# SEALUTIONS: LOOKING AT SEAWEED-BASED SUSTAINABLE BUILDING MATERIALS IN THE NETHERLANDS

Rianne Reijnders
Faculty of Architecture & the Built Environment, Delft University of Technology
Julianalaan 134, 2628BL Delft

***ABSTRACT***

*Seaweed is a promising potential building material, but so far, very little market ready seaweed-based building products are available. Because of the success of the sargassum adobe block in Mexico by Omar Vazquez, the potential of a seaweed loam bricks is researched in this paper, called the seaweed brick. The test show that the maximum percentage of seaweed in the loam bricks is 10%. In the ratio seaweed : loam : water = 1 : 7,4 : 1,6 . The seaweed bricks could be a new niche building material on the Dutch market. The loam brick is an natural and stable building material and the addition of seaweed can make the unusual sized bricks lighter and slightly more insulating. The realization of this seaweed bricks hinges on the seaweed having multiple purposes (water filtering, educational and bricks) and the use of waste streams from the proposed seaweedfarms and other manufacturing processes. Because of these seaweedfarms and the naturals soil compositing of the Netherlands there is potential for local production of this seaweed brick. Although this will probably be limited by the production speed and the supply of soil, which unlike seaweed, doesn't regrown. Nevertheless it could awaken the interest in seaweed building materials by the more mainstream building companies. In the sustainability comparison ($CO_2$, water use, energy use) the seaweed bricks seem to be in the same range a more natural building materials like reed. It greatly outperforms fired bricks and Trespa plate, which was expected due to the simple manufacturing process.(Please be aware that the term seaweed in this paper is used as an short term for seaweed/alginates and seagrass. When talking about specific products the specific species name and type will be mentioned when relevant.)*

***KEYWORDS:*** *SEAWEED, LOCAL BUILDING MATERIALS, SUSTAINABLE BUILDING ALTERNATIVES, BIOBASED MATERIALS, CIRCULAR ECONOMY, SEAWEED BRICK*

## I. INTRODUCTION

According to the report of the UN the building industry uses 55% percent of global energy consumption, making an impact on this front would have a high impact. The same report states that $CO_2$ emissions have risen compared to 2019 instead of decreased (Hamilton et al., 2020, p 4). The building industry is moving very slowly in implementing measurements that moves the industry to be more sustainable. One of the main causes of this is the lack of sustainable building materials. To put it lightly: standard materials like concrete, brick and steel do not have the most environmentally friendly production process. The research of sustainable alternative building materials is definitely an active field (Delgado, 2020; Yhaya et al., 2018), but so far not many products have made it to the shelfs.

One of these promising building materials is seaweed (in this case the term seaweed also includes seagrass, based on the dutch word for seaweed: zeewier, which often is used in a broader sense), research into seaweed has been thriving since 2012. So far, many promising materials have been presented (Baloo et al., 2021; Berglund et al. 2021; Dove et al.,2016; Widera, 2014; Yang, 2012), but there is still a lack of evidence of integrated use. The only avenue that has been properly explored and documented are traditional building methods with seaweed in Denmark and Coastal Asia and a newer experiment with seaweed in adobe blocks in Mexico (Mkrtichian, n.d.; Wang & Tong, 2013; Widera, 2014).

In the production of seaweed is already being heavily invested by the Dutch Government and Dutch Seaweed Farmers, which promises big steps in efficient seaweed production in the Netherlands according to the Execution program Circular Economy 2019 – 2023. So far their focus lies on food products made of seaweed (Het ministerie van Infrastructuur en Waterstaat et al. 2019, p13-16). But when claiming to become "*the best seaweed producer of the world"* (see figure 1), looking into other seaweed products like building materials is the next logical step. Especially considering the high food safety rules, which might make some batches of seaweed unusable. Here is a possible opportunity to use non-edible seaweed as building material.

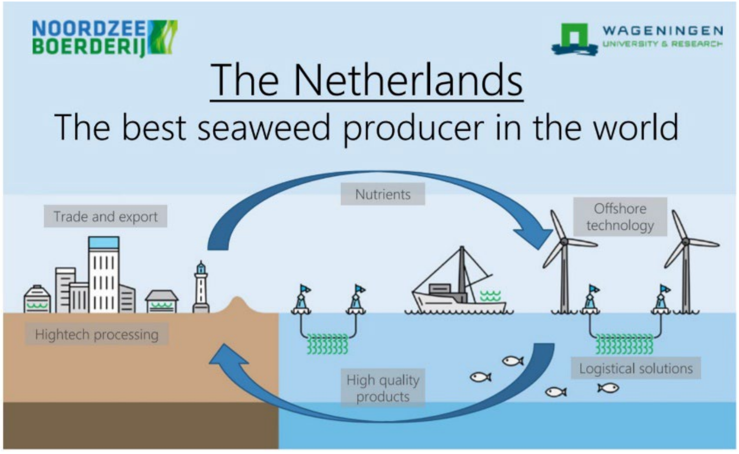



*Figure 1: Plan for seaweed production as part of the circular economy program of the Netherlands (Het ministerie van Infrastructuur en Waterstaat et al. 2019, p13-16)*

To limit the research, only building skin products will be considered, because of the easy recognition of the use of seaweed when used on the façade. After all the goal is to introduce seaweed as a new building material and a visual use on the outside of the building will be more impactful. Most important is that the building product can compete with standard building materials in terms of sustainability. Therefore the thematic research question is:

*Is a seaweed-based building-skin more sustainable ($CO_2$, water use, energy use) in the end than sourcing standard nonlocal building products?*

In this case the production site is located in the  harbour Westpoort of Amsterdam, Netherlands. The location and its natural resources influence the choices for materials when trying to keep the transport lines as short as possible. This is partly reflected in the sub questions:

- *What seaweed-based building skins are currently developed and is there potential for local production of this cladding?*
- *What base materials are needed for the production and how can these be locally sourced?*
- *What are the waste material flows from this production and how can these be locally processed?*
- *Is the seaweed-based building-skin more sustainable ($CO_2$, water use, energy use) than a facade made from reed, bricks or Trespa plate?*

## II. Method

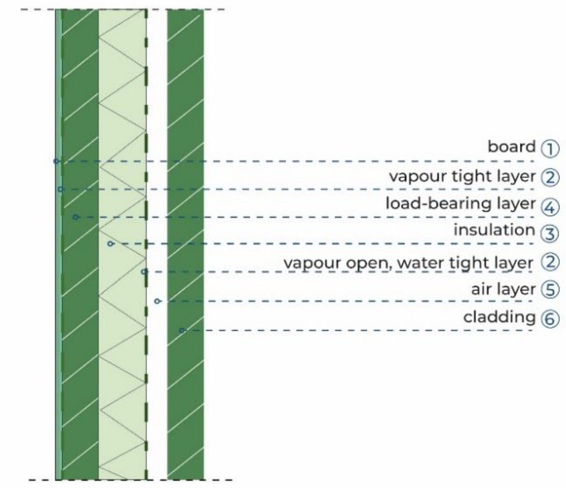
Literature studies will be used to source different applications of seaweed in the build environment. Two materials will be chosen to further develop. To understand the chosen products better, the products will be tested and replicated in this paper, see APPENDIX 2. The production line of the products will be described in a flowchart based the on the making of these prototypes and how this could be implemented in an industrial production. The base- and waste materials will become clear in this flowchart. To see how to responsibly source or dispatch these base- and waste materials, a location analysis and literature studies will take place. To conclude, the seaweed products will be compared on $CO_2$-emissions, water and electricity use to standard building materials like fired bricks, reed and Trespa plate based on acquired numbers from our own calculations, national statistics and literature studies.

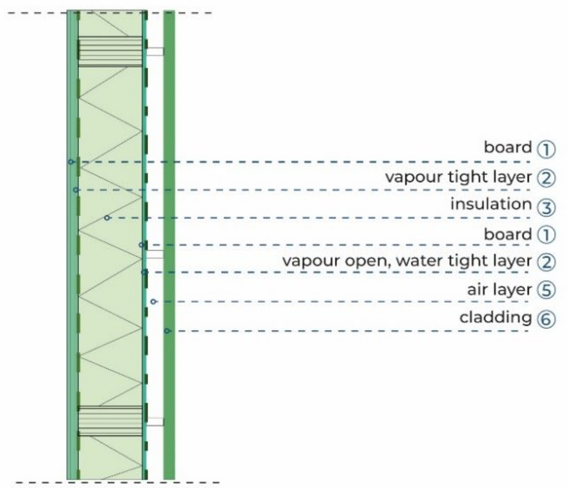
## III. SEAWEED AS BUILDING SKIN

In the Dutch Company Guide to Biobased Building 2021, a Dutch building company ranked different biomaterials (wool, reed, bamboo, flax etc), on their technological readiness in the Netherlands. Seaweed scored a 6, meaning: *Technology demonstrated in relevant surroundings,* a score of 10 would mean that the product is technical and market ready (Holland Houtland, 2021, p86). This score of 6, actually describes the position of the Netherlands towards Seaweed based building materials at this moment quite well. There is a raising awareness of the use of seaweed in insulation and other products, but seaweed is still considered as a very unusual building material. Without reintroduction and research into seaweed as a building product, we will not know the potential seaweed might have in the Netherlands as sustainable building material. In this chapter the potential of seaweed in a façade/building skin will be explored.

