On the Reconstruction of aisled Prehistoric houses from an Engineering Point of View

The article connects archaeological and engineering points of view in the reconstruction of prehistoric houses to reach more probable results.

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1. Introduction

The majority of articles dealing with the reconstructions of prehistoric houses reflect a purely archaeological point of view. It is only natural that the archaeological material should form the basis of these investigations, but since the construction of houses in general involves numerous technical problems, the return of single discipline investigations must remain limited.

One of this contribution's objectives is to show that tentative reconstructions of prehistoric houses, when based on both archaeological and engineering principles, will have an enhanced degree of probability.

The crucial point is that, in the majority of cases, the archaeological evidence is confined to the two-dimensional plane. Technical and static considerations, on the other hand, can make a valuable contribution to discussions concerning the appearance of the prehistoric house in the third dimension.

The conclusions presented here, though based on investigations of Norwegian Iron Age houses are, nevertheless, of a more general value. In the following, I shall discuss four different subjects, concerning the construction of postholes, and the position and spacing of the roof bearing posts in relation to the main axis of the house.

2. Wind force and its implications

Former research regarded the Norwegian farmhouses of the Iron Age as stone buildings with an internal, roof bearing framework of wood. However, the discovery of numerous constructional details in recent investigations has entailed a re-evaluation of the majority of Scandinavian Iron Age buildings as pure wooden constructions, equipped in some cases with a protective external wall of stone, earth or turf.

In static terms, these developments imply that the wooden houses were stable in themselves and the outer walls were free of any bearing function.

An examination of the Norwegian archaeological material shows that, in the vast majority of cases, the basal stabilization of the roof bearing posts in the subsoil was not sufficient to secure the buildings against displacements caused by wind pressure.

In Norwegian Iron Age houses, the depths of the postholes associated with the roof bearing system average roughly 20-40 cm (*Komber 1986*: 42). Furthermore, several cases are known where the posts were not anchored in the subsoil at all, but stood instead on flagstones (*Myhre 1980*: 40).

If we now assume that these posts reached a height of about two meters above the floor, we end up with an amount of 10%-20% of the total length of the post anchored in the subsoil. This low degree of stabilization is far from sufficient to absorb horizontal strains from in the roof zone.

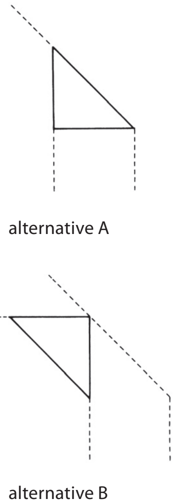
In an actual experiment carried out by Holger Schmidt (*1977*: 134, note 28), it was clearly shown that even if one meter of the length of the post was buried, it was still not enough to enable the roof bearing system to resist horizontal displacements.

It follows that, if we do not find traces of external buttresses (which are seldom found in the Norwegian material), we have to postulate bracing systems in the roof zone itself. This in turn necessarily demands the presence of "closed triangles" in the roof bearing framework, a structural feature that has long been disputed in connection with prehistoric houses.

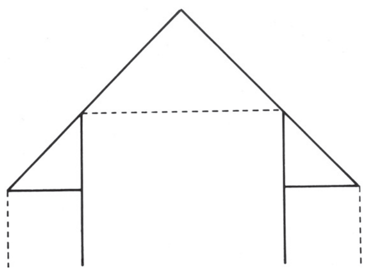
According to Bendix Trier (*1969*: 120), the closed triangle is a constructional phenomenon not to be taken for granted in prehistoric building technology. Adelhart Zippelius (*1953*: 38-39), on the other hand, has suggested that some kind of corner bracing must have been in use in Central Europe by as early as 500 BC.

The points outlined above support the latter conjecture, indicating the presence of closed triangles in at least some of the Norwegian Iron Age houses.

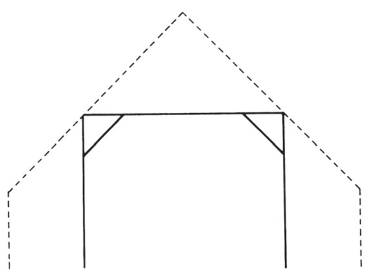
The upright post always constitutes one component of the triangle, which may be located either in the aisles of the house (alternative A), or in the nave (alternative B) (**fig.1**).



