FROM WATER TO STRUCTURE:
BIO-BASED MATERIALS FROM LOCAL AQUATIC ECOSYSTEMS FOR CIRCULAR FLOATING ARCHITECTURE

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Abstract

This paper investigates the potential of using bio-based materials sourced from local aquatic ecosystems for all aspects of a floating building. It addresses the pressing need for a shift to circularity in the construction sector, but also the regeneration need of old industrial ports. The research focuses on materials such as reed, willow, algae, and alder, assessing their characteristics and their potential uses in a floating building. A mixed-methods approach is employed, including interviews, research-by-design and computational analysis. Learning from vernacular architecture, material experts and current innovations offers a complete understanding of the topic. Results indicate the best material options that can be used for each part of a floating building according to the specific requirements. The research highlights that the life-cycle of materials before and after the construction of a floating building is a key aspect to consider.

Keywords: *Aquatic ecosystems, Bio-based materials, Floating Architecture, Circular building, Port regeneration*

I. Introduction

1.1. Problem statement

In recent years, a growing number of large European cities are conducting projects to transform and regenerate their industrial ports. The need for densification is the main motivation for cities to undergo such changes. Port regenerations usually happening in the context of port activity expansion or relocation, are an opportunity for sustainable urban development (Le Den, 2020). Polluting industries have had a lasting impact on the landscape and biodiversity. For instance, important wetland loss started in the Netherlands during the Industrial Revolution, with threats such as changing the hydrology, acidification, eutrophication and toxification (Best et al. 1993). Renaturation can be conducted to restore local ecosystems to their original state (European Environment Agency, n.d.). This healing process can be integrated into the planning strategies of new port redevelopments.

Redevelopments of former industrial ports hold the opportunity to implement flood-proof floating buildings on the former docks areas. However, construction methods of floating structures in Europe are unsustainable today with the main use of concrete and steel. These two materials alone account for 21% of the world's global CO_2 emissions (Global Alliance for Building and Construction, 2018). There is a necessary need for reinventing the construction systems. A change in paradigm includes going from a linear economy based on extraction to a circular economy based on regeneration (Ellen MacArthur, 2022). Circular buildings based on the circular economy principles, optimise the use of resources and minimise waste throughout their whole life-cycle while avoiding pollution and damage on natural ecosystems (van Eijk, 2021). To reach more circularity, bio-based materials including renewable resources like plants and organic waste (Garcia Saravia & van der Meer, 2022) are an essential part of the solution. Yet, they only represent 3% of the total mass and 10% of the volume of materials used in construction in Europe (Cardellini & Mijnendonckx, 2022).

In the use of bio-based materials, a landscape-based and ecosystemic approach is considered to be the most sustainable. It focuses on the potential harvest of materials from the local environment. According to Material Cultures (2022, p.20), "a regenerative approach to construction starts at a regional level, with a study of the quantity and character of materials that can be harvested from regeneratively managed land, [...]. Adopting an approach to construction grounded in regenerative resources requires a wholesale re-interrogation of the material palette that we use to make buildings". Based on this approach, the local context of a port that can be compared to a riverine and estuarine ecosystem holds the opportunity to grow a wide variety of plants, from trees to grasses and algae. The plants growing in aquatic ecosystems around or in a body of water (Gray, 2021) can be considered as the main renewable resource for building materials. However, there is a lack of information on bio-based materials sourced from aquatic environments suitable for building floating structures. The focus of the research is not only on one single perfect material but rather on the local ecosystem as a whole and the possible combination of materials available.

1.2. Research questions

To address the research gap and the problem statement, the following thematic research question is answered: ***How can bio-based materials sourced from local aquatic ecosystems be used to build a circular floating building?***

Six sub-questions are investigated to answer the overarching question:

Q1. What are the material requirements of a floating building?
Q2. Which bio-based materials can be sourced from riverine, estuarine and wetland ecosystems?
Q3. How are bio-based materials used in vernacular floating buildings?
Q4. What technical innovations are emerging in the use of aquatic bio-based materials?
Q5. How can bio-based materials sourced from aquatic environments be used in a floating building?
Q6. What are the life-cycle considerations for bio-based materials in a floating building?

II. Method

2.1. Shearing layers approach

The methodology is based on Stewart Brand's (1994) shearing layers concept, adapted to the requirements of a floating building. This concept is used as a framework for the research (see Appendix 1). It was reinterpreted with additional specificities like the floating platform and the mooring (Figure 1). Sub-layers have also been added to clearly distinguish the main building elements, such as the roof and facade (Cardellini & Mijnendonckx, 2022).

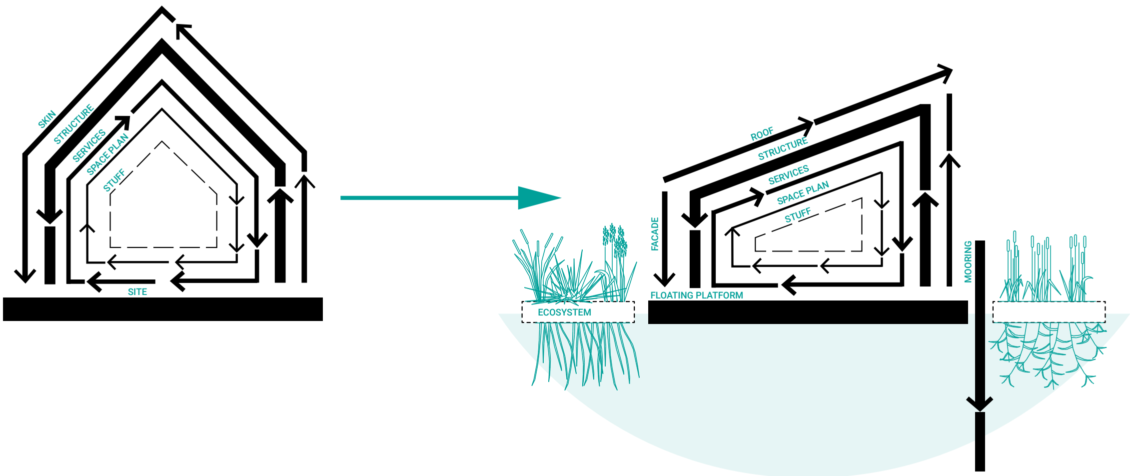

Figure 1. Reinterpretation of the Shearing layers diagram (Author's own image)

This adjustment allows for a more precise evaluation of material options. The new set of layers used in this paper is: ecosystem, mooring, floating platform, facade, roof, structure, services, space plan, and stuff. Additionally, a certain level of flexibility is kept in the layering system. In some cases for instance, the bio-based structure's insulating properties and aesthetic characteristics allow it to be integrated with the skin layer to reduce complexity.

2.2. Methods

In addition to the use of literature, five semi-structured interviews were conducted to get additional knowledge and insights from experts and professionals (see Appendix 2). The method was organised in six steps following the six sub-questions:

(1) The material requirements for a floating building were gathered with literature and with the interview of a researcher, urban technologist and expert in floating buildings.

(2) A study of the different kinds of materials from the local aquatic environment and their characteristics was done through literature and two interviews: the innovation lead of a willow exploitation company and the operations manager of a floating ecosystems company.

(3) Vernacular case studies of bio-based material use in floating architecture were researched through literature.

(4) The topic of innovation has been investigated through two interviews: a researcher on building with blue biomass and a biologist focused on sustainability and marine environments.

(5) The step-by-step research-by-design method was based on the results of all the previous steps and led to the elaboration of the research output as a design guide for material choices.

(6) The life-cycle question was explored through a new framework using the parametric software Grasshopper for material sourcing optimisation.

2.3. Limits of the method

The method is exploratory and thus non-exhaustive. It aims to study the different possibilities of materials. It is acknowledged that it was not possible to interview experts on all the studied materials. Additionaly, regarding the layers approach of the methodology, the 'services' shearing layer is considered as out of the scope of bio-based materials and has not been studied in the research.

III. Results

3.1. Requirements of a floating building

Different types of material constraints linked to the floating building typology have been categorised per shearing layer. The findings are summarised in a diagram (see Appendix 3). They include characteristics on weight, suitability for marine use and controllability of the materials. Beyond the material requirements, other design requirements influence the choice of materials for the different layers. For instance, the prefabrication of a floating building is an important part of the process to consider (Bayoumi, 2024).

3.2. Materials sourced from aquatic ecosystems

The port of Amsterdam was used as a base to anchor the research to a local environment. Plants growing in aquatic environments in the Netherlands and usable as building materials are categorised in 3 types (see Appendix 4): (1) grasses including Reed (Phragmites australis, Common reed), Cattail (Typha latifolia, Bulrush), Water sedge (Carex aquatilis), (2) trees including Willow (Salix Viminalis, Common osier), Alder (Alnus Glutinosa, Black Alder, Common Alder, European Alder), Ash (Fraxinus excelsior, Common ash, European ash), Birch (Betula pendula, Silver Birch) and (3) aquatic plants including Micro algae, Seaweed (Macro algae) and Eelgrass (Zostera Marina, Seagrass). Their characteristics are summarized in a table (see Appendix 5).

