Possibilities of applying biodegradable materials in solid building envelopes in the Netherlands

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Master thesis

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1.1 INTRODUCTION

While the purpose of architecture has remained virtually unchanged for millennia, struggling between basic functions, construction techniques and form, increased CO2 emissions and the shortage of fossil fuels have precipitated a shift towards greater ecological awareness. As questions pertinent to sustainable building take central stage in the planning process, this shift calls for a fundamental reconsideration of building concepts and the form and design of the building skin.

The alarming situation of environment from the one hand and the technological possibilities on the other, become the motivation mechanism that leads me towards deciding to work on the field of sustainable design. The technological miracles of today on material and construction sciences and the reinvention of the architectural tradition invite me to experiment and get involved in this field.

My background studies, starting with my bachelor thesis on sustainable industrial buildings revealed to me the field of green design where a variety of innovative and new ideas can lead to impressive building results that respect the natural environment.

This research is a sustainable approach on building skins. It deals with the application of biodegradable materials in solid walls. A biodegradable material is that which is able to be broken down by natural processes into more basic components. This is an attempt to approach the most extreme form of sustainable architecture. The desired and expected result would be a redesign of solid walls that produce less waste and are considered in some specific criteria more environmentally friendly where at the same time fulfill the demands and the standards of the market.

1.2 RELEVANCE

The demand for sustainable design is now more obvious than ever. Increasingly, private and public owners are requiring their building projects be designed and constructed in an environmentally responsible manner and be recognized as green buildings. This tendency is also depicted at the existence of third party rating systems that certify the sustainability of the construction (LEED, BREAM rating systems are just some examples). Special interest is given to the construction materials of the examined buildings (for instance, the LEED rating system has a specific category named “Materials and Resources –MR”).

There is a strong correlation between the design of a building envelope, sustainability, construction process and waste production. Thus if the purpose is the production of sustainable building envelopes, waste can be considered as one factor of great importance. A significant part of waste generation is caused by the building and construction industry. Waste is a major topic of the integrated chain management policy of the Dutch government (NEPP - integrated chain management, NEPP+ - energy saving, NEPP2 - and quality improvement). Waste prevention on site is an important issue in the integrated chain management policy in the sustainable-construction appendix of the NEPP+ (1990). Integrated chain management in the construction industry involves closing the cycles of resource use to the greatest possible extent. During the construction, it is about minimizing the environmental impact of the construction process on the environment through procurement, site layout and use, energy use, waste management and construction operation.

According to research that has carried out in the Netherlands (from April 1993 to June 1994- Glavinich, 2008), about 1-10% by weight of the purchased construction materials, depending on the material, leave the site as waste. The absolute annual amount of Construction and Demolition (C & D) waste in The Netherlands is 14,000,000 t (Implementatieplan 1993), and the share of this industry in the total amount of waste produced is 26% (Lanting 1993). This percentage agrees with the results of several studies in other countries. The importance of the C&D waste management has been officially accepted and the reduction of the construction wastes is one important factor at the government’s policy.

The following results are according to the research that has carried out in the Netherlands (from April 1993 to June 1994-Bossink 1994; Ottens 1994; Preventie 1994) [Glavinich (2008)]:

1_ TOPIC DEFINITION
Humanity has the ability to make development sustainable—to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs. The concept of sustainable development does imply limits—not absolute limits but limitations imposed by the present state of technology and social organization on environmental resources and by the ability of the biosphere to absorb the effects of human activity.

The sustainable development is that development which meets the needs of the present without compromising the ability of future generation to meet their needs.

definition: World Commission on Environment and Development (WCED)

A green building is a term that describes a building that provides the specified performance requirement while minimizing disturbance to and improving the functioning of local, regional and global ecosystems both during and after its construction and specified service life.

definition: American Society of Testing and Materials (ASTM) Standard E2114-06a
This research tests until what extend can we produce a biodegradable wall. What are the limits of applying such materials in a solid wall. This wall will be considered as preferable in matter of environmental footprint. However, considering all the other aspects that normally we take into account when designing and constructing a solid wall (for example, structure, aesthetics, availability, costs). Are these solutions applicable in real life?

The waste management is a big issue when considering a more sustainable construction. The choice of using biodegradable materials, is an attempt to minimize the construction and demolition (C&D) waste of the façade of a building. Prevention or minimization of waste is identified as the most preferred solution. Inspiration can be drawn and lessons can be learned from nature. The cyclical characteristic of natural processes, where plants grow, die and biodegrade becoming a resource for new growth, can be applied to building construction. Biodegradable materials are part of a naturally occurring closed loop cycle. The choice of biodegradable materials as alternative façade materials has been done as they generally require fewer reprocessing resources than any other material, even recyclable, and are associated with less pollution.

"Possibilities for applying biodegradable materials in solid building envelopes in the Netherlands"

The study is going to analyze standard concrete and brick solid walls systems according to their structure and material. This choice has been done as they are very successful types of facades worldwide and in the Netherlands. The expected outcome could be the replacement of as much as possible of the standard materials used in these two famous wall constructions, with alternative biodegradables or/and the inspiration of new building wall system structures that use biodegradable materials.

The location of the research has a determinant influence on the material choice and wall design. The climate conditions of the Netherlands with the swampy subsoil and the wet weather may exclude the application of some biodegrade materials or suggest special treatment and maintenance. What is more, historical, geological, economical or other parameters may have a determinant influence on the final wall design.
1.3 THE PROBLEM STATEMENT

Sustainable is only deemed possible when not only the government but also all other sectors of the society contribute to this goal. Thus, special interest should be given to the building industry that contributes to a tremendous extent to the existing environmental alarming situation.

Construction waste is an important topic to quantify and analyze despite the lower volumes in comparison with demolition waste, because:
- Construction waste is more difficult to recycle due to high levels of contamination and a large degree of heterogeneity (Brooks et al. 1994).
- Prevention of construction waste is preferable to recycling of demolition waste “at the end of the pipeline”.
- Construction waste contains a relative big amount of chemical waste (Lanting 1993).
- A cost reduction caused by preventing the generation of construction waste is of direct benefit for most of the participants that work on a construction project.

Though the building process and industry are very complex, if one possible solution of a more sustainable building envelope is applying biodegradable materials instead of the contemporary, then there are many more questions raised that need a proper solution. A change in the applied envelope materials will occur changes in the design, the construction process (which also should be taken into consideration during designing), the maintenance process the construction time and the cost estimation.

1.4 THE RESEARCH OBJECTIVE

This research is a study to propose new materials or the introduction of old ones at the market that can fulfill both the demands of the user and serve the new demands of green constructions. The attempt of this proposals is:
1. Understanding the limitations, possibilities and implication of applying biodegradable material to facades in terms of performance, design and construction.
2. Provide recommendations, and guidelines for designers, engineers and stakeholder that assist them in building with a chosen biodegradable material (if the results were satisfying)
3. Build the methodology according to which future researcher and engineers could improve the use of another chosen biodegradable material.
1.5 RESEARCH QUESTION

Main research question:

How can we apply biodegradable materials in the façade construction in the Netherlands?

To make a more sustainable wall system, alternative materials with a more environmental friendly orientation can be used instead of common. This thesis is going to enlighten biodegradable materials as possible alternative material in the construction.

The use of biodegradable materials in the field of constructions is not new. Actually these are the first materials used in the history of architecture. For instance, clay buildings are a live example that last for centuries.

The contemporary massive wall constructions in the Netherlands mainly use concrete and bricks. However in the past, biodegradable materials as peat sod, wattle and daub and wood were very commonly used materials in the constructions.

The aim of this thesis is to reintroduce and make the application of biodegradable materials more feasible and approachable. It also tries to clarify the weaknesses and the strong points of their application, and stabilize the necessary steps needed in order to apply such materials in the solid building envelopes in the Netherlands.

The main sub questions that this graduation thesis is occupied with are:

- Why biodegradable materials are not used that much though they are known from the ancient times?
- What happened in between?
- Considering the needs of the contemporary user are these materials still adequate?
- How are they used now?
- What are the techniques?
- What are the benefits of using biodegradable materials at the building industry?
- Are there tremendous difference on the properties and the construction techniques compared to the standard materials?
- What changes should be done in terms of design and construction in order to use these materials?
- Are the designers, the constructors, the workforce and all the members of the façade industry aware of how to build with biodegradable materials?

Biodegradation: The term describes the process by which organic substances are broken down by the enzymes produced by living organisms. Organic material can be degraded aerobically, with oxygen, or anaerobically, without oxygen. As a consequence, biodegradable material is that which is able to be broken down by natural processes into more basic components.

The first known use of the word in biological text was in 1961 when employed to describe the breakdown of material into the base components of carbon, hydrogen, and oxygen by microorganisms. Now biodegradable is commonly associated with environmentally friendly products that are part of the earth’s innate cycle and capable of decomposing back into natural elements.

http://mtbakerbio.com/Bio
1.6 METHODOLOGY

The research has been carried out by following the next steps:

**Research**
- Façade demands
- Concrete and brick wall systems
- Properties of biodegradable materials as possible building materials

**Design**
- Biodegradable material choice
- Presentation of the case study
- Design
- Evaluation

**Evaluation**
- Design evaluation from experts
- Suggestions for improvements
- Conclusion

**Research Step:**
This step is aimed to understand the functions and the properties of the façade and realize the characteristics that this intermediate layer between the outside world and the interior space should have. Furthermore it focuses on the way that the contemporary concrete and brick façade constructions are realized. Finally it examines the possibilities of the biodegradable materials application in the building envelope by studying mainly materials that exist in the wall systems especially in the traditional architecture. Materials with interesting properties that could be considered as façade materials are also exposed at this chapter.

**Design Step:**
This step focuses on the application of one chosen material as wall construction material of a real project. The aim of this step is to design proper wall systems by replacing gradually the existing functional layers of the construction with layers of the chosen material if the properties of this material allow that. The properties of the chosen material and its weaknesses will define the detailing.

**Evaluation Step:**
That final step is aimed to suggest improve of the designs according to the evaluation of the drawings and the advices of constructors that work with this material. Ideas for further research are also included here.
At this chapter there are analysed the façade demands and standards. As the main topic of this research is the façade systems and their improvement in terms of construction materials and environmental footprint, it is of vital importance to understand the requirements, functions and construction method of the façade system. At the end, the proposed solutions and design should also fulfil these parameters. As the research is focussed in the Netherlands, the SBR reference details are also presented here.

What is more here are also analysed the concrete and brick façade constructions in terms of material choice. These two categories, of the whole family of the façade systems, have been chosen as there are widely used worldwide and in the Netherlands. The concrete and brick wall systems have been analysed according to general information on the material, construction method and composition and properties of the final material (concrete and brick). This analysis, aimed to find the advantages of this materials’ application in the facade and the reasons that these constructions have been so popular nowadays.
2.1) THE FAÇADE

2.1.1) Requirements

The façade is the separation and filtering layer between the inside and outside environment. The main function of this layer is the protection against a hostile outside world and inclement environment. Apart from the protective functions there are also regulatory functions added to the function list: light regulation, control of the air change rate and visual relationship, definition of the boundary between the private sphere and the public area, and many more.

All these requirements could be divided into two main categories depending on how the façade is being considered: the external conditions requirements (specific to the location) which cannot be influenced by the design and the internal conditions requirements which are decided during the design and construction phase of the façade according to the use of the building. Thus all the fluctuations of the exterior environment should be filtered by the façade in order to guarantee a comfortable interior space.

An efficient façade is that which is able to handle climate related tasks as comprehensive as possible. In this way, additional measures such as air conditioning can be minimized and even omitted.

Supplementary measures with a direct effect can assist this task on both sides of the façade. If the requirements cannot be adequately handled by construction measures, then additional services are installed at the building. This installations could be part of the façade or of a separate room.

http://www.flickr.com

Aspects of the building envelope. (Schittich, 2006)

Key issues. Procedures for determining boundary conditions and requirements (HERZOH et al, 2008)
Requirements placed on the facade from the inside and outside

(Herzoh et al., 2008)

**Outside**

**FACADE**

**Inside**

**Conditions specific to the location**

- Solar radiation
- Temperature
- Humidity
- Precipitation
- Wind

**Sources of noise in the surroundings**

- Amount of gas and dust
- Mechanical loads
- Electromagnetic radiation

**Urban/formative surroundings**

- Local sources
- Socio-cultural context

Severe fluctuations in external climate

Minimal fluctuations internally

**Requirements**

- Comfortable temperature/humidity range
- Amount and quality of light (lighting environment)
- Air change rate/fresh air supply at comfortable air velocity
- Comfortable sound level

Visual relationship with external surroundings

Demarcation between private and public zones

Protection against mechanical damage

Fire protection

Limitation of toxic loads

Protective functions by way of permanent and also variable conditions (increasing or reducing the effect)

- Insulation
- Seals/barriers
- Filters
- Storage
- Redirection
- Physical barriers

**Regulatory functions**

- Controlling
- Regulating
- Responding/changing

**Supplementary measures with a direct effect**

- Thermal insulation
- Antiglare protection
- Sun shading (e.g., shutters, blinds, brise-soleil, lamellas)
- Privacy provisions (e.g., curtains)
- Measures influencing the microclimate (e.g., vegetation, bodies of water)
- Redirection of daylight
- Utilisation of internal components (floors, walls, ceilings)

**Supplementary building services**

- External collectors
- Photovoltaics
- Heat pipes, heat sondes, etc.

- Integral air/water collectors
- Solar walls
- Media transport/distribution
- Heat recovery

- Convecors/radiators
- Artificial lighting
- Air conditioning (centralised/decentralized)
<table>
<thead>
<tr>
<th>Main function</th>
<th>Primary functions</th>
<th>Secondary functions</th>
<th>Supporting functions</th>
<th>Detailed supporting functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1.2) Functions</td>
<td>Bear structural loads</td>
<td>Deviate loads</td>
<td>Wind loads</td>
<td>Create stiffness perpendicular to façade surface</td>
</tr>
<tr>
<td></td>
<td>Deviate impact loads</td>
<td>Deviate impact loads</td>
<td>Create stiffness perpendicular to façade surface</td>
<td>Fix to primary structure of building</td>
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<tr>
<td></td>
<td>Carry self weight</td>
<td>Carry self weight</td>
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<td>Integrate joints to allow movement</td>
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<td></td>
<td>Handle loads from structural and thermal expansion</td>
<td>Handle loads from structural and thermal expansion</td>
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<td>Allow damage free movement</td>
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<td></td>
<td>Secure a rain and vapour tight construction</td>
<td>Secure a rain and vapour tight construction</td>
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<td>Allow vapour tight connection of parts</td>
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<td></td>
<td>Secure a rain and vapour tight construction</td>
<td>Secure a rain and vapour tight construction</td>
<td></td>
<td>Increase vapour barrier properties from inside to outside</td>
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<tr>
<td></td>
<td>Allow exchange of materials and components</td>
<td>Allow exchange of materials and components</td>
<td></td>
<td>Incorporate water sealing system</td>
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<td></td>
<td>Allow maintenance and cleaning</td>
<td>Allow maintenance and cleaning</td>
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<td>Create internal drainage system</td>
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<td>Consider responsibilities of design team</td>
<td>Consider responsibilities of design team</td>
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<td>Allow surface treatment</td>
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<td></td>
<td>Refer to design and management processes</td>
<td>Refer to design and management processes</td>
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<td>Allow constructive protection</td>
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<td></td>
<td>Create interfaces between different crafts</td>
<td>Create interfaces between different crafts</td>
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<td>Separate materials when needed</td>
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<tr>
<td></td>
<td>Define level of standardisation</td>
<td>Define level of standardisation</td>
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<td>Allow disconnection</td>
</tr>
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<td></td>
<td>Create sections to block weight/vase</td>
<td>Create sections to block weight/vase</td>
<td></td>
<td>Make façade accessible</td>
</tr>
<tr>
<td></td>
<td>Allow tolerances during assembly</td>
<td>Allow tolerances during assembly</td>
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<td>Allow connection of cleaning machinery</td>
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<td></td>
<td>Control daylight radiation</td>
<td>Control daylight radiation</td>
<td></td>
<td>Block radiation</td>
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<tr>
<td></td>
<td>Control air exchange rate</td>
<td>Control air exchange rate</td>
<td></td>
<td>Let radiation pass</td>
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<td></td>
<td>Prevent unwanted energy losses</td>
<td>Prevent unwanted energy losses</td>
<td></td>
<td>Ventilate excessive heat</td>
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<td></td>
<td>Prevent surface temperature differences</td>
<td>Prevent surface temperature differences</td>
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<td>Maintain air tightness</td>
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<td></td>
<td>Control air exchange rate</td>
<td>Control air exchange rate</td>
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<td>Provide thermal insulation</td>
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<td></td>
<td>Adapt façade to changing climate</td>
<td>Adapt façade to changing climate</td>
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<td>Provide thermal insulation</td>
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<td>Adapt façade to changing climate</td>
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<td>Provide thermal insulation</td>
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<td>Add mechanical building services</td>
<td>Add mechanical building services</td>
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<td>Provide thermal insulation</td>
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<td>Acoustic insulation of façade plane</td>
<td>Acoustic insulation of façade plane</td>
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<td>Provide thermal insulation</td>
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<td></td>
<td>Acoustic insulation of façade plane</td>
<td>Acoustic insulation of façade plane</td>
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<td>Provide thermal insulation</td>
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<td>Insulation of connection to dividing wall</td>
<td>Insulation of connection to dividing wall</td>
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<td>Provide thermal insulation</td>
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<td>Insulation of floor connection</td>
<td>Insulation of floor connection</td>
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<td>Provide thermal insulation</td>
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<td>Provide a comfortable daylight level</td>
<td>Provide a comfortable daylight level</td>
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<td>Provide sun shading</td>
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<td>Provide glare protection</td>
<td>Provide glare protection</td>
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<td>Provide sun shading</td>
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<td></td>
<td>Alike visual contact</td>
<td>Alike visual contact</td>
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<td>Provide sun shading</td>
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<td></td>
<td>Adapt to changing climatic conditions</td>
<td>Adapt to changing climatic conditions</td>
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<td>Provide sun shading</td>
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<td></td>
<td>Prevent energy losses</td>
<td>Prevent energy losses</td>
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<td>Provide sun shading</td>
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<td></td>
<td>Allow natural lighting of interior</td>
<td>Allow natural lighting of interior</td>
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<td>Provide sun shading</td>
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<tr>
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<td>Provide sun protection</td>
<td>Provide sun protection</td>
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<td>Provide sun shading</td>
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<td></td>
<td>Adapt according to orientation of building</td>
<td>Adapt according to orientation of building</td>
<td></td>
<td>Provide sun shading</td>
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<tr>
<td></td>
<td>Use materials with low carbon footprint</td>
<td>Use materials with low carbon footprint</td>
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<td>Provide sun shading</td>
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<td></td>
<td>Minimise spatial distances in the supply chain</td>
<td>Minimise spatial distances in the supply chain</td>
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<td>Provide sun shading</td>
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<td>Allow production with low use of energy</td>
<td>Allow production with low use of energy</td>
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<td>Provide sun shading</td>
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<td>Allow separation of components</td>
<td>Allow separation of components</td>
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<td>Provide sun shading</td>
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<td>Choose recyclable materials</td>
<td>Choose recyclable materials</td>
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<td>Provide sun shading</td>
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<td>Collect solar thermal energy</td>
<td>Collect solar thermal energy</td>
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<td>Collect solar energy</td>
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<td>Provide sun shading</td>
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<td>Include thermal mass</td>
<td>Include thermal mass</td>
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<td>Provide sun shading</td>
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<td>Include components for artificial thermal mass</td>
<td>Include components for artificial thermal mass</td>
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<td>Provide sun shading</td>
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<td></td>
<td>Protect against fire</td>
<td>Protect against fire</td>
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<td>Provide sun shading</td>
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<td></td>
<td>Prevent structural damage</td>
<td>Prevent structural damage</td>
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<td>Provide sun shading</td>
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<td></td>
<td>Protect against attacks from the outside and burglary</td>
<td>Protect against attacks from the outside and burglary</td>
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<td>Provide sun shading</td>
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<tr>
<td></td>
<td>Protect against toxic loads</td>
<td>Protect against toxic loads</td>
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<td>Provide sun shading</td>
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<td>Protect against falling out of the window</td>
<td>Protect against falling out of the window</td>
<td></td>
<td>Provide sun shading</td>
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<tr>
<td></td>
<td>Provide good handling for the end user</td>
<td>Provide good handling for the end user</td>
<td></td>
<td>Bridge knowledge gap between stakeholders</td>
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<td>Allow for facility management</td>
<td>Allow for facility management</td>
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<td>Allow architectural variety</td>
</tr>
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<td></td>
<td>Monitor façade performance</td>
<td>Monitor façade performance</td>
<td></td>
<td>Support architectural design intentions throughout process</td>
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<td></td>
<td>Ensure Low running costs</td>
<td>Ensure Low running costs</td>
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<td>Induce arrangement</td>
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<td>Guarantee energetic performance</td>
<td>Guarantee energetic performance</td>
<td></td>
<td>Induce arrangement</td>
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<tr>
<td></td>
<td>Service and cleaning of façade and components</td>
<td>Service and cleaning of façade and components</td>
<td></td>
<td>Induce shape</td>
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<td></td>
<td>Choose appropriate materials and technologies (meaning)</td>
<td>Choose appropriate materials and technologies (meaning)</td>
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<td>Induce proportion</td>
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<td></td>
<td>Arrange components spatially</td>
<td>Arrange components spatially</td>
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<td>Induce scale</td>
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<td></td>
<td>Design visual, acoustic, haptic perception</td>
<td>Design visual, acoustic, haptic perception</td>
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<td>Apply texture</td>
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<td>Apply texture</td>
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<td>Induce color</td>
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<td>Induce material</td>
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</tbody>
</table>

**Note:** The diagram illustrates the functions of a building and how they are supported by various design and management processes, including consideration of sustainability and architectural intentions. The secondary functions include structural loads, water and vapour management, interior nature, and façade construction. The supporting functions encompass a range of activities from controlling daylight to managing energy consumption and ensuring a comfortable internal climate. The detailed supporting functions provide the necessary steps to achieve these objectives.
**Function: what is the practical purpose of the building/the building skin?**

The façade, as a structural element, carries some functions that assure the wellbeing of the users.

The function tree that describes this characteristic of the façade has a tendency to grow as technological progress give more and more construction possibilities to the engineers.

The principal of the architecture is still to create comfortable shelter. However there are many more and according to the importance are separated in groups (primary functions, secondary functions, …).

Only the façade functions that are related with the material are going to be influenced by this research. So, special interest will be given to the primary functions that:

1. Create a durable construction
2. Provide a comfortable interior climate
3. Handle the façade reasonably in terms of sustainability

**Meaning of the above referred functions:**

- **Create a durable construction:** this characteristic refers to all the decision made in the design that leads to a safe construction. This category describes all that parameters that get involved at the design and construction. The properties of the materials, the connections system between the components, the maintenance and the assembly and disassembly process.

- **Allow reasonable building methods:** this characteristic refers to all the decision made in the design that leads to a feasible construction. This category describes all that parameters that get involved at the construction. The transportability of the components, the construction management and the assembly and disassembly process.

- **Provide a comfortable interior climate:** this function reassures the comfort of the users. It includes all the parameters that the user can understand through the senses. So its purpose is to control the temperature, the humidity level, the climate, the noise level and the interior light.

- **Responsible handling in terms of sustainability:** this functions is increasingly gaining interest as the environment attracts our concern the latest years. This category includes all that features that reassure the less negative influence

http://archinect.com/simonwynjames/project/function-of-the-façade
Create a durable construction

This function is the most important for the existence of the construction. It is influenced by the mechanical properties of the materials, their composition and their durability towards fire, fluids and sunlight.

Provide a comfortable interior climate

Indoor climate is crucial especially in temperate climates as people spend a big part of the day inside, in enclosed spaces. Temperature, humidity, sound insulation and visual comfort are some of the factors that determine the quality of the inner space. Thus, the façade should control all these factors. There is some variation at the sense of comfort according to the region, habits, clothing, activities and individual sensitivity. The range of all these variations named ‘comfort zone’. There are no fixed target of any of these variations. Even psychological factors (materials, colours,...) and cultural aspects play a role of what the user concern as ‘comfort’ and should be taken into account.

The indoor air temperature is very much related with relative indoor humidity, surface temperature and air movement.

The relevant influencing factors related to the construction of the façade according to thermal comfort are:

1. temperature of interior air
2. relative humidity of the interior air
3. surface temperature of the building components enclosing the room
4. airflow across the body

<table>
<thead>
<tr>
<th>User requirements</th>
<th>Energy Consumption in Administration Buildings</th>
<th>Climatic parameters</th>
<th>factors influencing thermal comfort (HERZOH et al, 2008)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor air temperature</td>
<td>building skin</td>
<td>outdoor air temperature</td>
<td>Comfort zone in relation to air temperature and average (only slightly differing) surface temperature of enclosing walls (after Reiher and Frank). (HERZOH et al, 2008)</td>
</tr>
<tr>
<td>Surface temperatures</td>
<td>heating energy</td>
<td>air movement</td>
<td></td>
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<tr>
<td>Air change</td>
<td>cooling energy</td>
<td>relative outdoor air humidity</td>
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<tr>
<td>Relative indoor air humidity</td>
<td>artificial lighting</td>
<td>solar radiation</td>
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<tr>
<td>Luminance</td>
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<tr>
<td>Lighting intensity</td>
<td></td>
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<td></td>
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<tr>
<td>Building services</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
Indoor air temperature

The comfort zone for indoor air temperature ranges from 20-25°C maximum. In summer, temperatures of up to 27°C are still considered tolerable. When internal wall surface temperatures and the relative indoor humidity are properly adjusted, indoor air temperatures as low as 18°C are still perceived as comfortable.

Average surface temperatures

Whenever possible, these temperatures should differ by no more than 2-3 K from the indoor air temperature; the differential between various surface temperatures in surrounding areas should not exceed 3-4 K.

Air change and air movement

While a minimal air change rate of 0.3/h is sufficient in unoccupied rooms, this value rises to 1.1/h during work hours. This corresponds to a fresh air intake of 40-60 m³/h per person. Generally a value of 200 cm³/Vm/s of floor area suffices for intake and ventilation openings for natural ventilation. At the same time it is important to avoid draughts by ensuring that air velocity does not exceed 0.15 m/s.

Relative indoor humidity

Depending on room temperature, the comfort zone for relative indoor humidity ranges between 30 and 70%. Grandjean establishes a more limited range of comfortable relative indoor humidity, between 40 and 60%.

Luminance

The standard values for luminance at the work place are dependent on the activity, the room layout and the proximity of the workstation to windows. Typical values lie in the region of 300 lx for workstations near windows, 500 lx for standard cubic office and 700 lx for open-plan offices with a high degree of surface reflection or 1000 lx for open-plan offices with medium surface reflection.

Lighting intensity

The quality of lighting in a room is not only influenced by luminance but also by glare. The lighting intensity should be approximately 2/3 to 1/10 of the interior field lighting intensity. Hence, it is important to select and position glare protection elements in a manner that provides evenly distributed daylight without glare, while avoiding unnecessary cooling loads in the interior space.

All comfort-related parameters - with the exception of relative indoor humidity - can be directly controlled and regulated through the design of the facade and the roof and this is the principal guiding factor in the conception of the building skin. Thus the indoor air and average surface temperatures are the product of the exchange between internal and external heat gains, on the one hand, and transmission and ventilation heat losses through the building skin, on the other. Air change can be regulated through the number and dimension of ventilation openings. Luminance and lighting density are also influenced by the type, position and size of openings in the building skin.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>U-value</th>
<th>g-value</th>
<th>Diminution factor</th>
<th>Transmittance</th>
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<td>high</td>
<td>low</td>
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<tr>
<td>Summer, overcast</td>
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<td>n/a</td>
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<tr>
<td>Summer, night</td>
<td>high</td>
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<td>n/a</td>
<td>high</td>
</tr>
<tr>
<td>Winter, clear skies</td>
<td>low</td>
<td>high</td>
<td>high</td>
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<tr>
<td>Winter, overcast</td>
<td>low</td>
<td>n/a</td>
<td>n/a</td>
<td>high</td>
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<tr>
<td>Winter, night</td>
<td>low</td>
<td>n/a</td>
<td>n/a</td>
<td>low</td>
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</tbody>
</table>

Parameters that influence the comfort of the interior climate

Heat transfer

One of the main demands that a facade should fulfill is be adequately insulated. If so, comfortable levels of temperature is provided in the interior and the amount of energy for heating is reduced. Heat flows from warmer to colder bodies.
Heat can be transported through three ways:
1. conduction: heat transports in the material
2. convection: heat transports through flows (ex. Water, air, ...). It cannot take place in solids.
3. radiation: heat transports (emits) from the object itself

A construction with good insulation should have big heat resistance (R).

\[ R = \frac{1}{\lambda} \times d \]

- \( R \): heat resistance in \( \text{m}^2 \cdot \text{K}/\text{W} \)
- \( \lambda \): heat conduction coefficient in \( \text{W} / \text{m} \cdot \text{K} \)
- \( d \): the thickness of the material in m

**Thermal conductivity:** Thermal conductivity \( (\lambda) \) (or heat conduction coefficient) shows how much heat ‘flows’ through a layer of material 1 m thick and with a surface area of 1 m² where the difference in temperature is 1 K (10°C). It only depends in the material.

