RAW NATURAL BUILDING MATERIALS

Building a seaweed - processing farm with local raw natural building material on the coastal area of the Netherlands.

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1.Abstract - This report shows the potential of building with raw natural building material as a sustainable solution for reducing carbon dioxide (CO2) emission of the building sector. It is an attempt to define basic criteria for materials and criteria for the programme, design and climate of a building to allow more convenient choices of materialization, which will have a positive impact on the sustainability of a construction. Therefore research on the spatial programme of a seaweed - processing farm as well as on the organic design formed relevant ambient, spatial and structural criteria for the materialization of the structure. Furthermore the analyzed location and climate of the coastal area of the Netherlands and future climate change predictions gave information about factors that influence the durability of building materials. Finally thresholds for the full life cycle during the production/processing, use and disposal of a material defined criteria, on the one hand for the sustainability of materials in general and on the other hand for selecting locally available natural raw materials and building methods as an overview. The goal of this paper is to give an overview of natural building materials that can easily be compared, considering previous defined criteria of programme, design & climate.

Keywords: natural raw building material, sustainability, the Netherlands, seaweed-processing

2. Introduction - For decades human activities such as burning fossil fuels, the clearing of vegetation, and cattle and rice production (methane) have increased the concentrations of carbon dioxide, methane and nitrous oxide in the atmosphere, which results in a change of climate. (Singer 2010) It is widely recognized that anthropogenic climate change will have harmful effects on many human beings and is therefore one of the most significant global challenges that we will have to face in future. The change in climate is projected to result in severe weather events like flooding, heat stress, drought and deductive food insecurity (Caney, 2010). Nevertheless the predicted growing population, which is expected to reach 8 billion people in the spring of 2024 and even count 9.5 Billion inhabitants by 2050, implicates a rapid increase in consumption that causes greater greenhouse gas emissions and resource depletion (United Nations population division, 1999) **(**Hickman, 2011).

Future predictions estimate that by 2100 the CO2 concentration will be about 90-250 percent higher than in the preindustrial era and that the surface temperature increases from between 1,4°C to 5,8°C, comparable with a 4°C temperature difference between now and the last ice age. (IPCC, 2001) These predictions cannot be ignored any longer, therefore this report on the one hand deals with the challenge to provide adequate food for the growing world population and on the other hand with the challenge to fight climate change by stabilizing or reducing CO2 pollution caused by the materials used in the building sector. This paper combines possible solutions for both problems in one project. First seaweed farming in the Netherlands is researched as a solution for food scarcity and forms the programme of the architectural project. Second locally available natural raw building materials are investigated as materialization for the architecture of the seaweed-processing farm, in matter of minimizing the negative environmental impact of the construction.

Concerning the expected food shortage a major problem is the current excessive and abundant consumption of the wealthy privileged nations (Mackenzie, 2011).
“Worldwide meat production has tripled over the last four decades and increased 20 percent in just the last 10 years.” (Kumar, 2011, p.1) This resulted in an average meat consumption of 41.90 kg per person per year in 2010. If we

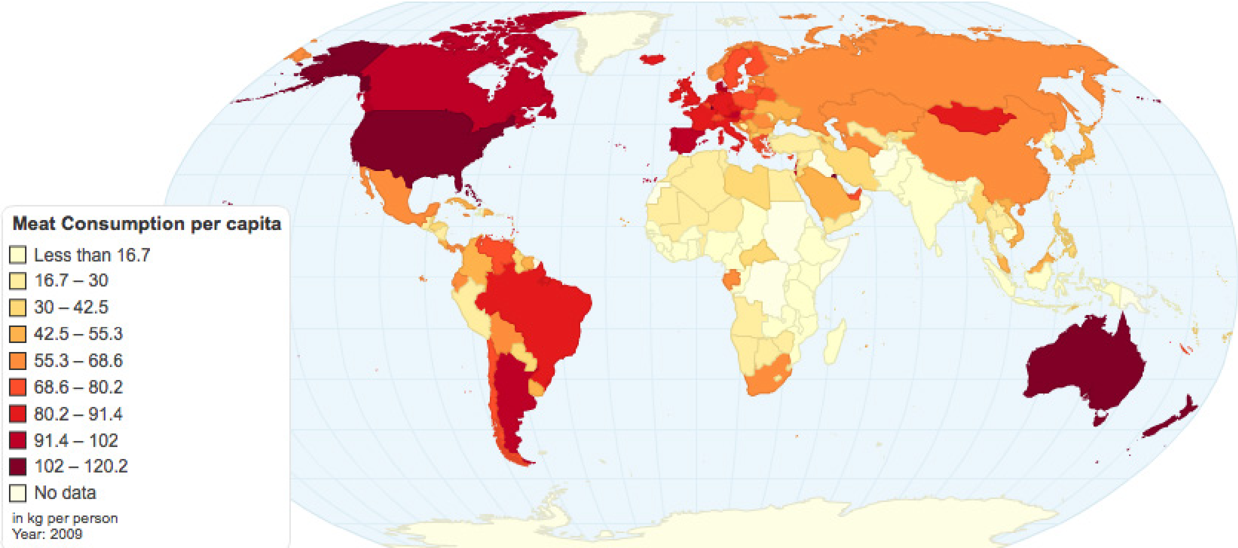
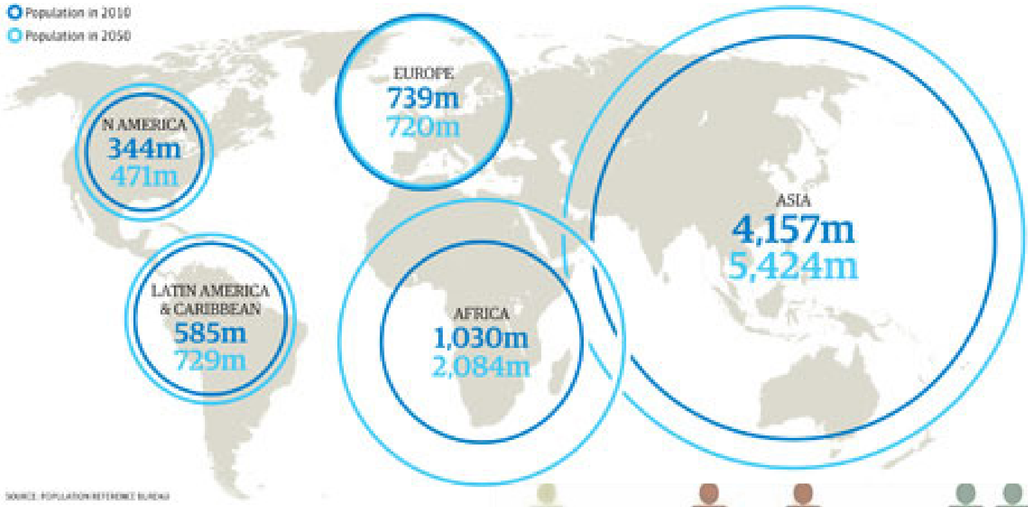


Illustration 1 - Annual world meat consumption per capita 2009



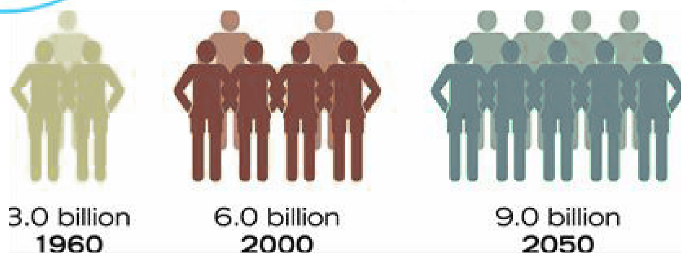


Illustration 2 - Prediction population growth 2050

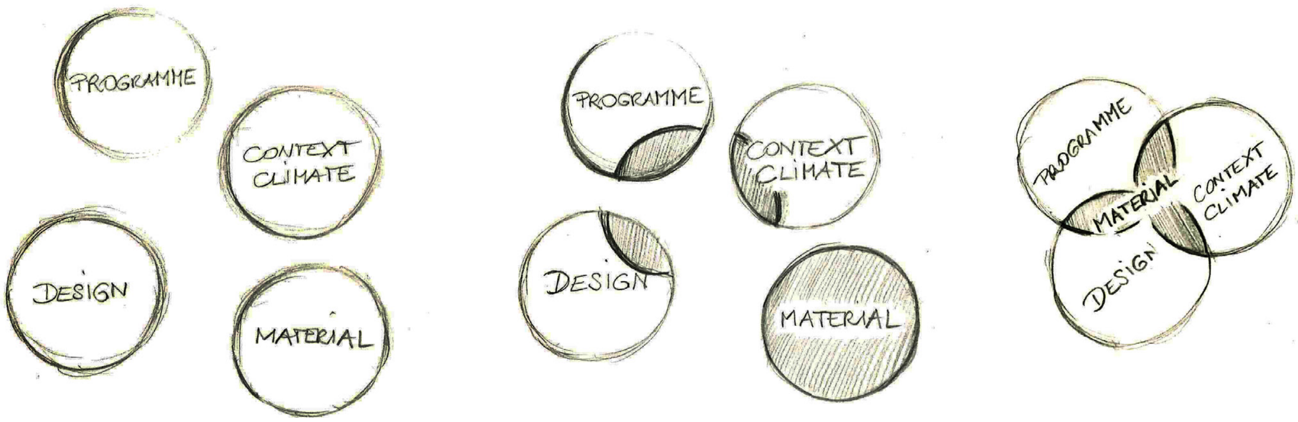
keep up consuming this large amount of meat, it will eventually be impossible to provide enough food for everyone in the future (Kumar, 2011). Since a meat based diet requires 7 times more space than a plant based one, a solution would be to reduce meat consumption by shifting the diet of the population of industrial nations more towards a plant based diet. By growing seaweed as food for people, a vast agricultural space can be developed in the ocean. Hence enough food for everyone could be produced in a more sustainable way for a longer period of time.

