# | PET Paradise |

## Turning a waste problem into a source to preserve the Maldivian Islands


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# Abstract |


*The Maldivian Islands are facing multiple challenges, including sea level rise, coastal erosion, and poor waste management. This research explores the development of a future-proof system using recycled plastic waste in order to protect the islands. The developed system includes an engineered artificial reef design, which is acting as wave breaking structure. This artificial reef is capable of withstanding extreme conditions, which occur more often as a result of global warming. Plastic waste will be recycled to construct the wave breaking structure, transforming the excessive waste problem into a solution. The system addresses a wide variety of problems, such as waste management, coastal erosion, and floods. It also creates awareness among tourists and local population, because it will make the island more attractive for eco-tourism and it will create more jobs on the island, which will affect daily lives of the local population. All together, the system offers protection to the coastal areas and preserves ecosystems. his pilot version of the sustainable and resilient system offers adaptability to other islands and incorporates traditional architecture for cultural preservation and future user needs. This leads to economic benefits, job opportunities, and increased awareness of waste management and environmental conservation.*

*This research is providing a strong foundation for the development and implementation of a future-proof system that contributes to the preservation and protection of the Maldivian Islands. By researching the possibilities of recycled plastic waste and integrating it into the designed system, a more sustainable and resilient future for the vulnerable islands and its communities is created.*



keywords: island preservation, island resilience, PET recycling, wave protection barrier, sustainable construction, Maldives,

# 1. | Introduction |

*Index*
*Problem statement*
*Research question*
*Methodology*

# Index |

# Problem statement | *definition*

*The Maldivian islands are famous for its beautiful white sandy beaches, clear blue waters, and divers marine life. Unfortunately this is not the current reality anymore. The Maldives are dealing with lots of problems and are facing even more in the future.*
*Sea level rise in the Maldives has a large impact on the liveability and ecosystems of the islands. The frequent floods and severe coastal erosion are causing an enormous amount of damage to the build and living environment, but also to the ecosystems on the islands and in the sea.*
*Because of the lack of treatment facilities and poor waste management, the collected waste is being exported or openly dumped. Toxic gasses, plastics, and microplastics are entering the marine environment, causing direct damage to wild life and marine ecosystems.*
*This level of contamination threatens fisheries and tourism, which rely heavily on the country's environment and are the most important factors for the Maldivian economy. Unfortunately tourists are generously contributing each day to the amounts of generated waste.*

# Research question | *sub-questions*

## PET Paradise

*"How can a future proof system be created from recycled plastic waste for the preservation and protection of Maldivian islands?"*

- How can sustainability be created in different levels of detail?
- How can a barrier be designed to decrease wave energy?
- How can the recycling of waste be incorporated in the design?
- What future proofing design possibilities can be applied to the islands and the system?
- How can we create awareness in sustainability among the local population and the tourists?

# Methodology | *research | assumptions | data*

### *Research*

In this research, the effects of climate change on the Maldives have been evaluated and thoroughly analysed. New and effective ideas are necessary to create resilience for the future and the increasing severe effects.
The effects on the Maldives which are being investigated in this research are the increase of floods, coastal erosion and the extinction of coral reefs and other ecosystems.
The poor waste management of the country is also contributing to multiple distresses among the population, nature and the environment.
The overall design is providing an example system and strategy for Maldivian Islands. It is addressing as much as possible to problems the islands are facing. Additionally, the design decisions are specifically made to create multi-applicability to other islands.
The system is based on literature research, research by design. The designed concepts together form the system/strategy which is open to other interpretation by experts on the specific matter.

### *The scope and focus:*

The research scope is narrowed down in order to create a more specific focus on the matter. The location are the Maldivian Islands which are located in the tropical zone. Focussing on this specific location has resulted into the creation of suitable solutions to the specific problems this location is facing.
The design has implemented the traditional architecture, the culture, multiple stakeholders, different levels of design, sustainability and future climate predictions in order to create a system.

### *Assumptions made:*

There is an enormous amount of data available on the prediction of sea level rise in the upcoming years. The data is evaluated and used in the design.
There is no up-to-date seawater depth map available. By taking all available data and information into account, an estimation and assumption is made regarding the depth of the sea water surrounding Maldivian islands.
As the coral reefs are rapidly disappearing and extinct, the assumption is made that there is no living coral reef present at the chosen location.

### *Data collections:*

- Websites, encyclopaedia's, research papers
- Google maps
- Literature review
- Data is collected by evaluating existing information regarding the research question
- Data is collected by designing and testing models and prototypes
- Create solutions from problems to solve other problems
- Combining existing research and at the potential of problems resulting in possible design solutions

# 2. | Problems |

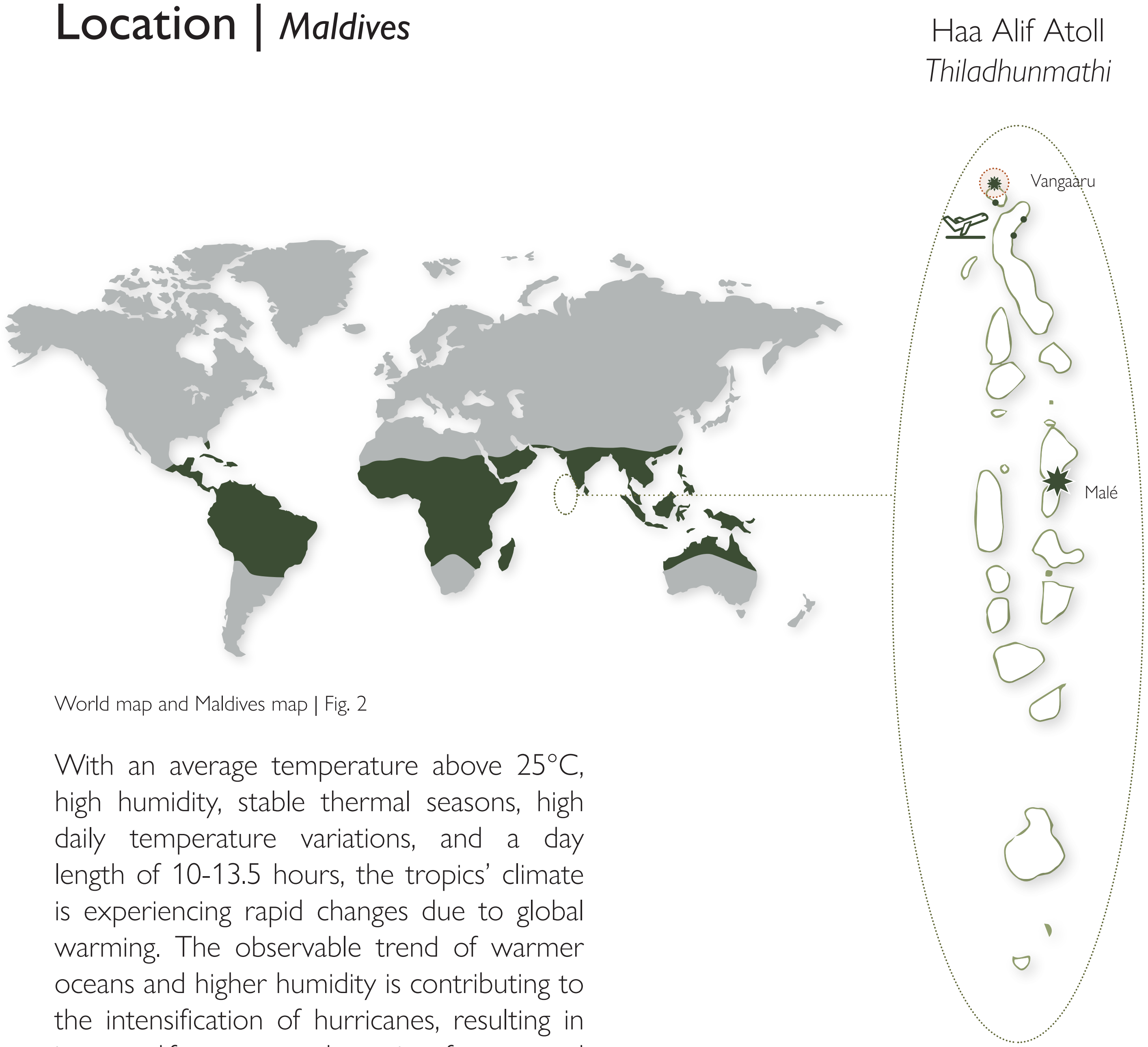
*Changing weather*
*Location*
*Global warming - sea level rise*
*Disappearing reefs - coastal erosion*
*Waste - toxic*

# Changing weather | *effects*

Climate change is creating problems worldwide. There is an increased frequency of natural disasters that cause significant damage to lives, infrastructure, and the built environment. Coastal areas are particularly affected with pressing hazards, such as more frequent storms, tropical cyclones, floods, and rising sea levels are causing problems. (Ferrario, 2014) Island buildings are often not constructed or equipped to handle the greater impacts and forces resulting from climate change. Tackling climate change is not a short-term solution, but it is crucial to provide protection and safety to people on the short term.


Changing weather effects | Fig. 1

# Location | *Maldives*




World map and Maldives map | Fig. 2

With an average temperature above 25°C, high humidity, stable thermal seasons, high daily temperature variations, and a day length of 10-13.5 hours, the tropics' climate is experiencing rapid changes due to global warming. The observable trend of warmer oceans and higher humidity is contributing to the intensification of hurricanes, resulting in increased frequency and severity of storms and floods. These storms, which are more humid and hotter, tend to be more intense, move more slowly, and are often accompanied by floods, storm surges, and airborne or floating debris. (Olson et al., 2022)

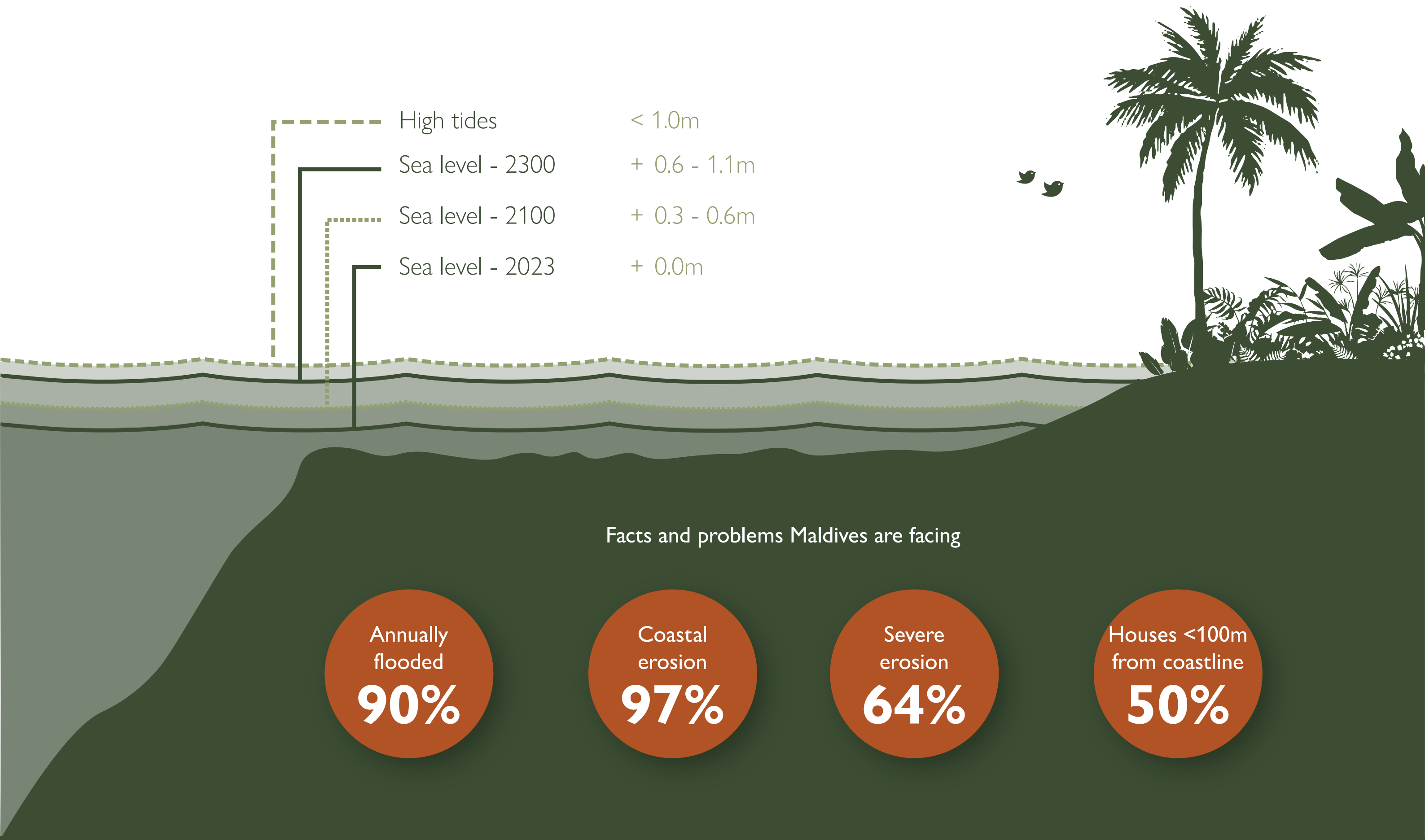
The islands in the tropical zone are suffering tremendously from global warming. These islands are in need of help and protection against the quickly changing severe weather.

The Maldives is a group of 26 atolls consisting of 1190 coral islands in total, located in the Indian Ocean. The islands have less than 400,000 island inhabitants, spread over approximately 300 km2. People inhabit around 200 islands. The national religion of the republic is the Islam. (The Editors of Encyclopaedia Britannica, 2023)

As mentioned, the Maldives are facing multiple problems. Due to its minimal natural resources, the country relies heavily on trade and commerce with external partners to foster sustained growth and development. However, this increased dependency on imports, such as food, fuel, and raw materials for construction, makes the country vulnerable to fluctuations in the global market. (Thamizoli, 2018) Additionally, the local population faces major risks such as beach erosion, sea water

inundation, strong winds with heavy rain, and shoreline changes. These risks are due to the islands' flat topography and susceptibility to tsunamis, floods, and sea water intrusion. (Thamizoli, 2018)
During heavy rains, waves can reach heights of two to two and a half meters, damaging homes, household items, coconut trees, and boats on the shore. In these instances, neighbouring islanders often provide immediate support. In the past, the local population would abandon the island and move to neighbouring islands if the natural disaster exceeded the manageable level. (Thamizoli, 2018)

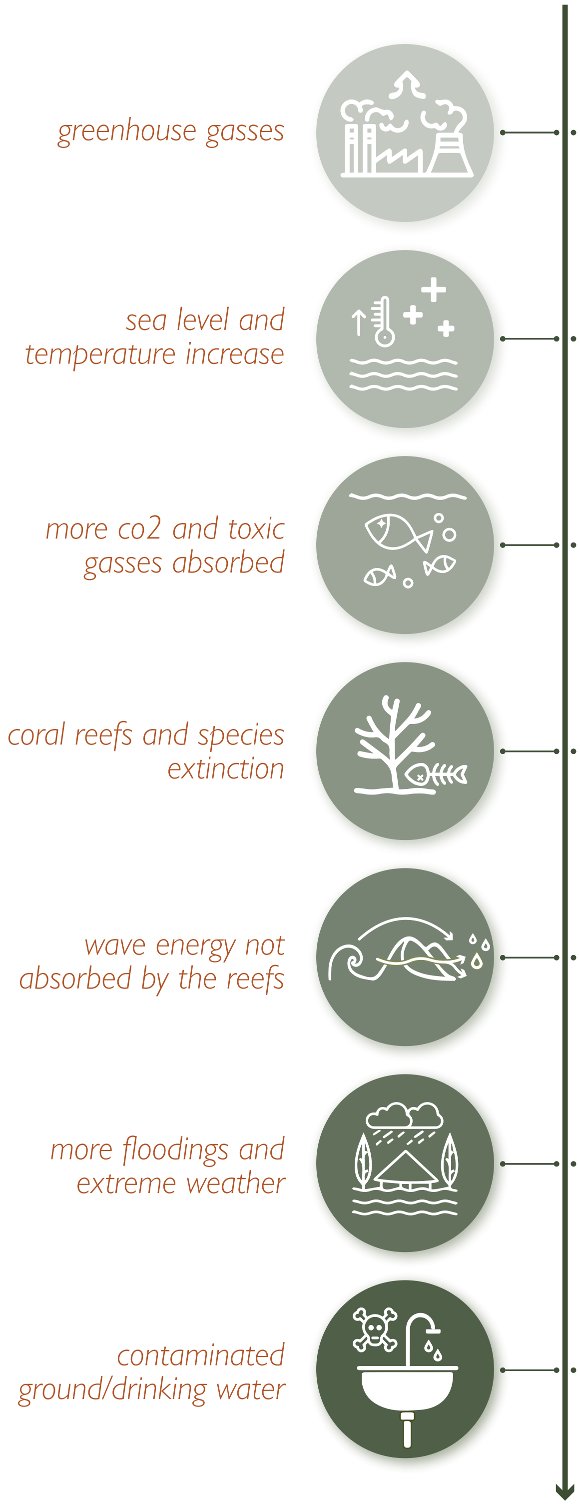
# Problems | *global warming - sea level rise*




Approximately 80% of the Maldivian Island are below 1 meter above sea level. (Gilchrist, 2021) Future climate change predictions state that the sea level will rise 0.6m – 1.1m in the upcoming 75 years. When the Paris Climate Agreement is pursued, the sea level will rise 0.3m – 0.6m in the upcoming 75 years. (Amores et al., 2021) Sea level rise in the Maldives has a large impact on the liveability and ecosystems of the islands. 90% of the islands get flooded annually and 97% of the islands are experiencing coastal erosion. (Gilchrist, 2021)

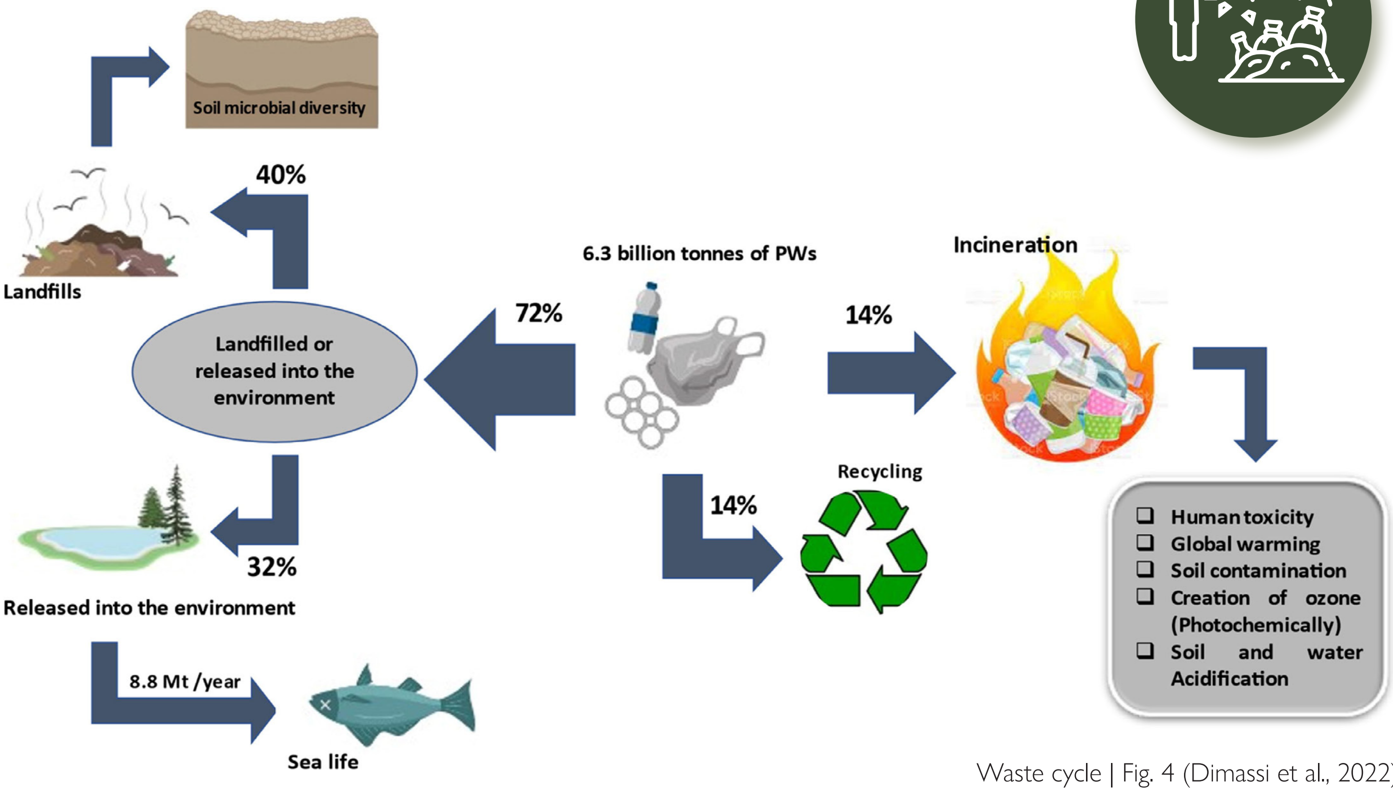
# Problems | *dissappearing reefs - coastal erosion*

The frequent floods and severe coastal erosion is causing an enormous amount of damage not only to the built and living environment, but also to the ecosystems on the islands and in the sea. Species tend to go extinct due to pollution and invasive species that are able to adapt to the changing climate circumstances. Coral reefs are also suffering as and tend to go extinct and disappear. The corals are not able to adapt quickly enough to the rapidly increasing sea water temperate.
Carbon dioxide concentration levels are much higher in warmer water. The tropical oceans are much warmer and therefore becoming large sources of carbon dioxide. (Goreau & Hayes, 2008)
Because of the raised toxicity concentration levels and increased water temperatures, coral reefs, including the species living in the reefs, have disappeared around 80% worldwide. Coral reefs are able to reduce up to 97% of the wave energy. (Ferrario et al., 2014) No coral reefs means no barrier between the coastlines and open sea, resulting in heavier and more frequently occurring floods.
Changing weather is also contributing to the more frequent occurring floods. Monsoons and rainfalls are becoming more intense and severe. Additionally, seawater expands with the increasing temperatures, again another contributing factor to the increased flood frequency. (Goreau & Hayes, 2008)




Timeline caused by global warming | Fig. 3

# Problems | *waste - toxic*




Waste cycle | Fig. 4 (Dimassi et al., 2022)

Everyday more than 800 metric tons of solid waste is generated from all inhabited islands, this amount includes 86 tourist resorts. (Asian Development Bank, 2021) Because of the lack of treatment facilities and poor waste management, the collected waste is being exported or openly dumped on Thilafushi island. With no control measures, the waste used to be burned on site. Toxic plumes of smoke were visible from Malé, the international airport, and nearby resorts suffered from poor air quality. (Asian Development Bank, 2021) Carbon emissions are entering the air, contributing to global warming and posing public health hazards. (World Bank Group, 2022) In addition to toxic gasses, are plastics and microplastics entering the marine environment, wild life and marine ecosystems, causing direct damage. Contaminating the marine life as food source, the coral reefs, and maritime economy. (World Bank Group, 2022) Consuming the contaminated fish and seafood is causing further health problems for both humans and other creatures. (Kumartasli & Avinc, 2020) This level of contamination threatens fisheries and tourism, which are dependent on the country's environment and are the most important factors for the Maldivian economy.

Unfortunately tourists are generously contributing each day to the amounts of generated waste. With an average of 3.5 kg per day the 1.7 million tourists produce 5,950 tonnes of waste each year. (Madina, 2022)

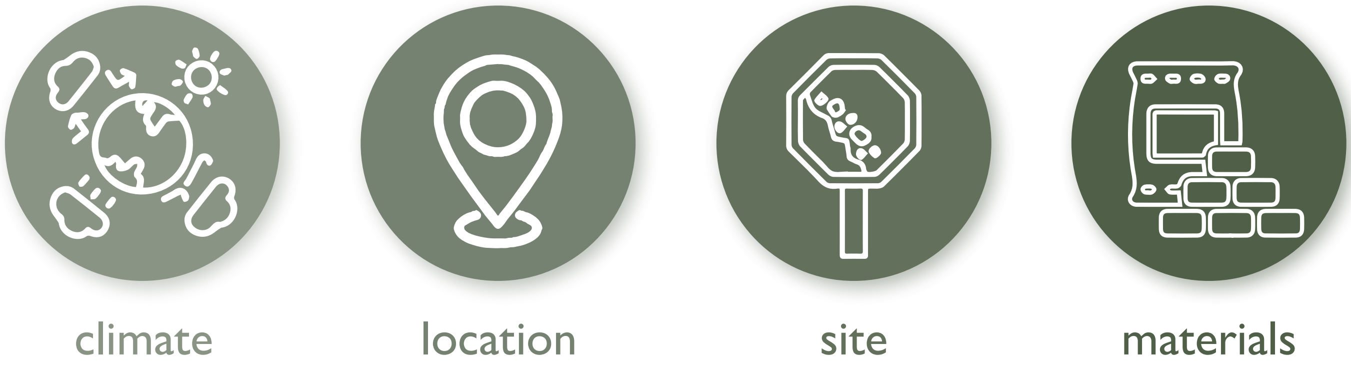
However, the situation at the landfills has improved, as fires and smoke have been stopped in Thilafushi since August 2021. (Asian Development Bank, 2021) The waste management system is shifting towards a circular economy with a sustainable future as the primary goal. Starting by increasing awareness of marine litter, encouraging alternative ways to cut down on single-use plastics, and incentivize citizen. (World Bank Group, 2022)

The most straight forward and effective solution to the plastic marine litter destruction is; recycling. (Kumartasli & Avinc, 2020)

# 3. | Vernacular |

*Vernacular architecture*
*Vernacular resilience | floods*
*Vernacular resilience | heat&humidity*
*Contemporary resilience*
*Tropical zone related*

# Vernacular architecture | *principles*




Vernacular architecture variables | Fig. 5

Vernacular architecture is based on the principle of building for specific needs of a specific location. The whole world contains thousands of microclimates, each with its own unique set of characteristics such as plant species, ecosystems, temperatures, humidity levels, solar radiance, daytime etc. (Giardina et al., 2015) As a result, local residents have been constructing their homes, creating an ideal living environment as possible and developing knowledge by working with the materials locally available and adapting to the constraints of the sites and microclimates. (Rashid & Ara, 2015)
In addition, vernacular buildings also have to take economic and technological constraints into account. Especially looking at the adaptation to available resources and constant changing circumstances are the local practitioners challenged in utilizing local resources extensively and the dynamic characteristics of technology. (Gautam et al., 2016) This evolution in building methods and knowledge is the result of a combination of research by design and trial and error. However, not all of this traditional architecture is still in use and had to make way for hi-tech solutions and materials, resulting in craftsmanship and information getting lost or forgotten.

