# PROMOTING EARTH

CHALMERS
UNIVERSITY OF TECHNOLOGY

# PROMOTING EARTH

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# ABSTRACT

Rammed earth (RE) is a sustainable, low embodied $CO_2$ building method. It is popular in hot climate zones for residential buildings where RE walls provides comfortable indoor temperature. However low insulation value and sensitivity to elements makes it less attractive in cold and temperate climatic zones. This thesis identifies potential usages of RE in climatic zones where exterior insulation is necessary and particularly in Sweden.

Earth was compared with other heavyweight building materials such as concrete and brick. Research showed that such qualities as earth humidity control, low embodied energy and surface aesthetics are unique only to this material. Stressing these three qualities RE core house concept was created. Located in the interior RE wall surfaces are doubled to effectively function as structures thermal battery, humidity controller and main design element. Passive solar design guidelines were employed to take the full advantage of the material.

The findings are illustrated with schematic plans. Two of them are further developed in detail also considering sun position and placed in particular property in Sweden, Särö.

Same thermal capacity could be achieved using brick/rock masonry or concrete wall, but humidity control, warm multi-level texture and low $CO_2$ embodied energy are unique attributes that cannot be replaced by similar conventional building materials. In industrialized countries where standards for living environment are high these are important qualities where RE should get more recognition.


*Aims*

To systematize and present popular methods of earth construction.
Find a best position for earth in contemporary house.

*Method*

This thesis combines Research for and by design methodologies. Influenced by material qualities several house design iterations are made and presented in traditional sketching/drawing/modeling techniques. Study of reference projects and search of the rammed earth potential as a construction element in cold climates are the main drivers of this project. Exact location for the project is chosen from the beginning so final product of the thesis is a master plan of a residential district.

*Limitations*

Sloping landscape situation influenced house design in a way that it has cantilevering volumes. It was not the outcome suggested by the use of rammed earth.

Planning regulations in Sweden. Main living space has to be wheelchair accessible. This eliminated possible scheme with technical ground floor(CASE STUDY5: see page 26).

*Delimitations*

I am not considering to use the known technology of insulated rammed earth where insulation is in between earth layers. The aim is to find where the use of rammed earth makes most sense and its properties are employed at the maximum.

Study is focusing on “core” element and uses rammed earth flooring. Other building components are not employing earth building methods even though it could be possible. Reason for that is their lower aesthetic impact and possible influence to the building structure.

Due to limited time program for a house is not researched in depth. House program with three bedrooms is used.

# EARLY INTEREST

I was always curious about old structures slowly decaying in the countryside of Lithuania. Mostly they were abandoned cattle sheds or whole empty homesteads (granges) scattered all around rural areas of the country (result of soviet collectivization in the 50'ys). Built more than a half a century ago they were normally constructed using local materials, window and glass being the most complex and alien among them. While homesteads were mainly built using timber, cattle sheds' walls were often erected using loam and straw mixture employing the technique called cob. Through decades some cattle sheds were maintained by adding asbestos roof on top of traditional shingle coating. Others were left completely unattended to elements what resulted in leaking roof and collapse of its wooden structure later on. Finally only cob walls remained visible, marking the perimeter of a building. By that time I had no particular interest in construction or architecture, but those cob walls standing alone in the fields exposed to rain and slowly merging to surrounding nature were always an object of special interest. What kind of wall is that? How come it is melting to the ground, disappearing with no traces?

## *Architectural and environmental trends*

Studying in the field of architecture I am constantly facing recurrent ideas that I understand as trends. I found it relevant for my research to mention two of them.

Ruins of cattle shed. In Mekiai village, Lithuania(Google Maps 2014)

### *Material choice*

One trend is highly stressed particularly by architects - materiality. Architectural community praise environment that is created out of materials that are tied to natural world such as stone, wood, clay, etc. Opposed to more man-made ones like plastic, synthetics, various dyes. If there is a choice, natural finish is preferred due to aesthetic qualities. Natural materials have non-repetitive look, texture of the surface is never the same and that is considered as an advantage opposed to highly engineered products. If material is available locally, it is also assumed that it creates spiritual bond between building and its location.

### *Environment and $CO_2$*

Second trend is Environmental and it is generally aiming for low CO2 embodied energy choice of materials. This holistic parameter is meant to define energy spent in a whole lifetime of a project (or material): resource extraction, transportation, project establishment, maintenance during lifetime, deconstruction and recycling. Therefore embodied energy is likely to be lower if chosen material is locally extracted, its preparation for usage is simple, it does not require maintenance during its lifetime and it is easy to disassemble and recycle it.

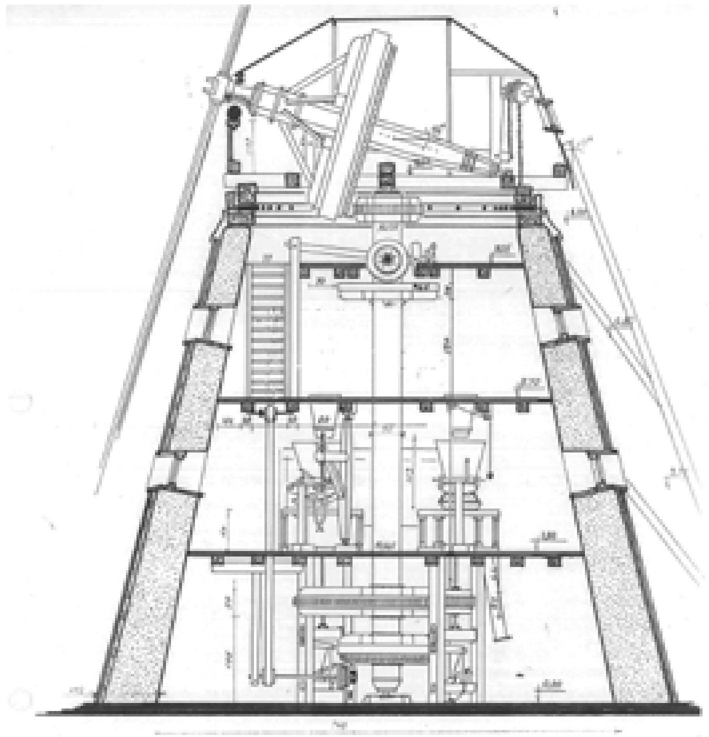


## *CASE STUDY 1: Melniai windmill*

Earth technique: Rammed earth
Mekiai rammed earth windmill was built in 1897. Exterior walls were clad with timber. Mill was used until 1982, later structure was abandoned. Earth walls reaches up to 8.8 meter in height(total structure - 12.5m), are 1 m in diameter at the bottom and 0,4 m at the top. Foundations are cleft and field stone masonry bond with lime mortar(malunai n.d.).
Decay started due to tin roof failure around 1990(seen in middle picture), exposing earth walls to direct rain.

(KPD 1988)

(KPD 2008)



Section of rammed earth windmill (Morkūnas 1966)

Top to bottom. Decay of earth windmill in Melniai village, Lithuania. Pictures from 1988 till 2009 (Galinskas 2009)

*CASE STUDY 2 Cattle shed*

Earth technique: Cob

I visited an abandoned homestead, where the only surviving building to this day was cattle shed built using loam and straw mixture. This reference allowed me to closely investigate aged material surface and detailing of the shed.
Building is in a poor condition but asbestos roof added on top of an original wood shingle surface and large 0,8 m overhangs protected structure from direct rain.
Foundations are made out of cleft rock masonry, major cracks
Walls has several major cracks, one related with roof leakage, others are around openings. Reinforcing horizontal wood straw elements, typical for cob technique are visible in some parts of the facade.
As seen in pictures facade is damaged by rodent animals also it looks like it is a habitat for insects on the southern side.


large 0,8 m overhangs protected structure from direct rain (Nainys 2014)


Animal made holes in the facade (Nainys 2014)


Reinforcing wooden elements (Nainys 2014)


Only building left in an old farm (Nainys 2014)


South facade is a habitat for insects (Nainys 2014)

# RESEARCH

*Where are the earth walls today?*

I haven't experienced examples of earth usage for modern construction in my near living environment, therefore I was curious to know the reason it is not used. Both architectural and environmental ideas seem to promote such material – it is in most cases locally available, has low $CO_2$ embodied energy and is aesthetically appealing. Curiosity and belief in the potential of cob walls I saw in my childhood has encouraged me to do a research in the usage of earth material.

*Worldwide usage*

Historically, earth construction worldwide plays completely different role than in my near living environment. This is how Gernot Minke starts his book "Building with Earth"(2006: 11):

"In nearly all hot-arid and temperate climates, earth has always been the most prevalent building material. Even today, one third of the human population resides in earthen houses; in developing countries this figure is more than one half. It has proven impossible to fulfill the immense requirements for shelter in the developing countries with industrial building materials, i.e. brick, concrete and steel, nor with industrialized construction techniques. Worldwide, no region is endowed with the productive capacity or financial resources needed to satisfy this demand. In the developing countries, requirements for shelter can be met only by using local building materials and relying on do-it-yourself construction techniques. Earth is the most important natural building material, and it is available in most regions of the world. It is frequently obtained directly from the building site when excavating foundations or basements."

*Usage in Sweden*

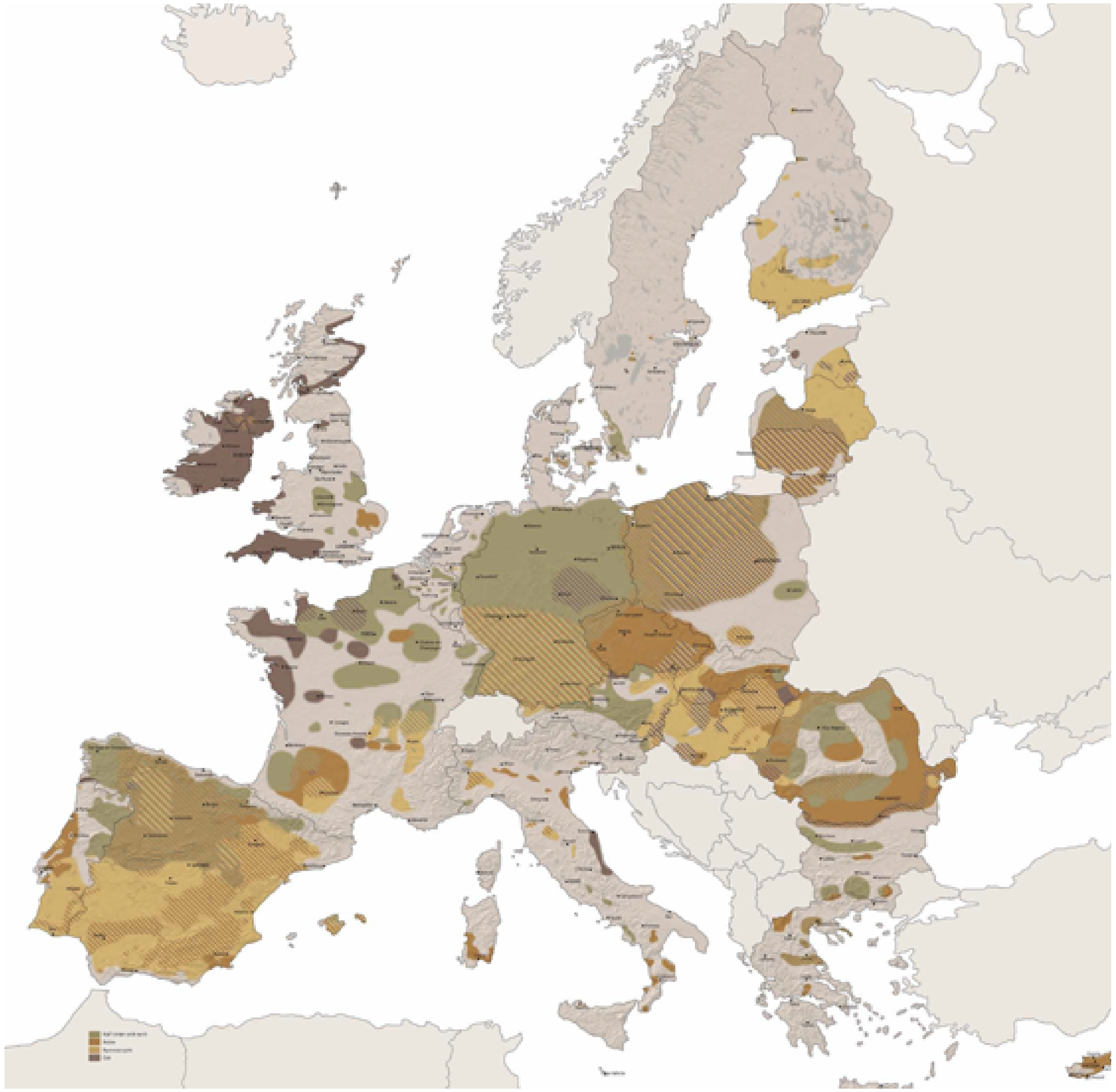
There are examples of earthen houses in Sweden, but they are more exceptions than the tradition. Reason for that is that other building materials are usually available and easier to handle.

Several rammed earth houses are built in Steninge, Halland. First one was completed in 1920. The material choice was related to economical reasons as owner couldn't afford regular building materials. Other houses, built recently simply follow the earth building tradition of the family. Buildings cant meet the contemporary building code in terms of proper insulation (Lindberg 2014: 35). It as well experiences problems of excess heat in hot summer days.
Looking at Steninge example it is obvious that earth houses were built without considering climate challenges.

Earth architecture in the world (Coeckelberghs 2014: 9)

Steninge, Halland. Rammed earth building (Lindberg 2014: 35)





2011 Map of Earthen Heritage in the European Union (Terra Incognita 2011)

*Historical rammed earth sites in Sweden:*

- rammed earth cottages in Norland and in Kvicksund;
- Rammed earth building in Sallerup;
- Rammed earth building in Upland Post office; municipal building made in rammed earth in Malmo;
- Restored rammed earth farm building now part of a Malmo Municipality recreational area;
- Rammed earth building in the city of Falkenberg;
- Gisselson house built in 1920; Estate managers' office built at the historic castle Hjuleberg, in Halland.
- Built in 1921; 'Villa Terra' built at Jordhuset in 1920.
- Baptist chapel in rammed earth in Oppmanna lake parish, Arkelstorp, Skåne.

(Terra Incognita 2011)

*Types of construction*

The purpose of my thesis is not to describe earth building technology, rather to identify what qualities each earth product offers.There are several ways to build with earth and it makes sense to group them in two major categories where they share similar qualities.

## *Load bearing earth*

### *Rammed earth*

Rammed earth walls are formed from soil that is just damp enough to hold together. The earth is tamped between form work with manual or pneumatic rammers. The form work can be removed immediately after completion of a wall panel. The walls are often left as they are "off the form" and reveal an appealing layered pattern from the ramming process.

This technique is very labor intensive and requires a lot of experience. Consistent workmanship is critical for both the appearance and the strength of rammed earth walls, so site work has to be of high quality.

One difficulty with rammed earth is that strict limits have to be placed on shrinkage to eliminate cracking. A sandy crumbly soil with a clay content around 15% is best. Often cement or hydrated lime is added to improve durability and for shrinkage control. This however isn't always necessary, as many successful structures have been built just from suitable soil without such additives.

### *Cob*

Cob is old and one of the most common earth building techniques. Cob construction involves layering a mix of gravely clay and straw directly onto the emerging wall. Mortar or a framework is not used during the process. Resulting surface is then trimmed up and rendered, which leads to a soft look of the walls. Cob walls in most cases are load bearing. Technique is not popular in modern practice, one of the reasons is that walls built in this technique tend to shrink, therefore cracks are hard to avoid.

### *Adobe*

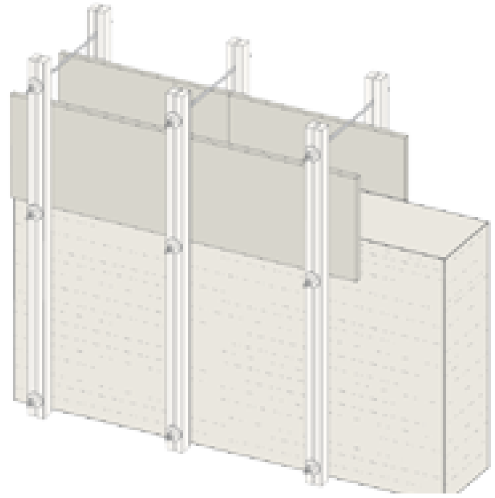
Adobe can be described as dried bricks of cob, stacked and mortared together with more adobe mixture to create a thick wall. Adobe structures are extremely durable, and account for some of the oldest existing buildings in the world. Adobe buildings offer significant advantages due to their great thermal mass.

Rammed earth (Green Building Elements n.d.)

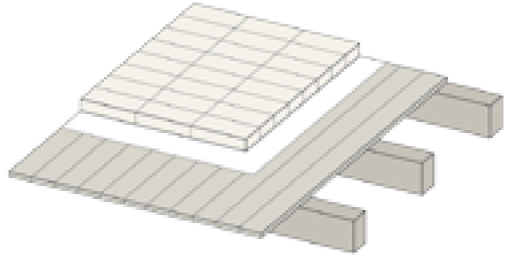
Cob (Green Building Elements n.d.)

Adobe (Green Building Elements n.d.)

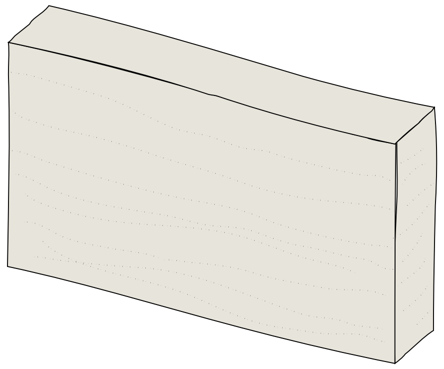




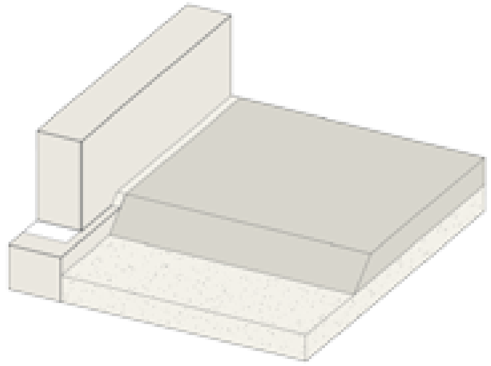
Rammed earth (Schreckenbach 2004: 10)



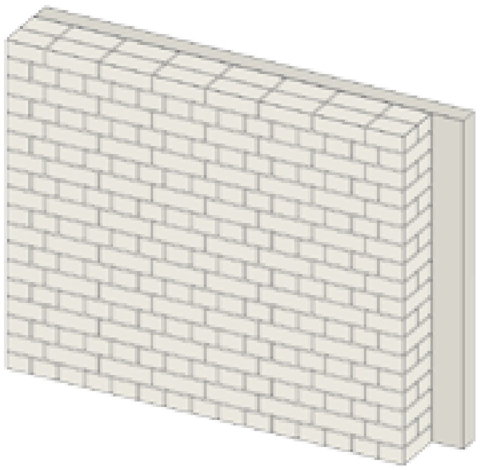
Earth floor on tinmer structure (Schreckenbach 2004: 13)



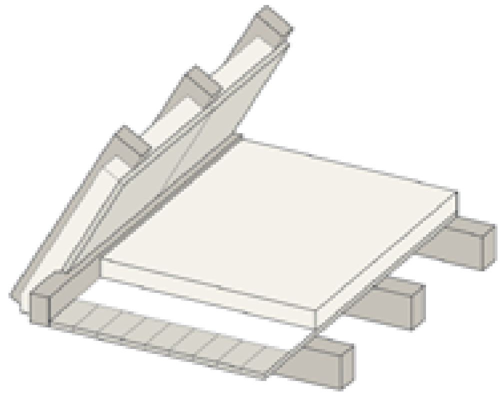
Cob (Schreckenbach 2004: 10)



Light earth (Schreckenbach 2004: 8)



Adobe masonry (Schreckenbach 2004: 11)



Light earth ceiling (Schreckenbach 2004: 23)

## *Non load bearing earth*

### *Wattle and Daub*

Wattle and daub starts with a lattice of vertical studs and horizontal wattles, worked together like a basket. A mix of earth and straw is then daubed onto this latticework, forced into the gaps and smoothed over to fill any cracks. The surface can be left as a rustic finish or rendered for a smoother finish.
Wattle and daub walls are non load-bearing and are built into a wooden framework.

### *Light Earth*

Light Earth involves tamping a clay mix containing a lot of straw or untreated wood chips into a timber framework and then cladding both faces. The method combines the good insulation property of the light additives with the advantages of earth. The construction is fireproof and very durable, because the clay acts as a natural preservative of the timber construction.
As with other earth building techniques, Light Earth balances the indoor climate, especially the moisture of the air. Because of its relatively low weight, it isn't suited to contribute to the thermal mass of a building. The construction acts more as a form of insulation, and therefore is mostly specified for external walls.
The material needs a waterproof cladding on the outside. This needs careful attention, because the wrong exterior finish can result in serious damage of the Light Earth filling. On the inside the walls can be finished off with an earth plaster.

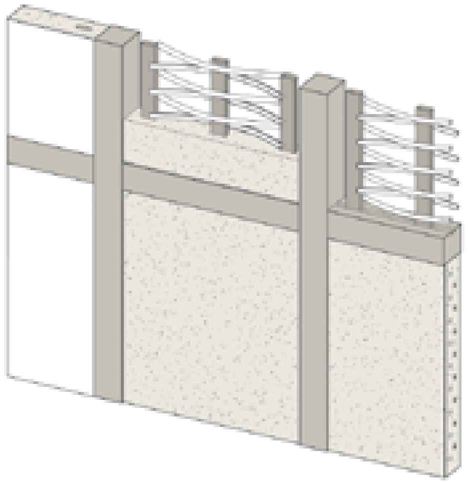
## *Thermal mass and insulation relationship*

Load bearing earth techniques requires to use heavily compacted loam with the resulting density of 1700-2200kg/m3 (*minke). Higher density ensures better thermal mass capacity but performs worse in terms of insulation.
Non load bearing techniques works better for insulation purposes, but at the same time has less thermal capacity and are more sensitive to rain and physical damage.