Beside the attempt of offering alternative solutions for sustainable food production in form of a seaweed farm another ambition is to use raw natural building materials for the materialization of the building to reduce pollution, waste and CO2 emissions. In fact Global CO2 emissions reached a historic high of 34,5 billion tones in 2012 and are constantly increasing (Oliverie et al. 2013). The International Energy Agency (IEA) states that residential and commercial buildings account for roughly 32% of global energy use, and over 30% of total end use energy-related CO_2 emissions (International Energy Agency IEA, 2012).

The structures materialization has big influence on the sustainability of an architecture, due to factors like it´s embodied energy and energy efficiency during use. As a matter of fact a major amount of CO2 pollution and energy waste of the building sector is already induced during the material processing, manufacturing and long transportation of building materials. On top of that some materials are hard to maintain and regularly even not disposable in a safe way.

To make a long story short, if we can somehow reduce pollution and the energy required to manufacture and dispose building materials we could well be on our way towards reaching a truly sustainable society (WILLMOTT DIXON, 2010).

Which local **RAW NATURAL MATERIALS** are suitable for **SUSTAINABLY MANUFACTURING PERMANENT** and **TEMPORARY, ORGANIC** architectural structures of a **SEAWEED - PROCESSING FARM** in the **COASTAL AREA** of the **NETHERLANDS ?**



STEP 1
DEFINING RESEARCH FIELDS

STEP 2
SETTING CRITERIA

STEP 3
FINDING MATERIALIZATION

Illustration 3 - Research method

3. Research question - The research question emerges out of previous acknowledgements of sustainable solutions. Hence the main considerations of this paper are the architecture of a seaweed farm combined with raw natural building materials in the Netherlands.

Which local raw natural materials are suitable for sustainably manufacturing permanent and temporary, organic architectural structures of a seaweed-processing farm in the coastal area of the Netherlands?

4. Background - Raw natural materials are defined as low processed materials that use less energy and produce less waste during manufacturing and are therefore considered as more sustainable. They are vastly available by local resources that are renewable and can be reused or recycled easily.

The design brief of a Dutch seaweed-processing farm provides the programme of diverse permanent and temporary spaces and defines the design and further the appropriate choice of materialization of the structure.
Using local low processed materials adjusted to its purpose could make a major positive impact on the emissions of CO_2. Therefore the main focus of this paper and the graduation project for Architectural Engineering is put on planning a seaweed-processing farm with locally available raw natural materials in the most sustainable way.

4.1 Objective and Methodology - The intention of this paper is to define criteria of the programme, context and design to be able to select a suitable materialization. Further it sets basic criteria to define sustainable materials and gives an overview of the different low processed natural building materials that are locally available and suitable for building on the coastal area of the Netherlands.
First, the method section analyzes the process of seaweed farming and the spatial programme of a seaweed-processing farm including specific required indoor conditions. The various processes will set constraints and define necessary qualities of the architectural space and hence of the design and its materialization. Furthermore, the organic architectural design is considered and will set demands for the materialization such as high flexibility.
Moreover criteria for sustainable materials are defined through references and literature research and conclude in accordance a selection of different raw natural building materials.
Then, the result chapter presents the materials that were selected and the material properties and characteristics, which were analyzed in the technical research. The suitability of the listed different sustainable materials is analyzed relating to the criteria of programme, climate and design.
A following discussion will critically point out the major points of the research and future prospects of material research. Finally the paper is completed with the conclusion.

5. Method - The starting point of the research was to define criteria that are relevant for picking sustainable materialization, which are the design, the programme of the architecture and the climate.

First, the conformance of the material with its functional purpose is of importance in matter of providing necessary ambient qualities as energy efficient as possible; therefore an analysis of the diverse functions of a seaweed-processing farm was necessary. Second, through research by design the appearance of the architecture and the aesthetical and structural requirements of the materials were worked out. Third, the necessary durability of the materialization according to the specific local climate of the coastal area of the Netherlands was investigated through intense research

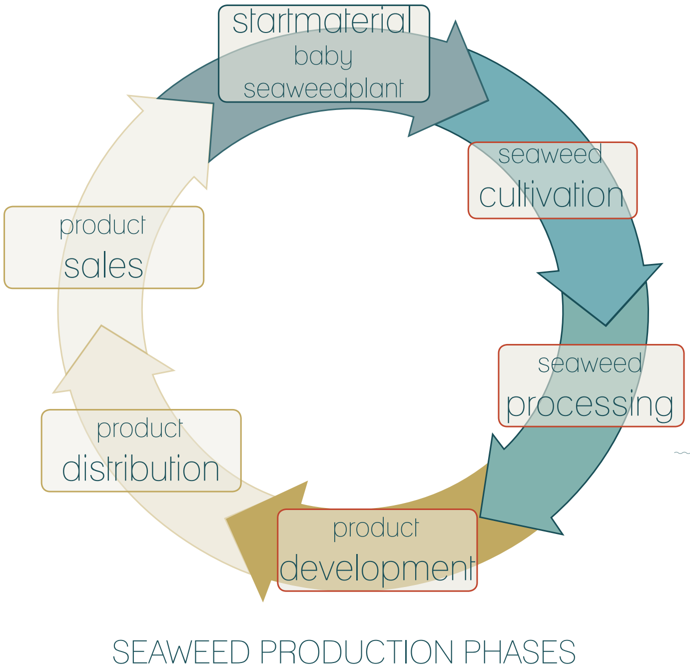


Illustration 4 - Seaweed production phases

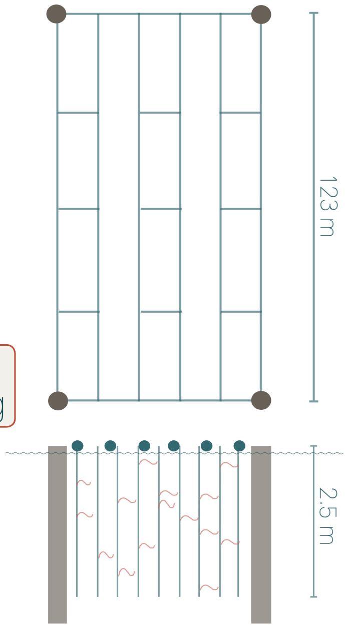


Illustration 5 - Seaweed cultivation

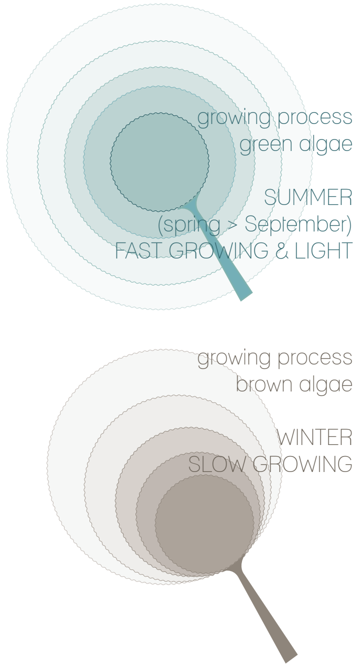


Illustration 6 - Seaweed growing

of climate predictions. Fourth, general constraints that define sustainable materials were researched and used to determine a list of raw building materials. Basic requirements for all materials are little processing and local availability, in terms of having their origin in the Netherlands. Finally, the raw building materials were reviewed for accordance and suitability to the various criteria of programme, design and climate.

5.1 criteria by function - the programme of a seaweed farm - The topic and the process of seaweed farming are very innovative and scientific information as well as literature is rather scarce and hard to find. Nevertheless an intense research on the cultivation of seaweed led to a pilot project, the “Zeewaar”, that currently takes place in the Netherlands. After interviewing involved researchers and employees of Rijkswaterstaat a first framework of the spatial programme for a seaweed farm could be formed. The main information however was gained through communicating with Rebecca Wiering, one of the partners of the Zeewaar project. She started the first sustainable seaweed farming in Europe with her colleague Jennifer Breaton in January 2013 in the Dutch Oosterschelde, in the South of Holland. In cooperation with Wiering a space-allocation plan was developed and a sequence of necessary spaces/ rooms with their required dimensions and specific room climates were elaborated.