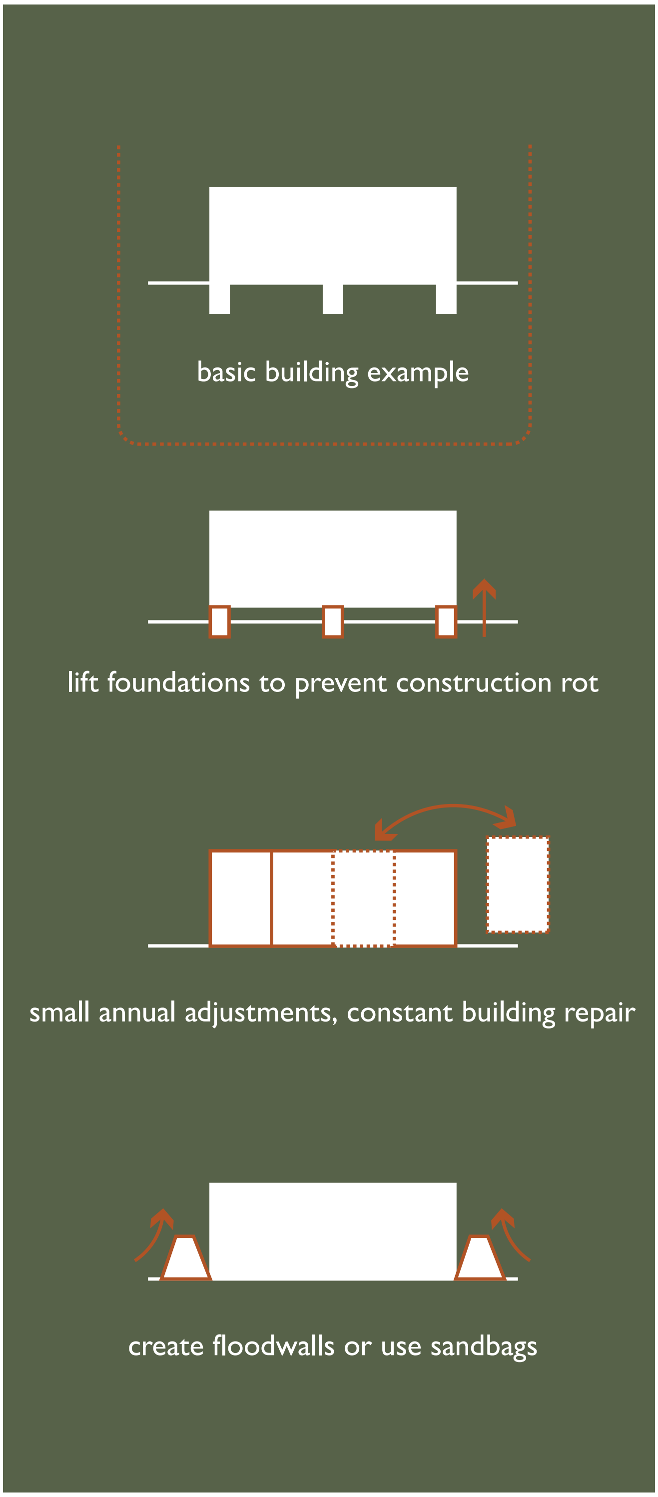
All of these simplified and ingenious ways in which vernacular architecture has coped with various weather types and climates can be reinterpreted, optimized, or used as a fundamental basis for building resilient structures.

In the tropical environment, vernacular architecture is adapted to the heat and humidity. To prepare the built environment for various types of disasters in the tropics, multiple factors must be considered. Buildings must be resilient against severe floods, storms, and extreme heat. (Giardina et al., 2015) Several vernacular interventions have been designed and described for each of these challenges. From both a sustainable and safety perspective, it is more prudent and secure to construct buildings using biobased materials. (Rashid & Ara, 2015) Modern materials such as concrete and metal roofing tend to collapse under high forces and damage the surrounding environment, endangering not only other buildings but also the inhabitants. While contemporary buildings are designed to be permanent, traditional architecture focuses more on creating temporary living spaces that can adapt to upcoming events or seasonal impacts.

# Vernacular resilience | *floods resilient interventions*

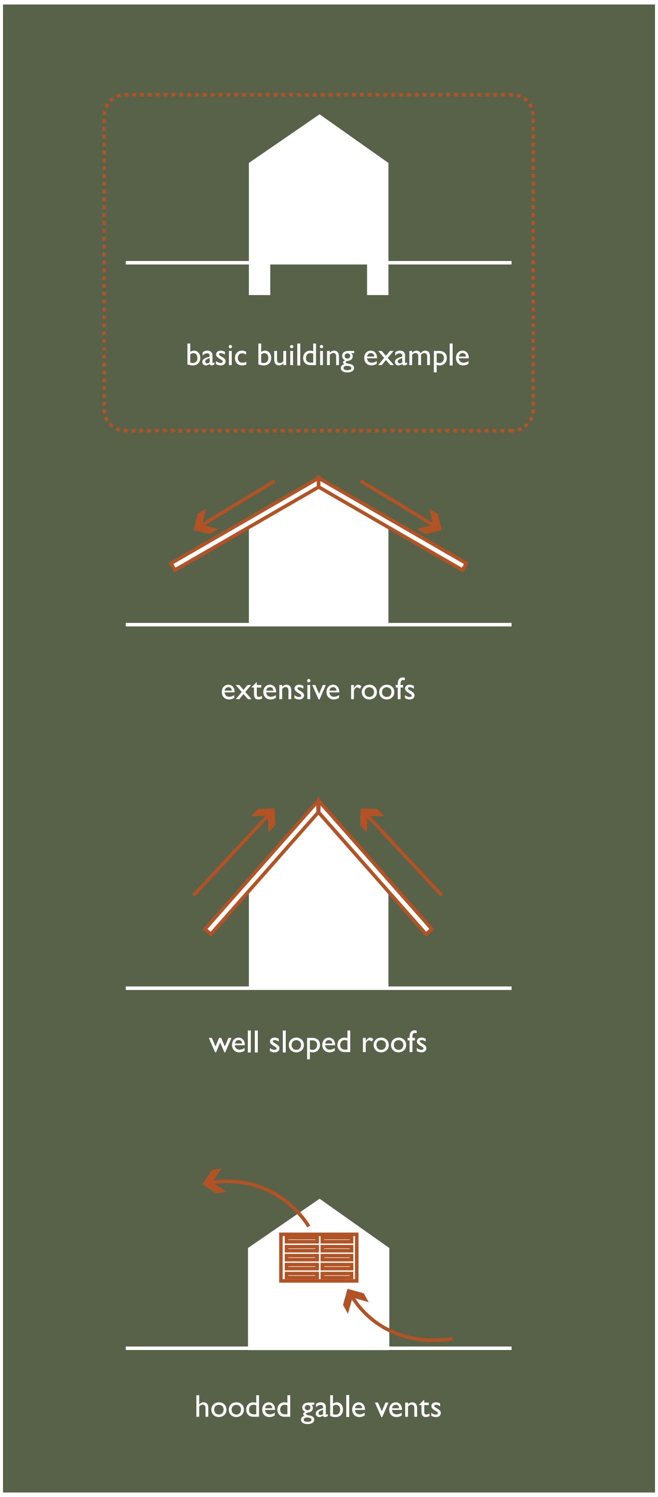
### *By monsoons and sea level rise and cyclones*

Building decay due to rot is a common issue for vernacular buildings located in flood prone areas. These structures are constructed using local materials and are often exposed to water, causing the timber materials to rot due to soaking and drying. The quickest solution to this problem is lifting the foundations above the flotation level of rising floodwaters. (Oliver, 1997)
Floods are an enormous catalyst when it comes down to erosion. Everything is washed away with the flood water. Waste, materials, sand, trees are colliding with buildings and other structures on land. The movement of water in combination with floating debris is the main cause of erosion in the built environment having a severe impact on wall materials. This is why vernacular architecture in flood prone-areas is not built with mud, wattle or daub. (Oliver, 1997)
However, the destructive effects of floods on the built environment in floodplains can be partially solved with a simple intervention.
If wood or bamboo is available, buildings can be constructed on stilts, lifting the floors above the rising floodwaters and allowing floodwaters to pass underneath. (United Nations Environment Programme, 2021) This approach also provides protection from dampness and animal pests. (Oliver, 1997)
For safety reasons, an access route to the roof or next level should be implemented so that residents can escape when the water rises until an extremely unexpected high level. (Oliver, 1997)
One of the primary factors contributing largely to the increasing frequency of floods on islands is the extinction of coral reefs around the islands. Reefs are protecting the shorelines by absorbing between 65% and 97% of the wave energy. (Ferrario, 2014) When the reefs die, the wave energy will no longer be absorbed. Resulting in a disappearance of a barrier between the oceans and the coastlines and leading to more frequent flooding. (Ferrario, 2014)
Additional visualised interventions on building flood resilience can be found in appendix A.




Flood resilient interventions | Fig. 6

# Vernacular resilience | *heat & humidity resilient interventions*




Flood resilient interventions | Fig. 7

When dealing with heat and humidity passively, the design decisions of elements of a building, such as the shape of the roof and openings in façade, all influence the level of a building's protection. Extensive roofs create large amounts of shade and when combined with well sloped roofs as well as the addition of hooded gable vents, a natural convection including stack ventilation will occur. (Oliver, 1997) An open space layout with numerous openings, minimal furniture or interior walls can greatly contribute to a pleasant indoor climate. Lightweight organic materials are often used in tropical climates. Preferably with floors lifted from the ground to stimulate ventilation beneath a building. (Oliver, 1997)
Extended periods of heat increases the risk of fire. Therefore, the building should be oriented and positioned in a way that it captures wind or strategically designed to channel cooling breezes indoors. Additionally, incorporating nature has its positive effects on coping with the excess heat, as trees provide shade and block direct sunlight, thereby reducing the indoor temperature. (United Nations Environment Programme, 2021)
Additional visualised interventions on building heat and humidity resilience can be found in appendix A. Other design guidelines, recommended by the Climate Consultant 6.0 software for building in tropical climate, can be found in appendix B.

# Contemporary resilience | *solutions*

### *Current solutions dealing with a tropical climate:*

A growing sense of responsibility towards building in an environmentally sustainable manner in the field of contemporary architecture has emerged over the past years. A shift towards organic and energy-efficient vernacular construction has become the new trend. Local construction not only demonstrates how buildings can be effectively designed, but also protect culture and tradition. (Rashid & Ara, 2015)

Despite the large variety of vernacular architecture around the world, research on techniques or technology-based approaches in vernacular architecture is very limited. However, some architects tend to adapt and incorporate the vernacular architecture on a detailed level, such as adaptive smart-space solutions and materiality. (Rashid & Ara, 2015)

The building envelope is the key focus point in modern construction. Technical features are crucial to control the indoor temperatures, especially in areas prone to hurricanes where buildings require exterior impact protection, including all impact-resistant elements such as doors, windows, and shutters. In addition, the roof needs to be connected to the basement or a concrete slab using roof straps and cables. (University of Rhode Island, 2020)With the presence of HVAC systems and other service equipment in homes, it is essential to raise them above the floodplain level to prevent potential fires caused by short circuited or damage to other installations. (Cao, 2021) Future developments will aim to combine the impact resistance in combination with the provision of energy efficiency. (University of Rhode Island, 2020)

New technologies such as insulated concrete forms and structural insulated panels can successfully withstand hurricanes and tornadoes. (Admin, 2022) Floodproofing can be achieved by using coatings, sealants, and waterproofing veneer to prevent floodwaters from entering buildings.

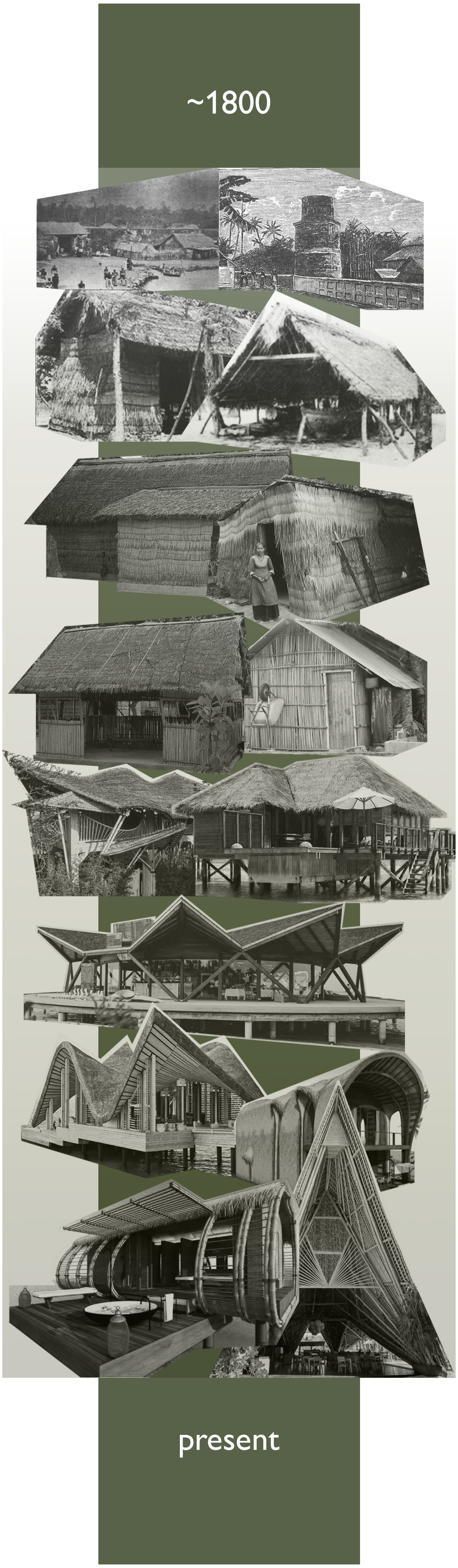
The selection of materials and other design decisions depends on the circumstances a building will face during its lifetime. For example, in hot climates, light-coloured paints and UV-deflecting glass are used. Contemporary architecture has no limit in the use of materials and design. The most influential factor on a design is the budget.

Hi-tech solutions play a large role in the modern building industry. Sensors monitor the sun, hurricanes, floods and other weather related extreme circumstances. (Climate-ADAPT, 2022) Programs can predict the location-specific elevation of flood levels, leading to additional requirements architects need to consider in their design. (Cao, 2021) The same can be done for wind, storm surge and wave action during hurricanes. Since this is all computer model-based, experiments need to be physically verified through disaster testing. (Olson et al., 2022) By monitoring a building and obtaining information, the design can be fine-tuned. Airconditioning, ventilation, shading panel orientation- everything can be optimized and regulated. (Climate-ADAPT, 2022)

Flexibility is one of the key objectives contemporary architecture aims to achieve through fine-tuning and optimizing load bearing constructions, standardization, and the prefabrication of building elements/ parts. Additionally, repairing, maintaining and upgrading building components can lead to new and contemporary improvements. (Rashid & Ara, 2015)

Modern buildings are designed to be permanent. However, traditional architecture focusses on creating temporary living spaces that depend on upcoming events or seasonal impacts.

# Tropical zone | *architecuture/materials/requirements*




*The architectural development of the Maldives throughout the years*

coconut palm timber
*construction*

cork wood
*building skin*

palm leaves
*building skin*

sea lettuce tree
*dampproof membrane*

sandstone
*foundation*

bamboo
*everything*

## *Vernacular building requirements Maldives*

- In order to provide a stable and sustainable foundation, materials need to be able to adapt to the soil conditions.
- Wall openings are big enough to allow ventilation, but small enough keep water out.
- The design should be flexible and demountable, allowing extensions to or relocation of the building.
- Floors are elevated above the ground using layers of stacked stones.
- Vertical and horizontal timber columns are used for the construction. Steep roofs stimulates rain water collection.

## *Materials and architecture*

The coconut tree can be used completely in buildings. The wood can be used for wall construction. The coconuts can be eaten and the husks can be transformed into ropes and cordage. These ropes and cordage are used for lashing, binding and knotting the structural components together. This is the most widely applied method of creating joints. (Oliver, 1997)

The palm leaves, also known as frond, are mainly used for wall enclosures and door and window openings. The leaves and thatch are particularly used for roofing. This can be applied directly to the construction or woven first.

However, in humid and warm climates durability of biobased materials is difficult to achieve. The dampness is a source of micro-organisms and fungi to grow. This way lots of materials need to be replaced every few years. (Oliver, 1997)

Up until the 1800's the traditional Maldivian house would be built with coral cement, thatched coconut or palm branches on top of the roof. (Hameed, 2017) However, the coral stone is a very brittle and crumble material which cannot withstand the hot and humid climate along with the salty environment. The material has a very temporary lifespan. (Hameed, 2017)

Additionally, not a lot of historical buildings are left. Due to the lack of land area, old buildings were demolished every time a new building was needed.

A typical trait of the Maldivian culture would be that the houses are not excessively decorated, but simply furnished. Another interesting feature of traditional Maldivian architecture is that on a plot of land the kitchen, or the 'badhige', is located separately from the main house. The bathrooms are also separately built from the main living compound. (Hameed, 2017)

# 4. | Design |

*Design task*
*Design concept*
*Design concept | waste*
*Design concept | barrier*
*Design concept | nature*
*Goals & objectives*

# Design task | *programme of requirements*

## *Design requirements*

- Preserving the Maldivian nature and islands
- Future proofing - flood resilience/ no coastal erosion
- Economic benefits
- Job opportunities
- Plastic/waste issues being tackled
- Pilot, create a sustainability identity
- Create awareness among the locals and tourists
- Use social media platforms
- Locals do not need to move in the future
- Culture preservation
- Smart design – self-sustaining
- Applicable to other islands
- Preserving a living environment of the population
- Holiday destination - eco-tourism

## *Including and addressing topics:*

- Design pilot
- Logistics
- Incorporate traditional architecture - incl. Future proofing
- Waste management solution
- Flood resilience
- Coastal erosion prevention
- Eco-tourism
- Applicability

# Design concept | *the island system*

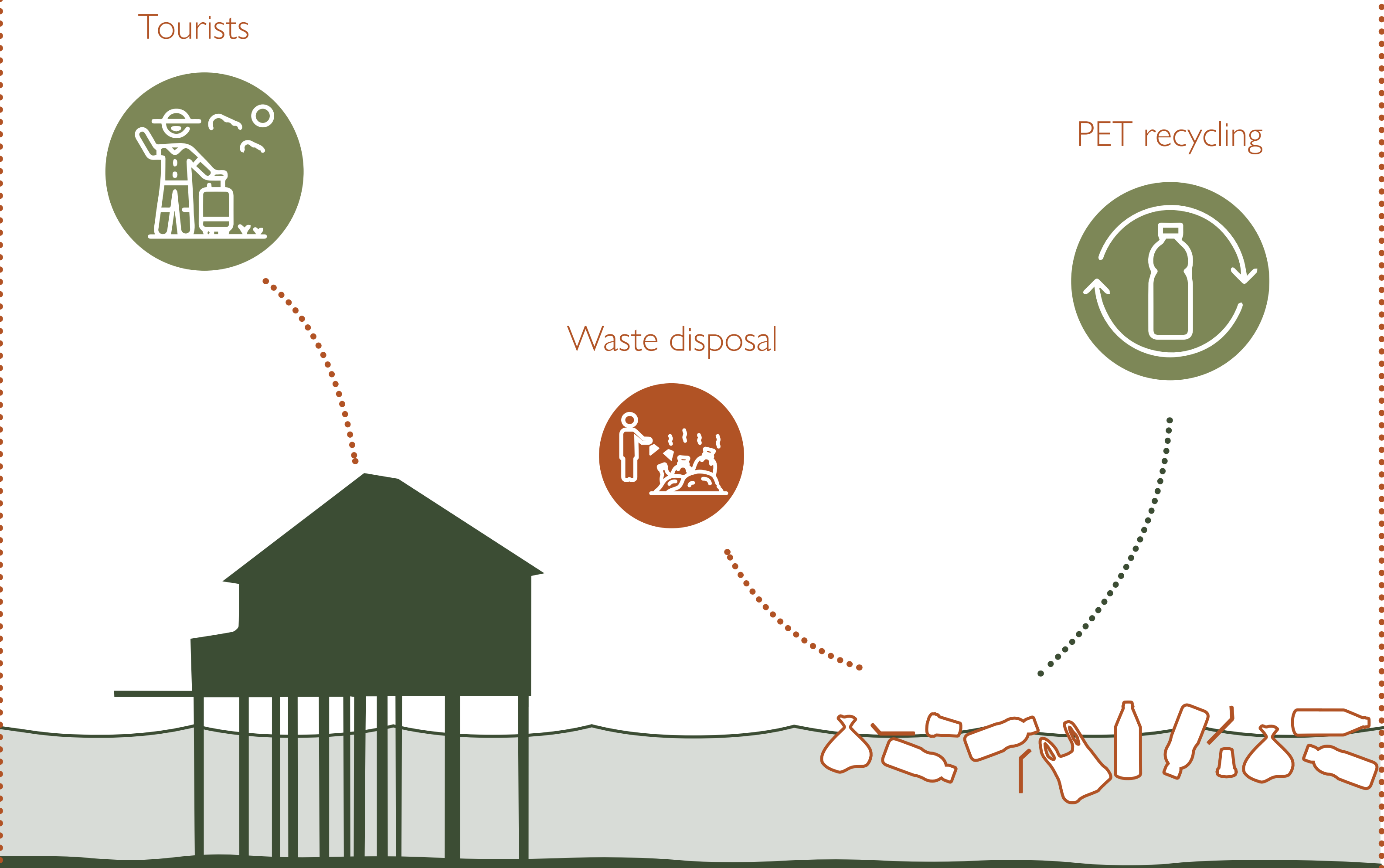
What the Maldives need is a new strategy and system to be able to withstand future hazards. The foreseen goal for this newly designed system that it should become an example and pilot which is applicable to other islands.
All factors and designs implied are going to form the system together and are depend on one and other.

The design needs to follow the function of coral reefs, which involves absorbing wave energy, protection against coastal erosion and allow ecosystems to thrive. To achieve this, the design needs to live up to these specific terms, thus be located in the sea at the location where the coral reefs were once located.
One of the primary objectives is the reduction of wind and wave action in shallow shoreline areas. Next to that, with the predicted sea level rise in the upcoming decades the new houses can be built already in the water and elevated above the expected sea level rise.
The space underneath the houses is not used. This space can be utilised to create a wave energy breaking and absorbing construction. This construction is going to be produced out of waste. The majority of the generated solid waste consist of plastic. Resulting in a wave breaking structure made out of recycled plastics.
A single construction in front of an island will not make a difference or create enough impact. By connecting multiple constructions together around the island a barrier is created. The barrier and villas enclose the shallow waters and islands creating a lagoon. When such a lagoon is created ecosystems in the ocean and on the island can peacefully recover.
In addition, to protect the islands from flooding, the design also becomes a tourist attraction.
While the ecosystems of the islands can slowly recover, a healthy environment for all sorts of flora and fauna on the islands and in the water of the lagoons is created.
By housing the tourists at a designated area the influx can be regulated as well as their actions, consumption and waste disposal. Tourist are spending a lot of money on these holidays. The funds can be utilized to build waste treatment and recycling facilities. The recycled plastics can be used to create new building elements. With the obtained materials and funding new additional resort villas can be build and added to the area. Closing the circle.

The design is going to break the vicious circle of the waste problem, it is going to take over the function of the coral reefs, it will allow becoming a sustainable holiday location and it is going to contribute to the recovery of ecosystems all at the same time.

