

BLENDING LIGHT EARTH AND TIMBER FRAME TECHNIQUES AS FUTUREPROOF CONSTRUCTION METHOD

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ABSTRACT: *In this research, the use of the light earth construction method is assessed on its possibilities to be implemented in existing building systems, especially its compatibility with futureproof timber construction, while meeting contemporary housing requirements. Combining clay and fibres in various proportions will achieve different technical properties, that can be applied in diverse building elements, to reach futureproof housing requirements. In the Netherlands, clay is available, and a sustainable approach involves reusing excavated soil to avoid overexploitation. The interaction of building elements in timber structures can lead to hybrid systems. Light earth, traditionally an infill for timber frames, can potentially be applied to various timber systems.*

KEYWORDS: *Light Earth Building, Biobased Materials, Timber Frame Structures, Fibres, Clay, Futureproof*

I. INTRODUCTION

1.1. Introduction

In conjunction with the significant housing shortage in the Netherlands, the building sector confronts environmental challenges, specifically related to the materials- and energy transition (MBZ, 2023). The integration of these aspects seems to be progressing at a slower pace than required. The commitment to build simultaneously affordable, sustainable and architecturally the best is considered as complicated. However, this transition is crucial. This urgency is not only driven by the need to achieve the Paris Agreement targets, but also due to the current ways of resource extraction for the building industry, often leading to the over-exploitation of ecosystems elsewhere. One approach to address this challenge is to integrate natural building methods into existing building systems to make the transition more feasible and widen the path to sustainable construction.

Ecosystems provide a great diversity of raw materials including wood, biofuels, and fibres from wild or cultivated plant and animal species. These are some of the material benefits people obtain from ecosystems called ‘provisioning services’ (United Nations, 2024). The most suitable means for harnessing resources for the building industry lies in these services. In the context of the Netherlands, wood and fibres are examples of such provisional services. Additionally, earth is categorized as a ‘supporting service’, another type of an ecosystem service. This means that the formation or preservation of soil within the ecosystem is essential for maintaining the functionality of the provisioning services (United Nations, 2024).

So, raw resources for building materials can be categorised as earth wood and fibres. A natural building method that incorporates these materials, is the light earth construction technique. Its notable potential stems from the diverse compositions of materials and the infilling of wooden structures. In timber construction there is a widespread demand for mass for, among other things, fire protection and as heat storage, a property that the light earth method possesses. Besides, light earth enables its application in various contexts, making it suitable for use on a regional scale.

In the Netherlands, timber frame construction is increasingly favoured for its environmental sustainability. However, the increase of processing of raw wood, in order to produce engineered wood or panels for timber framed structures, generally causes higher values of Embodied Energy and of other environmental indicators, also due to the use of glues and other chemicals (F. Asdrubali, B. Ferracuti, L. Lombardi, C. Guattari, L. Evangelisti, G. Grazieschi, 2017). This presents an opportunity to enhance the existing construction approach by integrating the light earth construction method.

1.2. Scope and research questions

The aim of the research is to explore and understand how the light earth method can be implemented in existing building methods, especially its compatibility with futureproof timber construction, while meeting contemporary housing requirements.

The study will specifically have its focus on the Gooi and Vecht region in the Netherlands as a case study. Consequently, the resourcing for the light earth method will be sought in the vicinity of this area. While fibres are considered provisional services, the extraction of the specific earth requires an examination of residual flows.

This has led to the following question: *‘In what ways can light earth construction methods be incorporated in prefabricated timber frame housing construction methods, using locally sourced materials (earth, wood, and fibres) from the Netherlands, addressing contemporary residential requirements?’*

This question is divided into three sub-questions, following;

1. *‘What types of fibres and earth do we find in the Netherlands and how can they provide for light earth building without over-exploitation?’*
2. *‘What technical performances can be achieved for the various building elements with the light earth construction method?’*
3. *‘How do conventional prefabricated timber structures work, what specifications are essential regarding relevant and futureproof building factors and how can light earth be incorporated?’*

II. METHODOLOGY

The research uses the Gooi- and Vecht region in the Netherlands as a case-study to verify, test and finally apply the research findings as part of a MSc graduation project in architectural engineering. This means that the provision of the resources for the light earth method will be sought in that surrounding using a landscape analysis. Although this research focuses on this area, the building method with light earth could also be used in other contexts.

The next part of the research, focusing on understanding the properties, performances and constrains of the light earth construction method, will be done by literature study. Franz Volhard's book *Light Earth Building* gives the technical performances that can be achieved with light earth building. Different types of mixtures of light earth, each with different properties, are compared on their technical performances. In addition to this, the aesthetic properties of light earth building will be taken into account. This is done by a prototyping approach. Options will be layed-out next to each other.

Following to investigating the light earth method, literature research is being conducted on conventional prefabricated timber elements. This provides an insight of how these structures are used today, which is important to understand for further development with light earth. Next, there will be looked at what needs to be adapted to the existing building method to add the light earth method into it and, in this way, blend the natural building method with the existing techniques.

The results of this research will be translated into a assembly of elements, as a prototype. Which materials are needed for which building elements in a residential building. This shows at once how to implement the use of light earth into existing prefab timber frame construction method(s), complying to future proof housing standards (insulation & comfort, aesthetics, sustainability, etc.).

