Essays

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ENTRANCE TO THE FIELD OF CORDWOOD MASONRY

PRE-SCIENTIFIC OVERVIEW OF TECHNIQUE AND ASPECTS

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Abstract

Scattered information about cordwood masonry was gathered from different sources such as books, professional articles, popular articles and websites. Historical cordwood masonry construction techniques and newer cordwood masonry construction techniques were included. Current teachings of ecological construction practices were added, and private and professional individuals' knowledge. Three main cordwood wall types were evaluated and the wall type - single log with centered insulation space - was found to be optimal. Spruce *(Picea abies)* was identified as the best suited tree species in Norway. Mixing of clay based mortar was explained. Load bearing can be done with post framework, or the cordwood walls themselves can be load bearing. Solutions for stabilising corners were found. It is optional to clad the house or leave it unclad. Momentums for future scientific research were pointed out, such as finding thermal transmittance U (W/m2K) for woods and mortars, and understanding humidity transportation efficiency in different types of wood with/without cladding. Unanswered questions were set forth. This is a pre-scientific literature study.

Keywords: cordwood; masonry; kubbehus[1]; construction; technique

AIM AND OBJECTIVES

Aim

The purpose of this investigation is to look into historical and newer cordwood masonry construction techniques, show fitting ecological construction practices – as a preliminary and pre-scientific basis – from where scientific investigation can continue.

Objectives

- Find historical cordwood masonry techniques and practices that can have a place in future construction.
- Find newer cordwood masonry techniques and practices outside Norway that can be introduced to Norway.
- Give a base-categorisation of variations in historical and current cordwood masonry techniques.
- Pair cordwood masonry construction techniques with current ecological construction practices.
- Conclude with an optimal cordwood construction technique.
- Suggest further scientific research.

On a larger scale, continued investigation into cordwood masonry construction techniques can diversify current ecological construction by putting to use cordwood masonry in real life eco-construction projects.

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[1] *Kubbehus* is the Norwegian word for the English term *cordwood masonry house*.

INTRODUCTION

Cordwood masonry is the construction technique of building the walls of a construction with logs of wood and mortar. This technique has many variations in use of tree species, wooden log format, mortar and insulation spaces.

It is unknown how far back in time cordwood masonry dates, but historical constructions from the mid 1800s are found in USA and Canada [Roy 2003], Sweden [Hagman 2013] and Norway [SINTEF Byggforsk 2017]. Finland also has historical cordwood construction [SINTEF Byggforsk 2017].

In Sweden and Norway cordwood construction was built continuously at least from that time, and until the 1940s in Sweden [Hagman 2013], and the 1950s in Norway [SINTEF Byggforsk 2017b]. In this last phase of this historical cordwood construction in Sweden [Hagman 2013] and Norway [SINTEF Byggforsk 2017b] it was common to use cut offs from the wood industry such as planks and beams. Such houses were called *knubbehus* in Norway.

In the USA and Canada a revival of cordwood construction started in the 1970s, which led to a number of cordwood houses being built in those two countries over the years [Roy 2003], and they are still being built there today. This revival of cordwood construction did not reach Europe (just a few projects), so the majority of newer constructions of cordwood construction can only be found in the USA and Canada.

House construction in Norway today has become a technically complex and costly affair. The layman is dependent on professional builders and cannot hope to put so much of his own physical effort into building his own house. In addition acquiring a home requires parental financial assistance and decades of mortage.

This whole set-up of conditions must be said to be an odd occurence. If we give in to the belief that we are at peak technological know-how as nothing before during thousands of years, then surely we would have developed a way for everyone to manage to build their own house instead of incapacitating people. We would also have found a way to allow people to have a home without decades of debt.

Fig. 1. A cordwood masonry construction site; photo by: [Roy, 2017]

Fig. 2. This is the construction technique of cordwood masonry. Cordwood logs are placed in clay based mortar to build a wall; photo by: [Cordwood Construction, 2020]

Fig. 3. Barn of cordwood for animal keeping built in the historical period at the farm Risgjerdet in Oppdal in Norway, with logs that are 30 cm long (Stenby, 2021b). The logs seem to be reused from a previous log house, and there are horisontal planks or battens for stability sandwiched in between each layer of logs; photo by: [Hemmingsen & Stensen, 2021]

Fig. 4. Newer cordwood house in North America; photo by: [Flatau, n.d.b]

Homo sapiens is a species characterised by needing a shelter against the environment and being capable of constructing such a shelter in order to complete their life cycle of reproduction with raising of offspring. All so called primitive civilisations on Earth have solved this but the modern technological industrial society has not, in fact it has deregulated mankind away from having such ability to self manage their own biological life cycle.

That is what gives incentive to exploring natural construction techniques such as cordwood masonry. It is one of several construction techniques that are simple and effective, and can be used by the self builder. By looking around at ground level in the local environment and picking up the organic and abiotic construction elements that we discover, we find a new starting point and we progress in the challenge of building a home.

A very great point about organic construction techniques is also the state of the planet today. The natural world is continuously being degraded into disappearance by over exploitation of energy and resources. Natural construction techniques such as cordwood masonry significantly lowers the usage of energy and resources by omitting the technological industrial pathway for the construction materials that are to be used for the house. In fact, omitting the technological industrial pathway makes natural construction techniques severly outcompete any green labeled construction technique coming out of a technological industrial production line.

By going back to a man-in-nature stance and thereby finding local and natural construction materials, we not only manage to lower the costs and gain increased financial freedom - and lower our environmental impact drastically - but we also succeed in restoring mankind's biological life cycle by abling people to take care of it themselves. Nature in man is restored by resorting directly to nature, and man in nature is also further restored.

1. MATERIALS AND METHODS

This article is based on the study of other written sources:

- Books about cordwood masonry
    - *Cordwood Building: The State of the Art*, by Rob Roy in USA.
    - *Väggar av ved*, by Olle Hagman in Sweden.

- Investigation series from Byggforsk
    - Byggforsk SINTEF is a research institution in Norway. It produces reports with solutions and recommendations for the field of construction. The reports are intended for use as documentation in building permit applications. The solutions can progress beyond the current construction practices but are still within the regulations. Byggforsk also produces reports about historical construction techniques such as cordwood masonry.
- Current professional articles from
    - NIBIO – Norwegian Institute of Bioeconomy Research
    - Bygg og Bevar – ideal enterprise for maintenance and conservation of old constructions
    - Forskning.no – science news in Norway
- Private blog
    - Norsk Bygningskunst – a blog about common cultural crafts and crafts tradition.

2. RESULTS

2.1. The advantages of cordwood – diffusion openness and thermal mass

A tree, while it is alive, works to transport water from the ground via the roots and the trunk up and out to the leaves or needles. For this reason the tree trunk is designed to prevent water loss through the sides and to move water efficiently lengthwise inside the sapwood part of the trunk. This capacity still resides in the tree after it has been felled and cut into logs. In construction terms this means that wooden logs are open to diffusion, which means transportation of water molecules.

This gives interesting perspectives in eco-construction since the conscious intent in ecological construction is to try to use the materials by the capacities that they naturally provide.

The logs have the capability to move humidity through the wall and release it on the other side. When the humidity is higher on one side of the wall than the other, the logs absorb the humidity, move it and release it in the air on the other side of the wall where the humidity is lower. This helps to balance the humidity level inside the house, in complement with clay based mortar which has the same capability.

Apart from it's openness to diffusion, a cordwood wall with wood and mortar also has thermal mass. This means that it will retain heat and slowly release it during some time, making the indoor temperature more stable.

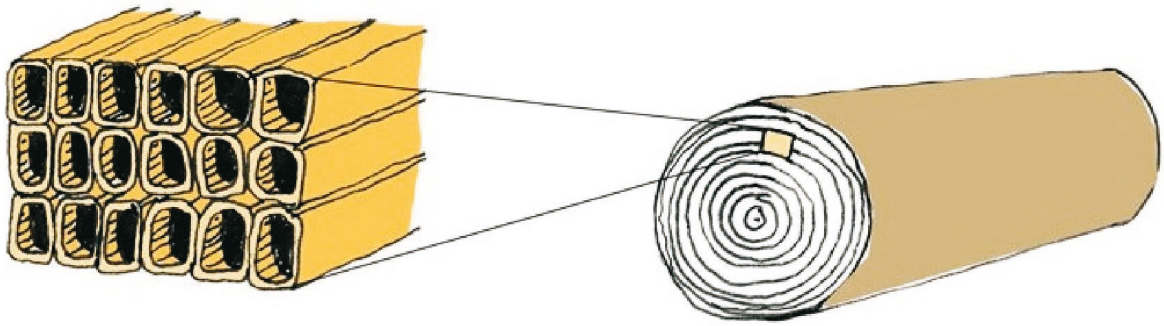


Fig. 5. The tree trunk is open to diffusion because of it's natural structure for water transportation; photo by: [Hemmingsen & Stensen, 2021]

2.2. The advantages of cordwood – economical advantage

There is an economical advantage in using cordwood. One thing is that the raw materials – wood logs and clay for the mortar – are not expensive. The other thing is that the self builder does the work of putting up the volume of the walls instead of paying a carpenter to do it. The self builder can cut down the trees in the forest himself with a chainsaw and bring the logs to an adequate place to dry, getting a good price on the logs. The local farmer who owns the forest probably has some patches of forest that are unprofitable for him to log by clear cutting, and he might be willing to sell those trees to the self builder at an even better price.