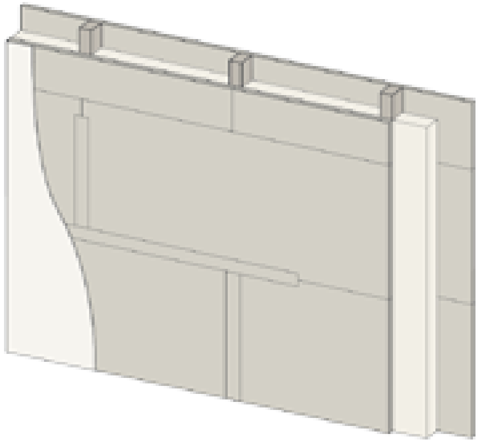
Wattle and Daub (Green Building Elements n.d.)

Light Earth (Green Building Elements n.d.)

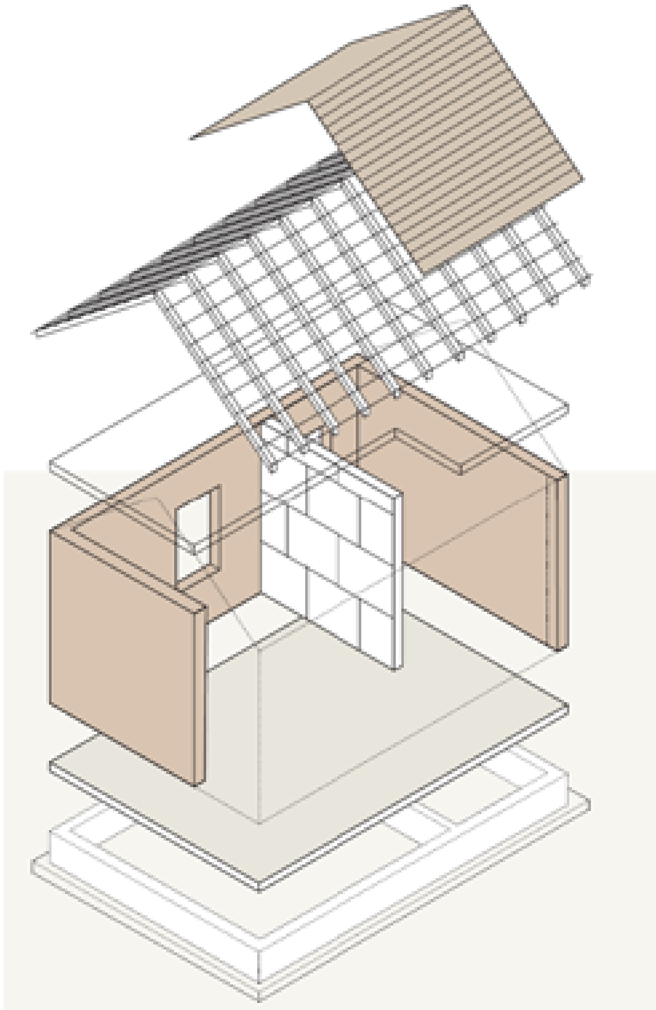




Wattle and Daub (Schreckenbach 2004: 13)



Light earth (Schreckenbach 2004: 12)



## *Other building components*

Earth can be used in flooring, ceiling fill and even as roof coating.

## *Indoor climate*

Indoor climate is the field where loam material comes into full power. Ideal micro climate consists of three conditions, highly influenced by earth walls:

### *Temperature*

Higher temperature results in headache, worse sleep, worse working condition, while lower feels uncomfortable. Correctly exposed to the sun rammed earth walls can keep building cool on hot summer day and accumulate warmth from low angled winter sun beams. High thermal capacity ensures more even temperature throughout the day.

### *Humidity*

Ideal range - 40-60 degrees.
Higher humidity results in better chance to freeze or overheat because of high conductivity of water, also higher chance for fungus and microorganisms to thrive. Lesser humidity – dried out throat and skin contributing to worse immunity and bigger chance of infections. Dry weather is as well bad environment for plants, pets, wooden furniture, art and musical instruments.

Comfortable and healthy humidity level is widely overlooked factor in the design of contemporary house (compared to e.g. more respected temperature and ventilation). Measures have been done showing that loam surfaces inside the house keeps humidity levels around 50 percent. Loam is the leader in this field compared to any other material.

### *Air flow*

It is important to maintain air flow from the outside, because interior air soon becomes contaminated. Fresh air flow of 0,3m/s is a recommended standard. In case of highly insulated house the right amount of fresh air becomes particularly important, on the other hand replacing hot air with outdoor air results in energy loss and temperature shift. Conflict that arises could be partially solved having more thermal mass in the interior of the house for heat not only in the air but as well in the walls. House should be able to absorb more radiant heat that it actually needs. This excess heat would be removed by fresh exterior air ensuring constant air flow.
In addition there is common perception(not proven scientifically) that loam absorbs pollutants(Minke p.15)

## *Rammed earth - most advanced method*

I decided to continue my research particularly in rammed earth technique. The reasons I choose this method compared to other earth techniques are:

- Rammed earth technique has been developed the most in contemporary architecture.
- Resulting surface has the strongest expression compared to other techniques., it is possible to alter the texture using different soil components and achieve crisp surfaces.
- High density and low organic content in rammed earth walls ensures that there will be no insects or chance of decomposition in them.
- Low maintenance, long durability and no coating after structure is built needed results in total lower embodied energy, compared to e.g. less durable wattle and daub or light earth techniques.
- High thermal mass allows to employ passive solar design.
- It is possible to prefabricate rammed earth elements.

## *Challenges*

### *Building code*

Non standardized building material. Is not standardized in Sweden, therefore it would require extra effort and resource to implement it as a load bearing element. It is hard to get loan for a building that is going to be built out of rammed earth.

### *Labor intensity*

The big shortcoming, stopping this technique from spreading in developed world is it's labor intensity. According to Gernot Minke traditional construction of rammed earth walls including preparation, transportation and construction takes up to 20-30h/m2 to build. He also points out that technology can speed up the process up to 2h/m2. Mechanizing the process also results in a larger amount of embodied energy in the project.



Swimming pool in Spain(Fernández Santos n.d.)

*Shrinkage*

Cracks occur when joining layers with different amount of water in them. It is possible to build a of layer rammed earth of about 50cm in height. Then form work has to be lifted upwards to continue. The problem occurs in the junction between these two layers because the lower one will always by dryer than the top one resulting in horizontal crack. To avoid cracking one must put lime layer in between.
Dry, warm weather and sufficient air movement is needed for shrinkage to stop in a few days. More time is needed in case of worse weather. So effective construction should go parallel to good weather.
Rammed earth has low shrinkage compared to other products – 0.4% to 2%, mud bricks, mortar – 3-12%.
If incorrect mixture of earth is prepared shrinkage is inevitable.

*Resistance to elements*

Typically large overhangs are recommended to earth walls, however Martin Rauch successfully uses horizontal stone dividers in the facade – stone plates to stop running water. In this case overhang roof is not necessary. Rauch in one of his interview points out that rammed earth wall is considerably eroded by rain just in the first years of exposure to elements. After some parts are washed away process stops and surface becomes stable (Echo-logis 2013). Another example exists in Lithuania where cob building wall is embedded in the same way, but wooden planks are used instead of stone plates.

*Relevance in warm climate*

Rammed earth as well as other load bearing earth construction methods is widely used in warm climate zones due to loam thermal mass ability to even out diurnal temperatures inside of the building. Other important factor is low level of industrialization, poverty and shortage of modern building materials in southern regions. Labor power is cheap, especially comparing it to baked bricks or cement.

*Relevance in cold climate*

Earth architecture was used but later abandoned construction method. Firstly because of industrialization and appearance of many new, more flexible construction products and secondly because high insulation value of a wall became a necessity. In addition to that highly increased living standard made labor power one of the most expensive components in the building so it is natural that today labor intensive earth techniques are not competitive. So is it really reasonable to resurrect this vernacular building method?
One new player in the game I already mentioned in the beginning is increasing interest in sustainability. Researches are being made estimating throughout embodied energy amounts in the buildings. If rammed earth structure is more expensive to build (high labor input), compared to baked brick masonry, it results in more than 60% embodied energy savings and up to 90% savings when compared to concrete. Besides high standard of living that raises labor costs on one hand, raises the bar for built environment on the other. So if inhabitants are conscious about the importance of healthy indoor climate, earth can be an alternative.

Cracks in rammed earth wall.

Example of water corrosion.



*Prefabrication*

Many disadvantages mentioned earlier can be discarded if considering that RE elements will be prefabricated. Company Lehm Ton Erde located in Austria provides prefabricated rammed earth elements. Advantages as described in companies website:
“The evolution and development of prefab-rammed-earth technique improve efficiency on the building site, scheduling becomes exactly calculable, and makes projects more feasible. Such a process enables a weather-independent production, also because the drying process is entirely in the production hall: construction coordination on site is therefore easier and more accurately predictable. This combination allows an optimal fit in the industrialized building processes and has the potential to be optimized and rationalized through modular systems.”
Pictures on the left shows workers sealing gaps between elements. Sealing gaps and any repair on earth wall is simply performed tamping wet earth mixture on a wall.

*Earth products/companies in Sweden*

Earth construction in Sweden is not a popular and commonly used building method, therefore there are no companies capable to carry big scale projects. However there are several individuals with knowledge and experience in the field:

Johannes Riesterer - builder with experience in earth mortars and plasters. Co-founder of the Swedish association of clay building.
Ulf Henningsson - builder with experience in earth mortars and plasters. Co-founder of the Swedish association of clay building.
Jenny Andersson - architect and co-founder of the Swedish association of clay building.
Hans Bulthuis - builder with experience in rammed earth.
Lars Palmgren - architect and researcher.

Assembly of prefabricated rammed earth(Ricola 2014)

Sealing process of prefabricated rammed earth blocks (Ricola 2014)

Assembly of prefabricated rammed earth(Ricola 2014)

# DESIGN GUIDELINES

Areas where rammed earth outdoes conventional materials that would be used normally e.g. concrete or baked brick masonry are:

- High thermal mass with low embodied $CO_2$ (Concrete and brick has high thermal mass as well but produces high amount of $CO_2$ )
- Significant effect to indoor climate
- Exceptional natural texture.

*Strategy of use*

Design should take advantage of these properties in order to be relevant in Swedish context:

- Low embodied energy of rammed earth should be supported with other design solutions. E.g. roof and facade materials, building shape.
- Advantage of thermal capacity of rammed earth should be employed with the help of passive(or active) Wsolar design.
- In order to improve indoor climate and aesthetic experience surfaces of earth should be exposed and wall area maximized.

*Passive solar design*

U.S. department of energy provides very brief and clear guide, explaining what passive solar design is(U.S. Department of Energy 2010):

“Passive solar design incorporates features in your home and its natural surroundings that harness the sun’s low rays in winter and deflect the sun’s high rays in summer to naturally warm and cool the interior.
A home’s orientation, elevation, room layout, materials, and surrounding outdoor landscaping all contribute to its passive solar design.

Elements of passive solar design
Aperture (Windows) – Windows should face within 30 degrees of true south, and during winter months they should not be shaded from 9 a.m. to 3 p.m.

Absorber – The hard, darkened surface of the storage element is the absorber. This surface – such as a masonry wall, floor, or partition – sits in the direct path of sunlight. Sunlight hits the surface and is absorbed as heat.

Thermal Mass – Floors and walls that absorb heat are particularly useful for naturally heating homes in colder climates. Thermal mass refers to materials that retain or store the heat produced by sunlight. The difference between the absorber and thermal mass, although they often form the same wall or floor, is that the absorber is an exposed surface whereas thermal mass is the material below or behind that surface.

Heat Distribution – Passive solar design allows solar heat to circulate from collection and storage points to different areas of the house.

Control – Elements such as roof overhangs or trees can be used to shade the window during summer months. Other elements for controlling temperature include electronic sensing devices.”

*Spacial program*

Program for the houses should satisfy the general needs for a family with children. Active kitchen, dining, sitting room spaces and private bedroom/workroom spaces should be provided.

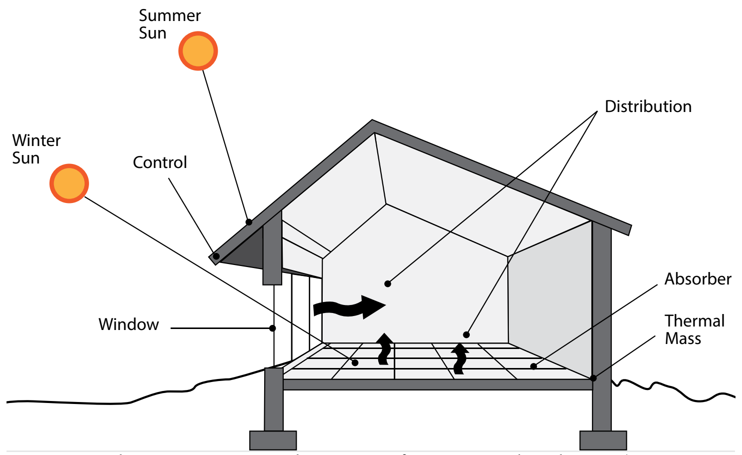


Diagram showing 5 main elements of passive solar design(U.S. Department of Energy 2010)



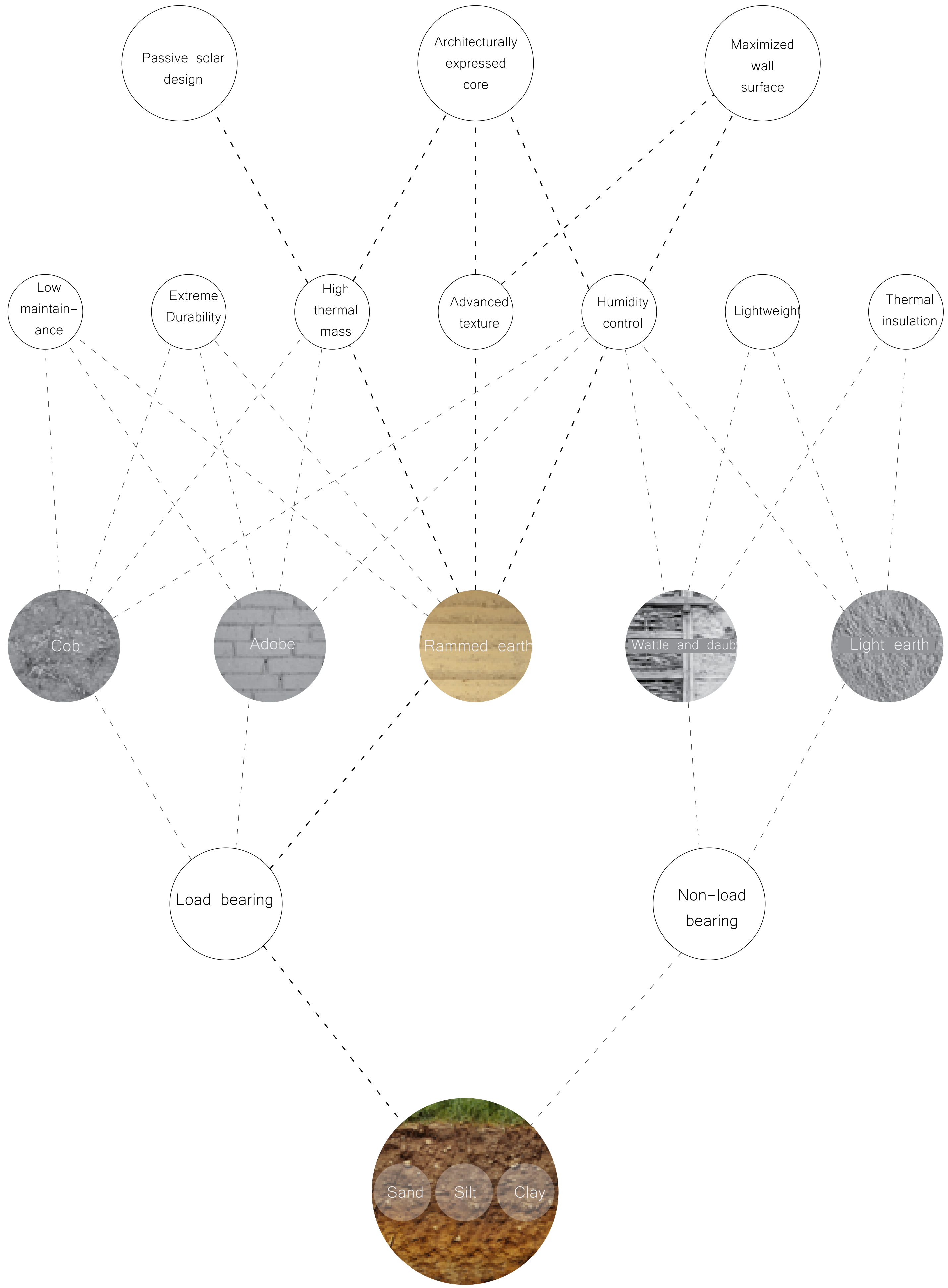


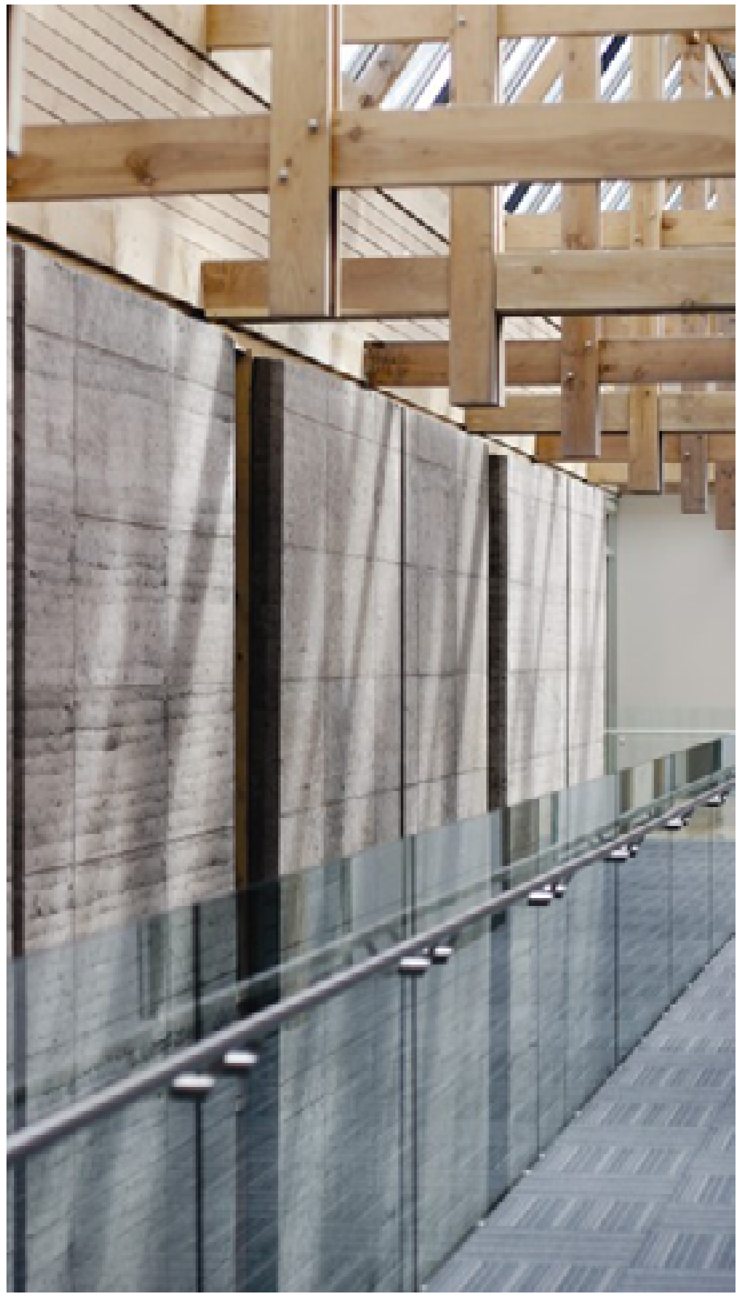
Diagram showing how material qualities transform into design guidelines

## *CASE STUDY 4 “the River Green center”*

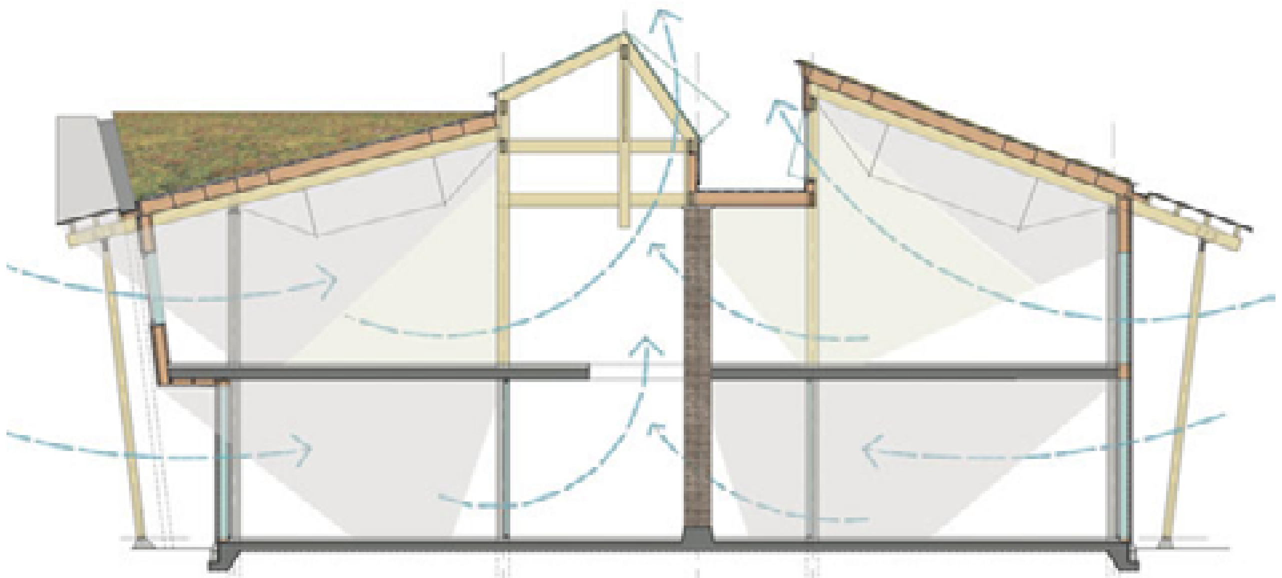
Architect: Jane Darbyshire and David Kendall Ltd

Developers aim was to create a dramatically pleasing building and a healthy place in which to work.
Usage of rammed earth in the project was of particular importance to me because it perfectly correlates with before mentioned design guidelines i had set for further research. Rammed earth wall is located in the very center of the building. Its climate control qualities are employed to the maximum because both wall surfaces are visible and interacting with indoor air. Its density and thickness acts as a heat store, reducing the daily temperature fluctuations and giving a more consistent thermal environment within the building. Located in the center it as well gives identity to the whole interior space and strengthens projects sustainable image. Earth wall is easier to identify as a sustainable component compared to e.g. passive solar roof overhangs of skylights.