III. RESULTS

3.1 LIGHT EARTH IN THE NETHERLANDS

As stated in the introduction, the research will first focus on the resources that are needed to make light earth. The question this chapter aims to answer is: *‘What types of fibres and earth do we find in the Netherlands and how can they provide for light earth building without over-exploitation?’* Due to the variability of soil composition across different regions in the Netherlands, resulting in diverse types of provisional services like fibres and wood, this research focuses on the Gooi and Vecht region. The aim is to use this area as a case study to investigate the regional-scale applicability of the light earth construction method. While the method can be adapted for use in other regions, such as incorporating different fibres more readily available there, the study concentrates on the provision of the resources found in that surrounding.

3.1.1 Building ingredient: earth

Earth functions as the binding matrix between the aggregate, with its cohesive capacity playing a crucial role. This cohesive capacity of the earth is very much depending on the grain size of the earth particles (Appendix A). The smaller the particles, the better the cohesion. Looking at the grain sizes occurring in the earth it is clear that clay would be most convenient. Sand has a round grain shape, meaning the sand particles only touch each other on small points on their surfaces. This where clay consists of crystalline sheets, so, when wet, the clay particles slide along each other. But when dried, the surfaces have a great binding capacity. The surfaces of the sheets touch on many places, causing great molecular attraction (Volhard, 2016).

The soil in the Gooi- and Vecht region consists mainly of sandy soil. It is part of the Utrechtse Heuvelrug, here lies an elevated sand layer as a deposit over other soil layers (Smit et al., 2022). But sand does not appear to be the most ideal option for the light earth method. The most convenient type of soil used for light earth is a soil that consists clay. In the Netherlands, we find clay more in the coastal provinces of the western and northern Netherlands, including near South Holland and Utrecht. Flevoland, for example, consists mainly of clay soil, but layers of clay can also be found in the peat soils in and around Amsterdam (figure 1). These so-called clay-on-peat soils occur where a clay deposit extends over a peat: after that peat was formed, it was inundated by river or sea water and clay was laid down on it (De Bakker & Schelling, 1966).

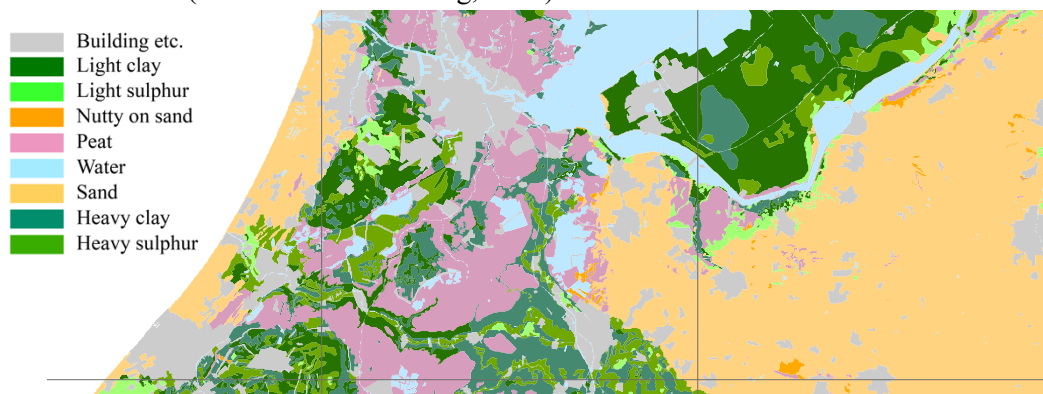


Figure 1. Map of soil types (Wageningen University Research, n.d.)

But how is this clay extracted without exploiting a landscape? You have several organisations for this, which try to reuse released batches of soil from excavation work directly. If this is not directly possible, the soil can also be taken to a so-called soil bank. If necessary, the soil is treated here and then reused in a high-quality manner. Their aim is to reuse this soil in, for example, other building projects where needed. In Amsterdam there is also such an organisation. The large residual soil flows of the big city move through this location. The amount of clay arriving highly depends on what type of construction projects are being done at the time, but it can be stated that between 1000 to 2000 tons of clay is deposited around ten times each year. When going for the lowest number, that is annually 10.000 tons of clay, being 10 million kilograms per year (Velu, 2022).

3.1.2 Building ingredient: fibres and aggregates

Volhard shows in his book more suitable options for the aggregates in the light earth mixture. The most common are straw, woodchip or mineral aggregates. Fibres seem to have a more stabilizing effect on the mixture than the mineral aggregates. There are many possibilities, including dry reed, flax shives, hemp shives or hay stems. The available aggregates also have great influence on the technical properties of the mixture: the insulating property is achieved mainly by the air trapped in the pores and cavities of the aggregate (Volhard, 2016).

In the Gooi and Vecht region there are a more such fibres available. This potential is offered by wet agriculture: reed and cattail in the ponds and peat meadows and arable farming on fertile clay soil of, for example, flax, hemp and straw. Straw yields an average of 4 tons of dry matter per hectare on clay soils, which is about 200 bales. Flax and fibre hemp both yield 6-10 tonnes of dry matter per hectare. However, these numbers can fluctuate a lot because yields are highly dependent on weather conditions and the specific soil quality (Smit et al., 2022). Given the large quantities of light aggregates required, it is simplest and cheapest to produce straw as an agricultural by-product (Volhard, 2016).