General information about seaweed farming - Seaweed farming in Europe is an innovative attempt of making use of the sea as a vast area for agriculture. The relocation of the food production offers several benefits over current systems. First of all, it is a more sustainable way of food production, since nutritious environments, like the Dutch seawater, do not need additional fertilizers. Moreover, additional seaweed could help to purify our oceans. Secondly, drinking water will not be wasted for watering since the plants are already growing in the seawater. Thirdly, current agricultural areas could be relocated in the ocean, what would give great new opportunities of reusing this spaces for public needs.

5.1.1. Seaweed cultivation

World wide there are 11.500 different types of seaweed known, but only about 100 can be found in the Netherlands. About 90 percent of the seven million tons of seaweed produced worldwide are cultivated in Asia and exported to countries around the globe. By cultivating seaweed locally, in the Netherlands, the import and long transportation of seaweed is reduced and a sustainable production can be guaranteed.

Seaweed in nature grows attached to objects like rocks or reefs, while the cultivated seaweed of Zeewaar is attached to an about 2,5 m long rope that is hanging from a substructure in the water. A system of ropes is strained between 16 massive steel pillars that form the edge of the farm, approximately about 1.400 m2 of area. Since seaweed needs as much sunlight as possible, it is a great priority to minimize the surface of the construction in matter of preventing shade. The seaweed gets harvested in summer months about every third day by hand from little boats or kayaks, which are stored with other harvest equipment in the boathouse.
A boat stage connects the cultivation structure on water with processing facilities on land.

5.1.2. Seaweed processing

After the harvest the seaweed needs to run through several processing steps before being ready for consumption or distribution. The primary goal of all processes is to avoid rotting of the product during processing and after distribution.

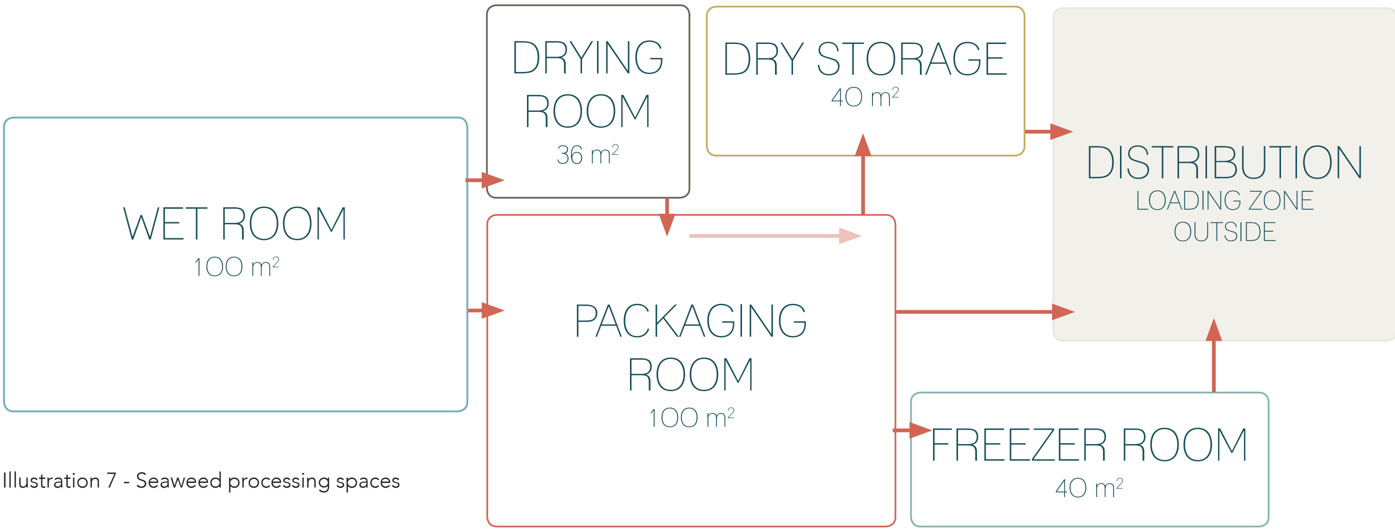


Illustration 7 - Seaweed processing spaces

<u>Processing step 1: washing and cutting</u>

The whole harvest is first transported on a conveyor belt upwards until it drops on a second sloped conveyor belt, where it is flushed with salty seawater of about 8°C. A constant vibration movement washes the seaweed and removes all unwanted by-catch, like little mussels and crabs. After cleaning the seaweed, it runs on a shaking belt to a cutting machine, which chops it.

There are three options of preparation for distribution of the washed and cut seaweed. It can stay fresh, be frozen or be dried. If the seaweed is distributed fresh or frozen it will immediately go from the washing and cutting process to the packaging process. The fresh packed seaweed is immediately ready for distribution, while the seaweed for freezing is first packaged in right portions before the freezing process commences.

<u>Process step 2: drying</u>

Drying of seaweed, however, follows immediately after the washing and cutting. The seaweed will be moved to shelves in the DRYING ROOM where the air-drying process with temperatures preferably not above 26 °C takes place. Seaweed contains a lot of water and will shrink during the drying process to 1/10 of its original wet mass. It will then be stored in the DRY STORAGE ROOM until packaging is possible.

<u>Process step 3: packaging</u>

All the fresh seaweed that does not go in the drying room will run to the PACKAGING ROOM. The seaweed packages will be put on pallets and moved either to a storage space for immediate distribution or moved further in the processing step, into the walk-in FREEZER ROOM. During the <u>process (4) of freezing</u> the packages are placed on shelves and left there until distribution. If fresh seaweed is packed the room climate should be around 12 °C to avoid bacteria. For packaging dry seaweed it is crucial to keep the temperature high and provide a dry space, since dried seaweed absorbs humidity easily and would start rotting faster.

Therefore it is relevant to create a room that is flexible in changing the room climate from a humid cold space to a dry warm space if needed.

5.1.3. Seaweed development

The consumption of seaweed as food has a very long tradition in Asia whereas it is almost unknown in Europe. Nevertheless seaweed is nowadays known as the ´super food´ of the future since it is very high in protein, vitamins and minerals. Since seaweed is a healthy sustainable solution for providing enough food, it is of highest importance to find ways to integrate the new diet in the Dutch cuisine. Recipes need to be developed that meet the eating habits and taste of the population. It is essential to plan a professional kitchen for this purpose, where the product development as well as workshops for the public will take place. The kitchen will be linked with a bar/ eating area that will be flexible in size.

5.1.4. Seaweed farm

All administrative purposes take place in the office area that is linked with the processing farm and hosts spaces for the staff. Due to hygienic reasons it is compulsory that there is an extra space or room between the wet cells and the packaging room. Staff changing rooms as well as toilets and shower facilities will be located between the office area and the processing farm. The entrance area is dedicated as a showroom and hosts an exhibition about seaweed.

The entire project involves three programmes; processing, office and development, on about 900 m2, excluding flexible outdoor spaces, and about 2ha cultivation space on water. The programme also sets functional and spatial thresholds for the design.