In Norway more or less one third of all agricultural land has clay-containing soil beneath it. Cities and towns have oftenly been built on top of old agricultural land. This makes clay-containing soil accessible both in the coun-

tryside and in urbanised areas. It is normal to see heaps of grey clay-containing soil at construction sites on farms and in cities. In urban and rural construction projects the clay-containing soil has to be deposited somewhere and is therefore an expenditure for the contruction project. This means that it can be possible to make a deal and obtain some clay-containing soil from such a construction project nearby.

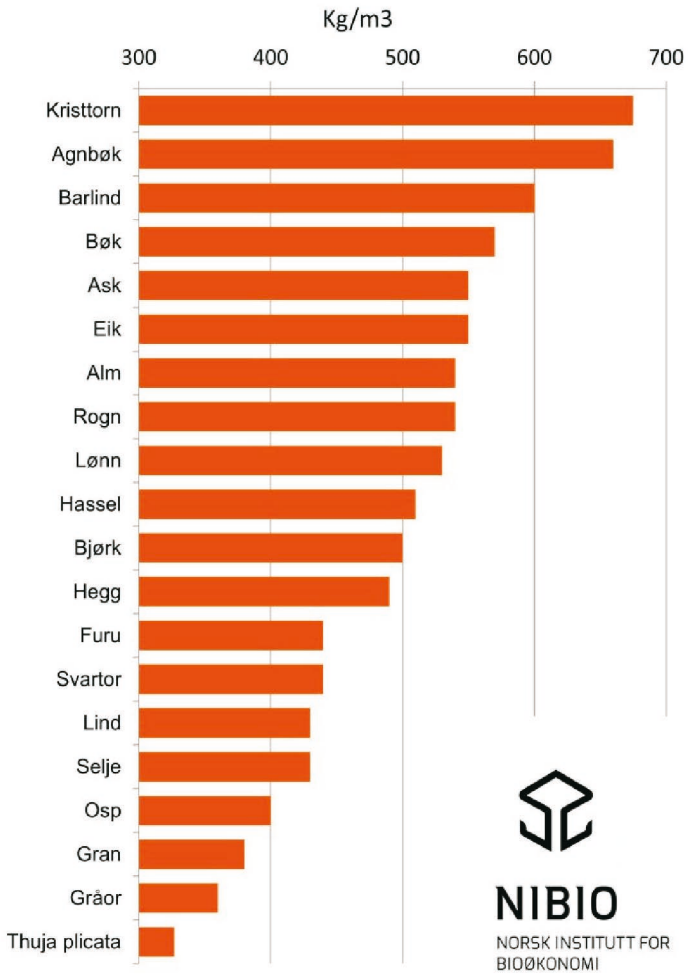
2.3. The cordwood logs – lighter versus heavier woods

Different tree species have wood with different qualities. When it comes to cordwood construction the wood should be light and airy. This is for two reasons. First, the lighter airier woods have better insulation values than heavier denser woods [Hagman 2013; p. 24, Roy 2003, p. 22]. Second, the lighter airier woods are more stable with less expansion and shrinkage in thickness when subject to changing levels of moisture [Hagman 2013, p. 24; Roy 2003, p. 22].

Heavier denser woods when dried have a much greater capability to expand in thickness when being re-hydrated [Roy 2003, p. 22; Stenby 2021). In cordwood masonry the logs are exposed to moisture when the wall is being built and each log is being put in moist mortar. This adding of water to a lot of denser heavier wood logs in the same wall has the capability to lift clear the top beam off the frame, push out the sides of the frame, and the cordwood wall itself can also come out inwards or outwards [Roy 2003, p. 21 – 22; Stenby 2021]. The expansion would be unstoppable [Roy 2003, p. 21].

2.4. The cordwood logs – tree species

Bar chart 1 [NIBIO 2019] The bar chart shows the specific weights of the wood of different Norwegian tree species.



Translations:
Birch = bjørk

Pine = furu

Aspen = osp
Spruce = gran

Source: NIBIO – Norwegian Institute of Bioeconomy Research

Historically speaking the tree species that have been used for cordwood construction in Norway are [SINTEF Byggforsk 2017]:

- spruce (*Picea abies*)
- aspen (*Populus tremula*)
- pine (*Pinus sylvestris*)
- birch (*Betula pubescens*)

Spruce, aspen and pine were most commonly used in cordwood houses [Stenby 2021].

2.5. The cordwood logs – debarking the trunks

Debarking must be done as soon as the tree has been felled. The space between the trunk and the bark is a favoured space for fungus and insects. Fungus is detrimental to human health and is not something to build into the walls of a house. The self builder who is logging forest himself should create the unflinchable habit of debarking each tree right after it has hit the ground. Fungus should be thought of as occurring immediatly after cutting the tree down, it occurs before the human eye can see it. There is no reason to let the trunks lie around for some days before taking off the bark.

Cutting a birch tree for example, during summer it takes just two-three weeks for fungus to completely infest the space between the trunk and the bark and this is very visible. During summer time there is a lot of sap underneath the bark which the fungus thrives on. Winter and early spring can be a better time for cutting trees.

2.6. The cordwood logs – cutting for drying

The logs should be cut to the correct length for the project before they are set to dry. Most of the moisture will leave the trunk through the cut endings, not so much through the side of the trunk. Therefore for efficient drying the trunks can be cut into logs of correct length. See the section 2.1. and Fig. 5 in particular.

2.7. The cordwood logs – splitting or not splitting?

Should the logs be split or left round and intact before drying? Both things will work for the cordwood wall. A cordwood wall with split logs will function, and a cordwood wall with intact round logs will function. Intact round logs will get more cracks, and some of them can be wide and deep and go all the way through the log lengthwise and connect the inside environment of the house with the outside environment. These bigger and deeper cracks can be filled with mortar so that they will not affect the functionality of the cordwood wall.

Fig. 6. Dried unsplit log where two major cracks have occured all the way into the center and continuing lengthwise in the trunk. There are also lots of smaller cracks in the log, 2015; photo by the author.

Splitting the logs through their center into several smaller logs is a way of not getting the larger cracks that run all the way through the logs [Roy 2003, p. 27]. It allows the tree rings to freely retract and become shorter. This can be understood by studying the drawings in Fig. 7.

During drying the growth rings in the logs will become shorter and retract. This means that something has to crack since the tree trunk is not so good at reducing its diameter correspondingly. A log can get smaller cracks spread out in the log, and they can get one or two larger cracks that go all the way into the center of the growth rings. These larger cracks can run all the way through the log lengthwise and thus create an opening between the outside and inside environment of the house. There can be variation depending on log size and tree species.

If the logs are split straight through the center before putting them to dry then the growth rings can freely retract and there will be no reason for creating so many cracks, in particular not the larger penetrating cracks, as this illustration points out.

Splitting or not splitting in the end can be a matter of personal aesthetical preference for the finished construction. If round logs are prefered then it just means that there will be some bigger cracks that have to be filled with mortar. If that is not an option then the logs must be split before drying.

Fig. 7. Wood drying process; source: [Roy, 2016, p. 28]

Fig. 8. Unsplit logs in cabin, photo by: [Cordwood Construction, 2013]

Fig. 9. Split logs in house; photo by: [Cordwood Construction, 2020].

2.8. The cordwood logs – size of logs

If some logs are of particularly big size, this means more movement in the wall at their local spots and bigger gaps can occur between the log and the mortar. These gaps can be filled with mortar afterwards.

The smaller the logs are the less movement they will produce and there will not be such big gaps. The same goes for split logs since they are also small.

2.9. The cordwood logs – drying of the logs

The logs should dry for a minimum of one year and can very well dry for two years. It can be attempted to dry them to 12% moisture content which is the value of straw bales dried in an industrial dryer. Moisture content can be measured by using a moisture meter which is an electronic device that does not cost much to buy.

The logs are best dried in a barn with protection against rain and snow. The logs should be set to dry in a well aired manner (not stacked so densly) and up from the floor with air underneath.

There must be entrance of new air into the barn so that there is exchange of air and humidity does not build up.

Follow the drying process of the logs. If some of the logs start developing a strange colour or if they are sensibly moist then act quickly to save the wood by giving more air to each log, or move them from the moist ground level of the barn to the dry second level etc.

2.10. Cordwood walls

There are basically three types of cordwood wall as shown in Fig. 10.

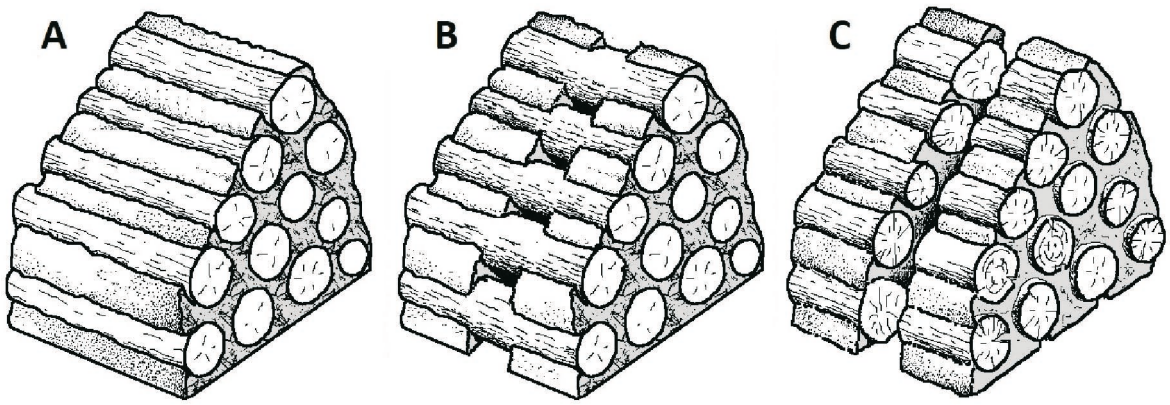


Fig. 10. A: Single wall with logs and mortar. B: Single wall with logs, mortar and insulation. C: Double wall with mid insulation layer; source: [Szewczyk, n.d., p. 10].