Some of the studied materials are commonly used in architecture. For example, it is the case of reed which is used in thatching (Smit et al., 2022) but also of willow which is utilised in walls, fences, cladding and shading elements (Interview 3, 2024). Alder on the other hand is suitable for underwater use. In the form of foundation piles, it lasts long if fully submerged. Alder was used alongside oak wood in the 17th century to construct houses in Amsterdam and Venice (Smit et al. 2022; Islam & Moatazed-Keivani, 2023). All common uses of the studied materials have been summarised in a diagram (see Appendix 6).

3.2.1. Local sourcing

For a local sourcing of the materials, the aquatic environment offers opportunities for paludiculture, a type of cultivation in wet conditions (Islam & Moatazed-Keivani, 2023). This wetland farming method could be done on floating structures, in the water and on adjacent land. Multiple floating wetland ecosystems have already been implemented around the world, mostly in cities, ports and polluted areas to clean and renature the water environment by growing native plants (Interview 4, 2024). Floating ecosystem islands contribute to biodiversity, water purification and store CO_2 (Posad Maxwan et al., 2024). The plants' roots create underwater habitats for animals (Interview 4, 2024). Algae also contributes to regenerating and cleaning the aquatic environment by extracting high potassium and heavy metals from the water (Interview 2, 2024). Eelgrass contributes to creating fish habitat and food. It also filters polluted water and reduces eutrophication by absorbing nutrients like nitrogen and phosphorus (Kimo, 2020).

Most of the plants studied in this report can be grown on floating islands, including some of the trees like willow and alder. The aquatic plants could also be cultivated on arrays of strings exposed to light next to the floating ecosystem islands (Interview 4, 2024). Eelgrass can be grown in port basins as well. (Kimo, 2020).

3.2.2. Structure of floating ecosystem islands

In terms of structure, the existing floating ecosystem islands are flexible and modular, allowing for any size of cultivation. The dimensions of the modules used by the studied company are up to 1.75 x 3 meters (Interview 4, 2024). They are usually made in a combination of expanded clay aggregate laid on top of a recycled plastic mesh held by a frame of recycled water pipes. The diameter of these tubes can be increased to add buoyancy in the case of heavier plants. In order to use bio-based materials, a wooden frame could be added instead of the tubes but the buoyancy of the structure would have to be rethought and recalculated to take into account the weight of the ecosystem. The wood also needs to be treated to last longer in the water environment with products such as vinegar (Interview 4, 2024).

The possibility of using these floating ecosystem islands as a structure base for a floating building has been investigated. The floating islands can hold a weight of around 105 kg per m^2. As a result, the relatively low buoyancy of such islands does not allow for use as a base for floating buildings. They can only be positioned around the floating building (Interview 4, 2024). The anchoring depends on the water dynamics of the site but it is mostly made of stainless steel chains of adjustable length attached to a boat anchor or a concrete block. For public access through a floating path, the studied examples include pontoon modules of concrete and steel next to the floating islands (Interview 4, 2024).

3.3. Vernacular case studies

Five vernacular case studies were examined on a systemic approach (see Appendix 7). They were selected for their diverse range of materials and construction techniques as well as their geographical variety. The focus was made on the most critical parts of the floating buildings. The result is a catalogue highlighting different construction methods of the case studies for the structure, the skin and the floating system (see Appendix 8).

The first case study is the Floating islands in Lake Titicaca in Peru. The islands and the houses are considered to be in a permanent state of creation, flux and decay (Montali, 2022). It takes around one year to build one of the floating islands (LTRL trend, 2019) but the reed is replaced every few weeks because of the rotting and decomposing with the contact of water (LTRL trend, 2019). They are built with Totora root, a subspecies of the giant bulrush sedge and with a local species of reed (Montali, 2022).

The second case study is the Floating Basket homes in Iraq. They are made of local reed arches and skin (Piut, 2023) and are lying on a floating base made of woven dried reeds and mud (Pedrinola, 2022).

The third case study is the Floating Manobo community in the Philippines. The floating houses are made of bamboo. This type of houses started to be built 60 years ago on this location because of repeating floods (Riggall, 2024).

The fourth case study is the Lanting houses in Kalimantan in Indonesia. It consists mostly of a wooden structure on top of logwood lanting, bamboo or plastic drums which can also be combined together (Mentayani & Hadinata, 2021). The structure is made of wooden columns and beams parallel to the row of poles to spread the weight and the non-structural walls are made of split and woven bamboo (Sari et al., 2024).

The fifth case study is the Backwaters Houseboats in Kerala in India. The floating structure is treated with a protective varnish of cashew nut oil to prevent the exterior wood from deteriorating and to make it water-resistant (ATDC, 2024). The window structures are made of plywood frames (Mathen, 2012).

When considering the vernacular case studies in the lens of different contexts such as the Netherlands, additional questions and challenges can be raised. Insulation needs are different in European countries compared to warmer countries. Reed structures, effective in Peru and Iraq, may deteriorate and rot faster in the Netherlands due to higher rainfall and humidity. On the contrary, floating houses from India and Indonesia, may be better suited to wet European climates. The weight capacity is another limitation of the case studies. The reed platforms in Peru only carry small houses and would probably not support larger buildings without modifications. These constraints highlight the need to consider local climatic, environmental and functional conditions when selecting bio-based materials for a floating building.

3.4. Innovations in aquatic materials use

Institutions in Europe are at the forefront of innovation in the use of aquatic resources and are promoting communication and exchange of knowledge between countries and universities. This new field is still mostly unexplored but the research is going fast thanks to a global push on circularity (Interview 2, 2024). In the report *Seaweed as a Growth Engine for a Sustainable European Future*, Vincent et al. (2020) recognise the importance of seaweed in industries such as food, packaging, pharmaceuticals and bio-fuels and mention the possibility of future additional segments. The *Blue Economy report* plans major investments in the sector of blue biotechnology within the European Union. Over 30 million Euros are set to be invested in the sector of seaweed for bio-plastic, bio-fuel and materials (Borriello, 2024).

More practically, several innovation programmes focus on aquatic materials such as algae and eelgrass to open the building sector to their use. Cooperation between the Centre for Information Technology and Architecture within the Danish Academy and the Queensland University through the network Building with Blue Biomass aims to develop new carbon-positive technologies based on ocean resources and materials. Within this program, research is conducted on different topics including uses in 3D printing, bricks, bio-plastics and pigments (Interview 2, 2024).

3.4.1. Application of the innovations in architecture

The potentiality of translating the innovations in aquatic material use into architectural elements for floating buildings was summarised in a diagram (see Appendix 9).

Eelgrass has thermal and sound insulating properties and can be used in compressed panels (Sould, 2024), but also in soft furniture infill (Mon Tang, 2024).

Algae can be used in the form of bio-plastics for foam and rubber in combination with other polymers (Bloom, 2024), but also for buoyant blocks (SeaBrick, n.d.) and algae-based acrylic. Unfired clay bricks are another possible way of using algae in construction. Nevertheless, it is mostly suitable for dry regions and not for a floating building. More generally, the advantage of algae-based materials is that they can be reused indefinitely and still maintain their characteristics (Interview 2, 2024).

Micro algae can be exploited as a living algae facade for generating heat for buildings in addition to producing biomass (Arup, n.d.). Harvested micro algae can also be a base for additive manufacturing and for algae-based cement (Nordic Blue Building Alliance & Arup, 2024).

Mussel shell waste can be used in tiles or in biochar for concrete with a smaller carbon footprint than traditional methods (Chandrasiri, 2019). In cement, to make clinker, sandstone needs to be fired with very high temperatures surrounding 1450 °C. Alternatively, shells only require a temperature of 500-700 °C to be burnt (Interview 2, 2024).

3.5. Research by design

All information on materials and their application found previously have been combined for the step-by-step research-by-design.

3.5.1. Evaluation of the material options

The material options were first evaluated according to the floating building requirements previously defined in the first step (see Appendix 10). This allowed to compare the qualities and suitability of each material option for the different shearing layers of a floating building. The comparison does not aim to directly provide a material choice for each layer, but it enlightens the choice instead. Architects have then the responsibility to adapt the designs to the additional needs of the chosen materials. When multiple material options are suitable for a floating building, an extra selection can also be based on additional criteria such as aesthetics, sustainability or growing time of the materials. Overall, the material evaluation has allowed to eliminate unsuitable options for the requirements of a floating building.

3.5.2. Best material choices

All suitable options of material use for each shearing layer have been summarised in a table (see Appendix 11). It can be used as a guide for material choices in the application to a floating building.

The best choices for the facade and the roof are cattail, reed, water sedge, ash, willow, micro-algae and eelgrass. All the studied options work on different parts of the layers with their specific qualities.

The best choice for mooring is alder as it allows for vertical movement and has a better water resistance when submerged.