The heat resistance of a structure, and thus of a façade, can be found by adding up the resistance values of the individual layers.

\[ R_s = R_1 + R_2 + R_3 + ... \]

**Thermal transmittance (or heat transition coefficient) U-value**

The U-value shows how much heat passes through a construction where there is a difference in temperature in 10°C. It is the opposite of heat resistance (R) on air on air transition.

\[ U = \frac{1}{R} \]

- \( U \): heat transition coefficient in \( \text{W} / \text{m}^2 \cdot \text{K} \)
- \( R \): heat resistance in \( \text{m}^2 \cdot \text{K}/\text{W} \)

**Responsible handling in terms of sustainability:**

Nowadays there is an instant concern about the environment and the future of our planet that has become the focal point of the building world. There is a tendency to a sustainable development in terms of construction in general. For that reason I am going to analyse this group of functions further.

- Minimized energy consumption during use
- Minimized embodied energy
- Minimized energy for production, transport assembly
- Enable reuse and recycling
- Generate energy
- Store energy
- Prevent energy losses
- Provide sun protection
- Use materials with low carbon footprint
- Allow production with low use of energy
- Minimize spatial distances in the supply chain
- Choose recyclable materials
- Allow separation of components
- Include thermal mass

For a given temperature difference, materials with a high thermal conductivity will conduct more heat than materials with lower conductivity. Likewise, materials with high conductivity will require a smaller temperature gradient to conduct a given amount of heat. (Hens, 2007)
2.1.3 Construction

The façade is primarily a vertical or planar structure in between the interior and the exterior space.

The choice of the materials are of great importance while designing the façade in terms of detailing and functions but there are various applicable features and engineering design principles regardless the material. According to physical, chemical and geometrical effects the structure of the façade is considered:

• In the plane of the façade (A)
• Perpendicular to the plane of the façade (B)

The façade can be a multi layered or a single layer structure. This depends on the catalogue of functions and requirements for it.

Structural principles

A façade must safely withstand the forces that it is subjected and transfer them to the loadbearing structure. Even a non load bearing façade must be conceived and designed as a secondary load bearing structure to carry:

- Vertical loads - Dead loads, special loads (e.g. temporary scaffolds, sun shading, plants), imposed loads (e.g. persons), snow and ice loads.
- Horizontal loads - Wind load, imposed loads (e.g. impacts).
- Restraining forces - These forces are caused by thermal or moisture related volume changes.

Layering

At a multi-layer/multi-leaf façade the individual layers carry different functions. In this way the performance profile of the façade matches very accurately the requirements, in contrast with a monolithic façade, where is hardly likely to fulfill the stringent thermal performance requirements placed on modern building envelopes. Furthermore, Individual layers and leaves can be added later, or replaced by others, which allows the building envelope to be adapted to other requirements profiles during the course of its life.

The allocation of individual functions to layers and leaves can also have disadvantages, depending on the quality of the materials chosen and the method of construction:

• the creation of many Interfaces between different materials and components carries risk of incompatibility between those materials
• an increase in the proportion of joints and hence potential weak spots
• the creation of uncontrolled voids and cavities
• fixing problems: penetration of water runoff or thermal insulation layers, creation of bending moments when anchoring facing leaves
• high production costs
• increased maintenance costs
• several trades and responsibilities within one wall construction, meaning increased coordination work and overlapping liabilities
• problems with separation and hence disposal of different layers.

According to the authors of the book Façade Construction Manual, there are four trends in the current economic climate:

• an increase in the efficiency of functional layers/leaves
• a reduction in the space requirements of layers (e.g., vacuum insulation), right down to miniaturisation of functional structures (e.g., prismatic light redirection systems with a thickness < 0.1 mm)
• surface coatings from the field of nanotechnology
• combining of several functions in one polyvalent layer.
2.3) SBR DETAILS

According to the SBR reference detail that are in use in the Netherlands, the façade systems applied in the country are separated in two main groups: Cold facades and Warm facades. In any case the façade system is a multi-layer façade. That means that each layer carry a specific function in the façade so that all together can fulfil the Dutch standards.

In structural terms every façade has:

1. The load bearing structure: It is that part of the façade that carries the loads of the whole building.
2. The insulation layer: Considering the main material used to form the mass of the wall (concrete and brick) which have low thermal performance this layer is responsible for the thermal comfort of the interior space. In general, this layer is approximately 14cm thick and the common material used is mineral wool (R=…..)
3. The weatherproofing layer: Thicker (ex. brick layer) or thinner (ex. Plaster) this layer serves the role of weather protection of the rest structure and the interior space. That means it should have resistance to rain and low temperatures and have enough cohesion to become the first barrier of water and air penetration. Maintenance of this layer is possible.

Schematic wall types in the Netherlands (according to SBR details)
see appendix for the detailed drawings

TYPE A: COLD FACADE:

TYPE B: COLD FACADE:

TYPE C: WARM FACADE:
2.3) BRICK MASONRY

Masonry is the building of structures from individual units laid in and bound together by mortar. The term masonry can also refer to the units themselves. The common materials of masonry construction are brick, stone, marble, granite, travertine, limestone, cast stone, concrete block, glass block, stucco, and tile.

2.3.1) General Information

In general it is a trustworthy and durable construction form. However, its durability depends on the material used, the quality of the mortar, the workmanship and the pattern on which the units are assembled.

Applications:

Masonry is commonly used for the walls of buildings, retaining walls and monuments. Brick and concrete block are the most common types of masonry. It may be weight-bearing or a veneer.

Concrete blocks, especially those with hollow cores, offer various possibilities in masonry construction. They generally provide great compressive strength, and are best suited to structures with light transverse loading when the cores remain unfilled. Filling some or all of the cores with concrete or concrete with steel reinforcement (typically rebar) offers much greater tensile and lateral strength to structures.

Advantages:

- The use of material such as bricks and stones can increase the thermal mass of a building.
- Most types of masonry typically will not require painting and so can provide a structure with reduced life-cycle costs.
- As a construction, masonry is very heat resistant and thus provides good fire protection.
- Masonry structures built in compression preferably with lime mortar can have a useful life of more than 500 years as compared to 30 to 100 for structures of steel or reinforced concrete.

Disadvantages:

- Extreme weather causes degradation of masonry wall surfaces due to frost damage. This type of damage is common with certain types of brick, though rare with concrete blocks.
- Masonry tends to be heavy and must be built upon a strong foundation, such as reinforced concrete, to avoid settling and cracking.
- Same for concrete, masonry construction does not lend itself well to mechanization, and requires more skilled labor than stick-framing.

Structural limitations

Masonry has an impressive compressive strength (vertical loads) but much lower in tensile strength (twisting or stretching) unless reinforced. The tensile strength of masonry walls can be strengthened by thickening the wall, or by building masonry piers (vertical columns or ribs) at intervals. Where practical, steel reinforcements can be added.

2.3.2) The brick in the facade

Bricks are one of the oldest known building materials. First appeared around 7000BC in Jericho (Turkey) and they are still in use. The first bricks were sun dried and then appeared the more reliable fired bricks. Today they are produced in different techniques and more precisely. They vary in shape and color according to the process and the ingredients. They can be made from variety of materials the most common being clay but also calcium silicate and concrete. During 2007 the new ‘fly ash’ brick was created using the by-products from coal power plants.

The brick technology came to the Netherlands during the 12th century from the Northern Italy. During this period the Gothic architecture was common in northern Europe. Thus the Brick Gothic architecture were in flourish. In difference with the Italian bricks, as the Dutch clay was less suitable for brick
making the Dutch bricks were smaller in dimensions than the Italians. The continuing use of bricks is a pure expression of Dutch vernacular building practice and a link with the ancient tradition. What is more, the brick is the characteristic feature of the Amsterdam School of architecture from the Art Deco decades of the 20th century. The bricks were originally made in an open-ended kiln in the yard. Since the 1900 the use of bricks become dominant in Dutch architecture.

The brick facades are typical in the Netherlands. Normally in a darker shade of brownish red than its standard American counterpart or sometimes in a washed-out yellow color, they become part of the tradition.

Turning bricks so they rest on edges and dry evenly, Haverstraw, N.Y. (Keystone View Co.)

There are 3 main brickmaking processes, varying primarily in the amount of water mixed with clay:

- Stiff-mud/extruded: during this process only enough water is added to the clay to make it into a stiff paste that can be extruded through a die into a long ribbon or column of clay. Then, the mix is sliced into brick-sized chunks by a brick cutter. It is also possible to use a vacuum pump in order to remove air from the mix to make it stronger and easier to handle.
- Dry pressed: Here, the clay mix is only damped. Then it is compressed under high pressure into molds. There is little water in the mix so they can be fired without long drying periods. These bricks are used as face and refractory bricks.
- Soft - mud: in this process, more water is used to make the mix a soft paste of clay. The mix is pressed into place and allowed to dry when molds are dipped in sand and water to prevent sticking. These bricks are hand-made bricks.

2.3.3) Composition

Clay + sand + water = building bricks ----> first used bricks

This is the basic synthesis of the building brick. Sometimes there is input of lime, ash or organic matter which speeds up the burning of the brick unit. The properties and the type of the brick depends on the type of the clay that is used:

Clay with sandy consistency, silicate or alumina which usually contains small quantities of lime or iron oxide – is used to form the most common everyday type of brick

In the Netherlands three types of boulder clay can be distinguished:
1. grey or brom boulder clay in the northern part,
2. brom, yellow, green or black boulder clay in the central and eastern part, and
3. red boulder clay in the northern and central part of the Netherlands.

As in this research the materials are tested under the prism of sustainability it is vital to examine the embodied energy. This is also linked, among others, with the available sources of the raw materials, and in this case with clay. Clay is found in delta areas. In the Netherlands, the availability of that material is high due to the synthesis of the landscape which is full of rivers running through and polders. That also justifies the great extent of brick use as the production is located directly next to the source.
PROPERTIES OF ADDITIVES

Silica: prevents cracking, shrinking, and warping when added to pure clay.
Iron oxide: enables silica and alumina to fuse and adds considerably to the harness and strength of the brick.
Iron: it is evident in the colour of the brick and makes it red (normally red bricks are stronger than yellow or white).
Lime: it stops the raw brick from shrinking and drying out. What is more, it acts as a flux during burning which causes the silica to melt and creates the bond which binds all the components of the brick together. (Too much lime can cause the brick to melt and lose shape.)

Today there are many different kinds of bricks with differences in their properties due to the great variety in possible substances.
According to their method of production there are 3 main categories:
• earth bricks (or dried bricks, this types include primarily loam building materials. “Mud bricks” and “adobes” in cases of handmade bricks, “soil blocks” in cases of compressed bricks, “rammed earth” when compacted with a formwork)
• fired bricks
• hardened bricks (Calcium silicate, concrete, and lightweight concrete types, among others. They are hardened by means of steam and pressure).

The first are used as unbaked raw material. Recently owing to their ecological relevance. The second are more durable and with relative impermeability which make them resist to wind, rain and fire. Due to all the above mentioned properties in the Netherlands there are used baked bricks. However these bricks are non-renewable. These clay bricks of the second category are available in many formats, hardness grades and colours.

2.3.4) Properties

The term “properties” may include many characteristics. From structural properties to aesthetics can be described by this general term. At this chapter I am going to focus on the structural and thermal properties of the final product which can be calculated numerically and will influence my final design.

Bellow there is information about the properties of bricks as building material and the brick wall.

BRICKS:
The durability of bricks is very important especially when they are exposed in extreme climate conditions such is the case of countries in North Europe. Freezing would be a problem and the soluble salt (http://www.extension.umn.edu/distribution/horticulture/components/1731-5-solublesalts.pdf) content of bricks can cause problems with the mortar. The properties of the bricks are of course influenced by the material used to form the unit, the density of the mixture, the production method, the shape and the dimensions.

According to CES 2012 here are the referred as “bricks” materials by name:
• Brick (common, hard) (2.03)
• Brick (common, hard) (2.25)
• Brick (low density refractory) (0.55)
• Brick (low density refractory) (0.75)
• Brick (low density refractory) (0.8)
• Brick (low density refractory) (1.3)
• Ceramic tile
• Engineering brick
• Facing brick
• Graphite (parallel to plane)
• Graphite (pure)
• Graphite (pyrolytic) (2.19) (parallel to plane)
• Mullite (dense, fused, pressed brick)(76)
• Porcelain (siliceous)
• Silicon
• Terracotta

According to this list of “bricks” below are the structural properties:
The properties of the brick wall depends also from the properties of the bricks themselves but there is not the only parameter. The type of mortar, the wall thickness and dimensions are also influence the final outcome.

The durability of a brickwork depends on the 2 factors which arise from the use of any particular brick: resistance to frost and the soluble salts content. Frost resistance falls into 3 classes: Frost Resistance (F), Moderately Frost Resistant (M) and Not Frost Resistant (O) Soluble salt content is classed as either Low (L) or Normal (N)
2.3.5) The brickwork

Solid brickwork is made of two or more layers of bricks with the units running horizontally (called stretcher bricks) bound together with bricks running transverse to the wall (called “header” bricks). Each row of bricks is known as a course. The pattern of headers and stretchers employed gives rise to different bonds such as the common bond (with every sixth course composed of headers), the English bond, and the Flemish bond (with alternating stretcher and header bricks present on every course). Bonds can differ in strength and in insulating ability. Vertically staggered bonds tend to be somewhat stronger and less prone to major cracking than a non-staggered bond. Parts of brickwork include bricks, beds and perpends. The bed is the mortar upon which a brick is laid. A perpend is a vertical joint between any two bricks, and is usually — but not always — filled with mortar.

A standard metric brick has coordinating dimensions of 225 X 112.5 X 75 mm and working dimensions of 215 X 102.5 X 65 mm.

Three devices for structural stability

A wall is subject to stresses acting vertically and from the side. The design and construction of the wall must take account of the need to withstand these forces, and incorporate the means to do so. If the wall is made of bricks, these considerations may affect — or even determine — the layout of bricks in the wall.

1. perpends do not vertically align in any two successive courses. If this rule is observed, then the weight acting on any brick is distributed across an area that widens with each downwardly successive course.

2. constructing brickwork that is thicker than the width of any of its individual bricks, and tying together some or all of these bricks into the depth of the wall. Historically, this was the dominant method for consolidating the transverse strength of walls.

3. A cavity wall comprises two totally discrete walls — each one of which is called a leaf. A cavity separates the two leaves so that there is no masonry connection between them at all. Typically the main loads taken by the foundations are carried there by the inner leaf, and the major functions of the external leaf are to protect the whole from weather, and to provide a fitting aesthetic finish. Although the two leaves may not share the structural load, their transverse rigidity still needs to be guaranteed, and must come from some source other than interlocking bricks.

There is a variety of arrangements for the cutting and layout of bricks utilizing one or more of these methods for stabilizing brickwork. These arrangements may generate anything from a wall of a single leaf with staggered perpends, to more substantial brickwork combining the vertical staggering of perpends with a transverse reinforcement through the wall. Any such arrangement is called a bond.
Fixings

The purpose of the fixings are to carry the loads of the brickwork and guarantee the stability of the construction. The number of fixings required per meter varies according to the position of the façade (5 are required in the middle and 9 at the corners).

At the openings in the façade, structurally effective fixings direct the dead loads of the respective façade segments via a lintel into the loadbearing components. Today there are manufactured different types of prefabricated lintels.

Joints

The purpose of the joints are to protect the masonry from the thermal expansions of the materials due to temperature variations. There are two types of joints:
- horizontal
- Vertical

The width of the joints is 10 to 20 mm and normally is sealed with permanently elastic material.

Horizontal joints have to take into account the height of the building. Up to a height of 12 m there is no need to include any movement joint at all. On taller buildings there is a need of joint every 9 m.

In between different elements (ex. Window-wall) and in special locations (ex. Corner) there is extra joint.

The ventilation of the vertical cavity in double leaf facades is being done through joints.

Examples of jointing, Deplazes (2005)
Brick wall ties

In cases of double leaf walls, where the outer leaf behave differently due to wind loads, temperature differences, etc. there is a horizontal connection between the two leaves to make the construction safer and stronger. Practically the wall ties are fixed in horizontal rows (2 or 3 per storey). In these horizontal loadbearing strips, wall ties made out of galvanised mild steel, stainless steel or plastic are placed.

Installation sequence, wall tie in mortar joint, Deplazes (2005)

Installation sequence, wall tie in concrete
2.3.6) Recyclability

In most cases, bricks are dumped into landfills, taking up massive amounts of space for long periods of time.

As a construction material it has long life span. Substantially it cannot degrade. What is normally done is be broken down and transformed into new aggregate materials. This crushed technique creates “brick chips” that can be used as landscape material or reground to manufacture new bricks.

It is also possible to reuse bricks after demolishing as they have great life span. However using old bricks in new builds means you must know the composition, load capacity, and durability of the bricks. That takes an expert. In addition, any mortar may have to be removed. That increase labour costs and it is rarely successful.

Characteristics

Advantages:
- Durability (high compressive strength)
- Standardization
- Quality control
- Availability
- No maintenance
- Long history of use: Bricks are also related with the Dutch traditional architecture
- Good fire protection and acoustic insulation
- Big life expectancy of the wall
- Possibility to build cavity
- It can increase the thermal mass of the building

Disadvantages:
- Labour intensive
- High Initial cost
- Long construction time if not using prefabricated elements
- Not easy to be recycled
- Heavy construction
- Extreme weather conditions can cause degradation of the masonry wall
- Not high tensile strength that leads to the need of reinforcement
- Brick walls have lower compressive strength than concrete (almost the half or less)
- Low thermal performance (an insulation material is needed)
- Weather depended construction: Cannot be laid when it is raining heavily or when temperatures fall below freezing
2.4) CONCRETE FAÇADE

2.4.1) General Information

Concrete has become a very important material in the evolution of the modern architectural form. Its name is connected with the modern architecture and urbanism. It has become such a success due to the fact that it is extremely durable, easy to work with, easy to connect and in conjunction with steel, has a high loadbearing capacity.

In terms of its constitution, concrete is a very old material. It appeared around 12,000 BC as lime mortar were it had been used as a building material. In the 2nd century BC, people were using opus ceamentitium. This form of the material helped Romans achieve masterly feats of architecture and engineering (ex. Pantheon in Rome). With the downfall of the Western Roman Empire, this material lost its significance for almost 1500 years.

In 1824 Portland cement make its appearance that after years developed further in the modern form of concrete.

During the mid-19th century there was the first attempts to reinforce the material by the French and English that wanted to replace timber and natural stone in their constructions. In 1854 we have the first reinforced concrete slab with iron in England.

At about the same time, Francois Coignet developed the temped concrete method (the “beton agglomere”) based on the idea of temped loam.

After 1900 there is the great expand in use of concrete, produced in many different constitutions and techniques, and the blossom of application for long-span loadbearing structures.

2.4.2) The concrete in the facade

The new material become established around 1900, primarily for industrial and commercial buildings. However the linear framework of columns and beams distinguish in fact the structure of concrete. Auguste Perret use it in that way at the façade of a residential house in the Rue Franklin in Paris (1903). The use of concrete in plates, slabs and continuous spandrel panels was distinguished by great architects like Tony Garnier, Le Corbusier and Ludwig Mies van der Rohe.

The technology of today make the application of concrete in the facades available in many different techniques, almost limitless colour and surface texture options such as:

- Lightweight/heavyweight
- Insulation/thermal mass
- Dense microstructure/open pores

In order to build a concrete façade it is possible to apply the material in site, use prefabricated elements or make a combination of these two forms of concrete by building a semi-prefabricated façade.

- According to the types of the concrete walls, they could be even monolithic walls or layered.
Aesthetic effects achieved by the application of concrete in the facades can be divided into five categories:

1. Fair-face concrete (normally when we speak to concrete façade, we are usually referring to in situ concrete, and in this case we usually mean fair-face concrete)
2. Precast concrete
3. Reconstructed stone panels
4. Facing concrete masonry units
5. Cement-bonded sheets

2.4.3) Composition

fine and coarse aggregates (sand and gravel respectively) + cement + water = normal weight concrete (density 2400–2550 kg/m³)

Concrete as a material, is an artificial stone produced by hardening of cement-water mixture (cement paste) to form hydrated cement. The aggregated is bonded into this to form a solid matrix.

Depending on the desired properties the ratio of the raw materials can change both during production and after hardening.

The composition of the concrete has been decided according to the demanding:
• workability of the concrete
• strength
• durability
• cost of its production

EN206 part1 is the most important standard of the design and construction of concrete elements.

Today concrete is produced in many techniques. There are a lot of possibilities and different properties achieved with different kind of additives and water level in the mix.

Ageing of facades due to the effects of the weather is a material-related problem that is frequently caused by defects in the detailing.
The individual constituents of concrete are:
- Binders (usually cement)
- Aggregates
- Additives
- Admixtures

Wet concrete should exhibit the following properties:
- easy workability
- good compactability
- plastic consistency
- easy mouldability
- good cohesion
- low segregation tendency
- good water-retention capacity
- no tendency to “bleed” (water seeping from the wet concrete)

The requirements for hardened concrete are as follows:
- good strength
- homogeneous, dense and consistent concrete microstructure
- uniform surface structure without blowholes
- resistance to the weather and external influences

2.4.4) Properties

The properties of concrete can vary a lot according to the mixture, the moisture in the mixture, the quality of aggregates and the chemical additives that are placed in the mixture in order to give special properties. New technologies are focusing on concrete and the outcome is new forms of concrete with a great variety of different characteristics. Insulating concrete, Water-Tight Concrete, High Performance concrete, Gradient Concrete, Calcium Carbonate Addition to Concrete, Breathable Concrete, Self-Cleaning Concrete and Transparent Concrete are just some examples of concrete with very different properties.

This research is going to focus at the most common forms of concrete used in buildings. According to the CES 2012 programme these are the following:

- Aerated concrete
- Asphalt concrete
- Concrete (conducting)
- Concrete (high alumina cement)
- Concrete (high performance)
- Concrete (insulating lightweight)
- Concrete (normal (Portland cement))
- Concrete (Pozzolona cement)
- Concrete (structural lightweight)
- Concrete (super sulfate cement)
- High density concrete
- High volume fly ash concrete
- Reactive powder concrete
Density graph

Compressive strength graph
Thermal conductivity graph

Tensile strength graph
2.4.5) Concrete constructions

In situ concrete

Around 1900 the idea of in situ concrete find many supporters in the field of constructions. Both architects and engineers were hoping that in situ concrete would bring many advantages. However the technology and the techniques of that time disappoint them.

After some decades, during the 1950s concrete evolved into an all-purposed building material.

More recently, architects have been attempting to express the monolithic method of construction more comprehensively, right down to the tiniest detail. There is a general attempt of produce minimal constructions in the smallest possible dimensions.

Semi prefabricated concrete

In this case a part of the concrete element is produced as a prefabricated element and the rest of the concrete is applied in situ.

It was produced as an attempt to take the benefits both of the prefabrication and the in situ application of the material. In such a way the limitation of the prefabricated panel sizes was overcome.

Prefabricated concrete

The prefabrication of concrete panels started around 1920 where the industrialization of reinforced concrete construction started to gain significance.

The idea of prefabricated concrete elements come as a result of the research to divide the construction into identical, transportable elements which could then be produced in series in precasting plants. In this way the construction was finally free of the weather conditions, the quality of the concrete was higher and there were better and accurate surface finishes. Normally, it indeed offer a number of advantages over in situ concrete as the production and processing of the concrete is carried out by one team.

Horizontal casting beds leads to very good compaction of the concrete, and that in turn leads to lower porosity at the surface.

However, the transportation and erection options limit the economic use of heavy and large precast components. In terms of the thickness, it can be produced much slimmer than the in situ concrete.

There are three types of precast concrete elements that are used in the facades:

- Single-leaf curtain walls (suspended from the loadbearing construction)
- Double leaf curtain walls (suspended from the loadbearing construction)
- Sandwich elements (can be used both as loadbearing and as non-loadbearing components.)

Depending on the system, the elements are suspended from cast in loadbearing brackets or screwed/bolted to anchors or cast-in rails provided on site. The fasteners must be made from stainless steel.

Cramps and face or concealed fasteners are used to resist wind loads and temperature fluctuations. The number of thermal bridges increases with the number of fasteners and cramps.
2.4.6) Concrete block

Apart from the bricks that are made out of clay there are also other materials. Among others, there are also concrete masonry units (CMUs) of blocs.

Blocks of cinder concrete (cinder blocks or breezeblocks), ordinary concrete (concrete blocks), or hollow tile are generically known as Concrete Masonry Units (CMUs). Concrete blocks are made from cast concrete, i.e. Portland cement and aggregate, usually sand and fine gravel for high-density blocks. Lower density blocks may use industrial wastes as an aggregate. They usually are much larger than ordinary bricks and so are much faster to lay for a wall of a given size. Furthermore, cinder and concrete blocks typically have much lower water absorption rates than brick. Surface-bonding cement, which contains synthetic fibers for reinforcement can impart extra strength to a block wall.

Production
CMUs can be manufactured to provide a variety of surface appearances. They can be colored during manufacturing or stained or painted after installation. They can be split as part of the manufacturing process, giving the blocks a rough face replicating the appearance of natural stone, such as brownstone. CMUs may also be scored, ribbed, sandblasted, polished, striated (raked or brushed), include decorative aggregates, be allowed to slump in a controlled fashion during curing, or include several of these techniques in their manufacture to provide a decorative appearance.

Uses
Concrete block, when built in tandem with concrete columns and tie beams and reinforced with rebar, is a very common building material for the load-bearing walls of buildings, in what is termed “concrete block structure” (CBS) construction. Large buildings typically use copious amounts of concrete block; for even larger buildings, concrete block supplements steel I-beams. Tilt-wall construction, however, is replacing CBS for some large structures.

Structural properties
Concrete masonry can be used as a structural element in addition to being used as an architectural element. Ungrouted, partially grouted, and fully grouted walls are the different types of walls allowed. Reinforcement bars can be used both vertically and horizontally inside the CMU to strengthen the wall and results in better structural performance.

The compressive strength of concrete masonry units and masonry walls varies from approximately 1,000 psi (7 MPa) to 5,000 psi (34 MPa) based on the type of concrete used to manufacture the unit, stacking orientation, the type of mortar used to build the wall, and other factors.
2.4.7) Recyclability

In most cases, concrete building waste are dumped into landfills, taking up massive amounts of space for long periods of time. As a construction material it has long life span. Substantially it cannot degrade. What is normally done is be broken down and transformed into new aggregate materials.

The used concrete, taken from the demolition sites must be free of contaminants in order to be used at the crushing facility. That means it must be free of trash, wood, paper and other such materials. Though, any kind of metal contaminants can be collected later with magnets and other sorting devices. The crushing process includes many repetition stages and each of them leads to different sizes of useful aggregate chunks.

Characteristics

Advantages:
- Durability (high compressive strength)
- Easy workability
- Quality control (if used prefabricated elements)
- Availability
- No maintenance
- Short construction time (if used prefabricated elements)
- Long history of use: many studies have been carried out on concrete
- Concrete has been related with the "Modern movement"
- Good fire protection
- Big life expectancy of the wall
- It can increase the thermal mass of the building
- Many structural possibilities
- Ability to manufacture pre-cast forms
- Additional properties can be achieved with different mixtures
- Very versatile as material. Great flexibility in shapes and forms of the final product

Disadvantages:
- Not easy to be recycled
- No quality control (if used in situ concrete)
- Long construction time (if used in situ concrete)
- Prone to climate changes which can occur during long construction times.
- Big environmental footprint especially due to the use of cement
- Not high tensile strength that leads to the need of reinforcement
- Design limitations (if used precast concrete)
- Joints between pre-cast panels are most often complicated and expensive so therefore require skilled workmanship
- Most on-site installations require a crane for lifting into place (pre-cast form)
- Heavy construction
- Low thermal performance (an insulation material is needed)
3_RESEARCH PART B: Biodegradable materials

“I just happen to think that in life we need to be a little like the farmer, who puts back into the soil what he takes out”

Paul Newman

The final part of the research step is a research of possible materials or natural mixtures that can be used in the facade construction. There are presenting 40 biodegradable materials and techniques. It is the outcome of literature study on natural materials, internet searching, visit at the Openluchtmuseum in Arnhem and interviews at researchers, architects, constructors and professors.

The presented materials belong to seven categories according to their source of production and use. There are materials and techniques that either were using in the past or are new eco-composites that are still in the research step or are used in other fields however, their properties make them possible solution for the wall systems. Similarly to the concrete and brick constructions analysis the materials are analysed according to their composition, wall construction method with these materials (if any) and properties (advantages and disadvantages of their use in the building envelope).

This step of the research tries to find answer on the reasons that natural and biodegradable materials are not used in the wall systems any more. What is more, it also tries to give a general overview on possible wall construction materials and techniques that at the design step could be combined together (either in terms of materials or construction method) to produce reasonable and proper wall solutions.