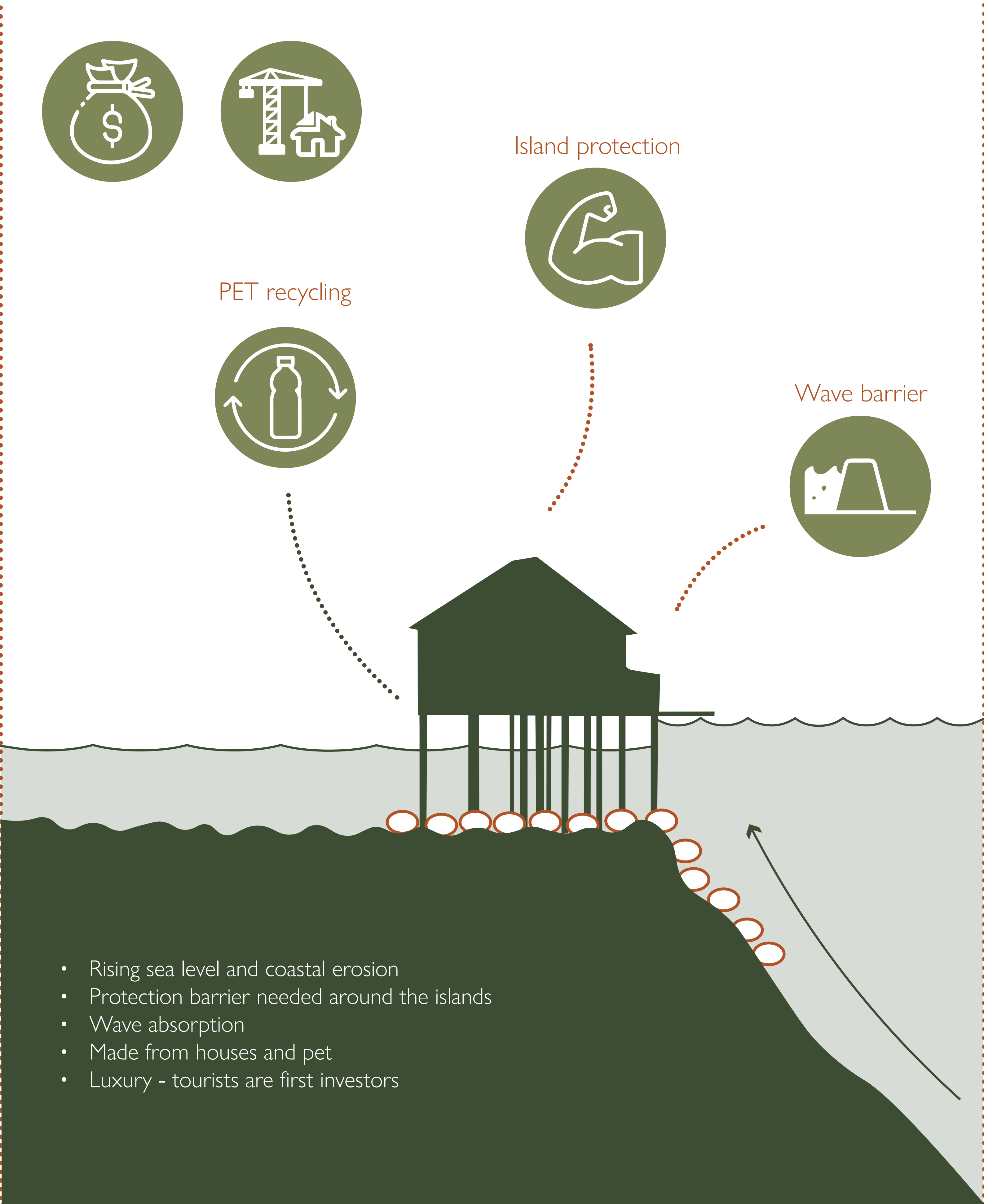
Design cconcept | Fig. 8

# Design concept | *waste*




- Tourists litter the environment
- Too much waste can't be treated properly
- Coral reefs are suffering
- Recycling required

# Design concept | *barrier*

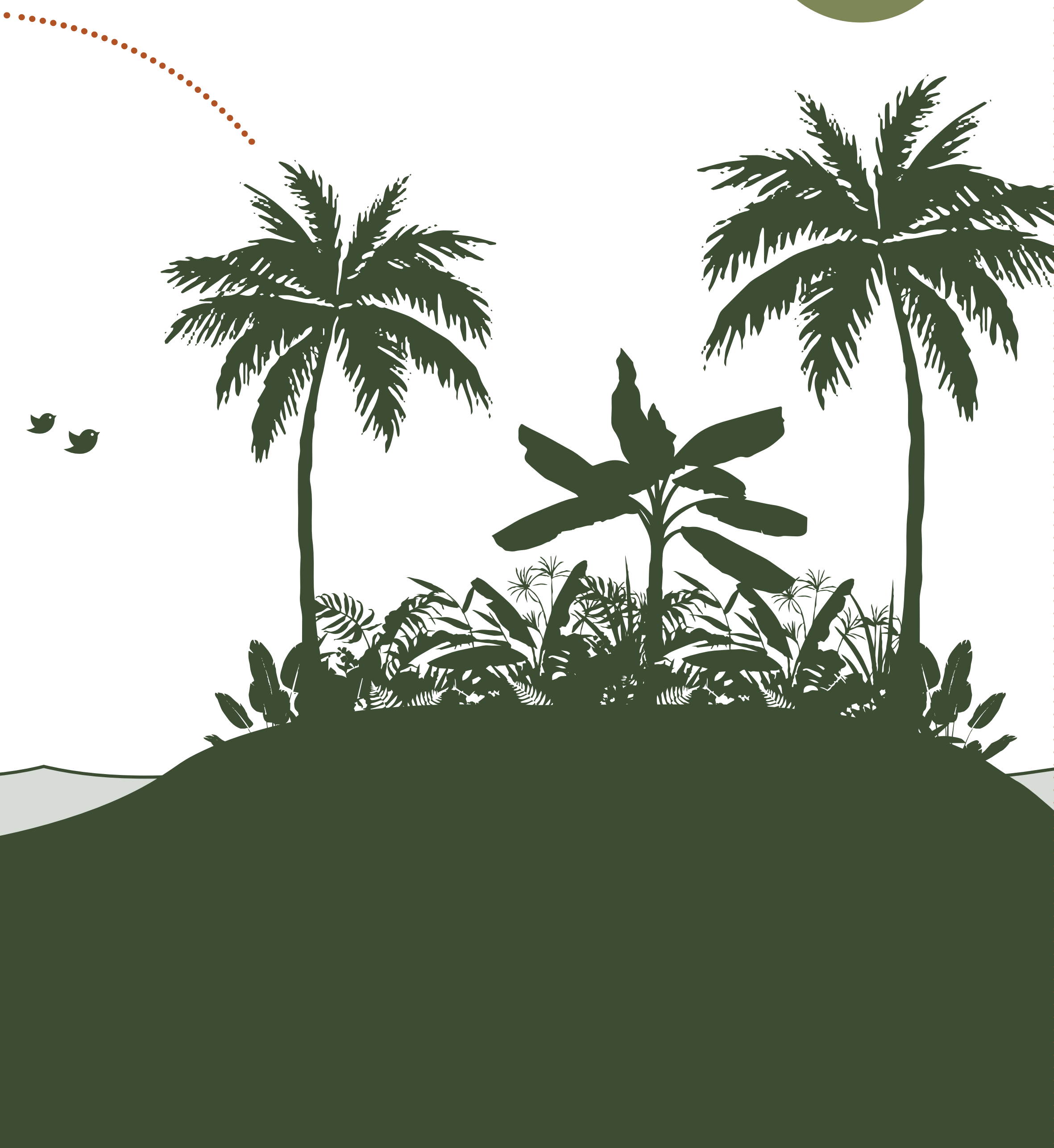



- Rising sea level and coastal erosion
- Protection barrier needed around the islands
- Wave absorption
- Made from houses and pet
- Luxury - tourists are first investors

# Design concept | *nature*

Protecting ecosystems

Nature is a selling point

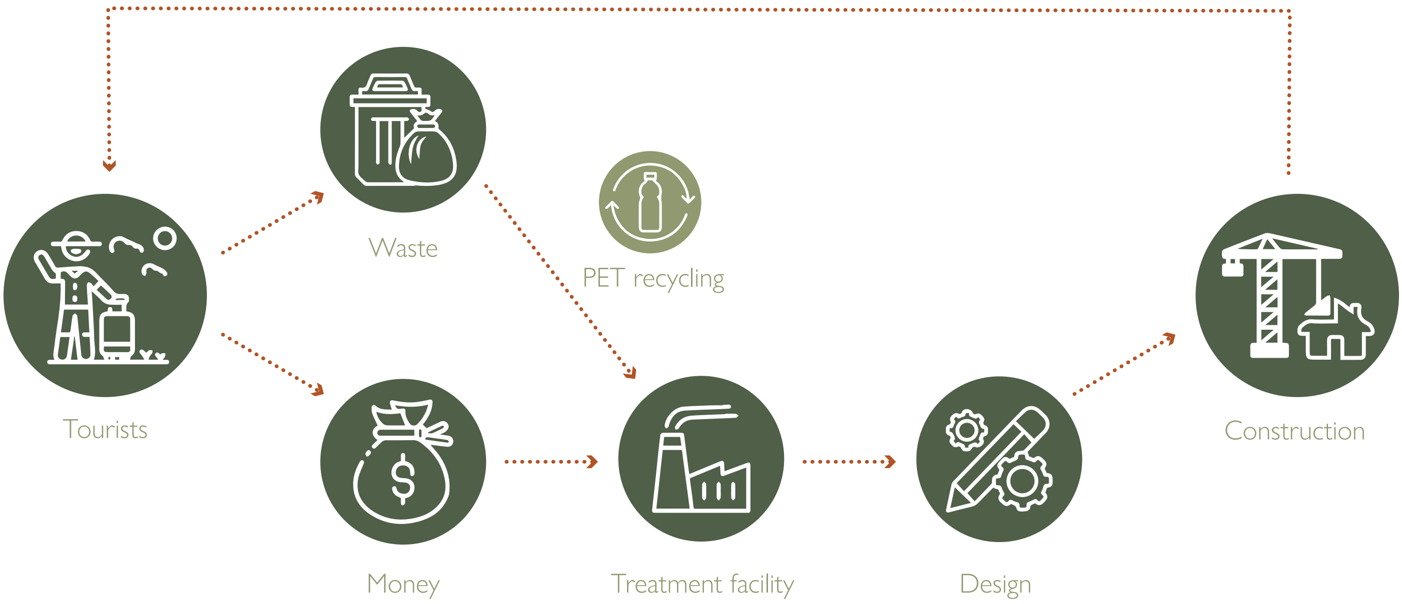


Protecting sealife

- Flora and fauna recovery
- Controlled tourists influx
- Untouched nature is a selling point

# Design | *goals & objectives*

The design requirements are translated into goals and objectives after defining the design concept.
All parties are connected and dependent on one and other. Resulting in a cycle of dependency and survival, shown below in fig. 9, to keep the Maldivian islands and its ecosystems from disappearing. The cycle is sustaining itself and keeps growing.




Circle of survival diagram | Fig. 9

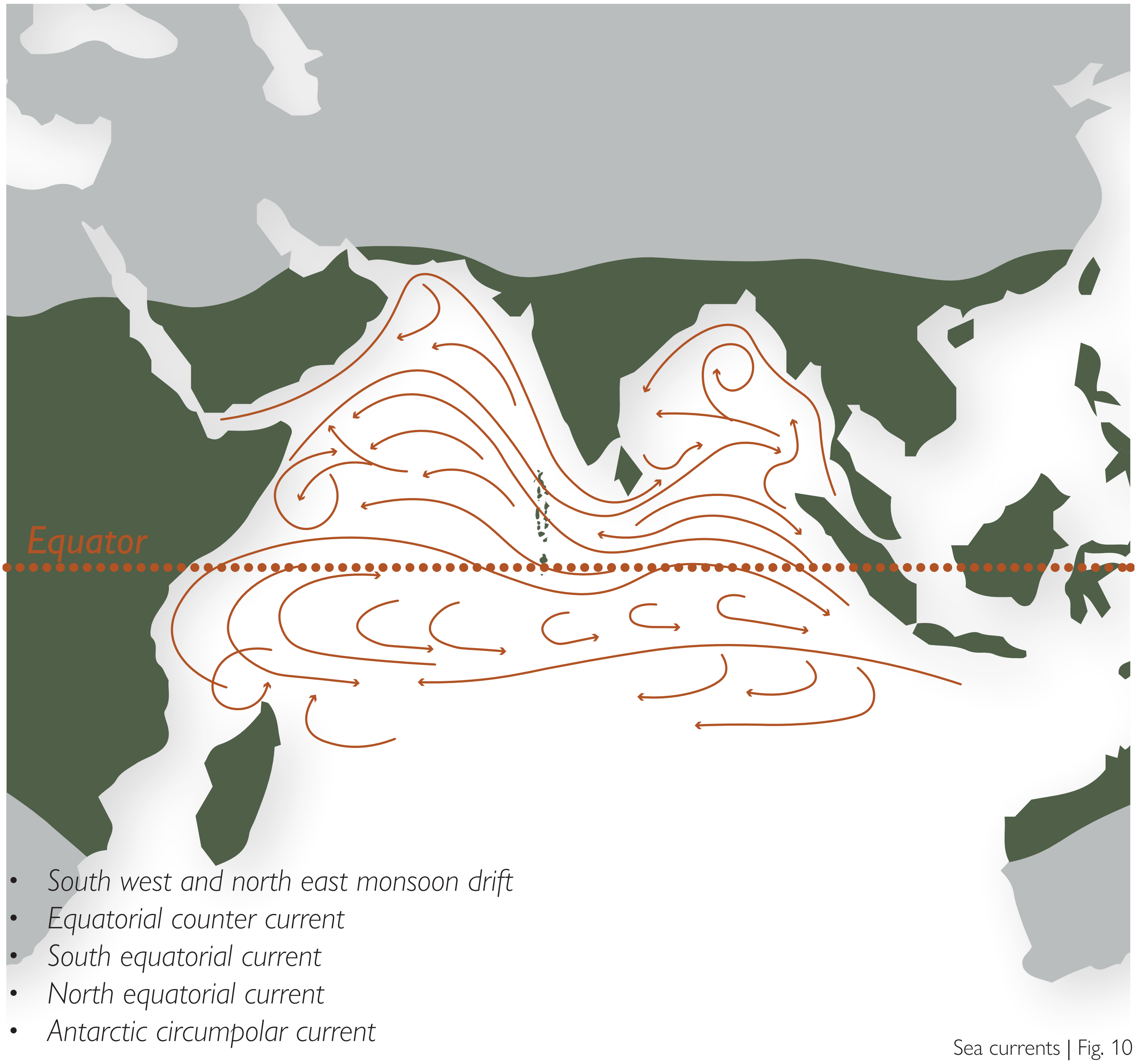
## *Objectives*

- The 'design-product' is a system
- A pilot version system for other coastal areas endangered by global warming
- System applicable to other islands
- Preservation of the Maldivian islands
- Create a new barrier, reef structure
- Flood control/prevention
- Coastal erosion prevention
- Houses elevated above the predicted water level and located in the water
- Use waste to create a wave energy absorbing construction underneath the houses
- Build houses in vernacular and traditional style around the islands, creating a lagoon
- By creating a barrier, the island is protected from the open water and waste
- Nature and ecosystems are protected within the lagoon allowing recovery
- Eco/sustainable tourism is encouraged
- The amount of tourists are regulated and controlled
- Money from the tourism is used for waste management, recycling, new houses, new projects, restoring ecosystems and nature
- Logistics, infrastructure, built environment, wave breaking structure, location, everything is part of the island, part of the system.

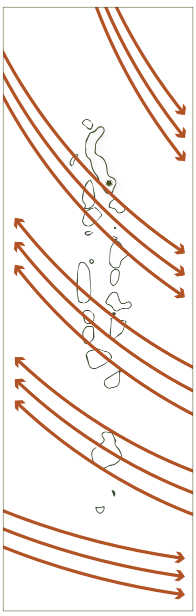
# 5. | Data collection |

*Ocean currents*
*Wind directions*
*Haa Alifu island*
*Haa Alifu island | dimensions*
*Haa Alifu island | mobility map*
*Haa Alifu island | section*
*Access to lagoon by boat*

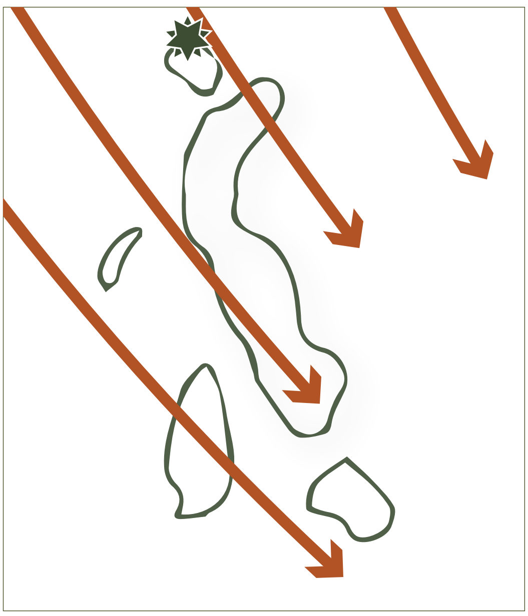
# Ocean currents | *location specific*



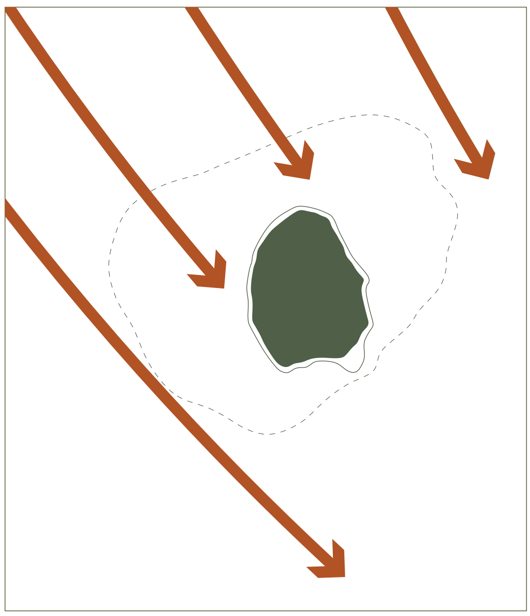

Sea currents | Fig. 10



*The Maldives*

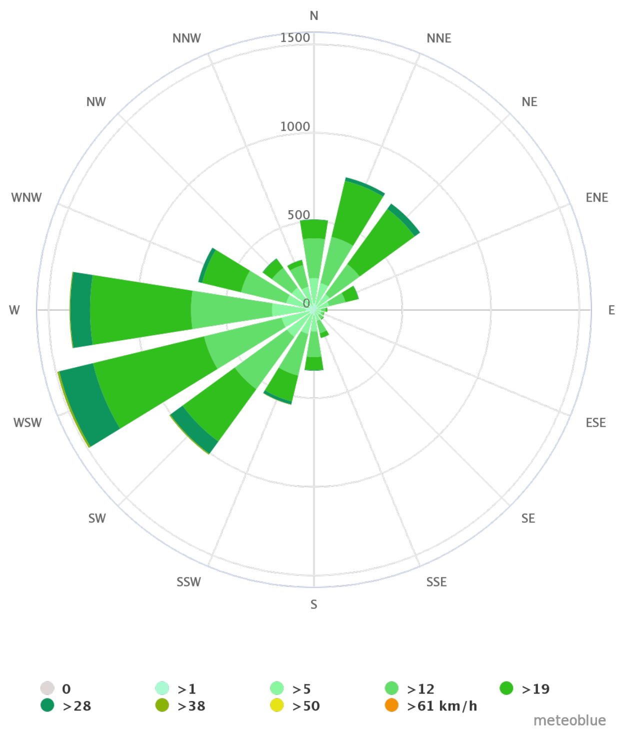


*Northern Atolls*

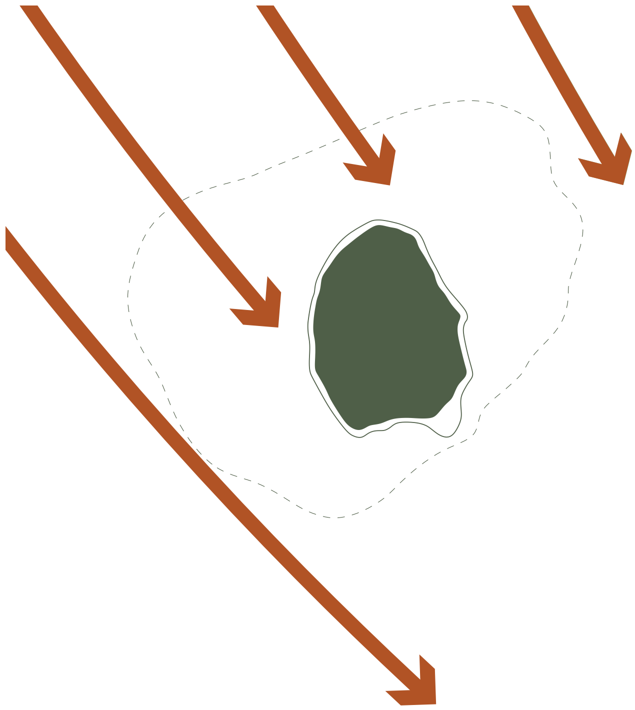


*Vangaaru Island*

# Wind directions | *wind impact on the design*




Average wind directions on the Maldives | Fig. 11

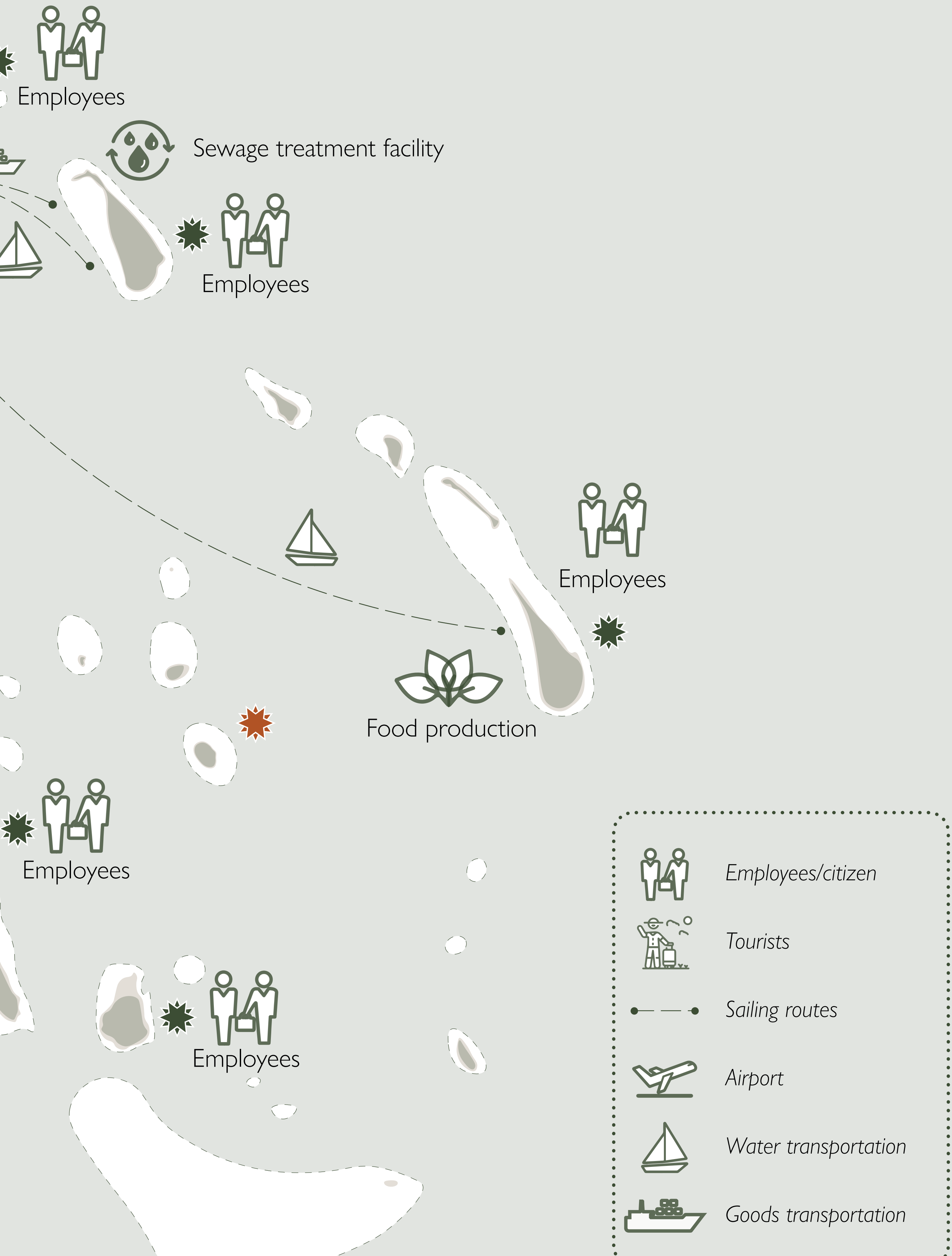


Average sea current around Vangaaru island | Fig. 12

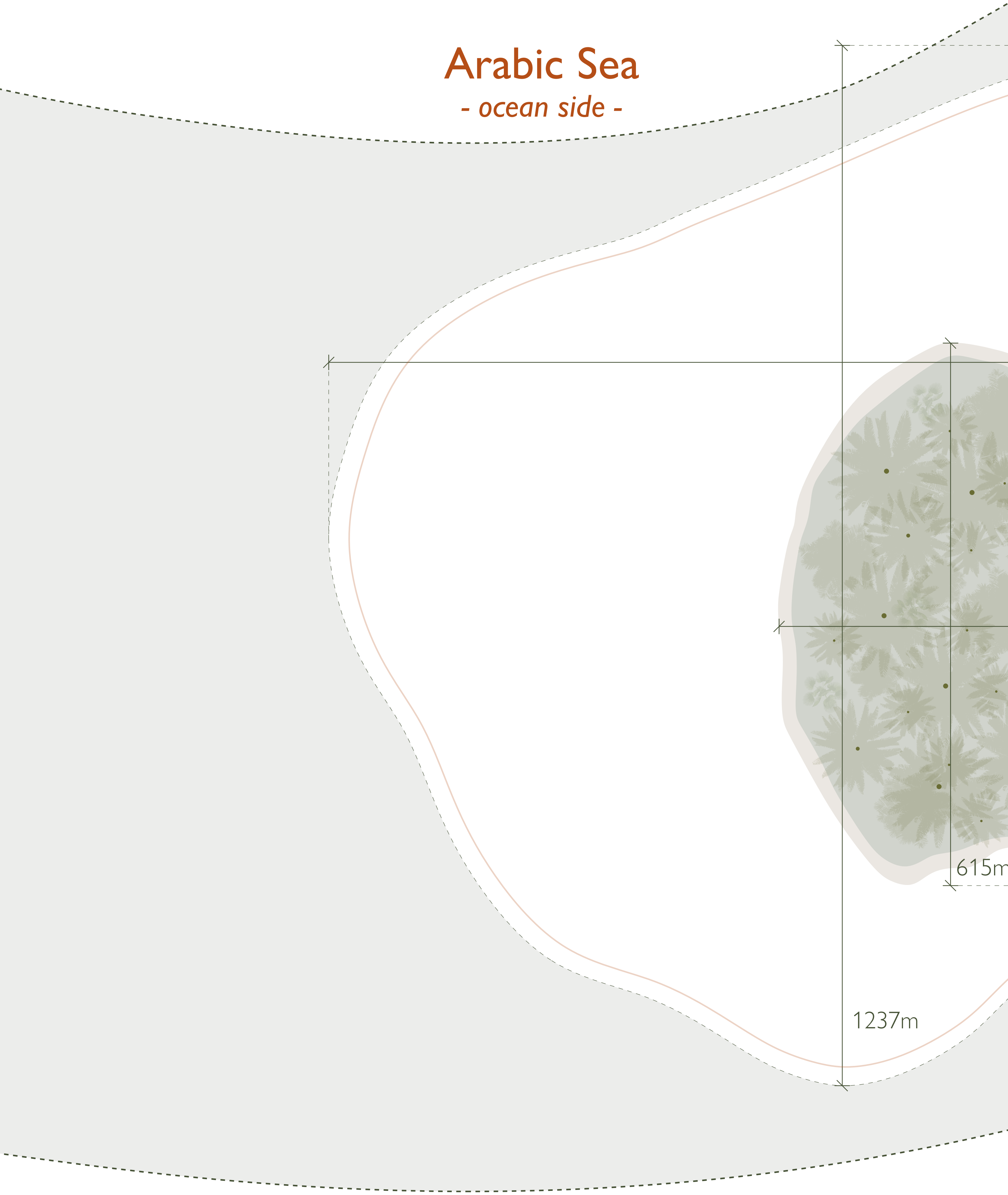
This wind rose diagram indicates the wind direction on the Maldives with the average amount of hours per year. The dominating winds blow from the west. The strong prevailing winds depend on the monsoon. The wind blows from south-west to north-west during the south-west monsoon and the prevailing winds from the north-east to the east blow during the north-east monsoon. However, the wind direction tends to change up to 90° during the day.
All weather and climate data are retrieved from Meteoblue webpage.
Average monthly wind rose diagrams can be found in appendix C.

