Possible Application of Seaweed as Building Material in the Modern Seaweed House on Læsø

Barbara Widera, PhD
Wroclaw University of Technology, Faculty of Architecture
barbara.widera@pwr.edu.pl

ABSTRACT

The aim of the paper is to present the possible application of seaweed in the contemporary environmentally friendly and affordable architecture. Properly used, seaweed can be an ultimate sustainable material, which is not only available in many areas of the word, but also reproduces itself in the sea and is very easy to gain on the seashore. In some regions, where the quantity of building materials is limited (e.g. Danish islands), seaweed was traditionally used in vernacular architecture. Today, when many countries are threatened with deforestation, we are looking for cheap materials alternative to wood. Seaweed has some important advantages: it is non-toxic and fireproof, provides good insulation, reduces CO₂ emission, has a life expectancy of more than 150 years and, what is also valuable, can be visually attractive. To the top of that, using seaweed can promote the respect for the uniqueness of regional architecture. Some examples of creative and contemporary dwellings made of seaweed as well as the brand new construction methods are presented and discussed in purpose to assess the promising possibilities of rediscovering this forgotten material.

Keywords: vernacular architecture, zero emission, building conservation, low energy materials

INTRODUCTION: ORGANIC MATERIALS IN VERNACULAR ARCHITECTURE.

Gaining building materials from the environment has been one of the most natural architectural concepts from the beginnings of humanity. As pointed by Torben Dahl “Throughout the world, the expressions of traditional architecture are based on and adapted to local conditions. This applies primarily to the local availability of materials and the response to the climatic conditions” (Dahl, 2008, p.8). Locally available, organic or non-organic substance, could be found not only in low-tech constructions but also in very advanced projects, based on the most contemporary technologies. In both cases such material choices increase the connection with local culture, create harmonious composition with the landscape and help reducing transportation. Organic materials deriving from the same climate zone are also well adapted to the climatic conditions.

In vernacular architecture natural materials were used almost exclusively. Today many architects combine them with concrete and steel to achieve modern appearance. In some cases the reason for abstention from the use of natural materials is the awareness of the threat of over-exploitation of the environment. For example the usage of wood needs to be carefully considered to avoid cutting valuable tree species and to maintain a balance of wooded areas, both on the local and the global scale. In some other circumstances the construction system, the functional requirements or even the artistic vision may entail the specific materials, not necessarily natural. Still, it is worth to remember that organic elements of the building also can have a contemporary appearance. Amazing wealth of materials found in nature endows architecture with the unique character. While timber and stone are highlighted in many projects, there is a lot of interesting but almost totally unknown (or forgotten) materials, that may be applied in modern, ecological and affordable architecture. One of such promising examples is seaweed.
SEAWEED CLADDING TRADITION

Nowadays the usage of seaweed in the building industry is observed in very few places in the world. However, it is worth to note that properly used seaweed can be an ultimate sustainable material, which is not only available in many regions, but also, as Jørgen Søndermark noticed "reproduces itself every year in the sea, (...) comes ashore without any effort from humans, and it is dried on nearby fields by sun and wind" (Søndermark, 2013). As a building material it seems to have a great potential since it provides good insulation (which is typical for mineral materials), it is non-toxic and fireproof, and it has a life expectancy of more than 150 years.

In some coastal areas, where the quantity of timber (or even straw) was limited (e.g. on small Danish islands like Læsø), while a lot of seaweed was thrown out by the sea, the eelgrass was used in vernacular architecture, mainly for the house cladding. According to Realdania Byg, the non-profit organization who initiated a preservation project “Seaweed Houses on Læsø”, there were hundreds of seaweed cladded houses on the island. Unfortunately today there are only 36 of such homes left.


Figure 1

In the continuation of efforts for preserving the cultural heritage of the small region of Læsø, in 2012 Realdania Byg organized the restoration of 150-year-old Kaline’s House on Læsø, with traditionally thatched seaweed roof. Simultaneously the same group launched the architectural competition with a goal to design the modern house on Læsø, referring to the local tradition but offering the contemporary standard. The Vandkunsten architectural studio, who won the competition, developed a very creative and contemporary dwelling made of seaweed. As a consequence the Modern Seaweed House on Læsø was built in 2012-2013, according to the project of Vandkunsten studio in cooperation with Realdania Byg. The designers decided to use the seaweed as a traditional material but they also proposed the new technology and the brand new construction method.