The materials are organized in 7 categories:

1. Traditional: here there are explained the two out of four traditional materials used in the Netherlands. The main source of information was the Openluchtmuseum in Arnhem where there are presented in reality all the kinds of traditional buildings that exist in the whole country
2. Earthen: natural materials taken from the earth
3. Forestry: natural materials taken from the forestry
4. Farming: natural materials taken from the farming
5. Agricultural: natural materials taken from the agriculture
6. Mattress materials: natural materials used at the mattress construction. Many are also used in the building field and the rest have interesting properties that make them potential wall materials.
7. New technologies – Composites: many materials referred in this category are still in the research level or they are used in other fields. However, there are possibilities to apply them in the architectural envelope in the near future.
### 3.1) List of Analyzed Materials

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>MATERIAL/MIXTURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional</td>
<td>• Peat sod</td>
</tr>
<tr>
<td></td>
<td>• Wattle and daub</td>
</tr>
<tr>
<td>Earthen</td>
<td>• Lime stone</td>
</tr>
<tr>
<td></td>
<td>• Earthbags</td>
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<tr>
<td></td>
<td>• Mud coating</td>
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<td></td>
<td>• Rammed earth</td>
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<td></td>
<td>• Cordwood</td>
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<tr>
<td></td>
<td>• Adobe/Mud brick</td>
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<td></td>
<td>• Compressed Earth Blocks (CEB)</td>
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<td></td>
<td>• Cob</td>
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<td></td>
<td>• Clay dyes</td>
</tr>
<tr>
<td>Forestry</td>
<td>• Cork</td>
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<td></td>
<td>• Paper tubes</td>
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<tr>
<td></td>
<td>• Papercrete</td>
</tr>
<tr>
<td></td>
<td>• Paperstone</td>
</tr>
<tr>
<td>Framing</td>
<td>• Wool</td>
</tr>
<tr>
<td>Agriculture</td>
<td>• Hemp</td>
</tr>
<tr>
<td></td>
<td>• Bamboo</td>
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<tr>
<td></td>
<td>• Straw bale</td>
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<tr>
<td>Mattress materials</td>
<td>• Coconut fiber</td>
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<tr>
<td></td>
<td>• Natural rubber</td>
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<td></td>
<td>• Horse hair</td>
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<td></td>
<td>• Seaweeds</td>
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<tr>
<td></td>
<td>• Cactus</td>
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<tr>
<td></td>
<td>• Cotton</td>
</tr>
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<td></td>
<td>• Linen</td>
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<tr>
<td></td>
<td>• Goose down</td>
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<tr>
<td>New technologies-Composites</td>
<td>• Ingeo – corn fibre</td>
</tr>
<tr>
<td></td>
<td>• Canatex</td>
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<tr>
<td></td>
<td>• Pine Sap</td>
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<td></td>
<td>• Mushroom material</td>
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<tr>
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<td>• Zeflo</td>
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<tr>
<td></td>
<td>• BatiPlum feathers</td>
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<tr>
<td></td>
<td>• Nettle textile</td>
</tr>
<tr>
<td></td>
<td>• Moniflex</td>
</tr>
</tbody>
</table>
3.2.1) TRADITIONAL

According to the materials they use there are 4 types of wall construction:

- Wattle and daub
- Peat sod
- Wood
- Brick

The research on the materials used in the Dutch traditional building envelopes will be focused on the “wattle and daub” and “peat sod” categories.
WATTLE AND DAUB WALLING

IN THE PAST:

The origins of wattle and daub stem from the primitive buildings, where huts were constructed of poles and earthen walls. Archaeology shows the techniques were numerous and their boundaries ill-defined.

The walls could be made with wattles, woven from brushwood or ‘withies’ (thin wands) coppiced from nearby woodlands. The filling in most cases was with straw, moss, leaves and earth. For easy layering, the use of turf and topsoil was common, but for binding into wattles, it was easier to use soil that could be pressed into position and would remain in place. For finishing there was a stucco plaster.

Problems:
• the wall was flammable
• the stucco plaster makes cracks from the inside by the arrangement of its studs and girts
• moisture

To overcome these problems chopped straw, hay, vegetable materials and dung were added to the daub to improve binding and reduce shrinkage cracking.

FINAL, IMPROVED VERSION OF WATTLE AND DAUB WALLING:

At the latest version they built timber framed structures. They filled the space between structural timbers with wattle made from thin flexible branches, which has been smeared with a daub consisting of clay, straw and dung. The finishing was a lime plaster layer. In order to improved weather resistance of both frame and the wattle and aub panels, they plastered the entire wall, often accompanied by decorative plaster known as pargetting.

Construction
• The wattle is made by weaving thin branches (either whole, or more usually split) or slats between upright stakes. The wattle may be made as loose panels, slotted between timber framing to make infill panels, or it may be made in place to form the whole of a wall.
• Daub is usually created from a mixture of certain ingredients from three categories: binders, aggregates and reinforcement. Binders hold the mix together and can include clay, lime, chalk dust and limestone dust. Aggregates give the mix its bulk and dimensional stability through materials such as earth, sand, crushed chalk and crushed stone. Reinforcement is provided by straw, hair, hay or other fibrous materials, and helps to hold the mix together as well as to control shrinkage and provide flexibility.[1] The daub may be mixed by hand, or by treading – either by humans or livestock. It is then applied to the wattle and allowed to dry.
• Often there is a final layer of whitewashed to increase its resistance to rain.

This process is similar in modern architecture to lath and plaster, a common building material for wall and ceiling surfaces, in which a series of nailed wooden strips are covered with plaster smoothed into a flat surface. In some regions this building method has itself been overtaken by drywall construction using plasterboard sheets.
The demise of the craft of daubing was driven by several compounding factors. Firstly was the replacement with brick nogging. Secondly, timber framing, using either new or reused timbers, diminished during the 17th and 18th centuries due to the inherent fire risk and the subsequent move to stone and brick: construction of half-timbered buildings had almost ceased by the turn of the 18th century. Thirdly, as half-timbering became less respectable through the 18th century Palladians’ desire for stone or brick façades, timber walls were frequently modernised by full plastering or by hiding behind mathematical tiles.

### Characteristics

**Advantages:**
- Flexible
- Availability
- Wind resistant

**Disadvantages:**
- Vulnerable to damp
- The panels required frequent repair or renewal
- Moisture problems
- Time consuming building process

<table>
<thead>
<tr>
<th>Daub mixture</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binder</td>
<td>Hold the mix together</td>
</tr>
<tr>
<td>Aggregates</td>
<td>Give the mix its bulk and dimensional stability</td>
</tr>
<tr>
<td>Reinforcement</td>
<td>Give extra structural properties</td>
</tr>
</tbody>
</table>
Peat (turf) is an accumulation of partially decayed vegetation by acidic and anaerobic conditions. Soils that contain mostly peat are known as a histosol. Peat forms in wetland conditions, where flooding obstructs flows of oxygen from the atmosphere, slowing rates of decomposition.

Peat material is either fibric, hemic, or sapric. Fibric peats are the least decomposed, and comprise intact fiber. Hemic peats are somewhat decomposed, and sapric are the most decomposed. Phragmites peat is one composed of reed grass, Phragmites australis, and other grasses. It is denser than many other types of peat. Engineers may describe a soil as peat which has a relatively high percentage of organic material. This soil is problematic because it exhibits poor consolidation properties.

Construction

The type peat/sod used at the constructions is this with strong and dense roots. Construction of a sod house involved cutting patches of sod in rectangles, often 600×300×150mm long, and piling them into walls. Often, the soil was excavated 30 to 60 cm below ground level. Footings were rarely laid.

In building the walls, the sod blocks were laid one course at a time. Each course was completed before the next was begun. Walls were generally two or three units thick. The vertical joints were staggered to avoid creating a direct path through the wall for wind and vermin. To bind the units and increase the stability of the wall, every second, third, or fourth course was laid crosswise.

Wooden door frames were set in place as the wall construction began. Window frames of wood were positioned when the wall reached the proper height. Sod was laid around the sides and on top of boards placed above the window frame. A gap, left at the top above the frame, was filled with rags or grass, which allowed the sod to settle without crushing the glass panes in the window. Pegs, driven into the sod through holes in the frames, held them in place. A variety of materials was used, depending on the locality and the finances of the builder. Cedar logs, when available, were used as ridge poles because they were rot-resistant and strong.

These houses accommodate normal doors and windows. The resulting structure was a well-insulated but damp dwelling that was very inexpensive. Sod houses required frequent maintenance and were vulnerable to rain damage. Stucco or wood panels often protected the outer walls. Canvas or plaster often lined the interior walls.

To protect against invasion by rodents, insects, and snakes, the interior walls were often shaved smooth and plastered with lime, or with a mixture of local clay and sand or ashes the lower portions of the exterior walls could also be reinforced, with planks or concrete if they were available, or with a second layer of sod to thicken them. Sometimes there is also a wooden frame.

Characteristics

Advantages:
- Very inexpensive construction
- Very quick building process
- Great insulation (but thick walls)
- Extremely wind resistant
- Moderate the interior temperature both during summer and during winter

Disadvantages:
- Extremely flammable even wet or dry. It is also used as a fuel.
- Highly compressible under even small loads
- Not considered as a renewable resource as it takes too long to be made.
- High levels of humidity
- Frequent maintenance
- Vulnerable to rain damage
- Thick walls
3.2.2) EARTHEN

- Lime stone
- Earthbags
- Mud coating
- Rammed earth
- Cordwood
- Adobe/Mud brick
- Compressed Earth Blocks
- Cob
- Clay dyes
Limestone is a sedimentary rock that finds many uses in many domains. One of these is in building constructions and where it is used in many different forms.

Limestone often contains variable amounts of silica and varying amounts of clay, silt and sand carried in by rivers. Some limestones do not consist of grains at all, and are formed completely by the chemical precipitation of calcite or aragonite, i.e. travertine. Because of impurities, such as clay, sand, organic remains, iron oxide and other materials, many limestones exhibit different colors, especially on weathered surfaces.

**SASCAB**

Also known as “decomposed limestone”, “breccia”, and “the lime gravel mixture the Maya used as mortar.”

Sascab is a naturally occurring mineral material. It has been used as a building and paving material in Mesoamerica since antiquity. It was used as a substitute for sand in the preparation of ancient and modern mortars and plasters.

It is a white to reddish compacted powder, frequently containing rounded boulders or stones. It is a powder surrounded by hard limestone. The largest proportion of sascab is formed of calcite (CaCO₃), but some sources sascab may contain magnesium, resulting in a dolomitic limestone.

**LIME MORTAR**

It is an environmental friendly alternative to concrete based plasters. There are two main types of lime mortar that are both used as lime plastering. These mortars are Lime Putty (Non Hydraulic Lime) and Hydraulic Lime.

1. **Non-hydraulic lime or lime putty** is lime in its purest form. It is an excellent material used to great effect with stones or bricks, which are weakened or weathered. It is an ideal consistency to be used for plastering, pointing and any face repairs to the bricks. It is often used in the conservation and restoration of buildings. Storage of lime putty is extremely important. It should be matured for at least 30 days and must be stored with aggregates in a wet condition or blended.

2. **Hydraulic lime**. Not as pure as non-hydraulic lime, hydraulic lime has the ability of being able to set under water. This characteristic is due to the impurities of the silica and clay in the limestone from which it is burned. It is able to accommodate movement and is excellent at retaining its water vapour permeability as well as being frost and salt resistant.
Characteristics of lime mortar

Advantages:
- Easy to remove from bricks and blocks allowing the reuse of the bricks
- During manufacture lime produces 20% less carbon dioxide than cement production
- Lime is essential in the building of any natural house (any house built using straw bales, timber, earth etc)
- 100% biodegradable
- Lime is burnt at a lower temperature than cement in the production process (900°C as opposed to 1300°C), therefore making lime production not only more environmentally friendly but also more economic as well
- Recyclable
- Allows the building to “breath” which is vital for walls built with natural materials (ex.straw)
- Water can escape by evaporation, unlike cement where the only way the water can escape is by being absorbed into the bricks and therefore, risking damp and erosion of the building substrate
- Is soft and flexible. It allows the building to move (as all buildings do!) without cracking and letting water in (unlike our old friend cement!) It has been dubbed “self-healing” because of this ability
- Lime plaster is more durable in wet climates than clay plasters
- Hydraulic Limes gain strength over time hence providing flexibility and avoiding the need for expansion joints

Disadvantages:
- If it is reinforced with natural fibers the outcome will degrade in damp environments.

LIME WASH

Lime wash or whitewash is pure slaked lime in water. It produces a unique surface glow due to the refraction of calcite crystals.

When limewash is initially applied it has very low opacity, which can lead novices to overthicken the paint. Drying increases opacity, and subsequent curing increases opacity even further.

Characteristics of lime blocks

Advantages:
- Very inexpensive
- Easy to apply
- Pigmented to a variety of colors or left pure white
- Can consolidate damaged substrates
- Is vapour-permeable, allowing a building to breathe from the inside to the outside

Disadvantages:
- Basic limewash can be inadequate in its ability to prevent rain driven water ingress
- Caustic material so it needs extra protection while working with it
- It will wash off over time if exposed to rain
- The lime layer needs many coats (the exact number is something to determine)
LIME BLOCKS

The walls that are made of lime blocks have the same construction process as brickwalls. Studies have been carried out in order to make blocks by combining lime with other products. Here is an example of combining lime with hemp

Characteristics of lime blocks

Advantages:

- High sound adsorption
- High thermal isolation
- Durable
- Small cost
- High compression strength
- Possible to have invisible joints
- Not skilled laborers needed
- High strength
- Wide range of product sizes from small brick up to elements
- Fast construction with high economic efficiency
- Using for inside and outside walls
- Bricks are possible in different colours for outside walls
- Small amount of mortar with the result of high cost reduction
- Easy handling
- High fire resistant
- Low tolerance in sizes through our high quality machineries

Disadvantages:

- I am not sure about the environmental impact
Earth Bag Home Construction

Earth Bag Wall Construction

Wall thickness: approximately 70 cm

Earthbag construction is a method to create structures which are both strong and can be quickly built. It is a natural building technique that evolved from historic military bunker construction techniques and temporary flood-control dike building methods. Standard earthbag fill material must have internal stability. Inorganic material usually available on site makes sturdy sacks.

Bag-fill material:
- Moist subsoil that contains enough clay
- Angular gravel
- Volcanic rock

Wall shape:
- Straight (if longer than 5 m it needs either intersecting walls, bracing buttresses or piers added)
- Curved (good lateral stability)

Construction:
Gradually built up by layering the bags in courses (like brick work).

Structural mechanics:
- The profile of an arch is set out to minimize horizontal thrust transferring to the wall
- Seismic activity can apply great horizontal accelerations, however the ductile nature of earthbags can reduce the effects (if movement allowed)
- Earthbags have been proven to have very high strength under compression

Reinforcement:
- To improve friction between each row of bags and finished wall tensile strength bared wire is often placed between the courses. Twine is also sometimes wrapped around the bags to tie one course to the next, serving to hold the in-progress structure together and add strength. Chicken wire is another option for reinforcement. It can tie around the whole construction and make it stronger. Rebar can easily be hammered into walls to strengthen corners and opening edges and provide more resistance against overturning.
Two strands of barbed wire are placed on top of each course to prevent slippage of subsequent layers, keep the bags in place and also resist any tendency for the outward expansion of walls (especially with domes).
If it is needed we can place a chicken wire around the construction.

Foundation

- We dig a trench down to undisturbed mineral subsoil.
- We fill it with cobble stones or gravel to create a rubble trench foundation. In high seismic risk regions a reinforced concrete footing or grade beam may be recommended.
- At the foundation, we put bags filled with gravel to prevent wicking moisture into upper courses. The bags sit directly on rubble trench. At the same time and with the same way we build the buttresses.
- We add soil around the sides of the dome and tamp solid to prevent the bags from moving.
Openings

There are various ways of attaching door and window bucks. On this dome we made six anchors with small pieces of steel welded together in a T-shape. Drill holes in the anchors and pin to the earthbags as shown with ¼” steel rod. Distribute the anchors, three per side, so there are two near the bottom, two in the center and two near the top of the arched door opening. A steel door buck was welded to these anchors after the dome was built.

Corners

Corners of cohesive soil earthbag buildings fail first in earthquakes unless they are reinforced. Reinforcement can be achieved with the following techniques:

- Weave barbed wire out of corners, up the wall, back into the next course.
- Hammer rebar through corner bags.
- Surround walls with plastic or wire mesh. Tie the mesh through the wall around bags or to mesh layers inside. Embed mesh in wall plaster.
- Use strapping to hold several courses of bags firmly together, anchored on barbed wire barbs.
- Pliers and corners exposed to extra stress will also be stronger with mesh in the plaster.
- Cut pins with 3 teeth out of wire mesh, bend, insert into bags over barbed wire barb.
- Use lumps of mortar as anchors to attach the wire to the individual bags.
Overview of the construction process in 3D

Finishing

There are four possible solutions:

- Plaster
- Stucco
- Adobe
- Lime

Earth bags - straw

There is also possible to combine construction methods and materials of natural buildings. Below is one example
The bags

There are numerous possible material and mixtures for bag-filling according to the demands and the technique. According to the material used at the bags there is also a great variation. Recently there is a tendency to apply more natural and ecological materials.

Bag types

- Polypropylene
- Organic/Natural material
- Burlap
- Hemp
- Gunny sack

Bag-fill material must have more clay

Inorganic materials

- Pumice (insulation)
- Volcanic rock (insulation)
- lime
- 5-50% clay
- reject fines
- road base
- subsoils
- Sand
- Stone dust
- Gravels
- Cement
- Bitumen stabilization

Characteristics

Advantages:

- Cost
- Construction time
- Strong structure
- Availability
- The construction process is not influenced by the weather conditions
- Low embodied energy
- Reuse or recycling of the constituents

Disadvantages:

- Extremely flammable. It is used as a fuel. Wet or dry, it can be a major fire hazard, as peat fires can burn almost indefinitely
- highly compressible under even small loads
- It is not considered as a renewable resource as it takes too long to be made.
- High levels of humidity
- Frequent maintenance
- vulnerable to rain damage
- Thick walls
MUD COATING

Mud is used to coat or adhere together items that dries hard such as plaster, stucco, concrete or other similar substances.

**Composition**

- Water
- 3 parts sand
- Fibers (straw/cattail fluff/or even cow manure)
- 1 part clay
- Additional additives (if needed)

**Material**

<table>
<thead>
<tr>
<th>Material</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>Provides structural strength + Fine, sifted sand is used to provide a smooth finish</td>
</tr>
<tr>
<td>Fibers</td>
<td>Make the plaster strong and resistant to cracking</td>
</tr>
<tr>
<td>Clay</td>
<td>Binding agent</td>
</tr>
<tr>
<td>Additional additives</td>
<td>Increase durability and stickiness</td>
</tr>
</tbody>
</table>
RAMMED EARTH

also known as taipa (Portuguese), tapial (Spanish), and pisé (de terre) (French)

Wall thickness: approximately 30 to 35 centimetres

Clear shapes

Composition

- Earth (sand, gravel, clay-between 5% and 15%) + cement for reinforcement
- Lime/cement/asphalt
- lime/animal blood (in the past)
- Chalk
- Gravel
- Colored iron oxides or other items, such as bottles, tires, or pieces of timber, to add variety to the structure

Construction

There is a need of framework, usually made of wood or plywood, to act as a mold for the desired shape and dimensions of each wall section. The form must be sturdy and well braced, and the two opposing wall faces clamped together, to prevent bulging or deformation from the large compression forces involved. Damp material is poured in to a depth of 10 to 25 cm (4 to 10 in) and then compacted to around 50% of its original height. The material is compressed iteratively, in batches, gradually building the wall up to the top of the frame. Tamping was historically done by hand with a long ramming pole, and was very labour-intensive; modern construction can be made less labour-intensive by employing pneumatically powered tampers.

Once a wall is complete, it is strong enough for the framework to be removed.

The compression strength of the rammed earth increases as it cures; it takes some time to dry out, as much as two years for complete curing. Exposed walls should be sealed to prevent water damage.

In modern variations of the method, rammed-earth walls are constructed on top of conventional footings or a reinforced concrete slab base. Where blocks made of rammed earth are used, they are generally stacked like regular blocks but are bonded together with a thin mud slurry instead of cement. Special machines, usually powered by small engines and often portable, are used to compress the earth into blocks.

These walls are plastered with soil mixtures rather than cement. Actually moisture-impermeable finishes, such as cement render, are avoided because they impair the wall’s ability to desorb moisture, necessary to preserve its strength.

If needed there is additional insulation and reinforcement in between.
TOP COAT: CEMENTITIOUS WATERSTOP SEALER TO TOP OF PARAPET
PUDDLED EARTH TOP LIFT
SAWN KERF REGLET FOR CONT. MEMBRANE FLASHING AND PRESSURE BAR - CAULK
PREFINISHED METAL FLASHING
LANDSCAPED ROOF (INVERTED TORCH-ON 2 PLY SBS MEMBRANE)
- NATIVE PLANTS
- 230 NATIVE SOIL GROWING MEDIUM
- ROOT RESISTANT MEMBRANE
- DRAINAGE PANEL + FILTER FABRIC
- 100 RIGID INSUL. (R5.5)
- CAP SHEET
- BASE SHEET
- PRIMER
- SLOPING SUSP. CONC. CW IN- SLAB RADIANT PIPES

RADIANT PIPING IN SLAB
CONCRETE SLAB BAND BEYOND (SLOPING)

REVEAL
HSS FRAME IN WALL BEYOND

EXTERIOR
TOP OF WINDOW OPENING

INTERIOR
PUDDLED EARTH
CONTINUOUS CLEAR FINISH
SOLID ASH-WD WINDOW STOP & TRIM (TOP AND BOT)
CONTINUOUS DOUBLE GLAZED SEALED FRAMELESS WINDOW - SILICONE IN PLACE

RAMMED EARTH WALL
- 250 RAMMED EARTH WALL: REINFORCED
- 100 POLYISOCYANurate INSUL.
- 250 RAMMED EARTH WALL: REINFORCED NOTT- LIFT HEIGHTS TO VARY 5MM-15-170

COLOUR TINTS TO RANGE BW SELECTED SAMPLES

RECESSED HALOGEN LIGHT CENTRED IN 76MM Ø OPENING

400 X 400 DOUBLE GLAZED FRAMELESS WINDOW - SILICONE IN PLACE
CONCRETE COLUMN BEYOND
SOLID ASH WINDOW STOP & TRIM

CONCRETE FLOOR SLAB ON GRADE
- CONCRETE SLAB ON GRADE CW RADIANT SLAB HEATING/COOLING PIPES
- VAPOUR BARRIER
- 50 HIGH INSULATION (510 AROUND OUTSIDE PERIMETER)
- GRAVEL BASE / NATIVE SOIL

RECESSED IN-SLAB LIGHT @3000 O.C.
SLOPING CONTINUOUS WATER TROUGH

Nk’Mip Desert Cultural Centre wall section
Openings

Any time a rammed earth wall runs over the top of a window or door, a steel lintel is required.

Characteristics

Advantages:

• Highly thermal mass
• Adequate compression strength (4.3 MPa (620 psi) (without any reinforcement) < concrete compression strength)
• Soundproofing
• Termite resistant
• Non-toxic
• Ultimately biodegradable
• Fireproofed
• Water tightness
• Strong
• Durable
• Simple to construct
• Method used in regions with different climates (includes the temperate and wet regions of northern Europe, semiarid deserts, mountain areas and the tropics)
• Low cost, could be built for no more than two-thirds the cost of standard frame houses
• No skilled laborers are needed
• Great availability of the raw materials
• Control humidity (Keep it between 40%-60%)
• Breathing wall (due to the contamination in clay) = avoiding condensation issues without significant heat loss
• Low embodied energy

Disadvantages:

• The texture at the wall should be worked within an hour (after that the structure is not workable any more)
• Construction is best done in warm weather so that the walls can dry and harden.
• Frequent maintenance
• Vulnerable to rain damage
• Thick walls
CORDWOOD
(also called “cordwood masonry,” “stackwall construction” or “stackwood construction”)

Wall thickness: normally 30-60 cm in extreme situations they can reach 90 cm thickness
Clear shapes

In this technique short pieces of debarked tree are laid up crosswise with masonry or cob mixtures to build a wall. Wood usually accounts for about 40-60% of the wall system, the remaining portion consisting of a mortar mix and insulating fill, woods that shrink and expand very little - wood species that are “light and airy”.

Cordwood walls can be load-bearing (using built-up corners, or curved wall designed) or laid within a post and beam framework which provides structural reinforcement and is suitable for earthquake-prone areas. As a load-bearing wall, the compressive strength of wood and mortar allows for roofing to be tied directly into the wall. Different mortar mixtures and insulation fill material both have an impact on the wall’s overall R value, or resistance to heat flow; and conversely, to its inherent thermal mass, or heat/cool storage capacity.

Construction

Method 1: Throughwall

Throughwall, the mortar mix itself contains an insulative material, usually sawdust, chopped newsprint, or paper sludge, in sometimes very high percentages by mass (80% paper sludge/20% mortar).

It is a monolithic construction. There is no insulation layer. The insulation material is incorporated in the clay mixture

Mortar mixed with

Sawdust

Chopped newsprint

Paper sludge

It is also possible to incorporate glass or other ornaments in the wall construction

Cordwood Shed with a thatched roof

Cordwood wall construction

Piet Hein Eek for Hans Liberg

It is also possible to incorporate glass or other ornaments in the wall construction

Cordwood house construction

Cordwood Shed with a thatched roof
Method 2: M-I-M (mortar-insulation-mortar)

This technique is more common. Here, the mortar does not continue throughout the wall. Instead, three or four inch(sometimes more) beads of mortar on each side of the wall provide stability and support, with a separate insulation between them.

Characteristics

Advantages:

- Can be cheap (it depends on the wood availability)
- Easy construction method
- Cordwood homes are relatively efficient. (take advantage of the thermal mass)
- Wood is a renewable resource
- Cordwood homes can be built with high-quality waste wood from discarded wooden fencing, waste sawmills or log home builders and peeler cores from plywood companies.

Disadvantages:

- Cordwood construction is extremely labor intensive.
- Enormous amount of wood is needed
- Trained laborers
- It might be expensive
- Regular maintenance - seal expansion cracks a year or two after you get in
Adobe/mud bricks

Wall thickness: approximately 40cm
Brick size: Approximately 25cm by 36cm
Clear forms

The mixture is placed in molds and get dry in the sun. Slow drying in shade reduces cracking.

Composition

<table>
<thead>
<tr>
<th>Composition</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td></td>
</tr>
<tr>
<td>Soil</td>
<td>55-75% fine sand</td>
</tr>
<tr>
<td></td>
<td>10-30% silt</td>
</tr>
<tr>
<td></td>
<td>15% clay**</td>
</tr>
<tr>
<td>OR</td>
<td></td>
</tr>
<tr>
<td>Coarser particles up to cobbles 5-8 cm with no deleterious effect</td>
<td></td>
</tr>
<tr>
<td>OR</td>
<td></td>
</tr>
<tr>
<td>15-25% clay**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stabilizer</td>
</tr>
<tr>
<td></td>
<td>Natural waterproof quality that also controls and combats humidity + sticks all the ingredients together</td>
</tr>
</tbody>
</table>

Organic material

<table>
<thead>
<tr>
<th>Organic material</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straw</td>
<td>Binding the brick together + allowing the brick to dry evenly + prevent cracking</td>
</tr>
<tr>
<td>Dung*</td>
<td>Binding the brick together + allowing the brick to dry evenly + prevent cracking + repel insects</td>
</tr>
<tr>
<td>Emulsified asphalt/Portland cement</td>
<td>Stabilizer</td>
</tr>
<tr>
<td>Clay**</td>
<td>Natural waterproof quality that also controls and combats humidity + sticks all the ingredients together</td>
</tr>
</tbody>
</table>

Construction

- Compress the ground before building (because the weight of adobe bricks is significantly greater than a frame house and foundation settings may cause cracking in the wall.
- Footing=60cm
- Stem wall=35cm
- Use a layer of mortar (same mud used to make the bricks), between the foundation and the mud bricks. Construction similar to brick construction. Adobe bricks are laid by course.
- Usually adobe construction do not exceed the height of a 2 story building (because they are load bearing and have low structural strength)
- Lintel is placed on top of openings (windows, doors)
- Atop the last courses of brick, bond beams made of reinforced concrete or heavy wood beams are laid to provide a horizontal bearing plate for the roof beams and to redistribute lateral earthquake loads to shear walls more able to carry the forces.
- Bricks made with stabilized adobe (cement/lime/asphalt) generally do not need protection of plasters.

Coating

- Mud plaster
- Whitewash
- Stucco

Reinforcement

- Wooden posts
- Rebar

Wall section and thickness comparison between different bricks application
Comparison of traditional adobe wall section with a modern evolution of the product and another standard massive wall made of concrete masonry units.

Characteristics

Advantages:

- Can be load bearing elements (they must have sufficient compressive strength (minimum compressive strength of 300 lbf/in.$^2$)
- Low cost
- Good stability
- Good thermal properties (insulation)
- Easy construction method
- Resistance to hurricane
- Rain resistance (according to the coating)
- Good desistance to insects
- Suitable for all climates except extremely hot dry climates
- Moderates interior temperature
- Takes advantage of thermal mass
- Fire resistant

Disadvantages:

- Time consuming
- No resistance to earthquakes

The Arg-é Bam was the largest adobe building in the world, located in Bam, a city in the Kerman Province of southeastern Iran. It is listed by UNESCO as part of the World Heritage Site “Bam and Its Cultural Landscape”. The origin of this enormous constructions is estimated at the 6th to 4th centuries BC and even beyond.

On December 26, 2003, the Citadel was almost completely destroyed by an earthquake.

Adobe-straw bale construction

There is also possible to combine construction methods and materials of natural buildings. Below is one example
COMRESSED EARTH BLOCKS (CEB)

Wall thickness:
Block size: 18 x 35 x 10 cm
Clear forms

Composition
- 15-40% dirt, non-expansive clay
- 25-40% silt powder
- Aggregate not needed if used modern machines)
- Sharp sand (40-70% small gravel)
- Water (only 10%)
- Stabilizer (cement/fly ash/lime/rice husks)

SHAPES
There is a great variety of shapes and sizes. There is even a possibility to make personalized blocks.