3.1.3 Light earth mixture properties

In 1944, light earth was first described as an earth mass mixed with a lightweight aggregate with a bulk density of less than 1200 kg/m³. Medium-grade light earth is 600 to 800 kg/m³ and very lightweight light earth mixtures of around 300 kg/m³ are possible when using a very clay-rich earth. Figure 2 shows that that when the more clay is added to the mixture, the lower the insulating property will be. So, the highest of possible insulation value goes together with the lowest bulk density and thus amounts of clay. The richer the clay, the lower the bulk density can be achieved, and the higher the insulation value can become. The more clay is added to the mixture, the lower the insulating property will be. The clay has a high thermal conductivity value and so transfers heat easily. The bulk density created by adding more clay leads to a higher volumetric heat capacity and fire resistance. In this way, the technique can respond to varying environmental criteria for different situations, using denser mixes on south facing walls, lighter mixes on north facing walls, for example.

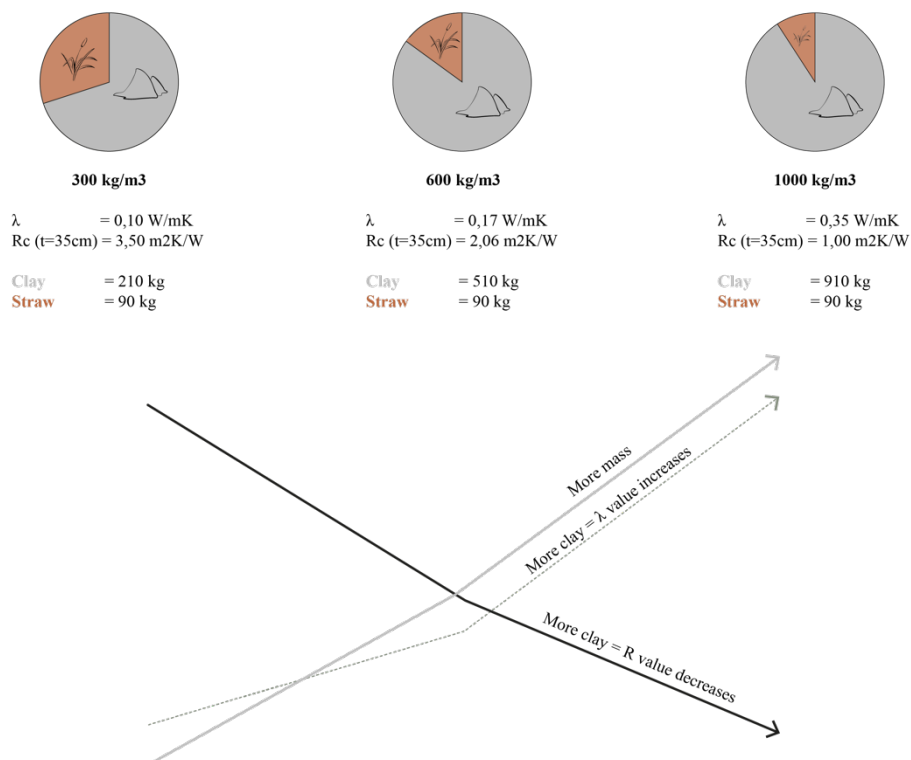


Figure 2. Mixing proportions of light earth (data from Volhard, 2016)

3.2 PROPERTIES OF THE LIGHT EARTH METHOD

Now that we know what materials the light earth method uses, the research will next focus on what properties this building method can achieve. The aim of this chapter has led to the question: *‘What technical performances can be achieved for the various building elements with the light earth construction method?’* To answer this question the book ‘light earth building’ by Franz Volhard is used as main guidance.

3.2.1 Insulation properties

Thermal protection

A material's thermal insulation and ability to retain heat are inversely related: lightweight insulating materials that trap air can insulate well, but do not store warmth well; heavy, dense materials are able to retain well, but also transmit warmth well and are therefore poor insulators. The low thermal conduction of light earth is a factor of the high proportion of air enclosed in the voids in the mass and the minute pores of the straw. The thermal conductivity coefficient, λ (W/mK), is directly dependent on the bulk density of the material, which in turn is determined by the mixing proportions and weight proportion of earth, as well as the degree of compaction. Thermal insulation is a factor of the wall thickness, t , and thermal conductivity, λ , of the material and is expressed as the thermal resistance per unit area: $R = \Sigma t / \lambda$ (m²K/W). The higher this R value, the better the thermal insulation (Volhard, 2016). Today these requirements for R are relatively high in the Netherlands, especially for new buildings, with the prospect of being energy-neutral by 2050. Requirements for a new building in the green landscape of the Gooi & Vecht region are even more demanding. For example, the R value for the façade must be 4,5 m²K/W according to Dutch regulations, but in Crailo - a new neighbourhood in the Gooi and Vecht region, and the casus for this study - this value must be at least 6,0 m²K/W. Roofs for new buildings in Crailo must be 8,0 m²K/W and for ground floors an R value of 5,0 m²K/W is required.