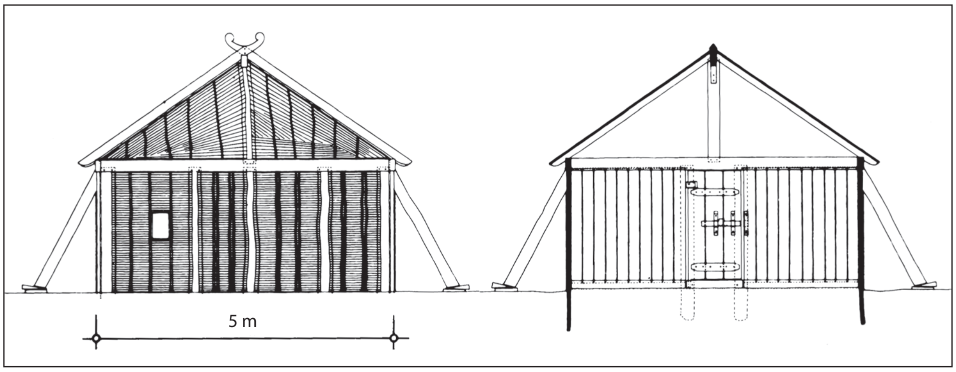
■ Fig. 1 Alternative locations of the closed triangle in the roof zone.



■ Fig. 2 Cross section of the house in alternative A.



■ Fig 3. Cross section of the house in alternative B.



■ **Fig. 5** Reconstruction of the Viking house from Hedeby (after Schmidt 1981: fig. 6).

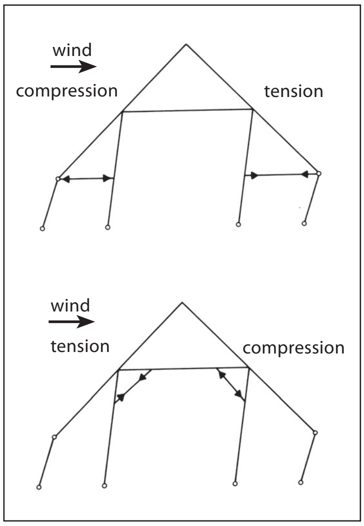
A complete cross section of the house shows that the closed triangle in alternative A consists of a post, a rafter, and a horizontal tie linking the post to the outer wall (**fig. 2**).

In alternative B, the elements of the triangle comprises a post, a tie beam and a diagonal brace (**fig. 3**).

One technical problem that had to be overcome involved the connection between the bracing elements (the tie in alternative A, and the diagonal braces in alternative B) at the junctions. Exposed to the displacing force of the wind, these Junctions had to be capable of resisting tensile stress (**fig. 4**).

Designing junctions in a manner that enabled them to withstand tensile stress has been a problem in building technology throughout history (*Hermanns 1951*: 80).

The well known Hedeby house, reconstructed at Moesgård in Denmark, is a notable late example of how Viking Age architects tried to avoid tensile stress. In this case, wind pressure was dissipated on the leeside of the house by compressive stress in external buttresses (**fig. 5**).



■ **Fig. 4** Tensile and compressive stress in the bracing elements.

It has been pointed out already that these buttresses were not a common feature in Iron Age building. Thus, in alternative reconstructions, we have to suggest some other mechanisms that would not only compensate for tensile stress in the roof bearing framework, but also keep it low enough to obviate the need for external supports.

Static investigations show that, due to the larger dimensions of the closed triangles, a bracing system based on alternative A involves the lowest degree of tensile stress in the junctions.

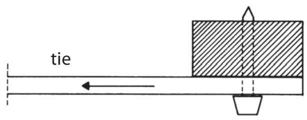
The only connecting devices definitely known to have existed throughout the Iron Age are wooden pegs. Other means of connection might be proposed, but there is as yet no evidence for these in the archaeological material.

A simple model of the joint between tie and post is shown in **fig. 6**. This type of device will generally hold in houses where turf was used as the roofing material. Turf requires a gently sloping roof, and wind pressure therefore plays a subordinate role in forces affecting this type of building.

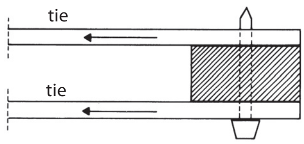
Thatched roofs, on the other hand, call for steeper gradients. The vast area exposed to wind with roofs of this type, often in combination with spacing of the pairs of roof bearing posts, will produce stresses exceeding the strength of the wooden pegs in **fig. 6**. Thus, in buildings with thatched roofs, we have to look for a sturdier type of joint. An improvement on the device shown above, we might hypothesize a kind of double tie (**fig. 7**).