The best choices for the floating structure in terms of weight and water tightness are either a combination of alder and bio-plastic blocks or simply an alder hull, similar to wooden ships. Other options like an alder raft or a bio-concrete pontoon are not favoured but they could still be suitable if the maintenance and buoyancy requirements are taken into account. The willow and reed options however, are excluded because they could not have sufficient stability and buoyancy for the consequent weight of a medium to large size building. Additionally, reed requires very frequent maintenance, difficult and costly in the case of a larger building.

The best choices for the building's structure are either alder, ash, reed or willow for their lightweight, flexibility and resistance to dynamic actions.

The best choices for the space plan and the stuff depend on the fire-sensitivity of the rooms as some material options are more fire-resistant than others. In general, cattail, reed, ash, birch, alder, willow, micro-algae and eelgrass can be used for these two layers.

3.5.3. Material combinations and implementation

In this step, a new design guide combines the material options suitable for each shearing layer's element (see Appendix 12). It focuses objectively on the materials to use rather than the architectural integration which depends on additional factors such as the program of the building or the design concepts. Various design possibilities can be elaborated with each of the materials. For example, a wooden structure can be in the form of a timber frame, a grid of columns and beams or even a parametric shell structure (RO&AD, 2019).

For the research-by-design application, a theoretical building fragment has been designed and modelled (see Appendix 13). It is based on subjective choices of materials for testing a possible coherent architectural integration. It acts as an example for the use of local bio-based materials sourced from aquatic ecosystems for circular floating architecture.

3.6. Life-cycle considerations

In a floating building, a whole life-cycle approach is critical for the decarbonisation of the building sector, especially with bio-based materials (United Nations Environment Programme, 2023).

3.6.1. New systemic approach

Instead of using a linear system, the material's life-cycle is rethought through the linking of the plant's cultivation cycle and the materials' lifespan in the building. The new double-loop diagram (Figure 2) details the different life-cycle steps. It considers the floating building as a constantly evolving and maintained entity.

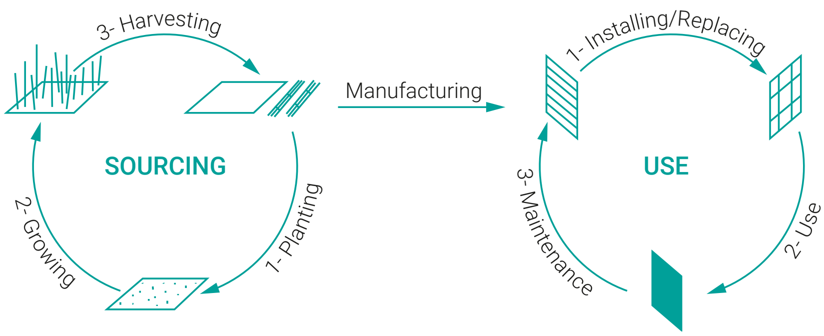

Figure 2. Life-cycle loops of bio-based materials (Author's own image)

The new proposed double-loop system has fewer steps compared to a linear process. When using bio-based materials, there is no extraction and usually no need for major processing. There is also no need for distribution because the materials can be sourced and assembled locally, and no need for disposal because the bio-based materials are biodegradable in the form of compost, or reusable for other purposes such as heating (Interview 3, 2024). According to this system, the construction and replacement cycles are a base for evaluating the need for growing materials locally.

3.6.2. Lifespan of materials

In the life-cycle considerations, the maintenance and replacement of materials are influenced by their lifespan in the building. It mostly relies on structural capacity, aesthetic conditions and insulation ability. The lifespan of load-bearing elements from fast-growing bio-based materials is around 60 years (Pittau et al., 2018). Willow can last 30 years underwater and 5 to 10 years in contact with oxygen (Interview 3, 2024). In the form of a pole, wood rots on the water line and needs to be replaced every 15 years. To prevent that, the top can be covered with a waterproofing material such as plastic (Interview 3, 2024). The floating ecosystem islands can last for a minimum of 25 years (Interview 4, 2024). Therefore, all lifespan data differ depending on the material and the conditions it faces in the building.

3.6.3. Computational analysis framework

To evaluate the appropriate surface of each material to grow in order to supply the needs of the building for the construction and replacements, a computational analysis framework has been elaborated. The parametric script (see Appendix 14) made on the software Grasshopper in Rhino, relates key parameters, including material lifespan, required volume, plant growing time, and harvesting volume. Their values depend on the material studied. The script is linked to the 3D model of the building to adapt to the exact volume of material needed.

The computational analysis framework has been tested successfully on the 3D model made for the research-by-design step. For a total of 1.17m^3 of willow material needed for the cladding, around 9.35 m^2 of willow need to be grown to meet the demand after one replacement cycle of 10 years. The value obtained takes into account the growing time of 2 years before harvesting the willow and the yield of 250 m^3 of material per ha grown (0.025 m^3 per m^2 grown) (Interview 3, 2024).

IV. Conclusion

The thematic research question was: *How can bio-based materials sourced from local aquatic environments be used to build a circular floating building?* The findings indicate that the use of bio-based materials in a floating building depends on their availability in the local aquatic environment and their suitability for the specific floating building requirements. The successful use of bio-based materials in a floating building also depends on their life-cycle. A critical factor is the connection between the local harvesting and the end-of-life, with the concept of sacrificial materials. This systemic approach aligns with circular economy principles.

4.1. Design implications

The results of this research are a base for guiding the design of circular floating buildings using local bio-based materials. The main design implication is a possible modularity of the floating structure. It allows for more flexibility in the construction and it facilitates reparability and replaceability of small portions when needed. In opposition, traditional floating buildings with large pontoons can difficultly be taken out of the water to be maintained in the way wooden boats are. Another implication is linked to the fact that floating buildings can move freely in the water environment. This possibility of movement allows for the reconfiguration of the building or relocation of some parts during maintenance for example. This adaptability enhances the longevity and functionality of the floating building.

4.2. Discussion

This research was done in the context of an Architecture graduation studio and focused on the site of Amsterdam's port. Because the local sourcing of materials was a key aspect of the research, the report is based on local plant species and climatic conditions of the Netherlands.

That being said, the findings and the conclusion can be generalised to any areas holding similar landscape conditions as riverine, estuarine and wetland ecosystems. The results demonstrate that constructing a circular floating building with local bio-based materials is achievable through a systemic approach.

Most of the research done on similar topics was either focused on land-based (Smit et al., 2022) or aquatic materials (Nordic Blue Building Alliance, Arup, 2024). This report integrates all types of materials surrounding the water environment, offering a unique perspective. The result goes beyond cataloguing possible materials. It proposes a new comprehensive framework guiding their application in a floating building. The investigation of bio-based materials through the lens of a floating building is also a new addition to the research field.

For further research, a possible suggestion would be to focus on elaborating a more developed parametric computational analysis for studying the influence of external factors on the lifespan of bio-based materials in floating buildings.

About the limitations, it is difficult to make the entirety of the floating building from bio-based materials sourced from local aquatic environments, especially for some elements like the windows. The use of algae-based acrylic still faces technical barriers like a yellow colouration when exposed to sunlight (Interview 2, 2024). Additionally, the research did not focus on the costs and labour needed to maintain the building and the ecosystem but instead on technical possibilities and feasibility. Finally, the exclusion of the building's program from the research scope allows to apply the findings to any type of floating building, but it still needs to be considered for further design decisions and material choices.

4.3. Acknowledgement

A warm thank you to Sridhar Subramani, Fred Fialho Alves Teixeira, Robert W. Pol, Ellen Hebdon and Peter Vangsbo for their valuable contribution to the research. Thank you also to Mo Smit and Dafne Swank for their insightful guidance throughout the research process.