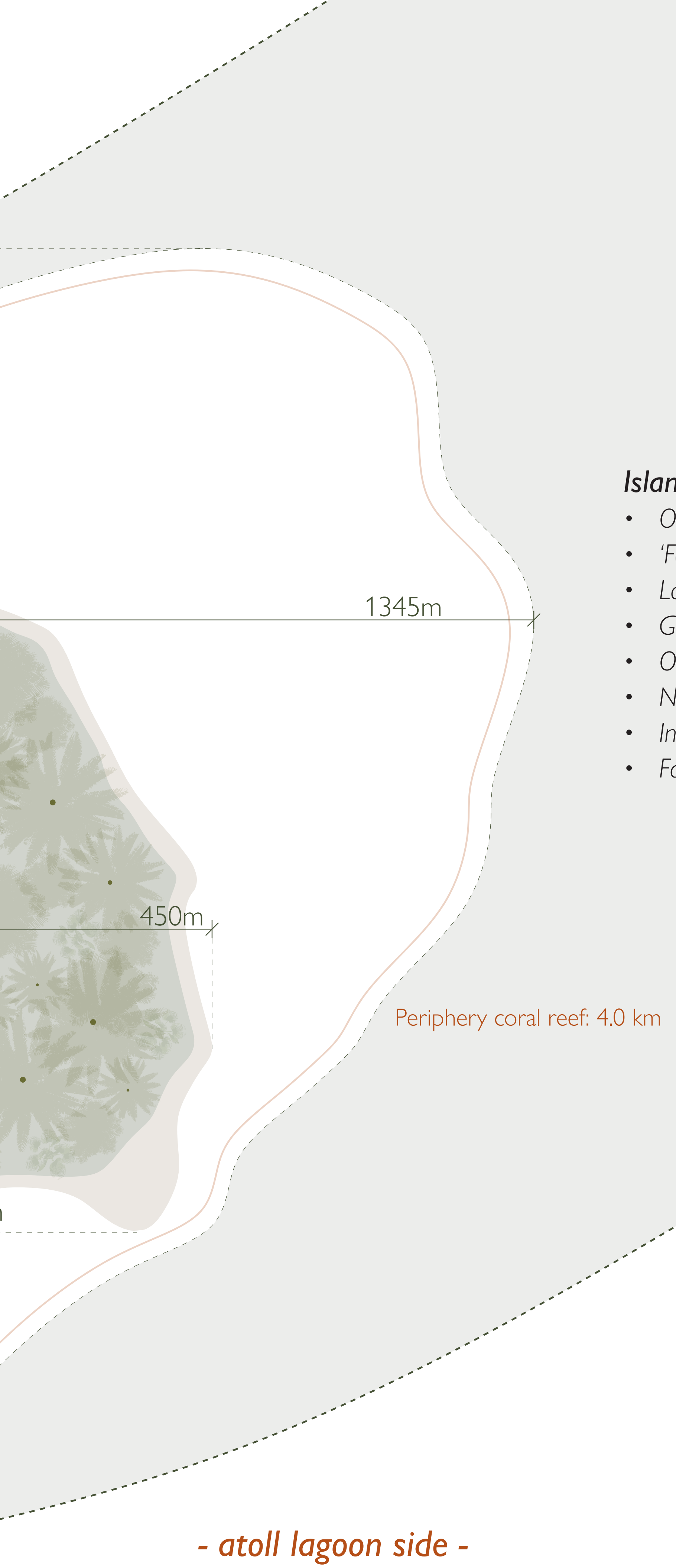
The docks around the island need to be positioned in such a way that boats can dock against the wind and currents as much as possible. Throughout the year the prevailing winds and currents tend to take different directions. With determining the most optimal positioning of the docks, the currents are the factor used as the main guideline as the wind direction can change during the day.

# Haa Alifu Atoll | *mobility and transportation map*


Employees
Sewage treatment facility
Employees
Employees
Food production
Employees
Employees
Employees/citizen
Tourists
Sailing routes
Airport
Water transportation
Goods transportation

# Vangaaru Island | *dimensions*





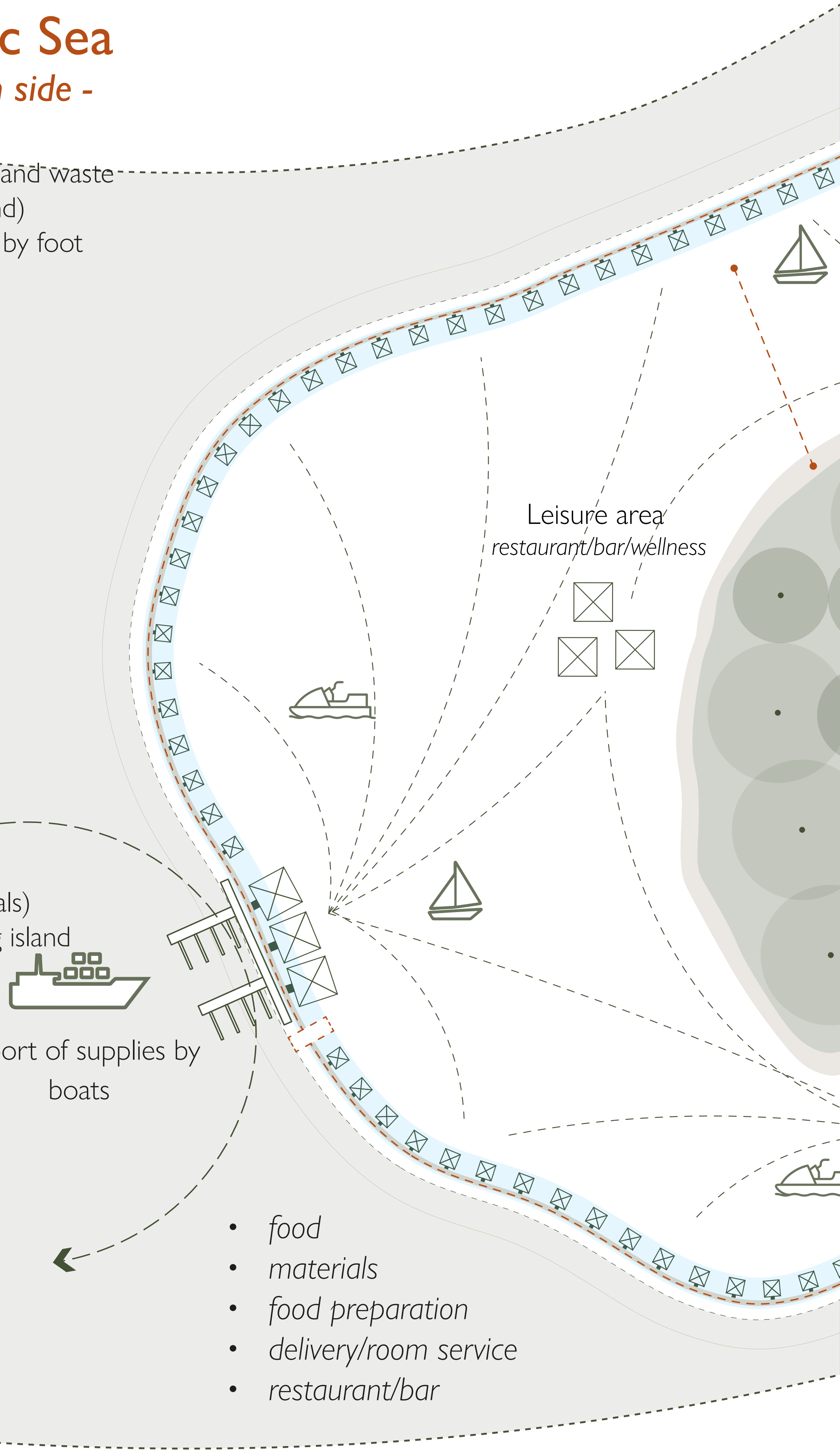

### *Island choice*

- *On the edge of the lagoon and atoll*
- *'Face first' to the open sea and currents*
- *Large waves from the open sea*
- *Google maps shows coastal erosion*
- *Only one other resort in the atoll*
- *No sustainability awareness in the atoll yet*
- *Inhabited islands nearby*
- *Facility islands*

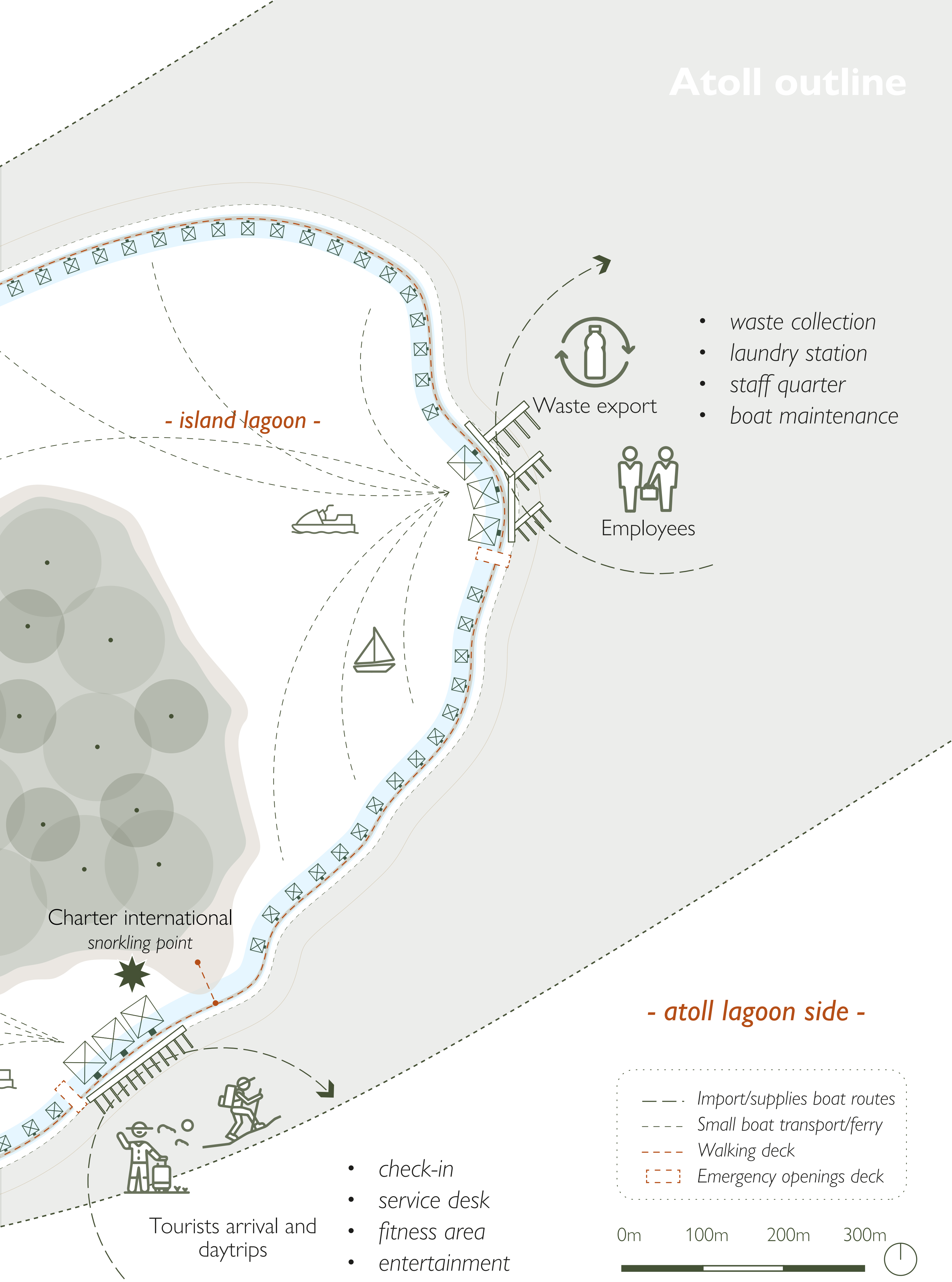
# Vangaaru Island | *mobility and logistics map*

## Arabic Sea
*- ocean side -*

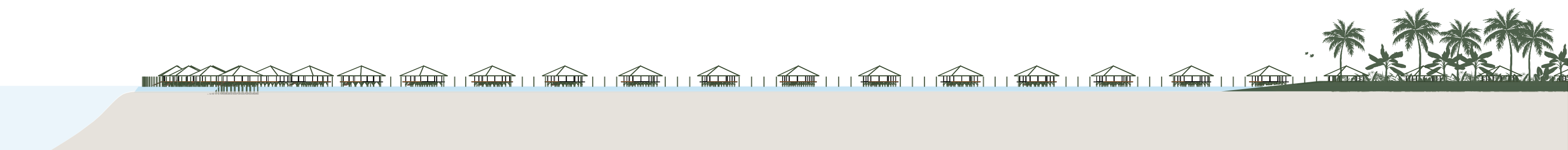
- Harbours
- tourists, import, employees and waste
- Main reception (not on island)
- Accessibility to island/house by foot
- Escape routes
- Boat docks by houses/path
- Energy hubs for the jet skis
-
- Food prep. station
- Food delivery service
- Daily activities
- Special island experience
- Fitness
- Water sports/diving
- Daytrips/ sunset trips
- Fieldtrips
- Educational trips
- Volunteering/helping trips
- Linen and cleaning storage
-
- Islands layout
- Food island
- Employees island (hiring locals)
- Waste collection + recycling island
- Example resort

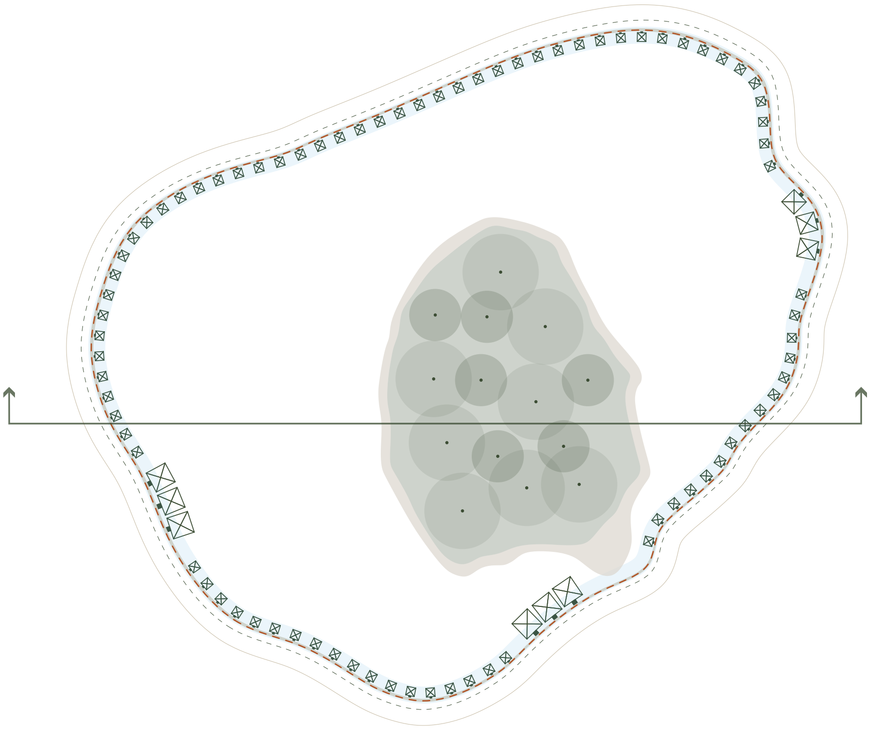


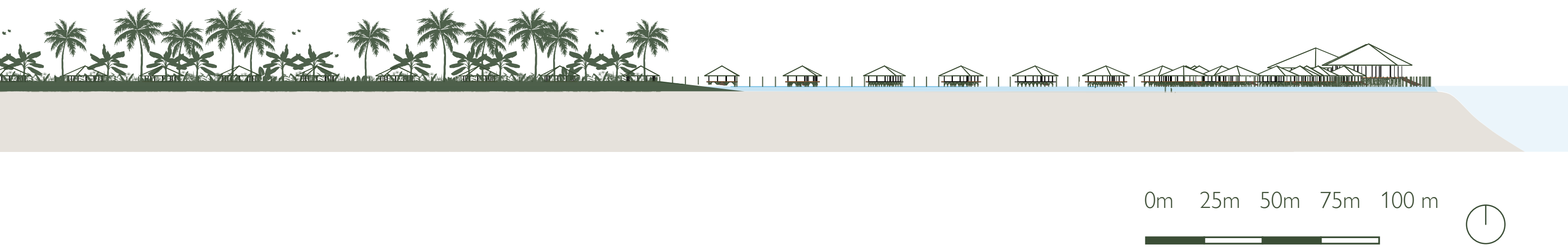
# Atoll outline



# Vangaaru Island | *section*







0m
25m
50m
75m
100 m

# Access to lagoon by boat | *suggestion of opening the deck*

# 6. | Goathi |

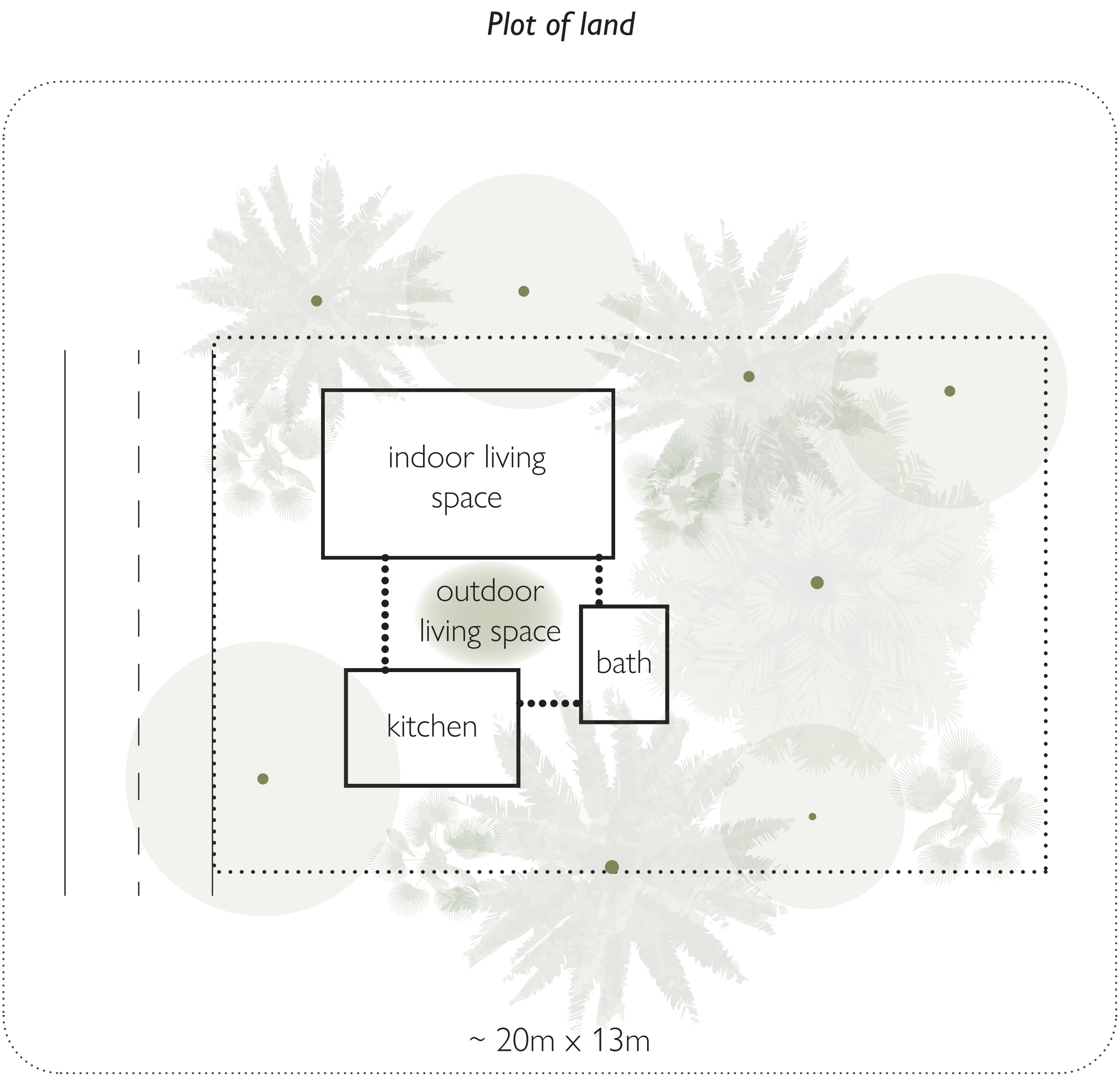
*Maldivian households*
*Maldivian house*
*Modules | function*
*Modules | build-up*
*Modules | wall panels*
*Modules | example*
*House compound | family*
*House compound | couple*
*Materials*
*Exploded view*
*Detailing*
*Timber load bearing structure*
*Climate concept | traditional*
*Climate concept | circularity*
*Climate concept | water*
*Climate concept | energy*

# Maldivian households | *families*

In the Maldivian Islamic society, the family serves as the fundamental unit. An average Maldivian households consist of 3-7 members, with an average of 5.2 on the atolls and 5.1 in the capital Malé, forming a nuclear family. (Hays, 2022) However, due to the high rates in divorce and remarriage in the country, the households do not typically accommodate extended family members. The man is generally the head of the family. The elderly live occasionally with family, but mostly alone. By law, children equally share the care taking of their parents. (Hays, 2022)

Fictional rendering of traditional Maldivian house | Fig. 13

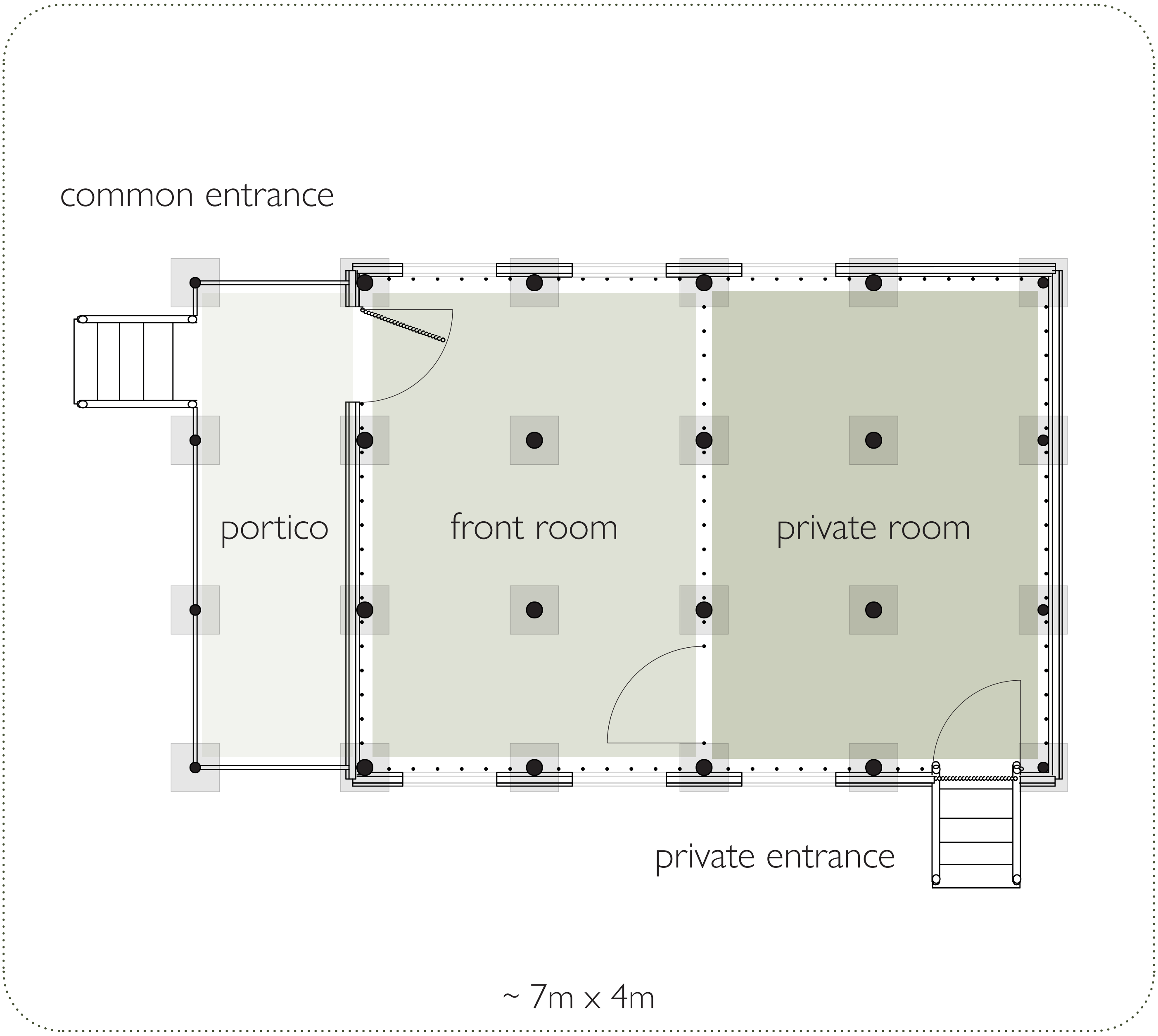
# Maldivian house | *room arrangement/positioning*




An intriguing aspect of traditional Maldivian housing architecture is the separation of the kitchen, known as the "badhige," from the main living area. Additionally, the bathrooms are built separately from the main living space and are typically spacious and open-air. The building method used for lighting and ventilation are also fascinating features that showcase the unique architectural style. (Ahmed, z.d.)