### 3.1. Types of Seaweed building skin products

Traditional and modern Dutch facades often rely on fired clay bricks for the loadbearing and/or cladding layers. Unfortunately due to the production process of fired bricks, such as the use of high temperature furnaces, these bricks have a high $CO^2$ impact (emission : 528,5 kg $CO^2/m^3$) compared to alternatives like wood (emission : -664,0 kg $CO^2/m^3$) (CINARK/The Royal Danish Academy and Vandkunsten, 2019). This, besides other factors like weight, is why other building techniques are gaining in popularity. Especially timber frame constructions (mainly CLT: Cross Laminated Timber) are more often considered to include in the façade composition (see figure 2). These two popular façade compositions will be used as base to study the layers with the building skin where seaweed could be used.




Seaweed (specifically seagrass) building products are currently in different stages of development but very few are already widely available on the market. In APPENDIX 1. there is an overview of current seaweed based building materials. From the overview of current seaweed based building materials, the products are categorized in the table on the next page (see figure 3). There are many potential options for the cladding and insulation layer. So far there are no options for the special vapour and water layers made from seaweed, but knowing the water absorbing qualities of seaweed, it's highly unlikely for this layer to be made partly with seaweed. For this layer, seaweed is simply not suitable.

With looking at the building skin, the cladding layer is the most directly linked to this. But the other layers in the façade should not be forgotten and are equally important in maintaining an function façade. For the next sections of this paper in two materials (unfired clay blocks) and the seaweed roofing from the cladding section are chosen to further develop for the Dutch situation, as the space in the paper is limited. Nevertheless the other layers will be further tested outside of this paper.

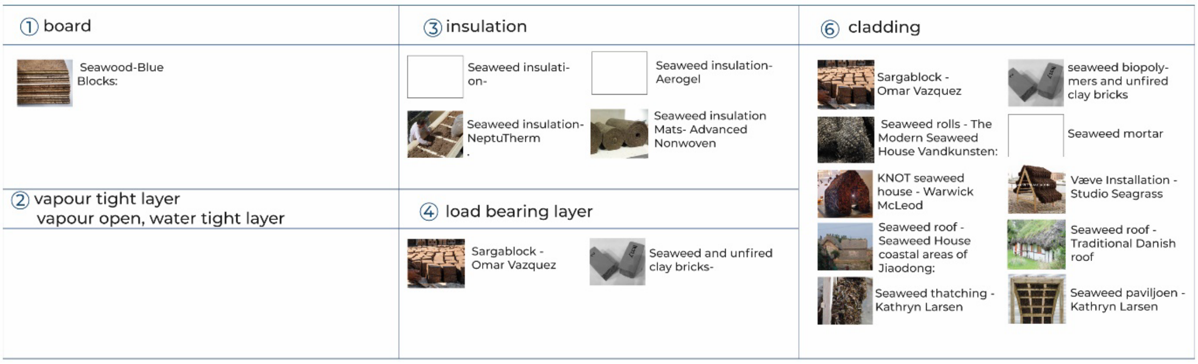



Figure 3. Different seaweed-based building product categorized by façade layer. See for more information APPENDIX 1

## 3.2 Compressed loam bricks with seaweed

The first product to be discussed is the unfired clay blocks with seaweed. There is no direct example to base this particular brick on but there are multiple tests and studies that come quite close in similarities. The use of seaweed in unfired bricks is mostly researched in the form of alginate additives. Especially the addition of alginate polymer has a positive effect on the compressive and flexural strength of earth bricks (Dove, 2014). The alginate polymer could replace the current use of cement or lime in earth brick to increase overall strength. Unfortunately the process of recovering of the alginate from the brown seaweed is quite difficult and because of this quite expensive. It seems only a profitable business when targeting high end uses such as pharmaceutical and medical applications (Mchugh and Food And Agriculture Organization Of The United Nations, 2003).

The closest example of low-tech bricks is the before mentioned Sargassum block made by Omar Vazquez (Mkrtichian, n.d.). The use of Sargussum in adobe bricks is very inspiring, but the Netherlands gets too little sun to properly dry the bricks. It would also make the work very seasonal due to the Dutch climate. Something similar to the adobe bricks that suits the Dutch geographical conditions more are loam bricks. Loam, a mixture of sand, clay and some silt, can be naturally found in many places in the Netherlands and the components (clay, sand and silt) can often be found around locations that lack preformed loam. These bricks, which are formed under pressure in molds and are suitable for load bearing walls. The integrity and water resistance of the brick can be improved by adding lime to the bricks (Oskam V/F, n.d.).

Although so far no produced samples have been found of loam bricks with seaweed fibres, the idea has already circulated the mind of Gernot Minke. Minke mentions in his book *Building with earth : design and technology of a sustainable architecture*. that adding porous materials like seaweed and straw to the loam can increase the thermal insulation of the brick (2013). Straw is often used as additive for earth bricks, not only as filler but also to minimize the weight and increase the compressive strength. Loam bricks are mostly available in bigger sizes than standard fired bricks due to minimizing the edges which are fragile. This however makes it heavier and more difficult for the bricklayer to deal with the bricks according to Dutch loambrick producer Rokus Oskam (from Oskam V/F). However the material properties seem to outweigh the bricklayers difficulties, as currently Oskam V/F is trying to introduce a new and bigger brick size, which is square and around 15 kg. To give some insight, their normal loam bricks are already 7 kg and 295x140x90 and a standard Dutch baked bricks is roughly around 2 kg and 210x100x50 mm. Adding seaweed to decrease the weight of these heavy bricks and can make them more manageable for bricklayers compared to the lighter and smaller baked brick. Although straw can introduce the same properties, straw is not locally produced. Currently straw is imported in big batches from Germany, UK, France and even Spain (Spöttle et al., 2013). The Dutch investment in becoming a big seaweed producer might make seaweed the more available alternative.

### 3.2.1 Samples/Testing

Because of the lack of research into seaweed based materials our own research was conducted by testing different kind of seaweed (Ascophyllum Nodosum, Fucus Serratus, Fucus Vesiculosis and Sargassum Muticum) in combination with loam to form unbaked bricks. For the full report, please see APPENDIX 2.

Some integrations of the seaweed with the loam were successful, although some preparations of the seaweed had to be done to receive the desired effect. The most promising bricks were made as follows: The seaweed, after airdrying for 3 days, is put in a 50 degree oven for 1 hour. With a blender the seaweed is pulverized as small as possible, this seaweed dust/flakes is then mixed with water. Then the seaweed and water mixture is mixed with loam and then pressed in a brick shaped mold. The maximum percentage of seaweed in the loam bricks is 10%. In the ratio seaweed : loam : water = 1 : 7,4 : 1,6 . The next step is after properly drying (around 30 days) to test the compressive strength of the bricks. It is highly likely that the bricks will be self-bearing. Although they could never withstand as much force as steel or concrete, they might be able to bear small loads like normal loam bricks. This however has to be discovered with the compression test in a follow up research.

## 3.3 Seaweed Roof

At first glance the Seaweed Rolls of the Modern Seaweed House in Denmark seemed a logical choice for a new seaweed roofing. Unfortunately due experimental nature of the product, it wasn't watertight and was replaced with a wooden roof (Nielsen, 2018). A more achievable product will be Studio Eelgrass' Væve installation and Kathryn Larsen's seaweed pavilion which, although also still in quite an experimental stage, is based on the old Danish thatching technic used for seagrass roofs. Sadly due to the thinness of the roof installation the Seaweed Pavilion has lost all its Eelgrass (a seagrass) according to Larsen herself, a roof thickness of 0,4-1m would not encounter these same problems. These thicknesses are also seen in the traditional Danish and Chinees seaweed roofs (Wang, Zhen Yu and Tong, 2013). The thickness of these roofs are often not seen as architecturally attractive and are a difficult and labor intensive work. The Chinese roofs also combine seaweed with reed, straw and/or clay to reduce the thickness of the roofs and to better fasten the seaweed on the roofs. The Danish and Chinese exchange knowledge on these vernacular building practices. Inspired by the thinner Chinese roof, Danish Henning Johansen wants to develop a thinner seaweed roof with reed instead of straw (www.tangtag.dk, n.d.). Reed, just like straw, is imported to the Netherlands, almost 75% of the reed in the Netherlands is imported according to the Dutch reed trade association (Spöttle et al., 2013, www.riet.com, n.d.).