In vernacular structures the seaweed was placed directly on the roof, one layer after another, to provide the demanded thermal insulation and impermeability. Within years new layers were added and some roofs became very thick, they would even reach the thickness of 1,5 meter. The drawback of that
system was not only the size, but also the weight of the roof, with the increased risk of collapsing. Although some of the houses could be perceived as beautiful from outside, the visual comfort of the user was often disturbed by small windows, additionally shaded by many layers of seaweed, that would block the sunlight penetration into the living areas of the house as shown in Figure 1.

THE CONTEMPORARY DWELLING MADE OF SEAWEED

The authors of the Modern Seaweed House on Læsø carried out Environment Behavior Studies (EBS) in purpose to use vernacular architecture as a model, as suggested by Rapoport, and consequently to improve the solutions observed in vernacular buildings instead of copying it directly (Rapoport, 2006). To provide the functional and comfortable dwelling the architects focused on the value of natural light and space. They developed the summer holiday residence with a big common space in the center and some smaller rooms on both sides of the building. The house is heated with a highly efficient heat pump, placed in an adjacent shed that can also be used as a storage (e.g. for bikes and kayaks). The building is tight, well insulated and fitted with an effective mechanical ventilation system with heat recovery. Due to the proper insulation it is possible to maintain constant temperature of minimum 10˚C throughout the winter, so that the house is frost-free.

Figure 2 The Modern Seaweed House (2012-2013) on Læsø, designed by Vandkunsten in cooperation with Realdania Byg. Photographer: Helene Hoeyer Mikkelsen/Realdania Byg (July 2013).

The light construction was designed without steel nor concrete. Instead, to emphasize the unique spirit of the island, the sea plant from the family Zostera marina was used as a building material i.e. as an insulation for ceilings, roofs and walls. As shown in Figure 2, in some elements it was introduced in the clearly visible form, while in others it is slightly hidden, both for functional and esthetic reasons.

The most obvious application of seaweed was the roof cladding shown in Figure 3a. Nevertheless, it was necessary to propose the brand new technology to achieve the lightweight and contemporary looking roof. On the other hand it was equally important not to lose the ambience of simplicity, connection with the environment and the obvious utilitarism, that stood behind the usage of the natural material that could be found on the beach. Therefore the seaweed was stuffed into the nets knitted from a woolen yarn as shown in Figure 3b. Each element is 6-8 meters long and closed at both ends. These nets were attached to the façade and to the roof, where they formed the original and expressive finishing. At the same time, the seaweed filling was placed inside the wooden cassettes made of low processed timber.
and divided into smaller inner sections. These prefabricated building modules formed the house framework and provided an excellent insulation of floors, walls and ceilings with the $\lambda$ value 0.0376 W/mK (Pedersen, Ransby 2005, p.4). Another innovative application of seaweed was inspired by traditional mattresses. The dried seaweed was used for internal finishing elements, which are stuffed with eelgrass and covered with natural colored linen so that they slightly resemble the mattresses as shown in Figure 4a. These elements were used for internal wall cladding. The bright linen corresponds well to the timber color and gives the interiors light and natural appearance as shown in Figure 4b. Furthermore such used seaweed has exceptionally good acoustic properties.

Another seaweed feature, which is very useful in building, is the ability to absorb and give off moisture. That contributes to the regulation of indoor air humidity parameters. Various solutions, based on the seaweed application, created truly comfortable interiors with high-quality indoor microclimate. The list of possible variants of seaweed implementation can be developed further, in purpose to expand

\begin{figure}[h]
\centering
\includegraphics[width=0.4\textwidth]{figure3a.png}
\includegraphics[width=0.4\textwidth]{figure3b.png}
\caption{(a) The seaweed roof cladding and (b) the detail of seaweed placed in the knitted nets.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.4\textwidth]{figure4a.png}
\includegraphics[width=0.4\textwidth]{figure4b.png}
\caption{(a) Dried seaweed inside white linen finishing elements and (b) natural bright interiors.}
\end{figure}
the prospective options for affordable sustainable building. The Modern Seaweed House has a very low energy consumption and due to the fact that the organic materials were used almost exclusively, the house accumulates more CO\textsubscript{2} than it was emitted within the whole process of production and transportation of the building materials (Realdania Byg, Walther, 2013).