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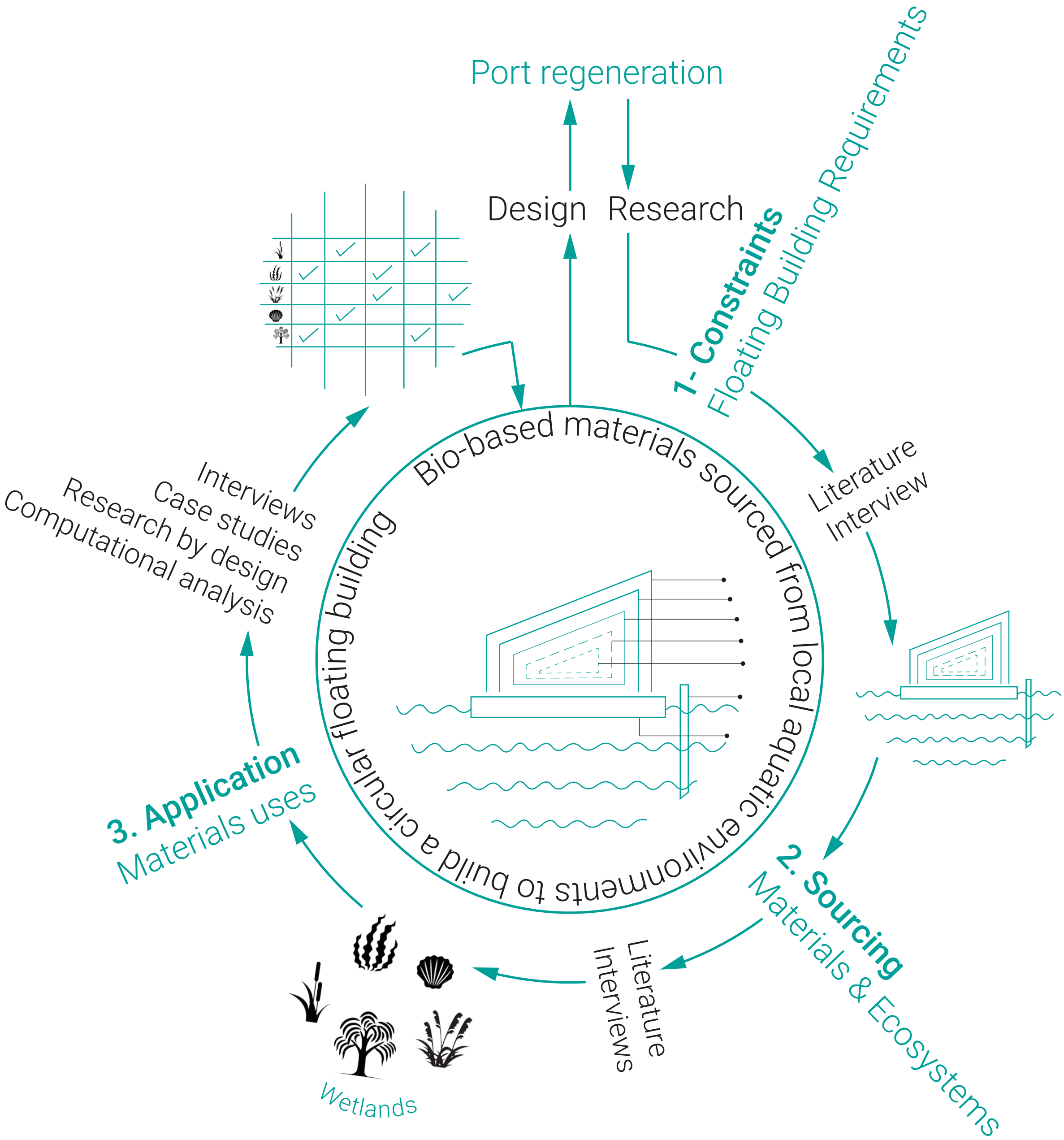
APPENDICES CONTENT

Appendix 1.
RESEARCH PLAN



Appendix 2.
INTERVIEWS

Interview 1: Researcher and urban technologist - November 20, 2024

Questions asked
Q1. What are the technical and physical requirements of a floating building for construction materials?
Q2. Do you think it would be possible to build a bio-based floating building rather than concrete and steel?

Interview 2: Researcher on building with blue biomass - November 29, 2024

Questions asked
Q1. What is the focus of the network "Building with Blue Biomass"?
Q2. Why is it especially relevant today / why has it been initiated?
Q3. What technical innovations are emerging in the use of new kinds of aquatic bio-based materials?
Q4. What are the potential new uses of algae and seaweed in Architecture?
Q5. Could this kind of material be used in a floating building?

Interview 3: Senior innovator at a willow products company - December 5, 2024

Questions asked
Materials
Q1. What type of Willow do you use?
Q2. Where do you source the wood from?
Q3. How/When is it harvested?
Q4. What volume of wood per tree can you use?
Q5. What are the specific physical characteristics of willow?
Construction
Q6. How is the willow attached/assembled?
Q7. Does willow get strengthened in water or does it rot?
Q8. What is the life-cycle of the willow structures in the water environment?
Q9. Could we imagine a floating structure made with willow?
Q10. What building components can the willow be used for?
Q11. What do you think about other materials for use in water like alder?

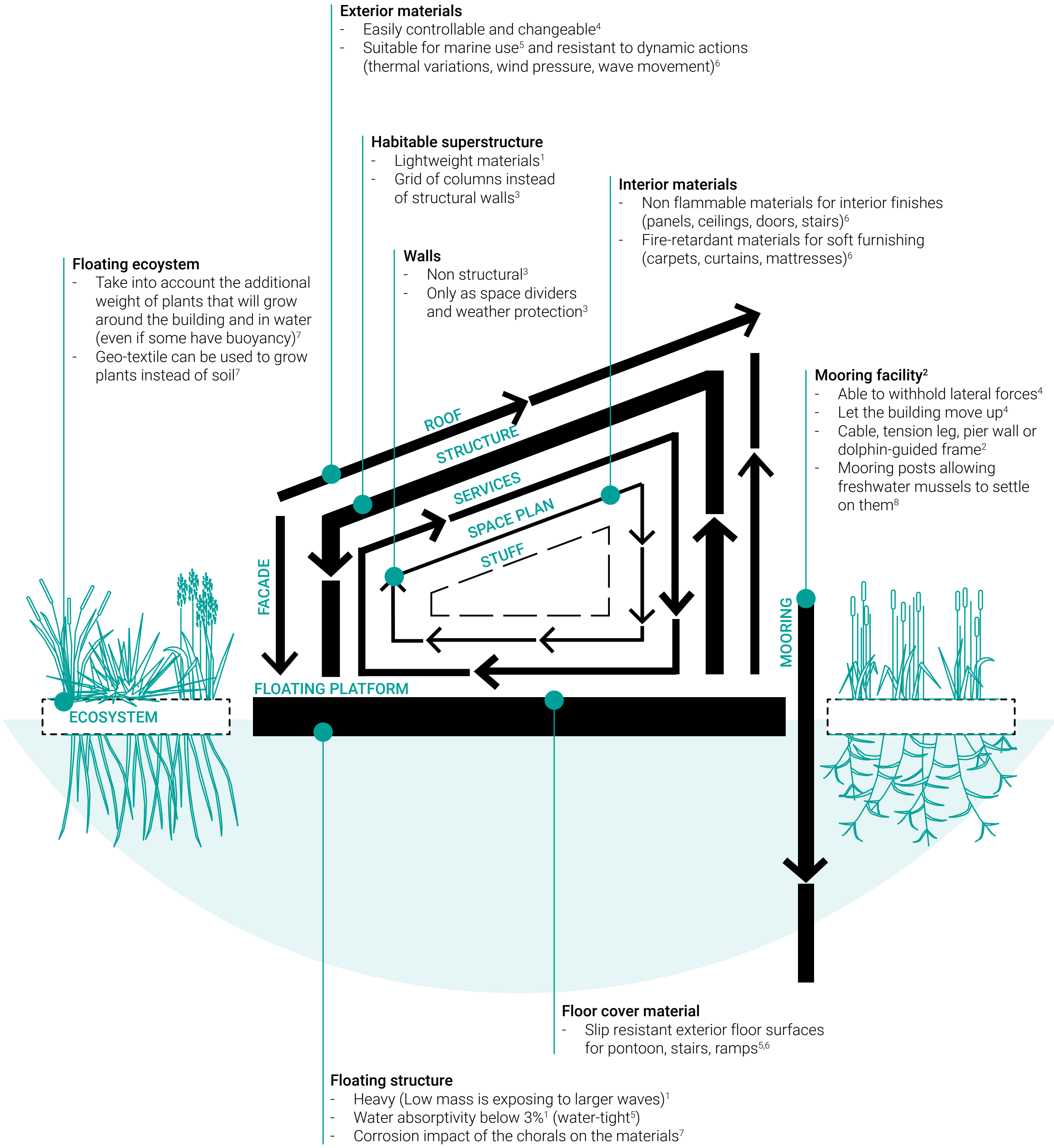
Interview 4: Operations manager at a floating ecosystem company - December 16, 2024

Questions asked
Ecosystems
Q1. Which plants are growing in the river floating ecosystems?
Q2. On which aspects does the floating ecosystem contribute to healing and depolluting the water environment?
Q3. Could the floating islands be utilized for a cultivation objective for production of bio-based construction materials (like reed, cattail, water sedge, algae, and eelgrass)?
Floating Islands
Q4. What are the technicalities of the floating islands' structures themselves? (Size, construction, materials, life-cycle)
Q5. How long can the floating ecosystems last?
Q6. How large can the floating islands be?
Q7. With which materials are made the floating walkways that are combined with the floating islands?
Q8. Could a floating structure similar to the floating island be considered to host a building on top of it?