CONSTRUCTION
This is an almost new technique. It is known since 195 and it had very limited use prior to the 1980s.
The material blocks are mechanical pressed. The outcome is similar with that of rammed earth but in different scale.
The construction is similar to the brick construction technique. In between each course we put connection material (like the mortar in brick constructions). Actually it is the same mixture used at the form of the blocks but with no aggregates and by adding more water to make the mixture soupy.
There is also 20cm stem wall

THERMAL ADVANTAGES
The thermal properties of compressed earth blocks are much higher than concrete blocks or even adobe units.
With a maximum ambient temperature of 107 °F (42 °C), the interior temperatures were:

<table>
<thead>
<tr>
<th>Material Module</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete Module</td>
<td>111 °F (44 °C) (four degrees Fahrenheit above ambient)</td>
</tr>
<tr>
<td>Adobe Module</td>
<td>95 °F (35 °C)</td>
</tr>
<tr>
<td>CEB Module</td>
<td>91 °F (33 °C)</td>
</tr>
</tbody>
</table>
Characteristics

Advantages:
- Can be load bearing elements (more durable than adobe blocks)
- Good stability
- Marvelous thermal properties (insulation)
- Easy construction method
- low moisture content
- Elimination in waiting time for the block to be ready for construction (A single mechanical press can produce from 800 to over 5,000 blocks per day, enough to build a 1,200 square feet (110 m²) house in one day).
- Availability (even not produced at the site they can be shipped).
- Uniformity of the blocks (as they are mechanically compressed) = easier design
- Sound resistant: an important feature in high-density neighborhoods, residential areas adjacent to industrial zones
- Good desistance to insects
- Takes advantage of thermal mass
- Fire resistant
- Mold resistant
- Great variety in the shapes of the blocks
- High compression strength (700-1500 PSI-pounds per square inch)

Disadvantages:
- Could be expensive depending on the compression technique and the composition
- Heavy walls
- Thick footings (at least 25cm thickness and minimum width that is 33 percent greater than the wall width)
COB

Wall thickness: approximately 60 cm
Organic forms

The cob material is a mixture of Clay, Sand, Straw and water. It is very famous natural construction technique also in North European Countries (England, Germany)

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-25% clay</td>
<td>Sticks all the ingredients together</td>
</tr>
<tr>
<td>Sand</td>
<td>Stabilize the clay</td>
</tr>
<tr>
<td>Straw</td>
<td>Reinforce the mixture and absorbs the extra water</td>
</tr>
<tr>
<td>Water</td>
<td>Make the mixture workable</td>
</tr>
</tbody>
</table>

Construction:

Depends on the weather
Horizontal layers of max 35 cm height
Each layer must dry. To do so, it needs high temperature and ventilation. But.. The longer it takes for the cob wall to dry, the harder and with less cracks the wall will become.

Foundation

There are two main construction techniques for the foundation:

Foundation 1: Single Excavation

- We dig for the foundation until we find stable earth (there must be an inclination for drainage reasons)
- We put a layer of gravel (aprox.15mm)
- We place the drainpipe (diameter > 10cm)
- We put the geotextile over the last layer of gravel

Foundation 2: Double Excavation

Exterior excavation (Excav.1)

- We dig for the foundation until we find stable earth (there must be an inclination for drainage reasons)
- We put a layer of gravel (aprox.15mm)
- We place the drainpipe (O > 10cm)
- We put the geotextile over the last layer of gravel

Interior excavation (Excav.2)

Normal building process
At every stone masonry, and thus at the stone base also, there are 6 different types of stones:

1. Foundation
2. Connection
3. Covering
4. Structuring
5. Filling
6. Kingpins (supporting)

Roof support

The roof is very important for protecting the cob wall against rain. It must protrude at least 50cm from the wall. If possible not supported on the wall (for fear of earthquakes...)

Finishing

One of the big advantages is that the structure can breathe. It is vital for this walls to breath as it can dry. If water stays in the construction it may be the reason for demolition or it can make the environment to cause mold. Cement based coatings are inappropriate as they cannot follow the small movements of the wall.

At the constructions, we use 3 layers of coating:

1. Filling: make the surface smoother. We use it on wet surface
2. Normalization: correct the 1st layer
3. Final

Each layer should slowly dry

<table>
<thead>
<tr>
<th>Type of coating</th>
<th>Mixture</th>
</tr>
</thead>
</table>
| Lime based coating       | • ¼ lime  
                          • ¾ sand [grit at the 1st and 2nd layer and black sand for the final]  
                          • Goat wool/fibers/straw  
                          • water                                 |
| Earth based coating      | • ¼ clay  
                          • ¾ sand [grit at the 1st and 2nd layer and black sand for the final]  
                          • Glutolin  
                          • Goat wool/fibers/straw  
                          • water                                 |

***According to studies carried out from the Campus Center for Appropriate Technology (CCAT) clay plaster may have the environmental benefits that CCAT is looking for, fewest emissions, lower cost and less materials, however, lime plaster is recommended to be used for the strawbale constructions in wet climates, such as in the Netherlands. Lime plaster is more durable in wet climates.
Dyes

They offer additional protection against the weather. As the coating, the dye must breath. There are two main types of natural dyes:

- Clay based (earth based coating)
- Lime based (lime based coating)

<table>
<thead>
<tr>
<th>Type of dyes</th>
<th>Mixture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lime based dye</td>
<td>• Lime</td>
</tr>
<tr>
<td></td>
<td>• Water</td>
</tr>
<tr>
<td></td>
<td>• Glutolin/egg/milk/oil</td>
</tr>
<tr>
<td></td>
<td>• Natural mineral dyes (if we want)</td>
</tr>
<tr>
<td>Earth based dye</td>
<td>• Clay</td>
</tr>
<tr>
<td></td>
<td>• Water</td>
</tr>
<tr>
<td></td>
<td>• Glutolin</td>
</tr>
<tr>
<td></td>
<td>• Hagiology dyes (if we want)</td>
</tr>
</tbody>
</table>

Characteristics

**Advantages:**
- durable construction
- weather resistant even in harsh climates
- resistant to earthquakes, even if it is not reinforced (due to its lack of mortar joints)
- fire resistant
- rot and insects resistant
- enormous thermal storage capacity, thus it is ideal for passive solar design
- not specialized laborers and machinery is needed
- low embodied energy
- low cost

**Disadvantages:**
- time-consuming construction process (to support the weight of new cob on top, the walls must be allowed to dry as they are built, making it impractical in most cases to add more than 30 cm per day.
- not standard mixture of the cob material (it is made empirically)
- cob is susceptible to water damage. In rainy climates the construction must be well protected especially in the basement and on the top (connection with the roof)
- Should be never constructed in flood plains.
CLAY DYES

In general the composition of clay based dyes is the following:

Composition
- Water
- Hagiology dyes (to add color)
- Clay
- Lime
- Glutolin

New technologies have influenced the composition of claypaints. Though the principle is the same. Below is an example of clay dyes compositions produced by a company (“earthborn”):

Composition
- Various clays
- Chalk
- Water
- Kaolin
- Vinegar ester
- Methylcellulose
- Titanium dioxide
- Pigment
- 0.1% synthetic preservative

Characteristics

Advantages:
- Traditional and contemporary shades
- Distinctive style.
- VOC free, acrylic free, totally oil free.
- Certified free of harmful emissions.
- Odor free.
- Highly breathable, creating a more comfortable living environment.
- Minimizes condensation, deters mildew.
- Static resistant.
- Fully biodegradable
- Can benefit allergy and asthma sufferers.
- Easy to apply, hardwearing, great covering power

Disadvantages:
- Cost (if the cost is very low then we do not have variety in colors)

Example of clay dyes application

Organic Moss Grove Hotel
(Company: Earthborn)

The owners of the organic Moss Grove Hotel, Nigel and Jackie Gorton, indulge their guests in luxury without compromising their environmental principles. They also said:

Jackie said: “In every aspect of the hotel we aim to be as sustainable and environmentally friendly as possible. We serve organic, local and fair trade foods, use furniture made from sustainable materials and have decorated all our rooms using natural, toxin-free paints.

“These days, organic doesn’t mean straw beds and lime wash, it means undyed luxury cotton and technologically advanced paints. Earthborn paints demonstrate perfectly that you don’t have to compromise luxury and quality in order to be environmentally friendly.”

The hotel opened in June 2006
3.2.3) FORESTRY

- Cork
- Paper tubes
- Papercrete
- Paperstone
In architecture cork finds two main application:
- as cladding
- as insulation material

Cork cladding

In recent years, Portuguese architects have been exploring cork as a cladding. The Portuguese pavilion in the Hanover Expo 2000 used cork blocks as a facade. Recently, the Portuguese Pavilion in the Expo Shanghai which was entirely covered in cork panels won a design award and also in Architectos Anonimos ‘s Cork House.
Cork insulation

The most common use of cork in the building industry is as insulation material. It can be used both externally and internally.

Characteristics

Advantages:

• sound insulation
• very fast renewable source (bark can be stripped every nine years)
• lightweight
• impermeable to liquids
• elastic
• resilient
• chemically inert
• anti-allergic
• resistant to insects
• Not rotting even if it is wet for a long time
• doesn’t release any toxic off-gassing when it burns
• behaves very well during construction, in good or bad weather
• Any cuts or changes needed during work are easily achieved on site
• if it used as cladding we save money from not rendering

Disadvantages:

• well qualified laborers for strippin (no machinery is available at the moment)
PAPER TUBES

Load bearing element

Paper tubes are hollow cardboard tubes made by recycled paper. The water protection can be done by varnishes and films. As paper is an anisotropic material, the spiral winding process yields a generally anisotropic structure. The specific structural properties of the material depend on the manufacturing process. Different levels of strength and thicknesses are possible according to the requirements.

Paper tube structure can last permanently. As construction material it becomes known through the work of the architect Shigeru Ban.

Shigeru Ban

Shigeru Ban (born 1957) is an accomplished Japanese and international architect, most famous for his innovative work with paper, particularly recycled cardboard paper tubes used to quickly and efficiently house disaster victims.

Paper tubes can be used simple or reinforced as construction column, beam or in sheets.

Table 1
Paper tube ultimate bending stress at 10% moisture content.

<table>
<thead>
<tr>
<th>Paper tube ID</th>
<th>Wall thickness</th>
<th>Ultimate bending stress at 10% MC</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 in. (75 mm)</td>
<td>0.5 in. (12.7 mm)</td>
<td>1922 psi (13.25 MPa)</td>
</tr>
<tr>
<td>4 in. (100 mm)</td>
<td>0.5 in. (12.7 mm)</td>
<td>1727 psi (11.91 MPa)</td>
</tr>
<tr>
<td>6 in. (150 mm)</td>
<td>0.6 in. (15.2 mm)</td>
<td>1579 psi (10.89 MPa)</td>
</tr>
</tbody>
</table>

Table 2
Paper tube Modulus of Elasticity (dynamic testing) [5].

<table>
<thead>
<tr>
<th>Paper tube ID</th>
<th>Wall thickness</th>
<th>Modulus of Elasticity</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.01 in. (76.83 mm)</td>
<td>0.33 in. (8.38 mm)</td>
<td>340,000 psi (2343 MPa)</td>
</tr>
<tr>
<td>5.94 in. (150.88 mm)</td>
<td>0.51 in. (13.00 mm)</td>
<td>600,000 psi (4132 MPa)</td>
</tr>
</tbody>
</table>

Properties according to the thickness of the paper tube at a standard composed material.
Properties according to the thickness of the paper tube at a standard composed material:

**Compression wrinkling**

**Failure of the paper tube in tension**

**Physical test performed to observe bending**

**Arch Geometry**

**Paper tube arch and cross section variables**

<table>
<thead>
<tr>
<th>Paper tube OD</th>
<th>Minimum arch radius</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 in. (76.2 mm)</td>
<td>17.86 ft (5.44 m)</td>
</tr>
<tr>
<td>4 in. (101.6 mm)</td>
<td>23.81 ft (7.26 m)</td>
</tr>
<tr>
<td>5 in. (127.0 mm)</td>
<td>29.76 ft (9.07 m)</td>
</tr>
<tr>
<td>6 in. (152.4 mm)</td>
<td>35.71 ft (10.88 m)</td>
</tr>
<tr>
<td>7 in. (177.8 mm)</td>
<td>41.67 ft (12.70 m)</td>
</tr>
<tr>
<td>8 in. (203.2 mm)</td>
<td>47.62 ft (14.51 m)</td>
</tr>
<tr>
<td>9 in. (228.6 mm)</td>
<td>53.57 ft (16.33 m)</td>
</tr>
<tr>
<td>10 in. (254.0 mm)</td>
<td>59.52 ft (18.14 m)</td>
</tr>
</tbody>
</table>

**Connections**

- Arch-to-arch connection
- Steel connection

**Characteristics**

**Advantages:**
- Very light weight
- No need of expensive foundation (it can be made of like a plastic beer crate, carriage pellet and so on)
- Eliminates the construction period (easy treated structural material)
- Inexpensive
- Made of local materials
- Great stiffness
- High compressive strength
- Flexible
- Very accessible material
- Versatile living conditions
- Contemporary constructions

**Disadvantages:**
- No moisture resistant. As cardboard is a porous material, for specific applications such as those for electrical wiring, layers of non-porous material may need to be added to the interior or exterior of the tube as a barrier against moisture.
PAPERCRETE

Papercrete is a construction material which consists of re-pulped paper fiber with Portland cement or clay and/or other soil added. First patented in 1928, it was revived during the 1980s.

The most common way that papercrete is used is in blocks. Econovate and Green Star Box are the only companies that commercially produce blocks.

Composition

- Cement
- Sand
- Paper
- Additives (for waterproof and fire resistant)

Additives

- Silicone-based formulas (waterproofing)
- Geobond (waterproofing)
- mix of boric acid and borax (fireproofing)
- Colorants (add color)

Using fireproof mortar between the blocks and fireproof stucco on the outside will limit a smouldering fire to the destruction of only one block.

Composition table concrete-papercrete:

<table>
<thead>
<tr>
<th>Uses</th>
<th>Concrete</th>
<th>Papercrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Façade cladding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In-fill wall in conjunction with structural steel beams</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insulation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mortar (interior+exterior)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Comparison table concrete-papercrete:

<table>
<thead>
<tr>
<th></th>
<th>Concrete</th>
<th>Papercrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement [Kg]</td>
<td>10</td>
<td>6,9</td>
</tr>
<tr>
<td>Aggregates [Kg]</td>
<td>19 dry sand</td>
<td>3,9- thin sand</td>
</tr>
<tr>
<td>Paper [Kg]</td>
<td>-</td>
<td>3,15</td>
</tr>
<tr>
<td>Water [lt]</td>
<td>4,5</td>
<td>44</td>
</tr>
<tr>
<td>Total weight [Kg]</td>
<td>65</td>
<td>10,7</td>
</tr>
</tbody>
</table>
Characteristics

Advantages:

• It reduces the cement in the mix (30% cement)
• Reduction CO2 emissions during production
• Low cost
• Lightweight (7 times lighter than concrete)
• Excellent heat properties (high R-value=2-3 R/inch)
• Excellent sound properties
• Flexible material
• Can take several surface textures and colors
• Big variety of shapes and sizes of the material block
• The rough-porous texture provides a very strong bond between the blocks and a potential facade material
• Easy production and method
• Availability

Disadvantages:

• Standard mix has not been established and there is no official data available about the structural behaviour and the long-term viability
• Poor compressive strength (5.5 MPa)
• Long drying period
• Difficulty to standardize the mix and predict its behaviour
• It is a brittle material (It expands and contracts frequently leading to cracks and buckling)
• very low tensile strength
• Deals with the general perception of paper as being a weak material
• Many imperfections that relate with the rarity of the surface
• Chemical additives used for water and fire proof (make the material less green)
PaperStone

PaperStone is a Certified (FSC, Smartwood, Rainforest Alliance) post-consumer, recycled paper architectural surface material. It is primarily used in applications for level surfaces and interior uses though after waterproofing layering it can be used as cladding material.

PaperStone countertops are made from 100% post-consumer recycled paper that is saturated with petroleum free resins containing ingredients like cashew nut shell liquid. The saturated sheets are fused together under heat and pressure, transforming ordinary paper into an extremely strong and durable solid surface material.

### Composition
- Recycled paper
- Petroleum free nut resins
- Natural wax and food grade mineral oil (heat/UV rays/color protection)

### Property

<table>
<thead>
<tr>
<th>Physical Properties</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water absorption</td>
<td>0.82%</td>
<td>by weight</td>
</tr>
<tr>
<td>Density</td>
<td>1.4-1.45%</td>
<td>g/cm³</td>
</tr>
<tr>
<td>Wt / square foot (3/8&quot;)</td>
<td>2.7</td>
<td>lb/sf</td>
</tr>
<tr>
<td>( 1/2&quot;)</td>
<td>3.6</td>
<td>lb/sf</td>
</tr>
<tr>
<td>Mechanical Properties</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal Bond</td>
<td>1,225</td>
<td>psi</td>
</tr>
<tr>
<td>MOR (Flexibility)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Face</td>
<td>24,320</td>
<td>psi</td>
</tr>
<tr>
<td>Edge</td>
<td>21,834</td>
<td>psi</td>
</tr>
<tr>
<td>Modulus of Elasticity</td>
<td>1,723,250</td>
<td>psi</td>
</tr>
<tr>
<td>Compressive Strength</td>
<td>45,324</td>
<td>psi</td>
</tr>
<tr>
<td>Coefficient of Thermal Expansion</td>
<td>3.64</td>
<td></td>
</tr>
<tr>
<td>Izod Impact Strength</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Face</td>
<td>3.29</td>
<td></td>
</tr>
<tr>
<td>Edge</td>
<td>0.73</td>
<td></td>
</tr>
<tr>
<td>Hardness Test</td>
<td>47 ave</td>
<td>Barcon Meter</td>
</tr>
<tr>
<td>Fire Test Results - ASTM E84</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flame spread</td>
<td>(20) Class A rating</td>
<td></td>
</tr>
<tr>
<td>Smoke developed</td>
<td>(110) Class A rating</td>
<td></td>
</tr>
</tbody>
</table>

### Cashew nut shell liquid

The cashew nutshell liquid (CNSL) or cashew shell oil (CAS registry number 8007-24-7) is a natural resin found in the honeycomb structure of the cashew nutshell and is a byproduct of processing cashew nuts. Its composition varies depending on how it is processed. Cold, solvent extracted CNSL is mostly composed of anacardic acids (70%), cardol (18%) and cardanol (5%).

### Characteristics

**Advantages:**
- Strong and durable
- Heat-resistant to 350 degrees
- Resistant to scratches and stains
- VOC free
- Can be fabricated and installed using traditional woodworking tools with high quality carbide-tipped blades
- Emits no radon gases
- Resistant to rain and all climate conditions
- Fire resistant (class ‘A’ fire and smoke rating)

**Disadvantages:**
- Price
- Availability
2.3.4) FARMING

Wool
**WOOL**

Wool insulation is made solely from sheep wool fibres that are either mechanically held together or bonded using between 5% and 15% recycled polyester adhesive to form insulating batts, rolls and ropes.

It can be held into place with staples or it can be friction-fit which involves cutting the insulation slightly bigger than the space it occupies, using friction to hold it in place.

**Characteristics**

**Advantages:**
- Excellent thermal insulation R-value (resistance to heat flow) of approximately 3.5 to 3.8 per inch of material thickness which is 0.3 to 0.6 points higher than some glasswool, cellulose, and some mineral wool.
- Water resistant (it is thought to absorb up to 30% to 40% of its own weight in moisture without becoming wet to the touch)
- Excellent acoustic insulation (When used as acoustic insulation wool provides rates starting at 44 dB for a 60 mm (2.4 in) thick partition, and goes up to 53 dB for a 100 mm (4 in) thickness.)
- Does not allow development of moulds
- Long life span and can be reused
- It has a low manufacturing energy (just over half of that of cellulose insulation and practically one sixth of the manufacturing energy required to produce mineral wool)
- High moisture regulation (Fire resistant Fire specifications complies to European Class E)
- Self extinguished and no dropping fire, no toxic smoke
- Non allergic
- Dermatologically friendly
- High sound absorption coefficient
- Easy to install

**Disadvantages:**
- Wool in comparison with other materials is more expensive
3.2.5) AGRICULTURAL

Hemp

Bamboo

Straw bale
HEMP

Hemp material started used widely after the 1990s. In the building field it is used as sound and thermal insulation. Compared to cotton insulation, hemp produces 200% times the yield of cotton, without the chemicals required by cotton production (Cotton production uses fully half of all the chemicals used in agriculture worldwide). And the short growth cycle, 100-120 days, allows for quick production.

Characteristics

The core hemp bio-fibre can be used as a filler for blending with thermoplastics. It is ideally suited to any application where the hemp bio-fibers are required to provide a combination of filling space and useful mechanical properties. The core hemp bio-fiber can be packages in a range of formats including bulk transport trucks, bulk totes or specialty packages. It can be produced in a variety of sizes with a number of standard materials or custom sizes.

![Thermal insulation in a wall](image1)

![Hemp acoustic ceiling insulation](image2)

![Hemp bundle](image3)

![Hemp stem showing fibers](image4)

Suitable climate zones for hemp cultivation

Depending on the process used to remove the fiber from the stem, the hemp may naturally be creamy white, brown, black or green:

Characteristics

**Advantages:**
- lightweight
- deformation resistance
- lamination ability

**Disadvantages:**
- limited shape and design forming
- off-cuts
- high price compared to mineral fiber insulation materials
Bamboo is a tribe of flowering perennial evergreen plants in the grass family Poaceae, subfamily Bambusoideae, tribe Bambuseae. They are some of the fastest-growing plants in the world, due to a unique rhizome-dependent system. Bamboo grow to their full height in a single growing season of three to four months.

As a construction material it has high strength-to-weight ratio that is useful for structures. It is traditionally associated with the cultures of South Asia, East Asia and the South Pacific.

Examples of bamboo uses:

1. Scaffolding at skyscrapers in Hong Kong

2. Arches

*India pavilion, Expo 2010 in Shanghai*

The world largest bamboo dome (34m diameter). The bamboo beams overlaid with ferro-concrete slab, water proofing copper plate, solar PV panels, a small windmill and live plants. 30 km of bamboo is used in total. The dome is supported on 18m long steel piles and a series of ring beams. The bamboo sections are joined with reinforcement bars and concrete mortar to achieve necessary lengths.
3. Load bearing elements

4. Reinforcement: In brick/adobe constructions

Bamboo applied at brick construction for reinforcement against earthquakes.
Axonometric perspectives of brick/adobe reinforcement:

An intermediate layer of bamboo elements is introduced in between the courses of the brickwork.

The building is reinforced horizontally and vertically. Among the courses there is placed a layer of bamboo bundles.
Reinforcement: In concrete

In contrast with steel, bamboo rods shrinks four times more than cement. In this way the new combination of cement with bamboo can not work together.

To overcome this problem there are many ways:
1. {asphalt + sand} A layer of bamboo rods is covered with a thin protective layer of asphalt. Then there is paced a layer of sand. The structure rest as it is 24 hours. (Asphalt layer: waterproof, sand: better connection with the cement)
2. {asphalt + sand + nails} The same technique as previously. Additionally there are nails placed on the bamboo rods.
3. {asphalt + sand + coconut fiber rope} The rope is used to bind the bamboo rods together.
4. Use only the outer skin of the bamboo. This part of the plant is stronger and it shrinks less due to its content in cellulose.

Reinforcement: In volcanic stone (Pumice-Crete)

There are experiment made at the combination of bamboo with volcanic stone. The outcome seems to have many potentials. There are even thoughts about using this technique to produce prefabricated elements.

Advantages:
- Lightweight
- Extremely high thermal insulation
- Extremely durable

5. Supplemental element

Bamboo is also used for wall filling.

Green Village Bali  North East hut
6. Cladding

*A forest for a moon dazier house, Costa Rica

Office building in France by Monica Donati

7. Entire buildings Example: Green Village, Bali

Characteristics

Advantages:
- One of the fastest growing plants in the world
- Great life span
- High strength-to-weight ratio
- Lower cost comparing to timber structures
- Possibilities to form sheets and planks
- It can be used as concrete reinforcement (after a specific procedure) instead of steel (it produces 50 time less CO2 emissions than steel production and on the other hand the plant is beneficial for the reductions of CO2)
- High tension strength (it can reach the level of 350 MPa)
- Ratio of tension strength/weight is 6 times more than that of steel.
- Lower cost comparing to steel (proper for reinforcement)
- Earthquake resistant structures
- Cyclone resistant structures
- Great variety of sizes
- Variety of compositions and products based on bamboo

Disadvantages:
- It needs protections against rot and insects (needs a mixture of borax and boric acid before use)
- If used as concrete reinforcement as untreated bamboo, it will swell from the absorption of water from the concrete, causing it to crack.
- The life expectancy of the material depends on the quality of the plant and the maintenance process.
- Not all the plants of the bamboo family trees are proper for the building fields.
- Difficulty in the quality control.
STRAW BALE

Wall thickness: approximately 60 cm
Organic forms

Straw is used in the building construction as structural element, insulation or both.
It is an agricultural by-product that, as the diagram at the right shows, it can be made up of many cereal crop. The dry stalks of cereal plants, after the grain and chaff have been removed.
In the constructions they are used even in bale form or just as bundles. Straw bales differs according to their density and humidity level.

Consistency:

Straw bales are produced from the stalks or byproducts of the harvesting process. It is used as construction materials since centuries in all over the world. Straw-bale construction was greatly facilitated by the mechanical hay baler, which was invented in the 1850s and was widespread by the 1890s.
There are two types of straw bales:

- Field bales (support around 600 pounds per linear foot of wall)
- higher-density "precompressed" bales or "straw-blocks" (bear up to 4,000 lb./lin.ft. and more)

Construction:

Straw bale building typically consists of stacking rows of bales (often in running-bond) on a raised footing or foundation, with a moisture barrier or capillary break between the bales and their supporting platform. Bale walls can be tied together with pins of bamboo, rebar, or wood (internal to the bales or on their faces), or with surface wire meshes, and then stuccoed or plastered.
Very vital for the straw bale construction is being waterproofed.

Water can enter the construction via four different paths:
1. From interior leaking via condensation (Relative humidity)
2. From ground via capillary action and vapor diffusion
3. During construction and
4. Through the exterior façade

There are three most popular straw bale construction techniques. the "post and beam", the "Nebraska-style" and the "Spar and Membrane Structure" technique.
In all cases, straw bales are stacked on a foundation to prevent damage from the seepage of water. They are usually held together with rebar pins that skewer the bales.
Construction technique 1: “Post and beam”

In this technique there is a framework of timber supports the building’s roof, and straw bales are used as filling. Straw bales are stacked between the weight-bearing timbers to make up the insulated wall.

This method most often is required in northern countries (the potential snow-loading can exceed the strength of the bale walls) and/or in wet climates (need to apply a vapor-permeable finish = no cement).

Characteristics

Advantages:
• Adequate earthquake resistant
• The wall can last large openings

Disadvantages:
• Higher cost comparing to the “Nebraska-style” technique

Construction technique 2: “Load-bearing” or “Nebraska-style”

The style is originated in that state around the 1880s, following the invention of the steam-powered baler. Some homes from that period still remain of use after more than a century.

Here the bales themselves are stacked directly together - much like bricks are used - to support the weight of the building and roof. No timbering is needed.
Construction technique 3: "Spar and Membrane Structure" (SMS)

Here, lightly reinforced [5 cm - 8 cm] gunite (Shotcrete) skins are interconnected with extended “X” shaped light rebar in the head joints of the bales. In this wall system there is a concrete skins that provide structure, seismic reinforcing, and fireproofing, while the bales are used as in-fill material and insulation.

The “Spar and Membrane System” is so called because the key structural elements are the spars which penetrate the straw bales and connect the concrete membranes that form the inner and outer wall surfaces.

- Once the bales have been stacked in a running bond with a gap at each head, the spars are placed in the gaps.
- Next, vertical rebars are attached to the spars.
- Then welded wire fabric is tied to the vertical steel. Light gauge fabric is used for nonstructural walls.
- Heavy gage mesh is placed to structural walls to provide better shear resistance.
- Gunite is shot to create the membranes (inner and outer wall)

Characteristics

Advantages:
- Low cost (no additional support is needed)
- No need for wooden frames

Disadvantages:
- Can not support the loads of big buildings
Characteristics

Advantages:
• Fire resistant (The SMS attains a minimum 4-1/2 hour rating, it exceed the fire rating of standard residential construction by 500%.
• Large magnitude earthquake resistant (30 times stronger than a solid 6 inch concrete wall in the out-of-plane direction providing unprecedented seismic performance.)
• Almost no maintenance
• The wall can last large openings

Disadvantages:
• Higher cost comparing to the other straw bale techniques
• Higher environmental impact. It is not that “green” building solution (due to the use of concrete)
• It requires trained laborers

Comparison of the three construction techniques.

Cost relation

Environmental impact relation

Construction difficulty relation
Straw bale constructions can be plastered either with a cement-based mix, lime-based formulation, or earth/clay render.

Types

- Cement based
- Lime based
- Earth-Clay render

Characteristics

Advantages:
- Highly insulated walls (sound and heat) (R-values of around 29-33 depending on thickness)
- Low building and maintenance costs
- Water repellent
- Extremely fire resistant
- Pest free
- Simple construction techniques
- Easy availability of construction material

Disadvantages:
- Susceptibility to rot
- High space requirements (thick walls)
3.2.6) MATTRESS MATERIALS

The following materials are used in the mattress industry but they have interesting properties that may also be useful in the building industry. Some of them are already used in the architectural envelope.

Coconut fiber
natural rubber
Horse hair
Seaweeds
Cactus
Cotton
Linen
Goose down
COCONUT FIBER

Coconut material is best known for its natural ability to breathe. Coconut fibers (or, coco-fibers, as we like to call them) are collected from the shell of the coconut.

In mattresses production, before using them, coco-fibers are sprayed with natural rubber to add firmness and elasticity. Then the rubberized coco-fibers are turned into layers.