Concerning alternative B, Holger Schmidt (*1981*: 137) has claimed that diagonal braces were not employed before the Middle Ages.

With this statement in mind, and referring to the technical problems that tensile stress generally evokes, I myself tend towards constructional solutions based on alternative A. The ties in the aisles might also have been part of partition walls, dividing the house into different functional units.



■ **Fig. 6** Joint between post and tie.



■ **Fig. 7** Joint between post and double tie.

3. The implications of the cross sections of posts

From various sites in Norway comes evidence for a rectangular shaping of the cross section of the roof bearing posts, with the greater axis parallel to the transverse axis of the house. The axial ratio of these cross sections is roughly 1:2 (*Komber 1986*: 34).

If we disregard a purely aesthetic interpretation of this phenomenon we might glimpse an underlying structural factor, with the posts apparently being exposed to a higher amount of strain along the transverse axis of the house than along the longitudinal.

What is the difference in static terms between a rectangular shaped post and a circular one of the same cross sectional area? If the post were exposed only to vertical loads, this shaping would serve no useful purpose. On the other hand, a rectangular cross section is able to assimilate a greater bending moment in one direction (**fig. 8**).

The significance of this phenomenon lies in a more economic utilization of the building material, than would be possible using circular posts. Thus, a rectangular shaping of the cross section of the roof bearing posts can be interpreted as a material saving device. As pointed out above, the average depth of the postholes is rather slight. Thus, a bending moment in the posts caused by their being anchored in the subsoil can be excluded.

The only elements connected with the post, and theoretically able to cause a bending moment in the lateral direction of the house, are the ties in the aisles shown in alternative A, and the diagonal braces in alternative B.

The existence of these two elements has been postulated with regard to the wind resistance capacity of the house. The question now is, whether the force of the wind could reach a magnitude that would give ground for a rectangular shaping of the posts. The answer is that it would in the case of thatched roofs, but not in the case of turf roofs.

As pointed out above, the pitch of the latter is rather gentle, with wind pressure therefore of minor significance. In thatched roofs, on the other hand, the wind pressure factor can reach a magnitude comparable to the weight of the roof itself.

Thus, in houses where turf was used as roofing material, a rectangular shaping of the posts cannot be explained as a protective measure against displacements caused by the wind. On the other hand, in houses roofed with reed or straw, it is theoretically possible as an explanation.

The crux of the matter, in the archaeological context, is that by far the majority of reports referring to rectangular shaped posts up till now exclusively come from Norway, where thatched roofs have no recorded tradition. One explanation for this fact might be that excavators in other countries have not been aware of this peculiarity as a relevant factor in the reconstruction of a house.

The static effect of a low angled turf roof causes in alternative A is that the lower part of the rafters presses the ties in the outer aisles towards the centre of the house, thus generating a bending moment in the posts (**fig. 9**).

In alternative B, kingposts transfer the roof load from the ridge piece to the tie beam, where they generate a bending moment. The diagonal braces in their turn distribute this bending moment from the tie beam to the posts (**fig. 10**). (In the context of alternative B, it is quite permissible to postulate the presence of diagonal braces as a structural element exposed primarily to compressive stress).

In both cases, the bending moment generated in the posts is of such a magnitude that it could definitely be the fundamental reason for a rectangular shaping of their cross sections.

In the context mentioned above, the amount of material saved through the use of these rectangular posts, in comparison to round, reaches 50% (*Komber, op.cit.:* 77).

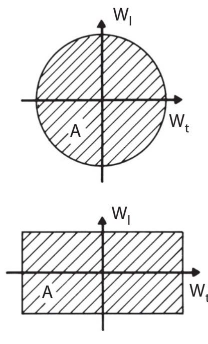
This constructional peculiarity can thus be explained as a result of the builder‘s understanding of the distribution of the static forces in the roof bearing system.

The appearance of rectangular shaped posts in Norwegian farmhouses is dated to the transitional phase between the late Roman Iron Age and the early Migration period. Botanical research indicates that a vast deforestation took place along the western coast of Norway at this time. Thus, the changeover to a more economical use of material may have been caused by the Operation of palaeo-ecological factors.