So far there seems to be no real frontrunner for a seaweed roof cladding that is already fully developed and achievable that meets modern technical standards. So for the flowchart, the next part of this paper, only the production of the seaweed bricks will be considered. However in the future some of the experimental products might be further developed and can be reconsidered. Eelgrass, which is prominent in most roof construction, grows best in salty shallow water. A typology that is becoming more and more prominent in the Dutch landscape due to the rising sea level.

## 3.4. Process and Flows

The production process will look different from the testing process due to the high volume that needs to be produced and the efficiency that is necessary. This production process, see also figure 4, will be explained with a standard two story house as example and will look as follows:

1. **Collecting of materials**

   First the base materials need to sourced and stored on location before further processing. The origin and sourcing of the base materials will be discussed in **3.4.1 Base Materials.** For one house 126750 kg loam and 16250 kg seaweed (dry weight), see APPENDIX 4 for the whole calculations. Beside active use of the materials, the materials also to be stored before, after and in between steps, See APPENDIX 5 for approximations of the needed workspace in $m^2$ . Lime is an optional additive to make the bricks water resistant. In building a small percentage of bricks come directly into contact with a lot of water and need this extra additive.

2. **Preparing base materials**

   The loam can be made with local earth (except peat) or excess earth from road work supplemented with clay or sand  to get the consistency right. The earth materials needs to be pulverized and mixed to loam with a machine (pulverizer) so that it gets a fine crumb, this benefits the mixing and pressing process greatly. Afterwards the loam is dried to lose the moisture that was trapped in de lumps.

   Seaweed can be harvested every 6-8 weeks from an active seaweed farm. The seaweed is laid out to dry on drying racks, which can be stacked to save space. They can dry in 3-10 days depending on season and weather. When drying indoors, the drying time is around 3 days. When drying outdoor the seaweed needs to be at least sheltered against rain, but drying outdoors in the Dutch winter is discouraged. After the seaweed is airdried, the final moisture is removed by an oven on 50 degrees for 3 hours. Afterwards the seaweed is dry enough to be finely process by a pulverizer.

3. **Combining**

   In a big mixer (800 liters) big batches of 10% seaweed,  70-75% loam and 15% water can be mixed to the right consistency. If needed 5% lime can be added to achieve water resistance.

4. **Pressing**

   After the combining the mixture can directly transported from the mixer to the loam brick press with a conveyor belt. The hydraulic press then presses from two sides into a brick. According to Oskam V/F, 320 bricks a day can be produced with 2-5 workers, depending on their skill level and the setup of the workspace (n.d.).

5. **Storage**

   Afterwards the bricks can be stored on pallets and need to dry about 30 days before they can be used on the building site.

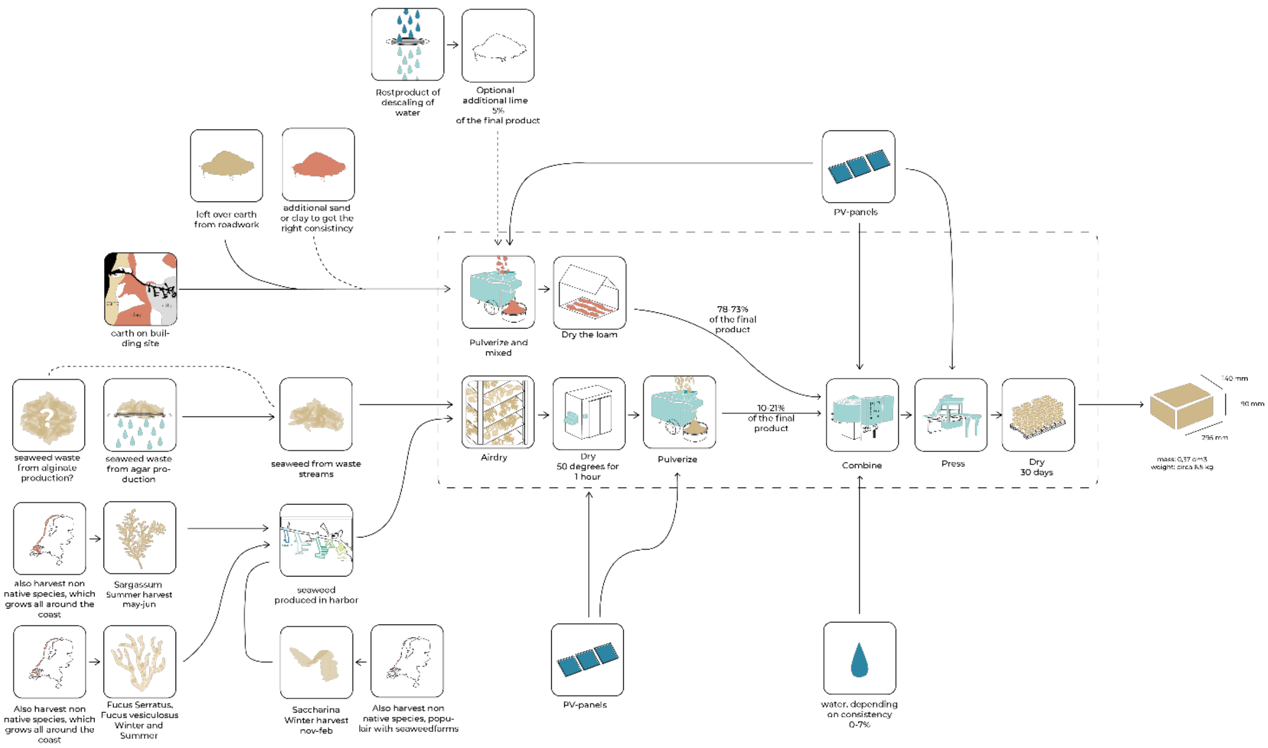



Figure 4.  Flow diagram of Seaweed loam bricks, see APPENDIX 3 for a bigger version

### 3.4.1 Base Materials

There are three main groups of base materials, the soil, the seaweed and additives. Besides those energy is a required “base material”. The production of the bricks will not be active all year round. By mainly producing in summer pv-panels can be used to directly power the machines. If the brick production is so successful that it outgrows this seasonal frame, investments in harvesting energy in winter, saving summer energy or more pv-panels have to be made.

Currently to acquire materials for the first group, soil, earth from the building site is used. Especially when making a basement or doing landscaping, a lot of excess earth becomes available. This can be mixed with additional clay or sand to get the right consistency (30-40% clay, 50-65% sand and 0-20% can be silt) According to the Dutch soilmap, the Netherlands mainly consist of clay, sand and peat. As the first two together create loam (and silt, although silt is often already in these soils) there is big chance these soils can sourced locally. In the case of Westpoort-Amsterdam, both clay and sand are available within a few kilometers (Pdok, n.d.). Westpoort itself seems to lay mostly on clay. This however is an educated guess as the area itself is not defined. But based on the confirmed clay soil type od the surrounding and the presents of the river, clay seems the most obvious soil option. Ofcourse digging is not possible everywhere, excess earth from roadworks would also be a useful source of material. This is already the case for the loambrick producer Oskam V/F, who get most of their loam from roadworks and the construction of the new Zoo in Emmen according to owner Rokus Oskam. Loam can be found “premixed” in parts of Drenthe and Limburg.

The second group is seaweed, the species that are tested with are Ascophyllum Nodosum, Fucus Serratus, Fucus Vesiculosus and Sargassum Muticum. These brown seaweeds all grow along the Dutch coast and are invasive species (Stichting Anemoon and NDFF, 2018). Most brown species are probably suited to be incorporated in the bricks. Green and red seaweed are not yet tested. The growing of seaweed can also take place in the harbour. A few kilometres downstream in the harbour of IJmuiden The Seaweed Farmers have small seaweed farm. They use a compact system of lines on boat parking places that are not in use, where the seaweed grows on(Spil and Laarhoven, 2021). This flexible growing system has also the potential to be temporary an makes the use of the harbor more efficient. A similar system could be installed in Westpoort. Beside growing the seaweed in the harbour itself, rejected batches of seaweed cultivated for food products could be used. The new seaweed farms proposed in front of the Dutch coast are in close proximity of the Wespoort harbour. The batches from this farm that not suffice to the high food grade standard can be easily shipped to Wespoort.

Also there might be potential in using waste material of agar production. Agar is a mostly used because of its gelling characteristics in many food products. Agar from certain types of red seaweed is withdrawn by treating it with 95-100 degree Celsius water for 2-4 hours. Then the seaweed residue is filtered out whereas the water has absorbed the agar from the seaweed (McHugh and Food And Agriculture Organization Of The United Nations, 2003). The treatment of seaweed with hot water should not interfere with how seaweed is used in the seaweed bricks, but the seaweed bricks are not yet tested with red seaweed. Currently the closest agar production facility is Sobigel in France. However with the plans of the off-shore seaweed farms the likeliness is high that this type of manufacturers will also come to the Netherlands. Another process that might be interesting to study is the process of producing alginate, in this process also a seaweed residue is one of the waste materials. This one however has experienced more modifications and seems to mainly consist out of the cellulose from brown seaweed(McHugh and Food And Agriculture Organization Of The United Nations, 2003). How this residue actually looks like is difficult to find out. As many producers are secretive about their process. When the process is discussed, however the focus lies on the alginate and not many details are given on the waste materials. It would be interesting to explore this possibility in depth in a different research.