NATURAL RUBBER

Natural rubber, before being processed into a more stable form, occurs as a milky juice extracted from the caoutchouc tree growing in tropical climates. It is pure and elastic. Once this natural caoutchouc stabilised into rubber, Natural rubber breathes perfectly and has a long lifespan.

HORSEHAIR

Horsehair thanks to its ability to regulate humidity is able to create a very dry environment. This material was also used in the building industry as reinforcement for plasters and finishings.

In mattresses production, the horsehair material comes from the mane and the tail of horses and after having undergone sterilisation is processed into thin layers, which are sprayed with natural rubber for greater elasticity.

SEaweeds

Seaweed contains iodine, which provides a natural shield against allergies, asthma and respiratory problems. In mattresses production it is used because of these properties.

However, it is also used in building construction. Seaweed house is special tradition at Jiaodong Peninsula, it has good ecological characteristics. This has much to do with the properties of the roof materials and the way of roofing construction. Due to its antibacterial substances that it contains it can protect straw (if in the construction) slowing down the decomposition process.

CACTUS

Cactus, a plant which evolved 35 million years ago and has remained untouched by humans ever since, is collected and manufactured into 3 cm thick layers of cactus-fibre. As a material it is highly durable, strong and humidity-absorbent.
COTTON

Cotton is one of the oldest materials used in fabric production. It is softness, absorbency and strength, paired with lightness and hypoallergenic properties. In the building sector it can be used as insulation material.

LINEN

Linen comes from the flax plant, Linum usitatissimum, and is one of the oldest textiles known to man. It is a very resilient and strong fabric and is valued for its exceptional coolness and freshness in hot weather. It is used to produce fibers.

GOOSE DOWN

Goose feathers are very well known for their thermal properties. As a material it is very lightweight and deliciously soft, thanks to its inherent ability to breathe.
3.2.7) NEW TECHNOLOGIES - COMPOSITES

- Ingeo – corn fibre
- Canatex
- Pine Sap
- Mushroom material
- Zelfo
- BatiPlum feathers
- Nettle textile
- Moniflex
**INGEO – CORN FIBRE**

Proposed use: Interior coating

This material is a fibre made material from petroleum-alternative PLA (polylactate) residues (straw, cornstalk) combines the properties of natural and synthetic fibres.

**Characteristics:**

- Strength and resilience
- Soft texture
- Reacts well with humidity
- Flame and stain resistant.

Available in woven and non woven version
Now it is used in fashion and furniture industry among others.

---

**CANATEX**

Proposed use: Interior - exterior coating

This material is a fibre made material from petroleum-alternative PLA (polylactate) residues (straw, cornstalk) combines the properties of natural and synthetic fibres.

**Characteristics:**

- Rough surface
- Flexible
- Lightweight
- Durable

Used as architectural textile. Applications include outdoor furniture.

---

**PINE SAP**

Proposed use: Sealing material

It is an altered chemically to become biodegradable versions of common plastics. The material is still in its research phase.

According to researches, molecules derived from trees are good sources of cycloaliphatic and aromatic structures which are good for polymerization. With rigid molecular structures and a dislike for water, they could become very good candidates for a whole host of new plastics. Coming from biological sources, they are also able to be recognized and broken down by microbes at the end of their life cycle.
MUSHROOM PACKAGING MATERIAL

Proposed use: Insulation material

The material is made from agricultural crop waste bonded together with mushroom “roots” (called mycelium).

According to the blend of packaging parts, based on what feedstocks is used, and how are grown and processed the parts of the material, a wide range of densities and material properties are possible

Characteristics:

• Renewable
• Soft texture
• Reacts well with humidity
• Possibilities to add characteristics and properties
• Home compostable.
•
It is used as packaging material

Example: packaging material used as building insulation material
Project: Naked House, by Shigeru Ban

The architect used extruded, white polyethylene fibers, that was placed in plastic membranes and used as insulation in his project. The outcome is a translucent wall.

Normally, extruded, white polyethylene fibers are used as a fruit packaging material.

ZELFO

Proposed use: Interior coating, Load bearing structure

It is made from cellulose derived from wood, hemp, bamboo, jute and so forth. There are added natural pigments.

It is used to makes all kind of objects that are made from conventional wood.

Characteristics:

• Durable
• Waterproofed
• Produced in many different types, colors and shapes
**BATIPLUM FEATHERS**

Proposed use: Insulation material

Composition: 70% feathers + 10% wool + 20% textile fibre

**Characteristics:**
- good thermal acoustics and hydrothermal insulation (meets the HQE requirements)
- High capacity of retaining air
- High capacity of regulating moisture
- Constant volume (it can absorb up to 70% of its weight in water without losing the insulation properties.

Used in building industry in roofs, walls and floors.

Thickness 10 – 100 mm


**NETTLE TEXTIL**

Proposed use: Insulation material

**Characteristics:**
- thermal properties: The long hollow fibres of the nettle trap air, thus contributing to a product that provides thermal insulation. This natural form of insulation can be regulated by twisting the fibres, limiting their capacity to entrap air which results to a cooler fabric for summertime use.

Nettle belong to a hardy plant family that can grow on nitrogenized and fertilized-saturated soils. There is no need for pesticides as insects tend to steer clear.

Used in clothing.


**MONIFLEX**

Proposed use: Insulation material

For more than 70 years this material, which is made from cellulose (vegetable product used in the manufacture of paper and textiles), has been uses as insulation in railway coaches.

It is produced by gluing together, transparent corrugated sheets of cellulose, with air trapped between them.

**Characteristics:**
- Good thermal and sound insulation
- Highly resistant to UV light
- Highly resistant to humidity
- Lightweight
- Nontoxic
- Durable
- Fibre-free

Maximum dimensions: 935-3000mm.
The thickness varies according to the number of layers.
In order to come up to conclusions about the weaknesses of the bio-degradable materials, understand how can I work with these materials, the construction process in practice, legacy problems and costs I decided to come in contact with constructors, architects, engineers and people working with bureaucracy to gain some knowledge from their experience. The strategy followed at the interviews can be separated in two groups.

**Group 1:** The goal of the interviews was to gain a general overview on the materials, their properties, weaknesses, problems and legacy limits. This set of interviews in combination with the theoretical analysis above and my personal taste as an architect lead me to make a choice of a material to work on the design step.

**Group 2:** These interviews has been carried out after the choice of the material. They are oriented on the selected materials and the goal is to gain knowledge about the construction method and limits, maintenance treatment, detailing, structural limitations according to rules and legacy and construction costs.

Here are presented the methodology and the conclusions. The whole questionnaire and the total amount of interviews are presented at the appendix.
INTERVIEWS GROUP 1
(GENERAL OVERVIEW INTERVIEWS):

INTERVIEWEES:
1. Benjamin Garcia Saxe: architect-constructor, Costa Rica
2. Steffen Nijhuis: Assistant Professor of Landscape Architecture at the Faculty of Architecture, Delft University of Technology, NL
3. Konstantinos Kontomanos: volunteer constructor at COB team, working with cob, adobe, straw bale, earthen bags, rammed earth, earthen constructions, clay mixed with straw, GR
4. Ramon Knoester: Principal architect at WHIM architecture, Rotterdam, NL
5. George Ritsakis: Owner, Built the house himself, working with straw, wood, adobe, Crete, GR
6. Fedde A. Zandstra: Director Stichting Bouwkwaliteit (SBK), NL
7. Bob Urzem: scientific director at TU Delft, Biotechnologist, NL
8. Defit Wijaya: architect and constructor, Bali

4.1) METHODOLOGY

The goal of this group of questionnaires is to understand further the properties and building construction with natural materials, understand their limitations, be alert of problems and drawbacks of their use, gain an overview estimation on techniques that in the future may lead to rethinking of the techniques used.

This first group of questions aimed to give an answer to the main sub-questions mentioned at the “research question” paragraph which are:
- Why biodegradable materials are not used that much though they are known from the ancient times?
- What happened in between?
- Considering the needs of the contemporary user are these materials still adequate?
- How are they used now?
- What are the techniques?
- What are the benefits of using biodegradable materials at the building industry?
- Are there tremendous difference on the properties and the construction techniques compared to the standard materials?
- Are the designers, the constructors, the workforce and all the members of the façade industry aware of how to build with biodegradable materials?

The interviewers are separated in two categories:
- Category a: architects, researchers and professional that are occupied with design in a theoretical base or are occupied with norms and legacy issues.
- Category b: architects, engineers and constructors that have experience in working and building with biodegradable materials.

Schematic form of questionnaires:

Personal questions about the background of the interviewer
How exactly he has been involved with designing/working with biodegradable materials
What was his motivation
Weather it was his idea or it was requested by clients/competitions
What was the reaction of the clients/public on using natural materials
What difficulties did he face in finding information
What limitations did he find in terms of legacy and norms
What does he think should be changed if the project/survey is going to be materialized in the real world
What does he think would be the benefits of this proposal/design/survey on biodegradable materials
Personal questions about the background of the interviewer
- How exactly he has been involved with designing/working with biodegradable materials
- What was his motivation
- Whether it was his idea or it was requested by clients
- What was the reaction of the clients on using natural materials
- What difficulties did he face in the design with biodegradable materials
- What limitations did he find in terms of legacy, norms, information
- Weather he find problems in finding and ordering this materials
- What changes did he do at the design while constructing
- What changes will he make at potential future designs with natural materials according to the experience he gained
- What problems did he face during his collaboration with builders, engineers and generally people that worked for this project
- Weather he is satisfied with the outcome and the final building
- Weather there are problems since now at the building
- What maintenance measures should the owner of the building take
- What approximately was the cost in comparison with the same project been realized by standard materials.

Questions for interviewers from category b

4.2) CONCLUSION OF THE RESEARCH

Below I am presented the analysis outcome in the form of “answer” at the research question and sub questions.

**Why, the natural materials, are not used in a great extend in the buildings and the building envelope anymore?**

The application of biodegradable materials in the building constructions is nothing new. However there was a turn to concrete and brick constructions that lead their use to marginalization.

The industrial revolution, the new technologies (In 1824, Joseph Aspdin invented Portland Cement, in 1849 Joseph Monier invented the reinforced concrete), the rapid population increase and the great need of shelters make the concrete and brick constructions the most popular since the mid 18-century. The idea of prefabrication, the number of construction and structural possibilities, the great number of scientific researches and the designers and engineers that were willing to test and work with these materials made them even more popular.

We could say that there was not only the needs of the time that lead to the use of concrete and brick but the story also goes the other way round. Due to the properties and the possibilities of these materials the structure of the society, especially for the developed countries changed. The new everyday life of the citizens changed. High-rise buildings and huge building blocks took their place in the city. The norms for building permits changed, the standards of building interior quality are higher, the design process and the architectural qualities changed, the structural properties and most of all the people emotional connection with the nature and its products changed dramatically.

On the other hand, the knowledge of working with the natural materials was stable. Even today, the techniques that are used are more or less the same as from the ancient times. The construction process is still weather dependent, the society, that was altered and grown with the great possibilities of the concrete hesitate to collaborate again with natural materials and the emotional connection of the mass public with the industrialized products put the use of natural construction materials to the side.

Until now, the main force that lead some researchers and architects to take a look back, at the prime natural material is the environmental situation. The alarming problem of pollution and the fact that some raw material sources are coming to an end. However, there could be more than that. As, the need of mass production of buildings around the mid-18th century leads to great investments, accordingly, the environmental situation can make us rethink of the traditional materials, reinvest them and time test them under the prism of create a healthier and more natural building environment.
The abundance of natural solutions and the use of concrete and brick materials in the building envelope in this great extend is the outcome of the combination of the industrialized materials’ advantages and the drawbacks of the natural materials and techniques. Below, there is a summary of these reasons:

<table>
<thead>
<tr>
<th>Concrete – Brick advantages</th>
<th>Natural construction materials and techniques drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Adequate structural properties</td>
<td>• Weather dependent construction process</td>
</tr>
<tr>
<td>• Flexible constructions (both in shape, construction techniques and in properties. More or thicker layers can be added in the architectural envelope, additives can be added at the material itself in order to change its composition and properties, additional reinforcement can be placed in the construction or different technique can be used according to the needs)</td>
<td>• Time consuming construction process (also due to the weather conditions)</td>
</tr>
<tr>
<td>• Standardized design process</td>
<td>• Old fashion techniques</td>
</tr>
<tr>
<td>• Famous architects have been worked and researched on these materials offering a great variety of inspirational architectural solutions.</td>
<td>• Empirical construction techniques</td>
</tr>
<tr>
<td>• Standardized construction process</td>
<td>• Not standardized mixtures and material composition</td>
</tr>
<tr>
<td>• Emotionally Reliable constructions (prediction of the final outcome)</td>
<td>• No possibility for quality control</td>
</tr>
<tr>
<td>• Long history in use</td>
<td>• Emotionally unreliable constructions</td>
</tr>
<tr>
<td>• Many researches and tests have been done for these materials</td>
<td>• Emotionally related with uncomfortable interior climate</td>
</tr>
<tr>
<td>• Their use is incorporated with the “Modern” constructions</td>
<td>• Availability (depends on the location of the site)</td>
</tr>
<tr>
<td>• Availability</td>
<td>• Legislation difficulties (building permit is difficult in some cases)</td>
</tr>
<tr>
<td>• Mass production</td>
<td>• Old fashion architectural appearance</td>
</tr>
<tr>
<td>• ability to manufacture pre-cast forms</td>
<td>• Limited structural properties (though adequate for low-rise buildings)</td>
</tr>
<tr>
<td>• Short construction time (if used prefabricated elements)</td>
<td>• Materials that are not in use for a long time</td>
</tr>
<tr>
<td>• Big life expectancy of the wall</td>
<td>• Maintenance requirements</td>
</tr>
<tr>
<td>• It can increase the thermal mass of the building</td>
<td>• Weather dependent construction (and thus we need maintenance)</td>
</tr>
<tr>
<td>• Quality control</td>
<td>• Lack of knowledge</td>
</tr>
<tr>
<td>• Good fire protection and acoustic insulation</td>
<td></td>
</tr>
<tr>
<td>• No maintenance of the constructed building</td>
<td></td>
</tr>
</tbody>
</table>
5_Design

All the above mentioned natural materials have the properties in order to construct comfortable building shelters. In this step I am going to focus in one material. The final outcome of this design process will be a group of wall designs and sections that have taken into account the properties and the weaknesses of the material and the weather conditions of the Netherlands and the. The material is going to be applied in smaller or larger extend in the solid building envelope.

In order to have comparable results and existing design situations I decided to make the application of the chosen natural materials on an existing well known and important building example of the contemporary Dutch architecture.
5.1) METHODOLOGY

At the first step, the existing building on which I am going to apply the natural material is selected. The choice of this study case will at the same time place some limitations on the choice of the biodegradable material. Then there comes the choice of the natural material. In order to obtain that, at this point is clarified the limitations of the design goal and the reasons of the final material choice. Finally, there is the design step. The methodology followed at the design step is analysed further below.

Schematically, the steps followed at this chapter is described at the following diagram:

![Design methodology diagram](image)

5.2) Case study: Hageneiland Housing, Ypenburg

The selected housing type is the Hageneiland Housing in Ypenburg of MVRDV. The project contains 119 privately owned and rented dwellings. This project has been selected for the following reasons:

- It is a representative design of contemporary Dutch architecture (MVRDV won the 2002 NAI Prize-The prize salutes the best buildings by Dutch architects who are younger than 40)
- The building unit has classical characteristics of the Dutch dwelling.
- The form of the building unit is pure and simple. There are highly archetypical houses that differ from each other only in their cladding materials (wood shingle, corrugated fibre cement boards, aluminium sheets, blue and green polyurethane panels and clay roof tiles).
- Each building has been designed by taking into account a more general urban plan (village like plan for the whole area), which is important, as the general goal is to apply biodegradable materials in the solid building envelops in the Netherlands in as big extend as possible. This will also influence the appearance of the building environment in the urban scale.

The wall system is post and beam load bearing structure with different cladding materials. The wall are lightweight and the corners are in some cases prefabricated (building covered with roof tile cladding). The windows and doors are pre-fabricated and are placed as boxes in the solid wall during the construction. Mineral wool is used as insulation materials. In every case there is a cavity behind the cladding systems (detail according to the SBR standards).

Some complains exist on the cleaning process of the claddings and the material behaviour to that (production of noise, green colour on the roof tiles, etc.). However the wall is lightweight and the construction process seem to be based in minimizing the construction time.
5.3) BIODEGRADABLE MATERIAL CHOICE

5.3.1) Rammed Earth

The target of this design project will be to produce design solutions for minimum 80% biodegradable walls and to make these solutions applicable for a project of 10,000 houses. This two criteria will on the one hand eliminate my choices and on the other hand produce a design project with remarkable environmental benefits.

All the above mentioned natural materials can produce biodegradable wall systems. Thus the criteria according to which I am going to select the natural material for this project is the availability. Below is the availability overview of the 5 main biodegradable materials that have been analyzed: Earth: The earthen materials are generally between the most approachable materials. What is more, in general they have no other use.
Forestry: Bamboo and cork are in tropical trees. Their cultivation here is possible but that will demand changes in the production plants. What is more, this change of the physical environment of the plant may influence the final qualities, properties and rate of growth of the plant. Wood, is available in grate extend, but for the existing situation it is not my priority to use this very well-known material apart from load bearing and supporting proposes. The rest are in limited quantities and are possible to be used for thermal insulation and supporting proposes.

Agriculture: wool is already used in great extend as a clothing material. Apart from that all the materials are not produced in that great extend in order to cover the needs of a whole building as the main material. The materials described here are in general used as reinforcement additives. Agriculture: the materials that belong to this category, are used for many uses. As food raw material, as mattress material, biofuel and many more. The use of them as a main material in the building wall could be considered as a storing use during the life span of the building envelope. Though, as I have a better option, this of the earth materials as a main building material, I will keep the use of agriculture material in limited extend.

Composites, New Technologies: In this material there are new ideas, freshly developed or still not produced yet. Some of them seems to have very interesting properties and be very promising but they are not available in considerable amounts or they are not available at all.

According to the above, earthen materials are chosen as the main building material. As these materials have very low R-values, the insulation properties needed will be given to the wall by using materials with high R-values. According to the previous analysis there is the following table presenting the R-values of the insulation materials:

<table>
<thead>
<tr>
<th>Name</th>
<th>R-value/inch</th>
<th>Common width (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>3.14</td>
<td>14</td>
</tr>
<tr>
<td>Natural</td>
<td>2.68</td>
<td>16,4</td>
</tr>
<tr>
<td>Cork</td>
<td>3</td>
<td>14,7</td>
</tr>
<tr>
<td>Papercrete</td>
<td>2</td>
<td>22</td>
</tr>
<tr>
<td>Wool</td>
<td>4.2</td>
<td>10,5</td>
</tr>
<tr>
<td>Hemp</td>
<td>3.5</td>
<td>12,6</td>
</tr>
<tr>
<td>Goose down</td>
<td>4.4</td>
<td>10</td>
</tr>
<tr>
<td>Cotton</td>
<td>3.4</td>
<td>13</td>
</tr>
<tr>
<td>Engineered bamboo</td>
<td>0.96</td>
<td>45,8</td>
</tr>
<tr>
<td>Sawdust</td>
<td>2-2.5</td>
<td>22</td>
</tr>
</tbody>
</table>

Each earthen material has the potentials to construct an adequate wall building shelter in a moderate maritime climate such as that of the Netherlands. In the existing graduation thesis I am going to narrow the scope to a more specific focus and realizable goal. After reading, researching and taking interviews about these techniques, I will focus at one existing wall technique and I will try to improve it by also taking into account the knowledge and the benefits of the rest. The technique of focus is rammed earth. It is chosen for the following reasons:

- It is a very clean process. Unlike the majority of the rest techniques where the main work is being done by hands, the construction process of rammed earth reminds that of concrete.
- It produces sharp wall shapes. The appearance is similar to the uncoated concrete wall, achieving the aesthetic values of the pure volumes of the Modern Movement, due to the use of formworks during the construction which offers precision. It is as resilient as concrete. Coloured iron oxides can be added at the mixture for color variations.
- It has considerably smaller thicknesses than the rest techniques. In comparison to the rest earth wall techniques which produce wall thicknesses of approximately 60 cm, rammed earth walls are 30-45 cm thick depending on the chosen construction (with or without additional thermal insulation board).

The thicknesses have been calculated by taking into account the given width used of mineral wool according to the SBR details. What is more there is not taken into account the rammed earth wood. In general the aggregate materials have a very low R-value but high thermal mass. However, if there are applied in a considerable big width they can provide some insulation which will influence the width of the additional insulation.
It is not so labour intensive and time consuming process comparing to the construction methods of the rest earthen materials.

**BENEFITS OF THE NEW HOUSES**

The new buildings have some benefits only because of the material choice.

- Balanced air humidity: earth walls absorb the humidity inside the house and maintain an almost constant air humidity of 40-60% for an entire year.
- Obtain high thermal mass: compared to other insulating materials, earth can store the heat captured during the day and release it in the house during the night after eight hours.
- Smaller environmental footprint: it consumes less energy compared to other industrialized building materials. For example, stabilized earth’s embodied energy is of 0.7 MJ/kg and cement’s embodied energy is of 5.6 MJ/kg.
- Easy material supply. It is a material (actually mixture of materials) that exist in great availability. They are almost anywhere in the world.
- The constructed wall achieve very good fire resistance.

5.3.2) Rammed Earth Composition

During the last 25 years there is the comeback of this material. The new technologies and the possibility of new additives have influenced the composition and the construction technique of the material. Rammed earth can work well in hot climates and with proper design it can also work well in wet and cold climates. The most common composition of rammed is 30% clay, 70% sand, 8% cement and 10% water. This composition is similar with that of concrete (approximately; cement 15%, crushed stones 55%, sand 26% and water 4%). Clay, should not exceed this percentage as it will cause cracks at the wall. Surface soil should not be used as they contain organic materials and that reduce the quality of the wall. Silt, which is usually found mixed with the sand should not exceed one third because silt is vulnerable to erosion from wind and rain.

The common additive in the two mixtures, cement, is that which cause the biggest environmental drawback of the concrete. Of course other chemical additives make the situation even worse.

The problem with the rammed earth mixture is that the existence of the cement prevents biodegradation. Thus I will replace cement with other material that could add strength and water resistance and thus can replace cement. What is more, the rammed earth mixture needs greater accuracy comparing to other earthen wall techniques (cob, earthbags, mud bricks, etc.)

There are numerous examples from the past where building structures last until our days. The most ancient one is the Great Wall of China. Traditionally, rammed earth was a mixture of mud, chalk, lime, gravel and water. So I am going to work with a mixture that contains lime instead of cement as a stabilizer. When lime is used instead of cement the amount used should be more (approximately the double).

5.3.3) Mechanical Properties

**Compressive strength**

In general, rammed earth has a relatively good strength in compression but it does not perform well in tension and has poor shear strength especially when moist. The strength of the rammed earth wall reaches its maximum very slowly. That may happen even after 2 years of the construction day of the wall (quite long comparing to concrete which reaches its maximum after 28 days).

The compressive strength is less than that of concrete but more than strong enough for use in domestic buildings. Similar to concrete, the compressive strength of rammed earth is influenced by the quality of gravels, soil and the rest additives and the amount of moisture in the mixture. What is more, the construction technique is an important factor that determines the durability. The mechanical strength is very much related to the void ration of the soil after ramming and the density of the soil. In general earths rammed by pneumatic rammers are more dense and thus more durable than these soils rammed with non-mechanical ways  .
earth is used as a structural element I will estimate the compressive strength of the mixture. As the structural behaviour of rammed earth is similar to that of concrete (good strength in compression but it does not perform well in tension and has poor shear strength) I will compare the compressive strength of the two mixtures (rammed earth and concrete). As the length of the wall is determined from the project (21.4 m) the comparison could lead me to the width. The mistake at this method will be the different safety factors that we should take into account at the concrete and rammed earth constructions.

Another method could be to use the “Lehmbau Regeln” standards. These are the German standards for earthen materials. These are also used here in the Netherlands, as there exist no Dutch standards. According to these codes for rammed earth that deem a compressive strength of between 1.5N/mm² to 3.0N/mm² for walls of height 3 to 6 m at a minimum age of 7 days to satisfy.

**Compressive strength of rammed earth: for a common natural rammed earth sample (33% clay, 67% sand) the results are 2.1 N/mm². The results become better if we add cement in the mixture.**

<table>
<thead>
<tr>
<th>No.</th>
<th>Name of the sample</th>
<th>Dimensions (mm)</th>
<th>Force applied (kN)</th>
<th>Compressive strength (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Natural earth cube</td>
<td>0.1×0.1×0.1</td>
<td>45.5</td>
<td>2.122</td>
</tr>
<tr>
<td>2</td>
<td>Earth and 25% sand</td>
<td>0.1×0.1×0.1</td>
<td>30.9</td>
<td>1.370</td>
</tr>
<tr>
<td>3</td>
<td>Earth, 50% sand and 5% Portland cement cube</td>
<td>0.1×0.1×0.1</td>
<td>55.1</td>
<td>2.449</td>
</tr>
<tr>
<td>4</td>
<td>Earth, 70% sand and 8% Portland cement cube</td>
<td>0.1×0.1×0.1</td>
<td>42.2</td>
<td>1.870</td>
</tr>
</tbody>
</table>

**Earth Recipes**

Comparative performance of some common rammed earth stabilizing agents (Guettala, 2006)

The compressive strength of rammed earth that has been stabilized with cement or lime can be up to 4.3MPa (620psi). Compressive strength of 10MPa and more can be achieved by adding additional binder (cement or lime) as per engineer specification. It is still lower comparing to the 10MPa to 40 MPa compression strength reachable by concrete. However there are examples of 8th century rammed earth building still standing today with a compression strength of only 1MPa (Gonzalez, 1999).

In general, buildings of more than two stories with rammed earth needs massively thick walls. I problematic point is that rather than in block and mortar constructions where there is a warning of failure with tensile cracking between brick and mortar, in rammed earth constructions the failure is not easily forecast.

**REINFORCEMENT**

Reinforcement is not always necessary. Though it is obligatory in locations that face hurricanes or earthquakes. There are three possible materials for reinforcement. Re-bars, bamboo or wood. For fear of erosion re-bars should be avoided. According to the other two solutions there are questions about the shrinkage ratio and the collaboration of the mixture with this materials. As the shrinkage of the rammed earth is very much dependent on clay present (type, amount), soil grading and moisture content they should be calculated considering the shrinkage behaviour of the reinforcement.
Here it is important to think about the collaboration of the reinforcement with the rammed earth mixture. The relevance of the reinforcement is relevant to:

- The strength of the rammed earth mixture (higher compressive strength means better collaboration with the reinforcement)
- The location and the inclination of the reinforcement in the wall
- The surface of the reinforcement (the more smooth the less collaborative)

RAINFALL EROSION

Rainfall erosion is one vital parameter for the durability of the rammed earth wall especially here in the Netherlands. The building element erosion is complicated as it is correlated with various parameters such as the exposure of the wall in rainfall, the shelter (roof design) and the maintenance. In general it is very important the foundation design and the roof design.

In the most cases there is not any extra coating on the wall as a weather protection in order to let the wall construction and colours to be obvious. As plasters there are often used plaster, bitumen or linseed oil.

Foundation design: the roof must protrude from the wall in order to protect it from the rainfall.

Foundation design: the rammed earth wall must have a distance from the ground.

RAINFALL EROSION

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Foundation design: the roof must protrude from the wall in order to protect it from the rainfall.

Foundation design: the rammed earth wall must have a distance from the ground.

Foundation: The foundation are either the same as that of the concrete wall construction or the rammed earth wall is placed over stone construction. In between a waterproof layer is applied to protect the construction from the water occurred due to capillarity.

HEAT CAPACITY

Rammed earth as a dense material has poor insulated properties. Thus, especially for the northern countries the use of additional insulation at the exterior walls is in many cases used. The heat conduction coefficient of a rammed earth is $\lambda=1.51$ W/mK. This means that the wall traps solar heat during the day and releases it inside the house at night. The value is smaller than the heat conduction coefficient of concrete ($\lambda=2$ W/mK)

$$R = \frac{1}{\lambda} \cdot d$$

That means that for a specific wall thickness $R_{\text{rammed earth}} > R_{\text{concrete}}$

The total thermal performance of the wall will be determined after calculating the wall thickness by taking into account the compressive strength. If the wall thickness is bigger in the case of rammed earth than that of concrete then it is possible rammed earth to have a better thermal insulation value.

RAMMED EARTH APPEARANCE

The shape of the rammed earth wall is sharp. The appearance is similar to the uncoated concrete wall, achieving the aesthetic values of the pure volumes of the Modern Movement, due to the use of formworks during the construction which offers precision. It is as resilient as concrete, rammed earth wall has obvious lines because of the rammed process during construction. Coloured iron oxides can be added at the mixture for colour variations. It is also possible to have obvious colour variation among each horizontal layer on the wall.

Below there is a comparison between concrete and rammed earth walls in order to clarify better the differences.
Obvious colour variations at the same height. In the rammed earth case, the colour variations is at the vertical direction.

In the rammed earth wall the holes produced during construction become smaller or even disappear some days later as the wall have a tendency to lose some cm of its height until it reaches its final strenght. That may be done even 2 years after the day of the construction.

Both concrete and rammed earth mixture, as very resilient materials take the shape of the mould. However concrete, due to its greater consistency in water, can illustrate more accurately the texture of the mould.

5.3.4) Methodology of the design

Study case: The Hageneiland Housing, Ypenburg

The contours of these houses are similar - the traditional shape of a two-storey house with saddle roof. Only length and breadth varies. The shell is formed as a timber-frame structure covered with multiple types of cladding (roof tiles, aluminum sheet, wooden boards, fiber-cement panels). Thus the exterior wall section belongs to the B1 type. It is a lightweight construction that can not be compared with a rammed earth construction. The project has been taken as example for its architectural qualities. The main question is how would this project look like if it had been designed with rammed earth exterior wall system.