2.11. Cordwood walls – single wall – logs and mortar

The most basic cordwood wall construction is to simply put the logs in the mortar and build the wall with that technique. This is type A in Fig. 10.

Fig. 11. Construction technique of cordwood masonry in it's most basic form; photo by: [Kalamazoo College, 2014].

2.12. Cordwood walls – single wall – with insulation

The insulation capacity of the cordwood wall can be increased by exchanging some of the volume of mortar with volume of insulation. This is done by using mortar to support the logs in the end sections of the logs (interior and exterior parts of the wall) and the free space which remains in between is filled with insulation. This is type B in Fig. 10.

Fig. 12. Mortar is not being used along the entire length of the logs, so that a free space is made in the center. This is filled with insulation, here sawdust; photo by: [Flatau, n.d.d].

2.13. Cordwood walls – double wall – mid insulation layer

The most well insulated cordwood wall is the double wall technique. It is actually two separate cordwood walls with some room in between them for a layer of insulation. This is type C in Fig. 10.

In ecological construction it is sought to avoid the use of solutions such as oil based membranes and glass wools.

Ecological insulation can be wool mats, straw bales or straw insulation elements.

One advantage with the double wall technique is that the outer wall can be built during the warmer part of the year while the temperatures are not too cold for the mortar. When the winter part of the year is getting closer, the outer wall is completed and the house enclosed. The self builder can thus complete his work inside a heated house and put in place the insulation and the inner cordwood wall.

2.14. Exterior of cordwood walls

A cordwood wall can be clad or left unclad. Unclad is often chosen for the aesthetical expression. Clad on the other hand gives an outer appearance as a regular wooden house with wooden boards, or as a cement house if clay based plaster has been chosen. Clad or unclad will work well either way for a cordwood wall.

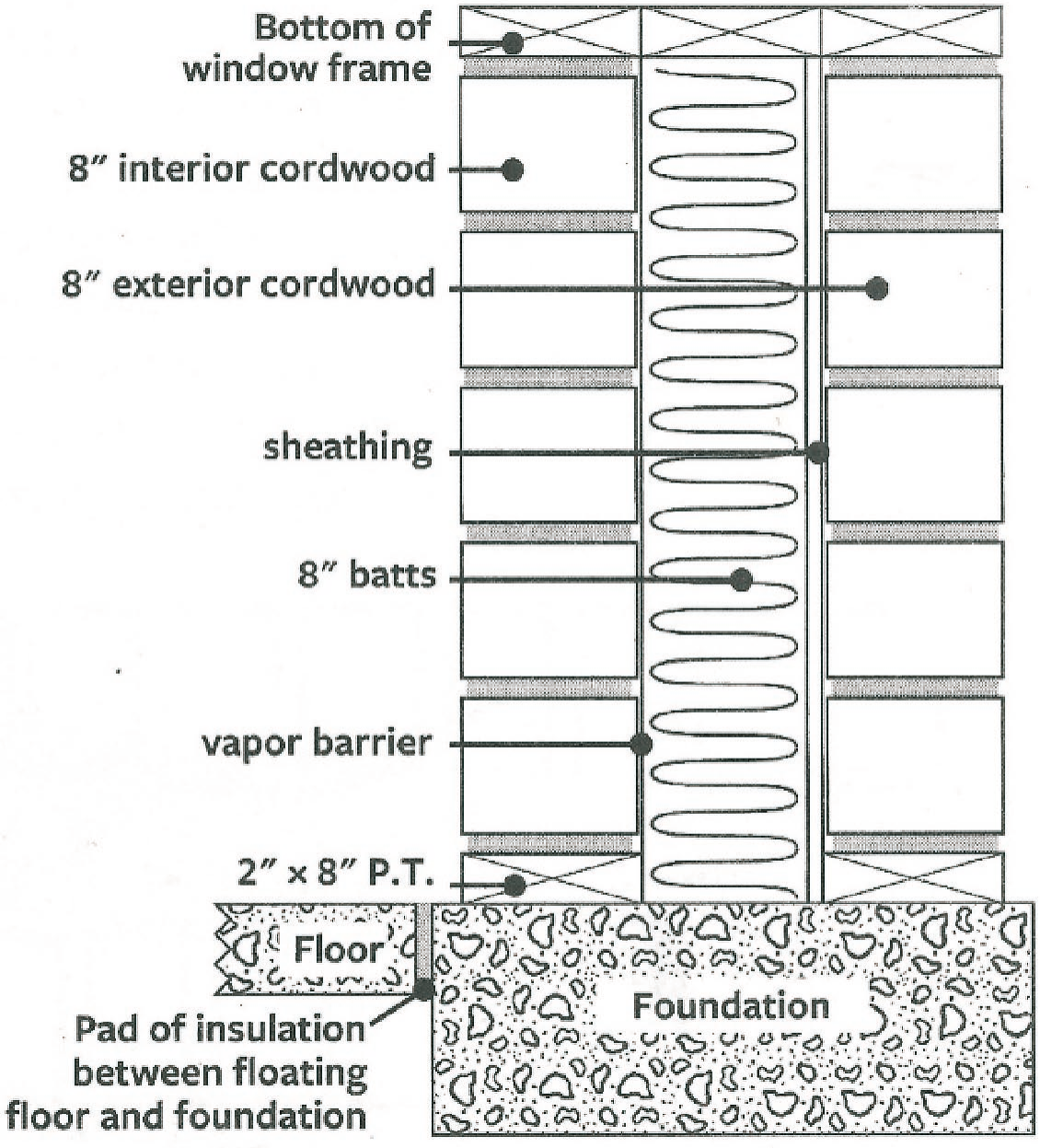


Fig. 13. This is the solution that has been used by Cliff Shockey in Canada; source: [Pichelman, n.d., p. 71].

2.15. Exterior of cordwood walls – unclad walls – log stacking

When the work has finally commenced and the walls are being built, then it is important that the exposed cordwood log endings are positioned with sufficient space in between them. They must not be in contact with each other or very near being in contact.

This is because if two wooden endings are touching or close to touching each other then liquid water can accumulate there. This will over time lead to rot or fungus in that part of the wood.

It is also worth noting that it is common among cordwood builders to let the logs stick out by 0,5 – 1,25 cm from the mortar part of the wall. This creates a visual effect that is attractive.

2.16. Exterior of cordwood walls – unclad walls – pointing

While the cordwood wall is being built with logs and mortar, it is also common to do something called “pointing”. By the use of a tool that has to be found or invented, for example a bent kitchen knife, the builders

apply pressure and movement against the mortar in between the log endings. This smoothens out the surface which makes the wall better looking, the exterior more water repellent and the interior less likely to collect dust particles.

2.17. Exterior of cordwood walls – clad walls

A cordwood house can be clad with wooden boards or clay based plaster. Cladding with clay based plaster seems to have a preserving effect on the wood.

The advantage of cladding is that it allows you to work faster when building the cordwood wall since you don't have to mind the aesthetical expression. The cordwood logs don't have to be placed so exact. In addition not having to do "pointing" is particularly time saving. A cladded wall is also easier to keep clean (O. Hagman 2022, pers.comm. e-mail 09.04.). See Fig. 17 where a clad cordwood wall has been opened, where the wood logs seem to have been a bit "thrown in". Obviously this made the work of building a lot more efficient.

2.18. Exterior of cordwood walls – clad walls - examples

Fig. 14. This cordwood house stands in Sweden. It was built in the 1870s or 1880s. It is clad with clay based plaster; photo by: [Hagman, 2016].

Fig. 15. A cordwood house located at Veset farm in Norway. It was built in the last part of the 1800s and is in use today as a house for living. It is clad with wooden boards like a regular Norwegian house. The cordwood wall can be seen in Fig. 16 and Fig. 17; photo by: [Nordbye, 2016].

2.19. The load bearing structure

A regular house has a load bearing framework that supports the entire house. Framework works fine for a cordwood house also. This entails that the cordwood with the mortar is used to fill in the frame sections of the house.

The advantage with load bearing framework is that the roof will be set up first, and this provides dry conditions for setting up the cordwood walls. The walls that are being built with mortar that needs to dry and the construction materials that need to be stored somewhere will be sheltered from rain. The self builder will be working under the shelter of a roof.

The other option is to build cordwood walls without framework. With such walls it is the cordwood and mortar that support the weight of the house. These are called load bearing walls, load bearing cordwood walls in this case. The self builder will have to think of solutions for keeping walls, materials and builders dry from rain.

2.20. The load bearing structure – historical load bearing frame in Norway

Fig. 16. A load bearing frame in a house that was built in the late 1800s in Norway. It stands at Veset farm and is still in use today as a house for living. The picture was taken during restoration. A closer look at the cordwood can be seen in Fig. 17. The finished result can be seen in Fig. 15; photo by: [Nordbye, 2004].

Fig. 17. A closeup of the wall in Fig. 16. The cordwood has horisontal battens in place in between each third row of logs for the most. This was done to give some stability to the cordwood and mortar filling of the wall; photo, by: [Nordbye, 2004].