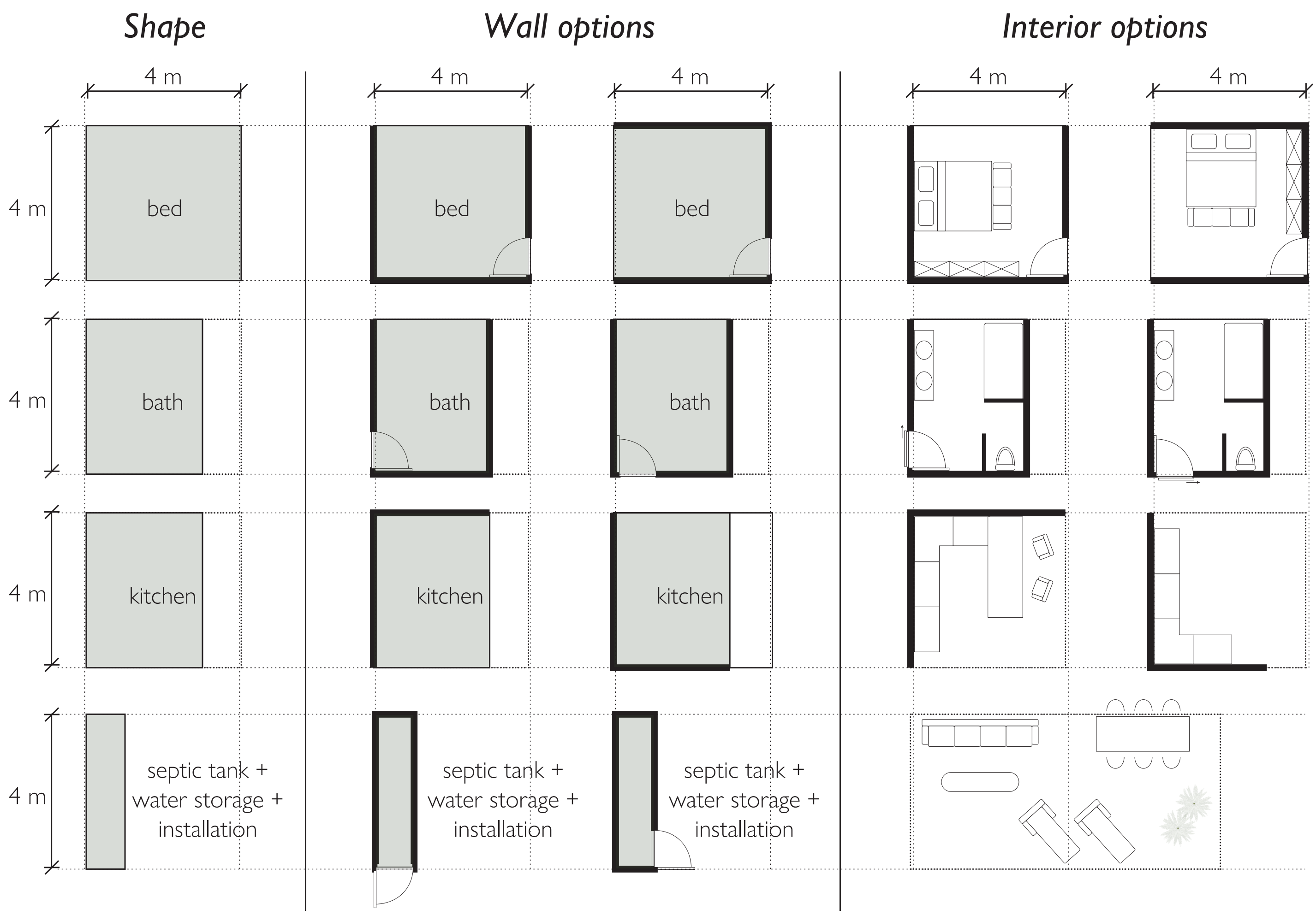
# Maldivian house | *indoor living space*

*Indoor living space*




Another noteworthy aspect of traditional Maldivian housing is the indoor living space, which is primarily used for sleeping, conducting religious rituals or hosting guests. The front room was typically used by men and male guests, while the private room was allocated for women and children. The architecture is influenced by religious beliefs, daily routines of the people, the climate, and the fact that Maldivians often spend more time outdoors. (Ahmed, z.d.)

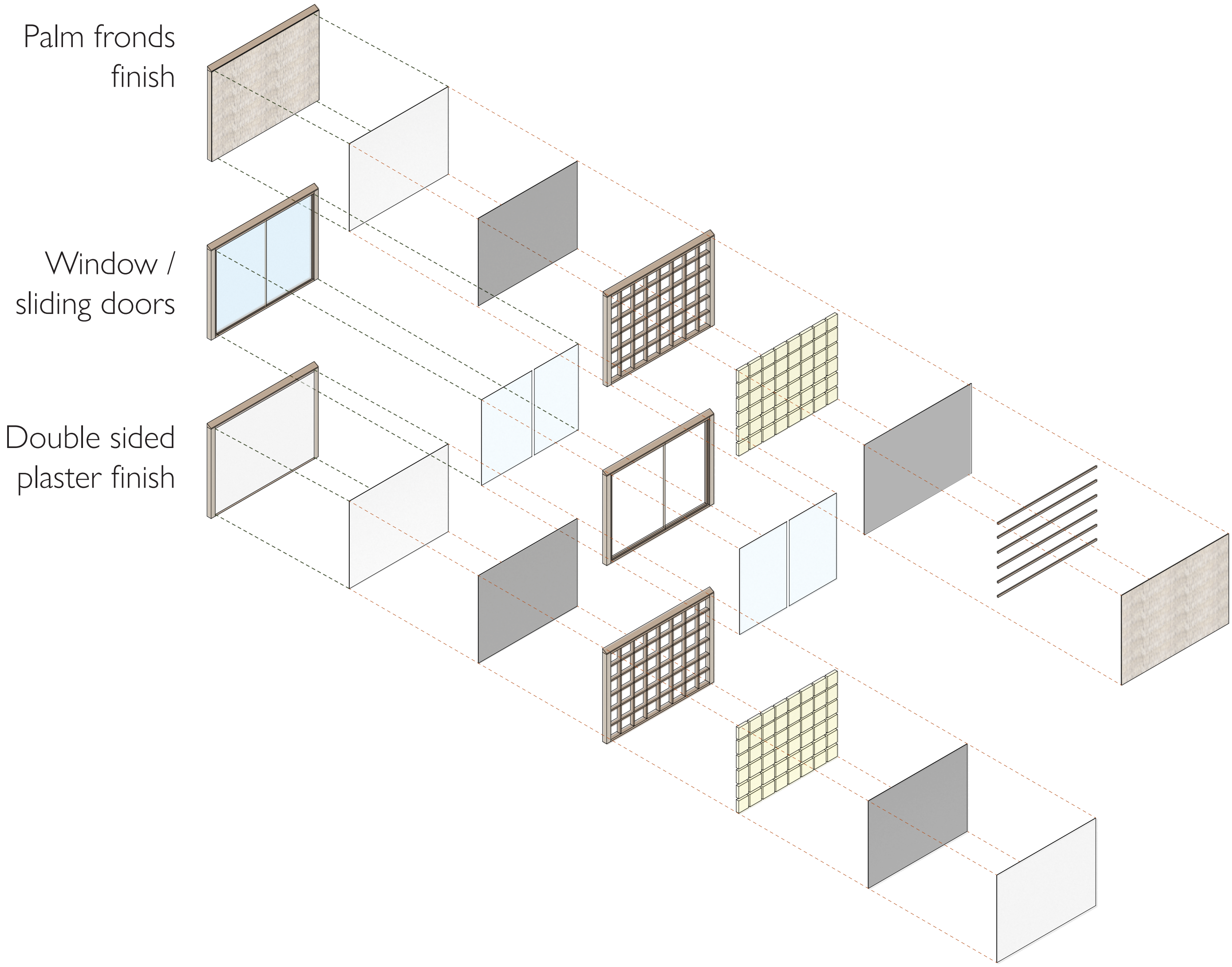
# Modules | *function specific*

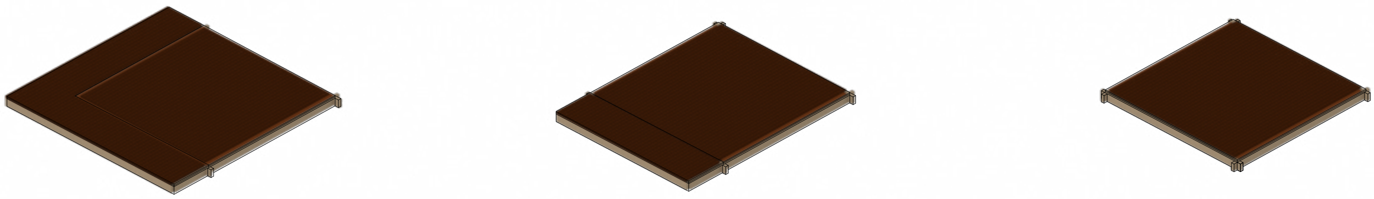


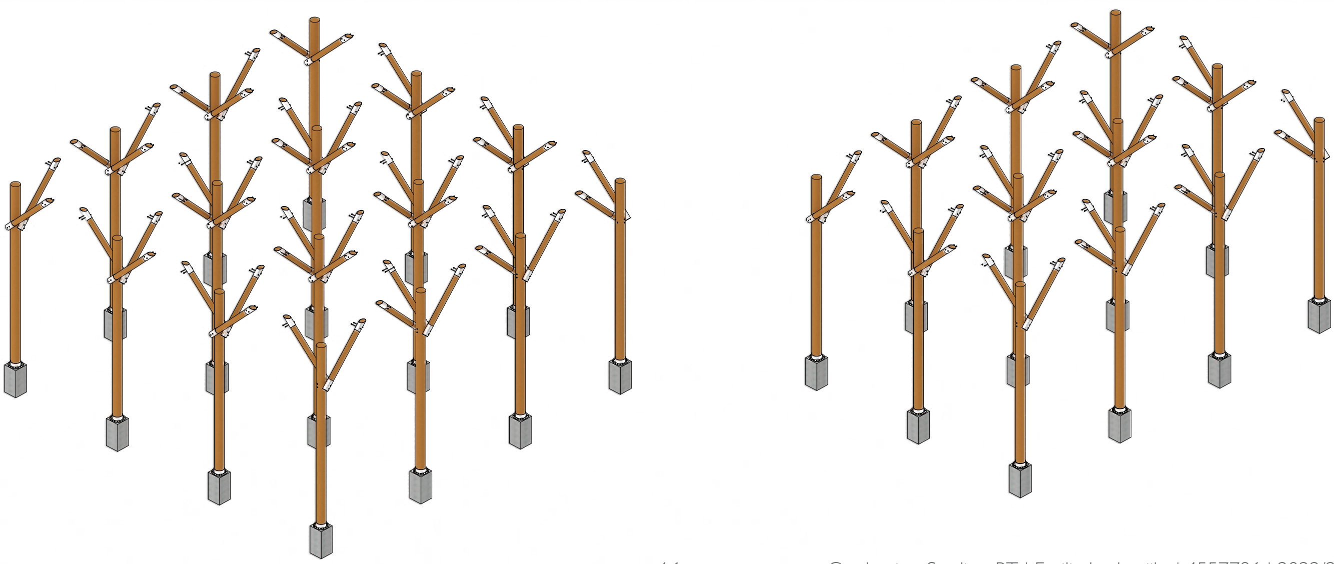

The traditional Maldivian way of building on a plot of land is splitting the functions in different buildings, by which an outdoor living space is created. Due to the hot climate people tend to live more outdoors than indoors.
The design of the floorplans of the goathi's is based on a fixed grid of 4m by 4m. Modules can be placed on this grid. Each modules has a specific function, bedroom, bathroom, installation room and a kitchen.

The walls of de modules vary from plastered wall, floor-to-floor windows and palm fronds finish and can be applied as preferred.
The modules can be combined in each desired way. This system of positioning the modules and choosing wall types is creating flexibility in the design.
The design of the goathi is open for interpretation and other design options.

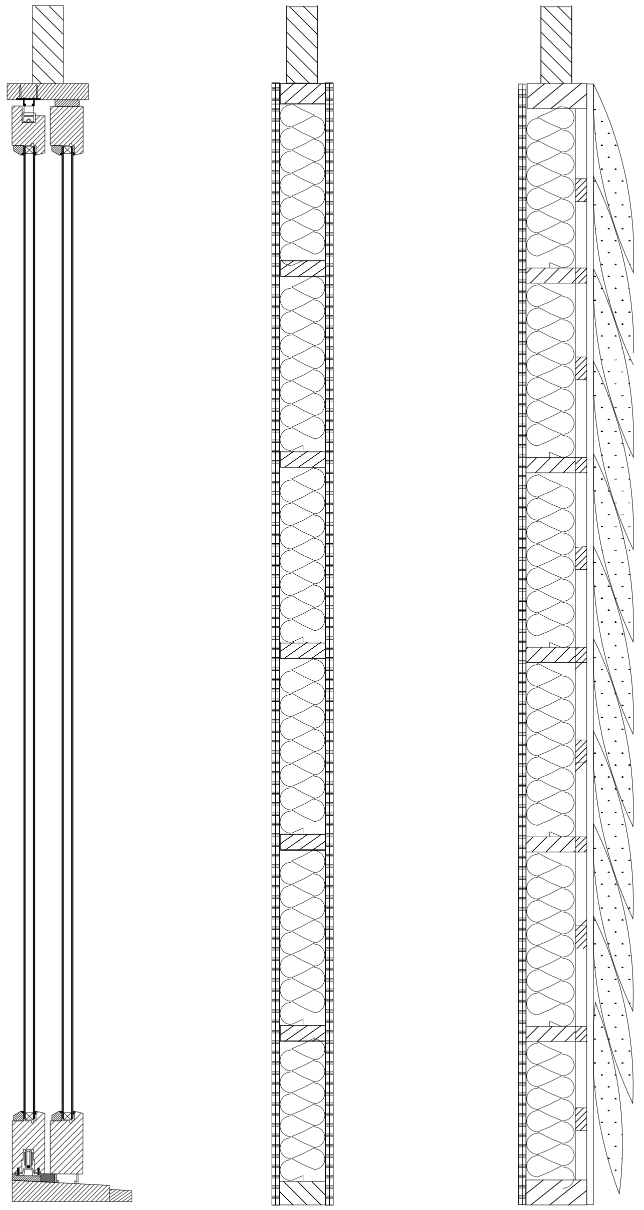
# Modules | *wall panels | floors | column grid*



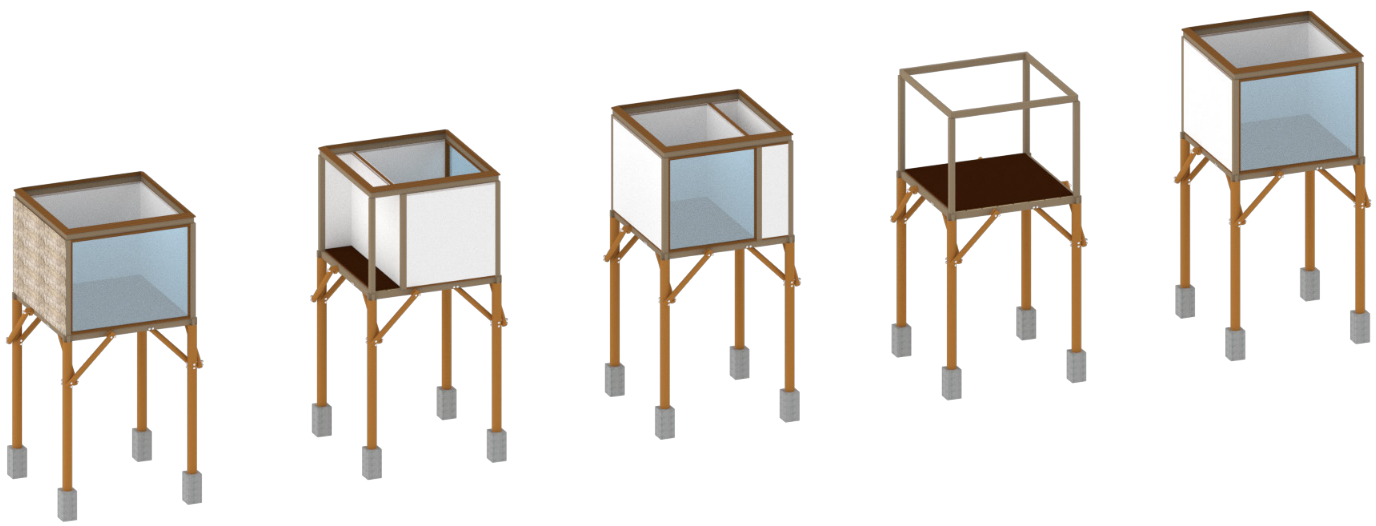





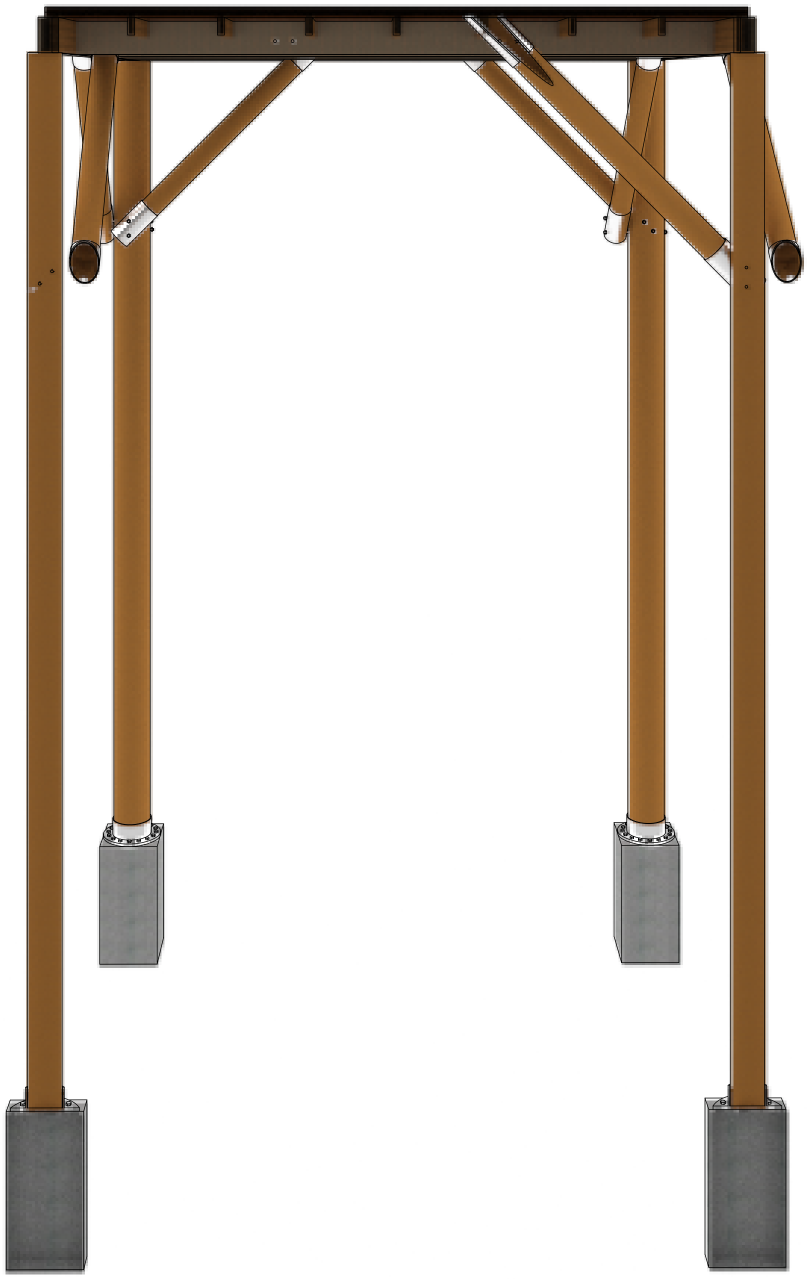
# Modules | *wall panels detailed*



The wall panels have different finishes and functions. The large glass sliding doors are only double glazed as there is no mechanical airconditioning. The timber window frames are a more sustainable option. The timber is a poor heat-transferring material, which is beneficial in the warm tropics. The wooden frames complement the character of the rest of the timber construction of the goathi. These large openings allow the facade to open up and create a seamless outdoor and indoor transition.
The plasterboard finish creates simple indoor room divisions and includes insulation for soundproofing the indoor spaces.
The palm frond facade finish fulfils the desire to create buildings with elements of vernacular architecture. Additionally, the facade finish creates a traditional appearance that blends with the landscape of the Maldivian islands.

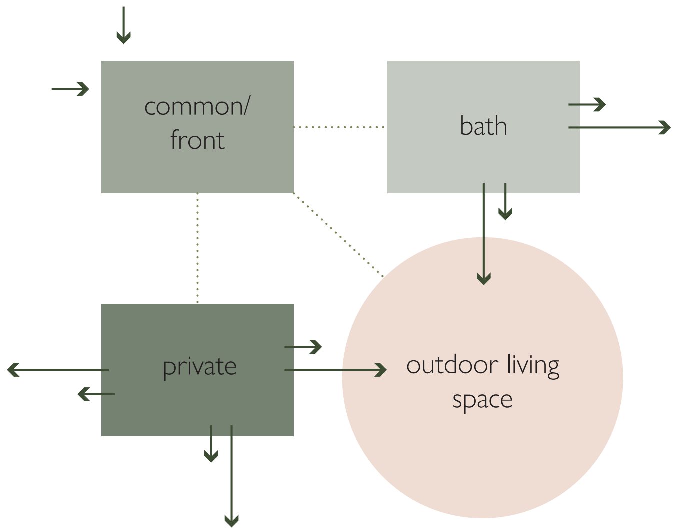


# Modules | *detailed example*

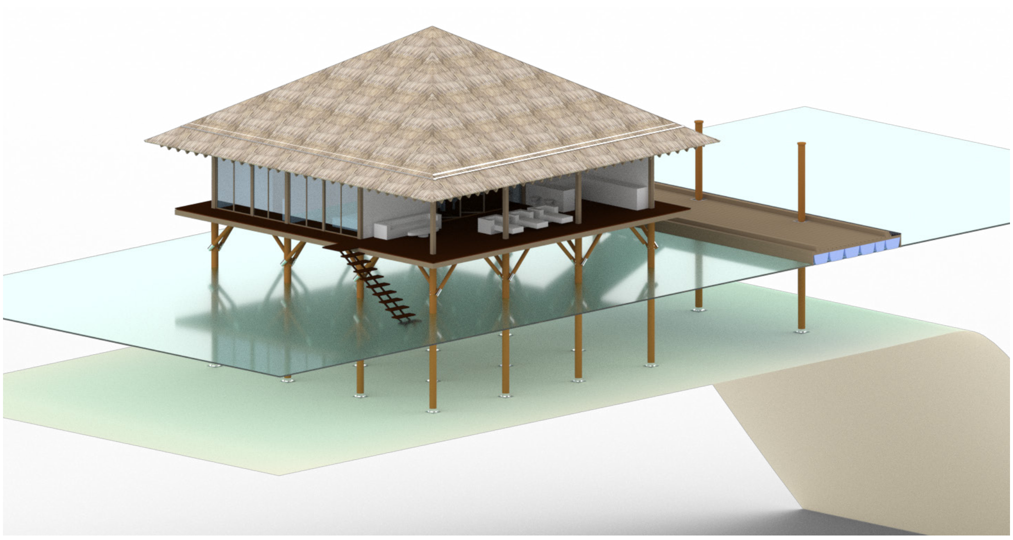


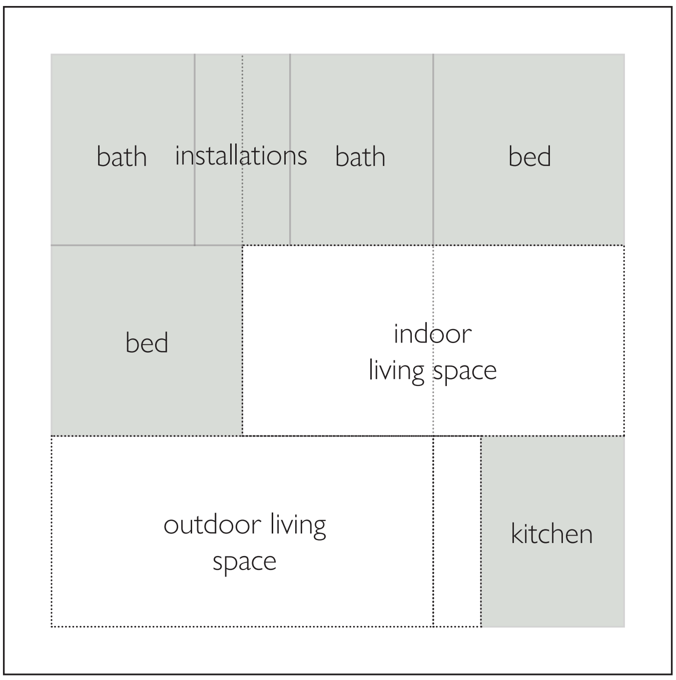
# Goathi | *house compound design family and couple*

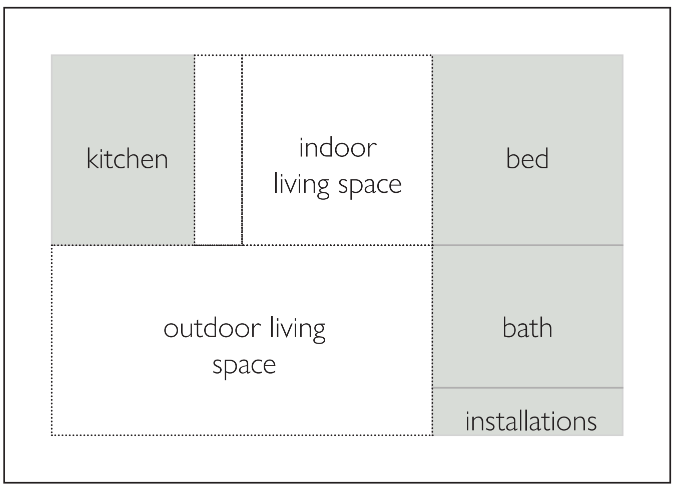
Similar to a traditional goathi, the rooms are separated per function and situated around the living space. In this particular goathi design the indoor living space can be opened up by large glass sliding doors allowing the indoor space to become an outdoor living space. The heart of the goathi is the outdoor living space functioning as a common space for family activities and socializing.
The outdoor living space is oriented towards the island. This way the beauty and nature of the island can be admired. Tourists will be foreseeing literally the precious environment that needs to be preserved.