The redesign is going to be done in three sequential steps. At the first step rammed earth is going to used only as cladding. At the second steps the materials will carry the loads of the structure and at the third steps rammed earth is going to be used in order to form as many parts of the construction are possible. These solutions are going to change the logic of the construction detail. Thus instead of the B1 SBR type that is used now at the project the wall section is going to form other types of the SBR detail standards.
5.3.5) The building

As a reference building it is taken the building No 89. According to autopsy, the width of the building volume is 10m and the length 21.4m. There are 2 sizes of openings. Their dimensions are: 1.80X2.30m and 1X2.30m. The apartment unit is multiplied in order to produce the building volumes.

The choice was random as it only serves to have some existing measurements of the structure. Below there are the general dimensions of the volume and the front and side façade.
5.3.6) Redesign parameters

After internet searching, interviews and reading I come up to some basic characteristics of the material that form the general frame according to which I designed the for critical parts of the wall section. These parts are:

- The foundation
- The main body
- The window connection
- The roof connection

**BASIC CHARACTERISTICS:**

- In general the material, as all biodegradables, are extremely sensitive to water. As the demand is to produce at the end biodegradable walls, I had to deal/face/accept this problem and avoid using as much as possible chemicals and synthetic additives.
- It is a breathing façade. That could be a useful tool against moisture
- The critical parts of the design and construction are the roof connection and the foundation. These parts are the most easy water permeable.
- It has many common characteristics with concrete but it is not. That means, it has different construction logic and method (and actually more labourer intensive), lower compressive strength and durability, different behaviour to water and different texture.
The new rammed earth construction.

The decision about the load bearing elements has been made considering the dimensions and the shape of the building unit. According to this the interior walls – which are at the same time protected from the rain - and the small exterior ones are going to bear the loads.

Designing the critical points

Foundation:

Here is normally used concrete footings or concrete slab edges. The rammed earth wall should not be in touch with the ground but it should have some distance.

Gravel are put around the foundation to absorb the rain water and eliminate the water that is reaching the rammed earth wall due to the impact of the rainfall to the ground. Additionally there could also be a drainage metal sheet. On top of the concrete foundation there will be two concrete blocks to form the necessary distance of the rammed earth wall and the ground. Metal reinforcement is placed only at the load bearing walls and the concrete blocks of the base. Incorporating steel reinforcement is very possible to create shrinkage cracking which should be plastered.

Main body:

To form the rammed earth wall, nowadays, pneumatic rammers and wooden or metal scaffolding are used.

Considering the diameter of the dimensions of the pneumatic rammer (approximately 12,5cm pistol surface) the cladding width will be approximately 17 cm.

Rammed earth is porous and in areas where snow or wind driven rain can be severe, moisture may migrate to the inside surface of the walls during prolonged storms. In this case the exterior walls could be sealed. In the case where the mixture contains cement (also waterproofing admixtures can be added) the wall will not be biodegradable any more. There are also some cases (in Australia) where the wall is sprayed with water-repellent chemical mixtures. More specifically they are using silicone/silane admixture called Plasticure. It actually influence the first one or two centimetres of the façade letting the rest still being biodegradable. In Southern countries, where the climate is hot and dry, there is no need of additional render. The durability of the wall must be tested before the construction as it is very much dependent of the quality of the soil. However, it test that have been done in natural rammed earth (with no stabilizer used-cement or lime) and at a wall composition of approximately 30%clay and 70% sand, the wall will fail if the rain corrosion exceed 13 cm in the construction. What is more, examples of natural rammed earth walls have been tested in the United Kingdom. The outcome was construction walls that could last for only one decade.

When insulation is required, the insulation needs to be in a stabilized shape. The material should be hard in order not to deform during construction. Metal rods are used to fixed its position in the wall.
According to the natural insulation material table (p.130) there are many options for alternative insulation material than mineral wool. The insulation should not be flexible for constructional reasons. While ramming earth, deformations and displacements may occur in flexible insulation materials. Thus I am going to use hemp which can be produced both in board form and it is in great availability here in the Netherlands.

Window connection:

The window frame can be supported on either wood blocks, concrete blocks or CEB (compressed earth blocks). I choose for this design CEB as they have similar composition with rammed earth wall (clay, gravel, silt, water, stabilizer-cement/fly ash/ lime/ rice husks). Actually the logic is the same with rammed earth. The difference is the process. One great advantage of CEB is that they can be produced even in very complex shapes. As the most vulnerable part is the sill I am going to use at this CEB cement stabilizer. The window is fixed in the wall with wooden beams that are incorporated in the mass of the rammed earth.

Roof

For water protection the roof construction should overlap. This is opposite to the existing architectural form of the MVRDV design, where the volume is as simple as possible. Wooden roof tiles are applied to minimize the environmental footprint of the building.

5.3.7) Drawings

Below there are four wall sections where rammed earth find application. According to the methodology:
1. In the first case, rammed earth is applied at the exterior surface of the wall as cladding. Thus, the layer of roof tiles was substituted with a layer of rammed earth (15cm thickness)
2. In the second situation rammed earth is placed in the wall system instead of interior coating.
3. In the third case, there is a rammed earth insulated wall that carries no loads. At the specific project, this wall system can be applied at the two big exterior walls of the building. Thus, weather protection has been taken into account.
4. The last drawing, describes the interior load bearing walls that in this case are made out of rammed earth.

Next to every drawing there is a table describing the thickness of the wall and the percentage of the biodegradable part in the wall.

The wall thickness varies as I am not working with one specific mixture of rammed earth with calculated properties and compressive strength. The design is based on examples of existing rammed earth stabilized with lime walls.

What is more, there are also variations at the roof material and roof detailing, as the purpose of this thesis is to produce a variation of drawings.
1. Rammed earth as cladding material

SCALE 1/10

According to the methodology, here only the cladding is replaced. The rest part of the façade construction remains the same with the existing detail of the MVRDV.

What is more, the cavity is removed as the façade is breathing and the existence of the cavity would not be as efficient as it is in concrete and brick construction. The main function of the cavity in the concrete and brick constructions is to obtain higher level of ventilation that at this case is obtained through the whole façade.

For the measurements I take into account the part of the wall that is over ground level. That means that I did not include the part of the foundations that is under ground level.
2. Rammed earth used at the interior

In this case the floor system is also changed. Instead of the hallowed slabs that is now applied at the project, a wooden floor is proposed.

Considering the structure of the building, the exterior wall could be a non-load bearing wall. That is taken into account at the estimation of the wall thickness.

The same wooden cladding that is already used at the project is applied. The rammed earth part of the wall is protected from the weather conditions due to its location in the wall section. That lead me to make no changes at the exterior of the facade.

| Solid part of the surface according to the measurements of the building without the openings: | E1=83.94m² |
| Wall thickness: | W=0.35m |
| Wall volume: | V1=29.4 m³ |
| Non-biodegradable material volume: | V2=1.07 m³ |
| Biodegradable percentage: | R=96% |

*For the measurements I take into account the part of the wall that is over ground level. That means that I did not include the part of the foundations that is under ground level.*
3 Rammed earth non load bearing wall

In this situation, rammed earth is applied both inside and outside of the facade. In this design there is an attempt to avoid steel elements in the mass of the rammed earth wall. Metal rods could rust due to the possibility of rain water penetration in the wall.

What is more, there is an attempt to keep the same material both at the exterior surface of the facade and on the roof. So, in order to keep this architectural principle of the original building Compressed Earth Blocks (cement stabilized) of small thickness are applied on the roof. There is also a decrease at the inclination of the roof. The specific dimensions of the blocks must be specified from the constructor. There will also be an increase at the weight of the roof.

The blocks are placed on the roof in the same way like tiles. The air space below the CEB layer is bigger than at the initial construction, to make sure that no water would stay on the roof. At the edge, a metal safety sheet is placed to support the compressed Earth blocks’ material if there is any failure.

Scale 1/10

Solid part of the surface according to the measurements of the building without the openings: $E_1 = 83.94 \text{m}^2$
Wall thickness: $W = 0.4 \text{m}$
Wall volume: $V_1 = 33.6 \text{ m}^3$
Non-biodegradable material volume: $V_2 = 3.44 \text{ m}^3$
Biodegradable percentage: $R = 90\%$

For the measurements I take into account the part of the wall that is over ground level. That means that I did not include the part of the foundations that is under ground level.
**4. Interior load bearing wall**

The interior walls (and the two small exterior walls) will carry the loads. Theoretically these walls will be approximately 40 cm thick if they have insulation in between, otherwise 30 cm are enough. For safety reasons I made the walls 45 cm. The material test analysis and the specification of the composition will give the exact dimensions and the loads they can carry.

At the bottom and top of the wall, there is placed a concrete block. The bottom one serves the separation of the wall from the foundation. It also forms a working plate. The top concrete block is placed there to support the roof.

In the wall mass, there are placed wooden columns (marked with dotted lines at the drawing) in aim to support the floor.

As the wall is an interior wall, there is no fear of the re-bars to get rust.

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**Solid part of the surface according to the measurements of the building:**

- Surface area: $E_1 = 77.5 \text{m}^2$
- Wall thickness: $W = 0.46 \text{m}$
- Wall volume: $V_1 = 35.65 \text{ m}^3$
- Non-biodegradable material volume: $V_2 = 1.2 \text{ m}^3$
- Biodegradable percentage: $R = 97\%$

*For the measurements I take into account the part of the wall that is over ground level. That means that I did not include the part of the foundations that is under ground level.*
5.3.8) Illustrated representation of the drawings

According to the general overview of the building, the above proposed wall solution with rammed earth can be separated into two categories:

1. The first category is represented by the drawing “rammed earth as interior coating where rammed earth is not applied at the outside surface of the façade.
At this case, the general overview of the building could be the same as it is now as the cladding remains the same. There is no need to change the volume and the exterior surface. The difference would be at the thickness of the wall and the interior wall texture as rammed earth will appear at the interior surface of the wall.

Overview of the first category: The rammed earth is applied as interior coating. The exterior appearance of the building is not influenced.

Overview of the second category: While rammed earth is exposed to the weather conditions, additional protection is needed. The roof is extended to block the rain water from above, while concrete blocks lift the rammed earth part of the wall higher to protect it from the ground water.

Overview of the second category: While rammed earth is exposed to the weather conditions, additional protection is needed. The roof is extended to block the rain water from above, while concrete blocks lift the rammed earth part of the wall higher to protect it from the ground water.
2. The second category, is represented by the wall solutions that let rammed earth obvious from the outside. The wall sections that are at this group are the drawings with “Rammed earth as cladding material” and “Rammed earth non load bearing wall”. At this situation, the roof extends and overlaps the wall and that changes the shape of the volume. What is more, at this situation the material variations of the wall are expressed on the exterior skin of the building. The wall material (rammed earth) is not suitable to be applied at the roof and the basement. Wooden or clay tiles will cover the roof while concrete blocks will make their appearance at the base of the wall.

Zoom in of the second category: The concrete lintels and sill that exceed some cm from the surface of the wall make the openings, a strong element on the façade.

Overview of the second category: Here the roof material applied is wooden tiles. It is an alternative of the common clay roof tiles (that match with the nature of the rammed earth wall). It is chosen as a more environmentally friendly solution.
Section overview of second category. The cutting line is indicated with black colour. The interior walls (that are forming a cross) are thicker than the exterior wall as these are the load-bearing walls. The exterior wall is insulated non-load-bearing wall.
In order to come up to conclusions about the weaknesses of the biodegradable materials, understand how can I work with these materials, the construction process in practice, legacy problems and costs I decided to come in contact with constructors, architects, engineers and people working with bureaucracy to gain some knowledge form their experience. The strategy followed at the interviews can be separated in two groups.

**Group 1:** The goal of the interviews was to gain a general overview on the materials, their properties, weaknesses, problems and legacy limits. This set of interviews in combination with the theoretical analysis above and my personal taste as an architect lead me to make a choice of a material to work on the design step.

**Group 2:** These interviews has been carried out after the choice of the material. They are oriented on the selected materials and the goal is to gain knowledge about the construction method and limits, maintenance treatment, detailing, structural limitations according to rules and legacy and construction costs.

Here are presented the methodology and the conclusions. The whole questionnaire and the total amount of interviews are presented at the appendix.
Interviews group 2 (material oriented interviews)

INTERVIEWEES:
1. Rick Lindsay: Professional rammed earth constructor, Working with Earth Structures Group, Australia
2. Charles Thuijls: Professional rammed earth constructor, LEEMWERK company, NL

6.1) METHODOLOGY:

The goal of this group of questionnaires is to evaluate my drawings and improve them in every possible aspect, understand further the properties and building construction process of rammed earth, become alert of problems and drawbacks during the construction process and realize the feasibility of constructing a real project of rammed earth (suppliers, legacy problems, maintenance, ...).

This second group of questions also aims to give an answer to some main sub-questions mentioned at the “research question” paragraph which are:
- How are the material used now?
- What are the techniques?
- Are there tremendous difference on the properties and the construction techniques compared to the standard materials?
- Are the designers, the constructors, the workforce and all the members of the façade industry aware of how to build with biodegradable materials?
- What changes should be done in terms of design and construction in order to use these materials?

Schematic form of questionnaires:

- What are the biggest problems of the rammed earth constructions
- How did they normally face the problems of weather protection and moisture
- What kind of mixture do they use (percentage of the ingredients, type of stabilizer)
- How do they maintain their constructions
- What was the reaction of the clients/public on these projects
- What difficulties did he face during the construction
- What limitations did he find in terms of legacy and norms
- Technical details on the basement, window connection, roof connection and slab connection
6.2) Drawings Evaluation

**Rammed earth as cladding material:** The wall is directly exposed to the weather conditions. Considering the weather conditions that makes the cladding vulnerable. Maintenance of the cladding should be applied. It is recommended to follow the horizontal lines of the pattern when the coating is applied to keep the final product as close as possible to the impression that the initial gives. It is possible, to plaster the wall in a way that will keep the colour variations.

The application of natural insulation - that is breathable, combined with a natural interior plaster or a breathable board may face in some point the problem of moisture but these measures cannot protect the structure efficiently. If though the cladding is plastered, there is no problem at all, but the wall will miss its rammed earth expression.

**Rammed earth as interior cladding:** In this case the wall is not bearing loads, the building takes the advantages of the mass of the wall. For that reason the wall can be made even thicker. As the rammed earth materials is protected from the weather conditions, there is no need of maintenance. What is more, there is no need of interior vapour barrier as it is a breathing façade.

**Rammed earth non load bearing wall:** In this situation the building takes advantage of the thermal mass. The thickness of the wall is approximately 45cm. As the wall is exposed to the weather conditions it needs maintenance. Thus, alike the first drawing (rammed earth as cladding material) the same measurements should be taken. This could mean a plaster after some time (9-10 years). The plastering process is suggested to take into account the lines of the pattern produced during the construction and be plastered in horizontal layers. It is possible to apply different colours in every layer in order to be more close to the natural rammed earth appearance. In this way of plastering is more time consuming.

The roof tiles of rammed earth seem to be an unfeasible solution. Roof, is the worst position for a material that should be protected from the weather conditions. What is more, it is not easily accessible in order to maintained the roof elements.

**Rammed earth interior load bearing wall:** The wall is sheltered and protected from the weather conditions and the water that can enter the construction through capillarity. It seems to have no problem . At a further improved design, prefabricated concrete blocks can be introduced in the wall instead of the wooden beams, to support the floor. This could minimize the construction time. As a negative point could be considered the wall thickness which is approximately 0.46m

**Window connection:** The compressed earth blocks (CEB) that are used to support the window seem not to be an efficient solution. The main reason is that these blocks cannot be reinforced. That means that it is difficult to support an opening of 1.80m or, in order to do so, their height might be too much.

Moreover, the window threshold is very much exposed to the weather conditions, due to its shape. Other solutions of material, like wood or concrete are more proper to overcome the problem.

Finally, the window installation is time consuming. In a further improved design, this could be done by using prefabricated window box that are placed after the construction of the wall.

In general, the thickness of the proposed walls are bigger than the contemporary construction of the MVRDV. However it is relatively small in comparison with other earthen walls.
Cost estimation

The cost estimation of a wall construction is in general a very complex process. It is dependent on many different aspects like the location of the site, the construction time, the detailing and the material supply. Some of these aspects are by themselves very difficult to be predicted such as the construction time estimation.

In general, rammed earth walls are considered to be a rather expensive solution. In the Netherlands, this technique could be even more expensive. That happens because the soil type of the Netherlands in most cases is considered to be inappropriate to be used in the rammed earth mixture. That increases the cost, as the materials should be bought from suppliers.

In general the following range of prices exist:

- **Prefabricated window**: 300-350 €/m²
- **Concrete wall designed according to the SBR details**: 250-325 €/m²
- **Rammed earth insulated wall**: 450-550 €/m²

The scale of the specific project could make the project more profitable. As the whole project consists of 34 building units rather than one, the final price could be around 400 €/m²

This price is very briefly estimated. They should be taken for granted. The idea of this chapter was to give an idea about the price range of the project.

The cost estimation has been done very briefly with the assistance of Ir. A.C. Bergsma (Technical Building Design) and Mr. Charles Thuijls (Professional rammed earth constructor, LEEMWERK company (www.leemwerk.nl), NL)
7_CONCLUSION

7.1) Conclusion

Rammed earth buildings are constructed since the ancient times. Entire cities were built of raw earth such as Jericho and Babylon, and included imposing monuments and temples. The technique was developed in ancient China around 4,000 years ago and then spread around the world. Historic rammed earth buildings can be found all over the world today including Africa, Morocco, Spain, India, Nepal and Germany.

The last 25 years there is a comeback of the technique, however, in the Netherlands it is not that popular. Therefore, there are not specific standards for rammed earth constructions according to the Dutch low. In the country, the construction context is determined by the German standards (Lehmabau Regeln- Dachverband lehm).

The main difficulties on working with this material, as happens in the majority of natural materials, is the request of mild weather conditions during the construction and the determination of the mixture composition. Steps have been made in order to simplify the construction. Pneumatic rammers make the compression of the material easier, maximize its mechanical properties and minimize the construction time. What is more, rammed earth suppliers provide the market with standard rammed earth mixtures instead of the separate ingredients of the mixture, in order to succeed in better quality and predictable product outcome in terms of appearance, durability and strength.

This graduation thesis has been carried out in order to give general guidelines on working with natural materials. The orientation of the research on rammed earth has as a goal to give a designed example on constructed a building wall with biodegradable materials. The design target was not to produce the optimal solution, but to present the methodology and produce a variety of proper solutions that fulfills the design goal. For that reason, in this project, there has been made an estimation of wall thicknesses as it is not focus on a specific material mixture. The dimensioning has been done according to literature study and rammed earth project overview. What is more, the design variations are here to present some of the possibilities that exist while working with this material (application of the insulations, roof covering, thickness of rammed earth wall in every situation).

Improvement of the drawings can be done according to the recommendations of the constructors and the construction limitations in every situation. The specific drawings are characterised as feasible and could be considered as proper solution of the material application on the building wall according to the constructor Mr. Charles Thuijs, (Company: Leemwerk) that has constructed rammed earth projects in the Netherlands. However, some ideas for further improvement in order to minimize the construction time or the intensity of the labour are also possible.

7.2) Contribution of the thesis

This thesis, attempts to enlighten the methodology under which biodegradable materials could be more approachable as façade building material. It also gives examples and ideas of their application, properties, possibilities and characteristics. Finally it gives an example of material application in a modern way in order to encourage the idea that the only thing that is needed to make the application of biodegradable materials in the solid building envelopes in the Netherlands possible is to think creatively and base the design on the nature of the material. My personal belief is that this thesis succeeds in:

- Reintroducing the idea of biodegradable wall systems in the modern society. The resident becomes again a visitor on earth, that has to return back what he has borrowed. The thesis takes into account the very large field of wall constructions. The drawings are produced considering the local and natural material resources, the construction process, the weather conditions, the law and the norms and the labour intensity.

- Producing feasible details. Considering the fact that there are no Dutch norms for earth buildings, these could become the base to produce the “SBR standard details for rammed earth” constructions. The drawings reach the scale of 1:10 or 1:5 providing basic information about the wall. They are not going down to smaller scales which are necessary for a real project when it is constructed. The idea is to give the basic guide lines for the construction.
• Improving the sustainability in the building sector by giving basic information about the weaknesses and the strong points of dealing with biodegradable materials. The thesis tries to encourage the use of these materials in the wall systems. Both engineers and people involved in the building industry are unfamiliar on working with them. This lack of knowledge has been witnessed through the interviews that I had with people working in the building sector.

• Producing a measurable and comparable example of biodegradable wall for further research. The idea was to changing the wall materials at an existing example of the contemporary Dutch architecture. In this way, the new and initial design could be compared according to what every researcher is looking for. At the existing moment comparisons on the percentage of the biodegradable parts of the wall in every situation has been done. Other comparisons according to the interest of every researcher are possible.

7.3) Further Research Suggestions

On the occasion of the methodology and the information that are included in this graduation thesis, there are some interesting points that could be researched further. Below are some ideas of future research topics.

1. Research on the possibilities of applying a chosen biodegradable material from the list included in this theses, it building envelopes. In the specific thesis, rammed earth was chosen for redesign and improvement. The same steps could be followed for any other material from the given list.

2. Material research: moisture is the biggest threat in the application of all the natural materials in the buildings. Especially in the cases where the desired outcome is a biodegradable wall some additives like cement or water repellent admixtures are forbidden. Production of biodegradable coating materials that can deal better with the Dutch weather conditions is a very important aspect for the biodegradable wall application. There are many new technological miracles on the field of materials. Eco composited are becoming more popular and their properties more challenging. Further research in this direction could bring fruitful results.

3. Further work on the rammed earth wall. There are still some dark points in rammed earth wall application that could be research more. I would suggest to search further in the following directions:
• The coating
  This is the simplest solution for wall weather protection. However, the big disadvantage of this solution, in the case of rammed earth, is that it is going to influence the architectural value of the wall. The natural texture, with all the colours will disappear under a smooth and homogeneous surface. Possible coatings are mud plaster, lime based coatings, whitewash, stucco, earth based coating. Challenging would also be the exploration of new technologies. For example silane-siloxane is used in some cases. Whether the result is still biodegradable is a question. Other oil-based or some kind of water-repellent material that are both transparent and water resistant could be interesting to explore.
• The use of absorption materials in the wall as a measure of moisture protection
  According to tests, there is a specific depth over which if the water succeed to reach, the rammed earth wall fail. This is in dependence with the composition of the mixture. In most cases this depth is approximately 13 cm deeper from the vertical surface of the wall. The incorporation of a water absorption layer before that level, could block this water. For example a layer of sawdust, that could be applying by ramming in the construction could act as water absorption material.
• The stabilizer
  A research on the proper type of stabilizer and the proportion of this material in the mixture is important in the case where the demand is high rise buildings. Possible natural stabilizer could be: lime, rice hulks (used in CEB: compressed earth block ), adhesive mixture of rice and egg whites (used in the Great Wall of China, the most ancient example of rammed earth wall)

4. Research the rammed earth wall disassembling process and the materials life after demolition.
This will complete the environmental footprint research of the rammed earth used in the building envelopes in the Netherlands. Changes at the demolition process might also influence the biodegrading time. On the other part, the reuse of some parts of the walls might have considerable advantages.
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9.2 Appendix - interviews
Questionaire No1

Name: Bob Urzem
Scientific director at TU Delft, Biotechnologist, NL

Date: 10/01/2013

QUESTIONS

1. What types of plants can grow here?
   There are a huge list of different kind of plants that grow here. There are information available and you can find that list.

2. Are there some left overs of plants that they are thrown away every year? If so, how many tones?
   Actually there are no left overs. At least officially. There are all used as biofuels. There are though smaller farmers and producers that are not involved in the biofuel process.

3. Do you think that it is possible to produce some specific types of plants like hemp instead of these that are more than needed and are thrown away every year?
   Yes, this is always possible. Even if you find a better use than biofuel it is possible to influence the market. It totally depends on which plant are you focused on.

4. What type of soil does the Netherlands have? What types of plants grow at each part of the country?
   This two parameters, the type of the soil and the plant species are very much connected to each other. I have given a lecture about the soil types at the university, which you can find on the blackboard describing the soil type. There are many different variations of soil but in general they can be categorized in four types: sand, peat, clay and loess. Accordingly, there are the plants species located. For example in Groningen there is production of hemp whereas in Zeeland there are cultivated fast growing trees like bamboo.
**Questionnaire No2**

Name: Steffen Nijhuis  
Assistant Professor of Landscape Architecture at the Faculty of Architecture, Delft University of Technology, NL

Date: 19/02/2013

**QUESTIONS**

1. According to my material list I am particularly interested in: reeds, several types of wood, clay, straw, flax, rattan/bamboo, wheat, lime, cork and wicker (only considering the plants and soil material). Do these plants grow here? What types of plants grow at each part of the country? Can they grow in big amounts?  
   - *Book: Scientific atlas of the Netherlands. The ground is closely connected with the grows and plants.*  
   - So search for the 4 main types of soils (river-clay, coast, pit-inland, sandy places) and look at what are the properties of these areas. Finally look at the natural processes and the cycle of these materials. In general take a look at the historical revolution. So:  
     - **STEP 1:** 4 types of landscape  
     - **STEP 2:** vegetation (ex. pit areas = grass land, clay areas = straw, for instance at Frishland, hinder land (μεσα απο τα dicks) = pine tree, for instance at Limburg)  
     - **STEP 3:** Natural processes

2. Are there some left overs of plants that are thrown away every year? Which plant produces the most left overs?  
   - A plant with many leftover is maise and wheat.

3. Do you think that it is possible to produce some specific types of plants like hemp instead of these that are more than needed and are thrown away every year?  
   - Yes these kind of propositions may be interesting but it must be tested and see the influence of these proposals.

4. Considering the geological situation of the country is the extraction of soil still possible?  
   - The extraction is not a problem. Sometimes it may be very beneficial for the water management. Look at the history and the traditional agriculture.

5. What kind of materials did they use in the traditional architecture? Where can I find the traditional ways of construction?  
   - Look at the cultural historical corner for landscape elements.
Questionnaire No3

Name: Kwnstantinos Kontomanos
Professional: economist
Working with the COB team as volunteer constructor

COB team: Is a team of volunteers and professionals that work with cob, adobe, straw bale, earth bags, rammed earth, earth constructions, clay mixed with straw.

Date: 08/03/2013

QUESTIONS

1. What are your criteria, under which you choose what method are you going to use in every construction?
   It is a combination of the climate, the availability and the desire of the client. In Greece for example the most suitable is the straw bale construction. Apart from the price (that is a little bit more expensive than the rest methods due to the need of the wooden infrastructure/frame) it is more durable to earthquakes, quick in the construction process, good thermal insulation and low weight.

2. During the construction of straw bale buildings there are some additional wooden or reed support that keep the straw bales in shape and in location. Do you remove this structure?
   No. In Greece at least not. It is better for the behaviour of the structure during earthquakes. In general I think is better to leave them in the structure to make it more durable.

3. In which cases do you need an extra thermal insulation layer?
   In all cases apart from the straw bale constructions. These materials have a great thermal capacity so according to the needs you insulate from inside or outside.

4. What kind of material do you use for thermal insulation?
   I use straw or perlite (a kind of stone)

5. What is the advantage of adobe walls?
   They have great thermal capacity. In cases that I need to construct a tromp wall I use these elements.

6. What types of coating do you use in these constructions? Is it a standard one or it depends on the type of the construction? For example in the case of earth bags we need a more sticky coating according to the material we use at the bags?
   It depends on the type of the construction. But generally we use either pure soil (that has a problem with moisture) or mixture based on lime. We don’t use cement at all. We use in the second case, lime with sand or, for more difficult situations, the so called “kourasani”. Kourasani derives from the Mesopotamian word “kourasand(?)” that means “the city of the sun”. It is a mixture that has a great percentage in pumice (Theraic earth). The pumice reinforce the mechanical and the hydraulic properties of the mixture. Especially at the earth bags there is not a problem because I use a system called hyper adobe. That means that it is not propylene used as materials for the bag but another one that is like a net, like fishnet stockings. So in this case there is not a problem. There is not even a need to put an additional metal wire net that it is used in the past. The coating sticks directly with the earth bag mixture.

7. In the case of moisture entering the construction, in every of these methods, is there a measure that you already have taken in order to lead the water out of the construction and let it dry? Are there openings or any kind of drainage system? Like the openings at the brick constructions for example?
   At the cases that we use earth products (that means in all cases but straw bale buildings), we do not have any problem at all unless the whole construction be under water. In these case the building will be demolished. That means that if there is an extreme case of flood and there is for example water that reach 20 cm over the ground level of the wall, then the construction
will fall down. Practical that means that you should build at a higher altitude of which the water level can reach. In all the rest cases, heavy rain etc., etc., there is no problem at all. The only you need is a durable coating according to its mechanical (not influenced by the direction of rain for example) and hydraulic properties. Do not forget that this type of constructions, for instance cod constructions, are very popular in England where the weather is very rainy.

Especially interest should be paid at the osmotic moisture. This kind of moisture can be faced by the breath of the wall. So this is not a problem. The only construction method that may have some problems is the straw bale buildings. In that case, if the moisture captured in the building envelope, either for example in the differences of the moisture in the interior space where in some cases is very high where the interior coating is more porous than the exterior, then the water will dry at the interior coating but it will be captured at the exterior coating. This situation, in straw bale constructions, if the captured moisture is more than 60%, it can occur fungus. If fungus occurred, the quality of the interior space becomes very low.