In Continental Iron Age houses, e.g. from the Netherlands and Northern Germany, the use of thatched roofs is well documented. On many sites, the excavators describe a quite different type of roof bearing post. These posts, showing a wedge shaped cross section, made from timbers split radially („Spaltpfosten“).

These observations emphasize that material saving devices also were used on the Continent. However, this type of post is far too slight to be used in combination with turf roofs.

Up till now, the appearance of rectangular shaped posts seems to have been associated with heavy roofing materials. Proof is still lacking for the use of this kind of post as a mechanism to improve the wind resisting capacity of the prehistoric house.

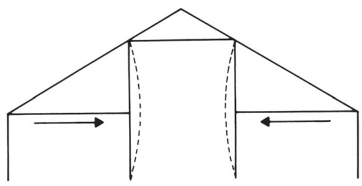


■ **Fig. 8** Resistance to bending of roof bearing posts with different shapes of cross sections.

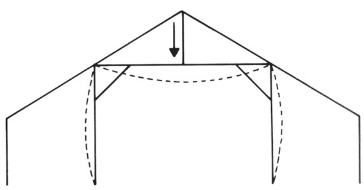
4. Foundation problems in prehistoric building technology

In winter, a roofing material such as turf, when saturated with moisture and covered by a thick layer of wet snow, represents an enormous weight. The bulk of this load is transferred to the subsoil by the roof bearing posts (**table 1**).

A review of the actual cross sections of these posts, as documented by archaeological evidence, leads to the conclusion that the pressures created under the posts, in the majority of cases, can exceed the supporting capacity of the subsoil.



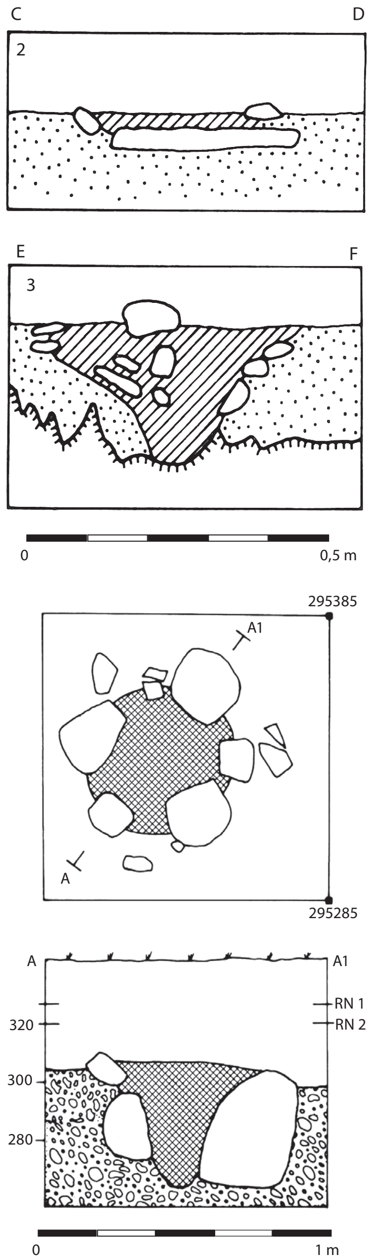
■ **Fig. 9** Bending moment generated in a roof bearing framework based on alternative A.



■ **Fig. 10** Bending moment generated in a roof bearing framework based on alternative B.

Solving the problem of these high roof loads calls for pressure dispersing measures under the bearing posts. Thus, when the archaeological material is to be analysed, this factor will» entail an investigation of postholes from an engineering point of view.

A closer examination of various postholes from Norwegian and Swedish sites shows how Iron Age architects applied various solutions to the problem of achieving stable foundations.



■ **Fig. 11, 12** and **13** Pressure dispersing measures under the roof bearing posts (fig. 11 and 12 after Myhre 1980: fig. 25; fig. 13 after Baudou 1973: fig. 40).

In spite of the enormous variety of posthole constructions, certain trends are evident. Basically, there were four different ways in which the problem could be solved:

1) By enlarging the pressure area, which was achieved by placing the roof bearing framework on flagstones whose size exceeded the cross section of the posts (**fig.11**).

2) Where the subsoil consisted of relatively thin sandy layers, the postholes were dug down to solid rock (**fig.12**).