Lastly the additives, which in this case only entails lime. Lime isn’t necessary in every brick, however bricks that are exposed to too much water will need around 5% lime to keep them water resistant. Traditional lime production from limestone releases a lot of $CO_2$ during the heating of the limestone (BBC, n.d.). Another method of harvesting lime in the Netherlands is reusing the lime that is filtered from drinking water (KWR, 2016). Currently two big facilities of Waternet (Dutch water treatment facility) treat water to produce drinking water in Westpoort for Amsterdam and smaller surrounding cities and villages. Acquiring lime from these facilities would reduce the $CO_2$ emissions immensely, not only because of the $CO_2$ produced in the limestone process but also because of the short transport route.

### 3.4.2 Rest Materials

The whole process is quite efficient in using all the materials in the brick. No real waste materials are made during the making of the block itself. Naturally the equipment used will wear out over time and will need to be repaired. The flow diagram only looks at the manufacturing process, but when the seaweed loam bricks reaches the end of its lifespan, the material can be easily be taken apart and reused. When using clay mortar, which is standard with loam bricks, the wall can be easily pulled apart especially compared to cement based mortars. The seaweed bricks can be, just like loam bricks (Oskam V/F, n.d.), be pulverized when damaged and pressed into a new brick when needed. Also when the bricks don't find a new purpose, they consist out of earth and organic matter. So with enough water, warmth and time the seaweed can be composted making an enriched earth for farming ground and gardens. (This process doesn't happen in the brick as the moisture levels, when not constantly adding water, are too low.)

## 3.5. Comparing Seaweed and Standard Building Materials

Below an overview is shown of the seaweed brick compared to three more standard Dutch building materials. In this comparison only the manufacturing process is considered. Transporting the final material is not included in the consideration although this can impact the $CO_2$ emissions also greatly. Due to the limited space of this paper only $CO_2$ emissions, water- and energy use are considered but an more in depth comparison would shed even more light on the sustainability level of the seaweedbrick. Other factors that play a role in the sustainability of an material are re-usability, flexibility, renewable resources, social impact and environmental impact.

Table 1. Comparison seaweedbrick, fired brick, Reed and Trespa plate, the thicknesses of the material are based on standard one layer thickness in façade or roof. Please be aware these are estimates as production processes can differ and not all numbers are as readily available. See for calculation APPENDIX 6.

| Material | quantity | kg CO2 emissions | m3 water-usage | MJ energy-usage |
|---|---|---|---|---|
| Seaweed brick (140 mm) | 1 m2 | 11 | 0,017 | 13,848 |
| Reed (250 mm) | 1 m2 | -32 | 0 | 38,546 |
| fired brick (100 mm) | 1 m2 | 74 | 0,022 | 172,800 |
| trespa plate ( 8mm) | 1 m2 | 37 | 0,840 | 259,000 |

Is not surprising that the natural materials score the best in terms of $CO_2$ emissions. The score of reed is based on the $CO_2$ emissions of straw as no research on reed could be found on this, straw was to be found most similar so this number was chosen. The seaweed brick underperformed compared to straw/Reed's number mostly due to the low percentage of seaweed in the brick, as seaweed itself also absorbs $CO_2$. Nevertheless the seaweed brick scores lower than the highly processed fired brick and Trespa plate. In terms of water-usage, the seaweed brick and fired brick perform quite similar. This is mostly due to the similar type of product. Reed on the other hand is often grown on peat and the landscape takes care of the watering and nutrients, just like seaweed. Manually there is often no extra water added. The Trespla plate shows a high water usage according to the Environmental Product Declaration by the International Committee of the Decorative Laminates Industry (2017) although it is unclear where this water is used. Finally for energy-usage the seaweed brick scores the lowest, this mostly because of its uncomplicated making process compared to fired brick and Trespa plate. Reed score surprisingly high. This has probably to do with the high maintenance reed harvesting machines. The seaweed on the other hand is mostly harvested manually, also for the production process an lot of manual labor is present which reduces energy-use. When sizing up the production these processes are often are taken over by machines, this could produce different numbers for energy usage. This however size of manufacturing is however not yet explored for the seaweed brick or the loam brick. So estimates can be yet made for that.

# IV. CONCLUSIONS

The main question was: *Is a seaweed-based building-skin more sustainable ($CO_2$, water use, energy use) in the end than sourcing standard nonlocal building products?* To answer this first the conclusions of the sub questions will be explained.

*What seaweed-based building skins are currently developed and is there potential for local production of this cladding?*
Seaweed building materials seem an up and coming niche with promising products. Unfortunately many are still in development at this moment. Nevertheless the further of the Dutch industry seems to be gearing towards seaweed innovations through the investments of the Dutch Government, University of Wageningen and the Dutch seaweedfarmers. Although these are manly meant for food production, rest materials and rejected batches could be used in building materials. Also the water filtering qualities of polluted areas are interesting in combination with production for building materials.

The seaweed bricks seem to have potential for a new niche building material on the Dutch market. The loam brick is an natural and stable building material and the addition of seaweed can make the unusual sized bricks lighter and slightly more insulating. The realization of this seaweed bricks hinges on the seaweed having multiple purposes (waterfiltering, educational and bricks) and the use of waste streams from the proposed seaweedfarms and other manufacturing processes. Because of these seaweedfarms and the naturals soil compositing of the Netherlands there is potential for local production of this seaweed brick. Although this will probably be limited by the production speed and the supply of soil, which unlike seaweed, doesn't regrown. Nevertheless niche small building projects could benefit form this seaweed building bricks and awaken the interest in seaweed building materials by the more mainstream building companies.

*What base materials are needed for the production and how can these be locally sourced? What are the waste material flows from this production and how can these be locally processed?*
The soil needed is clay and sand, earth can be sourced from the building site and additional sand or clay can be added to get the right consistency. Also excess clay, sand and loam from roadworks can be used. The seaweed can be harvested from temporary seaweedfarms that filter the harbour of Westpoort. Secondly rejected batches of seaweed for food production could be incorporated. Thirdly the cleanup of invasive species can provide seaweed an lastly the seaweed waste-residue of agar production can be turned into bricks. There might be potential in the seaweed residue from alginate production, but this needs to be researched more in depth. The last component is lime, which can be collected in collaboration with the water treatment plants in Westpoort. The process of the seaweed bricks is quite efficient in terms of materials and leaves no directly visible waste stream. The seaweed bricks are also easily demountable and re-usable.

The last sub question: *"Is the seaweed-based building-skin more sustainable ($CO_2$, water use, energy use) than a facade made from reed, bricks or Trespa plate?* " ties in with the main question: "*Is a seaweed-based building-skin more sustainable ($CO_2$, water use, energy use) in the end than sourcing standard nonlocal building products?".*
The making of seaweed bricks produce less $CO_2$ , use less water and energy than making bricks and trespa-plate. Compared to more raw building material like reed, the seaweed brick uses more water and produces more $CO_2$ but uses less energy although these margins were closer than compared to the highly processes materials. Of course the seaweed bricks cannot be produced in the same numbers with this production line as the fired bricks and Trespa plate. To summarize the seaweed bricks seem to be in the same range a more natural building materials like reed. It greatly outperforms fired bricks and Trespa plate, which was expected due to the simple manufacturing process.

It seems more sustainable options seem to require more time and research. For some people time is still money. For individual niche buildings seaweedbricks and loambricks might be an ideal sustainable solutions but for bigger projects the process needs to be scaled up and improved. This however will also take time, but you never know: in 20 years you might live in a seaweedhouse.