8. In straw bale constructions then, where the problem of moisture is more alarming, if we have a failure during the construction and the moisture succeed in entering the envelope, can we take any measure afterwards? Can we, for instance, remove the exterior coating, let the structure dry, create a drainage path, and put it again?

No, you must take the measures from the beginning. The most tricky points of the wall, in terms of water entrance, are: the top, the base, around the window frame and let the whole construction breath. The use of metallic infrastructure or interior support is completely forbidden for the fear of oxidation due to possible moisture.

9. In straw bale construction, where we use additional vertical columns that pass through the whole height and stabilize the straw bales. As the straw bales, during compression may lose even the 30% of their volume, this additional support have a load bearing role? Even as the main load bearing structure or as a safety structure? So that means that the construction doesn’t work as a monolithic construction but rather like a post beam construction and the straw bales are just used as filling and thermal insulation? If this is true, I guess that there are some standard minimum dimensions that these columns can take and the distance in between them must be also calculated.

The straw bale buildings have three types of loadbearing systems. At the first category there are the buildings that actually do not have any other load bearing structure apart from the vertical columns that pass through the body of the bales (these that you already mentioned). Historically, this is the first type of systems used in straw bale buildings. This type is forbidden in Greece as it is a county that face strong earthquakes and there is no chance of such a construction to last. Even if it doesn’t fall, it is sure that the coating will be destroyed.

At the second case we have additional load bearing construction, that here, we used to leave it even after the finish of the construction. So I could saw that the main reason is the face of earthquakes.

10. How is the window and door detail at the straw bale building? I have seen that in many cases they put the frame directly on the bales, without any wooden support underneath. Is that normal? I find it rather risky.

I guess that it has to do with the lows for earthquakes that each country has, and the standards that the constructions has to fulfill. In Greece this is completely forbidden and, if so, not only the window but the whole wall is in danger of falling down.

11. In earth constructions, why we do not want to have a mixture that has a big percentage of clay? What is this quality of the structure that lead to use that mixture?

Actually it is not a mixture, it is pure sand. We only need to use a sand that do not have clay, it is more sandy. On the other hand at the earth bag structures we need a clay base mixture in order to become more sticky.

12. The mixture of the material at a cob structure and the percentage of the water in that mixture, depends only on the workability that we need to get of the material or it also depends on geographical and climatic parameters?

See attached file..
13. At the rammed earth constructions, do we need reinforcement?
   In Greece we definitely need. In Australia for example they don’t use. In California, on the other hand, they add cement. There, they have the same earthquake standards with Greece.

14. What are the main advantages of choosing one of these natural ways of buildings over the most common ones like concrete and brick constructions? The reasons are only environmental or are there other advantages for the user? Better quality? And what are the disadvantages? Are there complaints for example of the users after leaving in a house for some time?
   These constructions are not used for a long time. Or, to be more specific, there is not much time that we turn back to these techniques. That means that in the past there were many problems. But now, with the technology and the knowledge of these times we can overcome all that problems. At least there are not mentioned any complains. We must see the results and have a statistic analysis after some years.
   According to the reasons, there are of course environmental reasons in first plan. What is more there are economic reasons. The prise is much more lower in cases of these constructions. And finally is the quality of the interior space. I leave in these constructions and I feel the difference. If for example forget a fresh fruit on the table, you will see that it is much more degraded after some days that if it was on a table at the interior of a concrete house.

15. So that means that the quality has to do with the maintenance? What is the needed maintenance?
   Not that much. In Greece you need to apply a new coating on the top after 50 years. But that is directly completed with the climate conditions of the area. In Africa for example they repeat this process much more often. I don’t know, they may do that for hobby...!!
Name: Ramon Knoester
Principal architect at WHIM architecture, Rotterdam

Project 1: Villa Al, Almere, 2011
(A modern villa, constructed from local and natural materials – wood, straw, clay, vegetation, used the latest technologies to fulfill the needs in heating and electricity. Conceptual project. 174m²)
Project 2: Recycled Island (recycled plastic)
Project 3: Villa Kb – Living with trees

Date: 19/03/2013

QUESTIONS

1. Generally I used to make a profile for the people I take interview from, could you tell me some things about yourself? (Background, type of office, size, kind of works)
Currently I have my own office since 7 years ago after working as a project leader or architect for several other offices. I started the office of course to run my own projects but also to do what is my interest for, so to work on projects and competitions but also to work on projects that capture my own interest. For that projects there is no real assignment or client, we try to work as an environment friendly office, sustainability and environmental friendly materials and that is how we come up with Villa Al.
I collaborate with constructors, I do not work as a constructor myself but I am an engineer. I graduated as a building engineer and I continued my studies as an architect. So I am an engineer as well as an architect.
At the way I work, in most of the times, I fist develop a concept/proposal and then I moved on on how can I realize the project and how it is constructed.

2. How come to the decision to produce the design for the Villa Al? Was it an experimental project derived for your scientific curiosity, from a client’s order or for an architectural competition?
Villa Al was a competition entry for the Europan (?). They asked for a pavilion or villa or something that can transform from the one to the other and work with local materials. It was something that caught my special interest so I really looked for indeed local materials. But I looked also for a let’s say modern architecture.
In this case we didn’t win the competition so in this case the project is in a conceptual mode.

3. Why in Almere?
The location and also the conditions and the fact that they looked for local materials were the demands of the competition. So this caught my enthusiasm to make a proposal for this.

4. What is the main idea – concept - behind the design? Did you got influenced by any similar project, architect or applied material?
I got inspired mostly form nature. In the plan there is a big green area but somewhere in the plan there is a small river and this river was like going like a curve into the area. And I took this curve of the river as a principle for the design.
I didn’t start my concept by considering the forms that I can get from a specific material but when I was making the design I was thinking also about materialization at the same time. But I didn’t get myself limited about the characters of the materialization. First I developed the concept and then I looked for materials suitable for the design. But I am not sure yet about how can I develop this in details.

5. The design is produced by taking into account the principle of the ecological design. What was your criteria for choosing the materials? What materials are you thinking to use at the architectural envelope?
Apart for the locality and the fact that I need ecological materials, it was also some properties. The insulation values was very important and the character. Wood: The area of the location was very green. It is a forest with a lot of trees so it was good to apply wood because you directly have the connection between the wood of the trees and the wood in the building.
Straw: I used straw as an insulation material because you can take it locally
as there are a lot of acres around and other agriculture so you can take it from there.
Clay: Then I took clay as a finishing material for the interior because it is locally available and because of the character. Most of the people like this smooth finishing for the interior and also works well with the straw. So I leave that as the final coating and I keep also its color.
Plants: At the exterior I made a green façade.

6. What kind of vegetation are you thinking for the façade? Have you made any study on the vegetation of the area and what kind of plants does the ground support?
   No I haven’t made any study yet.

7. What do you think are the advantages of applying natural materials in the facades?
   Well, I believe that it is also very healthy. When you use straw for the insulation you create a certain mass as well and also the temperature of the inside is regulated very slowly. The interior climate is more stable. Even if, for example at Villa Al, I put a lot of glass, the inside temperature should be stable. What is more the whole envelope can breathe.

8. As the façade is made of natural materials, and by taking into account the renderings, it is going to be a planed-green façade, what is the needed maintenance?
   I haven’t made any estimation yet about how often should you for example recoat the clay from the inside and generally I haven’t considered the maintenance issue.

9. The form of the villa is an organic form. Did that have any influence at the choice of the materials?
   What I tried to do and actually was the challenge for me to make this proposal was to produce a building that belongs to the modern style. I tried to make a statement because what you see very often is that if you construct with natural materials the outcome is an image that it looks very smooth, not modern and maybe boring. If we talk about modern architecture most people think about concrete, steel, glass and white buildings.

10. Do you think that produce modern architecture with natural materials is an achievable goal?
   Yes, certainly. I think that there is a lot to gain in this situation. Nowadays there is a lot more possible, the knowledge of construction is very high, new technologies calculate the construction and there should be a lot more possible in using and constructing with these natural materials.

11. Do you think that there is a difference in building and planning costs between this project, or more general a project with natural materials and a project worked out with standard materials?
   Yes there is a difference. It very depends on how you make the design but also what the extras are. In construction, basically, if you are going to work with simple materials, with local materials like straw and wood you can make a building that is less expensive. But then, if you really want to make it self sustaining by adding solar panels and maybe a heat pump then with these installations it become more expensive. However, you pay more for the installations you pay less every year for electricity and gas etc. so you take your money back.

12. Do you think that the working force, the laborers are not qualified enough to make constructions with natural materials?
   I don’t think so. I think that it is mainly very simple.

13. In general, the walls made with natural materials are thick. In average, they are approximately 60-70cm. Do you think that this could cause problems at the design? In terms of space or maybe the client has some hesitations.
   Well, it depends on the location. If you are dealing with an urban environment where space is more expensive than in rural environment, then the wall thickness is something to take into consideration.

14. Have you produced any drawing-detail-sketch of the wall section? How do you think this wall could be constructed?
   The main principle that I have in mind now is that from the inside there is a layer of plaster, like clay or lime I am not sure but there will be a natural plas-
ter. Then there is a layer of straw which is combined with a wood construction so you have something to bear the windows and also if you want to make something like a cantilever or something like this and from the outside there is a green façade but I haven’t developed yet how am I going to make the green façade onto the straw. What should be in beneath. A water barrier or something like this.

15. What is the system that you have in mind to use in the façade? What will be the load bearing structure? (Prefabricated elements, reused, easily assembled, post beam façade, cold façade, warm façade, curtain wall, …) The loadbearing construction should be wood, and the additional should be fillings and coatings.

16. What did you learn from this theoretical project and what would you do different today? (in terms of design or problems at the construction that you foresee even from this step)

I think that it could be a real project but of course now the next step it would be to talk with the structural engineer to see if we could make a modernist design like this with wood, cantilever and the overhanging parts. That would be the main challenge and the first think to look into.

17. Have you ever worked with these kind of materials? If so, what is your experience? I’ve seen some projects. The recycled island and the Villa Kb.

Yes. Actually Villa Kb we did it mostly as a wood construction and we combine it with a green roof and a wood cladding to the façade. But for this project we still used the more standard insulation.

18. What do you think would be the problems of working with natural materials? Why it is not used an more? It is the lack of experience, the collaboration with the laborers, the procurement of the raw materials, the costs, the clients desire and confidence at the contemporary methods and materials?

Well for high rise buildings it becomes more complex. And I think that a lot of people don’t see the potential any more in natural material. I think that they have an image that using natural materials is actually something very old fashioned. They think that the materials we are using nowadays is better than the natural that we used before. This is I think the general image. But for low rise buildings I think they could be better.

Now I am working on a new project. It is called “Rotterdam Arc”. It is based on the concept of Earthship. It would be a proposal to make two pavilions at the center of Rotterdam as an area of showcase for people of Rotterdam to see how could you actually build with waste and local materials. To show for example how you can use the sand as an element for your heating or how can you recycle the water in your building. It is actually all the principles of the Earthship into a new building and also take advantage of all the natural surroundings, like your garden and grow your vegetables.

Earthship is basically when you construct a building with old car tires and you fill them with sand or earth but mostly sand. Then you use a timber roof and then you make the building or at least the East and the North façade with a lot of earth buck from the façade to create volume and then at the south you make a glass façade. In this way, you take the heat from the sun in the winter and the temperature inside becomes very stable. In the summer, even there is a pick of heat, the temperature inside stays again stable. The temperature is very regulated.

It is a kind of competition where people from Rotterdam can make a proposal of what they thing is the best for their city. This started last year. This year is the second round and on April they are going to select the 5 best projects People from Rotterdam can also vote and say what do they prefer. Even if they did not select it we will see if there are other potentials.
QUESTIONS

1. Are there any standards that a product/material should fulfill in order to be characterized as building material?
   
   The NXZa are the standard for material. On the level of product here are the general regulation which come from the European Decree. There is also the Dutch Decree. However, in the case of materials, there is the European Decree that it is used for all the European members. That is actually the CE mark that a material can have.

2. As these standards find application in the whole Europe, are there differentiations according to the location?
   
   Traditionally there were standards in every country. But then, after the decision to have one European internal market, in 1981, we have one internal market for all the building products. Actually it wasn’t only for building products. It was for equipment, electrical products, for everything. The expression of that was the CE marking which mean that the product has to be tested under specific criteria. There are standards for all kind of products. However, this system did not function too well for the local market there are products at the local level that do not have the CE market. But these products are not sold abroad. On this issue, there are changes coming from the coming July (2013).

3. How can a building obtain a building permit it uses natural materials?
   
   This is way different. There is a building decree for building materials. these materials should have a CE mark. The final product, in this case the building, should fulfill some standards. For example the amount of daylight, the levels of interior comfort and so on. The Netherlands is one of the few countries in the world, that have legislations on the level of building. The most countries have legislations on the level of product. In other words, that means that you can build with whatever material but the building should fulfill some standards. So according to the characteristics of the product that you use, you can calculate and realize the characteristics of the performance of the building.

4. If some materials are local or natural and not have any CE mark can this material still be used in the building? For example how can you introduce a new material in the market?
   
   In this case, tests should be done according to the characteristics you are interested in, that are described from the European standards. For example for fire resistance, stability, etc. There are specific characteristics of products according to the potential location in the building.

   In general you can build with whatever material you like, but you should test them.

5. Where can somebody find the standards and characteristics that a wall should fulfill?
   
   There are not available on the internet. You can buy them at the website of NEN (www.nen.nl)

6. Do these standards change as the life standards become higher and higher?
   
   Yes, they do update them. They have standardization committees that are responsible for this subject. I think, at the moment we have 150 committees active and they update the standards in a regular basis.
7. What is the process if a building is tested in order to be honored and gain any certification for its sustainability (LEED, BREAM, GREEN STAR, ….)?
   In this case measurements should be done in every tested aspect. For example life cycle analysis, CO2 emissions during transportation and many more. Actually these days that is a very common test for many buildings. There are many institutes that are responsible for these tests as this is a rather complex process. There are also many software available like GreenCalc+.

8. Are there also some limits on criteria that cannot be measured? Like “aesthetics”, “workability” or “construction time”?
   In this case, there is a kind of contract between the client and the constructor/engineer/producer, that at the end you will gate the product you want, with a certain quality, appearance and it should be delivered in specific period time.
Questionaire No6

Name: Ibuku Design Team - architects, constructors (www.ibuku.com)
Project: Green Village, Bali

Date: 30/03/2013

QUESTIONS

1. I usually make a profile for the people that I take interviews from. Would you like to tell me some things about your work?
   My work and the other design team was in bamboo world as you could see it on www.greenschool.org and www.ibuku.com and www.greenvillagebali.com

2. Are you working mostly with natural materials?
   Yes, we’re here want to make changes, and set new paradigm and mindset for others

3. What kind of projects do you produce? (Small scale, residential buildings, public buildings)?
   Until now we already made international school, restaurant, public buildings, villas, residential house and now we’re developing a green resort

4. What were the restrictions that you have for this project? (Cost, material, time, size)?
   Natural material (green material), time, cost, design

5. How come to the decision to design a project and use bamboo as the only material that forms the whole construction?
   It’s start with John and Elora Hardy idea and vision, to make green + sustainable space and unite with the nature

6. Did it derive from your scientific approach and decision or from a client’s order?
   We’re move in special material, bamboo! And all the client who comes to us, already know the uniqueness of our special capability

7. What was your experience on convincing the client to use bamboo in his building?
   We don’t have to convince the client, we show our product results, (bamboo building) which save, strong, beautiful and unique

8. Where was there many hesitations at the beginning?
   I am also interested in the window and door connections. You could visit us at Greenschool and Green Village and have some tour. Please visit the web address that I gave you on the top

9. What method or material do you use to bind the bamboo elements together?
   We use many techniques, from traditional way until modern hi-tech joint

10. I am particularly interested in the architectural envelope. How did you form the shell?
    The shell was created by itself when the design + construction growing, we work with living material and we should apply the “living” method also in designing

11. As far as I can recognize there must be a load bearing structure made first, and then fillings with bamboo and reeds. Is that correct? How is the process exactly? How do you make the connections?
    Almost correct, sure we should build the skeleton first (bamboo skeleton) but there’s possibility to make the filler to help the load bearing also, for the connections you could search it on web, many connection techniques that we apply here same with the pages

12. Are there any climate restrictions of using bamboo?
    Yes. When you build with bamboo you should taking care the bamboo not have direct rain water + sunlight and also about the humidity
13. Can a bamboo construction last in the moderate maritime climate of the Netherlands? We never try it before, but I think now the technologies was beyond far away. I’m sure 100% there’s a way to make it happen with some adjustment for sure.

14. Are there any limitations while constructing? (for example weather limitations, need of dry environment or we can continue constructing regardless rain and humidity for instance). We build bamboo building without heavy machinery, we took the wisdom of our elders when build something, so we try to minimize the land impact from the machinery and total destruction of the land, we’re honoring the land itself.

15. I would be grateful if you could provide me with some drawings. I am interested about the wall section and the relevant details (window connection, door connection, wall details). I’ll try to collect some images, but please be patient a little bit because we’re on heavy dateline lately, but please remind me if I’m forgotten about this.

16. What is the life expectancy of this construction? What is the needed maintenance? The lifetime of the bamboo building approx 25 years with minimum maintenance, but if we could keep the maintenance good, then it would be for life :D. Simple maintenance such as recoating, change the broken bamboo, change the roof material something like that.

17. How long is the growing season of the plant? With bamboo you could harvested when it reach 3-5 years, very fast yah if you compare with wood.

18. What do you think is the advantages of using bamboo in the constructions? Its very light, and you will contribute to the world of being a little bit green, sustainable things, and its have thousands artistic things working with bamboo, its like combining hundreds or thousands of DNA unto become a tissue organs, and you could explore the design with suitable with the bamboo characteristic itself and many other cool and great things.

19. How do you treat to the interior walls? Do you use any extra sound insulation? We try to put some insulation, with our development material also used bamboo, but its not yet as good as the normal insulation at the market.

20. Did you use any extra waterproof layer in the roof? Yes and No, depend with the projects need and roof material.

21. Do you think that there is a difference in building and planning costs between this project and a project worked out with standard materials? As general it would be the same, but when you worked with living things you can’t make standard on it, you have to flow with the bamboo curve and play and imagine with it to achieve the best result.

22. Was the cost of the Green Village comparably low in comparison with that if you had used concrete, wood or standard materials? Its also depend on the design complexity, structure, building form, style, theme, client request etc.

23. How many square meters is the size of the project? How many tones of bamboo did you use? The largest bamboo structures was Heart of School in Green School the floor area approx 2500sqm.

24. How many different kind and forms of bamboo did you use? According to the photos I can recognize bamboo of different sizes, black bamboo, reeds, bamboo sheets (for the roofing) and bamboo planks. Are there more? Did you make them yourself or did you buy them from a company? We use many kind that we can, but ultimately we use 2 kind, the big one for the structures and smaller one for the lighter structure such as roof.
25. Did you use the bamboo elements directly as it is (after you buy them or you harvest them) or did you make any special treatment? (for example, using borax and boric acid to protect the material from rot and insects)
   We have to treated the bamboo first, and yes using the sustainable medicine of course such as borax and boric acid.

26. Do you think that the laborers, working force, the engineers and the designers need special knowledge and qualifications in order to construct projects with bamboo materials?
   Absolutely, the design team was specialized in bamboo architecture, and the labour+engineer also.

27. What did you learn from this project? What would you do different today? (in terms of design or problems at the construction that you faced, etc.) Where there some important changes during the construction that you haven’t foreseen them science the design step?
   I learn so many things, it’s great knowledge for me as an architect and I’m happy + proud that I become like I was to be now.
   Many issues happen during the design+construction, but there’s always a thousand way to solve it, and here we’re working as a team that carry each member load together.

28. What do you think is the main problem that bamboo are not using in a greater extend in the north Europe? (it could be the lack of experience from the engineers, architects, laborers, or the difficulties at the procurement and cultivation bamboo, the costs, the clients desire and confidence at the contemporary methods and materials or the durability of the material in wet and cold climates)
   First there’s no bamboo grow there, if you bring it from tropical country then the cost + the load to carry it make it become not green=sustainable material, and yes about the climates also, and the last is there’s no standardization yet about bamboo material, so if you want to build it in Europe where the building policy demand the standardization, it quite hard until now, but I’m sure there’s a time when everything is possible with special adjustment, and it become my dream and challenging to build the bamboo house in Europe.
**Questionnaire No7**

Name: Benjamin Garcia Saxe  
architect-constructor,  
Project: A forest for a Moon Dazzler, Costa Rica  

**Date:** 31/03/2013

**QUESTIONS**

1. I usually make a profile for the people that I take interviews from. Would you like to tell me some things about your work? Are you working mostly with natural materials? What kind of projects do you produce? (small scale, residential buildings, public buildings)?  
   We work on all scales...from master planning...houses...and even a 12,000 people auditorium. We believe that with a responsible approach to architecture which is intelligent and saves energy, with creativity and common sense we can bring beauty with the same budgets other use. The power of creativity to make something ordinary into extra-ordinary.

2. What was the restrictions that you have for this project? (cost, material, time, size)?  
   The main restrictions were cost (40,000 usd) and the climate which ranges from very rainy to very dry and hot (36+ degree C).

3. How come to the decision to design a project and use bamboo as the main facade material? Did it derive from your scientific approach and decision or from a client’s order? What was your experience on convincing the client to use bamboo in his building? Where there many hesitations at the beginning? I am also interested in the window and door connections.  
   We used bamboo because it was a free material on a farm that no one wanted to use. There is a lot of bamboo in tropical climates and people don’t use it because it has a “poor people” connotation. We wanted to dignify this material and use it in a creative way to show that any material can be made amazing with creativity and wit.

4. The facade is really impressing. How can this light construction control the interior climate? What are the demands of the area?  
   The bamboo and Rattan screen allows for constant and controlled flow of air in order not to use air conditioning.

5. How is the facade formed? As far as I can see, there is a load bearing frame which carries operable wooden panels filled with a fabric layer and a bamboo layer. What is the function of each element (fabric, bamboo)? To me, if we talk about the poetics of the space it seems that bamboo on the facade undertaken the difficult function of make the facade a vivid organism. An element that can react with the wind. However is that correct? Are the bamboo pieces steadily placed on the wall or can they move?  
   The facade is made of metal frames with metal rods that make a type of cage which in turn holds the bamboo. It was important to make a safe house that none can come in when it is left alone. The bamboo is weaved through the metal rods and it is free to move in the internal garden....and it is fixed in the bedroom and living room by the rattan screen.

6. What material did you use to carry the loads of the construction? Is that steel?  
   The construction is a concrete base with a primary metal frame and secondary metal doors with rods that hold the bamboo. The roof is tin.

7. How was the construction process exactly? How do you make the connections (operable wooden panels-frame, bamboo-panel, texture-panel)?  
   The main frame of the house was put up first and then the doors with the bamboo is placed on very large door/gate hinges...

8. Are there any climate restrictions of using bamboo? Can a bamboo construction last in the moderate maritime climate of the Netherlands?  
   If cut at the right moment, protected in the right way, and designed correctly bamboo can last as long as wood. I see no limitations for its use in the Netherlands.

9. Are there any limitations while constructing? (for example weather limitations, need of dry environment or we can continue constructing regardless rain and humidity for instance).
10. What is the life expectancy of this construction? What is the needed maintenance?
   The bamboo needs to be stained once every year.

11. How long is the growing season of the bamboo plant?
    Depends on the species…we used Guadua.

12. What do you think is the advantages of using bamboo in the constructions?
    It is a fast growing material with amazing natural properties of beauty and aesthetics.

13. How did you waterproof the roof? Did you place more layers of the same texture used at the walls or did you use any other kind of waterproof layer?
    We have a tin roof over the bamboo ceiling.

14. Do you think that there is a difference in building and planning costs between this project and a project worked out with standard materials? Was the cost of the Green Village comparably low in comparison with that if you had used concrete, wood or standard materials?
    We had a lower building cost because the bamboo was free but if we had to buy it then it would compare with normal building costs.

15. How many square meters is the size of the project? How many kg of bamboo did you use?
    100m² with more than 5000 pieces of bamboo.

16. How many different kind and forms of bamboo did you use? Did you make them yourself or did you buy them from a company?
    The same diameter of 6 inches.

17. Did you use the bamboo elements directly as it is (after you buy them or you harvest them) or did you make any special treatment? (for example, using borax and boric acid to protect the material from rot and insects)
    We treated it with Diesel, dried and then stained it.

18. Do you think that the laborers, working force, the engineers and the designers need special knowledge and qualifications in order to construct projects with bamboo materials?
    No…we used normal labor…

19. What did you learn from this project? What would you do different today? (in terms of design or problems at the construction that you faced, etc.) Where there some important changes during the construction that you haven’t foreseen them science the design step?
    We learned that it is very important to “play” with materials to find out what they can do. It would have been better to bring the large hinges from abroad for the doors as the ones we used are not very good.

20. What do you think is the main problem that bamboo are not using in a greater extend in the north Europe? (It could be the lack of experience of the engineers, architects, laborers, or the difficulties at the procurement and cultivation of the bamboo, the costs, the clients desire and confidence at the contemporary methods and materials or the durability of the material in wet and cold climates for instance)
    I believe that the main problem is that it is not native and there is not a tradition of its use. However more and more people realize its potential to be used in different climates and its beauty.
Name: George Ritsakis
Working: Volunteer worker, construct his own house
Construction materials: straw bale, lime, wood, mud, cob
Date: 01/04/2013

QUESTIONS

1. I usually make a profile for the people that I take interviews from. Would you like to tell me some things about your work? Are you working mostly with natural materials? What kind of projects do you produce? (small scale, residential buildings, public buildings)?
   
   I am working on the field of natural buildings since 2005 when I wanted to build my own house. I attended some seminars on stone building but I decided that I would prefer to search for alternative materials. While searching I found that working with cob could be very interesting and have very efficient results.

2. How did you come up with the selected material? What are your criteria, under which you choose the building method which you finally use in the construction?
   
   The Greek legacy system was very strict at that time. It was only possible to have a building permit for wooden structures. For that reason, I decided to work with cod and wood. What I do, is first build the wooden sub structure and then I fill them with cod. It was very difficult in general to find a building solution due to the Greek norms. With this type of construction we could build even three storey buildings. In general we could have higher buildings but in that case we would have to change the type of wood that we use to carry the loads.

3. What difficulties did you face?
   
   For me the greatest difficulty that I faced was the lack of knowledge. This types of constructions are not that popular any more, and it is difficult to find scientifically correct information. Apart from that, the most difficult part of the construction is the coating. It is the key of the good performance of the wall.

4. How did you made the basement of the construction? It is very important in general to protect straw construction from moisture and the basement is a critical point. Did you use any water repellent membrane?
   
   It is true that the basement is critical for the wall construction. In this case however, I didn’t use any kind of waterproof layer. I took the advantage of the soil type of the site that is rocky. Above the big rocks of the basement and footing construction, I placed big stones. In this way, the water that could possibly enter from the ground can easily lead out of the construction by the free space left in between the stones. But in any case, the wall can deal with small amounts of water as the wall is breathable.

5. How is the window and door detail at the straw bale building? I have seen that in many cases they put the frame directly on the bales, without any wooden support underneath. Is that normal? I find it rather risky.
   
   It is very important to have a wooden substructure (beams and columns) where you can build on the window frames. That is also important in terms of earthquake protection. I was trying to find answers to many questions through the internet.

6. What types of coating do you use in these constructions?
   
   There are three layers of coating:
   The first two layer is made out of mud, straw, sand and horse manure. At the last layer the coating must be finer. Thus we do not put straw and, instead of manure or lime, we put marble powder (it is called A3). We put this powder in order to test the new mixture (the one without the lime) but that doesn’t mean that the previous wasn’t efficient enough. We have tested both mixtures and they face no problem while exposed to extreme weather conditions. In general we like experiment with different materials. We also use oil-based dyes as a more natural solution.
In your case, in the Netherlands, I believe that there are two possible options for the last layer of coating. The first option, could be, the application of pure white lime. As we normally do at the Greek islands. It is completely waterproof. The second option is to apply linseed oil. It is transparent and can protect the wall from extreme weather conditions. However, it has an important disadvantage. It blocks the pores of the wall and make it not breathable any more. In this case you might treat to the wall as the brick wall with small openings at the upper and bottom part.

7. In the case of moisture entering the construction and destroying the wall is there anything that can be done?
   Actually you can replace that part of the wall completely. Though, the sooner you understand the problem the better it is.

8. How long did the construction take in total?
   The construction started last July. In total it takes us 4 months. But the most important issue in the construction are the weather conditions. You cannot construct under rain. That parameter may extend the construction time a lot. (for a single story, 60m2 house for example). The step that is time consuming, is that of the wall construction. It is vital to let the wall dry completely and that might take some time. If for example the wall is wet, it is not possible to apply the coating as it will definitely crack. I am at the moment constructing one more house where the roof is already there to protect also the wall during the construction.

9. What was the total cost of the construction?
   Normally it is as expensive as any other house made out of concrete or brick. In my case, I put personal effort that make the cost smaller.

10. What are the main advantages of choosing one of these natural ways of buildings over the most common ones like concrete and brick constructions? The reasons are only environmental or are there other advantages for the user? Better quality?
   Apart from the environmental issues that are of course very important, this shelters also create a healthier interior space. Last but not least, these type of constructions can pay you back while living in the house. That means that the cost for cooling and heating can be even 80% less. At this house for example I don’t use at all air conditioning during the summer and the during the winter I take advantage of the thermal mass of the walls to keep the house warm.