THE LIFE CYCLE ASSESSMENT FOR THE MODERN SEAWEED HOUSE ON LÆSØ

In purpose to assess the potential for the application of seaweed as a sustainable material for the contemporary, ecological and affordable architecture the Life Cycle Assessment (LCA) was carried out by Kauschen (Kauschen, 2013).

In general LCA is a technique that allows to assess the environmental aspects and potential impacts associated with products and processes by:
1. Compiling relevant energy and material inputs and environmental releases
2. Evaluating potential environmental impacts connected with identified inputs and releases
3. Interpreting the results for making more conscious decisions (EPA, 2006, p.2).

LCA method evaluates all stages of product’s life and includes all phases necessary to produce, operate and dispose a building (“cradle to grave”). The phases are divided into raw material acquisition, building materials and/or component production, use and maintenance, waste management (“End-of-Life”). The applied “End-of-Life” method includes also the possibility of recycling. In accordance to ISO14040 standard, the research involved:
1. Goal and Scope defining (at this stage the assessment context was established, the boundaries and potential environmental effects were identified, a functional unit as a reference value for the assessment was defined);
2. Life Cycle Inventory (LCI, i.e. the inventory analysis which identifies and quantifies energy, water and materials usage and environmental releases) with the model based on building description, drawings and data extraction from BIModel (Revit).
3. Life Cycle Impact Assessment (LCIA) that allows to assess the potential ecological effects and refers to all inputs and outputs defined in the inventory analysis.
4. Interpretation of the inventory analysis and impact assessment in purpose to select the products and processes “with a clear understanding of the uncertainty and the assumptions used to generate the results” (EPA, 2006, p.2). In this stage the results were interpreted and validated.

The categories and calculation methods used in LCIA match DGNB standard (DGNB, 2010), as a DGNB Denmark (Danish adaptation of German standard DGNB, Deutsche Gesellschaft für Nachhaltiges Bauen), is a standard certification system for sustainable building in Denmark (Green Building Council Denmark, 2012). The impact categories and characterization factors are based on CML 2001 method, developed by the University of Leiden (Guinée, 2002). The environmental data was taken from ökobau.dat database (2011). For new processes (already not existing in ökobaut.dat), the assumptions were based on similar processes from Ecoinvent database (2.2), information from experts and producers Environmental Product Declarations (EPD). The Excel tool developed for the calculation of the product system was based on the method described in DGNB manual (DNGB, 2010). It should be mentioned that this LCA was carried out to identify potential environmental impacts with a goal to optimize the project in these terms and no critical review was undertaken. Thus the assessment can be classified as the life cycle screening (hot-spot analysis) instead a full LCA according to ISO standard 14040. The following impact categories of the seaweed building were analyzed: global warming potential (GWP100) [kg eq. CO\textsubscript{2}], ozone depletion potential (ODP) [kg eq. R11], photochemical ozone creation potential (POCP) [kg eq. C\textsubscript{2}H\textsubscript{4}], acidification potential (AP) [kg eq. SO\textsubscript{2}], eutrophication potential (EP) [kg eq. PO\textsubscript{4}], non-renewable primary energy demand (NPED) [MJ], renewable primary energy demand (RPED) [MJ], total primary energy demand (TPED) [MJ], water usage [t], waste production [t], hazardous waste production [t], abiotic resource depletion [t], excavation residues [t]. For the LCA calculations the functional equivalent of a holiday property was set at 86m\textsuperscript{2} gross floor area, 30m\textsuperscript{2} loft and 124m\textsuperscript{2} terrace. The house has up to 10 beds and is used 168 hours a week, whole year, for
50 years (Kauschen, 2013, p.7). The building includes about 200 components and 38 different materials, which are divided into different building elements shown in Table 1 and 2. Electric air-water heat pump is used for heating and hot water preparation. The BE10-calculation shows a total energy requirement of 64,4kWh/m²a, while the total electrical energy need is 54,4kWh/m²a. BE10 is the software developed by the Danish Building Research Center (SBI), mandatory to be used in Denmark for energy calculations for reference purposes.