Main lobby (Mushen 2010)



Main lobby (Mushen 2010)



Section displaying rammed earth wall in the center (Jane Darbyshire and David Kendall Ltd n.d.)

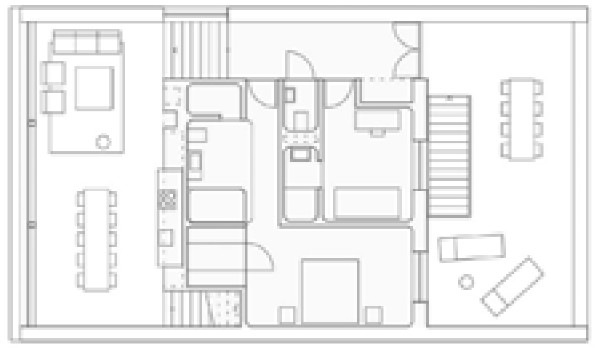


## *CASE STUDY 5 “Vogel House”*

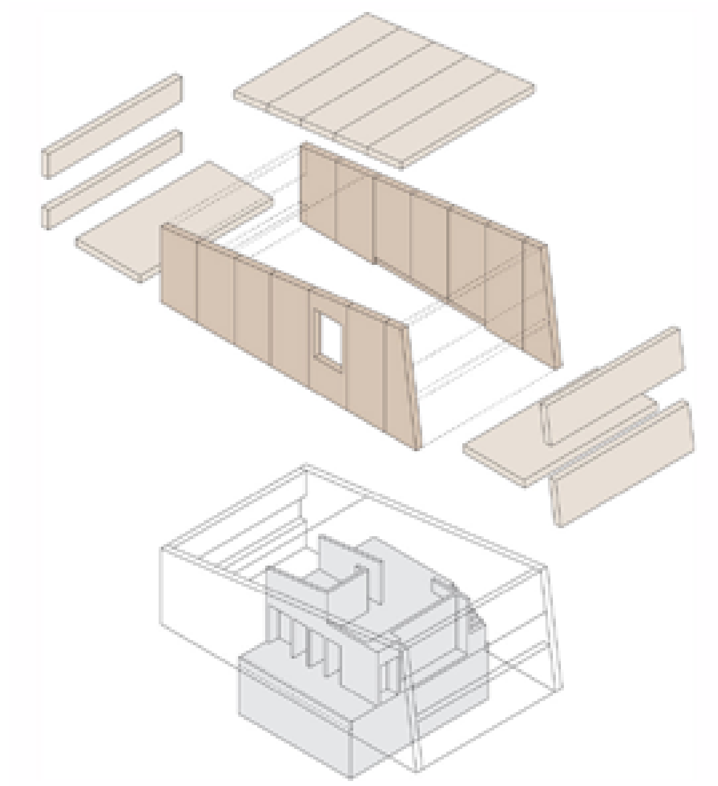
Architect: Diethelm&Spillman
Area: ~200m$^2$

House, meeting passive standard build in Switzerland. It is interesting in my research because it features concrete core(marked in gray) which is acting as a thermal storage mass inside the house. Concrete monolith sets interior character as well, forming contract with the exterior wood clad shell.
Besides, the way volume is lifted from the ground can be relevant in a complex terrain situation, minimizing footprint and at the same time expensive and energy intense foundation work.

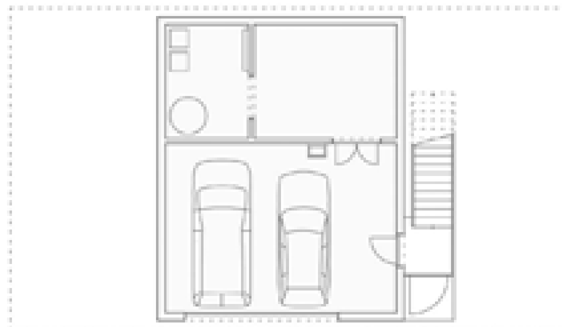
Upper floor (diethelm & spillmann n.d.)



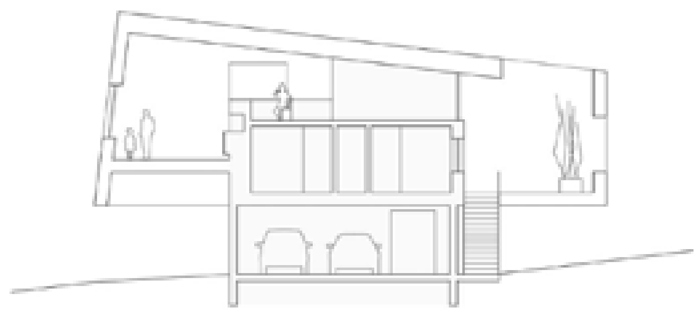
Main floor (diethelm & spillmann n.d.)



Axonometric view (diethelm & spillmann n.d.)



Ground floor (diethelm & spillmann n.d.)



Section (diethelm & spillmann n.d.)

# PROJECT LOCATION

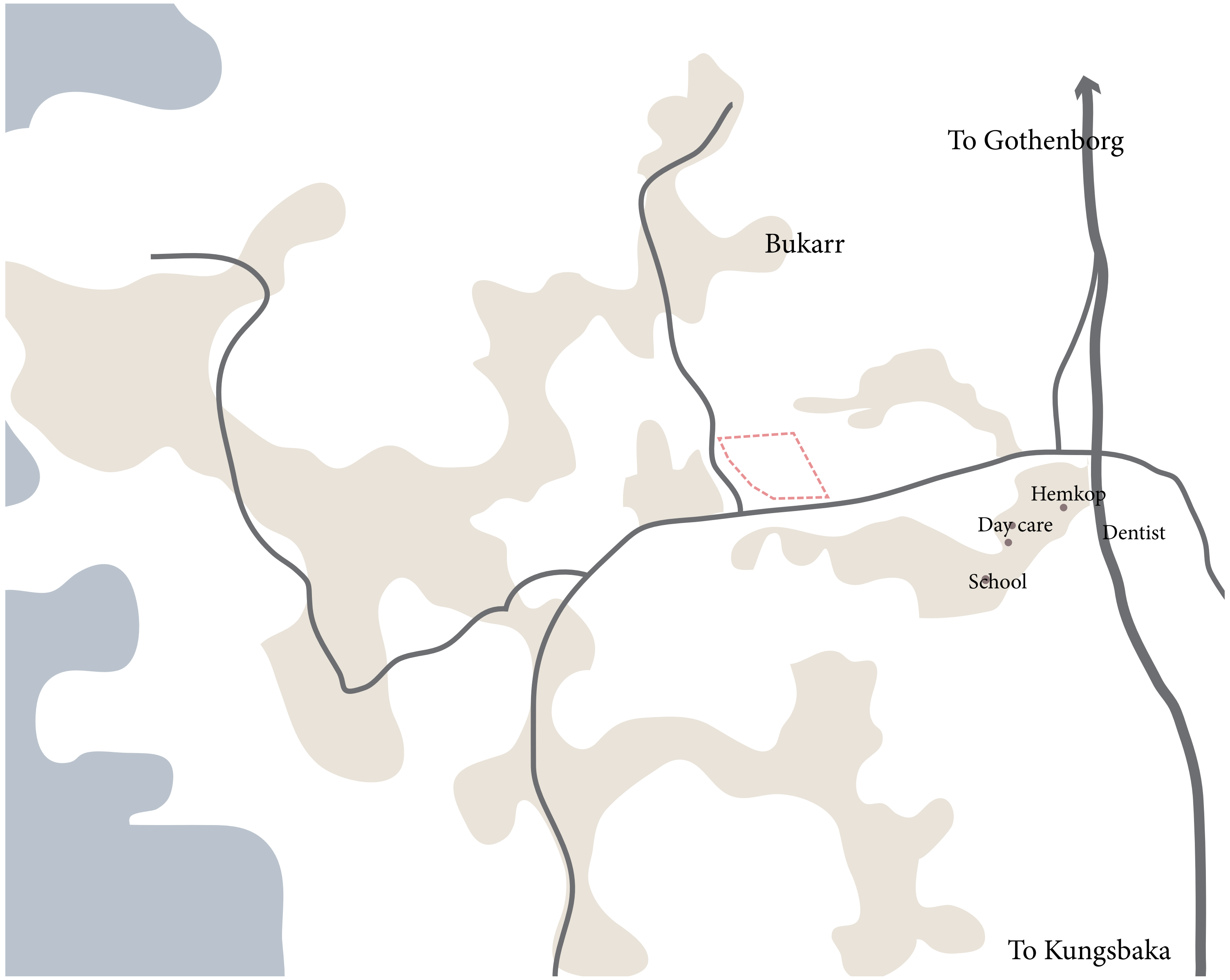


*Site analysis*

Särö is an area in Kungsbacka Municipality, Halland County, Sweden, with 3,165 inhabitants in 2010.It is located south of Gothenburg on the Särö peninsula. Geographically, the peninsula marks the transition from the Bohuslän archipelago in the north and the long, flat Halland coast in the south. The nature reserve Särö Västerskog is located nearby.

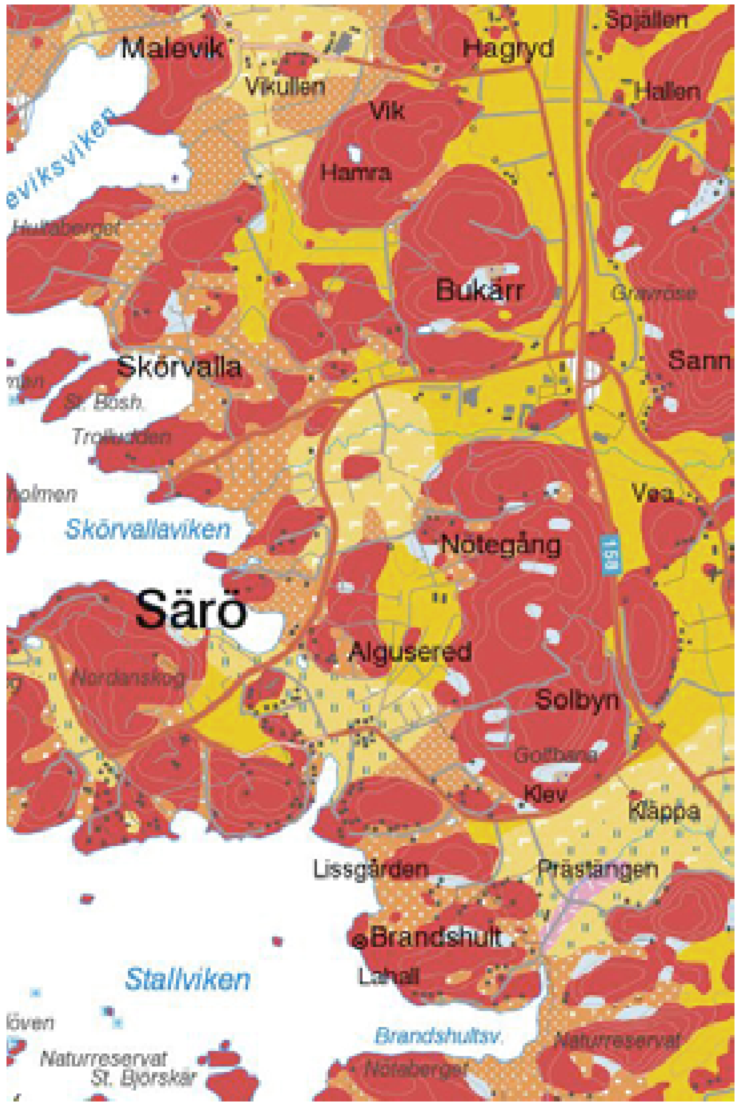
*Property*

Property planned for residential development is located on a rocky slope exposed to southwestern sun. Terrain shifts withing 24 meter amplitude.
Property is surrounded with already developed housing areas and borders with Särö functional center - kindergarten, school, shops and other smaller services.

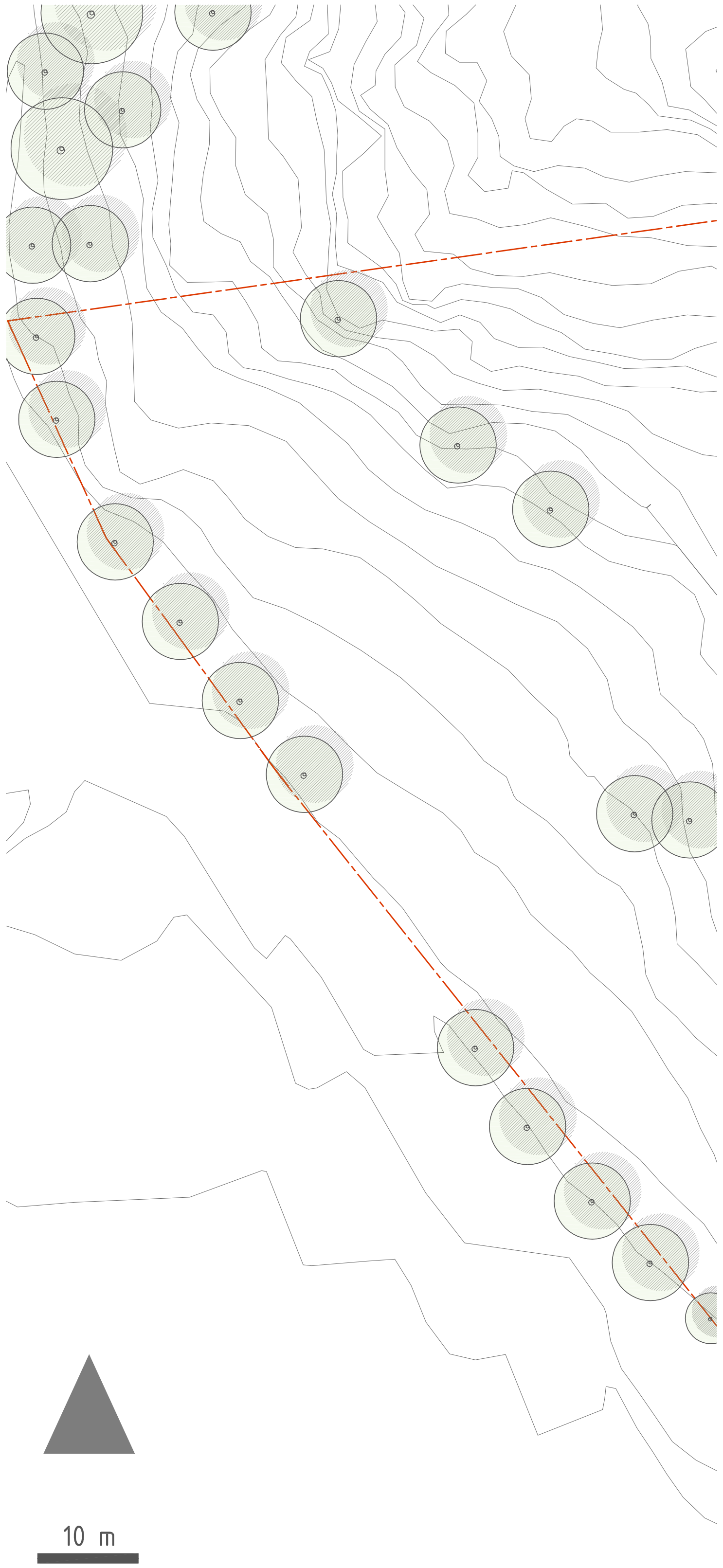
## *Geological data*

Excerpts from geological map displayed in this page shows earth composition in the project area.
Exact project plot is a single rocky slope, but surrounding Särö area offers diversity of soils. In a radius of 1km these types can be found.
Data shows that necessary components for earth construction are available in near surroundings.



Soil composition in Särö area(Geological Sourvey of Sweden n.d.)

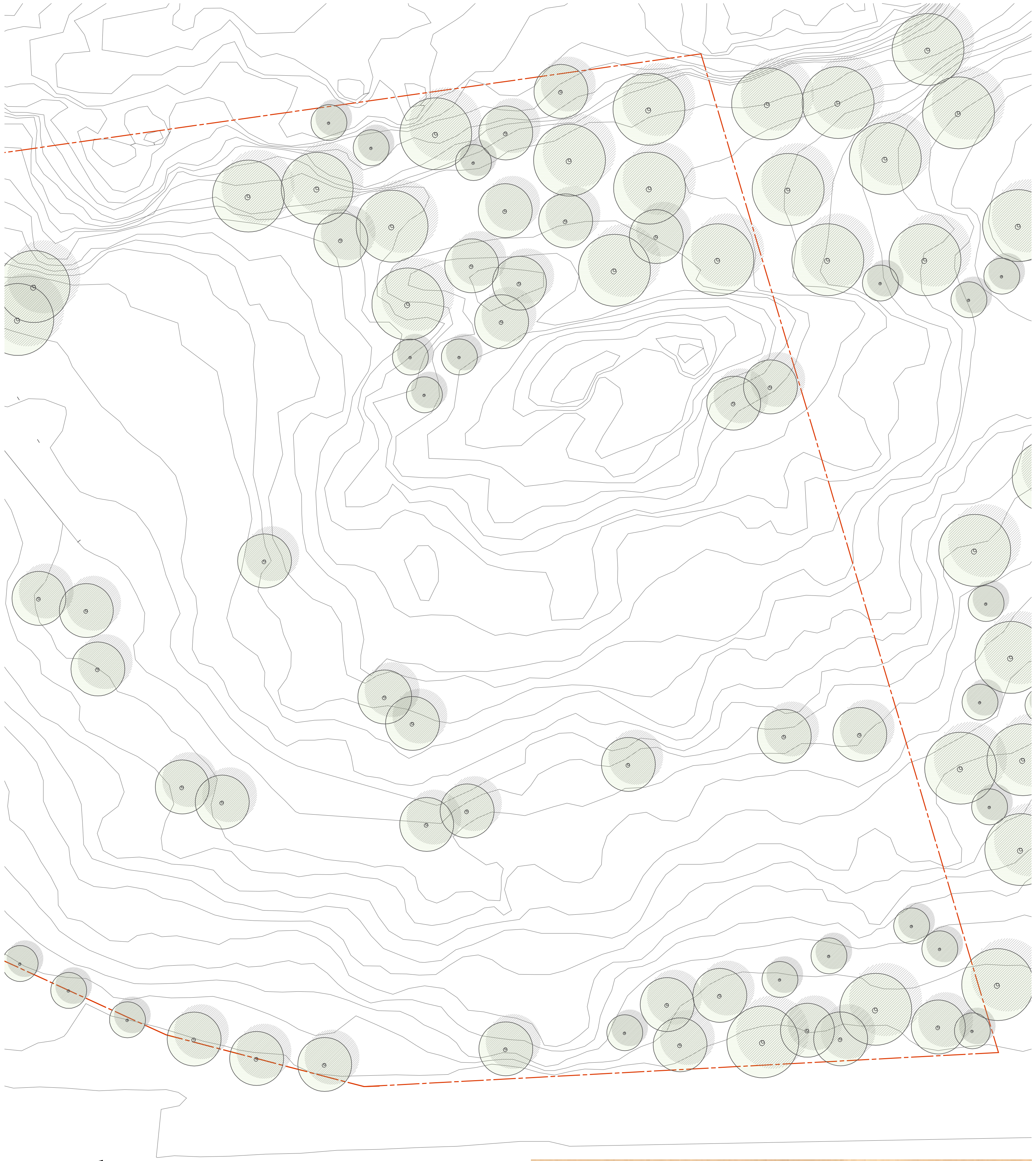
- Berg (rock)
- Glacier lera (Clay)
- Postglacier finlera (fine clay)
- Postglaciar sand
- Postglacier finsand




## *Nature qualities*

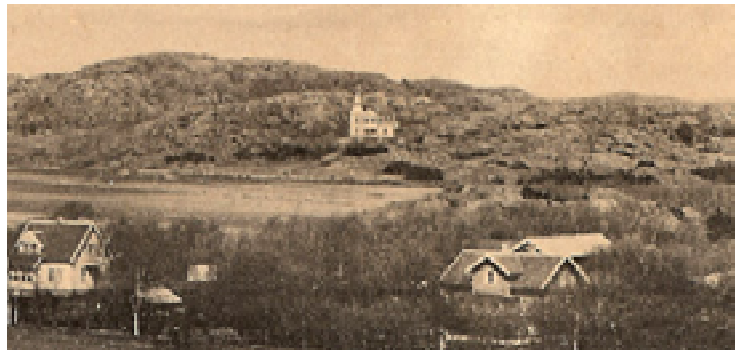
In the east side edge property is covered by mature deciduous and conifer trees, forming bigger forest massive in surrounding area.
North east corner of the plot is a unique green valley protected from prevailing winds by rocky slopes north and east sides.
From the top altitude of the property coast line of North sea can be observed.





## *Historical context*

In the center of the property there are rock foundations of former wooden villa remaining. Flat area around the villa was created by leveling the land - there is a 1,5 meter high rock wall on one side. Masonry is in a good condition and esthetically quality and therefore it should be considered to be preserved.


