Seaweed as construction material

Final wildcard project report

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1. Introduction

1.1 An innovative idea

Seaweeds are organisms that compose the majority of the marine flora. Whilst often being called plants, they are not. Seaweeds, or more appropriately called marine macro-algae, are phototrophic algae that thrive in saltwater systems and only need water, sunlight, carbon dioxide and nutrients to grow. Next to the many roles seaweed plays in the natural system, it has been gaining interest from our society as well. Where seaweeds have been used in Asia for many years, primarily as a food source, it is gaining ground as being a novel green resource in western countries. This interest originates from the broad potential of utilization of seaweed, but also from being an assumed low impact commodity as it does not require arable land, fresh water or any herbi- and pesticides to be cultivated.

Our idea focusses on the streams of seaweed that are not suitable for consumption (human or animal), nor for the extraction of compounds; for example: seaweed that periodically accumulates on beaches in large quantities. These large piles can cause negatively impact tourism and recreation and will have to be cleared. These streams may still hold value as the biomass could be used in a variety of non-food purposes of which we want to investigate the potential for using it as construction materials. Next to low cost, we also aim to see for low tech approaches so the technique could be implemented locally. The first step is to identify streams of seaweed which are likely not to be used for the food or extraction industry and are thus potentially interesting for our goal. Next is to determine the general chemical composition of seaweeds and what species of seaweeds the potential streams of resource consist of. These factors determine the feasibility of using them as building material. The last two steps are to investigate the potential ecological impact of extracting this biomass from the natural system, and to test seaweeds in using them for the production of construction material.

1.2 Relevance to the materials transition in textiles and/or building materials?

With an ever growing world population, the need for land to produce food, feed, materials, etc. grows simultaneously. Alternatives have to be explored to meet this need. As over two third of the earth surface is covered by sea, it is a vast space where opportunities are profound. Especially coastal areas are suitable for exploitation as they are relatively easily accessible, rich in natural resources and house large quantities of biomass, including seaweed. By using seaweed as a building material a novel resource is exploited, filling the demand and reducing the demand for arable land, and additionally resolve the problem of a waste stream. Furthermore, with seaweed available in almost all coastal communities it can provide an income for local communities improving livelihood in poorer regions of the world. If seaweed can be used, it can be a new and green source for building materials, fully contributing to the material transition for building materials.

1.3 What did you do?

Within the project we have identified three potential sources of seaweed, that are of potential interest and have performed multiple experiments to explore the actual suitability for producing construction plates. The identified streams are the following:

1. **Seaweed derived from mass strandings** – In some areas of the world massive quantities of seaweed drift ashore. This biomass is often not used and can cause harm to both health, society, economy and ecology. By utilizing these sources a major concern can be transformed in an useful resource.
2. **Seaweed from natural beaching** – Is some area's in the world seaweed naturally beaches which can occur in substantial quantities. This resource is often not utilized, but offers potential.
3. **Waste streams from cultivation** – Cultivation of seaweed is increasing more and more. Some parts are, however, not suitable for consumption like the parts attached to the (plastic) substrate. These streams could potentially be suitable for utilization for non-food purposes like construction materials.

After identifying potential resources we took a look at the species of these streams and their chemical composition. A well-known mass stranding of seaweed occurs in the Caribbean. Here vast quantities of *Sargassum* sp. beach in spring. Currently, the seaweed is removed by incineration or by combustion. Either way results in loss of the biomass and cleaning of the coastal area is expensive. Based on this, we have investigated the potential of *Sargassum* using a close relative of this species that occurs in the Netherlands: *Sargassum muticum*. For this reason, we selected this species as one of the three to work with. Natural beaching of seaweed often consists of a broad mixture of species, covering the three major groups (brown, green and red), making it rather difficult to target a specific species . One very common species in Europe and present in beaching events is *Ascophyllum nodosum*, a brown algae. The availability and the fact that it is a species often used for multiple purposes made us choose this species. Besides these two brown algae and keeping in mind that green seaweeds are often not suitable for construction materials due to the chemical composition, we selected a red alga as third species to investigate. This red algae is *Chondrus crispus*, a species used to produce carrageenan (plant-based binding agent) and commonly found in the Netherlands. A fourth species was selected for the initial screening since this species is one of the most common (if not the most common) species of seaweed in the Netherlands: *Fucus serratus*.

Having selected these species (*S. muticum, A. nodosum, C. crispus* and *F. serratus*) we have collected some material from dikes on the island of Texel. Material was dried and initial tests were performed using high pressure and temperature to make the first set of board-like samples to evaluate binding characteristics for panel and board applications. Samples showed limited bonding (as a result of a lack on fibers), the *Ascophyllum* exhibiting highest bonding strength.