So, thermally insulating light earth make comfortable interior with good room surface temperatures possible. But single-skin external walls made with light earth rarely fulfil today's extreme thermal insulation requirements, as seen in figure 3. With a wall thickness of 55cm and a bulk density of 300 kg/m³ it is nearly enough according to the Dutch regulations for external walls. If a smaller thickness is desired, extra insulation layer(s) are needed and are more efficient to meet these high R-values (figure 4).

Bulk density, ρ		R value (m ² K/W) at a thickness of $t= 20$	R value (m ² K/W) at a thickness of $t= 35$	R value (m ² K/W) at a thickness of $t= 55$
300 ($\lambda=0,10$)	(kg/m ³)	2,00	3,50	5,50
600 ($\lambda=0,17$)	(kg/m ³)	1,18	2,06	3,24
1000 ($\lambda=0,35$)	(kg/m ³)	0,57	1,00	1,57

Figure 3. R values reached by thickness (data from Volhard, 2016)

Moisture/drying

Dry walls are an essential for good thermal insulation, a comfortable indoor environment, and the durability of the building structures, especially for timber frame structures. Light earth, with its ability to absorb and release moisture, exhibits good vapour diffusion and capillary conduction properties at low equilibrium moisture levels. This ensures that walls remain dry and retain their thermal insulation efficiency (Volhard, 2016).

Sound insulation

Earth building materials add mass to a timber frame structure and it is possible to achieve good sound insulation using a simple, single skin construction. As a heavy but soft building material, light earth offers great sound insulation properties (Volhard, 2016).

Fire behaviour

In the German norms (comparable to the European standard EN 13501-1) earth is classified as a “non-combustible”, also when it is leaned down with organic fibres providing that the bulk density is not less than 1,700 kg/m³. For all lighter fibrous earth mixtures, like light earth with straw or woodchip as aggregates, the combustible fibres are coated with a layer of earth that offers a measure of fire protection which is classed as “not easily flammable”.

According to fire tests on light earth taken by Volhard (2016), the material responds passively to the effects of flames, i.e. it does not contribute to the spread of fire and neither smoke, nor fumes nor perceptible combustion gases were produced. These results suggest that straw light earth could be classed as “not easily flammable”.

3.2.2 Aesthetic properties

As shown in Figure 4, the choice could be made for a solid light earth wall of at least 58cm, which does not need further layers to reach the required R value. This has implications for the perception of space, finishes and openings in the façade.

The open-pore surface of light earth serves as a good substrate for various types of plaster. External render not only serves aesthetic purposes but must also function as a protective barrier against moisture infiltration. It should be water-resistant, elastic, and vapor-permeable to enable moisture escape. Earth plasters are possible for this purpose (Figure 4). In regions with exposure to driving rain, like the Netherlands, entire external façades can be rendered, but additional cladding is preferred for enhanced protection. Consequently, for surfaces highly exposed to weather conditions, a ventilated façade cladding system, such as wood, shingles, or slates, is more effective. This system can also incorporate external insulation into the underlying construction (Figure 4).

When a building is made out of earth materials, earth plasters are also a natural choice for internal wall surfaces. One approach is to use thin building boards that are made with the light earth technique. These are used as dry cladding boards to quickly clad a load-bearing structure, in combination with wall insulation. These flat surfaces can be plastered with a finer layer of earth plaster. However, it is important that the soil mix is leaned down with just enough predominantly coarse sand to prevent it from cracking when drying. In this way these plasters create a smooth surface suitable for leaving as is, painting, or wallpapering (Volhard, 2016).