## V. Acknowledgements

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# APPENDIX

## APPENDIX 1:

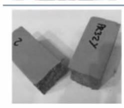
### Seaweed based Building materials - 2021

**Legenda:**

**Type of building material:** Stuff, Space plan, Services, Skin, Structure and Site from the work of Frank Guffy and Steward Brand

**Progress of build ready:**

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Just discovered | marketable product is being developed | production process is being set up | newly available | widely available on the market |

| What | type of building material | progress of build ready | specifics | source |
|---|---|---|---|---|
|  **Seawood-Blue Blocks:** fibreboard made from brown seaweed | Space plan | 2. Marketable product is being developed | | https://www.blueblocks.nl/portfolio/seawood/ |
|  **Seaweed rolls** - The Modern Seaweed House Vandkunsten: seaweed stuffed into netted bags | Skin | 2. Marketable product is being developed | | Widera, B. (2014, december). Possible Application of Seaweed as Building Material in the Modern Seaweed House on Laesø. 30th International PLEA Conference: SUSTAINABLE HABITAT FOR DEVELOPING SOCIETIES – Choosing The Way Forward, Ahmedabad, India. https://doi.org/10.13140/RG.2.1.1638.2881 |
| **Seaweed insulation**- The Modern Seaweed House Vandkunsten: panels of seaweed encased with wool | Skin | 2. Marketable product is being developed | | Widera, B. (2014, december). Possible Application of Seaweed as Building Material in the Modern Seaweed House on Laesø. 30th International PLEA Conference: SUSTAINABLE HABITAT FOR DEVELOPING SOCIETIES – Choosing The Way Forward, Ahmedabad, India. https://doi.org/10.13140/RG.2.1.1638.2881 |
|  **SeaCell-Smartfiber** cloth made of seaweed and natural cellulose fiber | Space plan | 4. Newly available | 2. Marketable product is being developed | https://www.smartfiber.de/en/seacell-fiber/ |
|  **KNOT seaweed house - Warwick McLeod** woven bull kelp | Skin | 0. testproject | woven bull kelp/Durvillea Antarctica and Cystophora Platylobium, | https://roomartspacenyc.com/artist-s/warwick-mcleod/knot |
|  **Seaweed roof -Seaweed House coastal areas of Jiaodong:** | Skin | 5. but vernacular building technic in asia, not know in europe | Seaweed roof needs four layers: the bottom is slope grass grass, laying seagrass, then wheat straw, each with a layer of seaweed to add a layer of straw, to be more strong. | Strategy Take Seaweed House and Oystershell Loculus for Example. Applied Mechanics and Materials, 368–370, 425–429. https://doi.org/10.4028/www.scientific.net/am-m.368-370.425 |
|  **Seaweed thatching-Kathryn Larsen** thatched eelgrass panels mixed with natural glues | Skin | 1,5. partly based on vernacualir architecture in Denmark, partly new research to improve the proces | eelgrass | Larsen, K. (2018). Seaweed Architecture - Eelgrass as a Construction Material. |
|  **Seaweed paviljoen - Kathryn Larsen** eelgrass panels mixed | Skin | 1,5. partly based on vernacualir architecture in Denmark, partly new research to improve the proces | eelgrass | Larsen, K. (2018). Seaweed Architecture - Eelgrass as a Construction Material. |
|  **seaweed biopolymers and unfired clay bricks-** a mix of compressed clay and seaweed biopolymers | Space plan | 2. Marketable product is being developed | Scottisch seaweed: Ascophyllum nodosum and Laminaria, Laminaria hyperborea, Laminaria saccharina, and Laminaria digitata | |
|  **Seaweed insulation- NeptuTherm** dried up pieces of seaweed balls that mold resistant, non-flammable, doesn't rot and can absorb moisture. | Skin | 4,5 Been available for a few years | Posidonia oceanica plant (better known as Neptune grass) | https://www.neptugmbh.de/anwendungen.html#fassade |
| **Seaweed insulation- Aerogel** Flame-retardant and heat-insulating aerogels were developed from seaweed by isolating CNFs rich in alginate, which act as a natural flame-retarding agent. | Skin | 1. just discovered | Gracilaria species | Berglund, L., Nissilä, T., Sivaraman, D., Komulainen, S., Telkki, V.-V. and Oksman, K. (2021). Seaweed-derived Alginate–Cellulose nanofiber aerogel for insulation applications. ACS Applied Materials & Interfaces, 13, pp.34899–34909. |

| | | | | | |
|---|---|---|---|---|---|
| | **Seaweed mortar-**<br>With appropriate mix design with seaweed ash, it can provide better stuffing ability and boost the compressive strength of mortar. | Skin | 1. just discovered | Gracilaria Sp. (powder) and Eucheuma Cottonii | Baloo, L., Kankia, M.U. and Wei, O.J. (2021). Usage of Seaweed as a Biocomposite Material in Green Construction. Lecture Notes in Civil Engineering, pp.127–138. |
|  | **Seaweed insulation Mats- Advanced Nonwoven**<br>Seaweed fibers are cut small then compressed and heated to form mats that are cut to size. (CRAFT -Technology | Skin | 4, Newly available | | https://advancenonwoven.dk/case-stories/ |
|  | **Sargablock- Omar Vazquez**<br>Bricks made of 40% Sargassum seaweed | Skin | 4, Newly available | coast of mexico, sargussum seaweed washing up on the beaches | https://undplac.exposure.co/sea-change<br>https://fortomorrow.org/explore-solutions/sargablock#presentation-tab |
|  | **Væve Installation- Studio Seagrass**<br>Eelgrass woven on a steel under-structure | Skin | 1,5. partly based on vernaculair architecture in Denmark, partly new research to improve the proces | | Larsen, K. (2018). Seaweed Architecture - Eelgrass as a Construction Material. |
|  | **Seaweed roof -Traditional Danish roof** | Skin | 5. but vernacular building technic in asia, not know in europe | Eelgrass roof | Gardiner, K. (2020). Denmark's 300-year-old homes of the future. [online] www.bbc.com. Available at: https://www.bbc.com/travel/article/20200805-denmarks-300-year-old-homes-of-the-future. |

APPENDIX 2:

# Report Loambricks with seaweed

In this small report the possibility of integrating seaweed in loambricks is research. The report is focus on the question: "*How much seaweed can be integrated in a loambrick?*".?".

## Materials:

For the bricks there are two main base components Loam and Seaweed. The addition of lime will help stabilize the bricks and make them water resistant but is not a necessary component. The experiments will focus on bricks without lime but the beneficial factors of the additional of lime are recognized.

**Loam**

Loam consist of sand, clay and silt, each of these components has a different particle size. A good mixture often consist of 30-40% clay, 50-70% sand and 0-30% silt. As seen the ratio's can differ quite a bit according to different sources. This has most-likely to do with the inconsistency of soil purity. This is also why generally to make loam just sand and clay are mixed as they often contain already some silt. For this experiment Drenths loam is used as starting point. Drenthe is an province of the Netherlands which has boulderloam, loam with big boulders, which were deposited there during the ice age.

Figure 1. Loam

**Seaweed**

The seaweed is collected Around the Oosterschelde, Zeeland. Due to the time period (November-December) mostly winterspecies were collected although some remnants of Summer species (sargassum) were also spotted. The species identified were probably Ascophyllum Nodosum, Fucus Serratus, Fucus Vesiculosis, Sargassum Muticum and Himanthalia Elongata. As the Fucus family and Ascophyllum had the largest quantities, these were selected for testing. The Seaweed was dried in 18-19 degrees Celsius room (next to a heater) for three days before being used.

Figure 2. Seaweed

**Water**
Normal Dutch tap water is used for the needed water in the experiments.

## Equipment:

The experiment makes use of an wooden brick press, that has been built for this experiment. The brick press is based on the Biomass Briquette Press by Engineers Without borders (http://leehite.org/ewb_project.htm).

Figure 3. Brick press, self-made by Rianne Reijnders & Nico Reijnders

## Methode:

The methode of producing loambricks is as follows:

1. Mix loam with water until the loam can be formed to a ball when squeezed that doesn't fall apart. The mixture should feel sticky.

Figure 4. Wetted loam, left squeezing. Middle forms a ball, but breaks so needs more water. Right holds shape and feels sticky, good to use for next step.

Figure 5. Left, fill mold. Middle stack until underbeam of lever mechanism is reached. Right press down on lever.

2. Fill mold, see figure 5.
3. Put the pressingblock on top of the filled mold, the pressing block should perfectly fit in mold. Stack other blocks on top if necessary to reach the underside of the lever mechanism, see figure 5.
4. Press down on lever, see figure 5.
5. Unmold the mold by turning it upside down and place a small block under the pressing block. Then slowly press the edges of the mold down, see figure 6.

Figure 6. Left, turn mold upside down and place a smaller block under the pressingblock. Right, slowly press the mold down until the loambrick is free.

In the next tests the loam mixture is perfected so that doesn't have an influence on the additional seaweed.

**Test A1:**

| Mixture | grams | Other |
|---|---|---|
| Loam | 1318 | Drenths Loam 1, no additives |
| Water | 11 | |
| **Total** | 1329 | |

**Test A2:**

| Mixture | grams | Other |
|---|---|---|
| Loam | 1048 | Drenths Loam 1, no additives |
| Water | 15 | |
| **Total** | 1063 | |

The first two test with the loam producted fragile bricks. This is because of too little clay in the mixture, see the test in picture above. The settled layer on top is clay and the ratio seems to be 15% clay and 85% sand and other particals. For the next batch B a different loam with more clay will be used with a ratio of 30% clay and 70% sand and other particals.

**Test B1**

| Mixture | grams | Other |
| --- | --- | --- |
| Loam | 1270 | Drenths Loam 2 |
| Water | 95 | |
| **Total** | 1365 | |

**Test B2**

| Mixture | grams | Other |
| --- | --- | --- |
| Loam | 1891 | Drenths Loam 2 |
| Clay | 233 | |
| Water | 123 | |
| **Total** | 2047 | |

# Results:

## Part A

Seaweed was cut into pieces of 3 cm with scissors and then mixed with water and Drenths loam 1. Due to having to much sand an to little clay in the loam mixture these samples were unstable and cracked which was also explained in the method. Nevertheless these samples were included to show the failed samples. In part B a retest will ben done but with better ratio loam.