Historically property was allocated for single wooden villa seen in the picture

*CASE STUDY 3 "Valo Fyr"*

Architects: LANDSTRÖM ARKITEKTER & RAMBÖLL
Location: Gothenburg,Sweden
Interest:
This reference project requires deeper analysis because in its approach it is similar to my project. Concept for arranging the houses to fit the landscape but not vice versa is the concept i seek to implement in my project as well. In addition to that, all houses are placed in a manner that each of them should have view towards a waterfront.

Project size is similar in size(Valo 26 000 m$^2$ Särö:20 000 m$^2$) and character of surroundings. Terrain is less distorted than in Särö case, but it still is a consideration since it has a shift in 10 meters counting from one end to another(Särö has 24).

Contains 49 single family houses in three different typologies :
104,125 two floors 4 rooms
138 m$^2$ two floors 5 rooms
103 two floors 4 rooms
Separate community building
1 parking place located near the house
1 parking place located at the entrance to the district.
26 000 m$^2$ site area, approx 500 m$^2$ per household


Connection to the ground (Lindman 2010)


(Lindman 2010)


Houses are carefully placed between the natural rocks(Ågren 2004)




Siteplan(HSB Göteborg n.d.)

# DESIGN



*Core concept*

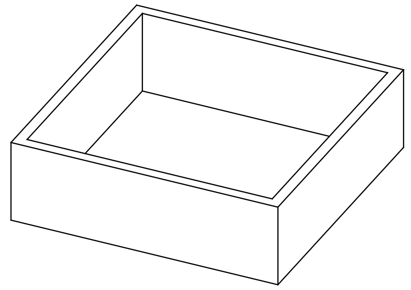
Rammed earth wall can be compared with brick masonry or concrete. Finished result is a heavyweight load-bearing shell that has to be additionally insulated if used in Sweden. That means that exterior surface would be masked and half appealing surface lost.
Because main re. advantages focus around indoor climate i decided to invert the shell and place re. inside the structure maximizing its indoor wall area. Placed in this manner thermal mass is sheltered from summer sunlight but still reached with low winter sun, also both faces of a wall are exposed.

*Site influence*

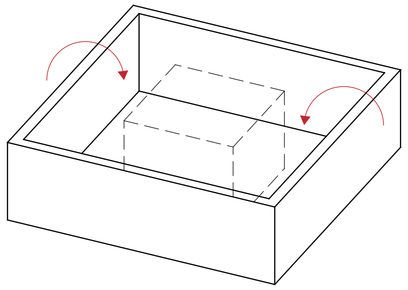
Property is located on a rocky southern slope. Topography requires each house to be carefully designed for specific spot if natural environment is a concern.
I want to create a flexible house suitable to be placed in random sloping terrains, minimizing ground works. At this point, rammed earth walls located inside can serve as a load-bearing structure.

*Program*

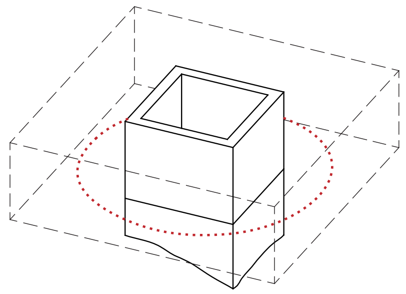
Two different floor-plans were developed with the intention that they could be merged into one bigger unit. One 9x9m and one 7.2x7.2m. Units were combined in groups of three or two and designed so that units could slide along one wall and adjust to varying landscape. Diagrams below shows possible ownership of joined volumes.



Basic building shell



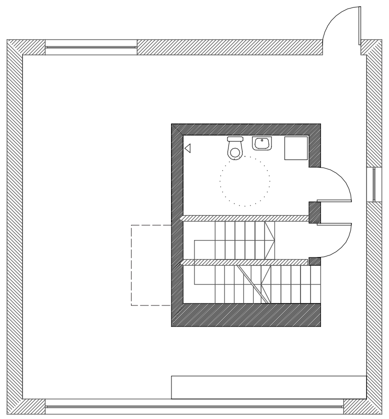
Structural walls are pushed inside



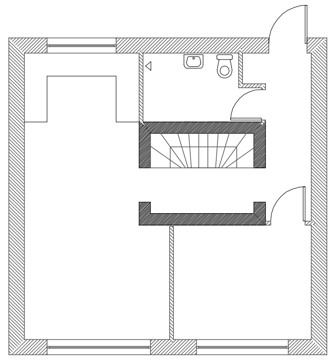
Core extended downwards to hit the terrain

*1st attempt*

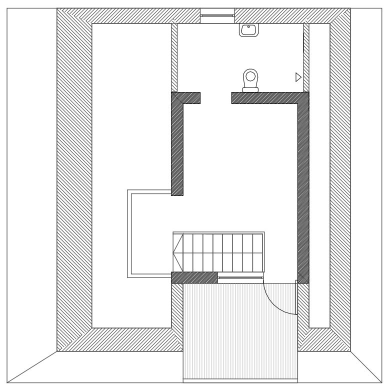
Spacial “core” organization seems to offer two possibilities - either move around the core(9x9 volume) or access spaces from the core(7x7 volume). Merging or splitting volumes results in rigid program. The resulting villa either has just one either 5 rooms.



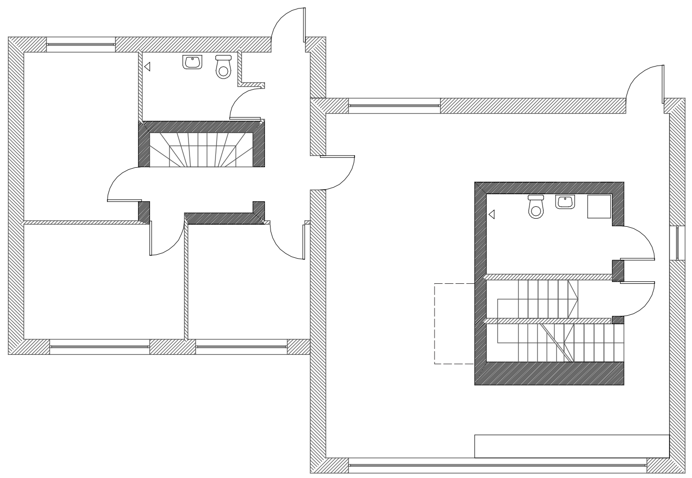
9x9 Entrance level. Earth core is defining entrance, kitchen and main room spaces M 1:200



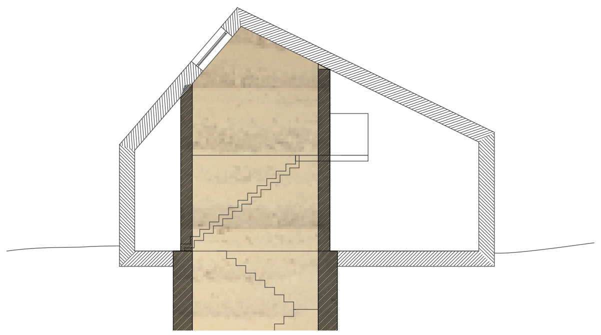
7x7 Entrance level. Earth core is serving as a communication hall M 1:200



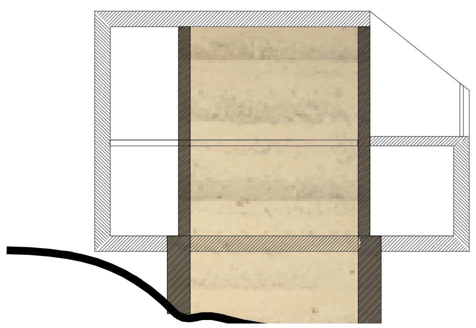
9x9 Mezzanine level. Earth core is allocated for master bedroom M 1:200



9x9 and 7x7 joined. Unit works as a 5 bedroom villa M 1:200



9x9 Section perpendicular to slope M 1:200

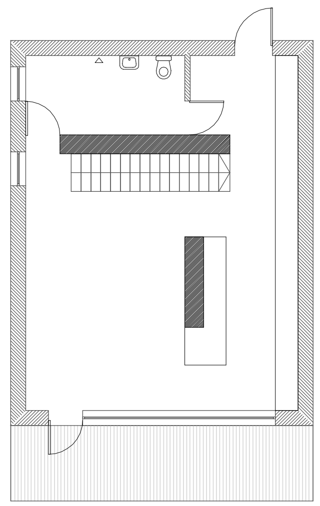


9x9 Section parallel to slope. M 1:200

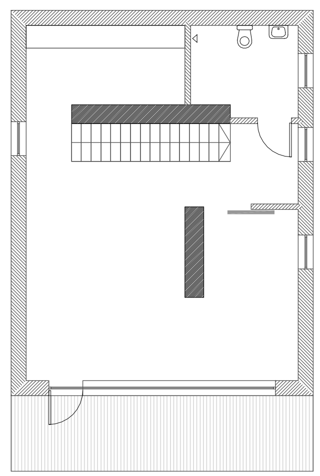


*2nd attempt*

Iteration with free standing rammed earth walls instead of a core was made. Open spaces such as sitting room, kitchen and entrance hall are divided in a smooth way, while private areas such as bathrooms and bedrooms requires additional partitions and doors for privacy. These additional partitions contributes negatively to the spacial experience and overall “walk around” concept.



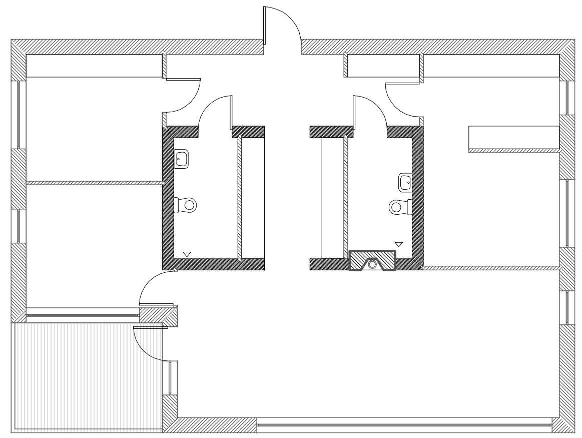
Entrance level. Version with free standing earth walls M 1:200



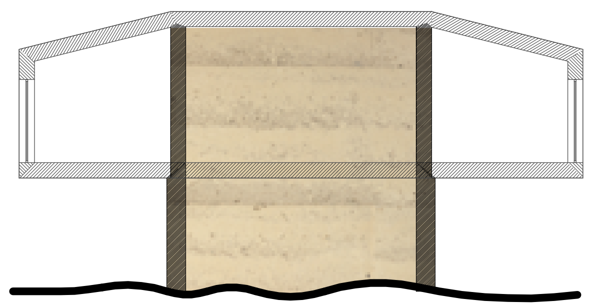
Upper level. Master bedroom on one side and working space on the other M 1:200

*3rd attempt*

Single floor version was made. In this arrangement all service areas are concentrated inside the core - kitchen and two bathrooms. While visible in the plan, core would be difficult to experience being inside the house.



Entrance level. Version with service core M 1:200



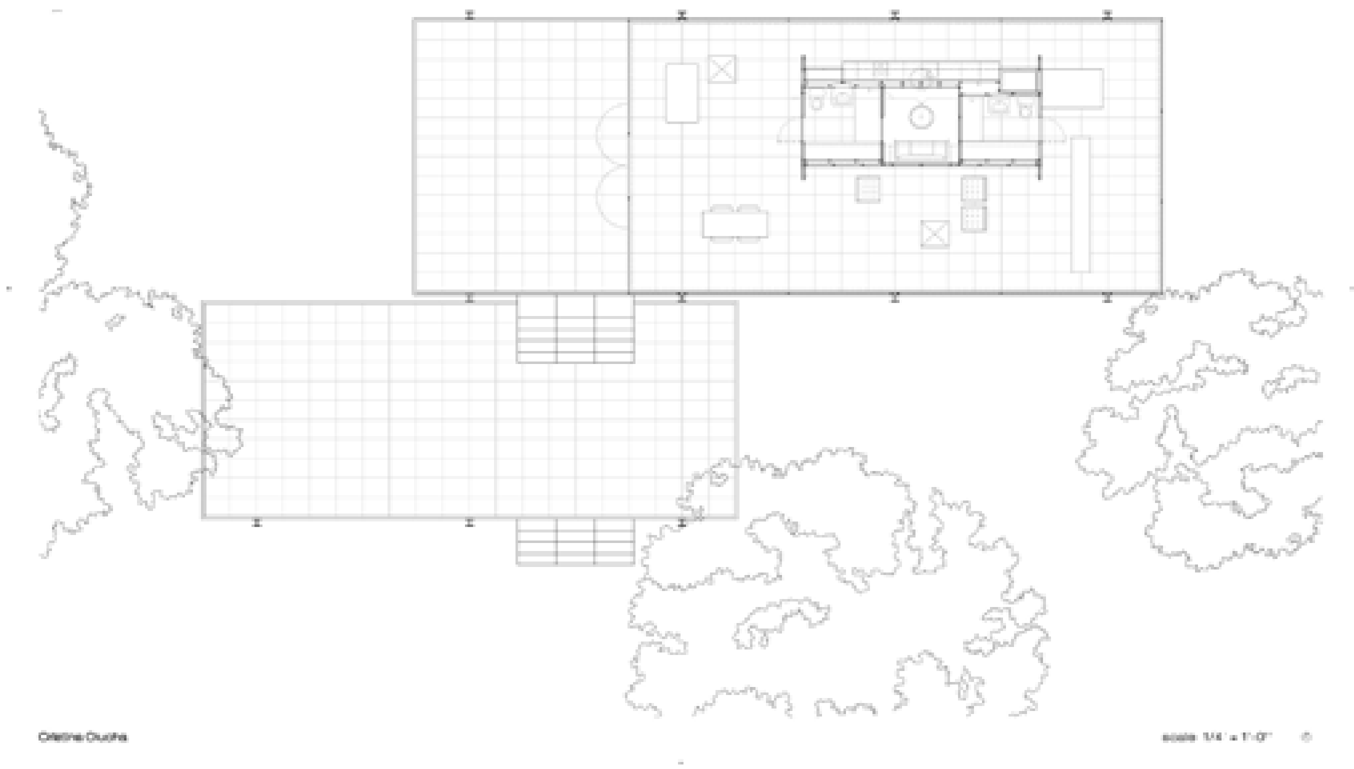
Section. Version with service core M 1:200

*CASE STUDY 6 "Farnsworth house"*

Architect: Mies van der Rohe
Area: 152m²

Probably the most famous house, featuring functional core and different spaces without wall subdivisions. Core is placed in a way that it forms spaces of different dimensions.
Scheme works well with the program for a vacation house. However architect had an ambition to evolve a dwelling for every-day life. Results are discussed in CASE STUDY 8.

Core element (Glyn 2007)



Entrance floor plan(Olucha n.d.)

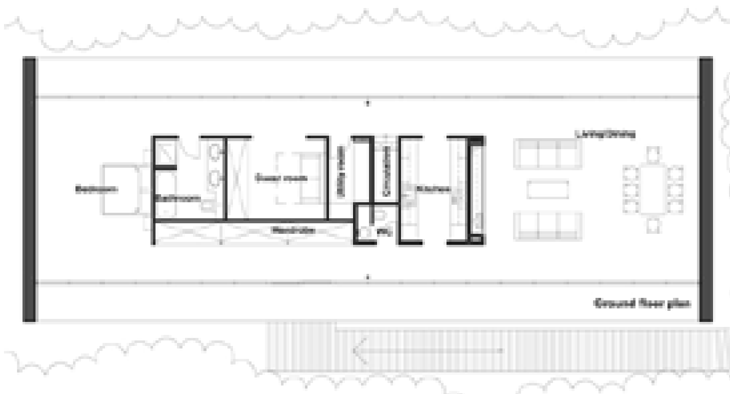
Farnsworth house exterior



*CASE STUDY 7 "Plan 520-4"*

Architect: McGahon Architects
Area: 170m²

In this project core absorbs all the spacial complexity, required for residential housing, leaving master bedroom, sitting and dining spaces extremely clean.



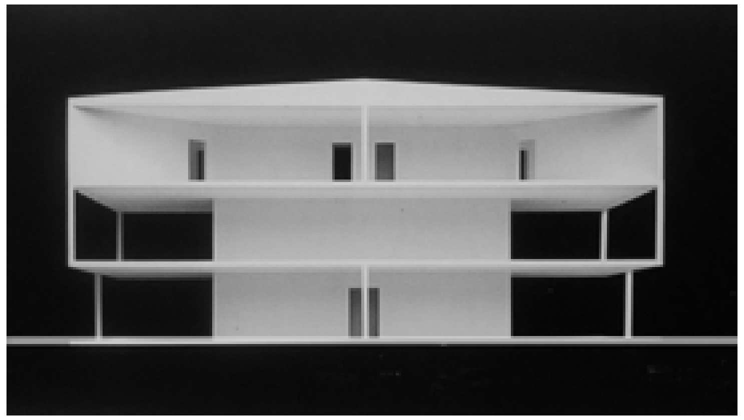
Concept plan of single family house ( McGahon Architects 2001)

Exterior visualization (McGahon Architects 2001)

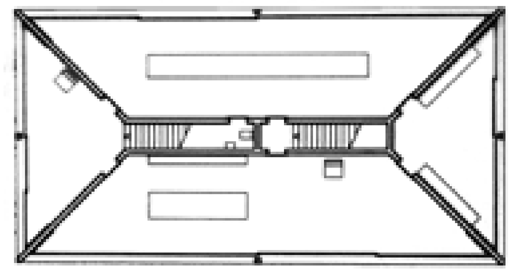
*CASE STUDY 8 "Office with two staircases"*

Architect: Pascal Flammer

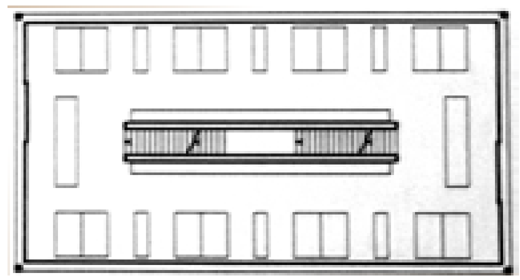
Core concept is a quite common architectural expression. This unbuilt office project by Pascal Flammer has ready-made plan scheme where rammed earth core would employed in the right way.



Model of the project featuring distinct core(Flammer 2000: 86)



Upper floor (Flammer 2000: 86)

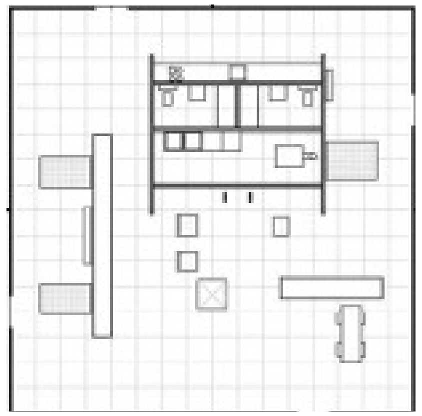


Middle floor (Flammer 2000: 86)

## *CASE STUDY 9 "Core House"*

Architect: Mies van der Rohe
Spacial interpretation: Luciana Fornari Colombo
Area: 116$m^2$; 207$m^2$; 324$m^2$

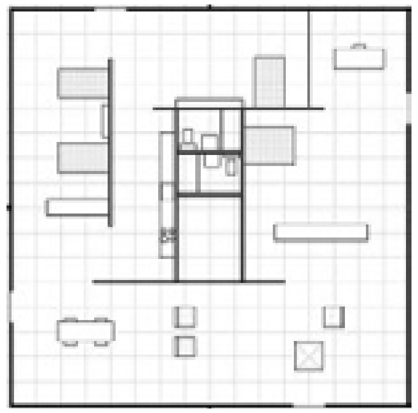
Zoning on 324$m^2$ house version proposed(Colombo 2011)



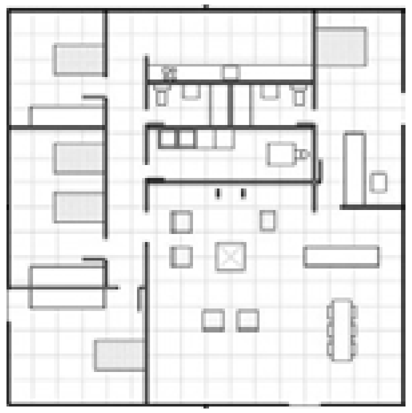
207$m^2$ Core House's original version(Rohe 1951)

Zoning on 116$m^2$ house version (Colombo 2011)

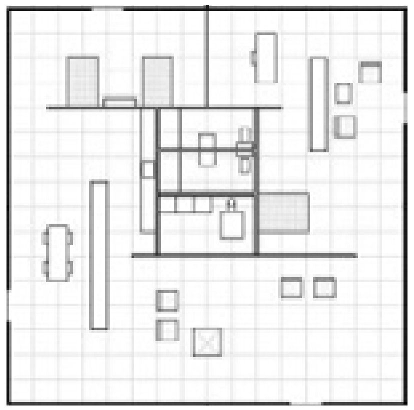
The idea was to create modular flexible house that would fit different needs on a client. Core house was intended by Mies to be built in three different sizes. However only 207 $m^2$ attempt was sketched with full furnished layout. Luciana Fornari Colombo made an attempt to put function in other two sizes and created alternative scenarios to the original 207$m^2$ house.