2.21. The load bearing structure – newer load bearing frame in North America

Fig. 18. An example of a load bearing frame with roof, and afterwards the work of making the cordwood wall; photo by: [Flatau, n.d.].

2.22. The load bearing structure – historical load bearing cordwood walls in Norway

Historical cordwood constructions in Norway can have load bearing cordwood walls. They have horizontal battens in between the layers of logs, and the corners are made with logs in a 90 degree overlapping pattern.

The battens are placed in between each layer of logs. The battens are thinner than the walls, therefore there is one batten in the outward facing part of the wall and one batten in the inward facing part of the wall. The space in between the battens is mortar filled. See Fig. 20.

The corners of the constructions have logs placed on top of each other in an overlapping pattern of 90 degrees to contribute to good anchoring of the corners.

The structure as a whole is made to be as stable as possible. The battens stabilise the walls and so do the overlapping corner logs. The mortar part is made very thin between the wooden parts. In some instances (some constructions) there is so little mortar that wood rests directly on wood.

In the constructions where there is mortar between the parts of wood, then it is both the mortar and the wood that are bearing the structure.

In other instances where there is less mortar so that for the most part wood rests directly on wood and the mortar is just filling empty spaces, in these instances the wood alone can be said to be bearing the structure.

The advantage of using little mortar is that it becomes more efficient to build the house. Less masses of clay-containing soil to dig up and transport, and less mortar to mix. In short, the volume of mortar in the walls has to be elaborated much more by the builder, while the wood logs to a greater degree bring a premade volume to the walls as premade construction elements provided by nature.

It can also be added that less mortar means less usage of water, which means less movements in the wall [O. Hagman 2022, pers.comm. e-mail 09.04].

There is always a part of mortar separating the parts of wood however thin, so there is no continuous vertical wood on wood contact. In this case both the wood and the mortar are load bearing.

Fig. 19. A cordwood construction set up in Norway in 2008. The logs are reused wood from an older log house (lafteverk[2]) that had to be demolished. It is based on the historical cordwood construction technique in Norway. There are horisontal battens in between each layer of logs. The corners have logs placed on top of eachother in an overlapping pattern of 90 degrees; photo by: [Stenby, 2021].

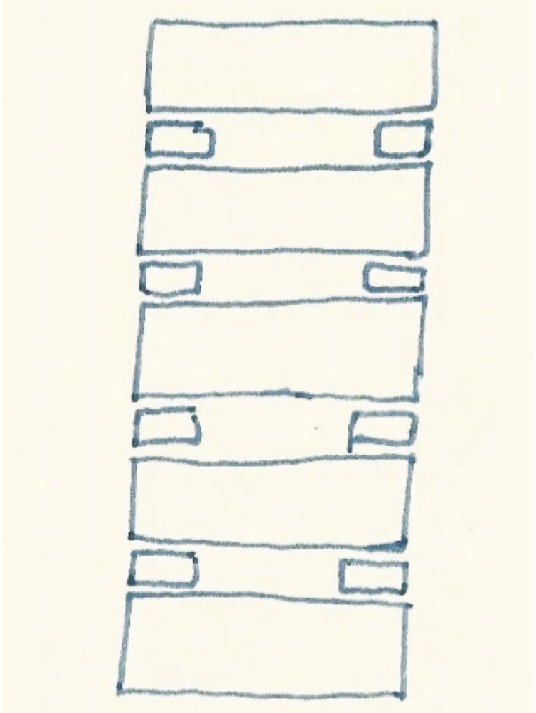


Fig. 20. A schematic drawing of the structure of the walls of the construction from 2008 in Norway in Fig. 19 and Fig. 21. The walls have horisontal battens in between each layer of logs. One batten in the outer part of the wall and one batten in the inner part of the wall. The space in between the battens is filled with mortar 2021; photo: by the author.

[2] *Lafteverk* is the Norwegian word for the construction technique of a log house.

Fig. 21. Closeup of the corner of the 2008-construction in Norway in Fig. 19. The corners have logs placed on top of eachother in an overlapping pattern of 90 degrees. There are battens in between each layer of logs. There is always a part of mortar separating the parts of wood; photo by: [Stenby, 2021].

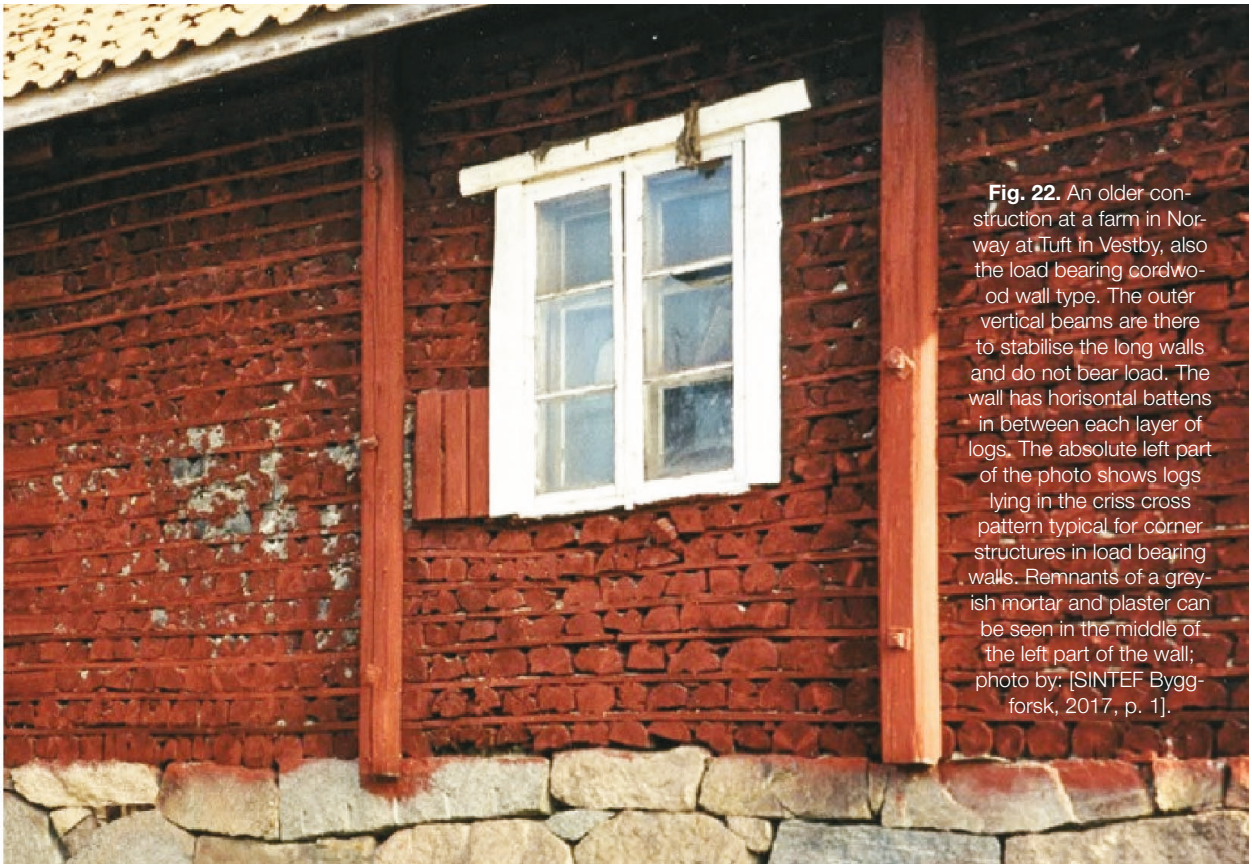


Fig. 22. An older construction at a farm in Norway at Tuft in Vestby, also the load bearing cordwood wall type. The outer vertical beams are there to stabilise the long walls and do not bear load. The wall has horisontal battens in between each layer of logs. The absolute left part of the photo shows logs lying in the criss cross pattern typical for corner structures in load bearing walls. Remnants of a greyish mortar and plaster can be seen in the middle of the left part of the wall; photo by: [SINTEF Byggforsk, 2017, p. 1].

Fig. 23. A closeup of the wall seen in Fig. 22. There is for the most part wood resting on wood, so there is continuous vertical wood on wood contact. In this case the wood can be said to be load bearing for the most part alone [SINTEF Byggforsk, 2017, p. 3].

2.23. The load bearing structure – newer load bearing cordwood walls in North America

The newer constructions in the USA and Canada (from the 1970s and onwards) seem to have a mortar that is based on Portland cement + lime as the binding agent, or solely a premade lime-mix as the binding agent.

The mortar part of the dried and finished cordwood walls based on these binding agents have more strength than clay based mortar can give. Such walls can be assumed to have the load bearing capability in the mortar part alone, not in the wood part. This seems to be confirmed by the prevalent theme about how to fill the gaps that occur between the wooden logs and the dried mortar due to schrinkage of one part or both. Since there are gaps then it seems to confirm that the mortar part is sturdy enough to bear the load alone.

Fig. 24. Two floors cordwood construction with load bearing walls in North America; photo by: [Roy, n.d.].