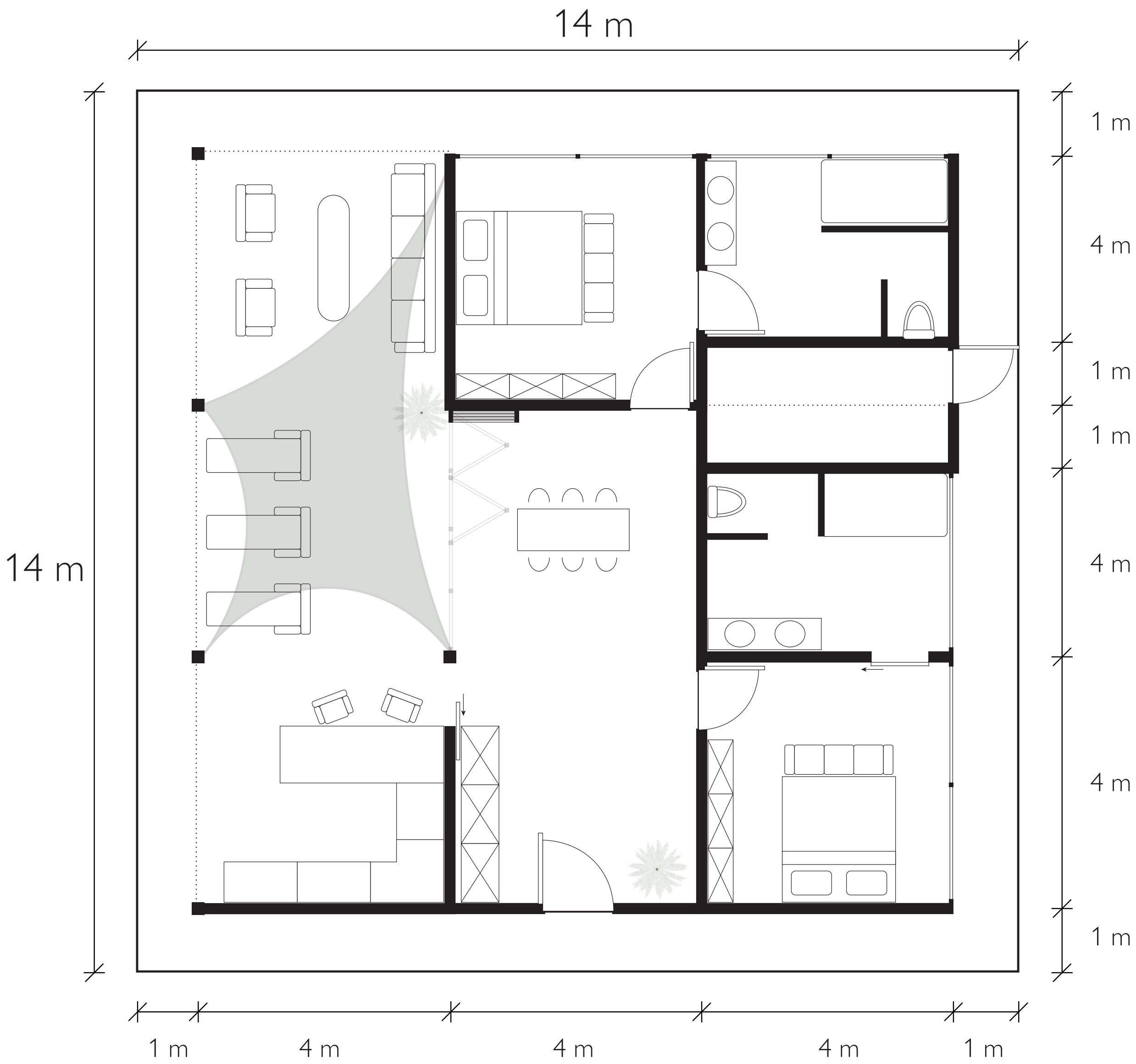

Concept diagram of traditional function arrangement | Fig. 14

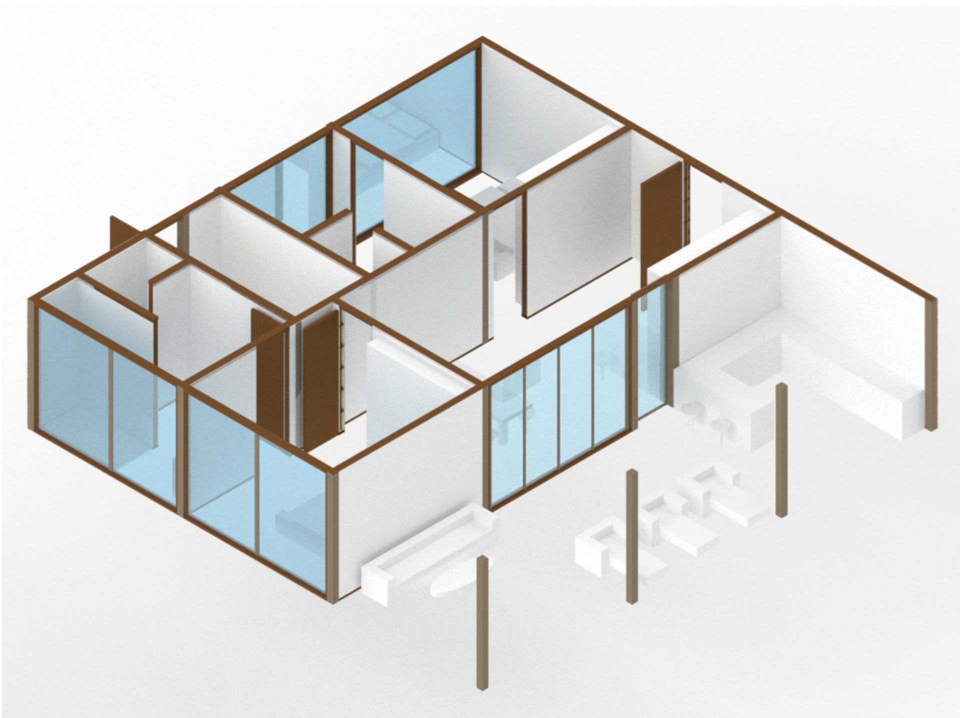


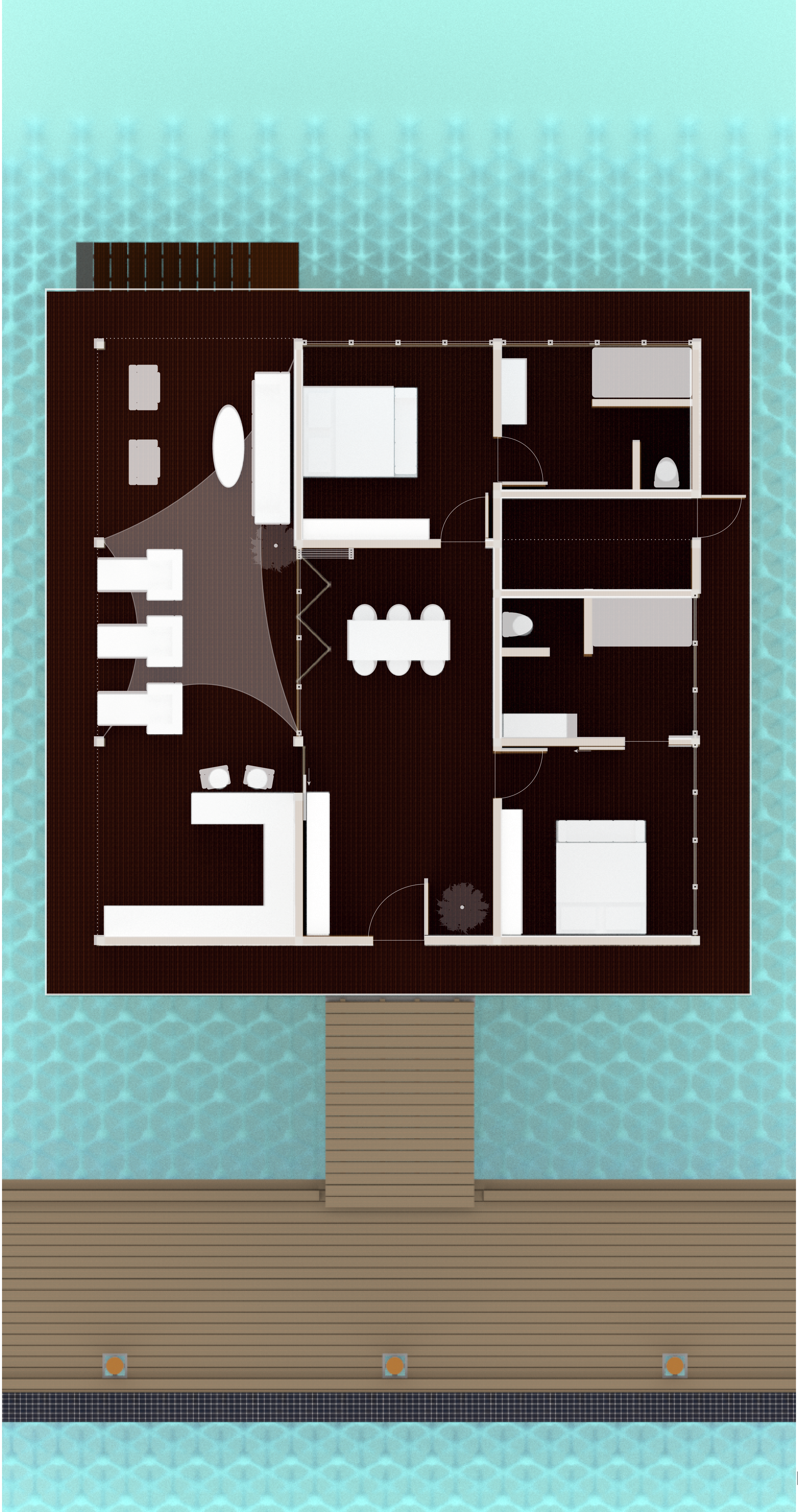


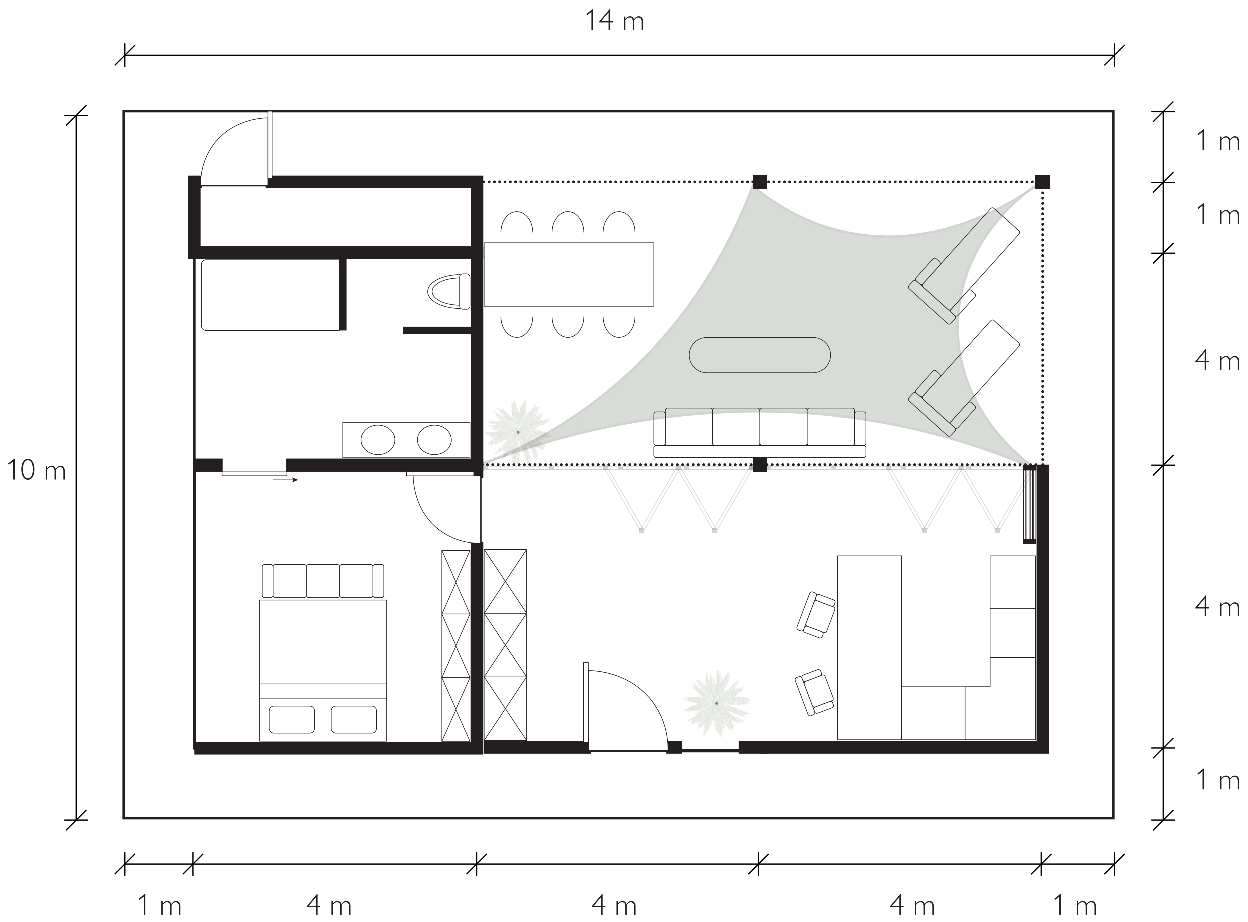
# Goathi | *house compound design | family*

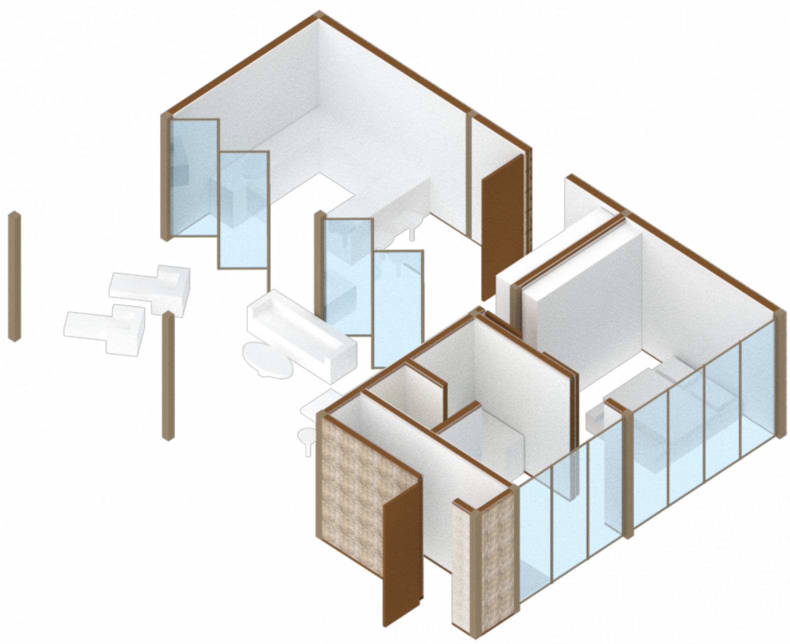


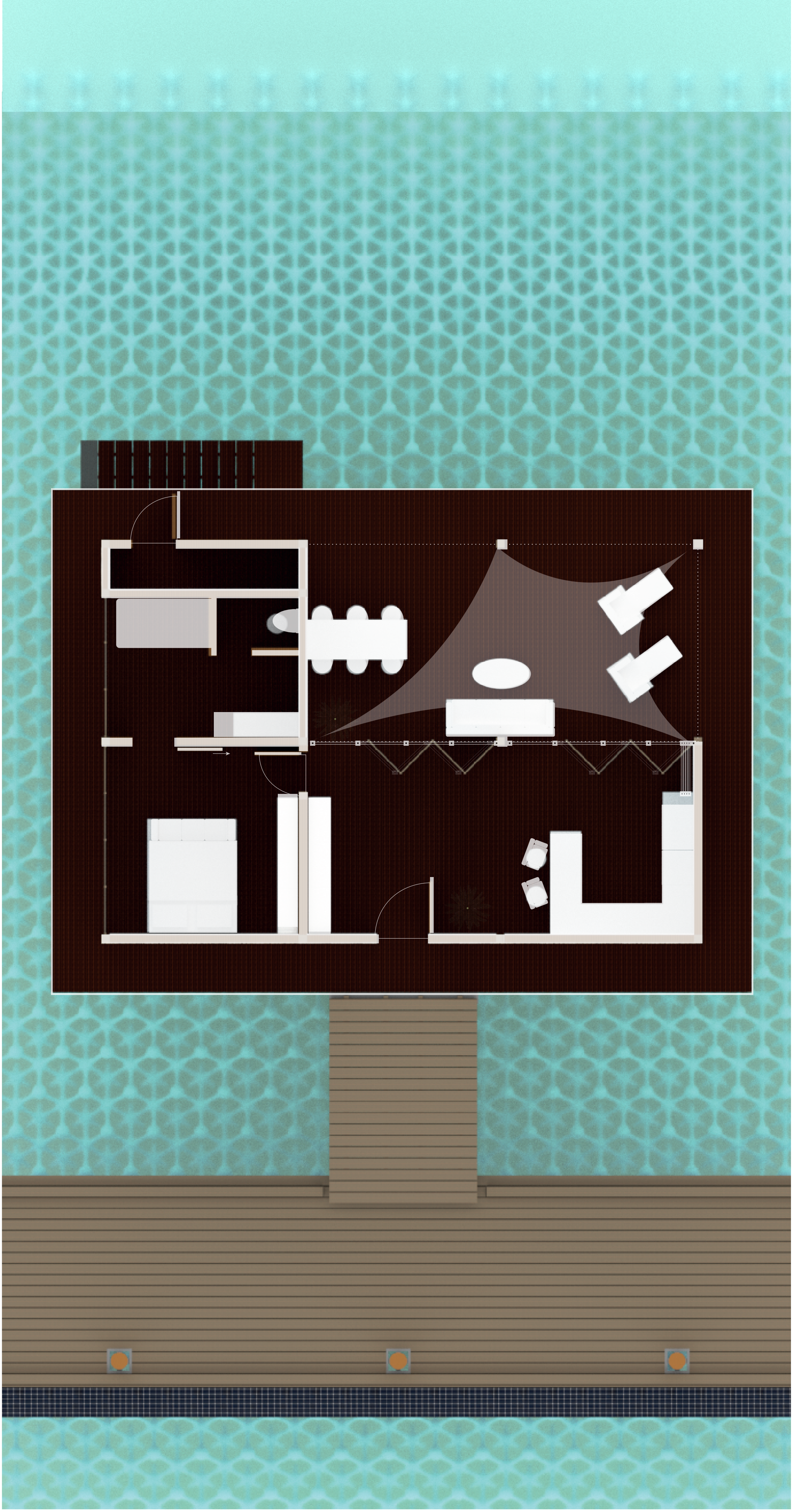





# Goathi | *house compound design | couple*





2022/2023

# Goathi | *waterproof materials*

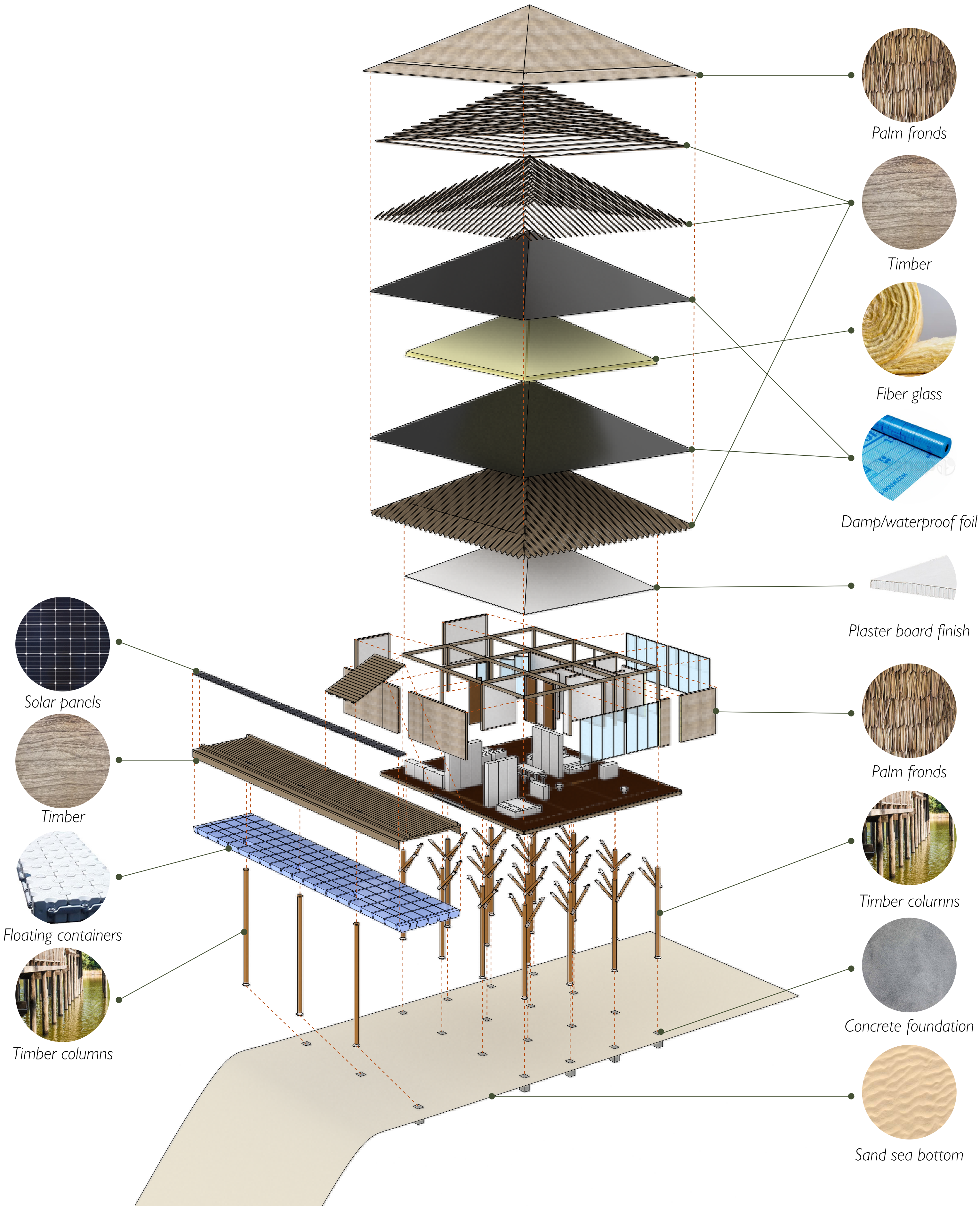
### *Insulation*

In tropics insulation is only needed to keep the heat out.
The roof is all day exposed to direct sunlight and heat. To stop the heat transfer through the roof into the goathi a large R-value of the roof is crucial. The optimal R-value of the roof in tropical climates is between R-50 and R-60. During the hottest time of the day there will be no direct sunlight on the facades because of the large overhanging roof. However, the walls are insulated with a R-value of R10 for soundproofing.
The floor is naturally ventilated as it is elevated above the water. The ventilation offers cooling and not insulation is further required in the floor. Regarding the concept of outdoor living the goathi is opened up throughout the day. This stimulates natural and passive ventilation. Airconditioning units are not part of the traditional lifestyle and design.
The best type of insulation in a tropical climate is fiberglass. Next to the fact that it is fire-retardant, it is also water-resistant. It is not moisture absorbing and helps to prevent the accumulation of water in the roof and walls. The presence of moisture can lead to the growth of mould, which can cause health risks. (Sheiner, 2021)