Aiming to increase the release of alginate binder from the seaweed cell walls, the material was milled. Milled *Ascophyllum* was boiled in water to further release the alginate. Also the effect of NaCl on alginate release was tested. To add structural strength, the boiled seaweed was mixed with reed particles (which are an underutilized lignocellulosic residue), dried and hot pressed to board-like samples. After some time, the board samples curved, due to the fact that the moisture content in the seaweed-reed mixture was not around the equilibrium level at the moment of pressing. The equilibrium level is needed, because if this is not the case water will evaporate resulting in the curving of the material. However, the resulting samples were promising enough to prepare board samples large enough for mechanical properties analysis.

In order to analytically evaluate the mechanical properties of seaweed based boards, a third series of trials was performed:, a larger batch of fresh *Ascophyllum* was sourced, dried, milled, heat treated, mixed with reed, hot pressed and tested for flexural strength and stiffness. Heat treatment of the seaweed at 80°C in the presence of acid to facilitate the release of alginate polymer from the cells resulted in about 60% higher strength and stiffness compared to treatment without acid. Pure alginate sourced from commercial suppliers resulted in again a 65% higher strength and stiffness. Yet the values are relatively low compared to commercial urea formaldehyde (UF) bonded particle board. It seems that the polymer has higher binding capacity after drying from the wet mixture (20% DM) of heat treated seaweed and reed than after drying and hot pressing. A first 'cook-and-look' test seems to confirm this hypothesis (organoleptic evaluation; analytical analysis would require further experimental trials).

In addition, these samples were investigated microscopically to assess the distribution of alginate containing seaweed material between the reed particles, as this could serve as a proxy for cohesive strength. These experiments showed that there is limited contact between seaweed and reed particles, suggesting that the strength of samples may be further increased by increasing the contact areas between both components and that microscopy may be an efficient tool to screen the quality of plates. When combined with specific cell wall stainings, further insight may be obtained about the localization of different cell wall components.

Furthermore infrared (IR) spectroscopy was used to analyse the board-like samples. IR spectroscopy identifies functional groups present within a material e.g. OH, COOH, C-O-C, CH groups etc. By identifying these groups in the seaweed and in the reed (the two materials which were combined to make a plate) and by identifying (and quantifying) the groups present in the plate insights will be gained on which groups are relevant for forming the plate. When this information is combined with the properties of the plates a fundamental understanding of the interactions needed to make a good plate will emerge. This is important for designing new materials with targeted properties beyond trial and error. To arrive at that point it needs first to be shown that IR can visualize differences between e.g. the seaweed, the reed and the combined material. Therefore here a preliminary IR study was performed on *Ascophyllum*, reed and a plate made by combing those two. IR was measured in transmission mode using a Bruker Vertex 70 (figure 1).

Figure 1: Bruker Vertex 70 used to obtain IR spectra.

The IR spectra recorded in transmission mode is shown in figure 2A using a dried KBr tablet of *Ascophyllum* and *Ascophyllum* + reed (the plate). For reference the spectra of reed and separately sourced alginate are included as well. It is interesting to note that the signals present at 1321 cm^{-1} and 877 cm^{-1} in the *Ascophyllum* (indicated by arrows) disappear when the plate with reed was pressed. This indicates that the groups represented by these vibrations do interact with the reed. The next step will be to identify the nature of the peaks to understand the chemistry of the interaction. Some indication of the identification of peaks in *Ascophyllum* is given in [Food Hydrocolloids 15 (2011) 1514] however the vibrations we see here are not identified in that publication. A comparison between *Ascophyllum* and *Sargassum* is shown in figure 2B. Clearly the spectra are different which already indicates that its interaction with reed must be different (the limited time in the project did not allow to study that further). Nevertheless with these initial experiments we showed that IR is a powerful technique to study seaweed interactions with other components which ultimately will allow the rational design of new material.