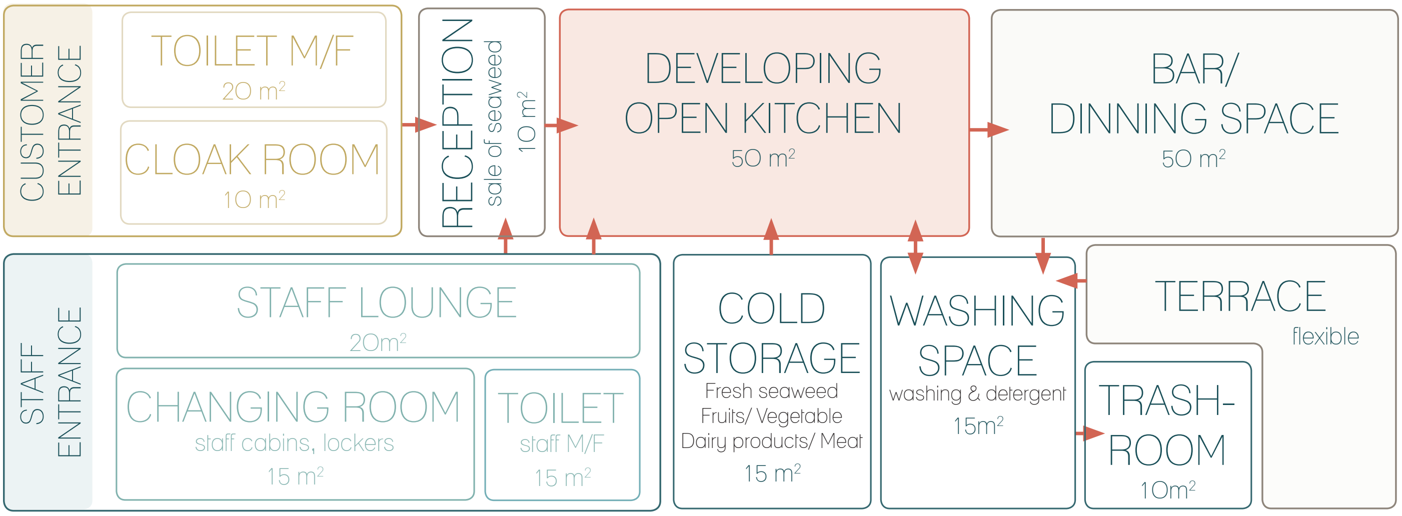


Illustration 8 - Seaweed developing spaces

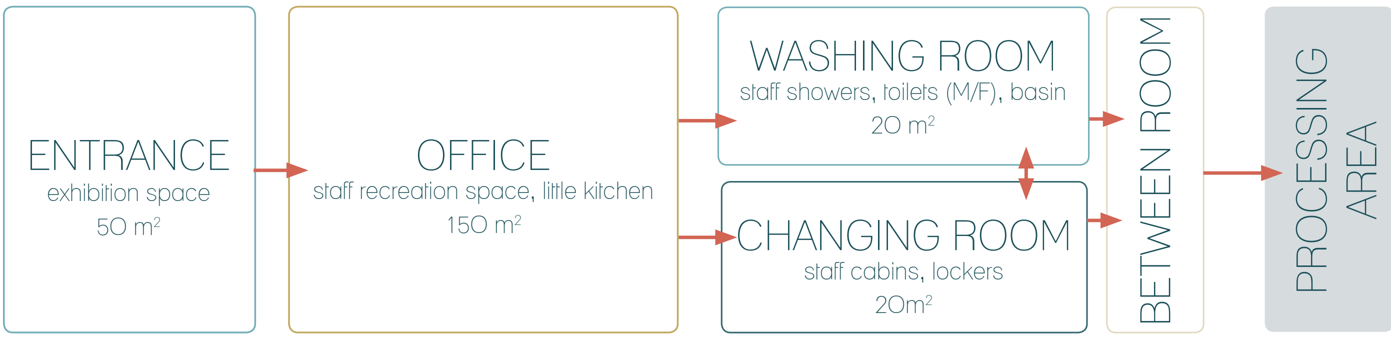


Illustration 9 - Seaweed office spaces

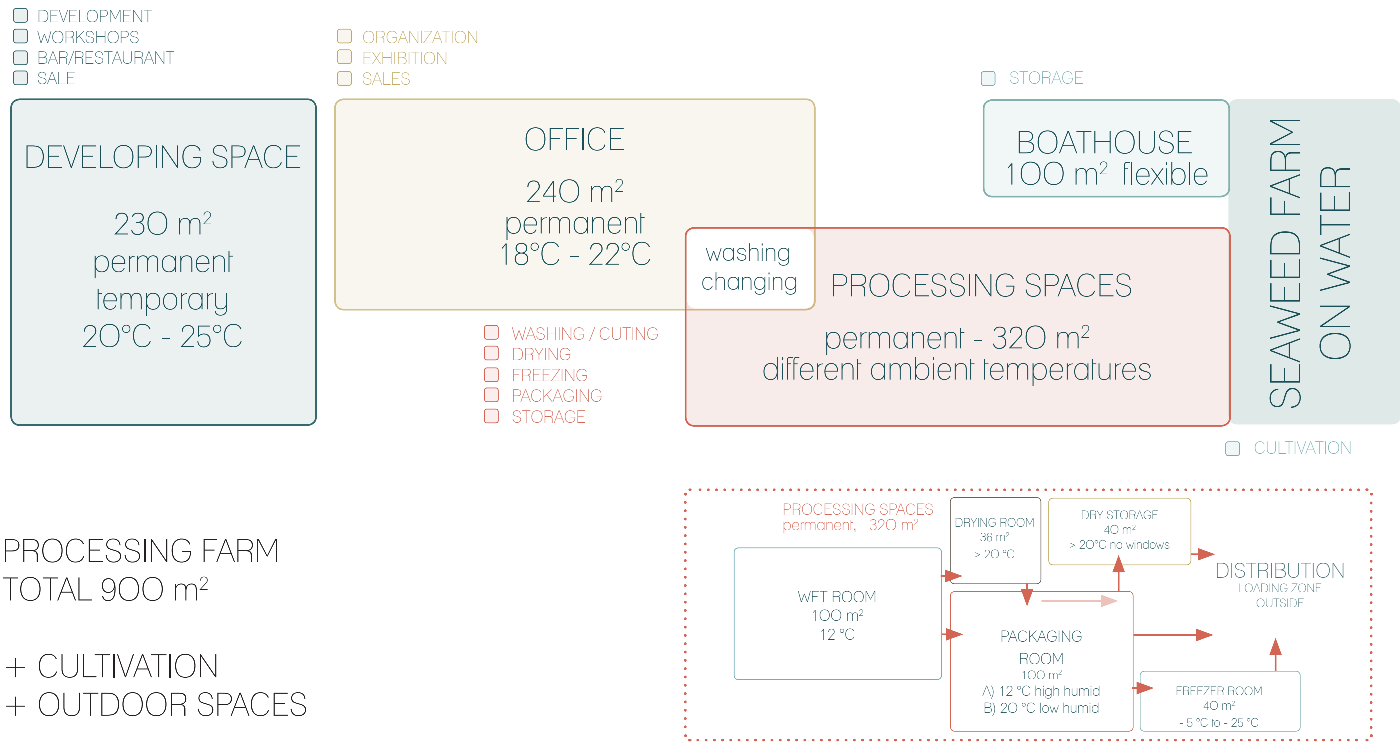


Illustration 10 - Seaweed processing farm - spatial programme

Illustration 11 - Casar de Cáceres in Spain, by Justo Gracia Rubio

Illustration 12 - structure of seaweed laminaria

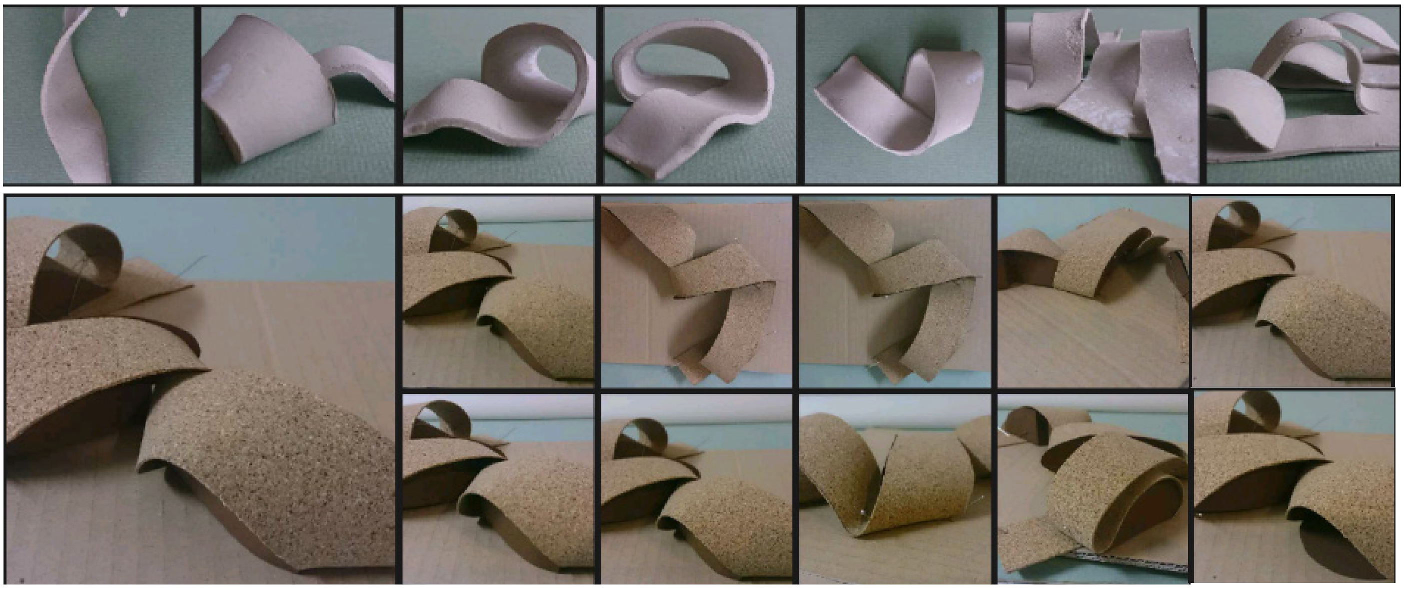


Illustration 13 - formmodells of clay and cork

5.2 criteria by the design of the architecture

The design of the architecture and its materialization are highly interrelated. On the one hand certain materials are chosen by their qualities, which make it possible to construct desired shapes and forms. On the other hand the material properties have strong influence on the design process itself and need to be considered, in matter of building more sustainably.