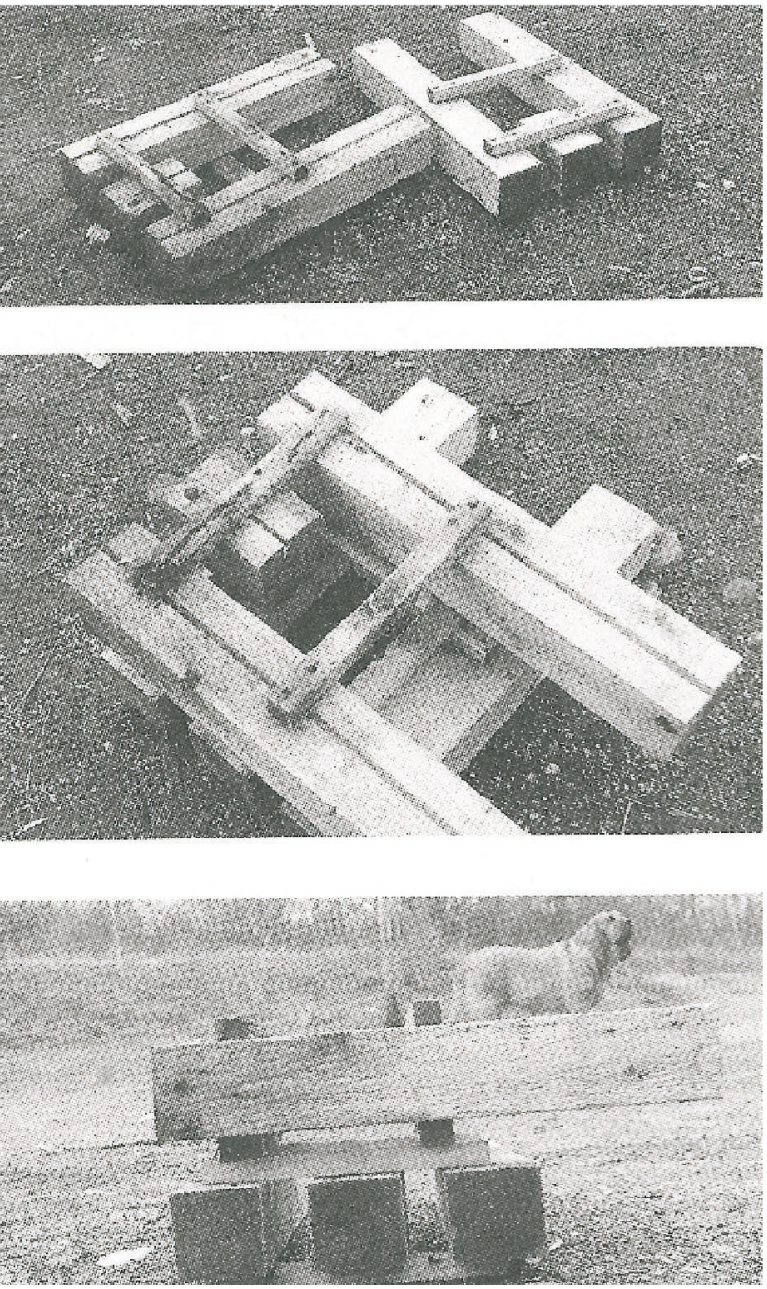


Fig. 25, 26 and 27. An overview of a type of a Lomax Corner unit to see the design and how they are stacked. The dimensions of the beams in thickness and length can be different for different projects, photos by: [Roy, 2003, p. 46]

2.24. The load bearing structure – corners

Regular cement houses can suffer from corners that have movement outwards, so that the corner tilts out and produces cracks going all the way from the ground to the roof. Cordwood houses experience the same forces acting upon the house, so that if there are no load bearing posts in the corners then the corners must be secured in some other way. The cordwood house must have secure corners that cannot tilt out and produce cracks.

This is done by anchoring the corners to the walls.

2.25. The load bearing structure – corners with horisontal battens

In the instance of cordwood walls with horisontal battens that run from corner to corner or to a window frame, the wall endings are secured to the rest of the wall. The horizontal battens stabilise the wall endings by anchoring them very well to the rest of the wall. It is important to criss cross the logs that make the corner so that the corners are unified. The battens and the criss crossing logs prevent the corners from tilting out and producing cracks.

See Fig. 19, Fig. 20 and Fig. 21 for examples.

See also Fig. 22, in the left corner of the photo where the corner structure can be seen.

2.26. The load bearing structure – Lomax Corner

Load bearing cordwood walls that have free stacking of logs in the mortar (no battens) must have the corners anchored in some other way. This is done by using a Lomax Corner.

The Lomax Corner is an anchored corner that consists of premade equal units that are stacked to make the corner. The units are made by the self builder at the construcion site and the measures are adapted to the needs of the construction project. It is a well tested, solid and time saving concept.

See the Fig. Fig. 25, 26 and 27. See also Fig. 28.

It is important to make all the units that are needed for the project at the same time. This saves time and gives an exact execution with reliable measures.

Important: There is a groove running lengthwise on one side of each square beam. This is made with a chain saw. It is for increasing the hold between the mortar and the wood, and it is very important.

Fig. 28. An example of Lomax Corner for securing corners. The units have one less batten in height than in the example in the black and white pictures designated Fig. 25, 26 and 27. They also have a central opening. This is the individual project variation; photo by: [Cordwood Construction, 2019].

It is recommended to stack them somewhat high first and fasten them, perhaps with vertical battens or boards nailed to the sides. This makes the rest of the work pass more efficiently.

2.27. The load bearing structure – anchoring of internal walls

This anchoring of the corners must also be done in internal corners where an internal dividing wall connects with an external wall. This will help interlock the entire house and make it a solid structure.

Fig. 29. Example of Lomax Corner type for anchoring also the internal corners (the nearer corner to the left in the picture); photo by: [Flatau, n.d.].

2.28. Mortar and plaster for cordwood – clay resources

The ideal for all ecological construction is to make use of local resources that have not passed through an industrial production process which uses energy and resources and involves longer distance transportation. Indeed also this gives a construction project a much nicer price for the self builder.

Clay is a good binding agent for mortar and plaster because clay has the ability to bind together other bodies such as silt, sand, gravel and fibers. This is what makes clay used as the binding agent in mortar with sand and straw.

In more or less one third of the agricultural land in Norway there are good clay resources. The soil profile has a marked transition between a brown and more organic top layer – and an underlying grey layer which has a higher content of clay. It is that grey, clay rich layer which is interesting for ecological construction. This clay-containing soil is commonly thought of as just clay and is known as blue clay (blåleire [3]) even though it is grey in colour.

Clay is defined as particles with a diameter below 0,002 mm and laminar in structural form, and the particles are of certain mineral origin. The Norwegian clay consists of a mixture of the minerals kaolin, illite and smectite, as well as crystalline quartz (Egge 2016).

Fig. 30. Dried Norwegian clay-containing soil, 2015; photo by the author

2.29. Mortar and plaster for cordwood – mortar ingredients

- straw 10 cm length
- clay-containing soil
- sand for construction
- water

(M. Aresta 2021, pers.comm. online conversation September)

The straw must come from bales that are dry and healthy, free of moisture and fungus.

The clay-containing soil is found locally.

[3] *Blíleire* is the Norwegian word for *blue clay*.

The sand must be construction sand, which means that the sand must be bought. Free sand found in nature or on the property will not suffice and will only result in a failed mortar. Sand grains need to have the right form so that the clay particles can get a large enough surface to connect to.

2.30. Mortar and plaster for cordwood – mortar ingredient functions

Sand is important in giving volume and load bearing capability to the mortar (M. Aresta 2021, pers.comm. online conversation September). The sand like the wooden logs do the job of bearing load in the wall.

Clay is the binding ingredient. It finds space in between the grains of sand and pulls on them, keeping them together. Without clay the sand would just "pulverise" and flow out like sand.

Straw reinforces the mortar by counteracting pull or push forces. Clay pulls hard enough together to produce cracks in the mortar, which is why we see clayish soil with cracks when the ground is dry. The load of the house will also exert force on the mortar. The straws extend in the mortar and counteract cracking movements.

2.31. Mortar and plaster for cordwood – mortar ingredient amounts

There is no exact recipe with the exact quantities. Making clay based mortar means using the local resources and see how they go together because the clay-containing soil, sand and straw are not standardised and will have local variation. The first thing to do is some experimenting and discover how different quantities of the different ingredients result.

These amounts are worth trying (M. Aresta 2021, pers.comm. online conversation September):

- 1 part straw
- 1 part clay-containing soil
- 2 parts sand

It is possible that the amount of straw can go up to 2 parts.

Just measure the parts by using a bucket as volume parts.

Mix in a cement blender with water.

How to know how much water to use? "*Take a ball out of the concrete mixer. It should be the size of a handball. Throw it straight and high up into the air using both hands and let it fall on the ground. The ball should hit the ground without falling apart and it should not make a splash. This is a dry mix.*" (M. Aresta 2021, pers.comm. online conversation September)

The purpose and functionality of this mortar is to fill out the space in between the logs and provide adequate foundation for the logs. This mortar is not meant for sticking to a vertical surface. It must not be added more water than making it possible to work with and raise the wall. The logs must not slide out because of a too watery mortar (M. Aresta 2021, pers.comm. online conversation September).