Table 1. Compiled Results of LCA, part 1. Based on Kauschen (Kauschen 2013).

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<td>5,52E-04</td>
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<td>231,94</td>
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Table 2. Compiled Results of LCA, part 2. Based on Kauschen (Kauschen 2013).

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<td>Roof</td>
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<td>0,09</td>
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<td>Structure</td>
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<td>84783,86</td>
<td>-1811,33</td>
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<tr>
<td>Interior</td>
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<td>132725,43</td>
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<td>-1,05</td>
<td>2,62E-03</td>
<td>4,31</td>
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<td>2,43</td>
<td>4,29E-04</td>
<td>237,91</td>
<td>0,01</td>
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To check the environmental impact of the holiday house three energy scenarios were proposed: without operational energy; operating with energy from DK wind power; operating with energy from DK Grid Mix (Tables 3,4,5). The option to use wind power was the most interesting since there is no need to produce renewable energy in the holiday house itself. Solar energy was not taken into account as the house is situated in the shadow of the forest and also because the photovoltaic panels would not fit to the concept of the seaweed roof that should preserve the unique spirit and heritage of the place.
The LCA analysis of the Modern Seaweed House on Læsø proved that with the proper insulation and the usage of wind energy the building has negative carbon footprint and minimal potential environmental impact throughout the assumed lifetime of 50 years. The conservative approach to the data selection for calculations was chosen, especially regarding the End-of-Life scenarios. Such conservativeness reduced the risk of obtaining too favorable assessment which could lead to the erroneous interpretation. In most impact categories the outcome is determined by the type of energy supply. The presented results of calculations carried out for scenarios 2 and 3 show the impact of the choice of the energy source on the environmental performance of the building. In the majority of cases DK wind power energy scenario allows to achieve much better results in comparison with DK Grid Mix.
energy scenario. The values achieved in scenario 1 proved a very low level of the environmental impact of seaweed used as the building material in the Modern Seaweed House on Læsø.

Due to the continuous emission of CO$_2$ to the atmosphere, the amount of seaweed in the seas and oceans is actually increasing. That should put our attention on this plant as a potential building material and a source of energy, especially today, when many countries are threatened with deforestation and we are looking for cheap materials alternative to wood. The important advantages of seaweed should be widely recognized: it provides good insulation, great acoustics, humidity control, visual comfort and the reduction of CO$_2$ emission. It is also non-toxic, fireproof, low-energetic, biodegradable with a life expectancy of more than 150 years. The seaweed is covered with the sea salt and thus naturally protected against bacteria or insects that could destroy the structure. However, it is important to note that seaweed is such a good material choice when it is harvested naturally, i.e. collected on the beach, dried on the meadows (not in ovens) and transported on short distances only. Used that way seaweed can promote the respect for the uniqueness of regional architecture but simultaneously can be easily adapted to the specific local conditions, including different cultural and climatic factors. This is in accordance with the statement of Peter Sørensen and Winnie Friis Møller that “Architecture is a connecting link between place, climate and human life” (Sørensen, Møller, 2008, p.13).

Finally, what is also valuable, seaweed can be visually attractive and its usage allows to establish the balance between the traditional and modern architecture. The preservation initiative of Realdania Byg helped to involve local community into the process which increased the awareness both of the natural and cultural heritage of the island. Consequently that leads to the protection of the architecture of the past and at the same time to the development of the sustainable architecture of the future.

ACKNOWLEDGMENTS

The author wishes to express her thanks to the non-profit organization Realdania Byg who build and preserve the seaweed houses in Denmark, Jørgen Sondermark and architectural studio Vandkunsten who designed the Modern Seaweed House on Læsø, Jan Schipull Kauschen who carried out LCA analysis and the photographer Helene Hoeyer Mikkelsen, Realdania Byg.

REFERENCES