The concept of the design of the architecture was explored through research by design and aims to combine the form (composition), function (programme), the technical layer (structure and detail), the physical context and the historical context in a harmonic way. A literature research on the topic of ´biomimicry´ and ´architecture inspired by nature´ inspired the first design attempts. The reference project of Casar de Cáceres of Justo Garcia Rubio in Spain gave the final impulse that lead to the design. (Bahamón & Pérez, 2007) While the bus station of Rubio in Extremadura, Spain is inspired by the form of seashells the seaweed farm is inspired by the analogy of brown seaweed, in particular of the species of laminaria.

The basic idea of the concept is to create an architecture that should evoke the imagination of a seaweed ribbon reaching from the coast into the sea. Several form models of clay and cork were developed and evolved in a preliminary form model.

This architecture, based on the continuous structure of laminaria, is configuring the architectural elements of the roof and the facade with a single form (Bahamón & Pérez, 2007). The particular shape as well as the double function of the shell as roof and walls require conformance of the material to the shape of the structure.

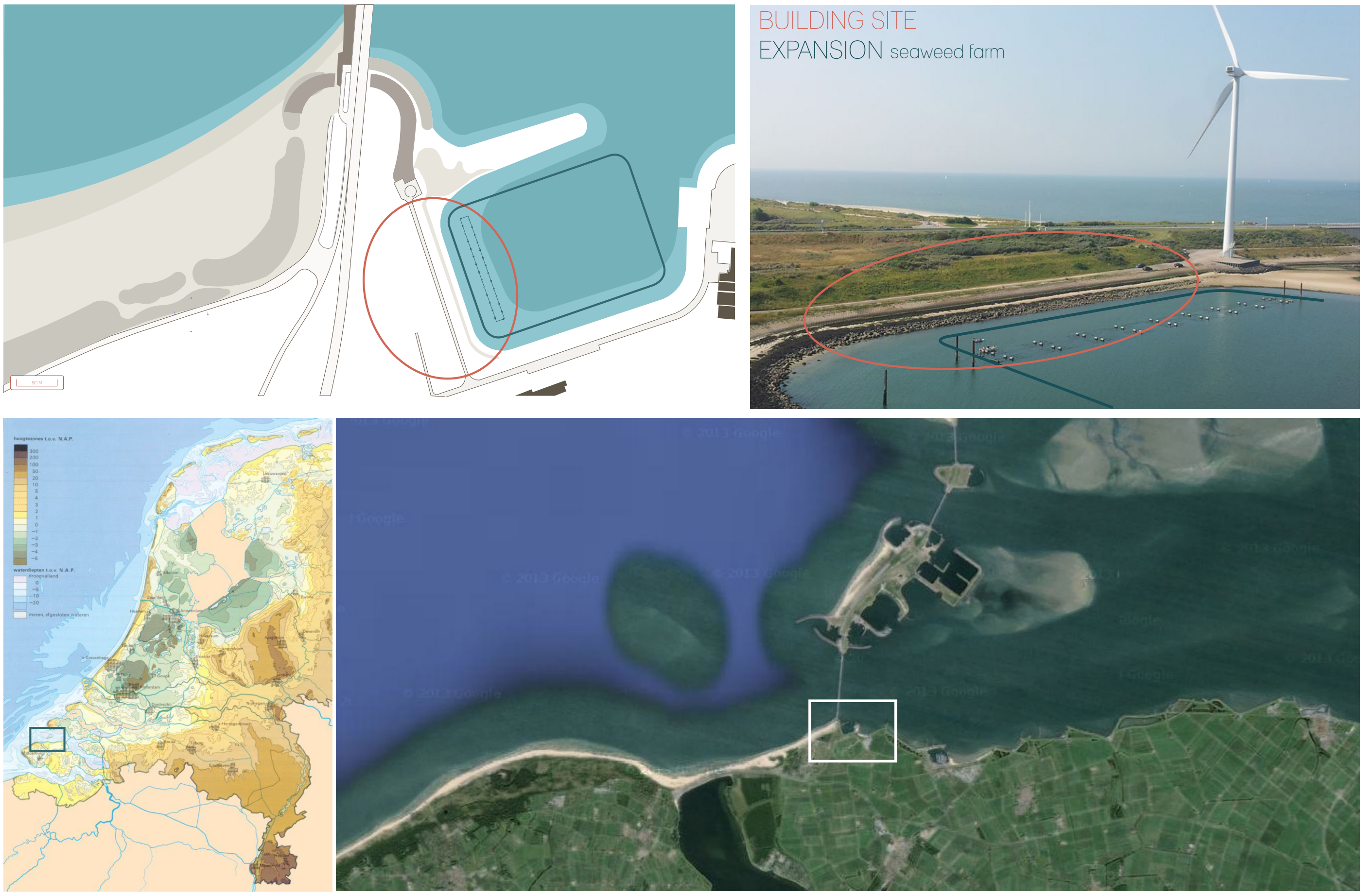


Illustration 14 - Building site in the Jacobahaven at the Oosterschelde in Zeeland, South Holland, The Netherlands

5.3 criteria by climate - the Netherlands

The materialization of architecture also needs to withstand the climate and predominant weather conditions on the building site. The Netherlands has a temperate maritime climate influenced by the North Sea and Atlantic Ocean, with cool summers and moderate winters. Daytime temperatures vary from 2°C-6°C in winter and 17°C-20°C in the summer. The average minimum temperature throughout the year in the Netherlands is above 0°C. However, there is still high risk of frost in wintertime and during extreme conditions air temperature can drop even below -20 as recorded in 1944 (Birznieks, 2013). The Netherlands is a flat country and has frequently breezy conditions especially among the coastal areas.

In future the weather conditions will be highly influenced by the predicted climate change. Effects of climate change, such as high temperatures, increased precipitation, (locally) increased ground water table and increased salt concentration of ground water will play a major role in the durability of materials in the building envelope (Nijland et al. 2009). The Royal Netherlands Meteorological Institute, KNMI, has developed four possible scenarios of climate change for the Netherlands in 2050, relative to 1990 (Van den Hurk et al. 2006).

All four scenarios show similar general tendencies:
• Temperatures will increase, resulting in a higher frequency of more temperate winters and warm summers.
• Winters will, on average, become more wet, and extreme amounts of precipitation will increase.
• Intensity of severe rain in the summer will increase, but, in contrast, the number of rain days in summers will decrease.
• Changes in wind regime will be small compared to current natural variation.
• Sea levels will continue to rise (Nijland et al. 2009, p. 38).

Further there are several other effects relevant to the durability of building materials like
• Specific and relative humidity; the first is likely to increase, but relative humidity may decrease, especially in the summer.
• The amount of solar radiation is likely to increase.
• Soil moisture content is expected to fall (Nijland et al. 2009, p. 39)

The durability of building envelopes, in particular their materialization will be strongly influenced by the changing circumstances. Higher temperatures will lead to faster biocolonization as more periods of convenient temperature will occur. Species typical for the Mediterranean area will eventually develop in the West-European maritime climate, causing accelerated biodeterioration. Concluding, the flexibility of the materialization to the changing climate circumstances is of relevance and needs to be considered during the buildings lifespan of about 35 years.

SUSTAINABLE MATERIALS

EMBODIED ENERGY OF A MATERIAL

MINIMALLY PROCESSED — processing - little energy & waste
LOCAL AVAILABLE — transportation - no CO2 emission
EASY AND SAFE — construction - little energy & waste
ADJUSTED TO PURPOSE — operation - good energy efficiency
RENEWABLE, REUSABLE or RECYCLABLE — disposal - little waste & energy

Illustration 15 - Basic criteria for sustainable materials

5.4 criteria of defining sustainable materials
Construction is one of the industrial sectors in which most resources and materials are used. Reduction of CO2 emissions by optimizing the material used in construction is important because construction and use of buildings in Western Europe is responsible for almost 30 % emissions (Goverse, 2003).
The sustainability of a building system is determined by the full life cycle and CO2 emissions during material production, processing, use and disposal (Dam & Oever; 2012). There are some general factors of sustainability that always need to be considered before going more into detail of the specific material benefits and disadvantages for the various purposes.

Less is more - As soon as the materials are chosen according to the purpose of the architecture, it is important to design while considering the material properties. Dimensions and size of building constructions can be adjusted to the available dimensions of materials and save a lot of waste, for instance of timber or frameworks. Another good example of how to save materials is the timber grid shell method. Grid shell construction enables very efficient use of small amounts of timber, yet can create very large span structures (Hall, 2008).

Local materials - Building with locally available materials helps to avoid long transport distances. It is of major importance to pay attention to the origin of a material and its processing. In this way it is possible to assess the whole chain of production and to make sure that the material has not been shipped/transported around the continent for different procedures of production.
As an example: Straw bales are a byproduct of agriculture and therefore plentiful and locally available almost everywhere. Straw is a 100 percent organic material and the construction method is easy and fast.

Raw natural material - Materials close to their original natural state are usually less processed and therefore have less embodied energy and cause less waste and less pollution.
Rammed earth is a form of unbaked earthen construction. The building technique uses the raw materials of sand, gravel, silt and clay to construct long-lasting walls. The natural aggregates are mixed and compacted into a framework creating monolith-building structures.