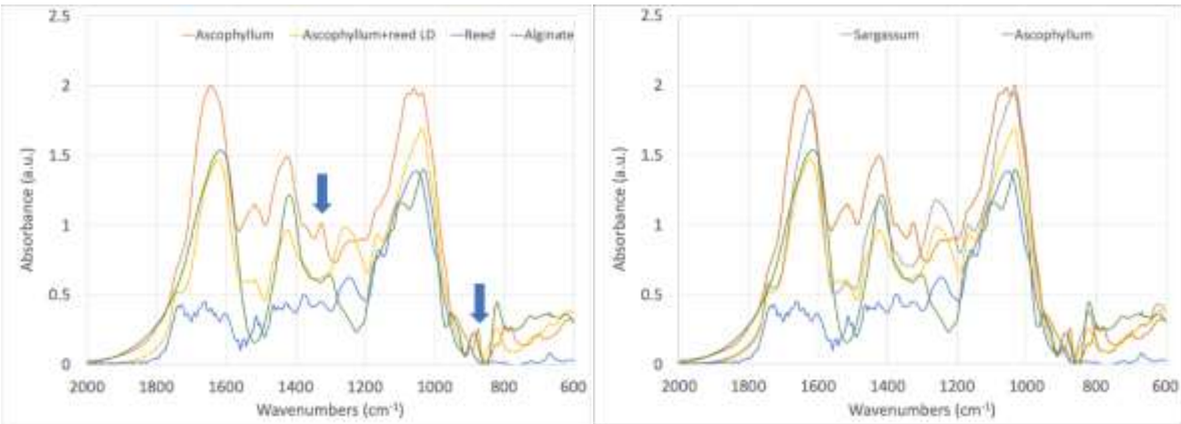


Figure 2: [A] IR spectra of the seaweed (*Ascophyllum*), reed and a combined plate (Ascophyllum + reed LD) to show the power of IR spectroscopy. **[B]** comparison of IR spectra of *Ascophyllum* and *Sargassum*

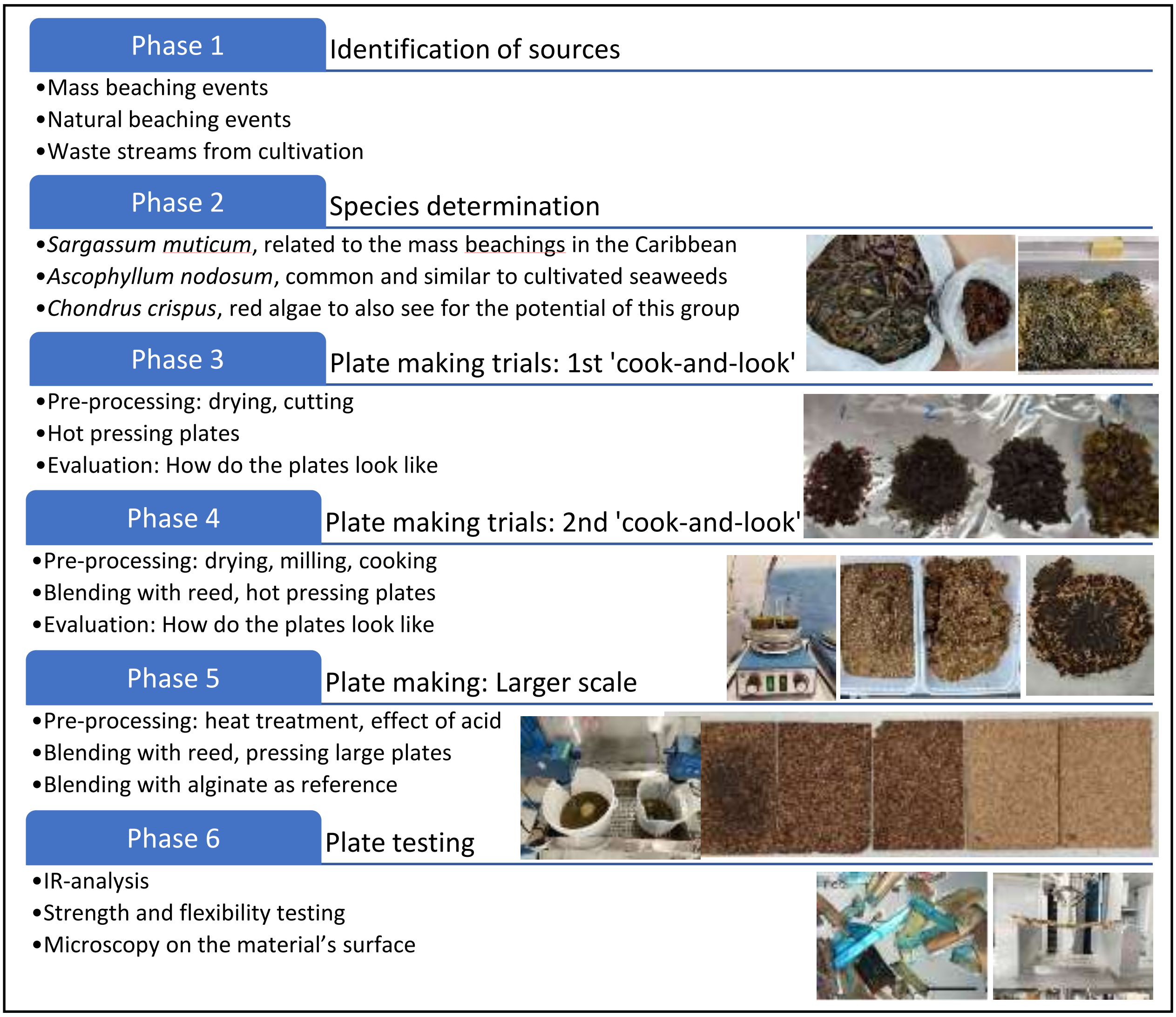
1.4 Main result, achievement and highlight