**Test A3:**

| Mixture | grams | Other |
|---|---|---|
| Loam | 1258 | Drenths Loam, no additives |
| Water | 23 | |
| Seaweed: Fucus family and Ascophyllum | 50 | Length: min 1cm<br>Max 3cm |
| **Total** | 1331 | |

**Test A4:**

| **Mixture** | **grams** | **Other** |
|---|---|---|
| Loam | 1185 | Drenths Loam, no additives |
| Water | 19 | |
| Seaweed: Fucus family and Ascophyllum | 50 | Length: max 1 cm |
| **Total** | 1254 | |

The seaweed infused bricks show cracks, the top bricks doesn't contain any seaweed. It unfortunately broke the next day when picked up.

## Part B

A better quality loam was used. Two types of seaweed were tested. 4 different methodes and/or combinations were tested next diagram. Finely chopped seaweed was oven dried seaweed put in a blender for 5 minutes to ensure a fine chop. The extra oven time ensures the brittleness of the seaweed so that is more easily pulverized in the blender.

| **Seaweed** | **3 days airdry, (seaweed chopped big) then combined with loam** | **Wetly mixed with clay (seaweed not chopped)** | **3 days airdry and 50 degree oven for 60 minutes (seaweed chopped fine), mixed with loam** | **3 days airdry and 50 degree oven for 60 minutes (seaweed chopped fine) then mixed with extra water, mixed with loam** |
|---|---|---|---|---|
| **Sargassum** | B4 | B7 | B6 | B11 |
| **Fucus family and Ascophyllum** | B3 | B9 | B5 | B10 |

**Test B3:**



| **Mixture** | **grams** | **Other** |
|---|---|---|
| Loam | 1232 | Drenths Loam 2 |
| Water | 122 | |
| Seaweed: Fucus family and Ascophyllum | 50 | Dry Crushed fine in blender |
| **Total** | 1404 | |

**Test B4:**


| **Mixture** | **grams** | **Other** |
|---|---|---|
| Loam | 1187 | Drenths Loam 2 |
| Water | 115 | |
| Seaweed: Sagassum | 32 | Dry Crushed fine in blender |
| **Total** | 1334 | |

**Test B5:**

| Mixture | grams | Other |
|---|---|---|
| Loam | 1184 | Drenths Loam 2 |
| Water | 117 | |
| Seaweed: Fucus family and Ascophyllum | 100 | ovendried for 1 hour at 50 degrees |
| **Total** | 1401 | |

**Test B6:**

| Mixture | grams | Other |
|---|---|---|
| Loam | 1260 | Drenths Loam 2 |
| Water | 172 | |
| Seaweed: Sargassum | 53 | ovendried for 1 hour at 50 degrees |
| **Total** | 1485 | |

**Test B7:**

| Mixture | grams | Other |
|---|---|---|
| Clay | 1216 | |
| Water | 48 | |
| Seaweed: Sargassum wet weight | 181 | Soaked for 15 minutes |
| **Total** | 1445 | |

**Test B9:**

| Mixture | grams | Other |
|---|---|---|
| clay | 1606 | |
| Water | 66 | |
| Seaweed: Fucus family and Ascophyllum wet weight | 150 | Length: max 1 cm |
| **Total** | 1820 | |

**Test B10:**

| Mixture | grams | Other |
|---|---|---|
| Loam | 1223 | Drenths Loam 2 |
| Water | 77 | |
| Seaweed: Fucus family and Ascophyllum, wett slurry | 50 | |
| **Total** | 1340 | |

**Test B11:**


| Mixture | grams | Other |
|---|---|---|
| Loam | 1185 | Drenths Loam 2 |
| Water | 120 | |
| Seaweed Sargassum | 54 | Length: max 1 cm |
| **Total** | 1328 | |

**Part C:**

In this part the seaweed is dried for 3 hours in the oven at 50 degrees Celsius instead of 1 hour. Also the ratio seaweed is increased in increments, see table below. The goal was to test 10%, 20% and 40 % seaweed. When the seaweed ratio increased more water was necessary than expected due to the absorbing qualities of the seaweed. Before drying the seaweed ratio's ended up at 10% and 17% with seaweed and loam. Due to the fail of the 17% seaweed with loam, a higher ratio was tried with clay, which is more sticky. Nevertheless this result also cracked.

| **Seaweed** | **4% seaweed with loam (part B!)** | **10% seaweed with loam before drying** | **17% seaweed with loam before drying** | **25% seaweed with clay before drying** |
|---|---|---|---|---|
| **Fucus family and Ascophyllum** | B10 | C1 | C2 | C3 |

**Test C1:**

| **Mixture** | **grams** | **Other** |
|---|---|---|
| loam | 1110 | Drenths Loam 2 |
| Water | 240 | |
| Seaweed: Fucus family and Ascophyllum wet weight | 150 | Length: max 1 cm |
| **Total** | 1500 | |

**Test C2:**

| **Mixture** | **grams** | **Other** |
|---|---|---|
| Loam | 970 | Drenths Loam 2 |
| Water | 521 | |
| Seaweed: Fucus family and Ascophyllum, wett slurry | 300 | Length: max 1 cm |
| **Total** | 1791 | |

**Test C3:**

| **Mixture** | **grams** | **Other** |
|---|---|---|
| clay | 540 | |
| Water | 525 | |
| Seaweed Sargassum | 360 | Length: max 1 cm |
| **Total** | 1425 | |

**Overview:**

| Number | seaweed | Loam/clay | Notes |
|---|---|---|---|
| A1 | none | Drenths loam 1 | |
| A2 | none | Drenths loam 1 | |
| A3 | airdried for 3 days, Fucus family and Ascophyllum (chopped max 3 cm) | Drenths loam 1 | |
| A4 | airdried for 3 days, Fucus family and Ascophyllum (chopped max 3 cm) | Drenths loam 1 | |
| B1 | none | Drenths loam 2 | |
| B2 | none | Drenths loam 1, with extra clay | |
| B3 | airdried for 3 days, Fucus family and Ascophyllum | Drenths loam 2 | (seaweed: ruffly chopped) |
| B4 | airdried for 3 days, sargassum | Drenths loam 2 | (seaweed: ruffly chopped) |
| B5 | airdried for 3 days, Fucus family and Ascophyllum | Drenths loam 2 | (seaweed: 1 hour in 50 degree Celsius oven, blender 5 minutes, pulverized finely) |
| B6 | airdried for 3 days, sargassum | Drenths loam 2 | (seaweed: 1 hour in 50 degree Celsius oven, blender 5 minutes, pulverized finely) |
| B7 | airdried for 3 days, sargassum | clay | (seaweed: whole pieces soaked for 15 minutes) |
| B9 | airdried for 3 days, Fucus family and Ascophyllum | clay | (seaweed: whole pieces soaked for 15 minutes) |
| B10 | airdried for 3 days, Fucus family and Ascophyllum | Drenths loam 2 | (seaweed: 1 hour in 50 degree Celsius oven, blender 5 minutes, pulverized finely, then soaked in water) |
| B11 | airdried for 3 days, sargassum | Drenths loam 2 | (seaweed: 1 hour in 50 degree Celsius oven, blender 5 minutes, pulverized finely, then soaked in water) |
| C1 | airdried for 3 days, Fucus family and Ascophyllum | Drenths loam 2 | (seaweed: 3 hour in 50 degree Celsius oven, blender 5 minutes, pulverized finely) |
| C2 | airdried for 3 days, Fucus family and Ascophyllum | Drenths loam 2 | (seaweed: 3 hour in 50 degree Celsius oven, blender 5 minutes, pulverized finely) |
| C3 | airdried for 3 days, Fucus family and Ascophyllum | clay | (seaweed: 3 hour in 50 degree Celsius oven, blender 5 minutes, pulverized finely) |