Various forms of earthen materials have the lowest environmental cost according to classifications of NIBE. Comparing rammed earth to alternative building materials such as concrete and brick masonry, its embodied energy is significantly lower (Birznieks, 2013).

Durability and maintenance - The durability of a material is a main criterion while choosing the appropriate materialization for a building. It is relevant to consider the needed maintenance of a building material and therefore judge its life span and make wise choices.
Traditional thatching experiences a revival in Holland and thousands new thatched dwellings are built. With a maintenance programme approximately every 15 years a well-thatched property, using long straw/ Devon reed material, can be expected to have a lifespan of between 30 and 45 years. Water reed and heather thatched properties can last up to 70 years.

Renewable and recyclable - Reusable and renewable materials can be reused easily and therefore produce less waste. It is important to consider the reuse already in the design and building process by for instance fixing materials mechanically. In this way materials can be easily disassembled and reused or recycled (K.Hall, 2008).
Flax is a renewable resource since the plant regenerates relatively fast in substantial quantities. In the context of sustainable building, the use of building materials from

Illustration 16 - Basic raw materials straw, reed, sand and timber

renewable raw materials is interesting, because they have low energy content. There is little environmental burden in production line and there are also good opportunities for local production, which can minimize transportation and the related pollution.
Further it is important to distinguish between biodegradable materials and bio renewable materials. The first category is obtained in a natural way and is naturally compostable. The second category concerns materials of biological origin which can be chemically produced in bio refinery. Some of these materials will not compost in nature, but are nevertheless considered as renewable. (Prinsen, 2013)

This research focus is put on the category of biodegradable and recyclable materials such as wood and different crops like hemp, flax and straw as well as on resources of the ground like sand, clay, lime and stone that confirm with the analyzed criteria.The Netherlands so far mainly encourages the use of sustainably produced wood in construction. However there is still a huge potential of sustainable constructing with more unconventional raw materials.

6. Result

6.1 Criteria of sustainable materials

The overview table in Appendix A lists basic raw building materials that can be sourced in the Netherlands. These basic natural raw elements in the categories of earth materials, crops and plants, farming and forestry are the main ingredients of the building methods explained in Appendix B, which confirm with the criteria of sustainable materials. Appendix C displays the materials and their possible application and in Appendix D each building method is analyzed and the properties listed for easy comparison.

Appendix A shows that in term of availability sand can be found across the entire area of the Netherlands, while gravel is limited available.
Straw, hemp and flax are plentiful available in the Netherlands.

The comparison of building methods indicates that straw bale construction has the lowest embodied energy of all listed materials. Straw bale and hemp crete constructions have good insulation values and show equal thermal conductivity values as flax insulation and wool insulation. Timber construction, cordwood and baked stones have good water resistance, while straw bale constructions are not resistant to water and need plaster finish to be sufficient resistance.

6.2. Criteria of programme

The table in Appendix E summarizes the earlier described different spaces of a seaweed-processing farm and their specific requirements. By comparing these criteria with the information gained from the tables in Appendix C & D, raw materials were evaluated and suitable as well as not preferable materials displayed in Appendix F. The results in Appendix F are explained below.

Moisture resistant
Earth constructions are relatively moisture resistant while earth-crops mixture constructions, such as cob and light earth building are less resistant. All earth constructions need to be protected from excessive wetting. Hempcrete is preferable over straw bale construction, which needs to be protected against moisture with a detailed finishing.

Flexible & water-resistant
Timber is commonly used in the Netherlands for constructions that are exposed to water. The pillars of the Zeewaar seaweed farm are made of Round Steel; a timber construction however is a sustainable alternative.

Illustration 17 - Raw building methods- Rammed earth - straw bale - grid shell - reed thatching

Permanent & low temperature (12°C)
Natural materials balance indoor and outdoor conditions; therefore it is difficult to regulate the temperatures. A solution is to insulate the construction sufficiently with insulation materials such as flax, hemp or wool.

low (12°C) versus high temperature
The research shows that natural building materials are not preferred if manual control of temperature is necessary. Sufficient insulation and technical installations for cooling and heating however provide the potential to change temperatures in a space.

Dry and high temperature above + 20°C
Earth constructions have great thermal capacity, while straw bale constructions have excellent thermal insulation, both however tend to regulate room climates and humidity.

Low temperatures from -5°C to -25°C
The suitability of the material for low temperature is not necessary, since a cooling/freezing unit, in the form of a walk-in freezer will be installed, which will provide the necessary temperature.

Ambient temperature of 18°C to 22 °C
All considered building methods are suitable for creating thermal comfort and a good working/living environment. Earth constructions however have high thermal mass and allow passive cooling. Furthermore rammed Earth walls and timber constructions score with their natural and beautiful aesthetic.

6.3 criteria by design

Grid shell structures allow large spans and are flexible in shape and therefore suitable for the wavy shell roof structure. A precise structural calculation before constructing is necessary.

Also reed thatching is suitable for organic architecture, it sets however the restraints of a minimal roof steepness of about 45°.

Some raw building techniques allow a greater freedom of shape and form of wall structure than others. Cob or straw bale are perfect for creating organically shaped structures, while rammed earth requires straight vertical walls for stability and only allows the freedom in horizontal forming.

6.4 criteria of climate

The combined effect of higher temperature and higher precipitation is likely to speed up biocolonization and increase effects of biodeterioration and biodegration, for stony materials, (organic) coatings and timber. New genera and parasites are a big threat to building materials; in particular constructions consisting of organic materials such as reed or crops as well as timber are in risk of bio colonization.

Further, the high and more extreme precipitation implicates a higher risk of moisture in a building structure. Higher relative humidity and wet building materials consequently result in more intense damage upon frost. Especially light earth and straw bale constructions need to be protected against excessive wetting which is a risk to the durability of the material. What is more a thatched roof for instance should have a minimum pitch of 45°, to guarantee that water will run off from the roof surface with minimum penetration into the thatch. At a pitch of less than 45° the thatch will decay and leak much sooner.

A higher solar radiation increases the degradation of painted timber construction elements. The main risk of lower soil moisture content is the possibility of shrinkage and resulting subsidence of foundations and walls causing cracks in solid earth constructions.

7. Discussion & Recommendations

The purpose of this study is to find and adjust the right natural raw materialization to the architecture of a seaweed processing farm in the Netherlands. The research looked at criteria of the programme, the design and the climate separately and therefore resulted in a number of possible materials that confirm with the individual requirements.
Architectural spaces however usually combine all this aspects in one building element, which means that there are different material possibilities for the same structural element.
That is to say that final decisions have to be made in favor of one previously explained aspect, such as programme, design or climate or out of a different motive, such as availability or financial reasons.
For instance: if more than one building method is suitable for a building element it is, from a financial point of view, logical to select the more economical material whereas from a design point of view, the more aesthetic material would be preferred.
What is more straw as an example is so plentiful, that the farmers, which have no use for it, often burn it. This creates a big amount of smoke, which is a threat for the environment. Therefore the government of the Netherlands is concerned with the problem and promotes solutions for the use of the extra straw in building construction.
Considering this problematic the use of the straw bale method should be in favor. Clearly it must be discussed whether the criteria of programme, design or climate or other motives are more relevant for the specific material choice.

As mentioned earlier the findings of the research show that most of the programme spaces allowed a wide selection of possible building methods, for instance rammed earth construction is suitable for most spaces. Nevertheless it is recognized that it was not always possible to assess the right raw building method to certain spatial requirements or ambient temperatures. The main reason is that natural materials tend to balance indoor and outdoor humidity & temperatures and make it therefore difficult to regulate specific climates within a building. It needs to be investigated whether temperature regulation is easier by adding sufficient insulation or stabilizers to the building materials.

The findings of the research cover a range of necessary building components such as the roof; walls and floors but don´t cover any research on transparent surfaces. Glass will be an important element that needs special attention and further research, in matter of finding a sustainable option.

Further research could also include processed building materials consisting of raw material, such as papercrete or corkboard.

8. Conclusion

The broad research investigates sustainable local raw building materials and methods that can be adjusted to the organic architecture of a Dutch seaweed-processing farm. Sustainable raw building materials, that are available in the Netherlands were listed and put in relation to criteria defined by the climate, organic design and spatial plan of the architectural project.

In conclusion the results of this study show that in the majority of cases it is possible and preferable to adjust natural raw building methods with suitable properties to spatial, thermal and design requirements. Natural raw building materials have lower embodied energy than conventional building methods and hence support the sustainability of a building structure.