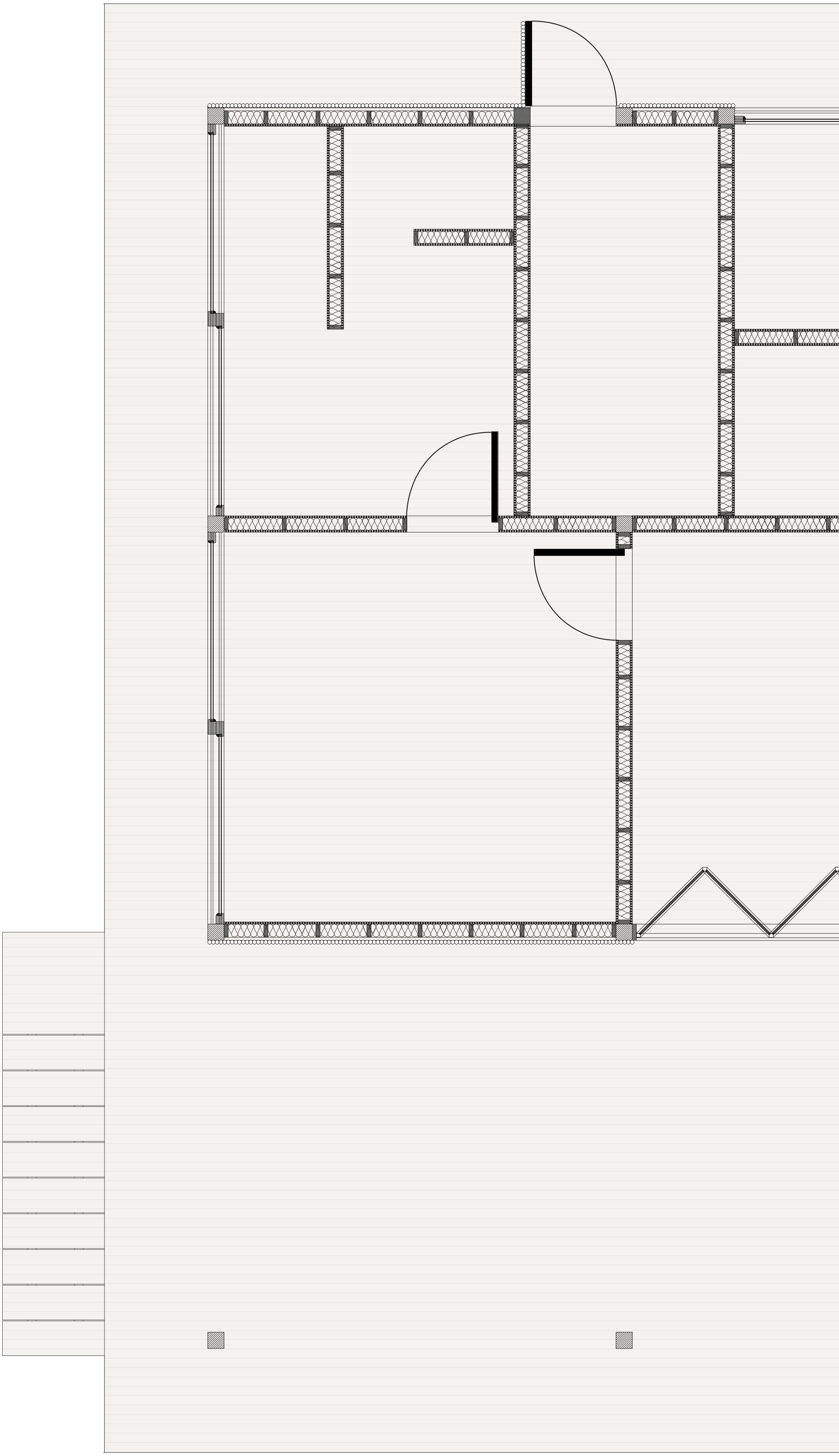
### *Timber protection*

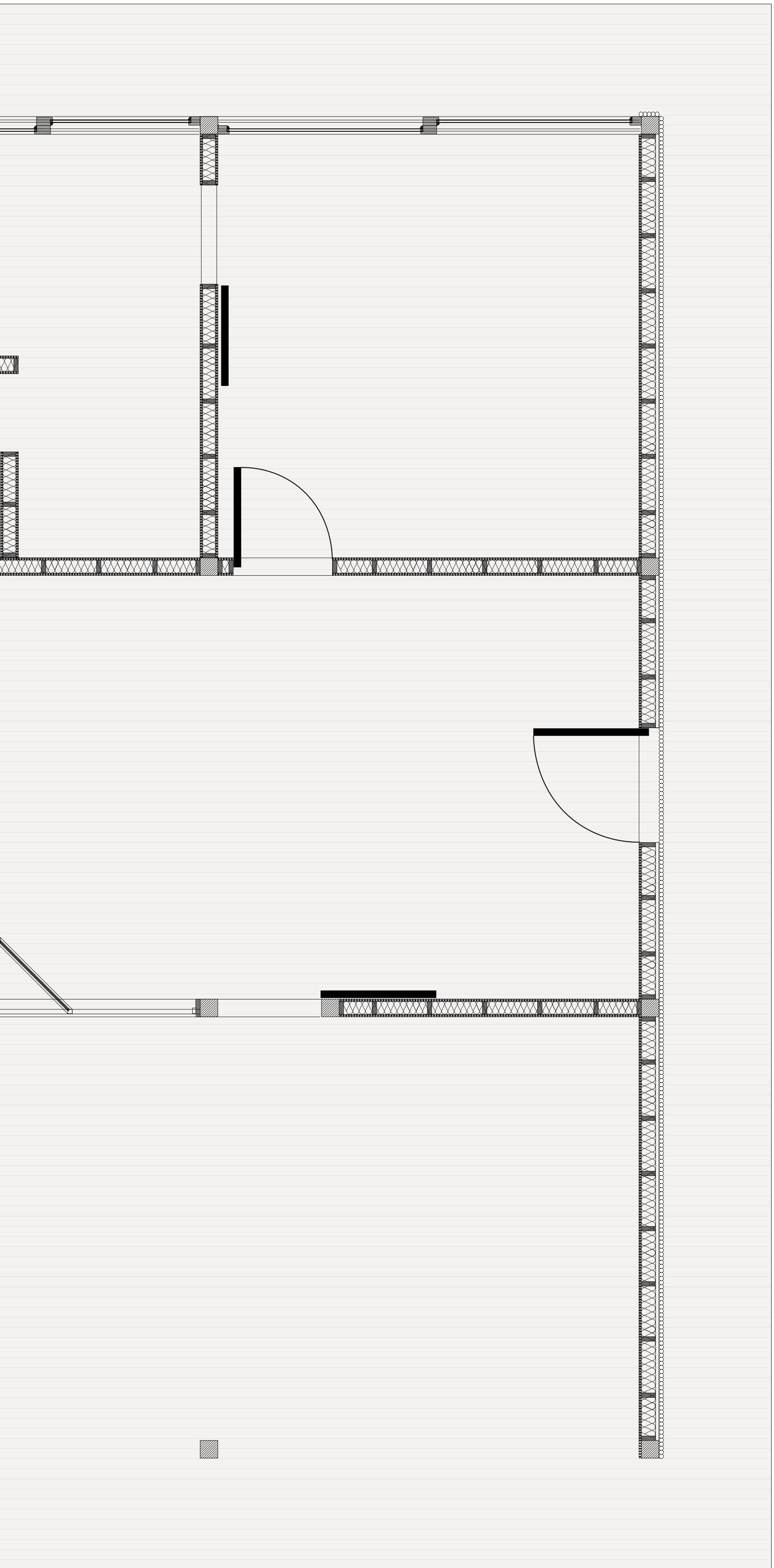
Constant and direct contact with saltwater can be damaging to wood, especially in the case of boat docks and decks that extend over the water. The saltwater penetrates the wood, leading to the formation of salt crystals in the timber cells. This process is causing a separation of the timber fibres, resulting in damage of the outer layers. However, the inner layers of the timber can retain theirs strength, allowing these timber structures to remain structurally sound for more than 30 years. (DevTeam, 2021)
Timber becomes vulnerable to fungi when it is exposed to damp conditions or in wet and dry conditions over a longer period of time. Fortunately, fungi are unable to grow in salty environments. (DevTeam, 2021)
To protect timber against UV rays and water damage timber coatings should be applied. This coating prevents the timber from cracking and splitting under conditions as direct sunlight and the corrosive effects of saltwater. For less maintenance the selection of a composite timber can be made. The materials is able to withstand the harshest elements without losing its natural look. It offers UV resistance, no risk of expansion, contraction, nor rotting. (DevTeam, 2021)

# Goathi exploded view | *materials*

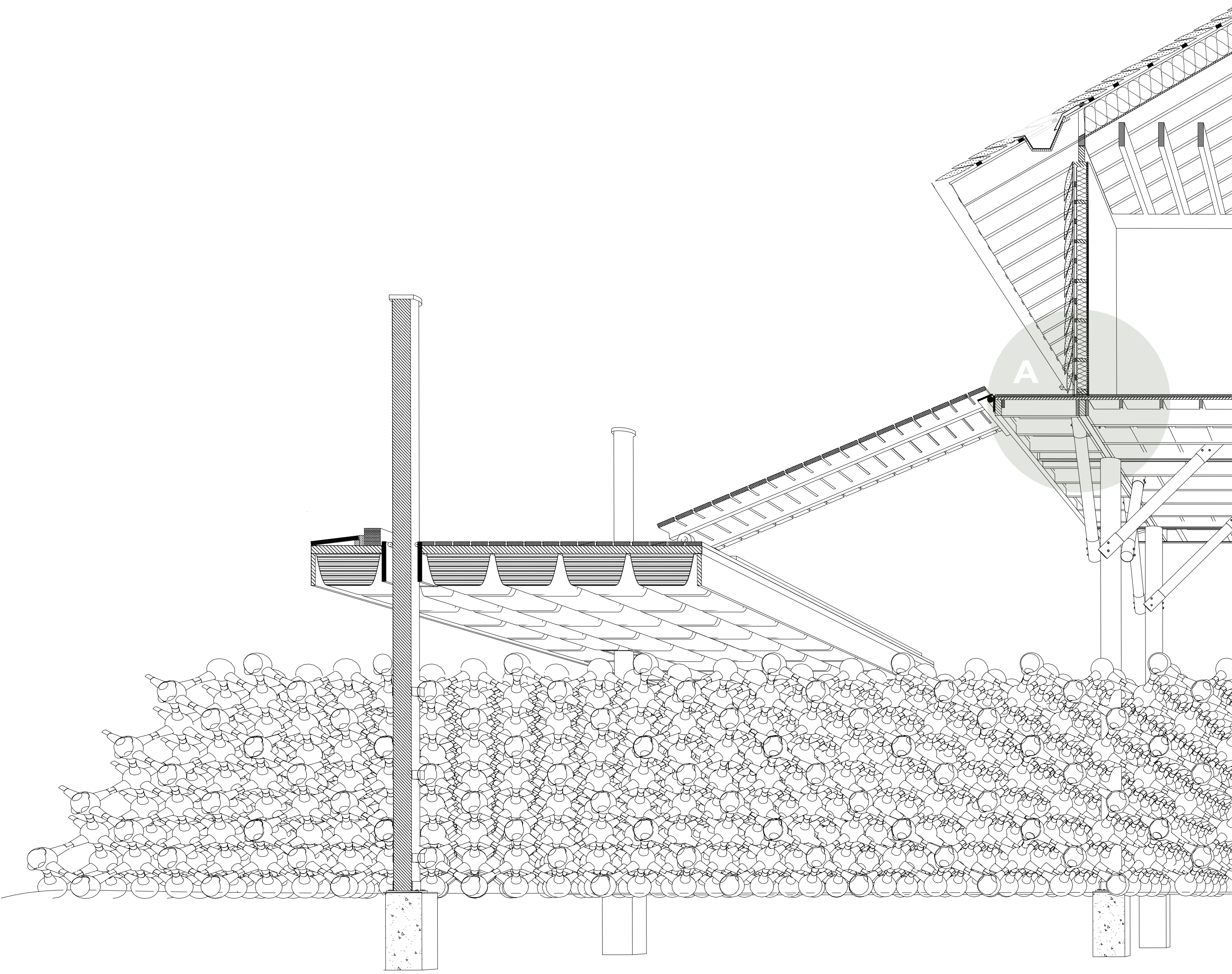


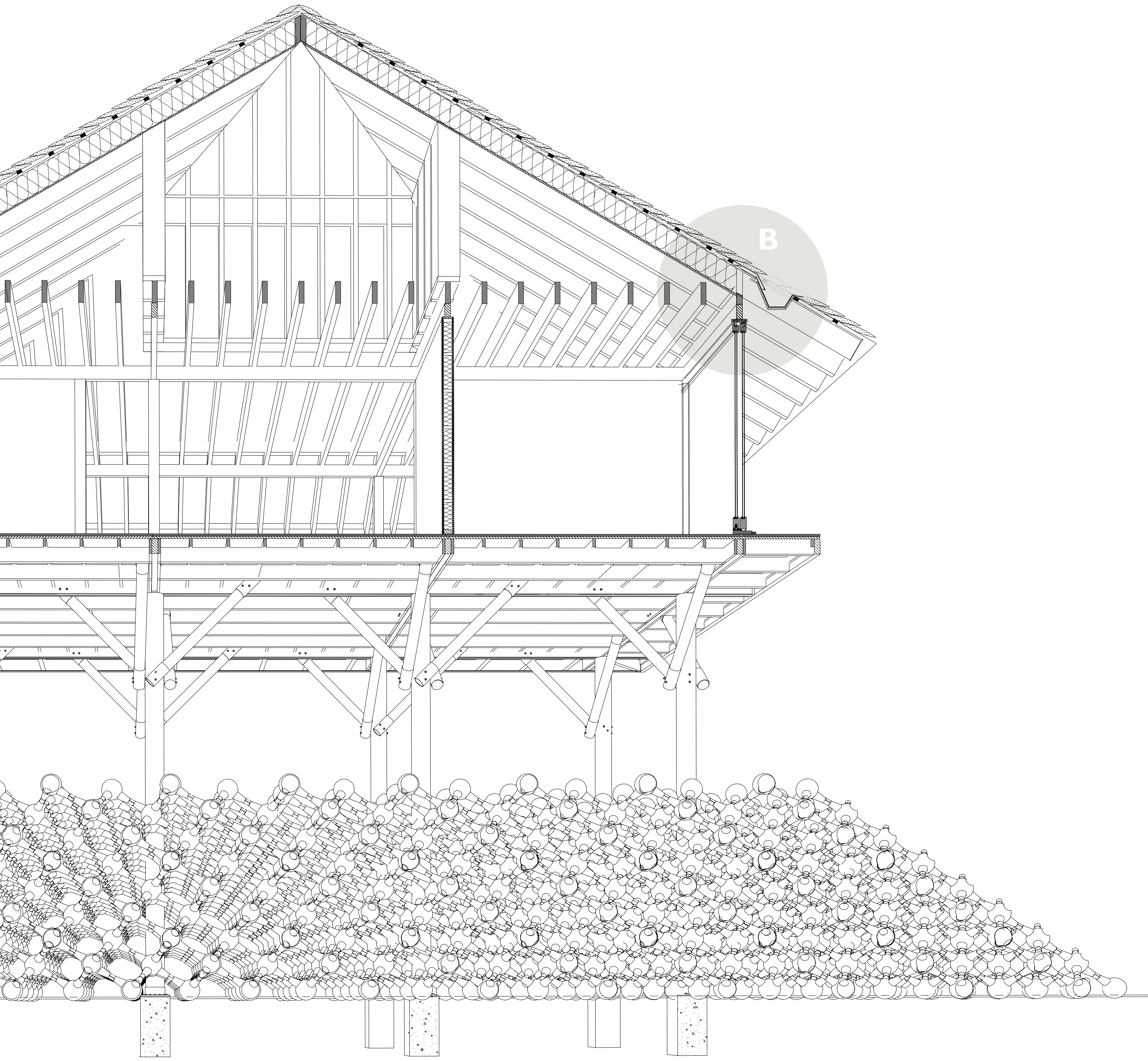
# Detailing | *1:20 scaled floorplan horizontal*



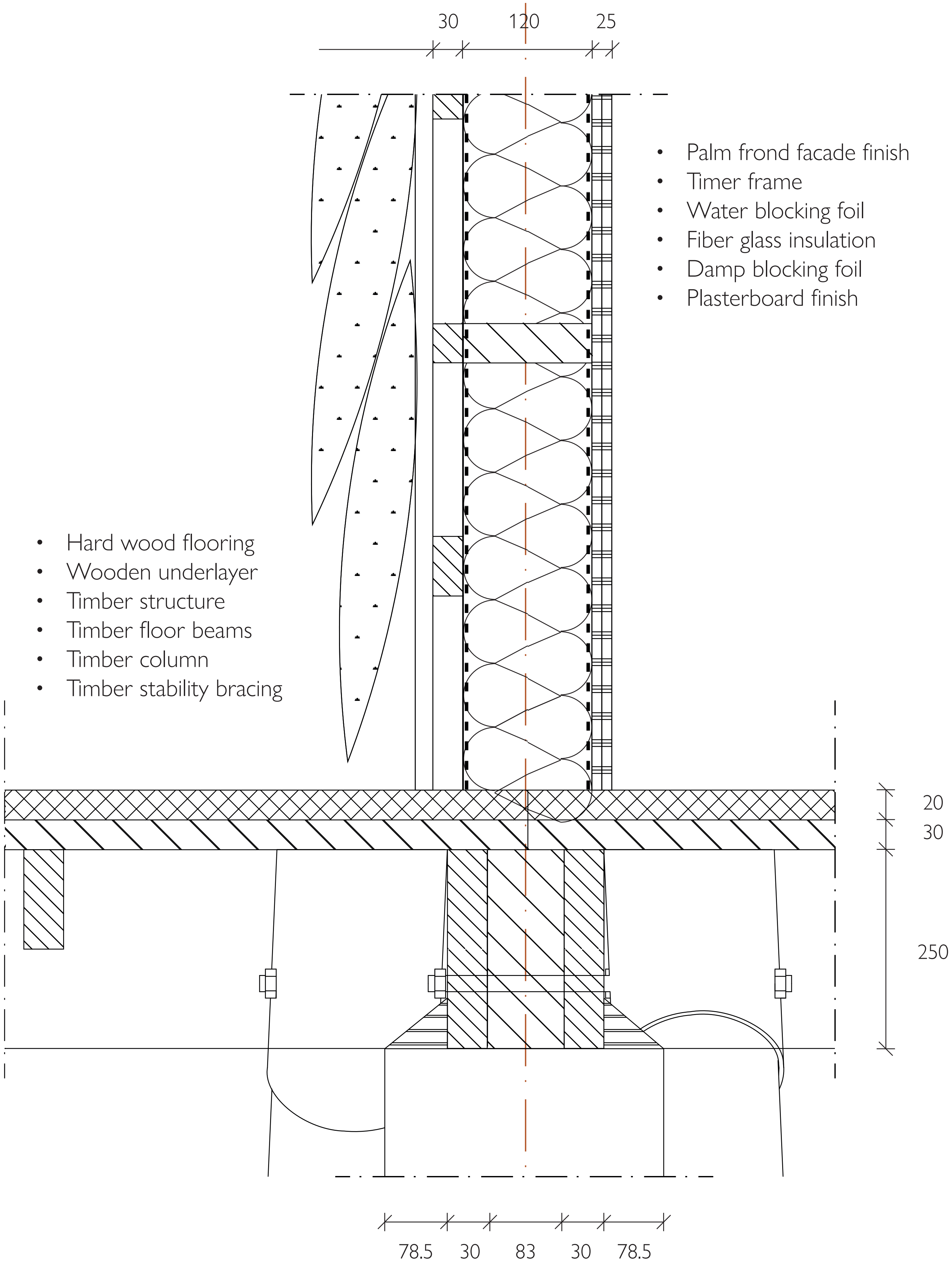


# Detailing | *1:20 scaled section*




B

# Detailing 1:5 | A | *exterior wall to floor and column connection*

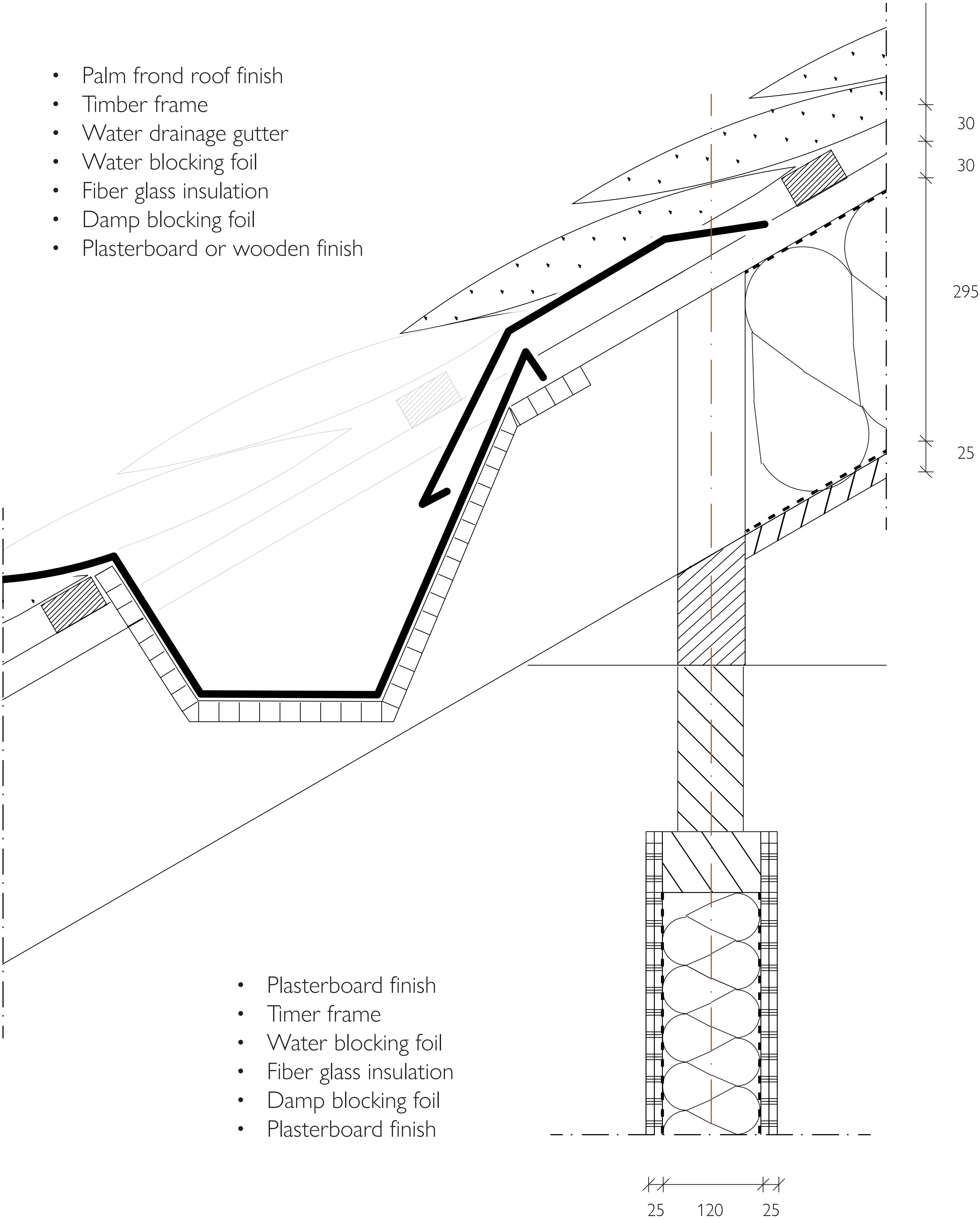



- Palm frond facade finish
- Timer frame
- Water blocking foil
- Fiber glass insulation
- Damp blocking foil
- Plasterboard finish

- Hard wood flooring
- Wooden underlayer
- Timber structure
- Timber floor beams
- Timber column
- Timber stability bracing