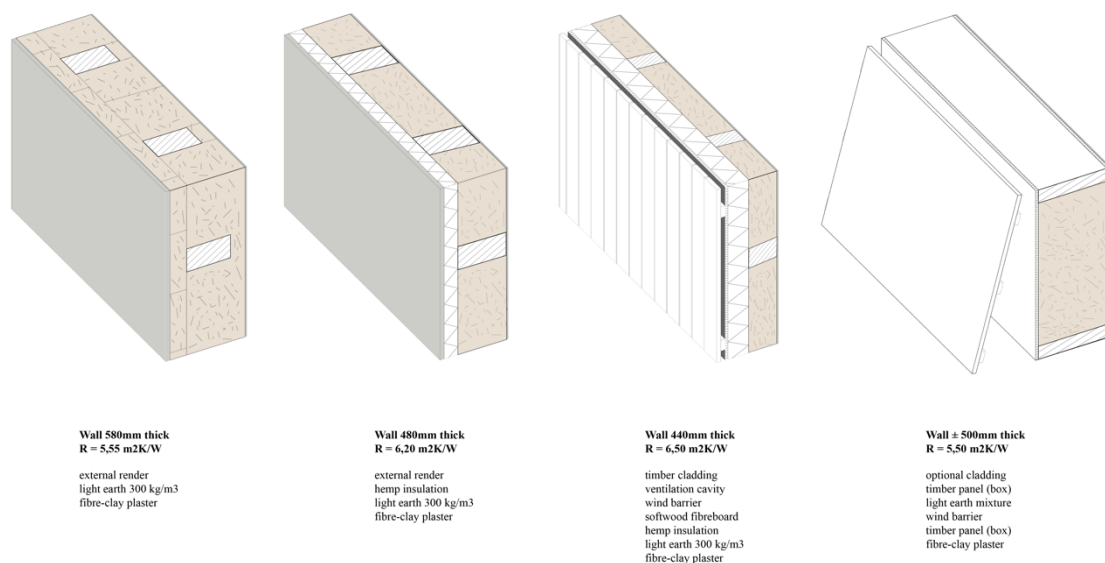


Figure 4. Example of external walls with light earth

3.3 LIGHT EARTH IN TIMBER STRUCTURES

The next part of the paper will gain an understanding about conventional prefabricated timber structures. In order to improve these structures by implementing the light earth construction technique and materials, it is essential to get to know the specifications. The question addressed in this chapter is therefore: ‘How do conventional prefabricated timber structures work, what specifications are essential regarding relevant and futureproof building factors and how can light earth be incorporated?’

3.3.1 Conventional timber systems

The application of wood in the history of architecture is characterized by tree main phases. Before 1850 wood was an irreplaceable material for buildings. Since the 19th century a decrease in the use of wood was recorded and new structural and building methods replaced wood. From the 1970s the renewable and versatile properties of wood gained increasing importance, starting a new phase for structures with wood. In particular, over the past two decades wood architecture has grown and new wood building systems and design strategies have been developed. This led wood to elevate from a mainly single-family residential standard to compete with concrete and steel construction for several types of building (Asdrubali et al., 2017).

The main types of structural timber systems can be divided in the following: *Log Construction, Timber-Frame Construction, Stud/Balloon-Platform Frame, Panel and Solid Timber Construction, Room Module Construction* and *Post & Beam Structures*. Up until the mid-90s, it was sufficient to be familiar with traditional systems such as log construction, timber frame construction and stud construction. The ‘*Platform Method*’, where the floor is placed on the walls of the floor below and then used as a platform to build the walls of the next floor (Appendix B), eventually became the most used method in the Netherlands. While being simple and efficient, the system suffers from significant structural height, little sound insulation and high vulnerability to fire and usually must be equipped with additional layers (Trummer, 2021). Also, this method requires internal walls either as separation or as load bearing structures, which, in terms of adaptivity, works to its disadvantage.

Fortunately, new load-bearing systems have been introduced and it is no longer the load-bearing systems alone that are important. The building envelope has become a self-contained functional medium to be coordinated with the load-bearing structure. The same applies to walls and suspended floors. Vertical elements are the backbone of any structural system. Timber panels are the vertical elements for timber frame construction and also columns are applicable. Horizontal elements are just as critical, acting as the body that spans the vertical elements. Specialized designs like box slabs, ribbed slabs, beams and joists are seen often (edX & Delft University of Technology, 2023).

As you can see from the diagram in figure 5 (Appendix C), the interaction between the different elements can lead to hybrid systems that utilize the strength of both approaches. When it comes to prefabrication, a distinction is made between 1D, 2D and 3D systems. Panel construction (2D) and modular construction (3D) are the most suitable and efficient for prefabrication. Since light earth is used as an infill for timber frame construction, this is a starting point. But light earth can also be incorporated in panel construction as an infill. For example, there could be a frame construction for vertical loads combined with panel construction for horizontal elements. This type of hybrid system offers a blend of stability and design freedom (edX & Delft University of Technology, 2023).

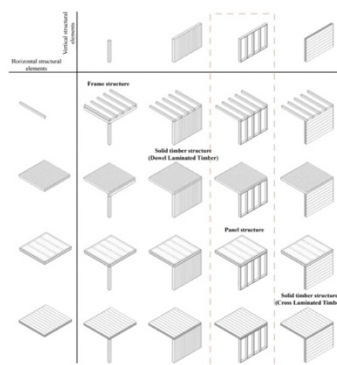


Figure 5. Hybrid timber systems (Ssse OvO architects associates Amsterdam, 2023)

3.3.2 Materials in timber structures

When it comes to façade finishes, there are numerous options (Noy & Maessen, 2011). For example, influenced by our brick culture and existing urban planning regulations, the familiar exterior masonry cavity leaf is often chosen in the Netherlands, but one can also opt for cladding with wooden boards or slats, to be more sustainable. Light Construction, such as wooden frames and beam floor slabs are traditionally filled with thermal insulating material. Flexible insulation materials such as mineral wool and glass wool are used mostly nowadays. However, this technique is also most vulnerable, and a vast number of layers has to be added to ensure spatial enclosure, fire safety, noise protection and thermal insulation, leading to increased fabrication complexity and low thermal mass (Trummer, 2021). It is important to choose the infill material wisely to reach more sustainability, like with the light earth construction method. The infill material plays also a role in stability. For example, earth contributes to energy efficiency while augmenting structural rigidity (edX & Delft University of Technology, 2023).

The application of insulating panels is usually in the external part of the wooden buildings to avoid the effects of thermal bridges linked to the discontinuities of envelope materials in wooden frame constructions (Asdrubali et al., 2017). This means that insulation panels possess specific properties to be suitable for use in the relatively wet climate of the Netherlands, or additional layers must be incorporated to ensure moisture resistance. An alternative approach is to design the building in a way that minimizes exposure to moisture, such as incorporating overhanging eaves.