The main result is that we have shown that it is feasible to use seaweed as a component in construction materials. Processing methods do affect the quality and should be investigated more. We have shown that the lack of fibrous components in seaweed is the problem if solely seaweed would be used. Addition of a natural material which is rich in cellulose could tackle this, as shown by the addition of reed. Furthermore, the chemical treatment of adding an acid to the boiling process does substantially affect the consistency of the plates. The chemical processes are, however, still unclear and should be investigated more, as being able to adjust material characteristics opens even more possibilities for application.

1.5 Key message

The application of seaweed in building material has a potential and can aid in more sustainable utilization of (marine) resources. Transforming seaweed that is not suitable for food, feed or extraction of components for pharmaceutical or nutraceutical purposes can in this way be used a 'building block' for society without the need for fossil or terrestrial resources. With vibrational spectroscopy (IR) the functional groups essential for the bonding between seaweed and binder can be studied. Ultimately this will allow targeted design of seaweed based building materials with desired properties.

Visual abstract



2. Questions about 'readiness' and possible follow-up

2.1 Starting point

The project started with an idea without knowledge on the utilization of seaweed in the production of building materials. As a team, this meant that we had to start from scratch with solely our personal knowledge and interest.

2.2 Present state

During the research we identified two initiatives related to this work. 1. Sargablock, where they use *Sargassum* mixed with clay to produce bricks. 2. SeaWood (by Blue Blocks BV) which are interior plates made with seaweed. Some other initiatives were also found, but these are initiated by industrial artists/designers and not (yet) in a commercial setting.

We have made some first 'Seaplates' which are the first step in becoming serious products, either in collaboration with private partners, or further in understanding the (chemical) processes behind this new product.

2.3 Potential and next steps

The 'Seaplates' are potentially a serious product that may contribute substantially to the material transition: Using a novel resource that nowadays is not (or very limitedly) used for this type of application. The next step would be to improve the production process (e.g. dealing with high water content) and match it with the identified streams of biomass. Within this follow-up it is important to understand the (chemical) processes and understand how the production methodology could and should be improved. For making better plates a fundamental understanding of the relation between functional groups present in both the parent material and the binder and their interaction in the final material is indispensable. We showed here that IR spectroscopy has the potential to give that insight.

2.4 Innovation readiness

To our opinion the SeaPlate is in level 2. In perspective of the SeaWood (Blue Blocks BV), we estimate them to be at level 4 or 5.

Table 1: Innovation readiness levels as distinguished by Sartas et al, 2020.

Innovation readiness score	Innovation readiness level	Description
0	Idea	Genesis of the innovation. Formulating an idea that an innovation can meet specific goal.
1	Hypothesis	Conceptual validation of the idea that an innovation can meet specific goals and development of a hypothesis about the initial idea.
2	Basic Model (unproven)	Researching the hypothesis that the innovation can meet specific goals using existing basic science evidence.
3	Basic Model (proven)	Validation of principles that the innovation can meet specific goals using existing basic science evidence.
4	Application Model (unproven)	Researching the capacity of the innovation to meet specific goals using existing applied-science-evidence.
5	Application Model (proven)	Validation of the capacity of the innovation to meet specific goals using existing applied science evidence.
6	Application (unproven)	Testing of the capacity of the innovation to meet specific goals within a controlled environment that reflects the specific spatial-temporal context in which the innovation is to contribute to achieving impact.
7	Application (proven)	Validation of the capacity of the innovation to meet specific goals within a controlled environment that reflects the specific spatial-temporal context in which the innovation is to contribute to achieving impact.
8	Incubation	Testing the capacity of the innovation to meet specific goals or impact in natural/real/uncontrolled conditions in the specific spatial-temporal context in which the innovation is to contribute to achieving impact with support from an R&D.
9	Ready	Validation of the capacity of the innovation to meet specific goals or impact in natural/real/uncontrolled conditions in the specific spatial-temporal context in which the innovation is to contribute to achieving impact without support from an R&D.