11. What kind of maintenance does the building need?
   To be honest I do not know at this moment. The construction is pretty new so we will discover it in a few period of time.

12. What do you think are the main advantages of building a house with natural materials?
   I personal believe that it is the best solution especially for residential houses, school and hospitals. Apart from the environmental issues, the interior space that is created is much healthier.
Questionnaire No.9

Name: Rick Lindsay  
Professional: rammed earth constructor  
Working with Earth Structures Group, Australia

COB team: Is a team of volunteers and professionals that work with cob, adobe, straw bale, earth bags, rammed earth, earth constructions, clay mixed with straw.

Date: 07/05/2013

QUESTIONS

1. Moisture problems:
   As far as I know the number one problem of natural buildings, including rammed earth buildings, is moisture. For that reason the natural walls should be breathing walls and the use of rebars (steel) as reinforcement is prohibited. However I have noticed that this is not a necessity for rammed earth buildings. Among other variants (walls with or without insulation, ...) in many cases there is steel reinforcement but at the same time there is cement input at the mixture. That means that we have two basic solutions: a. rebars as reinforcement + cement in the rammed earth mixture (no breathing facade) , b. wood/bamboo reinforcement + clay based rammed earth mixture (breathing facade). Is that correct? If so, what do you prefer to use?
   In many cases there is no coating. If a rammed earth building is located in the Netherlands, where the climate is moderate maritime, do you think that there would be problems if we use no coating?
   We use 8% off white cement but if possible no re-bars. Re-bars can cause cracking due to their resistance to the natural shrinkage of the walls. Also they rust over time.
   Our SRE walls still breathe, even with the small amount of cement we use. We also add a silicone/silane admixture called Plasticure which is manufactured by Techdry Building Solutions in Melbourne, Australia. Plasticure adds a waterproofing element to our walls which prevents rising damp and efflorescence which occurs when freshly stripped walls are hammered by rain. These RSE walls would be fine in the Netherlands maritime environment, if properly built.

2. Mixture
   a) The material consistency of the rammed earth is a very critical point. Unlike other natural building techniques (like cob, earth bags) here the limits of the precision are narrow. What analogies of water, sand, gravel and clay? Does this analogy change according to the location of the projects and the climate variants?
   b) My intention is to use no cement in the mixture of rammed earth. What is the role of cement in the mixture? Does it influence the strength of the wall and does it also have a waterproofing effect on the wall? What is the main advantage of the rammed earth walls used now comparing to the oldest form that contain no cement. There are examples that last for centuries (for instance: Great wall of China). That means that the biggest difference is at the dimensions of the wall? What is your opinion of using bamboo or wood reinforcement instead of re-bars?
   As a company that earns a living making earth walls, we could never build earth walls with no cement. We have seen it attempted in the UK where, for example, whole buildings have had to be dismantled because the walls failed after ten years. You can replace windows, or roofs, or floor tiles easily enough. But to replace solid masonry walls means you have to knock down the whole house. This is too much responsibility to allow us to sleep properly. It would be awful for the building owner, and very unfair to allow them to believe it would work in the first place.
   So we urge anyone building other people’s rammed earth houses, do not try bamboo reinforcement or other systems that seem to work in other climates and cultures. In the Netherlands, the lawyers would finish you (if the owner didn’t finish you first).
   Attached is a specification within which you will find a good break-down of

Above is illustrated the Peninsula House project designed by Robson Rak architects
the mixture. Note as a rule of thumb, we use only quarried aggregates from licensed quarries. The analogy does not change according to climates.

3. Maintenance
What is the process of maintenance include? How often should that happen?
The “feet” of the walls, where the walls meet the concrete slab or concrete footing, MUST be kept out of the surrounding ground. Otherwise they will be affected by rising damp.
The very tops of SRE walls need to be capped using cement render or metal capping systems. These caps must protrude min 18mm past the walls surface to shed rain water away from the wall face.
If these items are observed, there will be no maintenance.

4. General problems
Which do you think are the weakest points of rammed earth technique? Are there some specific problems that you face during the construction or the design?
The weakest point of the structure is the feet (must be kept dry) and the tops (must be capped).
Design must be kept simple to avoid frustrating the builders of the walls. Ask Kathryn for design parameters. She designs easy to build walls which are ultimately far more beautiful than the complicated ones.

ATTACHEMENT

PART I GENERAL

101 Scope
The work of this section includes but is not limited to supplying and installing a complete system of monolithic stabilised earth walls exclusively by a member of the Affiliated Stabilised Earth Group (ASEG) using the “Stabilform” formwork system and also includes:
Formwork
Earth materials
Cement
Waterproofing of admixture
Sealing of completed walls
Testing of materials by NATA approved laboratory

102 Related Work
Co-ordinate and co-operate with the following trades:
Site Preparation – Excavation
Concrete
Structural Steel
Carpentry
Plumber
Electrician
Mechanical Services
Wall Surfacing trades

103 Quality Assurance
Perform the work solely under the direct control of a member of ASEG, see clause 101, who will select the trades people for the work and ensure that the work complies with the requirements of relevant Statutory authorities.

104 References
Comply with applicable portions of the following Australian Standards:
AS 1141.51 1996 Unconfined compressive strength of compacted materials
AS 1289 Methods for testing soils for engineering purposes
AS 1289.3.1.1
AS 1289.3.2.1
AS 1289.3.3.1
AS 1289.3.4.1
AS 1289.3.6.1
AS 1289.5.2.1
AS 3610 1995 Formwork for concrete
Comply also with compressive strength tests in CSIRO Bulletin 5, Forth Edition, Appendix E and Bulletin 5, Table 2.2.
105 Submissions
The Subcontractor (member of ASEG) is required to submit for approval and
testing, the materials required for the construction of stabilised earth walls and
to provide written description of
A. The location of material source with an estimate of the quantity of
material available at the source.
B. Method of excavation of the material.
C. Proposed location of stockpiling of material, if necessary, at the site.

106 Laboratory testing of materials
The materials to be tested are listed in clause 201 of this specification.

Arrange for tests to be performed by a NATA registered laboratory in accord-
ance with its terms of registration.

A. TESTS REQUIRED INCLUDE:
Soil tests
Consistency limits (Atterberg limits)
Liquid limit: AS 1289.3.1.1
Plastic limit: AS 1289.3.2.1
Plasticity index: AS 1289.3.3.1
Linear shrinkage: AS 1289.3.4.1
Particle size distribution: AS 1289.3.6.1

B. TESTING BY METHOD 5.2.1: Soil compaction and density determination
of the dry/moisture content relation of a soil using modified compactive effort:
To AS 1289.5.2.1 - 1993.
Include in the test reports:
1. Cement content by volume.
2. Elapsed time between addition of cement and compaction.
3. Date moulded.
4. The dry density corresponding to the maximum point on the moisture
content/dry density curve as the “modified maximum dry density” in
 tonnes per cubic metre to the nearest 0.01
5. The percentage moisture content corresponding to the maximum dry
density on the moisture content to the nearest 0.5.
6. The percentage of oversize material retained on the 19mm sieve or
the 37.5mm sieve on which the materials is retained whichever is applicable,
to the nearest 1.
7. When required, the plot of dry density against moisture content.

C. UNCONFINED COMPRESSIVE STRENGTH OF COMPACTED MATERIALS
TO AS 1141.51 - 1996.
Samples to be retained in the mould for 12 hours and air cured in an open
environment for 7 days.
Test results on the specimens to include:
1. Material retained on the 19.0mm sieve as a percentage of the moist
mass in the original sample.
2. Details of replacement of coarse material, if applicable.
3. When a binder is used, elapsed time between addition of the binder
and compaction.
4. Moisture content at which specimens were compacted.
5. Details of curing.
6. Moisture content of specimens on completion of testing.
7. Compactive effort applied, method of compaction, and number of
layers.
8. Dry density of specimens as compacted, to the nearest 0.01 t/m3 and
if required percentage of maximum dry density of each specimen.
9. If required, the laboratory moisture ratio of the material prior to com-
paction.
10. The normal height and diameter of the specimens, in millimetres.
11. Unconfined compressive strength, as the average of the strength of
two test specimens to the following precision:
   For UCS less than 1.0 Mpa, report to the nearest 0.02 Mpa.
   For UCS between 1.0 Mpa and 2.0 Mpa, report to the nearest 0.1 Mpa
   For UCS greater than 2.0 Mpa, report to the nearest 0.2 Mpa.
12. When a binder is used, the method of preparation of the test sample.
13. Reference to this Australian Standard, ie AS1141.51.

CONFORMANCE TESTS
Characteristic adjusted compressive strength test: to CSIRO Bulletin 5 Fourth
Samples to be taken from batch being placed on construction site. One specimen shall be compacted for each test. Specimens shall be compacted in a 90mm diameter x 200mm high cylinder. Samples to be retained in mould for 12 hours and air cured in an open environment for minimum 7 days.

Report to include:
1. Identification of project and the manufacturer of the specimens.
2. Date and location of sampling if possible.
3. Identification of particular wall sample was used to construct.
4. Date of test.
5. Cement content by volume.
6. The compressive strength, in megapascals, of each specimen.
7. Aspect ratio of each specimen.
8. The adjusted compressive strength of each specimen.
9. The characteristic compressive strength.

Soil evaluation criteria: To CSIRO Bulletin 5 Table 2.2.

PART II  MATERIALS 200

201 Materials
A. Materials may be gravels, laterite soils and soil blends.

Soil contents:
- Organic content: Less than 2%
- Clay and silt content: Material below 0.075mm to be below 20%
- Sand content: Material between 0.075mm and 4.75mm to be not less than 50%
- Gravel content: Material between 4.75mm and 75mm to be above 30%
- Not more than 5% to be retained on 37.5mm screen size.
- Cement content by volume shall be 6% minimum to 12% maximum determined by Mix Design and Strength Evaluation test.

B. Materials may also be:
- Recycled crushed brick rubble
- Crushed building rubble ex nominated supplier to suppliers standard.
- Cement content shall be no less than 12%. Proportion to be determined by Mix Design and Strength Evaluation test.
- A minimum of 8% cement by volume shall be used in reinforced earth walls.

C. Compressive strength
- Minimum characteristic compressive strength (Cca) of 5.0 Mpa.

D. ASEG Plasticure
- To be added at a rate of between 0.125 and 0.75 litres per tonne (1000kg) of dry mix. Rate will be determined by specific mix designs.

E. Anchors and Fixing
1. STRUCTURAL FIXINGS
- Ramset Chem Set Injection System. Structural fixing should be located no less than 150mm from top or side edge of the stabilised earth wall. Holes should be drilled a minimum of 3mm larger than anchor diameter and be thoroughly blown out before injecting epoxy resin. Any overspill in visible areas will need to be wiped away immediately.

2. SECURING WALL FRAMES, WINDOW FRAMES, DOOR FRAMES.
- Secure by one of the following means;
  - Ramset Ramplug Nylon Plug Fasteners
  - Hilti HRD-H Plastic Frame Anchors
  - Avdel Excalibur Screw Bolts

3. FASTENING ALUMINUM WINDOWS, PIPES AND CABLES, TIMBER BATTENS AND COMPONENTS FOR ELECTRICAL AND PLUMBING INSTALLATIONS
- Secure by one of the following means;
  - Hilti HPS-1 Impact Anchors
  - Ramset Nylon Anchors
  - Ramset Masonry Anchors

PART III  EXECUTION 300
301 Examination
Inspect site conditions before starting work. Arrange with Contractor for rectification found necessary to facilitate wall construction. Start of work means total acceptance of conditions.

302 Damp proof course
Form a damp proof course (DPC) between the footings/slab surface and the stabilised earth walls, using an embossed plastic fabric strip suitable to the thickness of the wall.
Protect the face of a stabilised earth wall below finished ground level by application of a cement slurry "Silasec" admixture or similar. Do not compromise the damp proof course with surrounding soil or pavement built up higher than the footing or slab surface.

303 Formwork
Place formwork in accordance with ASEG written instructions and maintain in position for 12 hours after placement of material.

304 Vertical steel reinforcing
Avoid steel reinforcing wherever possible due to complications with vertical shrinkage along the embedded steel. Lag vertical steel reinforcing to prevent stabilised earth adhering to and shrinking along the bar.

305 Construction joints
Locate construction joints as shown on drawings. Form mechanical keys at each construction joint and fix 25 x 25mm bitumen impregnated foam strip to full height of wall. Foam strip to extend 100mm along floor or footing surface to ensure a complete seal at the bottom of the construction joint. Form 25mm v joint on both wall faces.

306 Chamfers
Form 45mm chamfer at ends of wall panels or exposed corners.

307 Electrical and other services
Seal electrical components to be cast in wall to prevent penetration of soil during compaction. Boxes to be located at heights specified. A minimum of 100mm cover should be allowed for cast in conduit, pipes, etc. Water pipes should be suitably lagged to prevent penetration by sharp stones during compaction.
Where conduits and pipes cross construction joints provide for a suitable means of absorbing movement without fracturing.

308 Placement and finish
Place blended material in forms in 200mm (maximum) layers and compact within two hours of blending.
Surface finish shall be generally consistent throughout to the colour and texture of an approved sample.

309 Construction tolerance
Finish work true and free from bulging in the wall surface. The maximum allowable deviation from true position shall be 8mm horizontally and 4mm vertically per 600mm formwork lift. Trueness of surface and joints shall be in accordance with AS 3610, Class 3.

310 Anchors and fixing
Locate accurately penetrations required for connecting walls to structural frames, window and door frames and other installations.
Refer clause 201 E for types of anchors.

311 Sealing of stabilised earth walls
Internal walls: Seal with a water born acrylic sealer diluted sufficiently with clean water to allow deep penetration and clear low sheen finish.
External walls exposed to extreme wind driven rain: Apply a flood coating of a solvent born silane-siloxane system at recommended application rate.

312 Protection of stabilised earth walls
Emphasise to other subcontractors that the stabilised earth walls are off-form finished. It will be the builders responsibility to remove any staining or markings
on the walls caused by other trades or staining caused by leeching of hardwoods onto the walls.

313 Cleaning
Remove formwork and debris from each work area after stripping forms. Leave area clean to the satisfaction of the Architect.

314 Completion
Complete contracted work in accordance with contract documents and written variation orders issued by the Architect.

END OF SECTION
Dear Hannah,

Re: Deakin Uni Design/Construction Project
Double-Storey She House

1. Footings / Flooring:

Full length plastic 0.4 C30
112 Ø bars, max 600mm high @ 600 c/s
MIN 75

CONC FOOTING TO ENG SPEC.

Top of wall to top of footing must be an increment of 300 mm.

400 or 300 mm.

20 April 2013

Member: Earth Structures Group

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Melbourne 0400 987 254
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France, Maubourguet open mid 2014
Sth Korca – Gongju 8210 5432 3234
Commercial Australia 0357 787 797

Members aseg: Affiliated Stabilised Earth Group - Leaders in the design and construction of stabilised earth buildings.
1.2 FIRST FLOOR WALL PLATE CONNECTION TO WALL

200 x 50 FLOOR PLATE (4CM)
CHEMSET 12 MM @ ALLTHREAED ROCS EMBEDDED MIN 200MM
@ 900 C'S

1.3 FOOTING DETAILS

a) COMMON

- 112 @ START BARS @ 600 C'S.
- BENCH MESH TM12/3
- MIN 75
- WIDTH OF CRE WALL, OR 100MM UNDER.

b) FOR EXTERNAL ENTRY WALLS ETC.

- DPC
- 50MM CHAMFER TO SHEO FLOOR

C) SLAB EDGES

- NO STARTER BARS!
- 50MM ALUM FLASING CUT INTO SLAB.
- DPC
- MIN 75 MM

WE PREFER CONC SLABS TO FOOTINGS AS THEY ADD \ COMPLEMENT
THERMAL MASS \ PROVIDE A CLEAN STABLE WORK PLATFORM FOR
CONSTRUCTION. STRIP FOOTING SITES BECOME BOGGY \ AT TIMES
DANGEROUS.
1.4 Ext Wall Connections

Ensure there is a visible section of the wall base to eliminate the chance of termite tunnel/access and gaps!

1.5 Ext Rammed Earth Steps

- Suggest using timber, brick, or concrete.
- Are not really up to traffic wear.
2. SERVICES

2.1 WIRING, PLUMBING, TIN ETC

25 MM CONDUITS FOR ELEC REAR.

WALL BOXES WITH EXPOSED FACE FOR SWITCH FACES.

HEIGHTS OF BOXES, PIPES ETC @ 300 MM INCS FROM FOOTING OR SLAB.

CONDUITS, PIPE TAILS ETC PROTRUDE TO TOP OF WALLS.

2.2 PROTECTION OF SHOWER AREAS

WE COAT ALL INT WALLS WITH AN ACRYLIC BINDER.

PLASTER, TIES ETC APPLIED DIRECTLY TO FINISHED WALLS.

DO NOT USE SLE SURFACES FOR DIRECT WATER SPLASHING (IE SHOWER RECESSES).

3.0 WALL DETAILS

3.1 INSULATION

50MM STYROFOAM BARRIER

VALUE OF
1 SE 4.62

RESIN BSC PINS @ 600 INCS VERT + HORIZ.
3.2 INT WALL STRUCTURES

8mm Ø DYNABOLTS @ 600 c's.

MIN 100

4.5 HM CHAMFERS TO ALL SIDE CORNERS

3.3 WINDOW CONNECTIONS / DOOR CONNECTIONS.

PACK SPACE USING COMPRESSIBLE

FASTEN USING 8MM DYNABOLTS

INT MOLDS

STORM MOLDS

BY "DAVCO"

3.4 TWO STORY SUE WALLS

600MM LONG THE DOWN ROODS @ 900 c's.

SILLs
DOOR SILLS + WINDOW SILLS @ 300 INCS FROM SUB OR FOOTING LEVEL.
4.0 ROOF / PARAPETS

4.1 Parapet Walls - MUST BE CAPPED

1. Folded metal cap

2. Cement render cap

Min. 18 mm to throw water

If unseen, flash this area as well.

200 Chemset anchors

I hope this covers all. Call me with queries.

Rick Lindsay 0418 569 985 or

info@earthstructures.com.au

The two common architect mistakes with GRC are 1. to bury base of walls
and 2. to leave GRC bars exposed. The more famous the architect the worse this!
Questionaire No10

Name: Charles Thuijls
Professional rammed earth constructor, LEEMWERK company (www.leemwerk.nl), NL

Date: 15/05/2013

QUESTIONS

1. Moisture problems:
   In general there is always a fear of moisture getting in the wall. In this case, rods that could be used as reinforcement might rust. Is it possible to use other materials as reinforcement. Like bamboo or wood? Can these solutions collaborate with rammed earth.
   
   Yes, this is possible. However it need careful in the detail. For example if we use wood as reinforcement we must be sure that there is enough rammed earth around so that the rammed earth wall does not crack. That means an increase at the thickness of the wall. In this case (of wooden reinforcement) it is also recommended to use reinforcement in horizontal layers. The reinforcement that in these situation is commonly used is a kind of polystyrene or polyethylene netting that it is also used to reinforce streets. This layer is applied approximately every 30 meters of compacted wall. So the process is as following:
   • Ramming 30 cm of wall (30 cm should be the finished wall that means we pure approximately 60cm of the material in the mould)
   • Apply a layer of the polyethylene leaf
   • Pure new loose material on top in order to ram it

2. According to the mechanical properties of the material is that possible to use it as load bearing material?
   Yes this is possible. However, here is the Netherlands there are very few people working on that material. With this climate, it is difficult to protect the wall from moisture. In Bath there is a university that make experiments and investigations on rammed earth (researchers: Vasilios Maniatidis & Peter Walker - Natural Building Technology Group, Department of Architecture & Civil Engineering, University of Bath, Bath BA2 7AY, Telephone: 01225 386646, Facsimile: 01225 386691).

3. What type of insulation do you usually use?
   It could be a common insulation material like mineral wool. However, when you use rammed earth both inside of the building and inside (situation 3 of my drawings: rammed earth non load bearing wall) you need to have an insulation material that is rather compressed and stable in order to fix it in place. This material could be a foam glass board, that is not environmentally friendly. So in general the way of construction indicate the type of insulation material you could use. Even in that case of wall (rammed earth in both sides of the wall), where the construction could be done in one mould, it is not possible to apply first the insulation and then continue with ramming the wall. What is normally done, is compressing the rammed earth material in parallel with applying the insulation.

4. At first I thought that it is not possible to make a cavity in rammed earth walls because of the construction method. But as it is possible, why you don’t make a cavity to help the ventilation of the wall and make it dry in shorter period of time, if moisture appear? Like what is happened in brick walls. Would that cavity make the construction more durable and more rain resistant?
   It is indeed possible to make a cavity in rammed earth walls. However, in practice, I think, you do not change anything in terms of ventilation as the rammed earth wall is a breathing wall. In brick walls, the material (brick) is more water resistant so the introduction of the cavity has a big difference in the humidity levels of the construction. In any case though, it would be worthy to test and experiment the results of a rammed earth wall with ventilation cavity. Maybe, it could be easier to test the results of a rammed earth wall where the insulation material is that big red hollowed blocks. This hollows can replace the ventilation cavity I believe. These blocks can expand and shrink more or less in the same degree as rammed earth because both contain clay. This might be practically the best solution.

5. What about maintenance? How you maintain the walls? You put any kind...
of plaster? I am asking because in this case you lose the typical appearance of rammed earth.

You can of course plaster it but indeed you will accept that that will influence the appearance of rammed earth wall. So if you take for granted that every 5 years you have to replaster it, then rammed earth is not a disadvantage because you can protect the wall even if you lose something from the appearance. So in structural point of view, rammed earth is a proper solution for an exterior wall. In the cases that I support that rammed earth is not a good solution for an exterior wall in the Netherlands, are in the situations where the typical appearance of rammed earth must be kept.

6. I agree with you and I believe that especially in the situation where you are using iron oxide additives to produce colour patterns on the wall the expression of the wall is destroyed. Is there anything that can be done in order to keep the pattern on the wall?

Well, yes. I always suggest that during plastering the worker should follow the natural lines of the walls. There is also possible to apply different colours at the coating to keep the final outcome close to the initial wall.

7. Are there other kind of coatings that are transparent and you can use them to plaster the rammed earth wall? Like for example lime wash (that is actually translucent) or any kind of spray? Have you ever used any of this products?

I have never used this kind of products. I always replaster the wall but I pay special attention at the process so that follow the pattern of the natural wall as much as possible. It is though possible to plaster with lime wash but you must be aware about the colour changes. The wall will not be the same.

8. What is the difference between the rammed earth and the compressed earth wall? Is it the same mixture but with less moisture?

Yes there are similarities. The mixtures are actually comparable, but in the case of compressed earth blocks the sand that is used is more fine.

9. That means that they have higher levels of compressive strength, because actually of the finest sand that is used?

Yes that is true.

10. I was thinking to use these blocks in order to support the window frames, instead of sills and lintels. They can produced in kind of shape and I was thinking that this could be a good idea as you can even form the curves to lead the rain water away of the construction. Do you think that this is a good idea? I also mention that this blocks could be cement stabilized because I can imagine that the y will be hardly exposed to weather conditions.

The problem with compressed earth blocks is that they cannot be reinforced. In your design, as I can see, the width of the opening is 1.80 m. That means you definitely need reinforcement. I would suggest to use concrete pre-cast blocks in this situation.

11. How do you normally install the windows in the wall? I was thinking of two construction processes. The first is ramming first the wall with a hole at the location of the window, and place the window afterwards, and the second is to build the window in parallel with the wall. Which method do you use?

The mostly used is the first you propose. You ram it as soon as you reach the level of the window, then you put a frame inside and you continue ramming.

12. How do you stabilize the frame on the wall?

It is possible to place some wooden beams in the rammed earth and support the window frame and screw it on these beams. It is also possible to use a very fine rammed earth mixture (without big aggregates) at drill the screw on there. In many cases they work with blocks of rammed earth. It is always necessary to use reinforced lintels even in the case of rammed earth without the wooden beams.

13. Does rammed earth wall need any kind of vapour layer from the inside? For example at the room of the kitchen where the humidity levels are higher?

That is a good question. I am not sure about that. Because there is a great amount of mass on the wall, it buffered and take the water. I do not know what will be the risk if you do not place any vapour layer or if it would be beneficial if you do. It will also depend on the type of insulation. If it would be a breathable insulation panel or if it blocks the breathing of the wall.
14. In the case of load bearing wall of rammed earth, which should be approximately the wall thickness? 
   40cm is the minimum. But it is also dependable on the height of the wall. The higher the wall the thicker it should be. There are also some guidelines on that. So I do not calculate every time what I want to build.

15. I have read that it is vital to have a very precise mixture. In some cases, as I read, they take samples of the soil that exist at the site, they make some mixtures with clay and all the rest ingredients and they test them. After that they make the dimensioning of the wall. Do you also follow that process? 
   If you want to use the soil of the site then of course you have to do this tests about the mechanical properties. In every case, you want to reach a certain number that is mentioned at the “standards”. In the Netherlands we do not have Dutch standards, we use the same standards with Germany (Lehmbau Regeln” standards: clay construction guidelines) So you make test until the final product reaches that numbers.
   In general in the Netherlands, in most of the cases, the soil is not suitable for rammed earth. For example in your site, in Ypenburg, the soil type is mud or sandy. So in Holland you can order a prefabricated mixture. Not an element but directly the mixture. Some companies here are Claytec (www.claytec.nl) or Serafino and you order directly the mixture you want to use. So you do not have to make any tests.

16. In general, rammed earth is a cheap or an expensive wall solution? 
   It is a more expensive solution in comparison with the standard building techniques (concrete or brick for example). Except for the more expensive logistics if you have to transfer the mixture a long distance, it is also more labour intense and thus more expensive. It depends very much on the situation, the complexity of the drawings and the construction limitations.

17. After the construction there is a period of wall shrinkage until it reaches its maximum durability. How long can this period last and how much height does a wall loose? 
   This period of shrinkage usually takes approximately one year. The height that it loses depends on the mixture of the material. It is one of the things you have to test. But in general, more or less, the wall loses 1% of its height. So a wall of 8m height measured at the day of the construction, it will finally become 8 cm shorter. At this period of shrinkage it is possible to appear some small cracks on the wall.

18. Are there differences a the logic of the design of a rammed earth wall compared to a concrete wall? Are for example some significant construction steps that influence the design? Is it also more time consuming because for example there are more engineers and experts that are involved at the decisions that should be made? 
   The design depends on the architects of course, but I think that the architects are not that familiar with the rammed earth constructions and they think in a “concrete” way. The architect should be aware of the rammed earth process. He should, for instance, leave space for the pneumatic rammers to work and treat to the space or the construction in a way that you have the needed space. We had an experience in Coevorden Stadskantoor where when we went at the site there was the ceiling already there. So it was very difficult to ram the earth at the top. This was also the reason that the project took much longer than we first estimated. This is something that the constructor should also have in mind, and be familiar with the rammed earth working system. Or for instance there would be changes at the location of the window. In one case, after discussing with the architect, he decided to put the windows 10 cm back because of problems that could the location of the window cause to the construction process.

19. Should the builders be specially trained in order to work with rammed earth? 
   No. The process is simple. The process is not very labour intensive. It is a very tough work but not complicated. There should be one person that should be aware of the process, be familiar with the casting and supervise the construction process and that is enough.

20. What is the main difference for the builder between working with concrete and working with rammed earth? 
   The main difference is in the casting. In the situation of concrete, the concrete mixture apply the maximum force on the casting at the base of the
construction. This happens because it is liquid. That means you should have better stabilised casting and more joints at the base. The difference with the rammed earth is that you only need to have in mind that the pressure is applied on the casting only at the point that you are ramming more or less. That gives you the flexibility to use the same casting as the construction grows. You can take the casting from the basement and use it on the top. There is no problem at all.

21. I noticed that at your construction you go very close to the ground. What I mean is that the distance between the ground and beginning of the rammed earth wall is smaller than I expected. What is the minimum distance? It is important to leave there a safety space. So let’s say lift the rammed earth from the ground level. It depends also on the material that the ground has but in general, about 10 cm are enough, in proportion of course.

22. How do you make the detailing at the base? Is there any waterproof layer between the basement and the rammed earth wall? Theoretically this is a problematic point. The main risk is to let the water goes in the concrete and then goes in the rammed earth. We use normal concrete footing and base and then we place a layer of DPC foil. But the main thing you should have in mind is to find a way to protect this point.

23. I have contacted some constructors from Australia who use a kind of transparent spray as a coating for the wall. Is that also a possibility here? Yes, I know this technique. It is a silicon oxide mixture that is transparent. It has the ability to harder the surface and make it more weather resistant. It reacts only with the surface, so it influence the first centimetre that will no longer been biodegradable but it protect the whole wall.

24. I would like your comments in my load bearing rammed earth wall detail. (drawing 4). I produced this detail, where I support the floor on wooden columns that are placed in the construction. Do you think that this is a good solution? Well, this solution indeed can work. You can also use some concrete there if you don’t mind. So instead of the wooden columns you can use precast concrete blocks like these that you have at the top to support the roof. It might be better in terms of stability also. Because these wooden beams have a tendency to rotate because of the floor weight. Rammed earth wall resist to this rotation and keep them in place but don’t forget that it is not as strong as concrete. This could also be more easy in terms of construction. Even if you have prefabricated holes to connect these blocks with the floor elements. Last but not least, you can deal better with the norms in this way. Because you easily support the idea of concrete in the construction in such a critical point.

25. What other construction limitations exist in the case of rammed earth? There are of course the weather limitations. While constructing and ramming the earth it shouldn’t be raining. I did have an experience of problems occurred because of rain during construction.
Possibilities of applying biodegradable materials in solid building envelopes in the Netherlands