3.3.3 Timber structures with light earth

There are various construction methods for filling a timber frame structure with light earth. There are wet and dry options. In this study, we look at the best option in need of prefabrication. The option of using light earth blocks - dry construction - seems suitable for an assembly line with larger quantities. In prefabrication, the wooden frames, panels or boxes can be filled with light earth blocks. This could also be done with a wet mixture of light earth, but involves more time due to the drying process.

Apart from this, light earth blocks are also suitable for interior walls, weighted floors and thermally insulating exterior walls - with or without additional insulation, depending on the bulk density of the bricks. However, it should be noted that light earth is non-load-bearing, and can only support its own weight (Volhard, 2016).

IV. CONCLUSIONS

To answer the research question: ‘*In what ways can light earth construction methods be incorporated in prefabricated timber frame housing construction methods, using locally sourced materials (earth, wood, and fibres) from the Netherlands, addressing contemporary residential requirements?*’

Light earth mixtures need clay and fibres. Together, the clay and fibres can make mixtures of different proportions with different technical properties. In the Netherlands, we find clay in the coastal provinces of the western and northern of the Netherlands. To extract clay without over exploitation, we can reuse released batches of soil from excavation work on a regional scale.

Thermally insulating light earth make comfortable interior with good room surface temperatures possible. But single-skin external walls made with light earth rarely fulfil today’s extreme thermal insulation requirements: thicker walls or extra insulation layers are a result of this. Because of the mass added to a timber structure, light earth achieves high performance on fire behaviour and sound insulation, a certain improvement on conventional timber constructions.

Interaction between different building elements in a timber structure can lead to hybrid systems that utilize the strength of both approaches. Since light earth is traditionally used as an infill for timber frame construction, this is a starting point. Nonetheless, light earth could also be applied in other types of timber systems, as seen in figure 6.

There are different construction methods to fill a timber element with light earth. The option to use light earth blocks seem the most suitable for prefabrication, because prefabricated elements (panels, frames or boxes) could be filled with these light earth blocks in the prefabrication process, without any extra drying-time. Light earth blocks are suitable for internal walls, weighted floors and thermally insulating external walls – with or without additional insulation depending on the bulk density of the blocks.

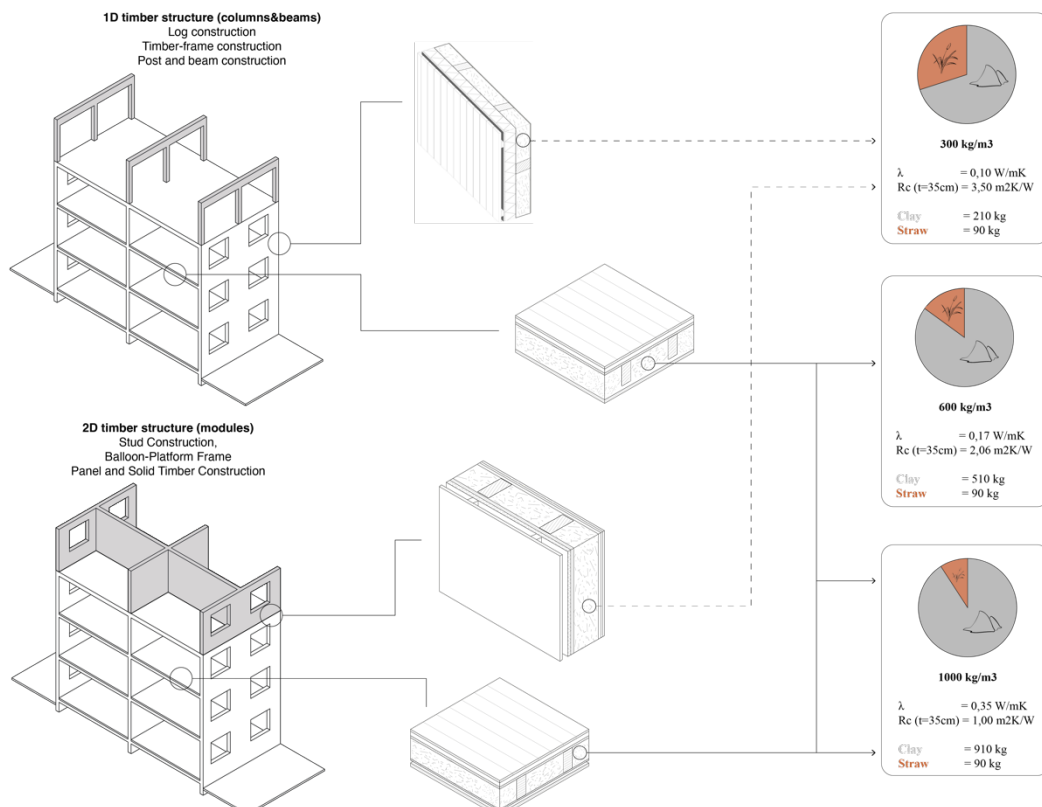


Figure 6. ‘Menu’: examples of different building elements in timber structures (diagrams self-made and from Ssse OvO architects associates Amsterdam, 2023)