9. References

Bahamón, A.,& Pérez, P. (2007) *inspired by nature: animals*, The building/ biology connection

Benyus, J.M. (1997) *Biomimicry*, Innovation inspired by nature

Birniznieks, L. (2013) Architectural Engineering Graduation Studio, Delft University of Technology, *designing and building with compressed earth*

Dam, J.Van, & Oever, M. Van Den(2012) Catalogus biobased bouwmaterialen, *Het groene bouwen*
Available online at:
http://www.groenegrondstoffen.nl/downloads/Boekjes/15Catalogusbiobasedbouwmaterialen.pdf

European Commission (2013) DG Energy final report, *Energy performance certificates in buildings and their impact on transaction prices and rents in selected EU countries*

Goverse, T. (2003) UVA, Thesis.
Hall, K. (2008) the Green building Press, *the green building bible volume 1*, 4th edition

Hickman, L. (2011) The Guardian, Friday 14 January 2011, *the population explosion*
Available online at:
http://www.theguardian.com/world/2011/jan/14/population-explosion-seven-billion (assessed 20 November 2013)

Hurk, B. van den, & Klein Tank, A., & Lenderink, G., & Ulden, A. van, & Oldenborgh, G.J. van, & Katsman, C., & Brink, H. van den, & Keller, F., & Bessembinder, J., & Burgers, G., & Komen, G., & Hazeleger, W. & Drijfhout, S. (2006): *"KNMI climate change scenarios 2006 for the Netherlands"*, KNMI, De Bilt, report WR 2006-01.

International Energy Agency IEA (2012) Energy Technology Perspectives 2012, *Tracking green energy progress*

IPCC (2001) Intergovernmental Panel on Climate change, report
Kumar, S. (2011) Worldwatch Institute, State of the World 2011: Innovations that Nourish the Planet, *Global Meat Production and Consumption Continue to Rise*
Available online at:
http://www.worldwatch.org/global-meat-production-and-consumption-continue-rise-1 (assessed 18 October 2013)

Mackenzie, D. (2011) Magazine issue 2795, *How to engineer a better future*
Available online at:
http://www.newscientist.com/article/dn19947-we-can-feed-9-billion-people-in-2050.html#.UqnObKWJrR1 (assessed 4 Dezember 2013)

Nijland, T.G.,& Adan, O.C.G., & Hees, R.P.J.vd, & Etten, B.D.van (2009) TNO Built Environment and Geosciences, The Netherlands Organisation for Applied Scientific Research TNO, *Evaluation of the effects of expected climate change on the durability of building materials with suggestions for adaptation*

Oliverie, J., & Janssens-Maenhout, G., & Muntean, M., & Peters, J. (2013), report no. 1148, *Trends in global CO" emissions: 2013 report*

Prinsen, N. (2013) *Biobased Bouwen: bouwen met grondstoffen uit de levende natuur*

Available online at:
http://www.duurzaamgebouwd.nl/visies/20131127-biobased-bouwen-bouwen-met-grondstoffen-uit-de-levende-natuur (assessed 29 December 2013)

Singer, P. (2010) One Atmosphere, Climate Ethics: Essential Readings

Strobouw Nederland (2014)
Available online at: http://www.strobouw.nl (assessed 31 December 2013)

United Nations Population Division (1999), Department of Economic and Social Affairs United Nations Secretariat, ESA/P/WP.154 12 October 1999, *the world at six billion*
Available online at
http://www.un.org/esa/population/publications/sixbillion/sixbilcover.pdf (assessed 25 October 2013)

U.S. Department of Energy DOE (2008) Section Buildings Overview, *Buildings Energy Data Book*,

VROM, 2010. Protocol 0054: Procesemissies niet fossiel, t.b.v. NIR 2010.

WILLMOTT DIXON (2010) 07TBN33 The Impacts of Construction and the Built Environment 21/09/2010

Illustrations:

Zeewaar.nl
Illustrations 4,5

Google.com
Illustrations 2, 12, 13

Hofer, S. (2013),
Illustrations, 1, 3, 6-11, 14-18

APPENDIX A, PART 1/2 : TABLE OF BASIC NATURAL RAW BUILDING MATERIALS AND THEIR AVAILABILITY IN THE NETHERLANDS

	Basic raw materials		Availability in the Netherlands
Earth Materials	Lime	Lime originates in ground currents of rocks (erosion) in the earth´s crust.	It occurs mostly in layers of river deposits and in Limburg. Mesozoic Limestone (Winterswijk)
	Clay & Silt	The quantity of clay and silt was formed during the last ice age.	Holocene peri-marine deposits in the coastal provinces, and Quaternary fluvialile clays, deposited on the floodplains of the Meuse and the Rhine, as well as peri-marine clays in the province of Groningen. Other deposits are in Gelderland and Overijssel, Noord-Brabant and Pleistocene eolian silt deposits in Limburg.
	Sand	Sand is a naturally occurring granular material composed of finely divided rock and mineral particles.	Sand deposits are covered across the entire area of the Netherlands, but especially in the southern and eastern parts of the county. The central and western part is dominated by fine sand, while the eastern and southern areas contain coarse sand deposits.
	Gravel	Gravel is composed of unconsolidated rock fragments that have a general particle size range and include size classes from granule- to boulder-sized fragments.	The largest locally available coarse aggregate resources are located in Limburg and relatively minor surficial occurrences of gravel and gravely sand located in the Dutch sector of the North Sea. At the same time most of the gravel and crushed –rock aggregates are imported from Germany, Belgium and British sector of the North Sea.
Farmi ng	Sheep wool	Wool is the textile fiber obtained from sheep. Wool has several qualities that distinguish it from hair or fur: it is crimped, it is elastic, and it grows in staples (clusters).	Blaricum, Roermond, Gouda
Plants/Crops	Straw	Straw is a 100 percent organic material. Wheat, rye or barley with long stalks of good quality are dried and used for the straw bale.	Straw bales are a byproduct of agriculture and therefore plentiful and cheap.
	Hemp	Highest green credentials of all agricultural corps (also flax and jute) Hemp is one of the fastest growing corps and purifies the air from large quantities of CO2 during growth.	Alkmaar, Groningen, Oude Pekela & Belgium, Germany, France It grows on all types of grounds. Therefore hemp products save CO2 even before they are used as insulation material. d to almost 4 meters in 100 to 120 days.
	Flax	There are two main types of flax : flax and linseed.Flax is a renewable resource since the plant is relatively fast in regeneration of substantial quantities. The entire flax plant is used, for example, to make linen, to make or linseed oil, animal feed, linoleum, wood composites and natural building insulation.	Flax is an arable crop that grows well on clay soils in the Netherlands (Oisterwijk), Belgium and northern France.

APPENDIX A , PART 2/2 : TABLE OF BASIC NATURAL RAW BUILDING MATERIALS AND THEIR AVAILABILITY IN THE NETHERLANDS

Basic raw materials		Availability in the Netherlands
Timber	American oak - *Quercus Rubra* Beuken - *Fagus Sylvatica* Douglas - *Pseudotsuga menziesii* Oak - *Quercus Robur* Ash tree -*Fraxinus excelsior* Maple tree *Acer - pseudoplatanus* Scots pine - *Pinus Sylvestris* Elm tree - *Ulmus hollandica* Larch - *Larix* Poplar - *Populus* Black locust - *Robinia pseudoacacia* Sweet chestnut - *Castanea sativa*	Available in the Netherlands, it is relevant to make sure that the timber used comes form a reliable sustainable source.

APPENDIX B, PART 1/3: TABLE OF NATURAL RAW BUILDING METHODS of the category earthern, plants/crops, farming and forestry

	Building material	Ingredients	Possible additive	Processing	Construction	Finishing
Earthen	Rammed earth	Clay, silt, gravel, sand, water (10%)	Stabilizer: Cement	1. Soil preparation 2. Formwork 3. Compaction 4. Post processing	Mixture is compressed gradually in horizontal layers in a formwork (compaction)	Earthwork should be brushed to remove loose particles and to smoothen the surface.
	Compressed earth blocks	Clay, sand, water	Stabilizer: Cement (8%), lime, fly ash, rice husks or other	Blocks are compressed in a hand or mechanical press and baked by sun	Bricklaying with earth mortar	Finish with earth plaster or another natural breathing material if required.
	Adobe/ Mud brick	Raw clay, Sand Water	Stabilizer: Emulsified asphalt Portland cement (up to10%)	Adobe pre-formed blocks are air-dried (Unburned)	Quick construction comparable with masonry of brick	Protective coating (not necessary if stabilized with 5-12% asphalt)
	Baked Clay stones	Clay		Backed with low temperature of 900 -1080°C (10% of energy used for conventional clinker bricks)	Construction comparable with masonry of brick	
	Earth bag	Sand/earth, clay		Sand is filled in bags made of Polypropylene (filling stays dry) or more organic/ natural material such burlap, hemp and gunny sack (bag-fill material needs more clay)	Sandbags are stacked to a wall and sometimes reinforced with a chicken or bared wire, twine or rebar	Finished in plaster, stucco, clay, lime
	Light earth	Clay, straw, water		Mixing of ingredients.	Mixture is lightly compressed between temporary or permanent shuttering and a loadbearing framework. Walls should be no wider than 300mm in general.	Finished in lime or clay based plasters and renders
	Cob	Clay (binder), sand (stabilizer), fiber/ straw, water		Mixing of ingredients.	Cob is compressed in series of layers (30-50cm) on a plinth and trimmed from the side. Each layer needs to dry for at least 3 days.	Soft, breathable and flexible lime and earth render

APPENDIX B, PART 2/3: TABLE OF NATURAL RAW BUILDING METHODS of the category earthern, plants/crops, farming and forestry

	Building material	Ingredients	Possible additive	Processing	Construction	Finishing
Plants/ Crops	Hemp Crete	Hemp, lime, sand	Stabilizer: Cement	The material is mixed in mortar mixers for 1-2 minutes.	The lightweight material is stuffed by hand between a temporary “shuttering” and a loadbearing construction.	
	Straw bale	Straw (by product)		Straw bale are formed. 480 (Width) x 360 (Height) x 800 mm (Length)	Straw bale building typically consists of stacking rows of bales.	Straw bale constructions can be plastered either with a lime-based formulation or earth/clay render.
	Flax products	Flax fibers Recycled adhesive binder (Polyester) Fire retardant substance		Manufactured as building insulation material in the form of blocks or fleece. (Rolls) Solid insulation panel	Insulation panels for roofs, walls, and flooring. Groove insulation between doors & windows. Solid panels for robust partition.	
	Reed thatching	Reed		Harvest of reed	The roof is thatched in layers by hand. The Schroefdak is a closed structure where the reed is screwed onto a dense surface. (Insulation panels)	
Farming	Sheep wool	Sheep wool, Recycled polyester		Sheep wool fibers 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.	