Alternative zoning on 207$m^2$ house. 3 bedrooms (Colombo 2011)



Alternative zoning on 207$m^2$ house using conventional walls (Colombo 2011)

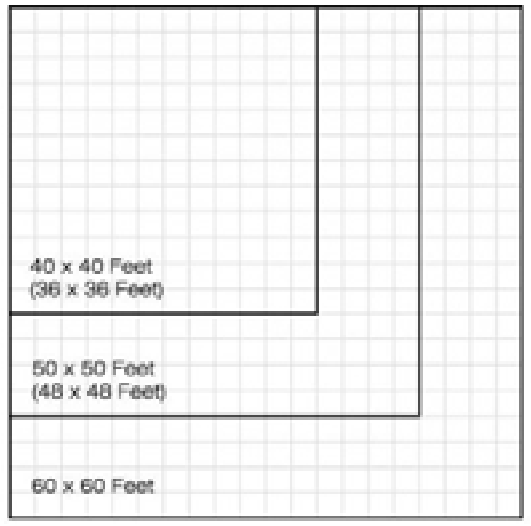


Alternative zoning on 207$m^2$ house. 2 bedrooms (Colombo 2011)

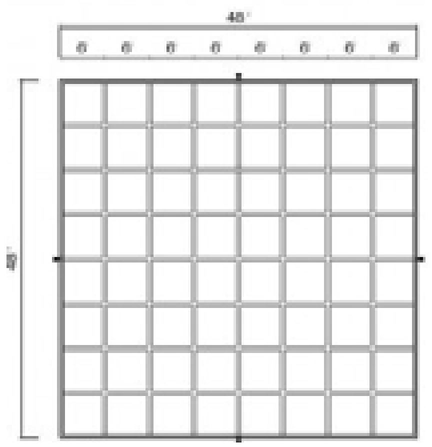


Core house perspective. (Fornari Colombo 2011)

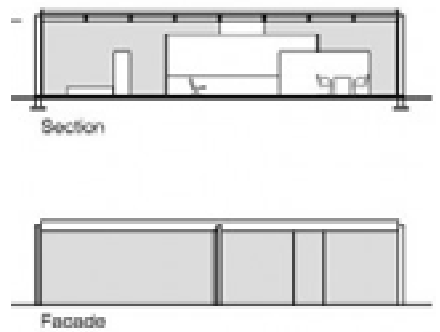
Core house project was never built, author of the research suggests that the reasons this house was not built and introduced to mass productions are unresolved issues of privacy required in some parts of the house.
It is simple to imagine how life in open space is possible in vacation house context with one bedroom(e.g. farnsworth house), but it becomes complicated when program is bigger. Project results either in spaces that have no proper privacy either core and openness idea becomes diluted.
In my project i was trying to do exact the same thing - fit all standard housing program with the idea of openness around the core, but the results were not convincing.
After discovering this study on Miess drawings i decided to split house program between two floors and provide different spacial qualities - private for bedrooms and open for kitchen/dining/sitting spaces, at the same time keeping core as the dominant element.




Three intended sizes for a core house. (Rohe 1951)



Core house roof(Rohe 1951)




Core house sections. (Rohe 1951)

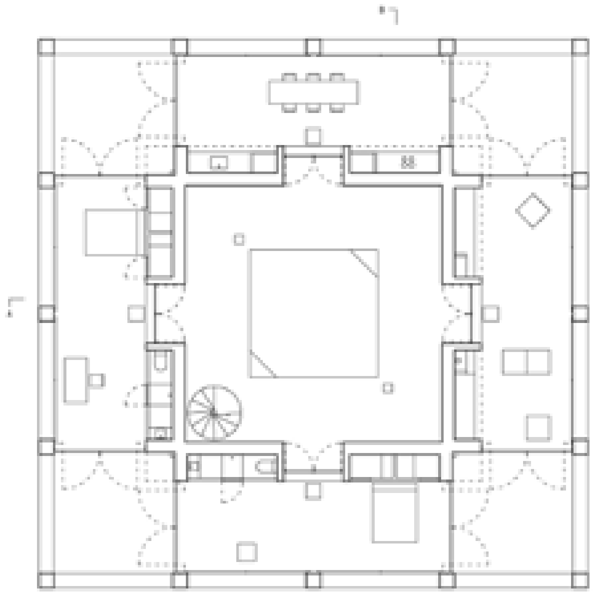
*CASE STUDY 10 "Solo Pezo"*

Architect: Pezo Von Ellrichousen
Area: $310m^2$

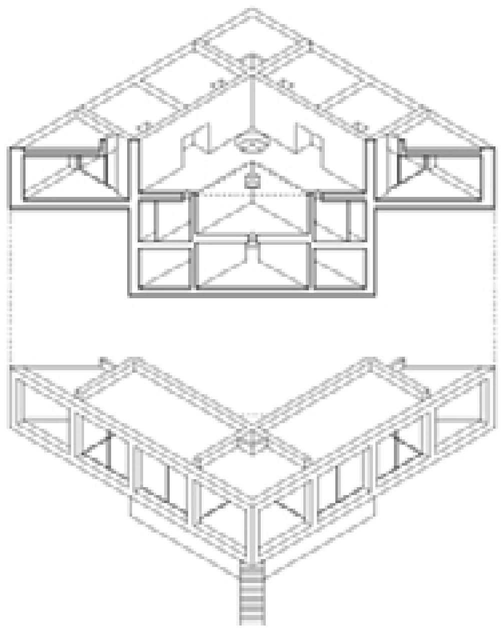
Built in Spain, two hours south of Barcelona, in the Mattaranya region this house is one built example of the "Solo houses" exclusive real estate development project.

This project displays extremely strict symmetry based concept in plan zoning/structure/facade. In main level core part is hosting swimming pool with generous circulation area around it. Adjacent to external core walls all service areas such as bathrooms, kitchen, storage, fireplace are squeezed in 95 cm layer. Two sides are allocated for bedrooms, one for dining and one for sitting room, all four corners that are harder to access directly from a core serve as outdoor terraces. Even subdivision of a plan allows to achieve great openness as any window unit can be slided from the central part towards the terrace inverting open space. Spiral stairs inside the core leads to lower level where storage spaces and connection to ground level are located. 95 cm service area layer in sitting room merges to the whole space, making it bigger than the rest of the rooms, but still maintains same grid. Core house idea proved to be successful as company developed another Guna House based on the same principles.

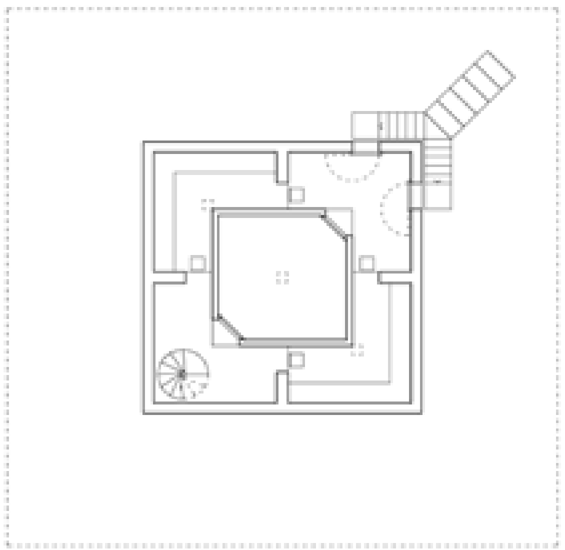
Night view of the house (Pezo n.d.)



Upper floor (Pezo n.d.)



Axonometric section (Pezo n.d.)



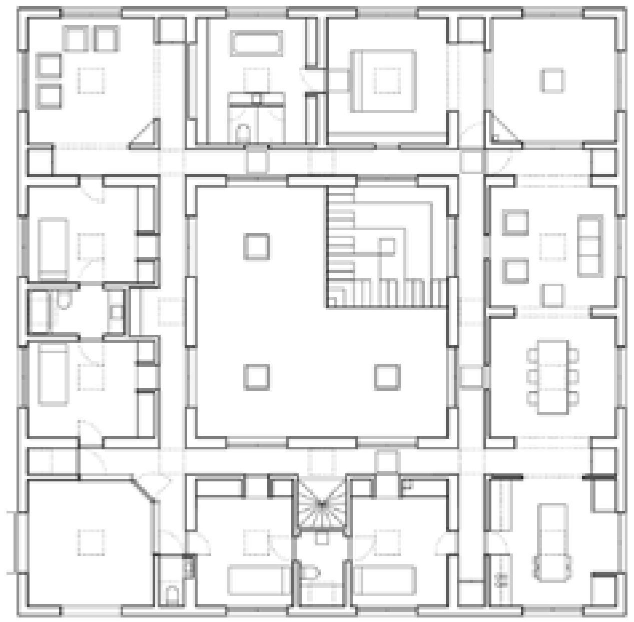
Entrance floor (Pezo n.d.)



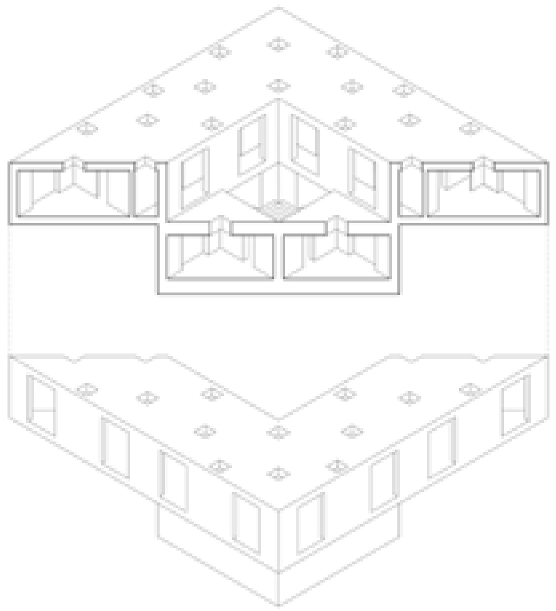
*CASE STUDY 11 "Guna House"*

Architect: Pezo Von Ellrichousen
Area: $410m^2$

Similar in shape to Solo house this project has different qualities. Most interesting from my point of view it is how core courtyard offers extreme privacy and at the same time is connected with the surroundings via sloping corner. Project is surrounded by nature, but with this spacial scheme it has a great potential to be used in densely urbanized environment.



Upper floor (Pezo n.d.)



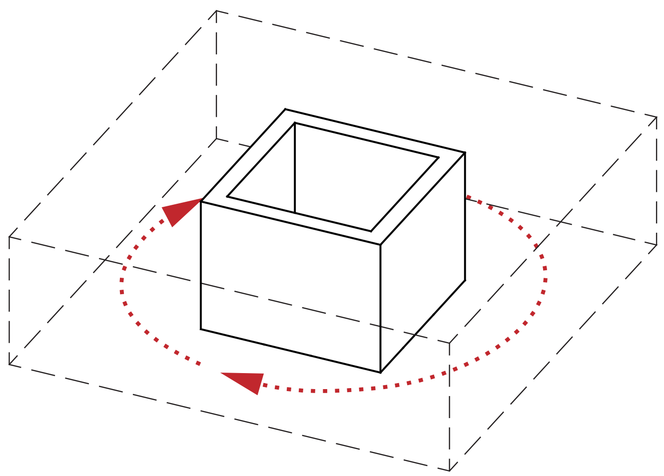
Axonometric section (Pezo n.d.)

Entrance floor (Pezo n.d.)

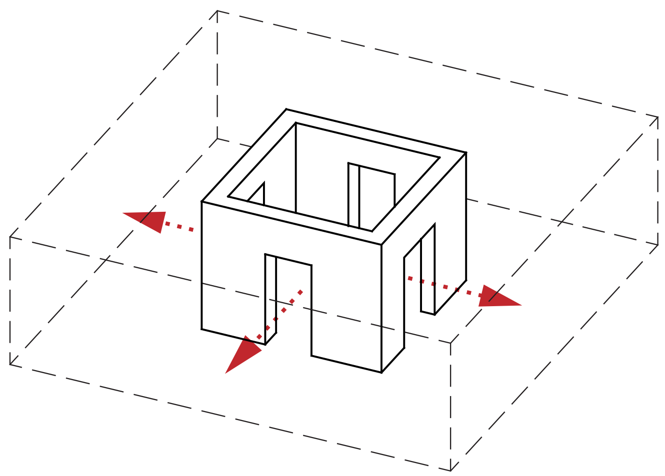
*Bird eye view of the final project*

*House 1*

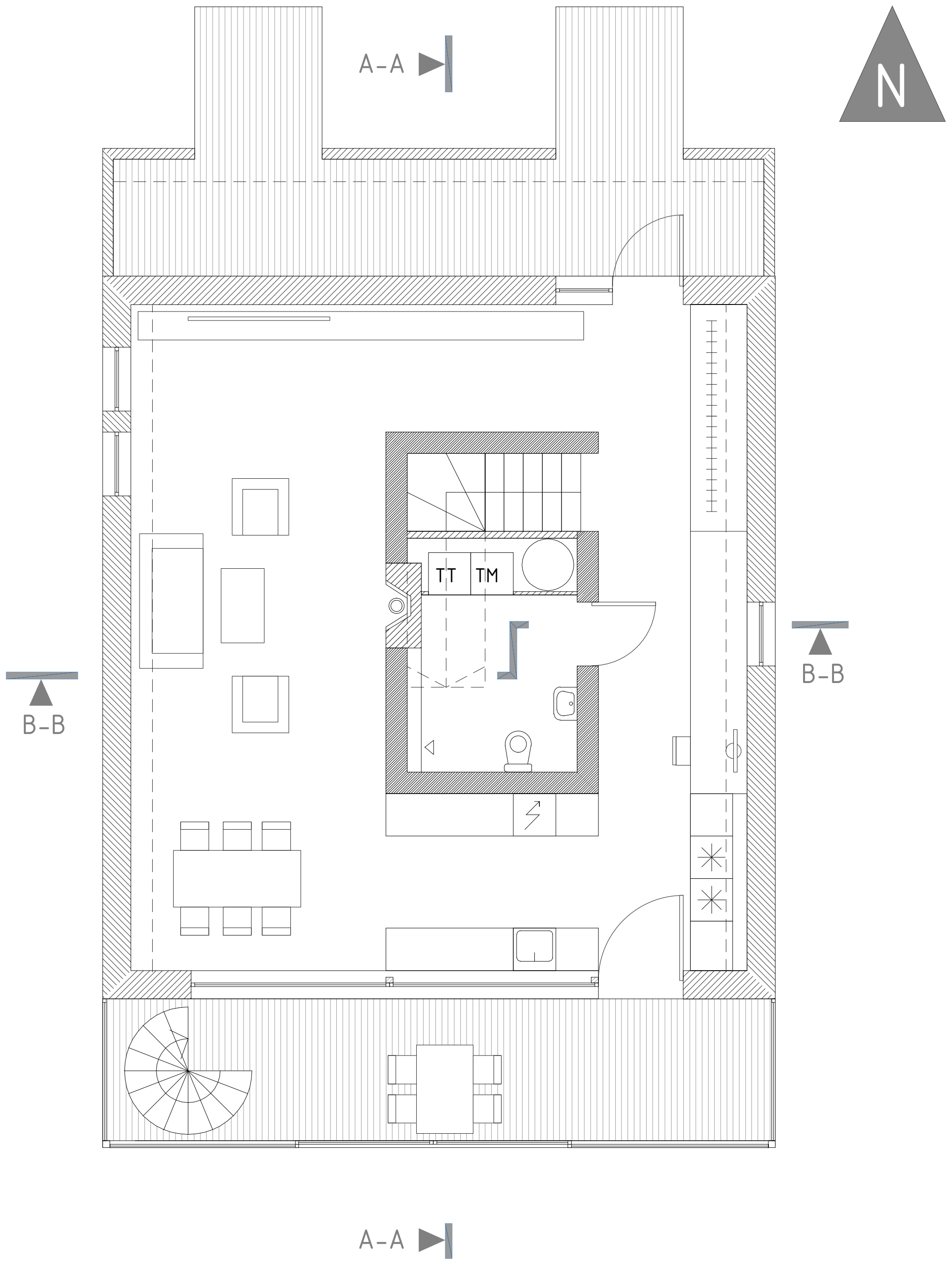
Final floor plan derived from 1st attempt scheme. Design employs two spacial organization methods. In the entrance floor all movement is organized around the core and there are no other space dividers. In the upper floor all rooms are accessed from the core ensuring it is still the main spacial element.