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APPENDIX A
DIFFERENT TYPES OF SOIL IN THE NETHERLANDS

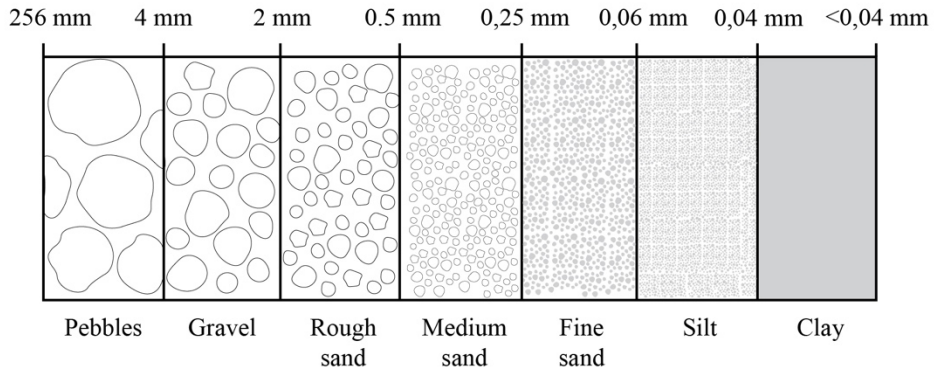
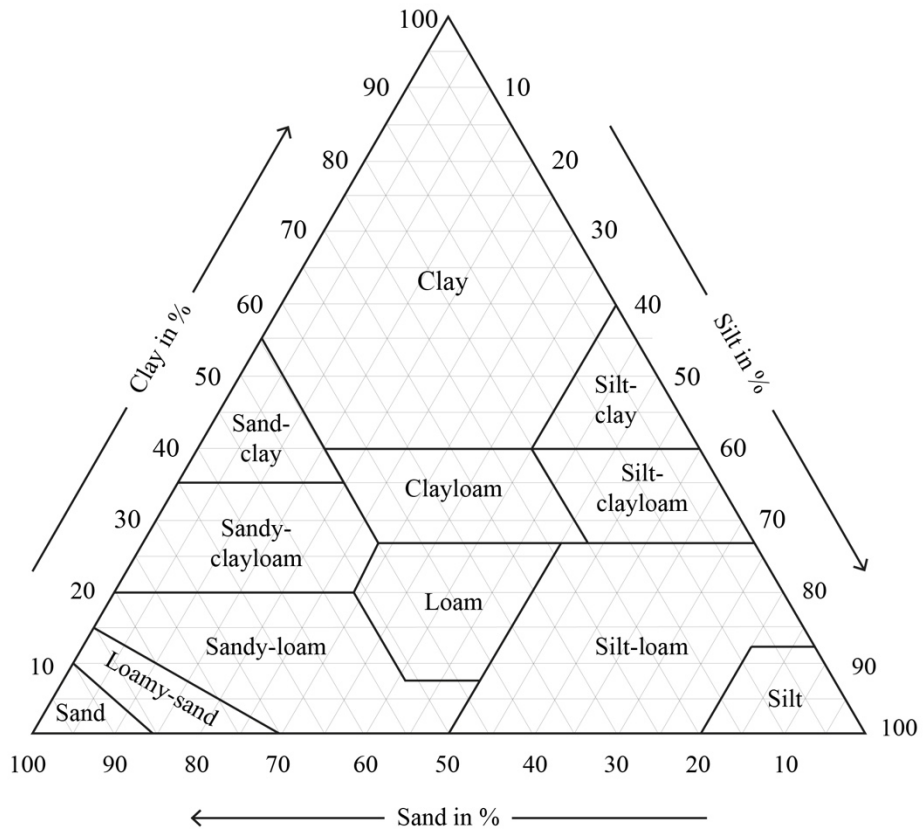


Figure A1. Composition of different types of soil and grain sizes. For example, if soil is 40% sand and 20% clay, the soil is classified as loam (USDA Soil Texture Triangle, n.d.)

