot and added parts. The metaphor of an old building as an old person has been put forward, and the fact that there are values connected to the imperfections and the visible traces of old age.

[2] Linscott, K (2007): Medeltida tak: bevarade takkonstruktioner i svenska medeltidskyrkor, Göteborgs universitet. [In Swedish.]
[3] Ibid.

Figure 6 Marka church. a) and b) Rot damages. c) Tie beams have been cut off and struts removed where vaults are built in. Extra parts have been added to compensate for lost ones. Photos: Carl Thelin.

Restoration measures will lead to a choice as to which cultural-historical values to preserve and which to sacrify. Either we restore the function of the different parts of the structure by cutting off damaged timber and joining the existing parts with new timber. Thereby we preserve the values of the roof truss as a load bearing structure that can carry load for almost 900 years. But we loose original material and diminish the value of the object as a source for historic research. Or we leave damaged material as it is and strengthen the structure with additional pieces in order to preserve as much historic material as possible and as much of it's a value for historic research as possible. But we loose the function of the parts and thereby the roof construction as a load bearing structure with exceptional age.

For Marka, we suggest further investigations. Firstly and most important, we suggest a careful cleaning of the attic and archaeological survey with a documentation of findings. Damages will be invented and visualised with great detail. The structural behaviour of the roof constructions will be studied in order to determine if rot and damages, in principle, could be kept. Hopefully, the approach chosen for Marka church will represent one step forward towards a museum-like care of our oldest timber structures.