APPENDIX B, PART 3/3: TABLE OF NATURAL RAW BUILDING METHODS of the category earthern, plants/crops, farming and forestry

	Building material	Ingredients	Possible additive	Processing	Construction	Finishing
Forestry	Timber frame	Wood		Produced into dimensioned timber planks	Timber planks are raised into place and bolted or screwed together to a frame. The Walter Segal method uses timber efficiently.	
	Round pole	Wood		Round poles need a minimum processing if not dimensioned (retains entire strength)	The poles are either used as dimensioned poles (higher pre-processing) or direct logs as in Log building.	
	Grid shell	Wood		Produced in laths and planks. Enables very efficient use of small amounts of timber, yet can create a large span structure. A precise calculation is essential.	A regular grid of slender timber laths is laid out flat, at each intersection point the members are connected by special connectors; finally the grid is shaped so that it takes up a double-curved form.	
	Green timber	Wood		Freshly felled and not yet dried timber (green timber)	Green oak frame building	
	Wattle & Daub	Timber frame, Wattles or woven from brushwood, daub: chopped straw, clay, dung		The wattle is made by weaving thin branches (either whole, or more usually split) or slats between a timber frames.	The daub is mixed and applied to the wattle and than allowed to dry.	Often there is a final layer of whitewashed to increase its resistance to rain.
	Cordwood	Wood (40-60%), Cob, Mortar (Sawdust, chopped newsprint, paper sludge)		Wood is debarked and cut in same pieces	In this technique short pieces of debarked tree are laid up crosswise with masonry or cob mixtures to build a wall. Method 1: Through wall Method 2: M-I-M (Mortar-insulation-mortar)	

APPENDIX C : TABLE OF NATURAL RAW BUILDING METHODS AND POSSIBLE APPLICATIONS

	Building material	Walls Load bearing	Walls	Insulation	Floors	Ceiling	Roof
Earthen	Rammed earth	x	x		x		
	Compressed earth blocks	x	x				
	Adobe/ Mud brick	x	x		x		
	Baked clay stones	x	x				
	Earth bag	x	x	x			
	Light earth		x	x	x		
	Cob		x	x	x		
Plants/ Crops	Hemp Crete	x	x	x			x
	Straw bale	x	x				
	Flax products		x	x			
	Reed thatching						x
F.	Sheep wool			x			
Forestry	Timber frame	x	x		x	x	x
	Round pole	x	x			x	x
	Grid shell	x					x
	Green timber	x	x				
	Wattle & Daub		x				
	Cordwood	x	x		x		

APPENDIX D: TABLE OF NATURAL RAW BUILDING METHODS AND THEIR PROPERTIES

		Density	Embodied Energy	Thermal conductivity	Heat Capacity	Sound Reduction	Water penetration resistance	Lifespan	Reusable Recyclable	Bio-degradable
	Symbols	ρ	Em.En	λ	Cp	Rw				
	Units	Kg/m^3	MJ/Kg	W/mK	J/Kg k	dB		Years	Yes/No	Yes/No
Earthen	Rammed earth	1460-2200	0,7	1,100	1260	50	Acceptable	60 <	No	Yes*
Earthen	Compressed earth blocks	1460-2200	0,7	1,130	1303	40cm thick wall is 56dB	Acceptable	For centuries	Yes	Yes*
Earthen	Adobe/ Mud brick	640-1800	0,45	0,180-0,710	840-1009	44-48	Limited	100<	Yes	
Earthen	Baked clay stones	1800	0,9	1,200			Good		Yes	No
Earthen	Earth bag						Acceptable		Yes	Partly
Earthen	Light earth	< 250-1200					Limited	Indefinitely	No	Yes
Earthen	Cob						Limited		No	Yes
Plants/ Crops	Hemp Crete	220-350	2,0-5,0	0,053-0,075	1500-1700	50-59	Acceptable		Yes	Depends
Plants/ Crops	Straw bale	19-25	0,1-0,91	0,035-0,039	1720-1800	50-57	Bad		Yes	Yes
Plants/ Crops	Flax insulation	20-50	11-30	0,035-0,042	1550-1660	>12	Acceptable		Yes	Depends
Plants/ Crops	Reed thatching	130		0.20			Good	30-70	No	Yes
	Wool insulation	80-191	70	0,50-0,070	1660-1710	-	Acceptable	30-100	Yes*	Yes*
Forestry	Timber construction	480-720	10				Good	70	Depends	Yes
Forestry	Wattle & Daub						Acceptable		No	Yes
Forestry	Cordwood						Good		No	Yes

APPENDIX E
TABLE OF SPATIAL PROGRAMME OF A SEAWEED PROCESSING FARM
including dimensions and requirements for the materialization

	FUNCTION	USE	Dimensions	Design Lifespan	(Material) Requirements	Ambient Temperature
CULTIVATION	Boat stage	To connect the sea farm with the land and enable excess for harvesting.	Minimal Floor space	Flexible	Water resistant	
	Boathouse	Storage space for the about 10 kayaks/boats and harvest tools, like buckets. During the winter period there will be additionally hundreds of meters of rope stored.	100m^2	Flexible	Resistance against moisture, Low humid dry	
PROCESSING	Wet room	Space for washing and cutting of the seaweed	100 m^2	Permanent	Cool temperature	12 °C
	Packaging room	For packaging (a.) Fresh seaweed or (b.) Dried seaweed	(a. & b.) 100 m^2	Permanent (Flexible in changing room climate)	a. High humid b. Low humid (dry)	a. 12°C b. 20°C
	Drying room	Space for drying the seaweed with drying machines	36 m^2	Permanent	Low humidity	> 20 °C
	Dry storage room	Space for storing dried seaweed	40 m^2	Permanent	Low humidity No windows	> 20 °C
	Freezer room	Space for freezing the seaweed packages	40 m^2	Permanent	Low temperature	- 5°C to - 25°C
DEVELOPMENT	Developing space	Professional kitchen, food storage, wash & trash room	100 m^2	Permanent (kitchen) Flexible (eating area)	Restaurant ambient climate	20°C to 25°C
	Office space	Space for office, staffroom, entrance and showroom	150 m^2		Office ambient Temperature	18°C

APPENDIX F
TABLE OF SPATIAL REQUIREMENTS AND POSSIBLE MATERIALIZATION

	FUNCTION	Design Lifespan	(Material) Requirements	Ambient Temperature	Suitable Natural Materials	Not preferable Natural materials
CULTIVATION	Boat stage	Flexible	Water resistant		Timber construction	Earth constructions, Crop constructions
CULTIVATION	Boathouse	Flexible	Resistance against moisture, Low humid dry		Soil bags, Baked clay stone, Hemp elements, Timber construction Cork Cordwood	Adobe, Cob building, Light earth or Straw bale construction
PROCESSING	Wet room	Permanent	Cool temperature	12 °C	UNDERGROUND! Rammed earth Soil bags Clay stones Adobe Cork Cordwood	
PROCESSING	Packaging room	Permanent (Flexible in changing room climate)	a. High humid b. Low humid (dry)	a. 12°C b. 20°C		
PROCESSING	Drying room	Permanent	Low humidity	> 20 °C	Rammed earth Soil bags Baked clay stone Adobe Straw bale construction	
PROCESSING	Dry storage room	Permanent	Low humidity No windows	> 20 °C		
PROCESSING	Freezer room	Permanent	Low temperature	- 5°C to - 25°C	-	-
DEVELOPMENT	Developing space	Permanent (kitchen) Flexible (eating area)	Restaurant ambient climate	20°C to 25°C	Rammed earth Timber construction All earth & crops constructions	
DEVELOPMENT	Office space		Office ambient Temperature	18°C	Rammed earth Timber construction All earth & crops constructions	