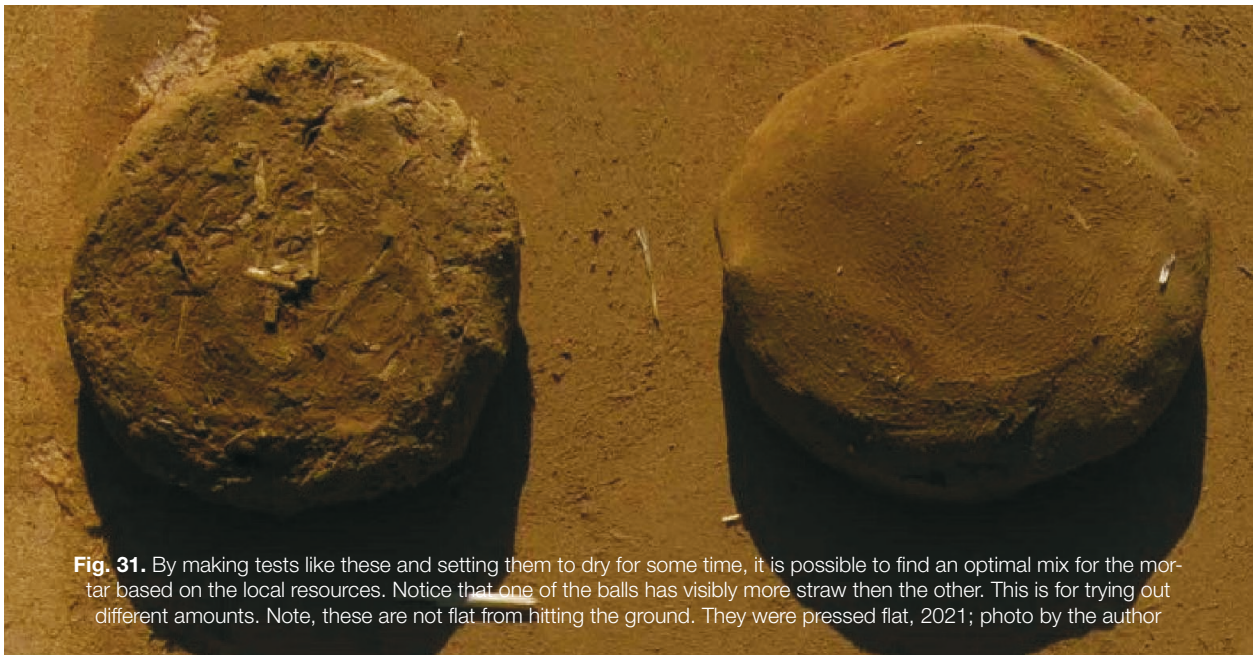


Fig. 31. By making tests like these and setting them to dry for some time, it is possible to find an optimal mix for the mortar based on the local resources. Notice that one of the balls has visibly more straw then the other. This is for trying out different amounts. Note, these are not flat from hitting the ground. They were pressed flat, 2021; photo by the author

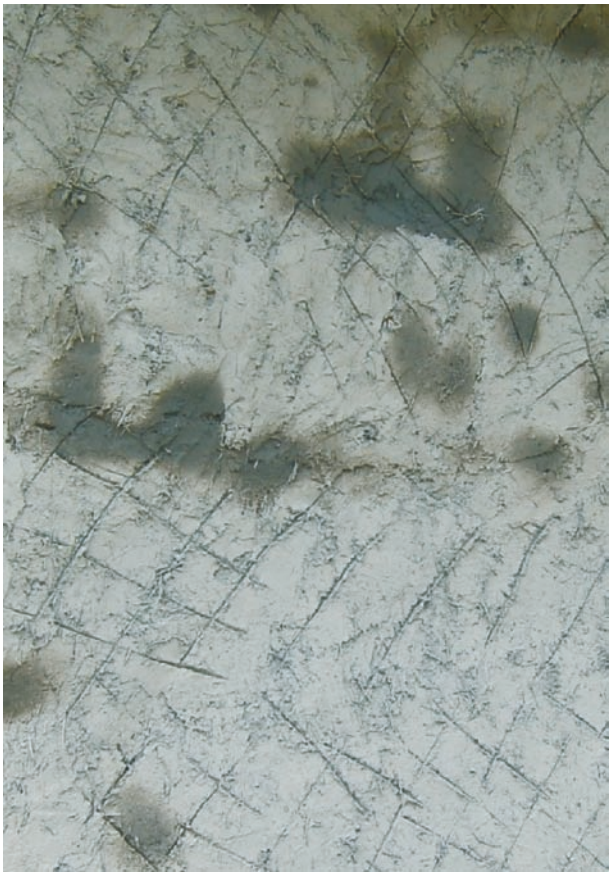


Fig. 32. Clay based mortar on a straw bale house. The mortar is naturally coarse and intentional cut marks have been made to make the coming plaster layer stick better, 2015; photo by the author

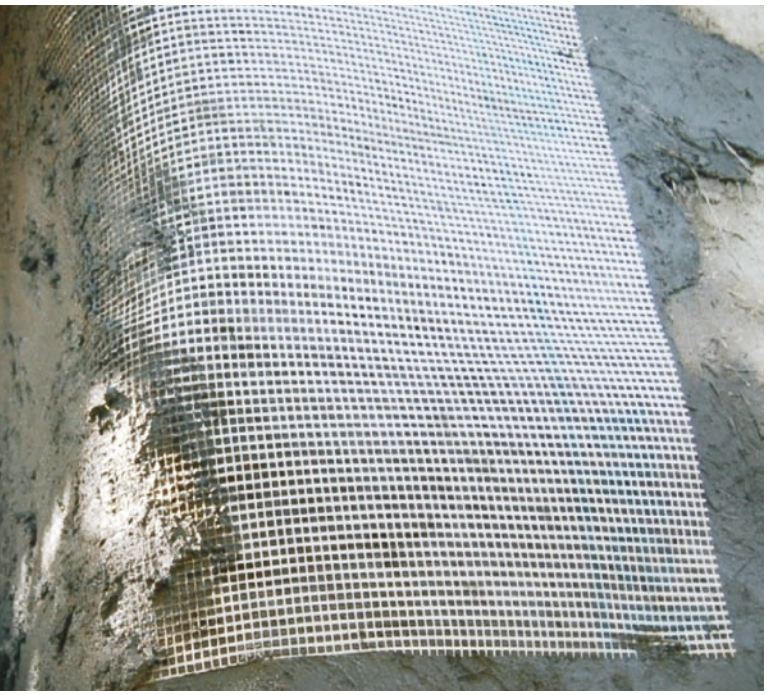


Fig. 33. Photo from straw bale house. Glass fiber mesh on first layer to give adherence to the next layer, 2015; photo by the author

2.32. Mortar and plaster for cordwood – mortar mix tests

It is also a good suggestion to build a test cordwood wall or a miniature house, even a year before the real walls are to be built, and see the result.

2.33. Mortar and plaster for cordwood – mortar mix test interpretations

Cracks in any mortar could mean that the clay has too much power since clay pulls things together. A solution could be less clay-containing soil or more straw.

Did the mortar dry in the sun? It could be that it cracked because of the direct sunlight. An experiment to dry the mortar in the shade can be done. If shade works then the mortar mix is fine and the cordwood walls should also be given shade while drying.

If the ball falls apart then there is not enough clay, or straw.

Experimentation is the solution.

2.34. Mortar and plaster for cordwood – plaster for cladding

The cladding consists of three layers;

Layer 1: Foundation

Layer 2: Coarse plaster

Layer 3: Fine plaster

Before the foundation can be put on, the wall must be prepared. First it must have an adherable surface structure. Second, a liquid clay-water mix must be sprayed on for connecting the foundation with the wall.

The steps of the process are elaborated below.

2.35. Mortar and plaster for cordwood – creating adherence on the wall

For anything to adhere to the wall then first the wall must be adherable. For this reason the wall must have or be given a rugged surface which serves as something to grab hold to for the next application.

The clay mortar in between the wooden logs should already have a coarse surface from when put in place. It could also help that it was intentionally made coarser and with markings for the layer of plaster to grab into.

The endings of the wooden logs should also be crude in their surface. This can be made by using a chain saw (M. Aresta 2021, pers.comm. online conversation September).

The endings of the wooden logs can also be fitted with nails that will give the plaster something to grab onto. The nails should be directed slightly upwards.

A mesh can also be fitted on the cordwood wall to give adherence to the plaster. It needs to be set in wet mortar, and at the same time nailed to the wooden logs.

It can be a mesh of jute fiber or other organic fiber that can be found. Some also use a glass fiber mesh.

2.36. Mortar and plaster for cordwood – clay-water mix

With rugged adherable surfaces on the cordwall wall, a clay-water mix is sprayed on. This mix is necessary for bridging the wall and the foundation. The surface is already sufficiently rugged, but there must still be a connection or a glue that binds the foundation to the rugged surfaces. This is what the clay-water-mix does. Without it, the foundation will fall off the wall.

It is made by dispensing the clay-containing soil in water in a barrel. A sifter can be used to prevent stones from entering the barrel. The barrel is left over night allowing the heavier earth particles to settle closer to the bottom, and the lighter clay particles will be found in a higher phase. The absolute top layer will be more water. All these phases are easily distinguishable. It is the clay rich phase in the middle that is to be extraced and used.

The purpose of this separation of phases is to extract and use the clay particles to the greatest degree and have the highest possible consentration of clay particles. Since clay particles have the ability to hold other elements together, then a clay rich layer sprayed onto the wall will tie the foundation to the wall.

See the making and application of clay-water mix in the figures 34, 35, 36 and 37.

Important: The clay-water mix must dry before the foundation layer is applied.

2.37. Mortar and plaster for cordwood – Layer 1: Foundation

The foundation is made out of long straw because of the need for long fibers. It should be very rich in fibers.

The other ingredient is clay (clay rich soil).

Of course, an amount of water is added.

Fiber gives structure and clay gives hold. This is a structural and holding layer. The purpose of this layer is to coat the wooden logs and prevent that they contract and that the next layer, the coarse plaster, loosens or cracks (M. Aresta 2021, pers.comm. online conversation September). This layer can also be used to even out irregularities on the wall surface and make the wall more even.