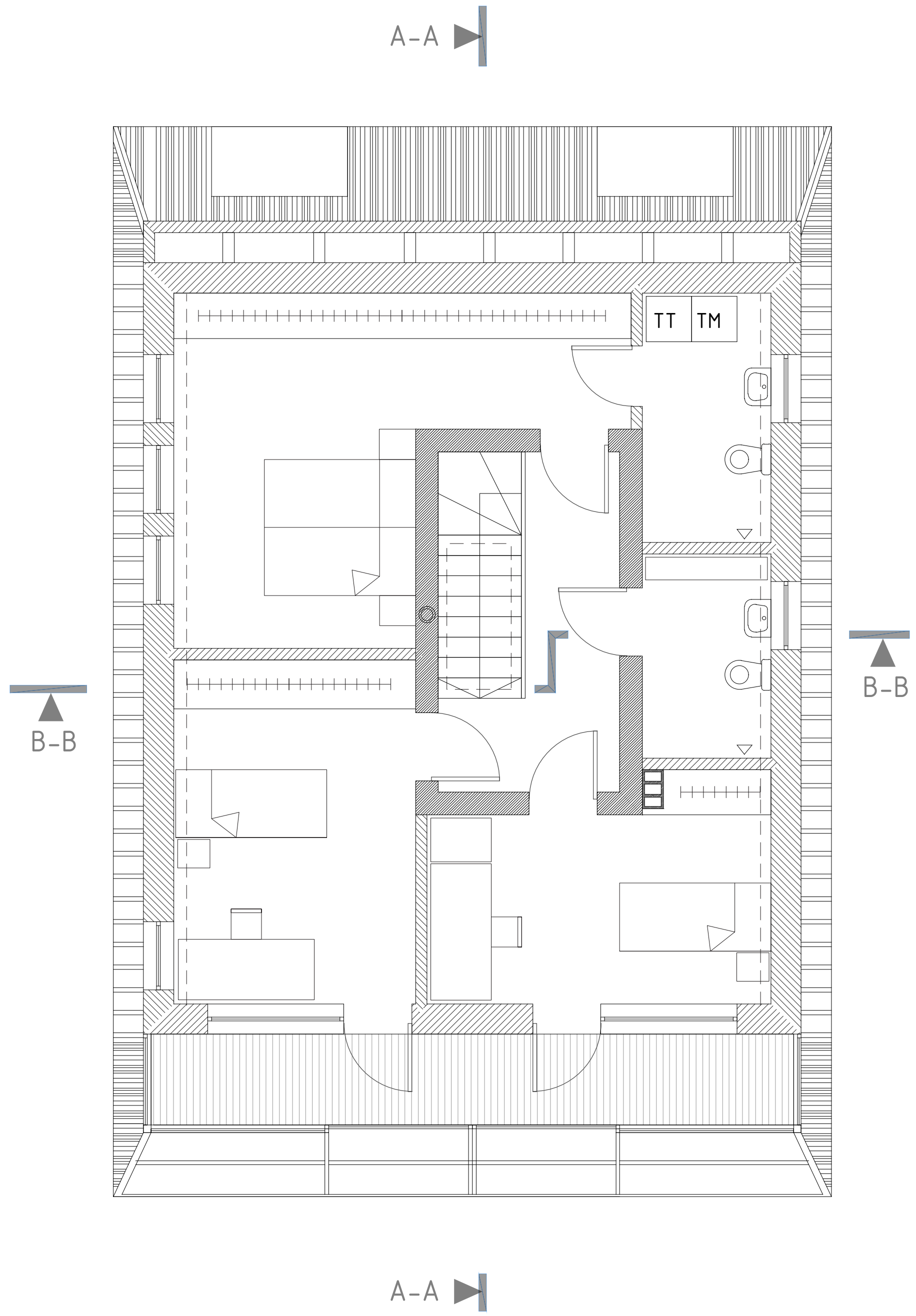
Movement around the core



Movement from the core

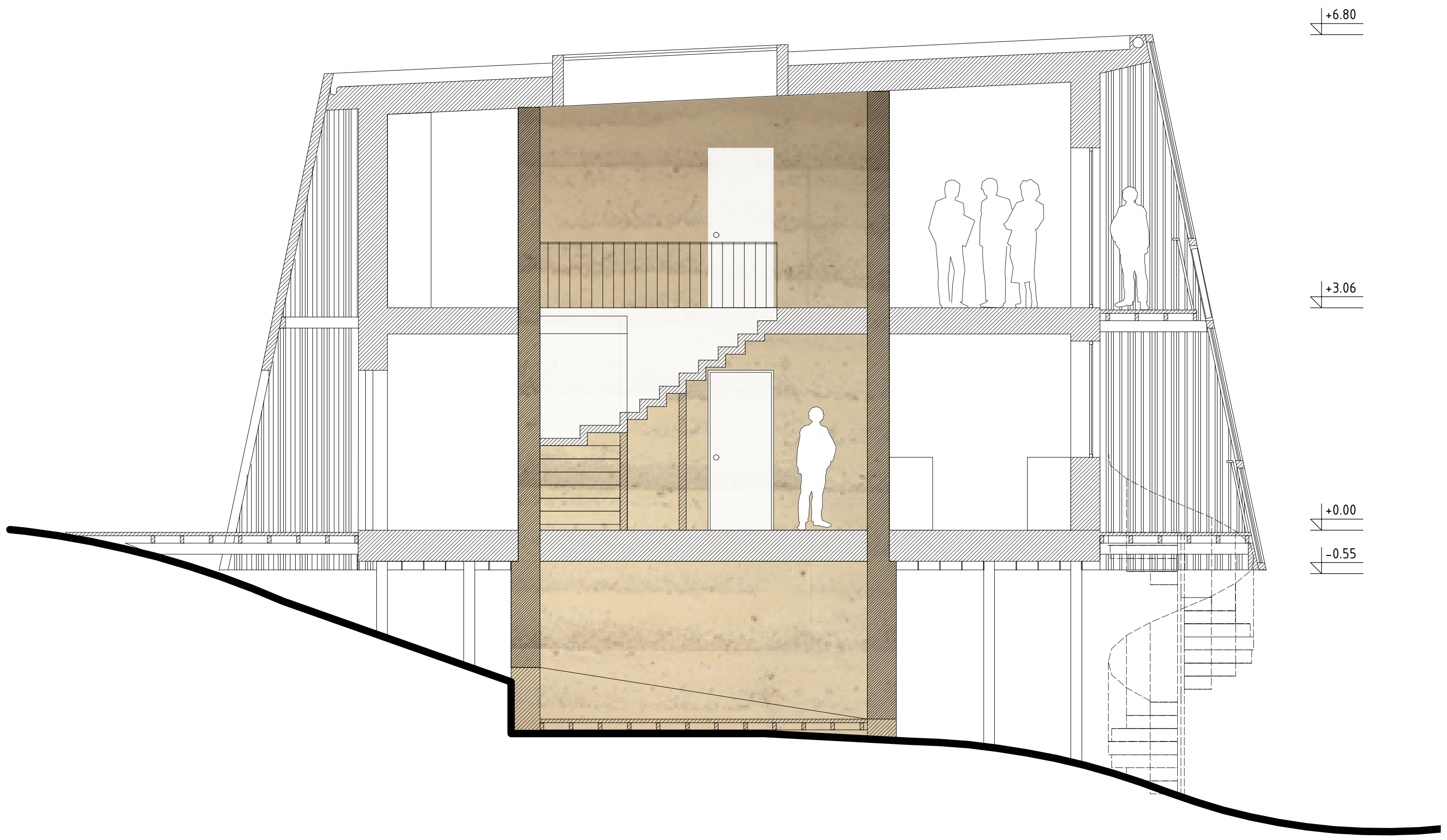



*Entrance floor M 1:100*



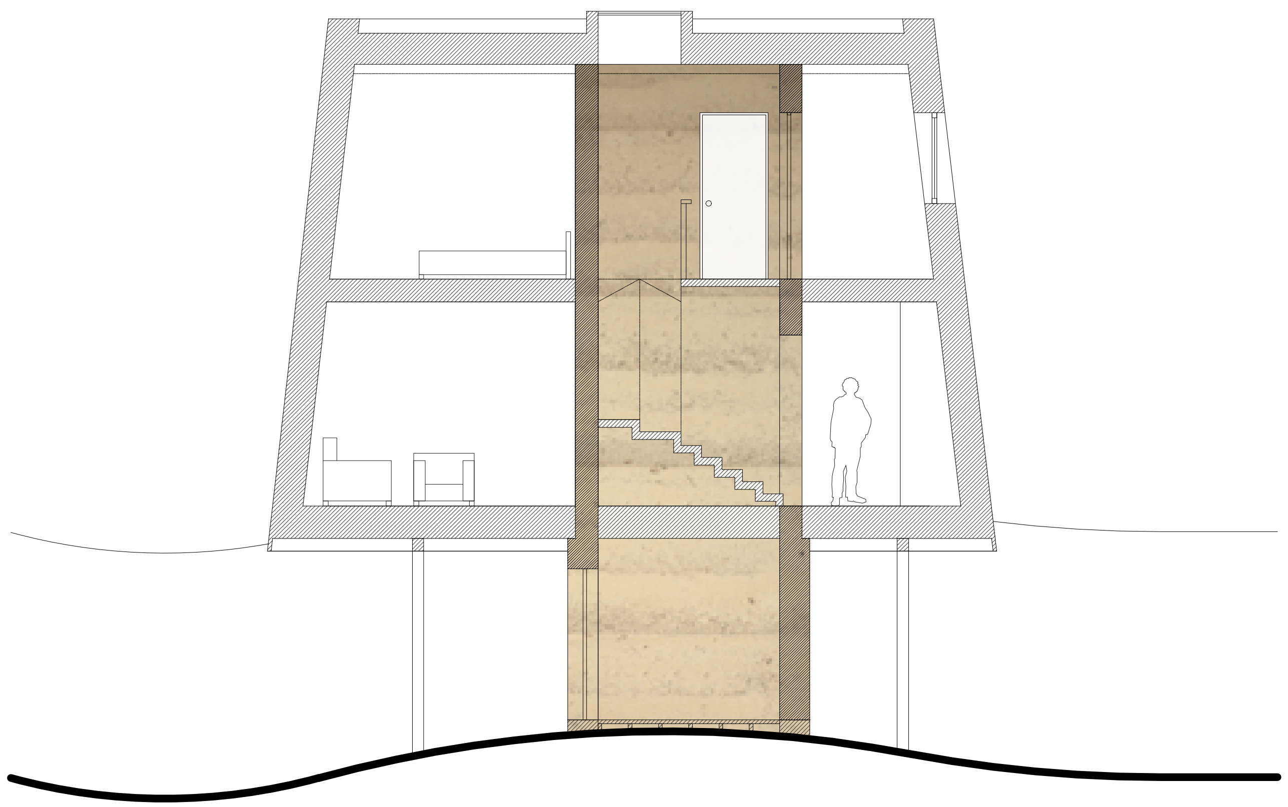

*Upper floor M 1:100*

*Entrance floor interior. View from the terrace.*

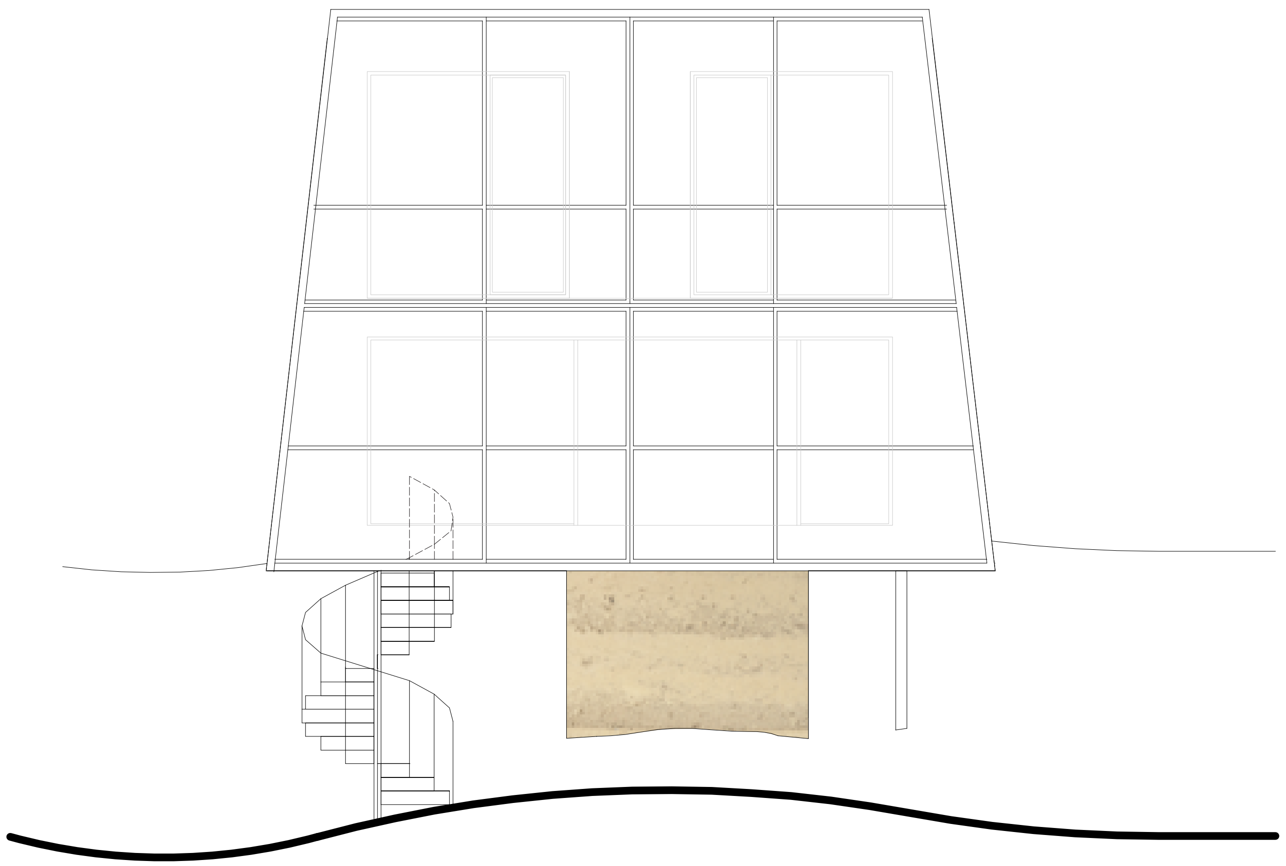



*Section A parallel to the slope. M 1:100*





*Section B perpendicular to the slope. M 1:100*

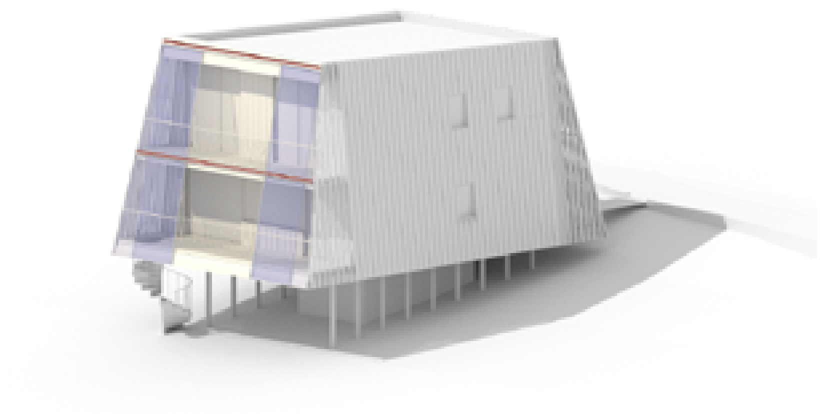


*South facade. M 1:100*

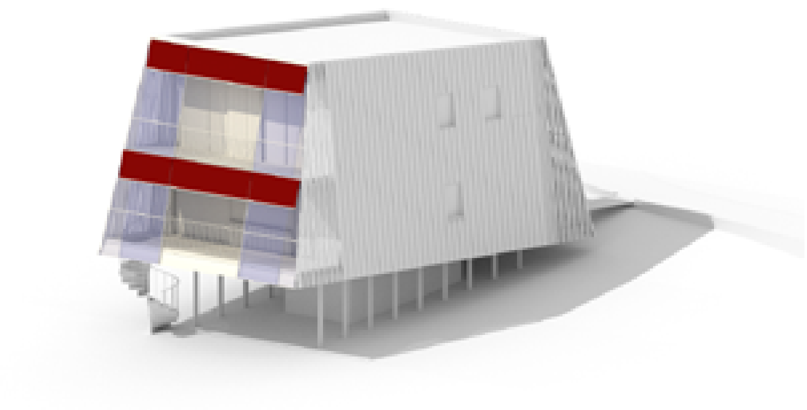

*West facade. M 1:100*

*View from the North side*

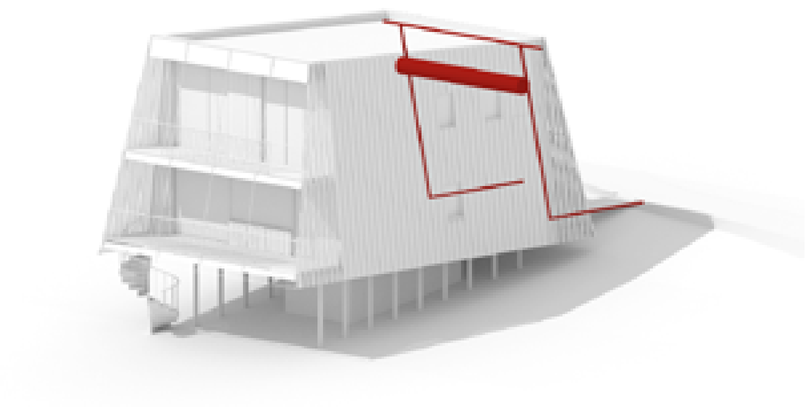




Terrace glazing allows to avoid strong sea winds or can be opened to allow fresh air.



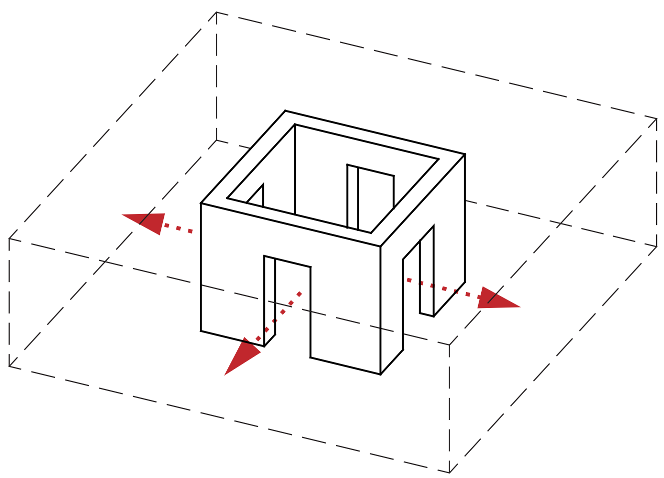
External shutters blocks excess sunlight

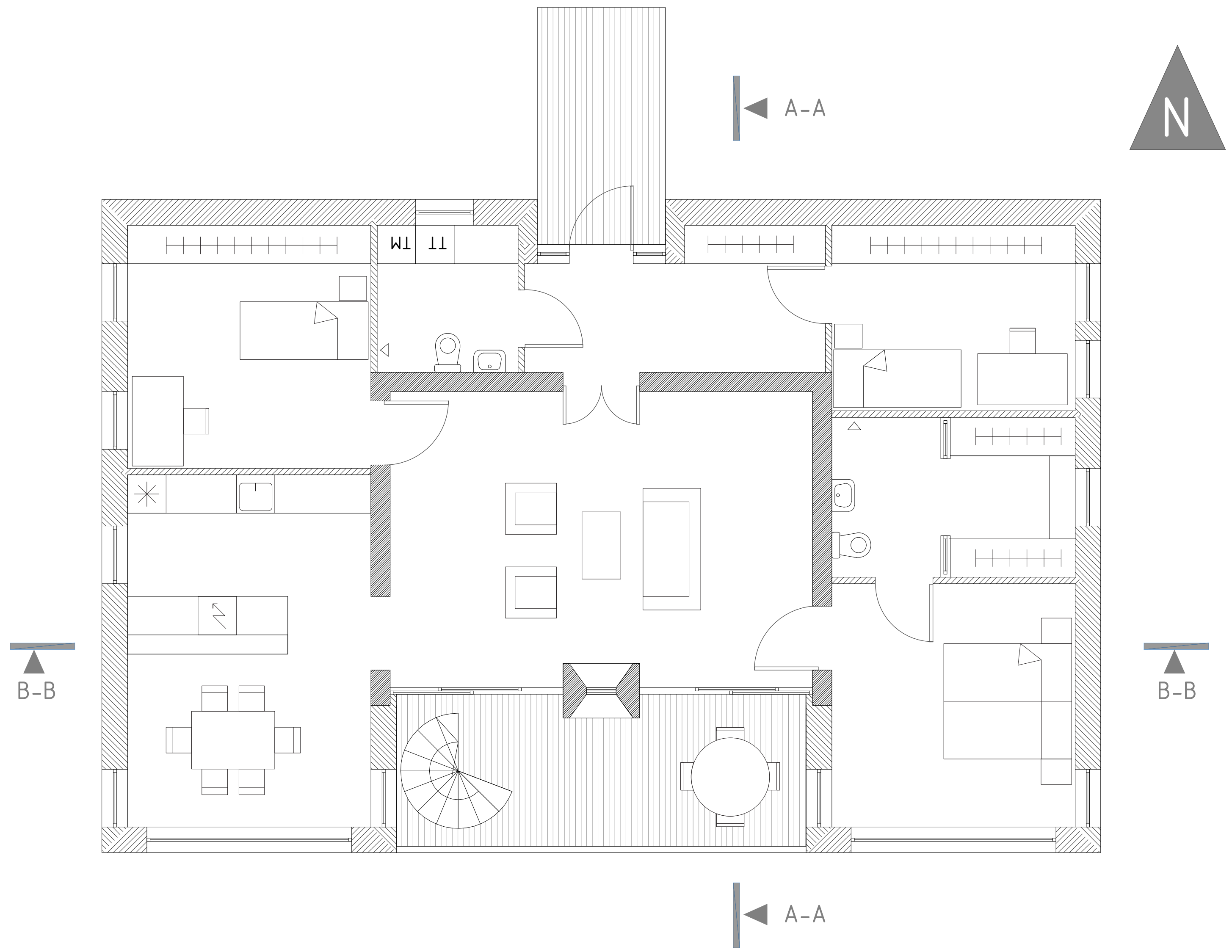


Rainwater is collected in a tank for various uses

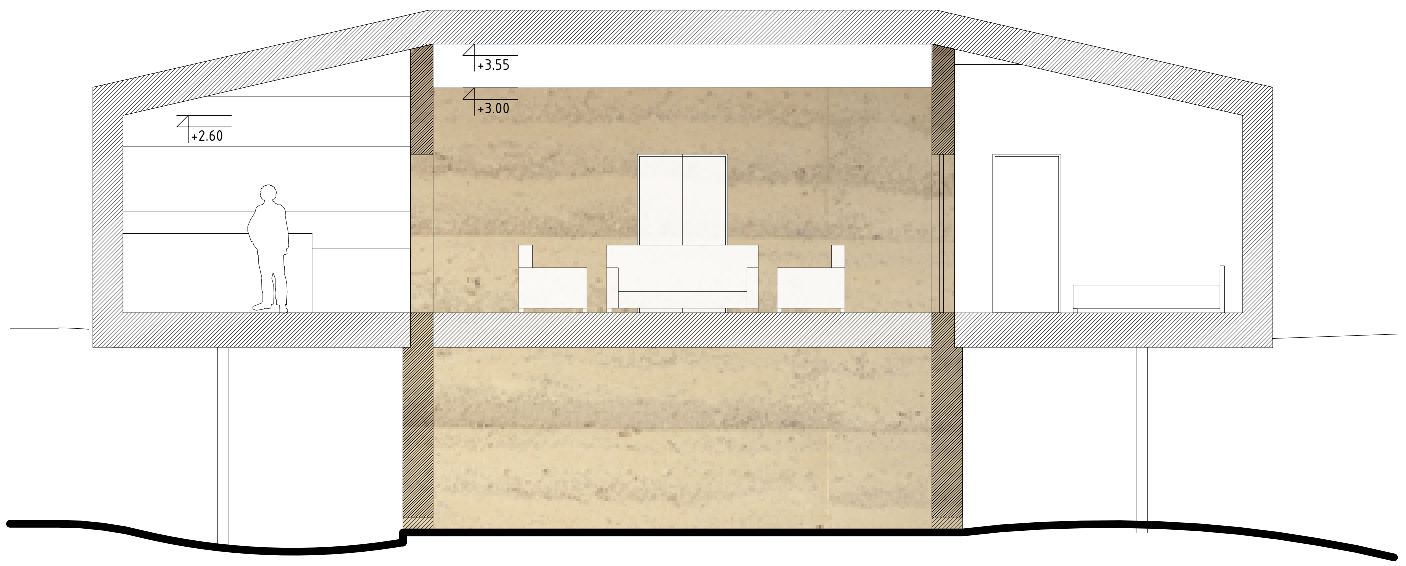
*House 2*

In order to have variation in the property and explore core idea further i decided to populate it with two different volumes. One vertical and one horizontal. Horizontal volume means that both private and open spaces has to be in the same floor. Same spacial organization method as in “house 1” second floor was used, where all rooms are accessed via the core. In this situation the core is a sitting room. It is relatively open to the south and closed on the other three sides. Windows and core openings are aligned in a manner that it is still possible to experience glimpses of east west and north sides while being in the center of a house. The intention is to create experience as if person would sit near a trunk of a tree and could see light coming trough the foliage.