APPENDIX B

CONVENTIONAL TIMBER CONSTRUCTIONS

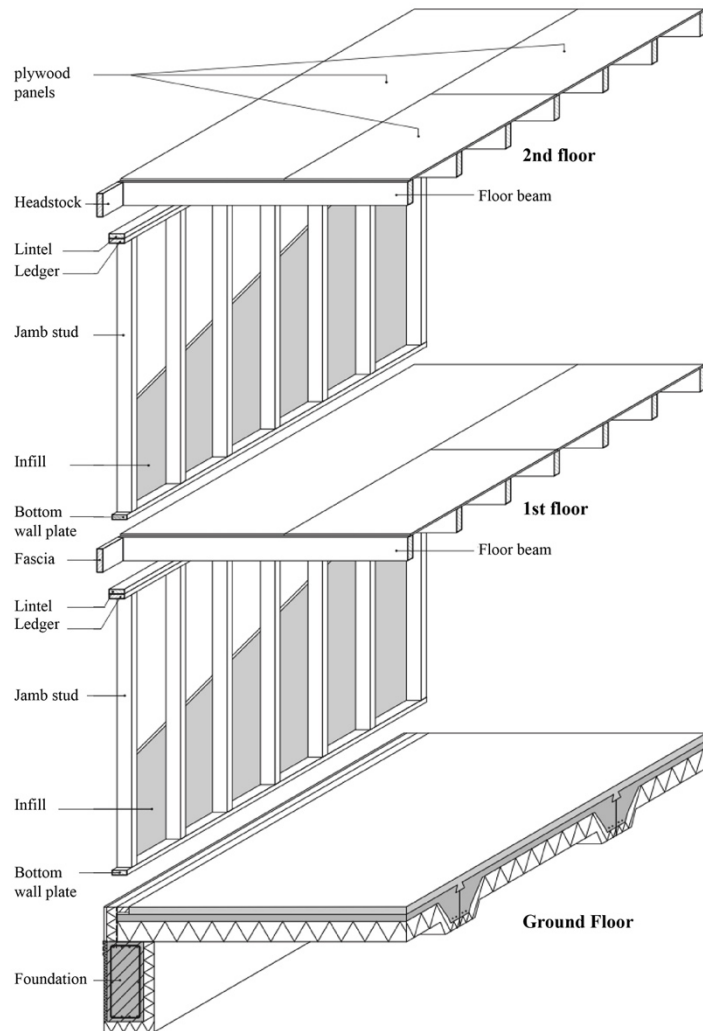


Figure B1. Conventional Timber Frame Structure: the Platform method (Noy & Maessen, 2011)

APPENDIX C

HYBRID TIMBER SYSTEMS

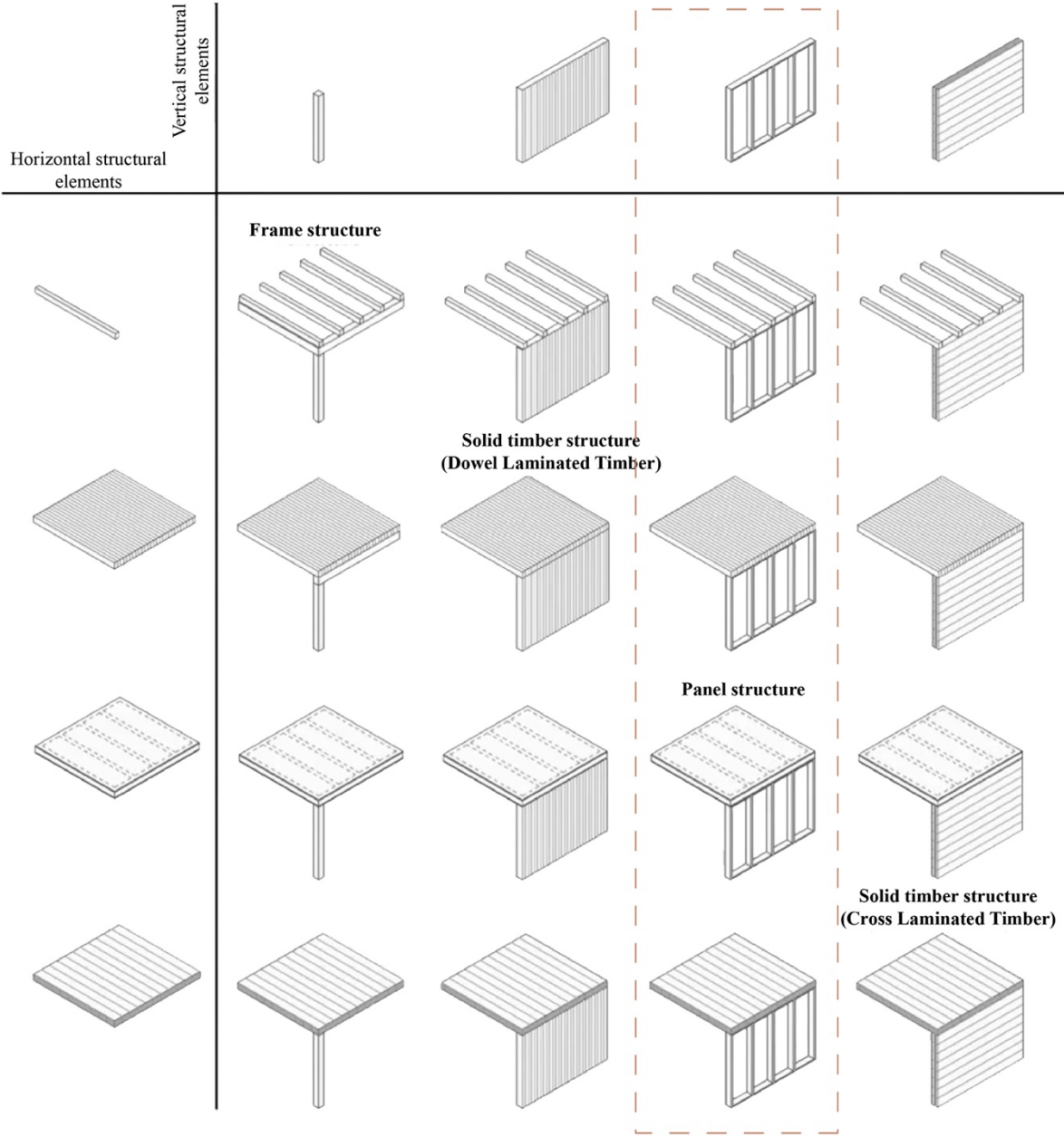


Figure C1. Hybrid timber systems (Ssse OvO architects associates Amsterdam, 2023)

APPENDIX D

'ASSEMBLY'