3) The posts were wedged between stones which in turn distributed the roof loads by friction to the surrounding subsoil (**fig. 13**). This hypothesis may enable us to re-evaluate the reason why stone packing is such a frequent feature in association with postholes. There has never been any doubt that the presence of these stones had to be interpreted as a device to counter pressure. However, it has been shown that the majority of posts were not intended to be immovably anchored, and since horizontal forces at the base of the posts are relatively weak, the best explanation for the presence of stone packing is that it served primarily as a countermeasure to forces exerted in the vertical plane (*Komber, op .cit.*: 61 f). However, a permanent wedging effect will only be possible if we assume a slight tapering of the post (**fig. 14**).

4) The lower part of comparatively deep postholes was tightly packed with stones, providing a larger base for the roof bearing framework (**fig.15** and **16**).

Investigations carried out at the site of Feddersen Wierde, near Bremerhaven, show that foundation problems were not exclusively associated with the use of heavy roofing materials.

The thatched buildings of the village were erected on a soft type of soil in the North German marshlands. To prevent the roof bearing framework from sinking into the subsoil, the bottom ends of the posts were pierced right through with small horizontal timbers, thus providing additional support (*Haarnagel 1979*: 92).

This is a further example of a structural device designed to prevent overloading of the subsoil's supportive capacity.

5. The implications of the trestle quotient

One of the key factors in modelling the superstructure of prehistoric houses is the positioning of the roof bearing posts in the building's ground plan. In the majority of cases, it can be assumed (with a probability approaching 100%) that each pair of roof bearing posts was connected by a tie beam, thus forming a cohesive unit. This unit can be termed a „trestle".

The most natural way to view the layout of the posts is in relation to the principal axes of the house. This will produce two values: longitudinally, the spacing between the trestles (trestle interval), and laterally, the trestle width (T_W).

The significance of the latter value increases when related to the house width (H_W). In mathematical terms, this relation can be formulated as the trestle quotient (TQ). This quotient is defined by the ratio of house width to trestle width (*Komber, op.cit.*: 26):

$$TQ = H_W/T_W$$

Consequently, narrow trestles will give high TQ values, whereas moving the posts in the direction of the outer walls will reduce the TQ toward the value of 1.0.

Since the application of the TQ in reconstructions of prehistoric houses seemed to be rather limited, researchers gave it little attention. The only result of discussions so far is that the TQ can serve as an Index of the distribution of the roof load.

In this discussion, however, one specific TQ value has undeservedly been assigned too much importance. In the case of TQ=2.0, where the rows of posts are situated midway between the outer walls and the central axis of the house, the posts were believed to balance the roof surfaces, thus absorbing the total weight of the roof load. Characteristic of this view is the following Statement: „*The aisle posts are positioned precisely in the centre of the span of the rafters, in which case, theoretically, the walls need have taken no roof load*“ (*Huggins 1976*: 91).

This assumption is based on a misconception of the distribution of the static forces in the roof bearing framework. In fact, the sole implication of TQ=2,0 is that the respective roof loads exerted on the ridge piece and the outer walls are equal.

Table 1 shows the amount of the roof load exerted on the trestles, for three values of TQ and roof pitch, demonstrating that TQ=2,0 is not in fact an exceptional value.

TQ =		1.6	2.0	2.7
pitch:	27°	91%	81%	75%
	35°	83%	74%	68%
	45°	69%	61%	56%
	▲	▼	▼	▼

■ **Table 1** Percentage of total vertical load exerted on the roof bearing posts, in the case of a purlin roof; ▲ - increasing, ▼ - decreasing (Komber, op. cit.: tab.6-1).

The most significant conclusion to be drawn from the above is that, as trestle width decreases, so does the pressure on the foundations under the roof bearing posts.

Up till now, TQ values higher than 3,0 have only been observed in houses found on sites in Norway and Sweden. Since this peculiarity thus seems to be confined to the Scandinavian Peninsula, and since foundation problems (under normal subsoil conditions) only arise in connection with heavy roofing materials, it may be justifiable to propose the hypothesis that high TQ values indicate the presence of turf roofs.

The interesting point now is that there seems to be an association between TQvalues higher than 3.0, and a wide spacing between the trestles up to six meters and more (*Komber, op.cit.:* 126). Such long intervals between trestles are otherwise quite unusual in prehistoric turf roofed houses.

House II from Gene in Ångermanland, Sweden, revealed the very high TQ of 3.8, associated with a maximum trestle interval of 9.2 ms (*Ramqvist 1983*: tab.7.3). House II from Forsand in Rogaland, Norway, had a TQ of 3.7 combined with a trestle interval of 5.8 m (*Løken 1983*).