3. Learning Journey

1. Did your Wildcard project involve new collaboration with disciplines or people? If so, briefly explain what was new.

Yes, due to the complexity of the research a interdisciplinary team was needed and we have been able to bring this together. With that, collaboration between WR and WU has been new on different areas of expertise. We have been able to link the (cell)physiological knowledge with the application helped understand the potential and the challenges between the resource (seaweed), both chemically and environmentally, and the product (chipboard). Furthermore, collaboration that already was present (WMR-WFBR, WMR-WU PS, WFBR-A&F) have been strengthened and deepened.

2. If applicable, did the new collaboration alter your original thinking about the topic? Did it change research directions or courses of action? If so, briefly characterize how.

Where the proposal writes that we aim to work to a proof-of-principle, it was due to the collaboration that it was feasible to indeed make this work and come to a physical product. This product also lit a spark at the dept. of A&F where colleagues were skeptical, but our results showed that it has indeed been possible to produce a 'chipboard' glued together with seaweed.

3. Did interactions during community days and/or meetings organized by the investment theme alter your original thinking about the topic? Did such interactions change research directions or courses of action? If so, briefly characterize how.

No.

4. Did you meet any challenges during implementation of your wildcard project? If so, what kind of challenges where these?

As a researcher will always reply; time and budget were limiting. But, within the possibilities it is perceived that we have done a very insightful, interesting and useful research with a substantial indication to use seaweed as a novel green resource for non-food purposes. In addition, very limited knowledge was available in literature about chemical composition of seaweed cell walls. This knowledge would have allowed a more rational approach towards mixing and pressing seaweeds and reed under suitable conditions.

5. If applicable, how were these challenges eventually addressed? Did activities organized by the investment theme contribute to overcoming challenges? If so, briefly indicate how.

Available time is to be tackled by the core team with the intention to move the new call forward in time, making it possible to better use the full length of the year. In parallel projects that focus on seaweed and its cultivation (e.g. 'SeaSeeds' and 'From Sea to society' - NWO-KIC), knowledge is generated that will be applicable to follow up research.

6. Has your involvement in the investment theme resulted in any new initiatives or spin-offs that would probably not have emerged if you had not participated? If so, briefly indicate how these new initiatives came about.

Yes, new initiatives are added to the seaweed portfolio concerning the utilization of waste streams in the field of seaweed (either being from natural causes or from cultivation). This has not been a full topic for those who work on seaweed within this team and is likely to be in the near future.

4. Additional project specific deliverables

4.1 Additional deliverables proposed when submitting the Wildcard project

-Copied from the proposal-

In this proposed research we want to investigate what the diversity and the potential of this seaweed source. Therefore, we will look into the following topics:

1. What species and quantities of seaweed wash ashore at the chosen locations (e.g. Sweden, Dutch Antilles, Namibia)?
2. What environmental impacts connect to the removal of this biomass?
3. What is the biochemical composition of the beached seaweeds? From literature
4. What building materials may be produced from these types and amounts of seaweeds and can the quality demands that these products pose on the raw material be met? (aiming for a proof-of-principle product)

4.2 Status of each project specific deliverable

Reflection on the status per deliverable:

1. Three potential sources have been identified. Quantities and/or volumes of these streams are, however, very difficult to obtain, but in case of mass blooms can exceed millions of tons. For more natural beachings the volumes are measured in tons, but amounts are often more stable over the year compared to blooms that occur seasonally.
2. Impacts do differ substantially between sources. Mass blooms have a negative effect on the (coastal) community, both natural as social. Utilizing this stream could aid in dealing with and mitigating this problem, but does not solve the problem. Natural resources do often play a role in the nutritional cycle. The biomass is used by both microbes and macro-organisms which, in turn, play a role in the coastal food web. Sustainable extraction of biomass should be possible, but require research and subsequently policy.
3. Literature on the biochemical composition is very limited and often focused on the specific interest of the authors, making it difficult to compare data and get detailed

information on the biochemical composition. It is, however, clear that composition is subject to seasonality, but also differs (strongly) between species.

4. In the work and brainstorm sessions within the team it became clear that there is a potential for seaweed to be used as some sort of chipboard. This is due to the alginates and other related binding agents present in seaweeds. These compounds provide the seaweeds with strength to deal with the harsh conditions in which they can grow. They do however largely lack compounds that provide rigidness and stiffness, which is the role of cellulose in terrestrial plants. By combining reed with the processed seaweed we were able to compensate for this.