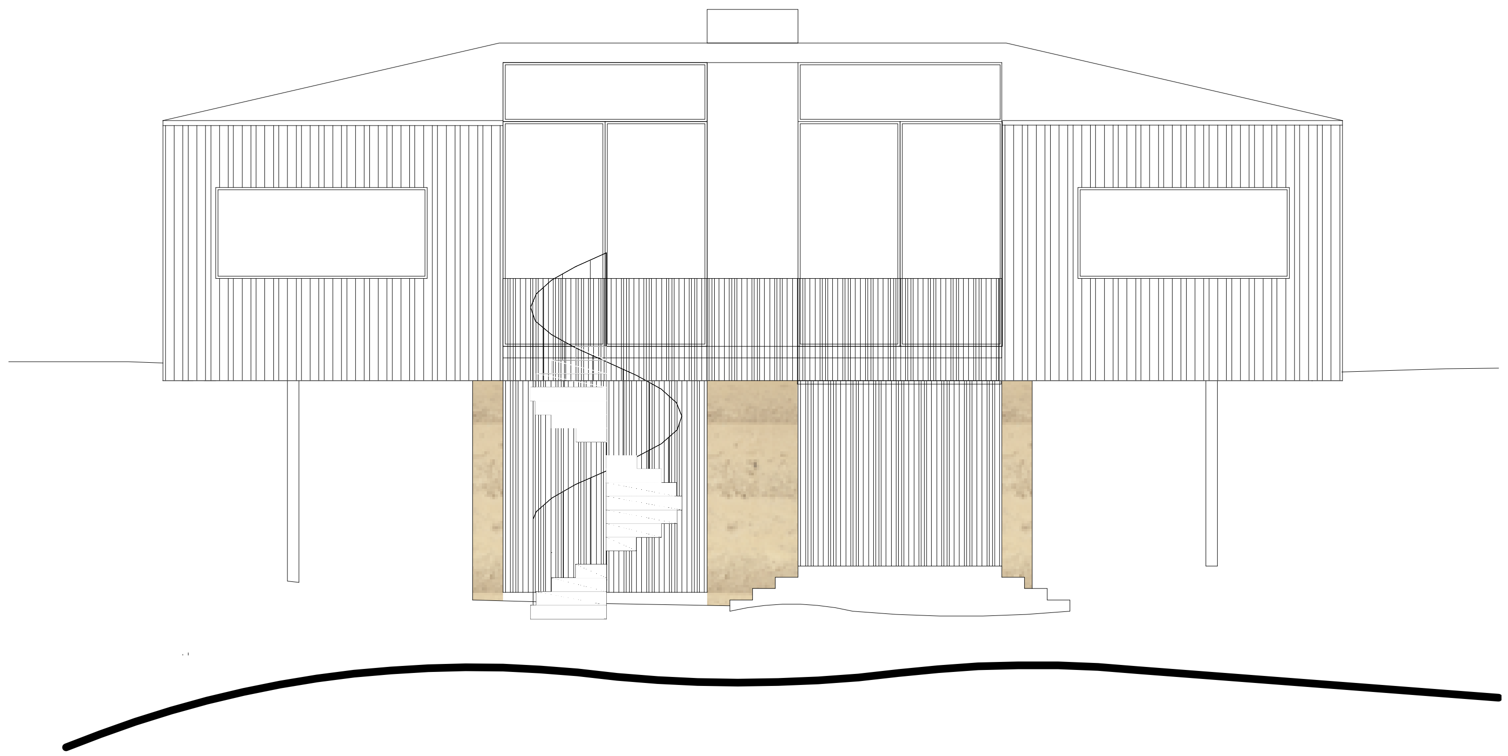



*Entrance level M 1:100*



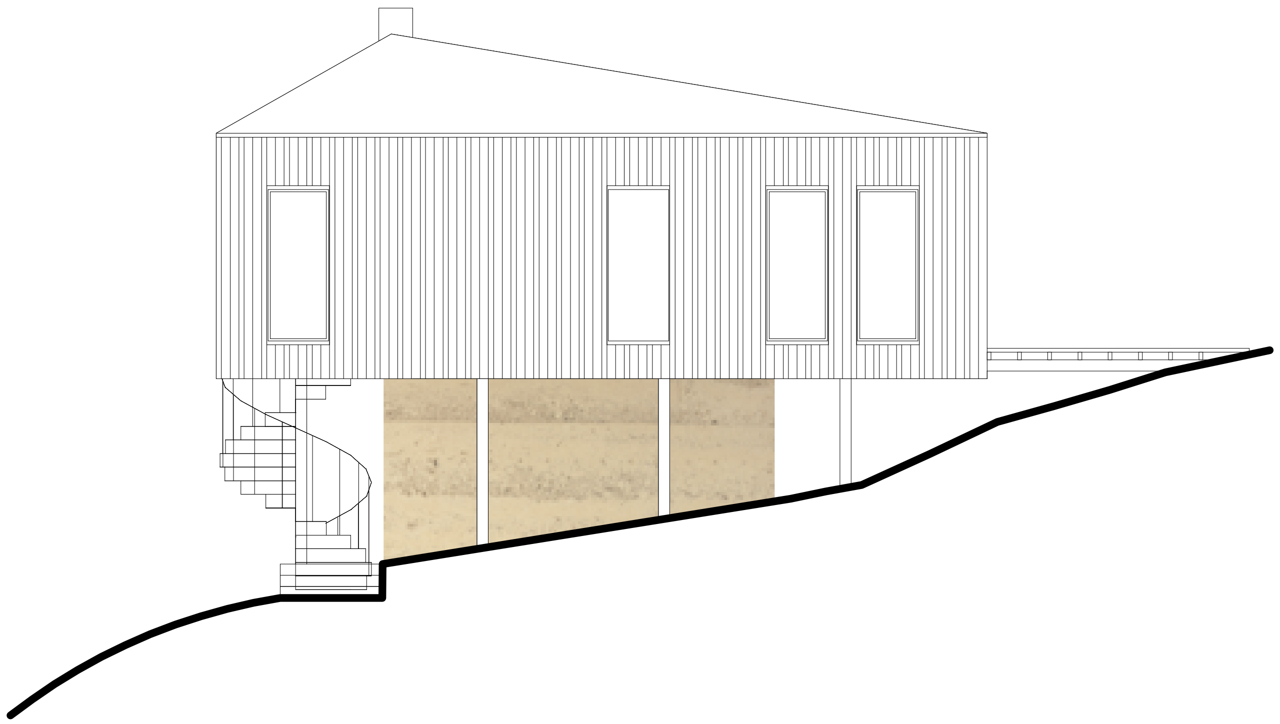

*Section A perpendicular to the slope M 1:100*



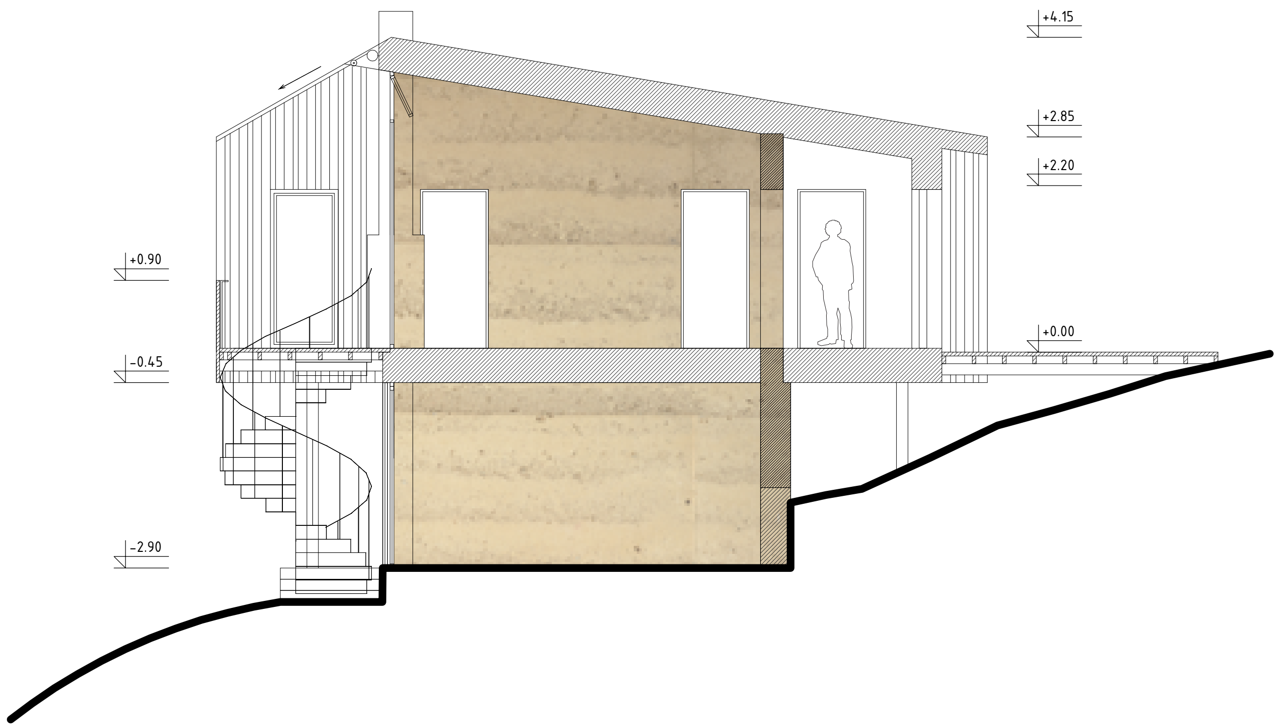


*South facade  M 1:100*

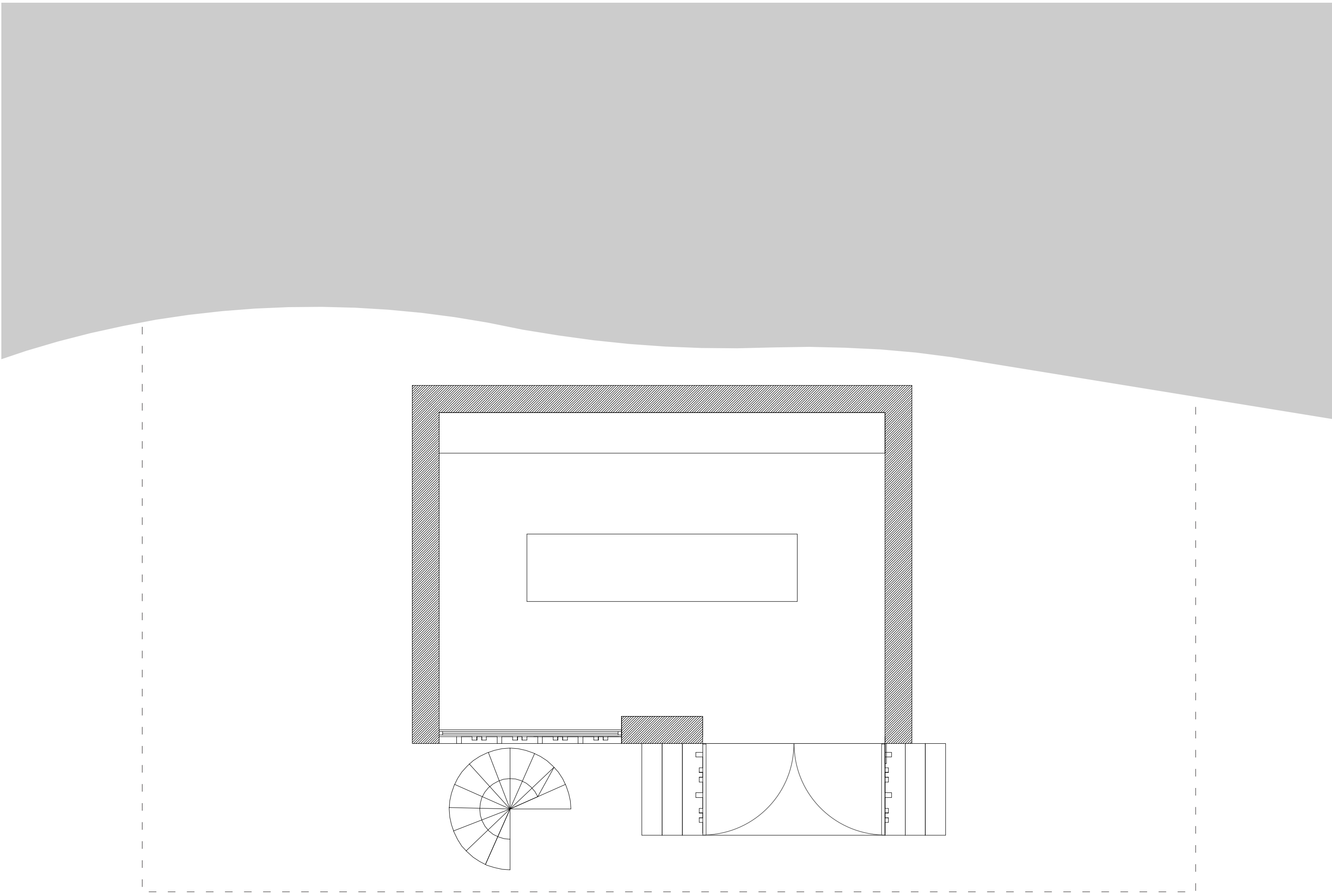
*Entrance floor interior. View from the sitting room*



*East facade M 1:100*



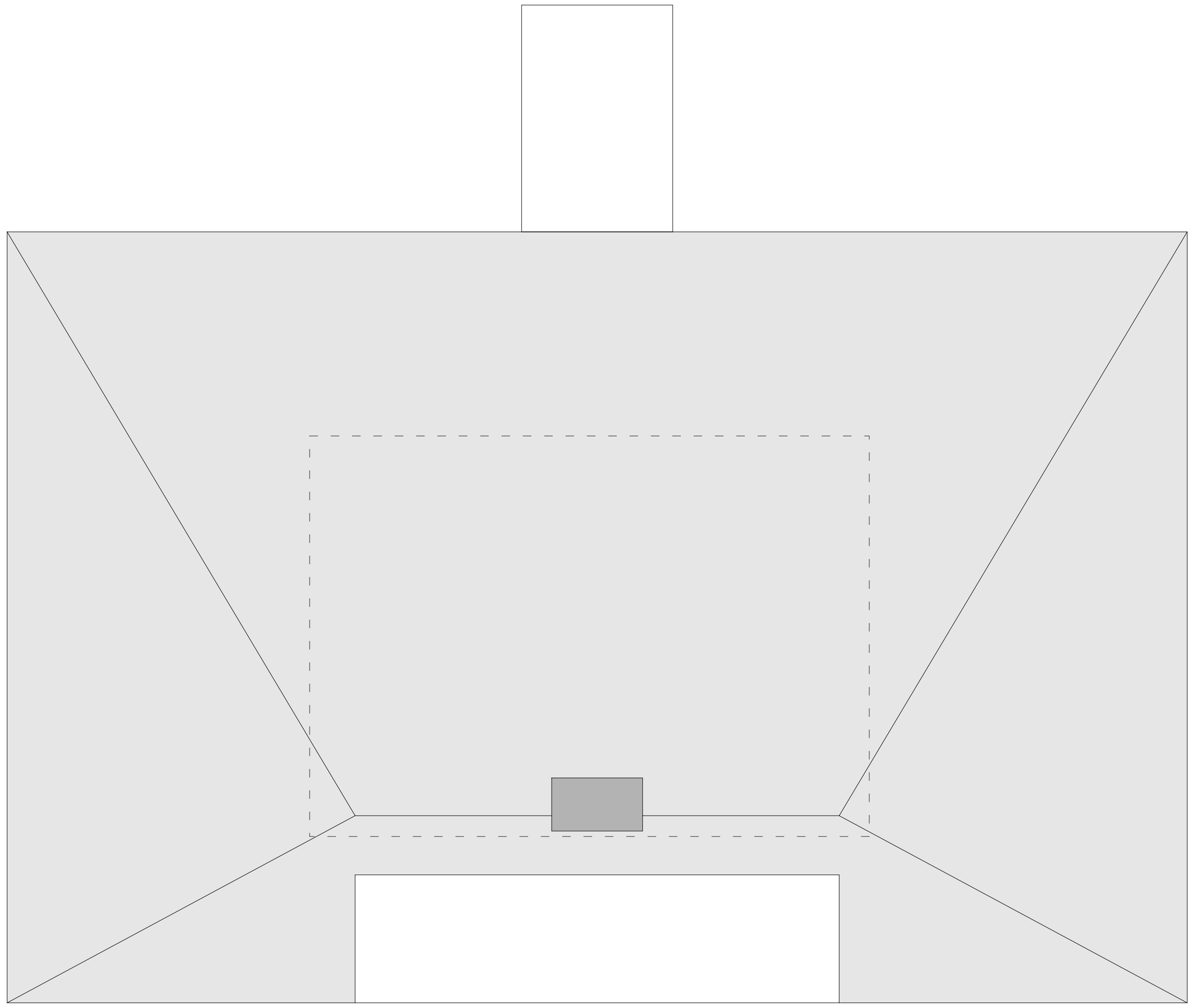

*Section B parallel to the slope M 1:100*



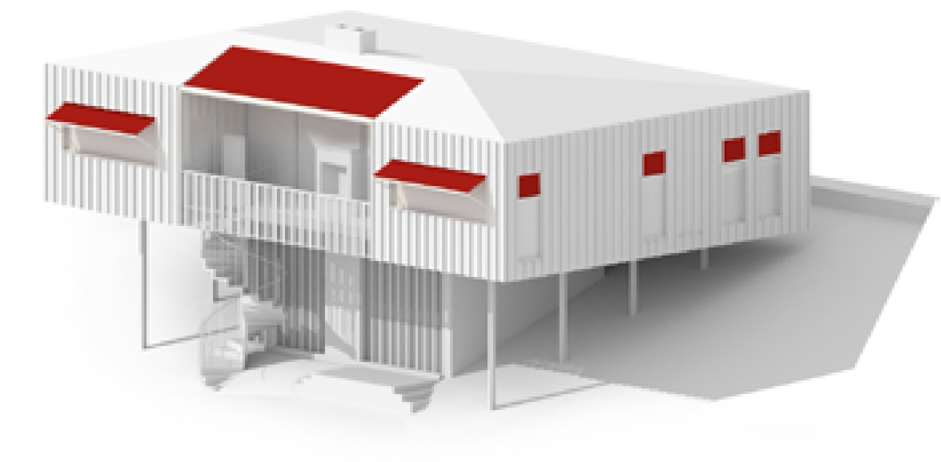
Uninsulated lower level open to the south side and with direct contact with the ground could be used for specific needs of a house owner. It could be a workshop, gym or a storage space.

*Lower level M 1:100*

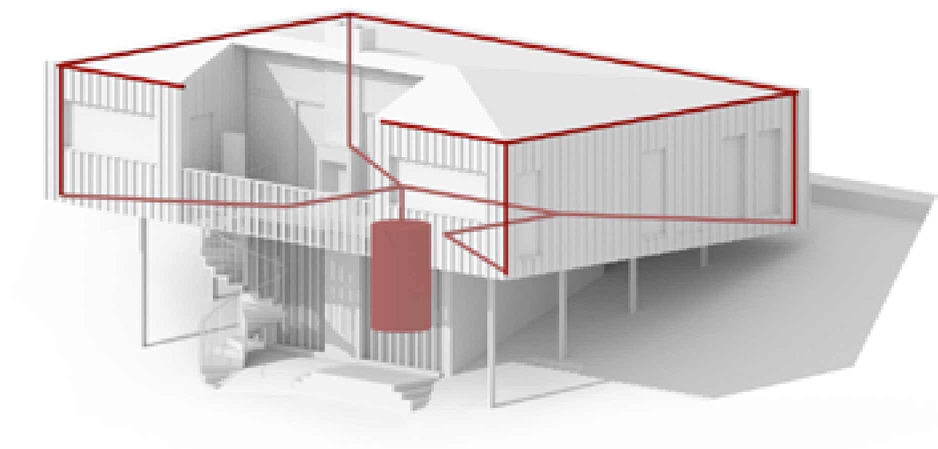




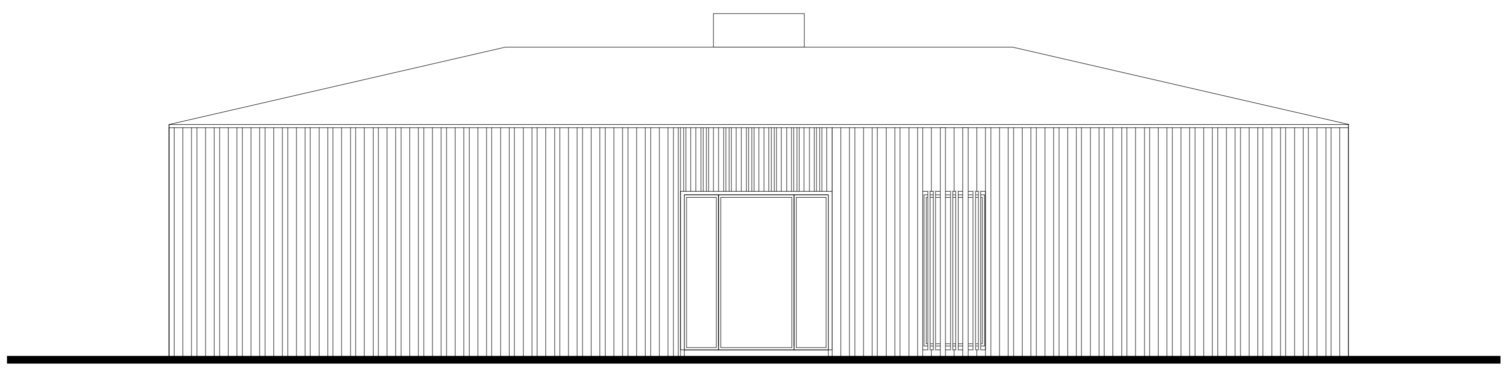
*Roof M 1:100*



External shutters blocks excess sunlight



Rainwater is collected in a tank for various uses



*North facade M 1:100*

*Site plan M 1:800*

*Roads*

Two car accessible streets are created with parking spaces arranged around them. Other paths are intended for pedestrian/bicycle traffic only. Each house has one covered parking place at the same level as the house(wheelchair accessible) and one extra open parking further in the plot.

*Orientation*

Each house is aligned parallel to the terrain, but rotation of south facade never exceeds $30^{0}$ true south so that passive solar design elements are effective.

Core structure occupies only a fraction of the land

Green roofs makes property greener than it was originally. 2000 m² additional green surface appears in the terrain.