Interview 5: Biologist focused on sustainability and innovation - December 17, 2024

Open discussion

MATERIAL REQUIREMENTS FOR A FLOATING BUILDING



Footnotes

[1] Ostrowska-Wawryniuk & Piatek (2020) [2] El-Shihy & Ezquiaga (2019) [3] Sari et al. (2024) [4] Bayoumi (2024)
[5] Queensland Development Code (2007) [6] Calcagni et al. (2024) [7] Interview 1 (2024) [8] Posad Maxwan et al. (2024)

Appendix 4. Sub-question 2
MATERIALS

WILLOW[1]

REED[5]

SEAWEED[8]

ALDER[2]

WATER SEDGE[6]

MICRO ALGAE[9]

BIRCH[3]

CATTAIL[7]

EELGRASS[10]

ASH[4]

SHELL WASTE[11]

Image sources

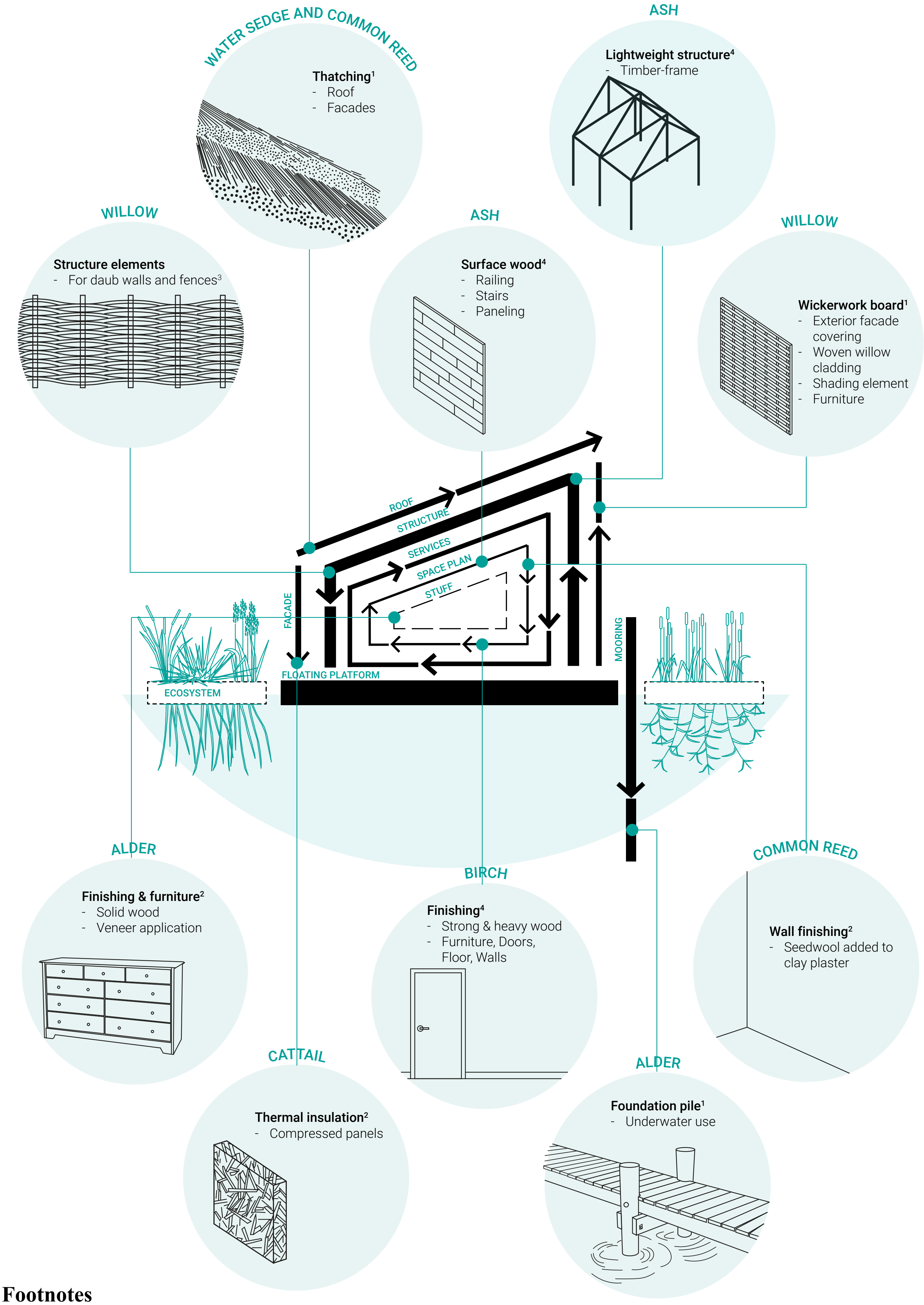
[1] https://farmpep.net/topic/feeding-willow-lambs-reduce-cobalt-deficiency-trials-and-agroforestry-network
[2] https://en.wikipedia.org/wiki/Alnus_glutinosa
[3] https://en.wikipedia.org/wiki/Betula_pendula
[4] https://edis.ifas.ufl.edu/publication/ST264
[5] http://science.halleyhosting.com/nature/basin/poaceae/phragmites/australis.html
[6] https://www.mwt.im/wildlife-explorer/grasses-sedges-and-rushes/greater-pond-sedge
[7] https://www.britannica.com/plant/cattail
[8] https://www.globalseafood.org/advocate/not-just-for-noshing-seaweed-startups-focus-on-industrial-uses-for-the-fast-growing-biomass/
[9] https://materialdistrict.com/article/bio-foam-algal-bloom/
[10] https://prepestuaries.org/osprey-and-eelgrass-suffer-from-rainy-conditions/
[11] https://en.reset.org/carapac-could-shrimp-shells-hold-key-fully-biodegradable-plastic-alternative-10132020/

Appendix 5. Sub-question 2
MATERIALS CHARACTERISTICS

Material	Material Characteristics	Plant Characteristics	Plant dimensions	Growing time & lifespan	Growing potential	Harvesting need
- Willow	- Flexible, strong - Can be attached in bundles with ropes[3]	- Fast growing wood like reed - Can be flooded without impact on growth[3] - Stabilises river banks with its fibrous roots	- Up to 15m tall[3]	- 30 to 50 years[3]	- 1 ha = 250 m^3 every 2 years[3]	- In the winter - Using machines or by hand for the big trees[3]
- Alder	- Soft hardwood - Rots slowly in water[5]	- Pioneer species - Can grow in wasteland areas with poor soil[5]	- Up to 30m4, 0.6m trunk diameter	- Fast growing[4] up to 1m per year[6] - Ful height in 20 to 50 years[5] - Lifespan of around 60 years[5]		- When the leaves are fallen
- Birch	- Strong and heavy wood - Good for furnitures, doors, floor & walls[10]		- Up to 20m tall[11]	- Mature size in around 20 years[11]		
- Ash	- Lightweight structure, timber-frame - Sports equipment - Railing, stairs, paneling[13]	- Adaptable to damp soils[12]	- Up to 35m tall[9]	- Ultimate height in around 25 years[10]		
- Reed - Water sedge - Cattail	- Insulating properties - Water resistance[4]	- Pioneer species[1]	- Up to 1-3m tall - Blades are 1.5 to 5.5mm thick	- Grow in 2-3 months - Lifespan of 10 to 15 years[2]	- 1 ha for 1 house[1]	- Regular cutting[1] - Harvesting in winter[1]
- Seaweed	- Fibrous, malleable and plentiful material[8]	- Can grow on ropes attached to floating raft[8]	- Varying size depending on the species[8]	- 2 months[8]	- Squares of 2x2m[8]	- Harvesting by hand[8]
- Micro Algae	- Bioactive compound and chlorophyll pigments[15]	- Improves the water quality - Can grow in photo-bioreactors with polluted river water[7]	- 2–50 µm[7]	- Double every 24 hours[7]	- Around 500 mg/L of water[7]	- Coagulation and flocculation, flotation, centrifugation and filtration[15]
- Eelgrass	- Small diameter fibres[14]	- Flowering plant - Grows in sheltered waters 0 to 5m deep - In marine and estuarine environment [14]	- 50cm, up to 200cm long leaves[14]	- Up to 200cm per year[14]		- Harvesting by hand[14]

Footnotes:
[1] Islam & Moatazed-Keivani (2023) [2] Rankel (2024) [3] Interview 3 (2024) [4] Smit et al. (2022) [5] Designing Buildings (2022) [6] Roberts (2021) [7] Ummalyma & Singh (2022) [8] Behera et al. (2022) [9] Woodland Trust (n.d.) [10] Bradbury (2024) [11] Love the Garden (2024) [12] Dobrowolska (n.d.) [13] W L West & Sons (n.d.) [14] Tyler-Walters (2008) [15] Gulab & Patidar (2018)

Appendix 6. Sub-question 2
COMMON USES OF THE MATERIALS



Footnotes

[1] Smit et al. (2022) [2] Islam & Moatazed-Keivani (2023) [3] Interview 3 (2024) [4] Woodland trust (n.d)

Appendix 7. Sub-question 3

CASE STUDIES

FLOATING BASKET HOMES, IRAQ[1]

FLOATING MANOBO COMMUNITY, PHILIPPINES[4]

BACKWATER HOUSE BOATS IN KERALA, INDIA[2]