Fig. 34. Making of clay--water mix, 2021; photo by the author

Fig. 35. The propeller, 2021; photo by the author

Fig. 36. The right consistence of clay-water mix, 2021; photo by the author

Fig. 37. Spraying on the clay-water mix. In this case it is on straw bale but it serves as an example, 2021; photo by the author

Fig. 38. Clay and straw mix being made, 2021; photo by the author

Fig. 39. A finer plaster layer has been plastered onto a coarser layer. Still the finer layer can be worked even finer. This is ”blue clay” in Norway, 2014; photo by the author

Fig. 40. Experimentation with plaster mixes. The mix on the right has cracked because of the power of the clay to pull together. The mix on the left has the same amount of clay but it has been reinforced with straw. Straw counteracts the contracting of the clay and thus prevents cracking, 2021; photo by the author

There is no particular minimum or maximum thickness of this layer. This is simply a layer needed to apply the next layer.

The foundation has to dry before the next layer can be put on.

2.38. Mortar and plaster for cordwood – Layer 2: Coarse plaster

This is the main body of the two plastering layers with 2,5 cm thickness. The mix is the same as stated above for the mortar that was to put in between the cordwood, in the section 2.31. *Mortar and plaster for cordwood – mortar ingredient amounts*. The only difference might be more water so that it becomes more applicable on the wall.

2.39. Mortar and plaster for cordwood – Layer 3: Fine plaster

- 1 part clay (clay rich soil)
- 2 parts very fine sand
- 1 part dried horse manure (contains fibers worked by the horse's digestion)
- 4% sunflower oil or linen oil
- or also up to 10% paste (premade glue mass, made out of flour or starch boiled in water)
- water

This is a finer layer that will display a final smoother surface on the outside of the wall. This finer layer can be applied with some care and finer motions, and with a less crude tool. Of course the finer sand is part of what makes it a very fine surface, but the craftsman can also add smoothness by a careful execution and contribute in this way to the great result.

The thickness of the layer is not its purpose, the functionality of the layer is its purpose. Therefore, this layer should be used to smoothen things out and achieve a finer surface. If the coarse plaster has some uneveness then this finer plaster can be used to even that out.

2.40. Main structures – electrical wiring

In new houses today all electrical wiring is put inside the wooden walls in bendable tubes. The same principle applies to cordwood walls as long as there is internal insulation in the cordwood walls.

If the choice has been a cordwood wall without internal insulation then the electrical wiring can be put on the exposed indoor part of the wall.

Before starting the building of the house there must be a plan, a wiring diagram for all the electrical wires, connecting points, switches, fuse box etc. Every detail in the house's electrical set-up must be in the plan so that the cordwood walls can be built for that set-up and the tubes for the electrical wires can be built into the walls according to the plan.

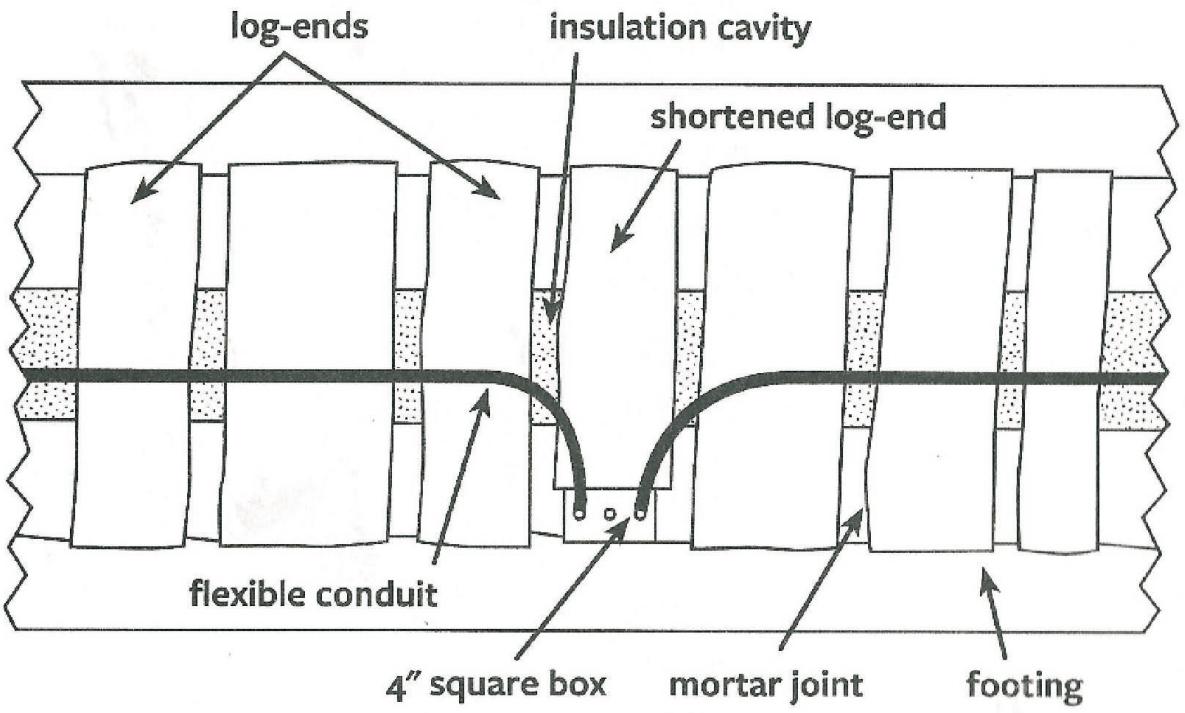


Fig. 41. Example of how electrical wiring can be built into the cordwood wall in the insulation part; source: [CoCoCo, n.d., p. 100].

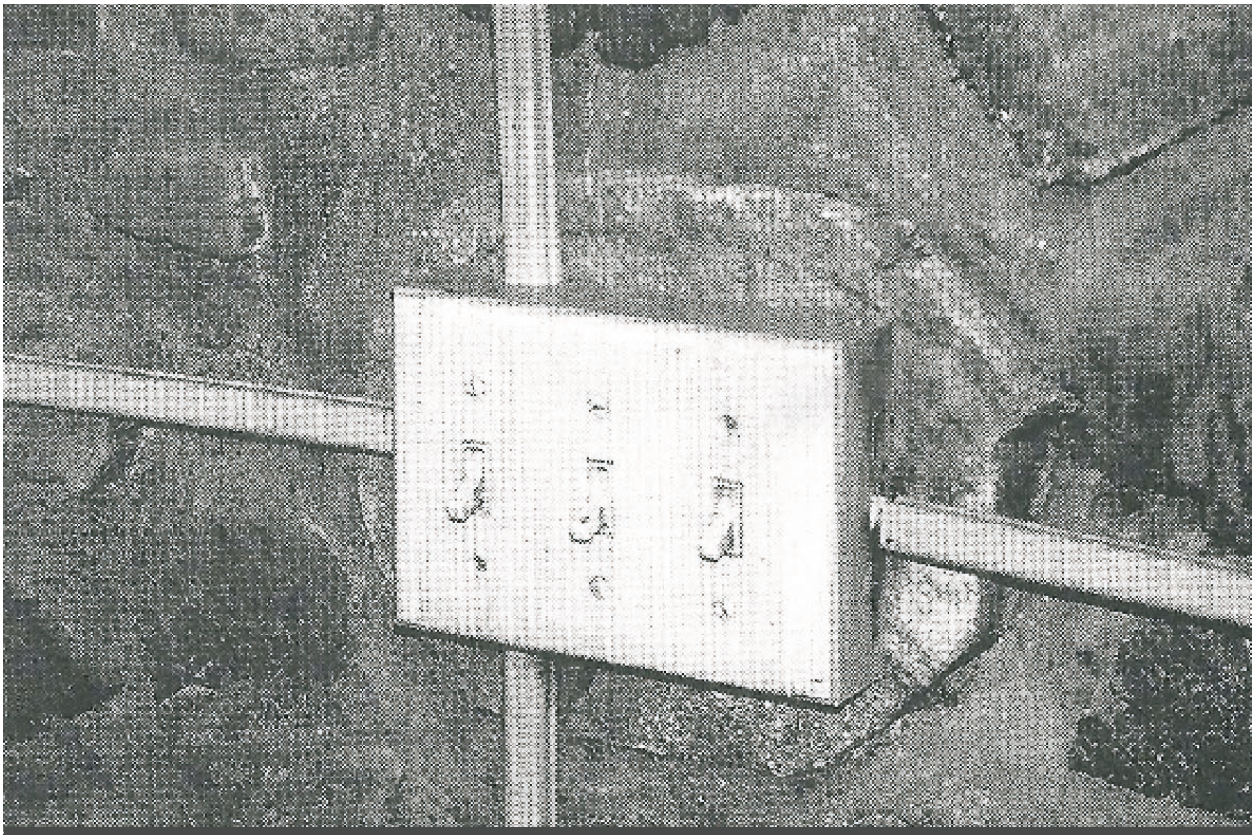


Fig. 42. An example of how electrical wiring and applications can be mounted on the exposed inside surface of the cordwood wall. The wires are protected in adequate tubing that can be mounted to the wood; photo by: [Roy, 2016, p. 101].

2.41. Main structures – foundation

The foundation for the entire construction can be a sole made of Portland cement. This is a common practice in Norway when building a house.