| **Num ber** | **Ratio seaweed : loam : water** | **Percentage seaweed wett brick** | **Fail/ success** | **Reason** |
|---|---|---|---|---|
| A1 | - : 1318 : 11 | 0% | | Broken after drying. Too low quality loam, too little water. |
| A2 | - : 1048 : 15 | 0% | | Broken after drying. Too low quality loam, too little water. |
| A3 | 50 : 1258 : 23 | 4% | | Cracked during drying. Too low quality loam, too little water. |
| A4 | 50 : 1185 : 19 | 4% | | Cracked during drying. Too low quality loam, too little water. |
| B1 | - : 1270 : 95 | 0% | | Different loam, more water was added |
| B2 | - : 1891 : 123 : clay 233 | 0% | | More clay was added to the loam, more water was added |
| B3 | 50 : 1232 :122 | 4% | | Cracked while drying, seaweed seemed to absorb too must moisture, pieces are too big and expand too much |
| B4 | 32 : 1187 :115 | 2% | | Cracked after drying, seaweed seemed to absorb too must moisture, pieces are too big and expand too much |
| B5 | 100: 1184 :117 | 8% | | Seems unstable and cannot be picked because of crumbling risk, seaweed seemed to absorb too must moisture |
| B6 | 53 : 1260 :172 | 4% | | Seaweed was chopped finer (oven drying makes it easier for blender to pulverize) |
| B7 | 81 : - : 148: clay 1216 | 6% | | Clay encapsulated seaweed, needed long time to dry |
| B9 | 50 : - :166 ; clay 1606 | 3% | | Clay encapsulated seaweed, needed long time to dry |
| B10 | 50 : 1123 : 177 | 4% | | Soaking the pulverized seaweed beforehand made sure that the seaweed didn't absorbed the moisturefrom the loam |
| B11 | 54 : 1185 :120 | 4% | | Soaking the pulverized seaweed beforehand made sure that the seaweed didn't absorbed the moisture from the loam |
| C1 | 150 : 1110 :240 | 10% | | Soaking the pulverized seaweed beforehand made sure that the seaweed didn't absorbed the moisture from the loam |
| C2 | 300 : 970 :521 | 17% | | The seaweed needs so much extra water that loam ratio becomes really low |
| C3 | 360 : - : 554 : clay 540 | 25% | | The seaweed needs so much extra water that clay ratio becomes really low |

## Conclusion:

As seen in the failed samples A1/A4 is important to work with quality products and to test base ratio of other components. In B1 and B2 these problems were solved and a stable loambrick with no seaweed was created.

Adding airdried seaweed in bigger pieces (max. 3 cm) made the bricks unstable due to too much movement of the seaweed when absorbing water in the loam brick as seen in B3 and B4. To pulverize the seaweed smaller it had to be oven dried (50 degrees Celsius, 1 hour) otherwise the seaweed was not brittle enough for the blender to chop finely. This was then mixed dry with the loam and then water, see sample B5 and B6. B5 had an higher percentage seaweed than B6 due to a low availability of the sargassum. B5 experienced the same problems as B3 and B4, the seaweed seems to absorp the moisture in the brick making it crumbly. B6, on the other hand fared better due to the lower percentage seaweed and had more water added in comparison.

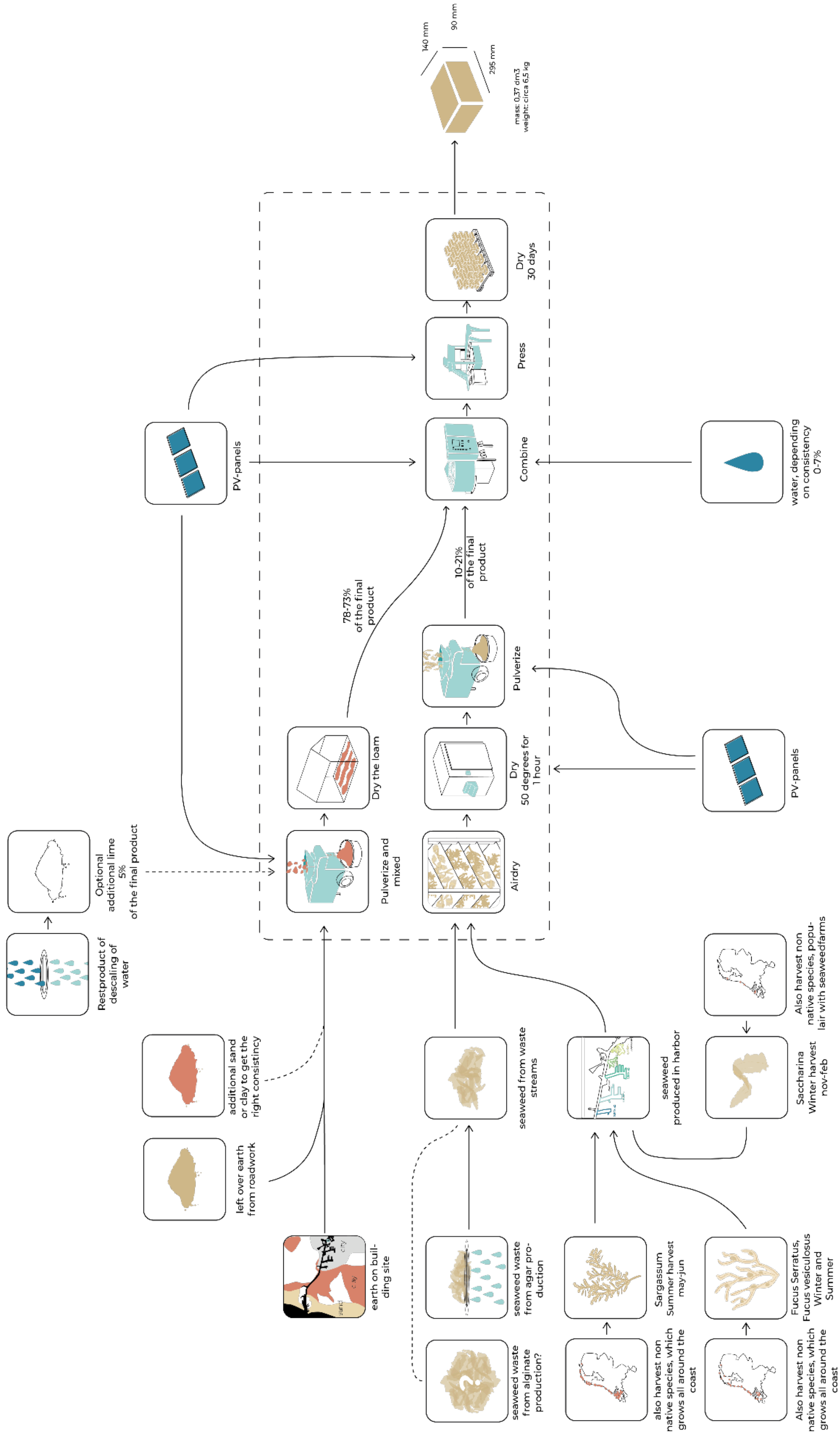
To combat the absorption of the water from the loambrick by the seaweed, the finely pulverized seaweed was soaked before added to the loam and water in B10 and B11. This resulted in a higher overall water content but also the seaweed and the loam dried at a more similar rate. When dried the bricks could be picked up without problems and seemed quite stable for loambricks.

In the last part the percentage seaweed were upped with this new methode. C1, with 10% seaweed seemed quite textured but held together fine. C2 cracked quite fast. The seaweed needs so much extra water that the loam percentage get quite low (when including water in de weight of the loam brick, so wet weight). This probably minimizes the 'stick" of the brick which holds together everything when drying. The seaweed was put 2 hours longer in the oven compared to the batch of the B test. However this didn't make any difference as the blender couldn't get the seaweed finer than the seaweed from batch B. If the seaweed is properly airdried 1 hour at 50 degrees Celsius is enough to get it brittle.

Beside loam, also experiments was conducted with clay. In B7 and B9 whole pieces of wet seaweed were encapsulated in clay, These dried very well and seem stable. This was more of a side experiment as the material was available. When the pulverized seaweed was tried the brick with clay failed, see C3, this was probably because of the high percentage (25% seaweed). The bricks were dried inside and dried very slow. It is more difficult to obtain pure clay compared to loam (clay, sand mix). Nevertheless the clay seaweed bricks give incentive to further study in a separate research.

The report focused on the question; "*How much seaweed can be integrated in a loambrick?*". The results show that a maximum om 10% can be integrated in a loambrick when the seaweed is processed a certain way. Important is the preparation of the seaweed, which is to oven dry to pulverize finely and then soak before mixing with the loam. The ratio is seaweed : loam : water = 1 : 7,4 : 1,6 (150 : 1110 :240).