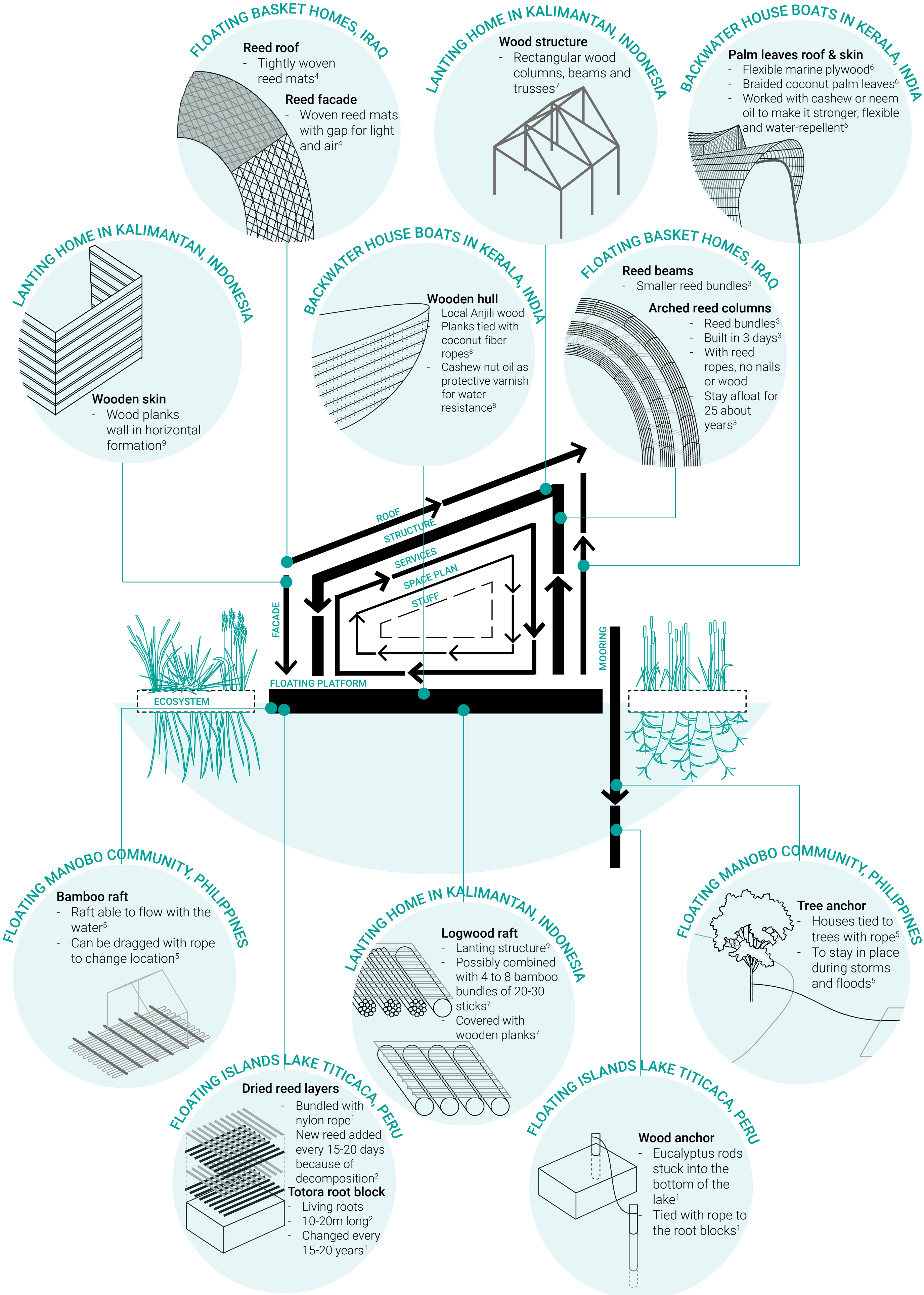
FLOATING ISLANDS LAKE TITICACA, PERU[5]

LANTING HOME IN KALIMANTAN, INDONESIA[3]

Image sources

[1] https://www.messynessychic.com/2014/11/12/the-floating-basket-homes-of-iraq-a-paradise-almost-lost-to-saddam/
[2] https://www.atdcalleppey.com/architecture-and-design-of-alappuzha-houseboats/
[3] https://koransulindo.com/arsitektur-rumah-lanting-rumah-terapung-suku-banjar/
[4] https://www.bbc.com/future/article/20240531-the-floating-houses-built-to-withstand-typhoons-and-flooding-in-the-philippines
[5] https://www.journeylatinamerica.com/destinations/peru/places-to-visit/peruvian-lake-titicaca/things-to-do/visit-lake-titicacas-floating-islands/

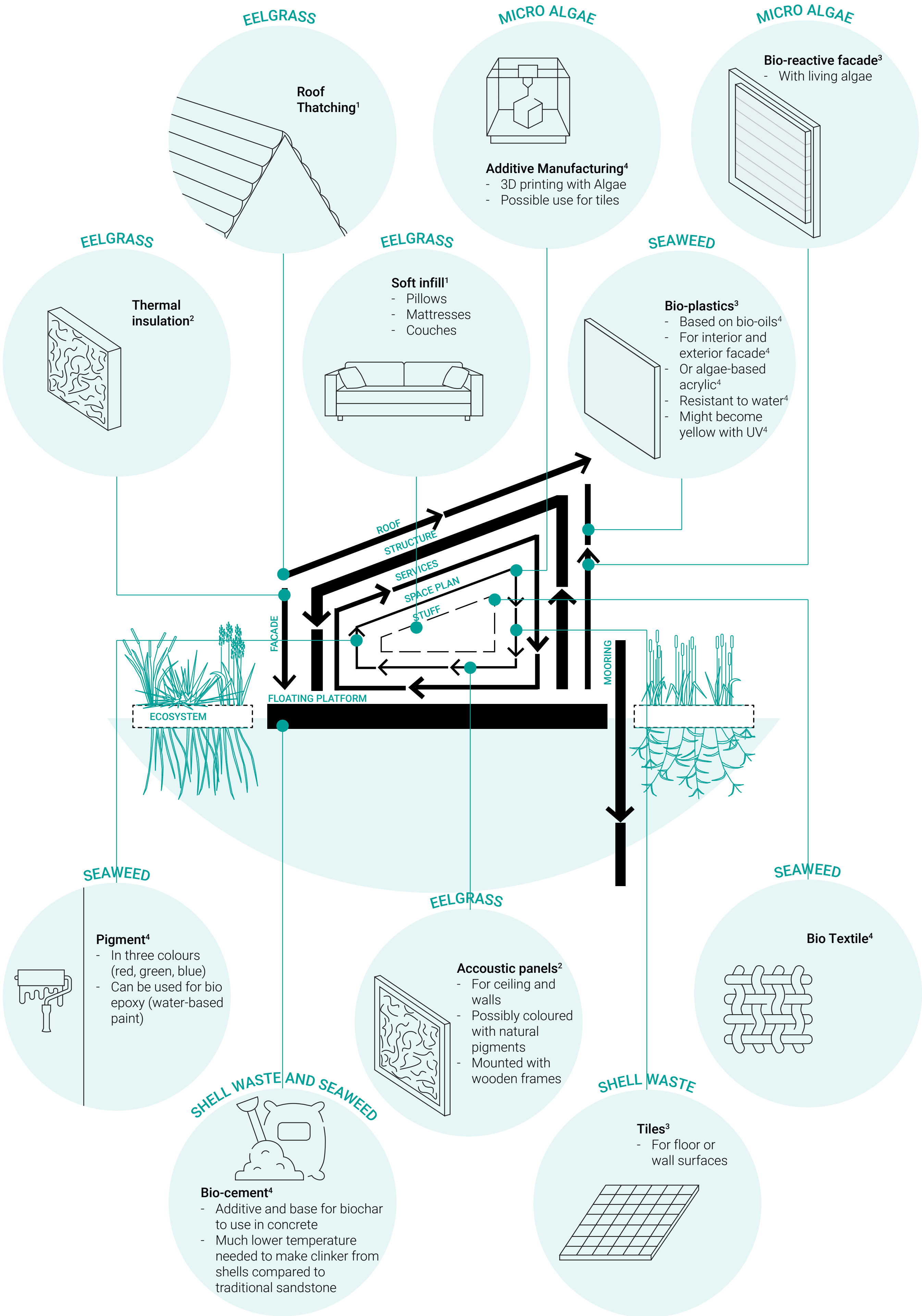
Appendix 8. Sub-question 3
CASE STUDIES



Footnotes

[1] Montali (2022) [2] LTRL trend (2019) [3] Piut (2023) [4] Pedrinola (2022) [5] Riggall (2024) [6] Mathen (2012) [7] Sari & Sir (2024) [8] ATDC (2024) [9] Mentayani & Hadinata (2021)

Appendix 9. Sub-question 4
INNOVATIONS



Footnotes

[1] Mon Tang (2024) [2] Sould (2024) [3] Nordic Blue Building Alliance & Arup (2024) [4] Interview 2 (2024)