*Exterior visualization of the property*

# DETAILING

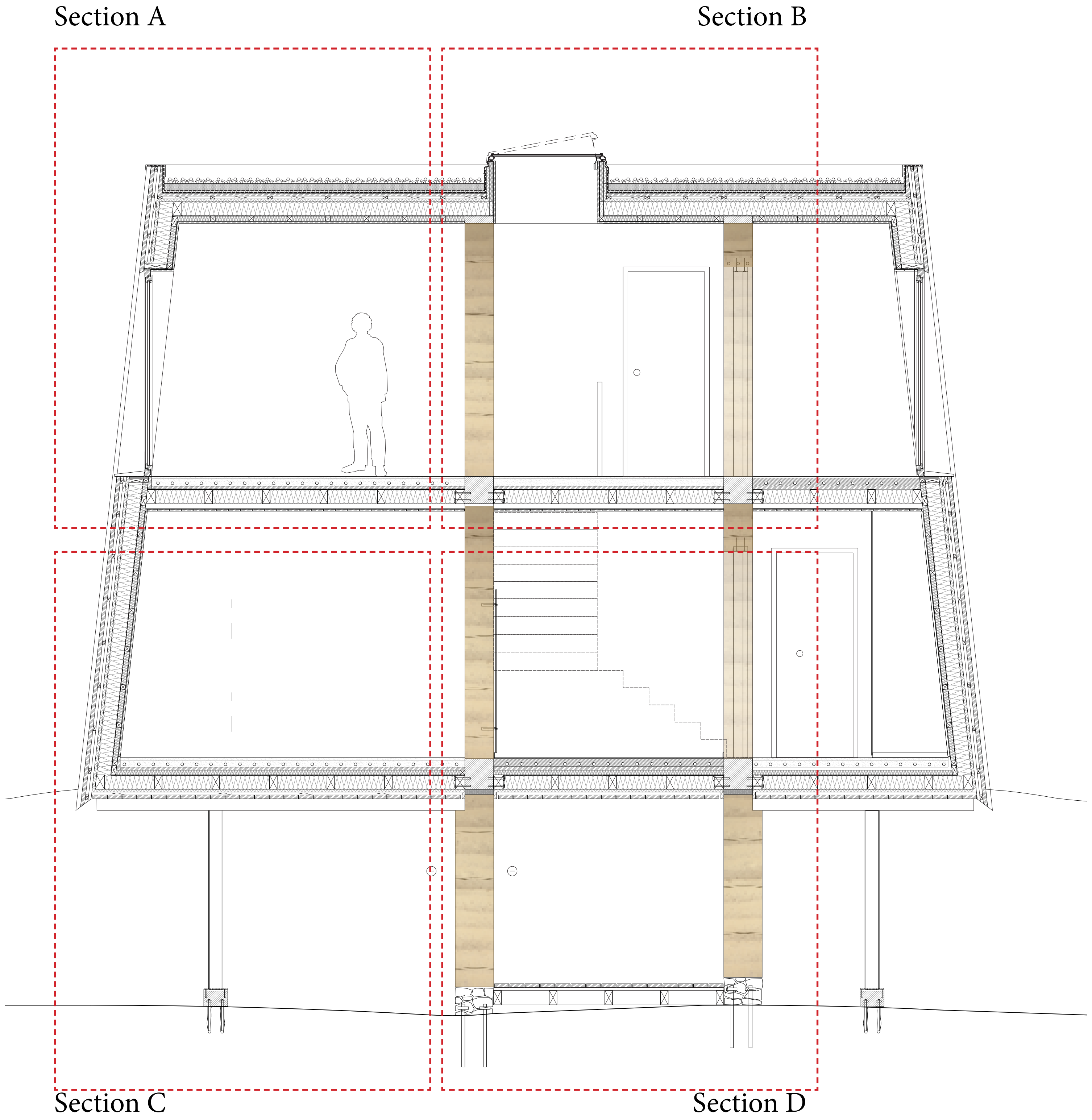
*Load bearing capacity*

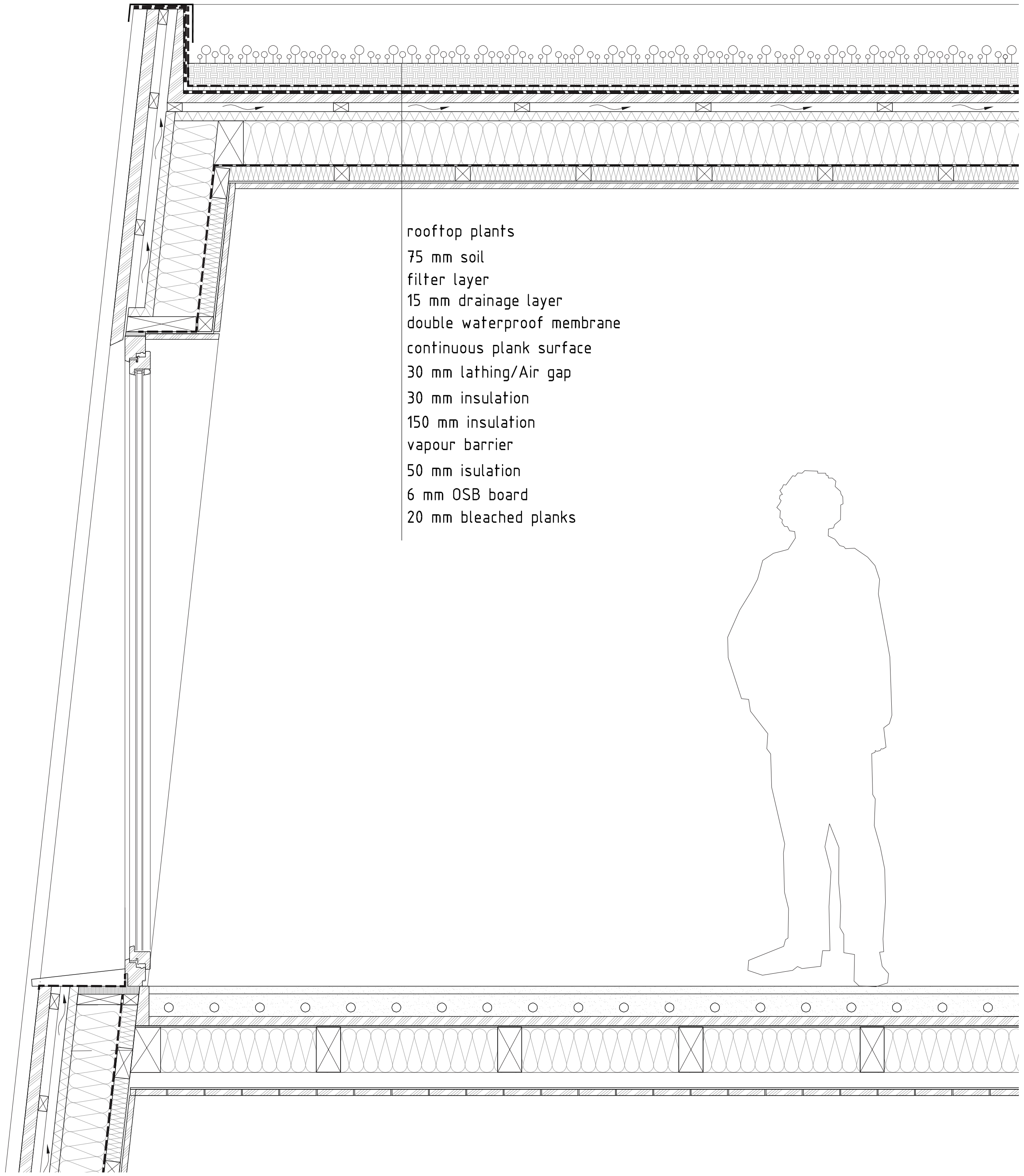
Load bearing capacity of rammed earth in my project is estimated based on test performed in CTU(faculty of civil engineering in Prague). Test of load bearing wall from prefabricated rammed earth panels was conducted. 3m high 20cm thick wall was built (300*180*20cm) stacking prefabricated elements (90*60*20cm). Then it was tested with vertical pressure and collapsed when force reached 50.000 kg. This allows to assume that one square meter of prefabricated rammed earth wall surface is capable to carry ~130 t.
In my project rammed earth wall load bearing surface is $5.7m^2 = 57000\ cm^2$. So structural core in my project theoretically is capable to carry: $5.7\ m^2 * 130t/m^2 = 741$ t.
I roughly estimated that final buildings mass would be around 200 t, rammed earth core alone weighting 100t. Numbers show that load bearing capacity is three times as much as needed for the house. Detailing and thin earth element production is more restricting factor rather than its load bearing capacity.

Prefabricated rammed earth panels test in CTU, Prague.

*Materials and textures*

Outer shell of a house is a wood frame construction clad with wood planks inside ant out. Interior walls and ceiling have the same calm expression and are in a contrast with saturate and texture rich earth flooring and core. Rammed earth floor adds to a total thermal mass amount inside the house and acts as important passive solar design element - radiant heat absorber. It has embedded floor heating using water that is prepared with the help of solar water tubes.
Building is covered with green roof, further reducing total $CO^2$ amount embodied in the building and adding even more green surface to the property than it was before the project.
Locally harvested rock masonry foundation is added to protect earth core from possible downhill running water

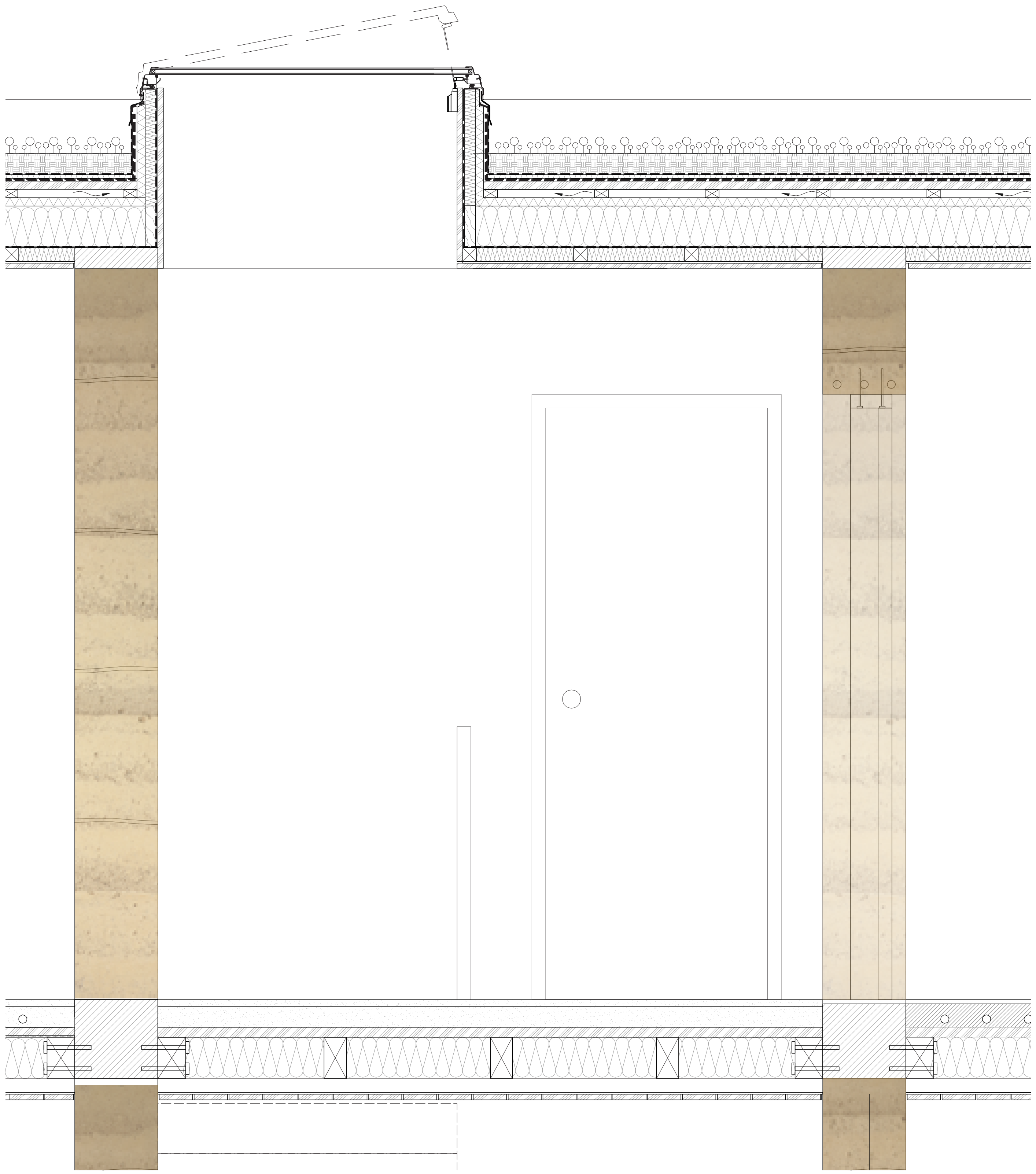





Windows are placed vertically in inclined walls, providing easy handling and creating spacious outdoor sill that can be used as a French balcony or area to place plants.

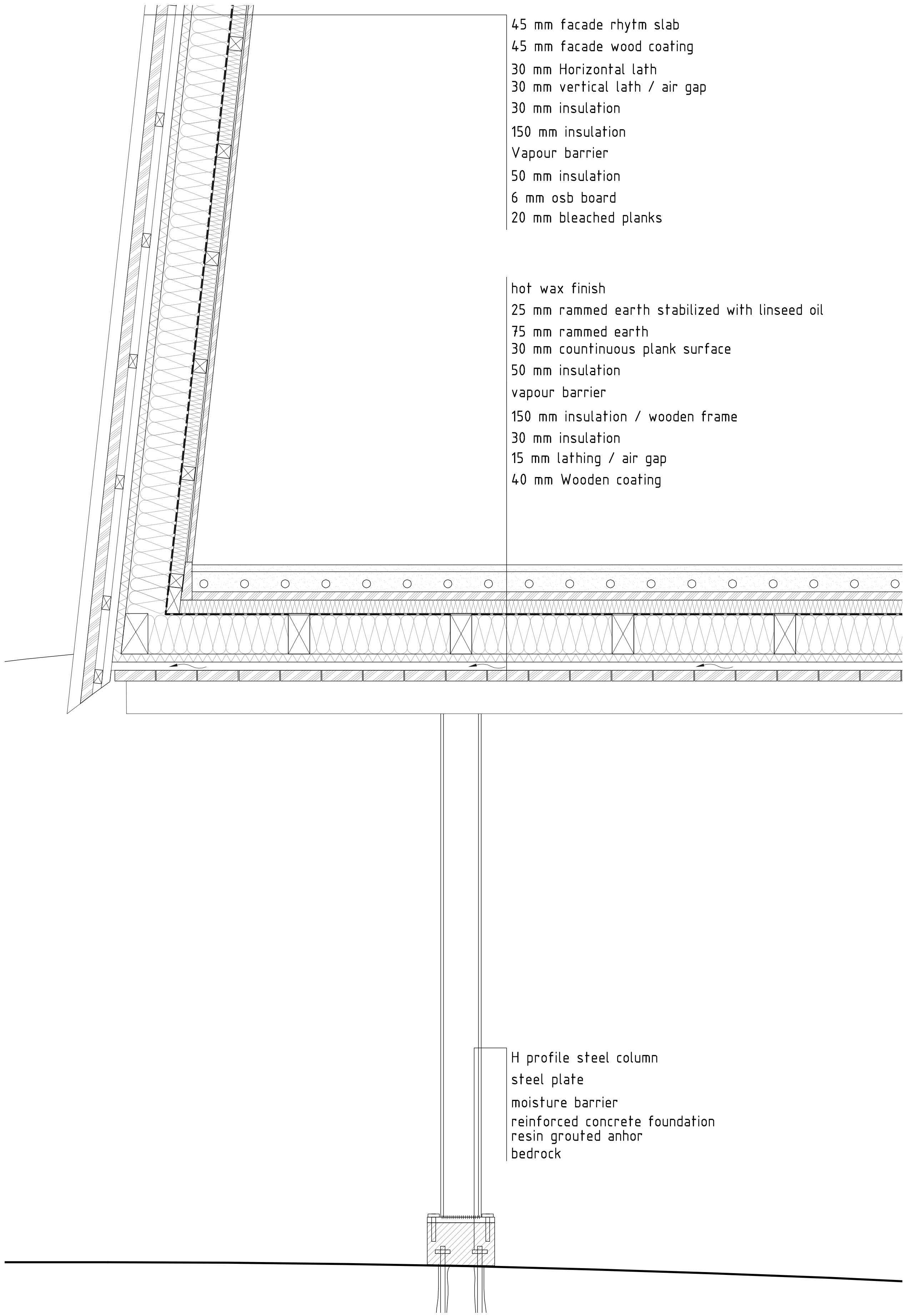
*Section A M 1:20*





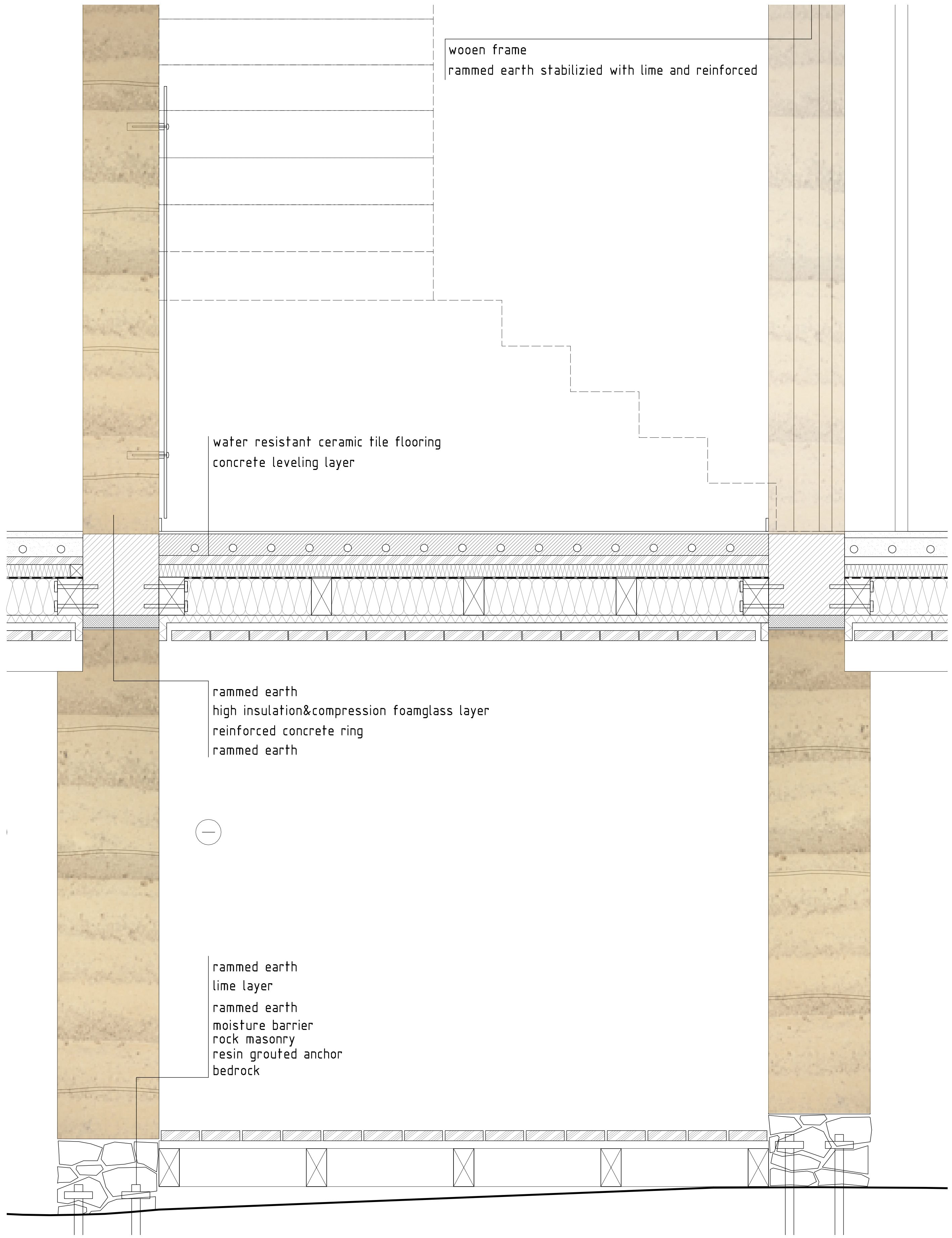
Remotely operable skylight placed the highest point of the house allows for effective control over air movement.

*Section B M 1:20*




*Section C M 1:20*






In the bathroom walls that are likely to get water splash are fitted with glass panels. It his way surface is protected and at the same time its humidity absorption and aesthetic qualities remain active.

*Section D M 1:20*

# CONCLUSIONS

*Field of use*

Rammed earth in cold climate context works best in cases where insulation is not required and shelter from direct rain is provided. It could be used in situations where concrete or brick masonry is usually chosen because it can offer similar characteristics. I identified three qualities that makes earth unique:

*Warm texture*

Surface it not only aesthetically appealing but also the color tone is warm. That means it is likely to please larger spectrum of people. E.g. Concrete aesthetic is recognized as well but in real life many people perceive it as cold and unappealing.

*Climate control*

Effecting all three micro-climate aspects such as humidity temperature and air flow earth has no serious competitor material in this field.

*Low embodied $CO_2$*

It results in up to 90 % lower $CO_2$ emissions than concrete and around 60 % lower than brick masonry. Prefabrication of elements is relatively new in rammed earth  building, but it proves to be a very effective strategy and allows for bigger projects to be built meeting todays speed. Transporting distance for this heavy material becomes the crucial factor in environmental impact. At the moment there is only one company in Austria producing prefabricated wall elements.

*Core concept outcome*

Researching earth core concept I come up with two ways to organize spaces:

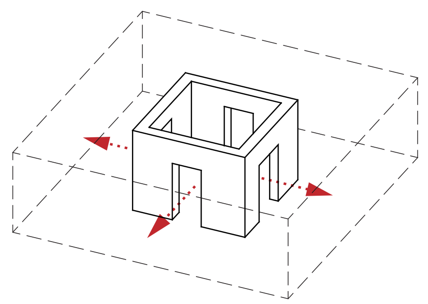
1-st one is when circulation is organized around the core. In this way it is convenient to plan a summer house where additional rooms with high privacy are not needed and structure can function as single space around the core (CASE STUDY6 farnsworth house).

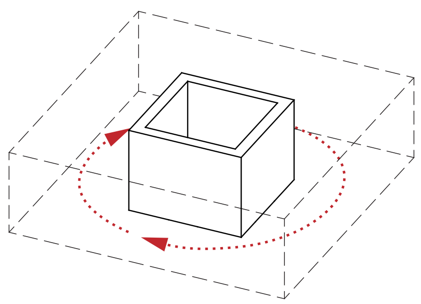
2-nd is when circulation is organized from the core and it is a main living space. This method allows to have all necessary functions with considerable privacy for a family (House 2) and still retain the feel of an earth core.

Combination of these two methods is possible when one floor has circulation around the core and the second one is accessed from the core(house 1).

*Final statement*

In cold climate it is not a straightforward solution to build a regular house out of rammed earth, because there are easier materials to build with. There are some built rammed earth houses, but the reasons why  they were built are poverty and lack of other materials at that time. I see rammed earth potential when it is just one part of a house rather than the whole shell. Placed in the core, earth material can enrich air quality, architectural expression and thermal performance. Core concept is a common  expression in architectural world whether it is a house or an office. I think projects with core concept should be the main users or rammed earth in the context of cold climate.







# DICTIONARY

Loam - mixture of clay silt and sand, sometimes also gravel or stones.

Clay - matter consisting of particles with diameters smaller than 0,002 mm.

Silt - matter consisting of 0,002-0,006 mm diameter particles.

Sand - matter with particle size between 0,06 - 2 mm.

Gravels and stones -  particles with bigger than 2 mm diameter.

Adobe; mud brick - handmade, unbaked bricks.

Soil block - compressed unbaked brick.

Rammed earth - loam compacted within a form-work.

Cradle to gate - The portion of a product's life cycle from inception to the point where it leaves the manufacturer

Embodied Energy -  is the sum of all the energy required to produce any goods or services, considered as if that energy was incorporated or 'embodied' in the product itself.

Equilibrium moisture content (EMC) - is the moisture content at which the material is neither gaining nor losing moisture; this however, is a dynamic equilibrium and changes with relative humidity and temperature.

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