These observations might indicate that in attempting to create large room units in turf roofed houses, Iron Age architects were obliged to move the roof bearing posts closer to the central axis of the house.

An estimation of the wind stability of aisled houses supports the hypothesis mentioned above. The pressures exerted by airflow are absorbed by the roof bearing framework. High TQ values imply high narrow trestles, which are much more sensitive to wind forces than the lower and broader trestles associated with low TQ values.

Table 2 shows the wind sensitivity in one particular case (width of house 8 m, wall height 1.5 m), for three different values of TQ and roof pitch (*Komber, op.cit.*: tab.64).

TQ =		1.4	2.0	3.7
pitch:	25°	0.9	1.1	1.3
	35°	1.9	2.4	3.0
	45°	4.3	5.6	7.1

■ **Table 2** Wind sensitivity of an aisled house with a width of 8 ms and a wall height of 1,5 m.

This table shows that, from a structural point of view, in the case of a layout featuring narrow trestles, a gently sloping turf roof will be the most probable reconstruction.

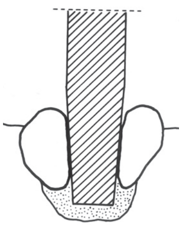
On the other hand, considering a thatched roof with a pitch of 45° or more, the most favourable solution is provided by a layout with low TQ values.

One may therefore conclude that TQ values can be used as a basis for inferences concerning roofing materials.

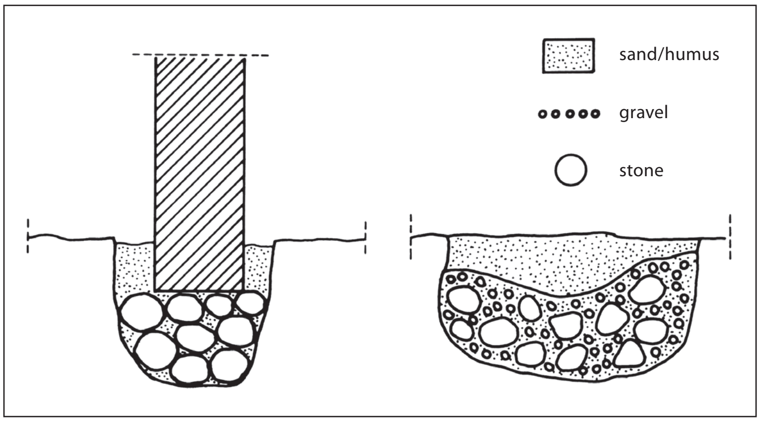
The arguments presented above can be supported by material drawn from archaeological sources. Björn Myhre (*1980:* 178) called attention to a contraction of the trestle width to Norwegian houses during the Late Iron Age. A review of Viking Age buildings in Norway, Scotland, Iceland, Creenland and Newfoundland, clearly indicates a general tendency toward TQ values between 2.5 and 3.0 (*Komber, op.cit.*: tab.81) In all these areas, turf roofs have a long historical tradition.

The conclusion may be that the inherent constructional advantages provided by a combination of turf roofs and high TQ values were already recognized and utilized to a large extent in the Late Iron Age.

On the other hand, in regions possessing a long tradition of thatched roofs, such as Denmark, a trend toward very low TQ values during the Viking Age is to be observed. For example, several houses from the sites of Sædding and Omgård show TQ values ranging between 1,3 and 1,5 (*Komber, op.cit.*: tab.82).



■ **Fig. 14** A permanent wedging effect, achieved by a slight pointing of the post.



■ **Fig. 15** and **16** The lower part of postholes was tightly packed with stones, providing a stable base (fig. 15 after Løken 1982).

6. Future research

The application of engineering knowledge has hitherto played a fairly subordinate role in problems concerning the reconstruction of prehistoric houses, and thus lacks a detailed background in a wider context.

Testing the hypotheses mentioned above on the archaeological material from other areas will therefore be a challenge for future research. The potential that engineering knowledge can offer, is not limited to the subjects presented here, but covers a broader spectrum, the presentation of which would exceed the scope of this article.

However, amongst such subjects can be mentioned the calculation of the heat insulating properties inherent in various roofing and walling materials, and the role of partition walls in this context. Such investigations would provide valuable Information about microclimatic conditions in prehistoric houses, and the amount of solid fuel necessary to maintain a given temperature.