Appendix 10. Sub-question 5

MATERIALS EVALUATION FOR A FLOATING BUILDING

STRUCTURE

Material	Resistant to dynamic actions	Grid structure	Lightweight
- Ash (Timber-frame)	High	Suitable	Moderate
- Alder (Beams & columns)	High	Suitable	Moderate
- Reed (Arched columns and beams)	Moderate	Moderately suitable	Light
- Willow (Daub wall structure)	Low	Unsuitable	Light
- Willow (in bundles)	Moderate	Moderately suitable	Moderate

SPACE PLAN

Finishing

Material	Fire resistant	Lightweight
- Ash (Surface wood)	Moderate	Moderate
- Birch (Finishing)	Low	Moderate
- Alder (Finishing)	Low	Moderate
- Seaweed (Pigment paint)	High	Light
- Eelgrass (Acoustic panel)	High	Light
- Shell waste (Tiles)	High	Moderate
- Reed or cattail (Seedwool in clay plaster)	Moderate	Light
- Reed (Ceiling finishing/Partition wall)	Low	Light
- Micro Algae (3D printed tiles)	High	Moderate

ROOF

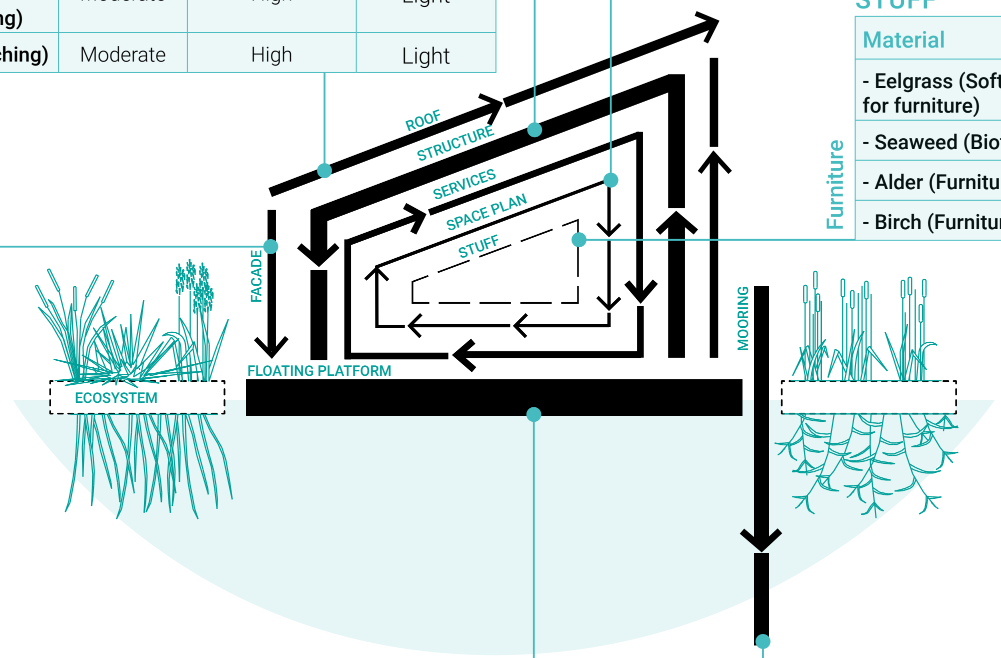
Thatching

Material	Resistant to dynamic actions	Controllability/ Changeability	Lightweight
- Water sedge or reed (Thatching)	Moderate	High	Light
- Eelgrass (Thatching)	Moderate	High	Light

STUFF

Furniture

Material	Fire retardant
- Eelgrass (Soft infill for furniture)	High
- Seaweed (Biotextile)	High
- Alder (Furniture)	Low
- Birch (Furniture)	Low



FACADE

	Material (method)	Resistance to dynamic actions	Controllability/ Changeability	Lightweight
Insulation	- Cattail (Compressed panels insulation)	Moderate	High	Light
Insulation	- Reed (Insulation)	Moderate	High	Light
Insulation	- Eelgrass (Insulation)	Moderate	High	Light
Cladding	- Alder (Wooden cladding)	High	Moderate	Heavier
Cladding	- Willow (Wickerwork board cladding)	Moderate	High	Moderate
Cladding	- Micro Algae (Bioreactive windows)	High	High	Heavier
Cladding	- Seaweed (Bioplastic cladding)	High	Moderate	Moderate
Cladding	- Reed (Woven mats cladding)	Moderate	High	Light

MOORING

Material	Water resistance	Withhold lateral forces	Allow vertical movement
- Alder (Foundation pile)	High	Strong	High
- Reed (Rope anchoring)	Moderate	Weak	High

FLOATING PLATFORM

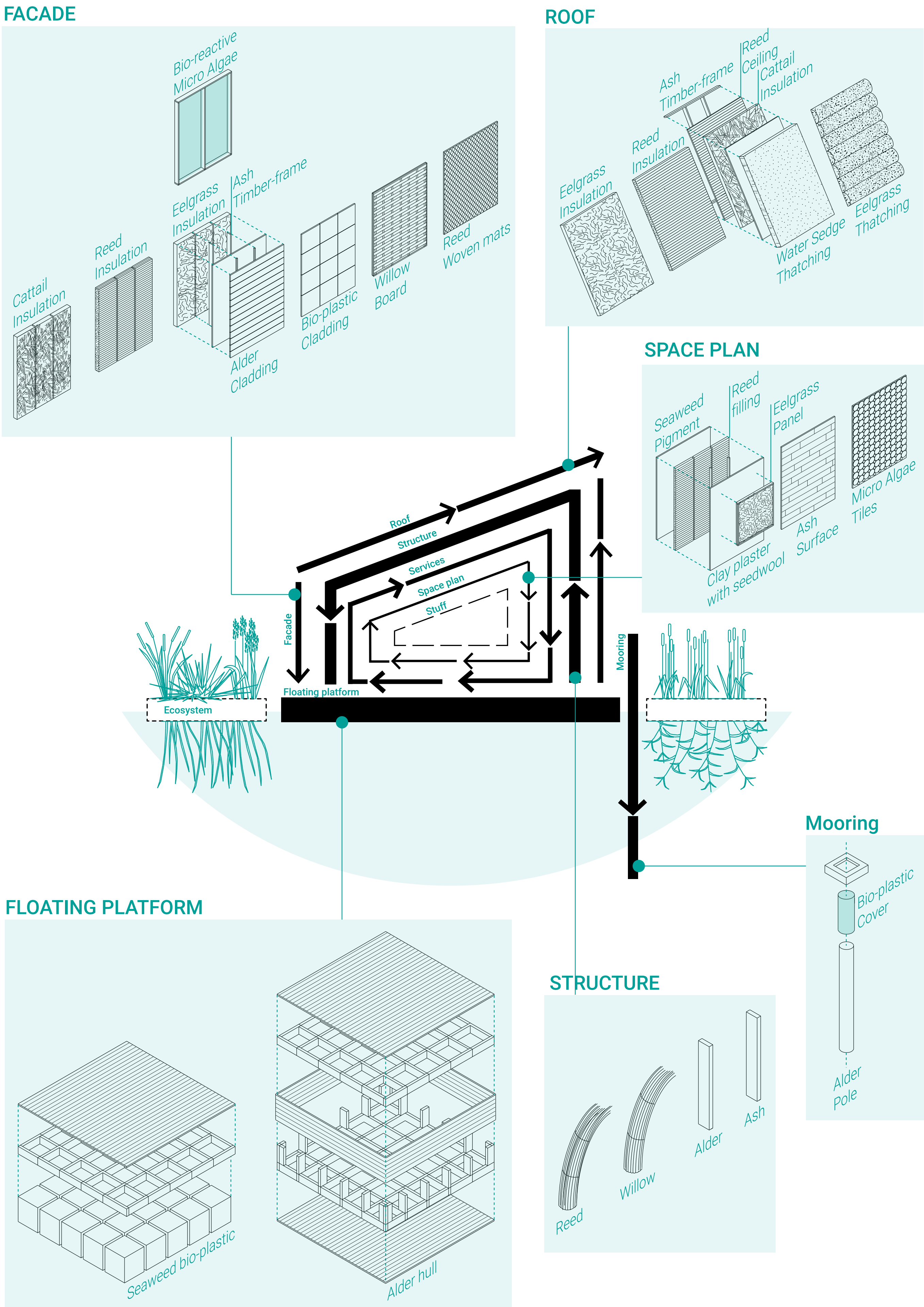
Material	Heavy weight	Water tightness	Buoyancy	Resistance to waves
- Reed (Dried layers)	Light	Low	Moderate	Moderate
- Alder (Rafts)	Moderate	High	High	High
- Willow (Bundles)	Moderate	Moderate	Moderate	Moderate
- Alder (Wooden hull)	Moderate	High	High	High
- Shell waste & Seaweed bioconcrete (pontoons)	Heavy	High	High	High
- Seaweed bio-plastic (Buoyant blocks)	Light	High	High	High