# APPENDIX 3: FLOWCHART



## APPENDIX 4: EXCEL CALCULATIONS, SEAWEED BRICK PROCESS

(currently calculated bricks of one house with exception of the last table)

| production time | hours | days ( 7 hours) |
|---|---|---|
| production speed: bricks per hour with 2-5 workers | 320 | |
| time it takes to produced bricks for one house | | 11,16071429 |

| Other Numbers | |
|---|---|
| amount of bricks for an average 2 story house | 25000 |
| dry weight kg seaweed per hectare each year | 20.000 |
| westpoort west bays in hectares | 585 |

| baseproducts | kg |
|---|---|
| clay | 45500 |
| sand | 68250 |
| lime | 8125 |
| seaweed (dry) | 16250 |
| water | 24375 |

**making loam**

| ingredients | % | kg |
|---|---|---|
| clay | 40 | 45500 |
| sand | 60 | 68250 |
| silt* | 0 | 0 |

*Silt is already present in natural clay and sand as these are almost never pure in natural deposits

**making brick**

| ingredients | % | kg |
|---|---|---|
| loam | 70 | 113750 |
| seaweed | 10 | 16250 |
| lime | 5 | 8125 |
| water | 15 | 24375 |

| endproducts | amount | kg |
|---|---|---|
| Bricks | 25000 | 162500 |

| needed seaweedfarms | hectare | % of the bay |
|---|---|---|
| for x houses a year | 8,125 | 1,388888889 |

↓

| | |
|---|---|
| x | 10 |

## APPENDIX 5: EXCEL CALCULATIONS, ESTIMATE SQUARE METERS PRODUCTION FACILITY

| opslag | amount | m^2 excl walking space | total m2 |
|---|---|---|---|
| loam (clay, silt, sand) dried | | 1000 | |
| seaweed dry (indoors) | | 300 | |
| (temporary before placed on the airdring racks) | | 100 | |
| lime | | 20 | |
| extra machine parts | 1 | 40 | |
| finished bricks, 96 bricks per m2, amount for 5 houses | 125000 | 1302,083333 | |
| tractor/forklift | 2 | 50 | |
| breakroom | 1 | 25 | |
| | | | **2787,083333** |

| preparation | 1 harvest amount seaweed in kg dry | m2 drying space 2,4 kg Seaweed (dry) per 1m2, | m^2 excl walking space, (stacked 4 high for airdry) | total m2 | source |
|---|---|---|---|---|---|
| air drying seaweed | 6500 | 2708,333333 | 677,0833333 | | https://www.fao.org/3/ac287e/ac287e04. |
| Oven (XL1800) 30 m2 per cycle. 3 cycles needed | | | 2,5 | | w.france-etuves.com/PDF/PR |
| | | | | **679,5833333** | |

| proces | machine | other | m^2 excl walking s | m^2 incl walking space/forklift | total m2 |
|---|---|---|---|---|---|
| | temporary place basematerial | | 4? | 8 | |
| | pulverizer | | circa 1m2 | 6 | |
| | Mixer 800 L incl spray dosing machine | | circa 4m2 | 10 | |
| | 1 compressed earth block machine incl dosage computer | 2,3 x 1,9 x 1, 6 m | circa 5m2 | 16 | |
| | **temporary place bricks**, 320 bricks in a hour, 7 hour of production = 2240 bricks a day max. | each pallet (circa 1 m2) 12 bricks a layer, Stacked 8 layers high: 96 bricks a pallet -> 2240/96= 24 pallets | 24 * 1m2 = 24 m2 | 35 | |
| | | | | | **75** |
| | | | | | |

| activities | rooms | amount | m2 | total m2 |
|---|---|---|---|---|
| restaurant | kitchen | 1 | 30 | |
| | restrooms | 2 | 10 | |
| | dining area | 1 | 70 | |
| | storage | 1 | 30 | |
| | | | | 150 |
| workshops | | | | |
| | workshop room | 1 | 40 | |
| | storage | 1 | 20 | |
| | | | | 60 |
| hotel | | | | |
| | entrance/ desk | 1 | 15 | |
| | rooms w bathr | 5 | 25 | |
| | sitting area | 1 | 20 | |
| | storage/cleaning supplies/bedding | 1 | 10 | |
| | | | | **170** |

APPENDIX 6: EXCEL CALCULATIONS, SUSTAINABILITY SEAWEED BRICK PRODUCTION

| Material | quantity | kg CO2 emissions | m3 water-usage | MJ energy-usage |
|---|---|---|---|---|
| **Seaweed brick (140 mm)** | 1 m2 | 11 | 0,017 | 26,808 |
| **Reed (250 mm)** | 1 m2 | -32 | 0 | 38,546 |
| **fired brick (100 mm)** | 1 m2 | 74 | 0,022 | 172,800 |
| **trespa plate ( 8mm)** | 1 m2 | 37 | 0,840 | 259,000 |

| Material | quantity | components | procent | kg CO2 emissions | total CO2 emissions |
|---|---|---|---|---|---|
| **Seaweed brick** | 1 m2 | unfired earth brick | 90 | 13,1 | |
| | | seaweed* | 10 | -1,722 | |
| | | | | | 11,378 |
| **Reed*** (based on straw)** | 1 m2 | | | | -32 |
| **fired brick*** ** | 1 m2 | | | | 74 |
| **trespa plate** ** | 1 m2 | | | | 37,4 |

*24,6 % of dried weight of seaweed is co2, 1m2 seaweed is 63,4 kg. Duarte, C. M. (1992). Nutrient concentration of aquatic plants: patterns across species. *Limnol. Oceanogr.* 37, 882–889. doi: 10.4319/lo.1992.37.4.0882

**International Committee of the Decorative Laminates Industry (2017). *ENVIRONMENTAL PRODUCT DECLARATION: Decorative High-Pressure Laminates* . [online] Available at: https://www.pro-hpl.org/assets/uploads/prohpl/files/Umweltproduktderkla rung.pdf [Accessed 19 Dec. 2021].

***CINARK/The Royal Danish Academy and Vandkunsten (2019). *Byggeriets Materialepyramide* . [online] www.materialepyramiden.dk. Available at: https://www.materialepyramiden.dk/.

| Material | quantity | m3 water-usage |
|---|---|---|
| Seaweed brick | 1 m2 | 0,017 |
| Reed | 1 m2 | 0 |
| fired brick** | 1 m2 | 0,022 |
| trespa plate*** | 1 m2 | 0,84 |

**The brick Industry Association America (2006). *Manufacturing of Brick* . [online] Available at: https://www.gobrick.com/docs/default-source/read-research-documents/technicalnotes/9-manufacturing-of-brick.pdf?sfvrsn=0.

***International Committee of the Decorative Laminates Industry (2017). *ENVIRONMENTAL PRODUCT DECLARATION: Decorative High-Pressure Laminates* . [online] Available at: https://www.pro-hpl.org/assets/uploads/prohpl/files/Umweltproduktderkla_rung.pdf [Accessed 19 Dec. 2021].

| Material | quantity | components | MJ energy-usage | total MJ energy-usage |
|---|---|---|---|---|
| Seaweed brick | 1 m2 | pulverizer | 0,205206453 | |
| | | Mixer 800 L incl spray dosing machine | 0,0475475 | |
| | | 1 compressed earth block machine incl dosage computer | 0,12375 | |
| | | Oven (XL1800) | 25,92 | |
| | | electric boat for seaweed harvesting (1,5 kW for 8 km/h) roundtrip circa 10km | 0,511875 | |
| | | | | 26,80837895 |
| Reed | 1 m2 | Energy use including transport* | 50 | |
| | | 40% Dutch 75 km by truck* (31500 kg per truck, 1m2 is 32kg) | 0,318171429 | |
| | | 10% Turkey 2500 km by truck* | 2,651428571 | |
| | | 50% rest 1600 km by truck* | 8,484571429 | |
| | | | | 38,54582857 |
| fired brick** | 1 m2 | | | 172,8 |
| trespa plate*** | 1 m2 | | | 259 |

*Mkrtichian, F. (n.d.). Sea Change - Programa de Naciones Unidas para el Desarrollo en America Latina y el Caribe. [online] Exposure. Available at: https://undplac.exposure.co/sea-change [Accessed 7 Dec. 2021].

** based on 2 bricks cr m2 and Yüksek, I., Öztaş, S.K. and Tahtalı, G. (2020). The evaluation of fired clay brick production in terms of energy efficiency: a case study in Turkey. Energy Efficiency, 13(7), pp.1473–1483.

***International Committee of the Decorative Laminates Industry (2017). *ENVIRONMENTAL PRODUCT DECLARATION: Decorative High-Pressure Laminates* . [online] Available at: https://www.pro-hpl.org/assets/uploads/prohpl/files/Umweltproduktderkla rung.pdf [Accessed 19 Dec. 2021].

| machine | function | capacity | energy use | price Euros | |
|---|---|---|---|---|---|
|  pulverizer | grinds base materials to required grain size | 53m2/hour | 11 kW/400V elektromotor | 10.000 | https://oskam-vf.com/en/leemsteen-machines/pulverizers/pulverizer-11kw-400v |
|  Mixer 800 L incl spray dosing machine | mixing clay, sand, silt, lime nd seaweed | 32 tons a day, constant mixture every 3-5 minutes | 11 kW/400V elektromotor | 30.000-40.000 | https://oskam-vf.com/en/leemsteen-machines/mixers/stationary-automatic-mixer-800-liters |
|  1 compressed earth block machine incl dosage computer | compressing the bricks | 390 bricks each hour (12 m2) or 14.000 bricks in a week (425 m2) with 2-5 workers | 11 kW/400V elektromotor | expensive.... | https://www.block-machine.net/product/lt5-10-clay-compressed-brick-machine/ |
| Oven (XL1800) | drying seaweed | 30 kg dry seaweed | 18 kW/400V | | https://www.france-etuves.com/PDF/PROD.FE.EN/FRANCE-ETUVES-XL-EN.pdf |