Up from the cement sole it would make an adequate solution to put a ring wall of bricks of 40 cm height. This is the minimum height from the ground that the cordwood wall must have at any point around the house. 40 cm is a height used for ecological constructions such as strawbale constructions in order to keep a sufficient distance from the humidity of the ground so that the walls will not suffer from moisture damage over the years.

The cordwood wall can rest on the 40 cm brick ring wall with an impermeable membrane in between the cordwood wall and the bricks. An example of a somewhat different solution can be seen in Fig. 43.

Fig. 43. The outside of a straw bale house, showing a sufficient height from the ground level of the sole of Portland cement. There is first a sole of Portland cement, then blocks and finally bricks. There is an impermeable membrane laid on top of the bricks, 2021; photo by the author

2.42. Main structures – roof

A cordwood house with exposed clay based mortar or plaster must be built with a roof that extends far enough out from the walls so that the cordwood walls do not recieve any direct rain. Over time, direct rain could wear away the mortar.

2.43. How big can the house be?

The size of a cordwood construction to set up for two persons should be no more than 110 m^2 [Roy, 2003, p. 186].

The time window for setting up a cordwood house is during the warm period of the year. The drying of the mortar must take place during the time when there is no night frost. Night temperatures below zero while there is still water in the mortar will cause frost damage in the form of expansion. The mortar needs some weeks to dry before frost nights set in during autumn.

Fig. 44. Cordwood house with large roof overhangs so that rain will not hit the mortar directly in any place. (There can also be seen a good ringwall up from the ground); photo by: [Flatau, n.d.].

For the integrity of the construction, and commonly for having a place to live in, it is important to be able to close the outer wall of the construction in good time before the winter. The construction must not have an open outer wall during winter.

It should not be underestimated how work intensive such a project can be. The work load is big enough to put a strain on a relationship and can very well result in a divorce. However with good enough planning and keeping the project within limits it will be a strengthening experience for a couple and a family. If 110 m^2 is too little then the house can be expanded during the years.

3. DISCUSSION

3.1. Techniques

The three cordwood wall types 1) single wall, 2) single wall with insulation, and 3) double wall technique, are three easy to build logical adaptations to building with cordwood and mortar. From the first and simplest technique of just a single wall of logs and mortar to the next of single wall with an insulation chamber, there is a natural step of adaptation and improvement ending in more complexity and better function. The double wall technique with an entire mid insulation section is yet another step in a natural evolution of the cordwood wall technique for improved insulation performance.

3.2. Techniques – characteristics

Type 1 single wall - gives an impression of being the most straight forward and easy wall to build for an unexperienced self builder. It must also be the most stable wall type of the three types due to the massiveness of the mortar and full log-length-thickness of the wall. Type 2 single wall with insulation – is less massive than Type 1 but still seems stable, and it has a better insulation value. Type 3 double wall technique – gives the impression of being the least stable wall because you would have to reduce the length of the logs, however it would get the best insulation value due to the uninterrupted centered insulation space.

3.3. Tree species

The historically used tree species in Norway show that there was a clear knowledge of which species to use. Spruce, aspen and pine were most used. Birch could also be used but it was less common. These are all lighter airier woods which provide better insulation and less expansion during construction. The newer cordwood construction in North America also prefers the use of lighter airier tree species.

3.4. Clad or unclad

Cordwood masonry results in wind proof walls in unclad state. The exposed end pieces of wood logs of the unclad cordwood walls have no particular problem with external humidity. Rain is not a problem with sufficient distance from the ground and a well extending roof. A cordwood house with exposed logs can last for a hundred years and still be in good condition.

Cladding gives the advantage of a faster execution because of not having to make the cordwood masonry aesthetically pleasing. Cladding with wood boards can be done during the cold season and cladding with clay based plaster can be done next warm season.

3.5. Load bearing

Cordwood functions well with a regular framework for houses as a load bearing structure. Of course, a load bearing framework has the great advantage of providing a roof which gives protection from rain and sun during the construction period of the cordwood walls. For this reason it is highly recommended.

Load bearing cordwood walls is a possibility. In particular the historical technique much present in Norway with horizontal battens put in between each layer of logs for stability, gives the impression of it being a quite stable construction. The same impression is given by Lomax Corners in other load bearing cordwood walls.

3.6. Execution

The wood and the clay-containing soil are unaltered natural resources and can have some natural variation, but as long as they are used correctly they will not be the reason for any unwanted results. The wood will work fine as long as it is dry enough and has not suffered any moisture damage during drying.

The mixing of mortar and plaster has more potential to produce a more variable result, and it is therefore important to try it out and get some experience before starting to build a house. There is much valuable experience in participating in courses and making some minor construction projects just to test things out in practice beforehand.

3.7. Unanswered questions – heavier denser woods

Might there be a third advantage to using light and airy woods instead of heavier denser woods? Reason one and two were stated to be better insulation and less expansion. Could there be a third factor – that heavier, denser woods might be less efficient at transporting humidity through the wall? The reason would simply be that higher specific weight means more wood and less air in the same volume of wood log, and thus the humidity will not have so much free space to move through.

3.8. Unanswered questions – birch bark

Birch bark is water proof. It has traditionally been used for roofing in Norway. Birch bark was laid first and then turf was laid. Greens would grow on top of it. The durability of the birch bark could easily be 70 - 100 years if all was done correctly.

This raises the question if using round unsplit logs of birch with the bark still intact on the logs would prevent the water in the mortar from reaching the logs during building of the cordwood wall. Would there be no swelling and expansion of the logs in the wall? Would there be less movement in the wall during construction than with the other lighter woods?

The problem with fungus beneath the bark can be avoided by felling the birch tree at the right time of the year.

3.9. Unanswered questions – clad vs unclad and transportation of humidity

Possibly the transportation of humidity from the inside environment of the house passes more efficient when the cordwood wall is not clad with clay based plaster. Possibly the transportation of humidity from the inside

environment of the house to the outside environment goes much less efficient as the log endings do not have free respiration.

Possibly cladding the cordwood wall with wood boards will also hamper the transportation of water molecules through the wooden logs. Wood placed sideways should transport water molecules slower than wood placed in accordance with its original lengthwise transportation route for water molecules.

3.10. Suggestions for further research

- Finding values for thermal transmittance U (W/m^{2}K) for the corwood wall. These values are for using in the building application by the self builder:
    - Values for different woods lengthwise.
    - Values for different mixes of clay based mortar.
- Do lighter, airier woods transport humidity more efficiently than heavier, denser woods because logs of heavier woods have more wood volume and less free space volume for movement of water molecules?
- Does intact birch bark on unsplit logs stop water in the mortar from entering the wooden log, and do such logs produce less movement in the wall than other lighter wood species without bark?
- Is humidity transported more efficiently through an unclad cordwood wall than a clad cordwood wall, due to the log endings being open and having free diffusion?
    - Diffusion through unclad logs.
    - Diffusion through logs clad with clay based plaster.
    - Diffusion through logs clad with wood boards.

CONCLUSIONS

Technique of recommendation – single wall with insulation

It is my recommendation to use technique number 2; single wall with insulation. This wall will be better insulated than the single wall that has no space for insulation. This technique is also easier to make stable than the double wall technique.

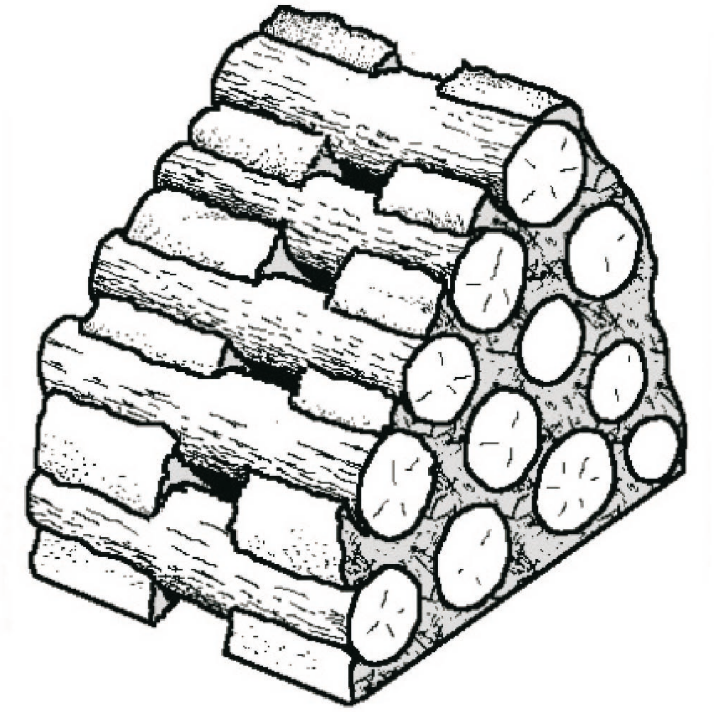


Fig. 45. Single wall with insulation; source: [Szewczyk, n.d., p. 10].

Recommended tree species

Spruce is the lightest and airiest among the historically used tree species in Norway and will yield the best of the desired prestations. Because of that I recommend it as the choice of wood for building a cordwood construction in Norway today.

Clad and unclad

Unclad can be a question of preferred aesthetical expression, while clad can be a preference of faster execution of the cordwood masonry. There are many old cordwood houses with clay based plaster cladding and wooden board cladding. Both options work fine. Cladding thus is optional.

Load bearing

Cordwood masonry works fine with load bearing framework, and cordwood masonry is capable of carrying load by itself when built properly. It is therefore a question of choice depending on the conditions one wishes to put into the project.

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