Appendix 11. Sub-question 5

SUMMARY OF MATERIAL USES IN A FLOATING BUILDING

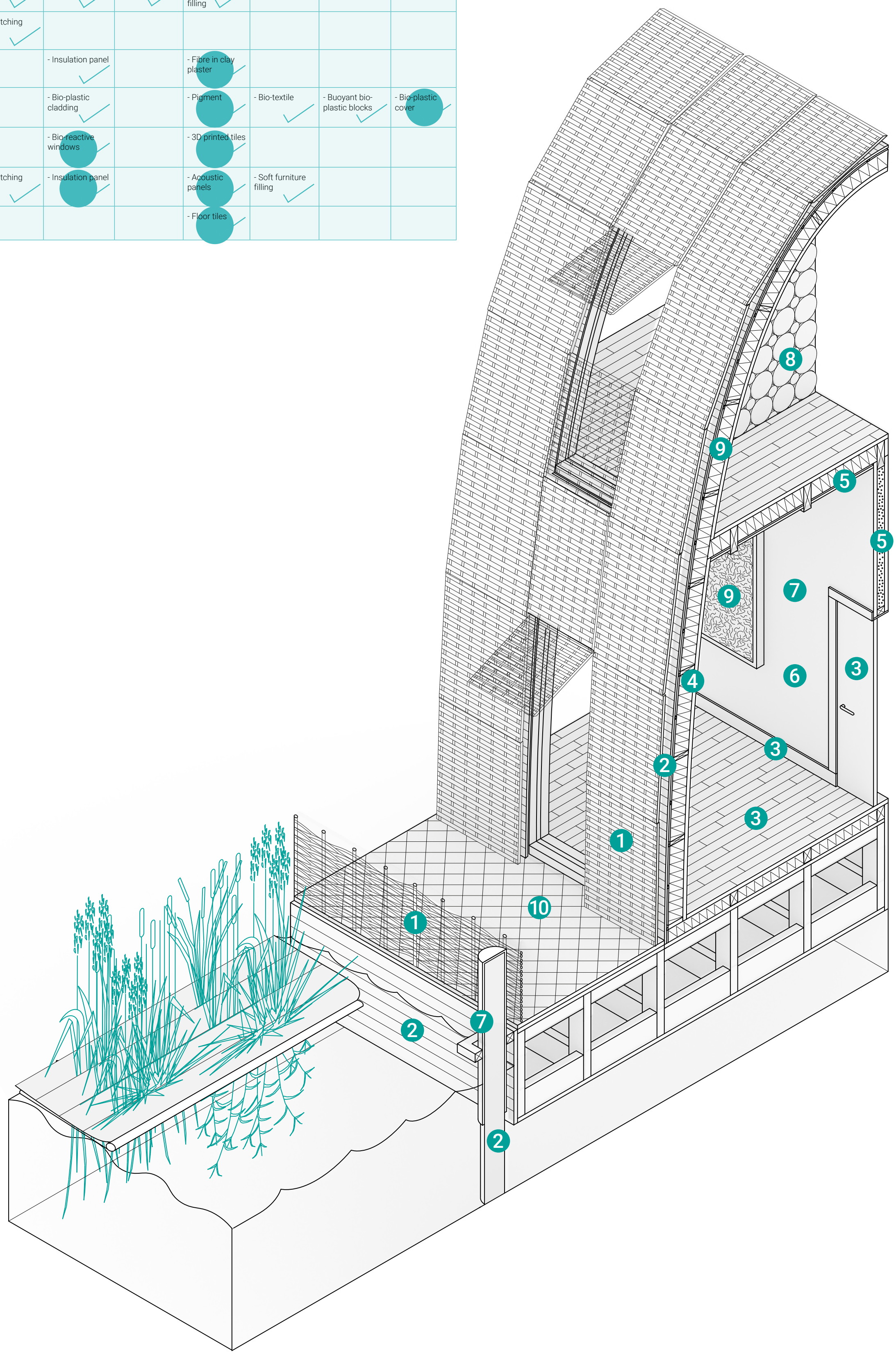
Material	Roof	Facade	Structure	Space plan	Stuff	Floating platform	Mooring
- Willow		- Wickerwork board cladding ✓	- Bundle ✓		- Wicker furniture ✓		
- Alder		- Cladding ✓	- Timber ✓		- Furniture ✓	- Hull ✓	- Pole ✓
- Birch				- Floor, finishing ✓	- Furniture ✓		
- Ash			- Timber ✓	- Panels, surfaces ✓			
- Reed	- Thatching ✓	- Woven mats - Insulation ✓	- Arches ✓	- Ceiling, partition wall filling ✓			
- Water sedge	- Thatching ✓						
- Cattail		- Insulation panel ✓		- Fibre in clay plaster ✓			
- Seaweed		- Bio-plastic cladding ✓		- Pigment ✓	- Bio-textile ✓	- Buoyant bio-plastic blocks ✓	- Bio-plastic cover ✓
- Micro Algae		- Bio-reactive windows ✓		- 3D printed tiles ✓			
- Eelgrass	- Thatching ✓	- Insulation panel ✓		- Acoustic panels ✓	- Soft furniture filling ✓		
- Shell waste				- Floor tiles ✓			

DESIGN GUIDE FOR MATERIAL COMBINATIONS

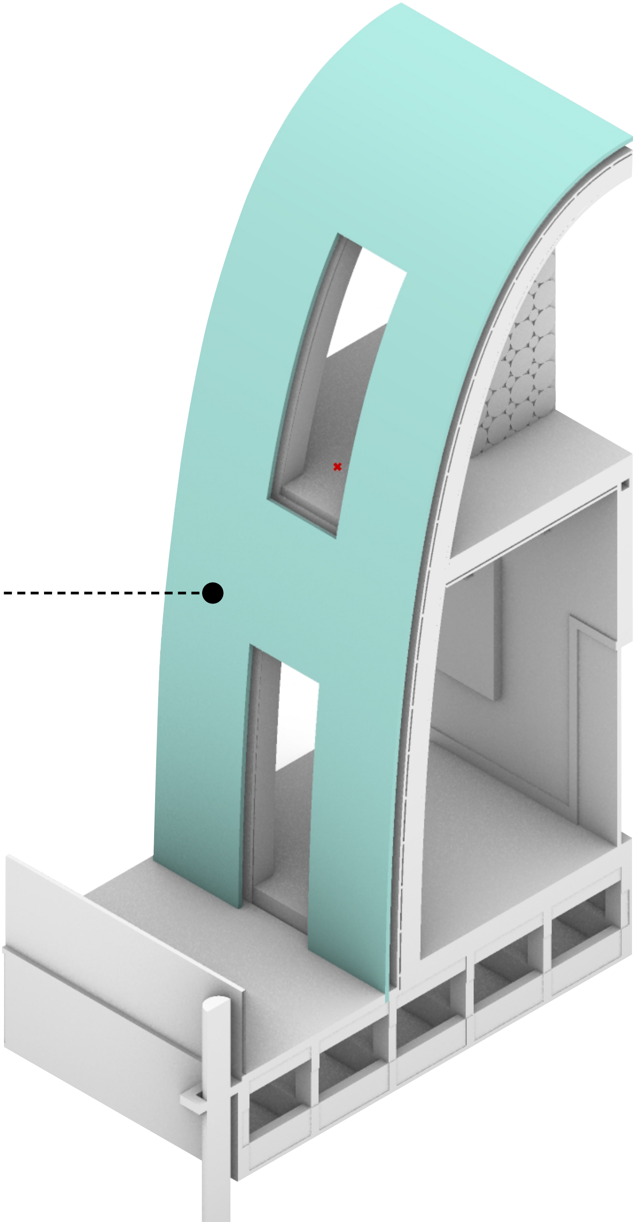


APPENDIX 13. SUB-QUESTION 5
RESEARCH-BY-DESIGN APPLICATION

Material	Roof	Facade	Structure	Space plan	Stuff	Floating platform	Mooring
- Willow		- Wickerwork board cladding	- Bundle		- Wicker furniture		
- Alder		- Cladding	- Timber		- Furniture	- Hull	- Pole
- Birch				- Floor, finishing	- Furniture		
- Ash			- Timber	- Panels, surfaces			
- Reed	- Thatching	- Woven mats - Insulation	- Arches	- Ceiling, partition wall filling			
- Water sedge	- Thatching						
- Cattail		- Insulation panel		- Fibre in clay plaster			
- Seaweed		- Bio-plastic cladding		- Pigment	- Bio-textile	- Buoyant bio-plastic blocks	- Bio-plastic cover
- Micro Algae		- Bio-reactive windows		- 3D printed tiles			
- Eelgrass	- Thatching	- Insulation panel		- Acoustic panels	- Soft furniture filling		
- Shell waste				- Floor tiles			



Appendix 14. Sub-question 6
COMPUTATIONAL ANALYSIS



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