My Intention in this contribution is to show that reconstruction models of prehistoric houses will possess a greater degree of validity if the approach is based on a combination of both archaeology and engineering science.

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Summary

Zur Rekonstruktion von mehrschiffigen urgeschichtlichen Häusern aus technischer Sicht

Forschungen zu eisenzeitlichen Bauernhöfen in Norwegen ergaben, dass es sich bei dem Großteil von ihnen um hölzerne Strukturen handelt, die in einigen Fällen mit einem äußeren Schutzwall versehen sind, falls die Hauptstabilisierung der dachtragenden Pfosten nicht ausreichte, um die Gebäude gegen Winddruckschäden zu schützen. Falls wir also keine äußeren schützenden Strukturen finden, müssen wie davon ausgehen, dass es entsprechende Konstruktionen im Bereich der Dachzone selber gegeben haben wird. Auch der Nachweis für eine rechteckige Ausgestaltung des Querschnitts der dachtragenden Pfosten zeigt an, dass die Pfosten möglicherweise einem größeren Biegedruck in eine Richtung ausgesetzt waren - obwohl das Vorhandensein solcher Strukturen auch in einer ökonomischeren Nutzung des Baumaterials begründet sein mag.

Im Winter stellt ein Dachdeckungsmaterial wie Torfsoden, wenn sie mit Feuchtigkeit durchtränkt und mit einer dicken Lage von Schnee bedeckt sind, ein enormes Gewicht dar. Der Großteil dieses Gewichtes wird auf den Boden durch die dachtragenden Pfosten übertragen. Um das Problem zu lösen, werden druckausgleichende Maßnahmen unter den tragenden Pfosten benötigt, die den druckauffangenden Bereich vergrößern; dies kann durch Eingrabung in eine feste Steinfläche oder durch das Einkeilen der Pfosten zwischen größere Steine geschehen.

Eine der Schlüsselkomponenten für die modellhafte Rekonstruktion des aufgehenden Bauwerks von urgeschichtlichen Häusern ist die genaue Positionierung der dachtragenden Pfosten. Die räumliche Ausgestaltung kann durch das Verhältnis zu den Hauptachsen des Hauses erkannt werden. Dies lässt zwei wichtige Maße erkennen: In der Länge das Intervall zwischen den Pfostenstellungen und in der Breite den Abstand zwischen den Pfostenstellungen. Wenn der Abstand zwischen den Pfostenstellungen geringer wird, nimmt auch der Druck auf das Fundament ab. Die skandinavischen Häuser haben relativ enge Abstände zwischen den Pfosten, was vermutlich mit den statischen Problemen aufgrund des schweren Dackdeckungsmaterials zusammenhängt.

Aspects techniques des reconstitutions de longues maisons préhistoriques

Les recherches des maisons de Norvège datées de l'âge du fer suggèrent une construction en bois, parfois protégée par une paroi extérieure, malgré une implantation insuffisante des poteaux porteurs qui devaient résister aux vents. Ainsi, si on ne trouve pas de vestiges de parois extérieures d'appui, il est à supposer qu'un système d'appui ait été incorporé à la charpente du toit. Les découvertes des poteaux porteurs de section rectangulaire témoignent d'une pression plus forte exercée dans un sens unique ce qui pourrait encore refléter un comportement économique concernant les matériaux de construction.

L'hiver, la couverture comme celle en argile, mouillée et recouverte d'une grosse couche de neige constituait une charge énorme dont la plupart du poids était transféré au sol par les poteaux porteurs. On peut prendre en considération plusieurs solutions de ce problème dont la décomposition du poids sur un plus grand plan, implantation des poteaux porteurs dans la roche ou fixation des poteaux avec des blocs de pierre.

La disposition des poteaux porteurs représente l'un des aspects essentiels des reconstitutions des maisons préhistoriques. On peut l'examiner par rapport aux grandes axes des constructions. Ainsi, on en obtient deux données: longitudinalement celle de l'intervalle entre les paires de poteaux porteurs enchaînés avec des pannes et transversalement leurs écartements. Plus les paires de poteaux se rapprochent, moins le poids de la toiture pèse sur les fonds. Les poteaux porteur des maisons de Scandinavie sont peu écartés ce qui aurait résulté de ces problèmes des toitures lourdes.