# Detailing 1:5 | B | *integrated water drainage*

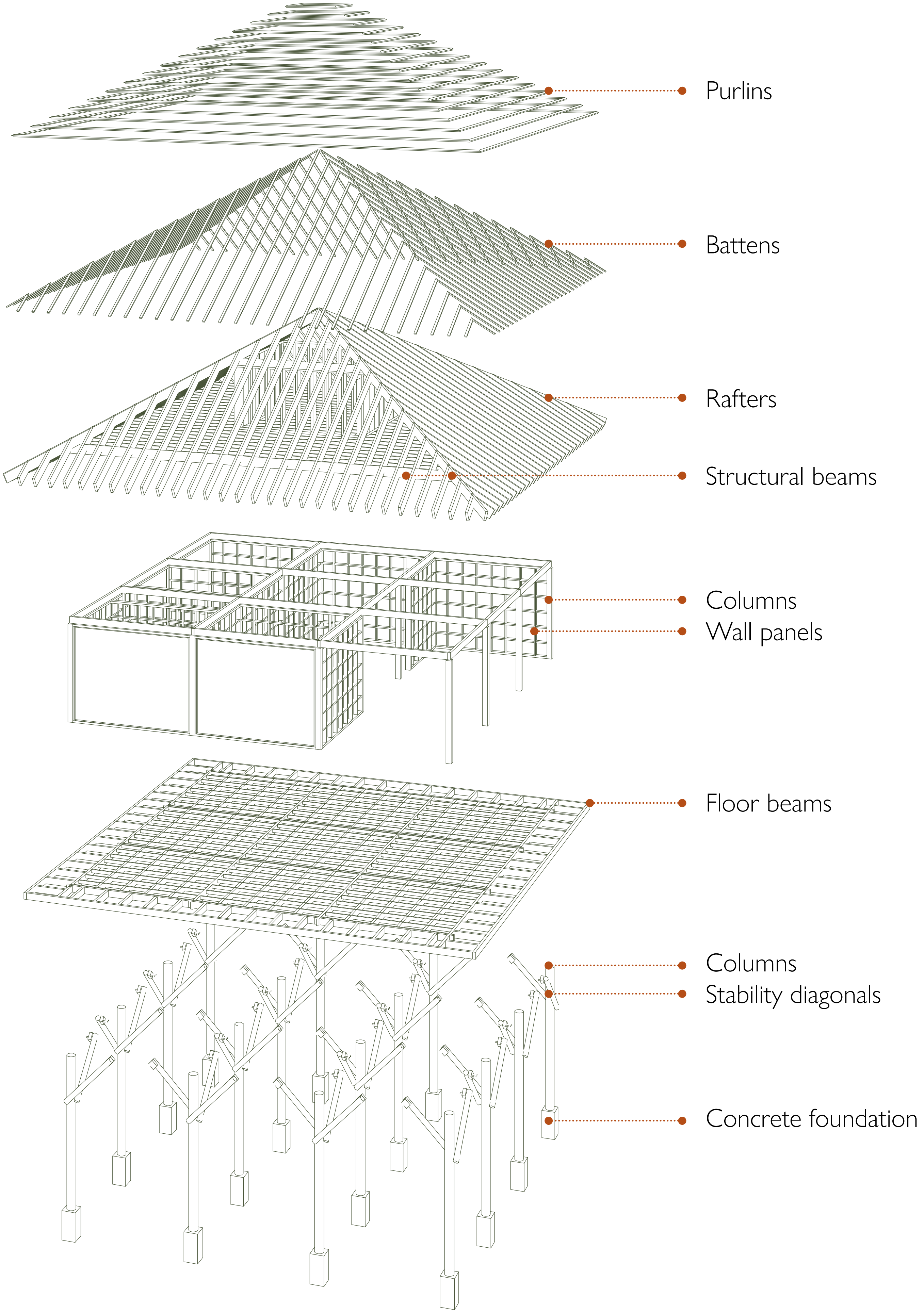
- Palm frond roof finish
- Timber frame
- Water drainage gutter
- Water blocking foil
- Fiber glass insulation
- Damp blocking foil
- Plasterboard or wooden finish




- Plasterboard finish
- Timer frame
- Water blocking foil
- Fiber glass insulation
- Damp blocking foil
- Plasterboard finish

All other 1:5 details can be found in appendix D

# Timber load bearing structure | *roof to foundation*



# Timber load bearing structure | *goathi's*

*Rules of thumb applied on timber construction*

*Columns in the water:*

Diameter = 6.0m / 20 =  300mm

4p goathi: 48x stability diagonals/bracing
2p goathi: 34x stability diagonals/bracing

*Floor beams:*

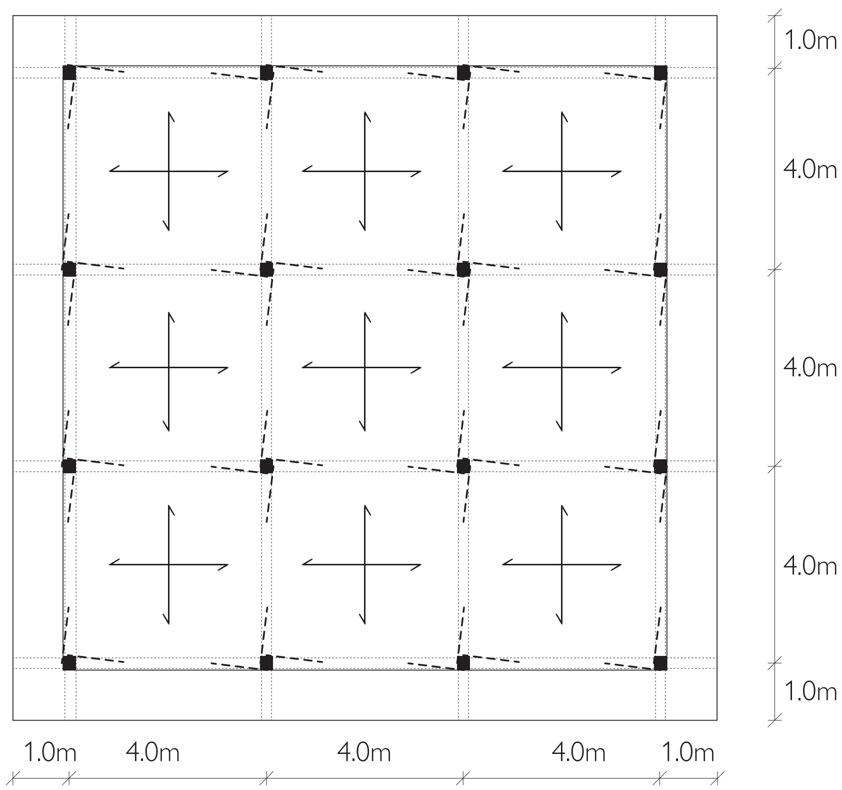
Floor beams no cantilever:
height = 4.0m / 20 = 200mm
width = 200 * (1/3) = 67mm

Floor beams with cantilever of 1 m:
height = 5.0 / 20 = 250 mm
width = 250 * (1/3) = 83mm

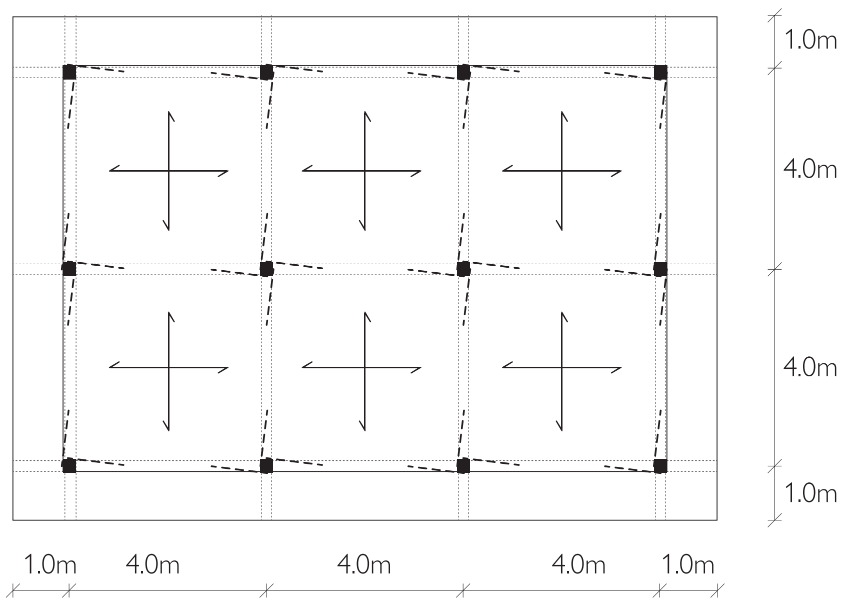
*Columns of the goathi:*

Walls/panels:
height ~ 3.0m
width = 3000 / 20 = 150mm

*4 persons 14m x 14m*

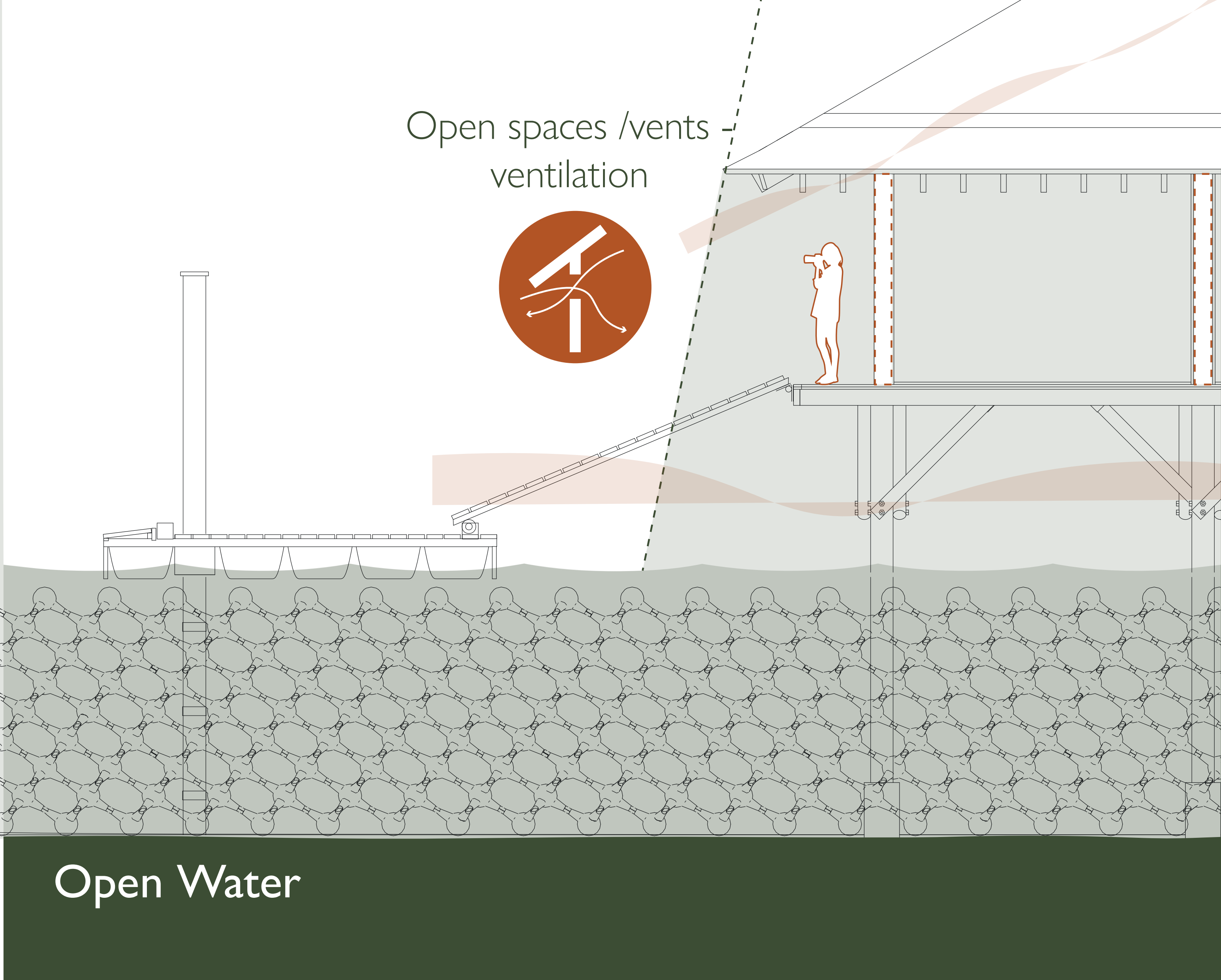


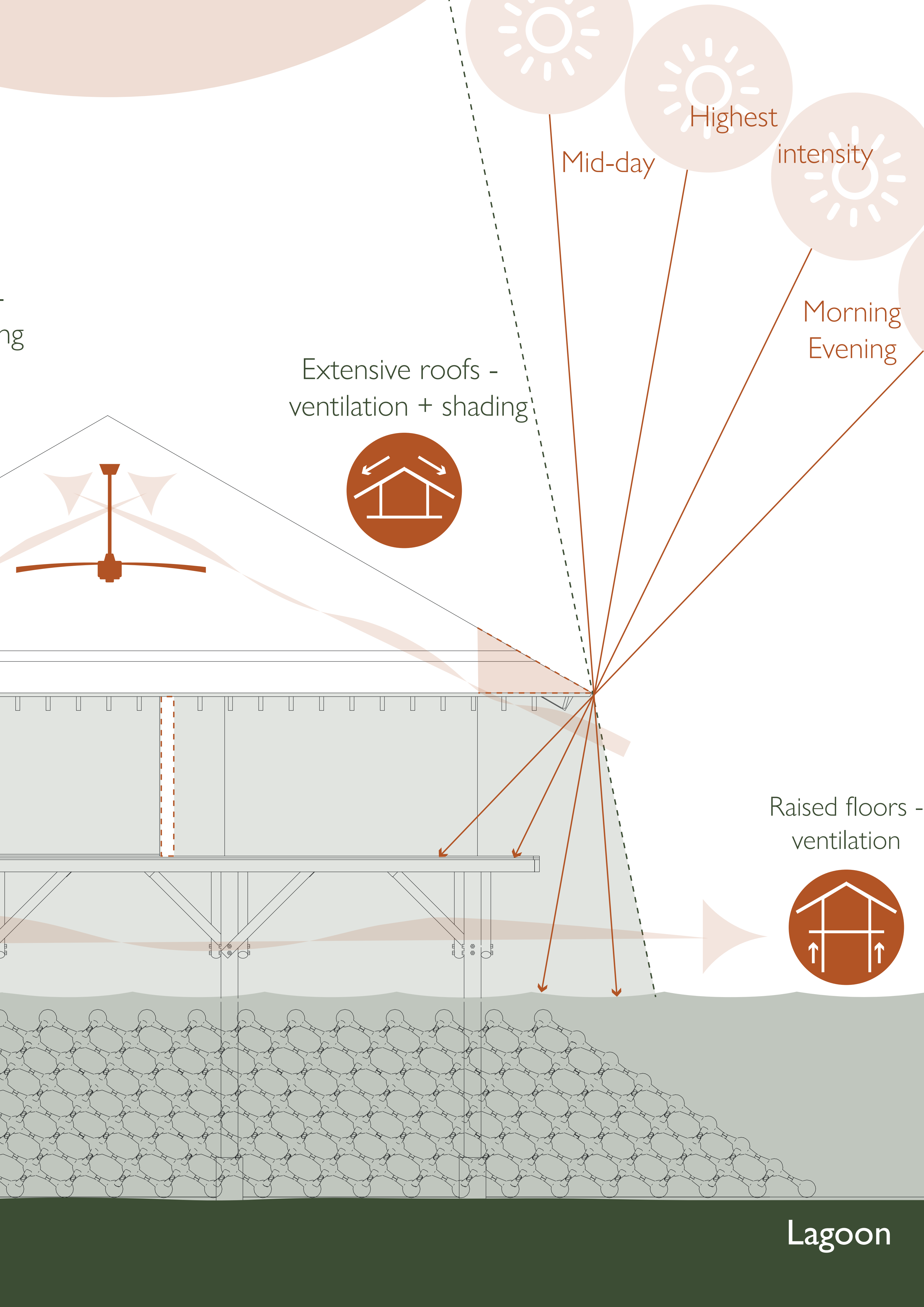

*2 persons 14m x 10m*



# Goathi climate design | *traditional interventions concept*

The traditional interventions are based on the techniques, materials and culture of the Maldives. The main goal is to utilize as much as possible passive methods to create a comfortable indoor climate. The optimal sloped roof with and angle of 30° stimulates passive ventilation. The open concept and openings in the goathi also allows air to flow. The floors are raised above the sea water allowing air to pass underneath each goathi creating a cooling effect on the floor.
Extensive roofs provide shading to the building and the outdoor spaces. No direct sunlight will enter the facades during the hottest time of the day. However, the open walls and floorplan are allowing a sufficient amount of daylight into the goathi.

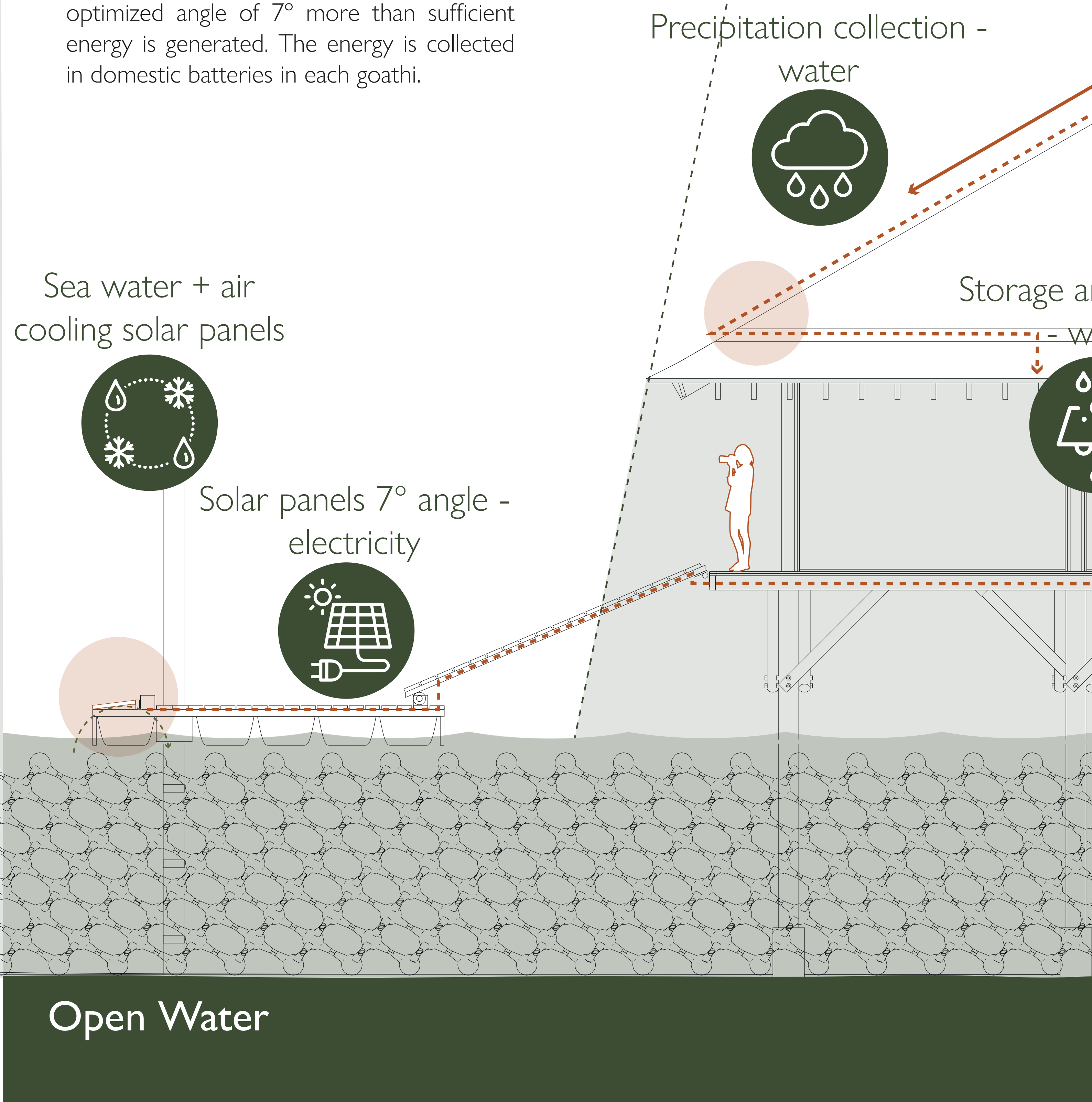



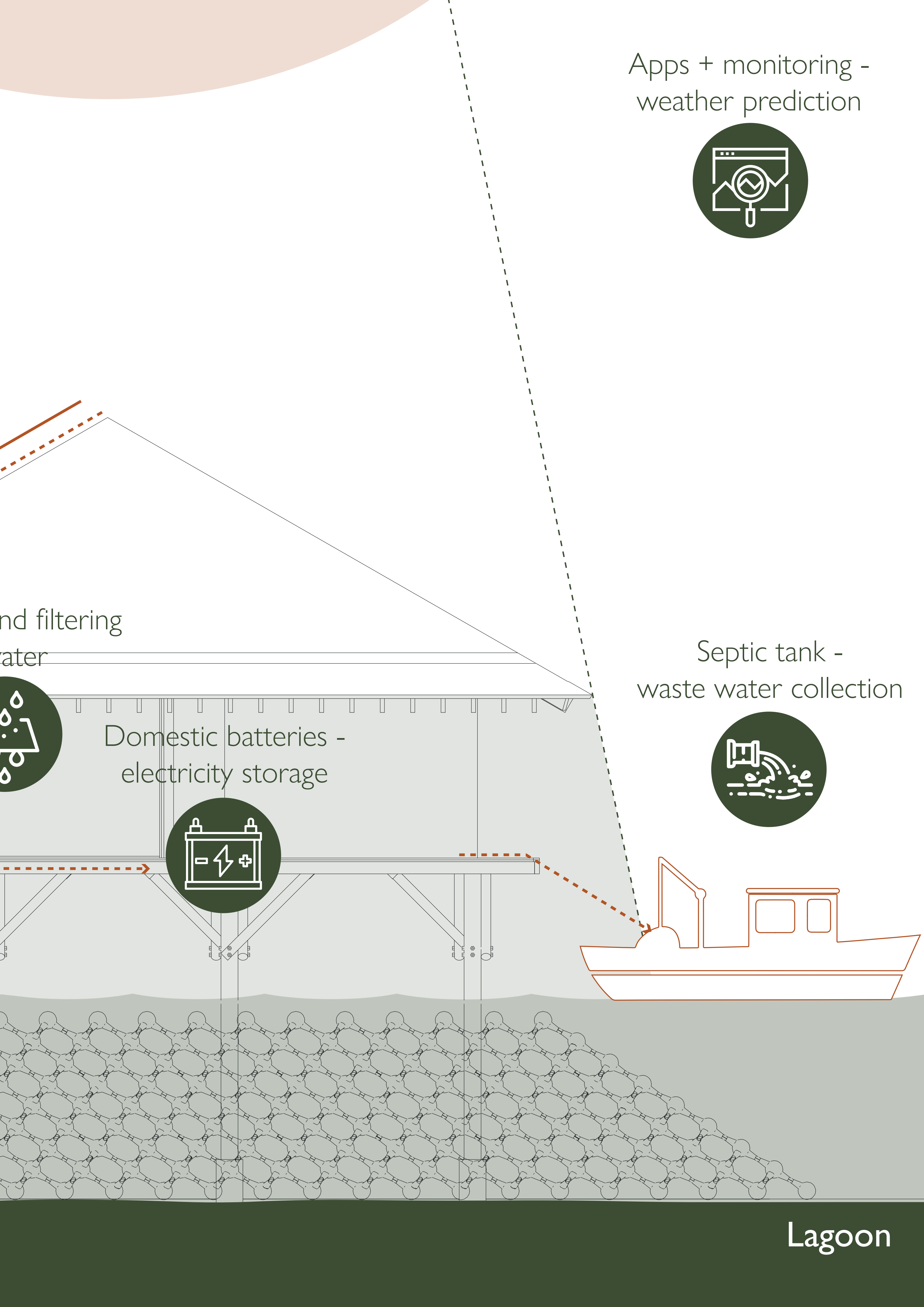


Highest
intensity
Mid-day
Morning
Evening
ng
Extensive roofs -
ventilation + shading
Raised floors -
ventilation
Lagoon

# Goathi climate design | *circularity interventions concept*

The smart design makes it possible for each goathi to become a self-sustaining ecosystem. Precipitation water is collected from the roof, filtered and stored. Waste water is transferred to a septic tank. This tank will be emptied every week and can be accessed on the outside of the goathi. The solar panels are situated on the walking deck surrounding the entire island. Due to the amount of solar panels, the cooling of sea water and air, and optimized angle of 7° more than sufficient energy is generated. The energy is collected in domestic batteries in each goathi.





Apps + monitoring -
weather prediction
nd filtering
ater
Septic tank -
waste water collection
Domestic batteries -
electricity storage
Lagoon

# Water | *consumption | collection | calculation*


Concept drawings of water use | Fig. 15

*Fresh drinking water and water consumption*

- Average annual rainfall on northern atolls 1,790 mm

- Rainwater is used for drinking by almost 40 per cent of households across the country.

- Average water consumption in the Netherlands: ~130 L per day per person

- Goathi 2 persons: 250L+ per day consumption per year: 250 x 365 = 94,170L
- Goathi 4 persons: 500L+ per day consumption per year: 500 x 365 = 188,340L

- Goathi 2 persons roof area: 11m x 11m x 75%~ 91 m2
- Goathi 4 persons roof area: 14m x 14m x 66,7%~ 130 m2

- Goathi 2 persons water collection per year: 17.9dm x 9100 dm2 = 162,890L buffer: 162,890 - 94,170 = 68,720 L
- Goathi 4 persons water collection per year: 17.9dm x 13000 dm2= 232,700L buffer: 232,700 - 188,340 = 44,360 L

*Black and grey water in septic tanks*

- Emptied once per week.

- Goathi 2 persons:
- 2p * 130L * 10days = 2600L
- 3000L septic tank (2700x1190x1440mm

- Goathi 4 persons:
- 4p * 130L * 10days = 5200L
- 6000L septic tank (5400x1190x1440mm)

# Energy | *consumption | production | calculation*

The tilt angle for the most optimal solar gain varies between 3° and 10° for the Maldives. The exact angle depends on the specific geographic location. A universal tilt angle of 7° can be selected for all sites. (Solargis, 2018)

- Average energy consumption per capita Maldives: 717 kWh per year
- Average energy consumption per tourist: 5.92 kWh/guest/day (22.3 - 1.34 kWh/guest/day)

- Average energy production (angle of 7º): 5.57 kWh/m2
- Average m2 needed to meet the demand: 5.92/5.57= 1.06m2 of solar panels per person

- Approximation of solar panels: positioned on the deck with a 0.6m width and 4000 length
- Area: 0.6 * 4000= 2400 m2 solar panel
- Generating: 2400 * 5.57 = 13,368kWh = 13,4 mega Watt hour for the entire resort

Additional data on temperature, global tilted irradiation, daily average sum of electricity production by PV, and surface meteorology, can be found in appendix E.

# 7. | Plastic waste recycling |

*Plastic selection*
*Recycling process*
*Reproduction processes*
*Entire recycling process*

***"One waste stream less would help in the waste problem and potentionally delaty the extinction of coral reefs. A vigorous and acute solution is required to break the vicious cycle."***
***~ Author***

# Plastic selection | *polyethylene terephthalate plastic - PET*

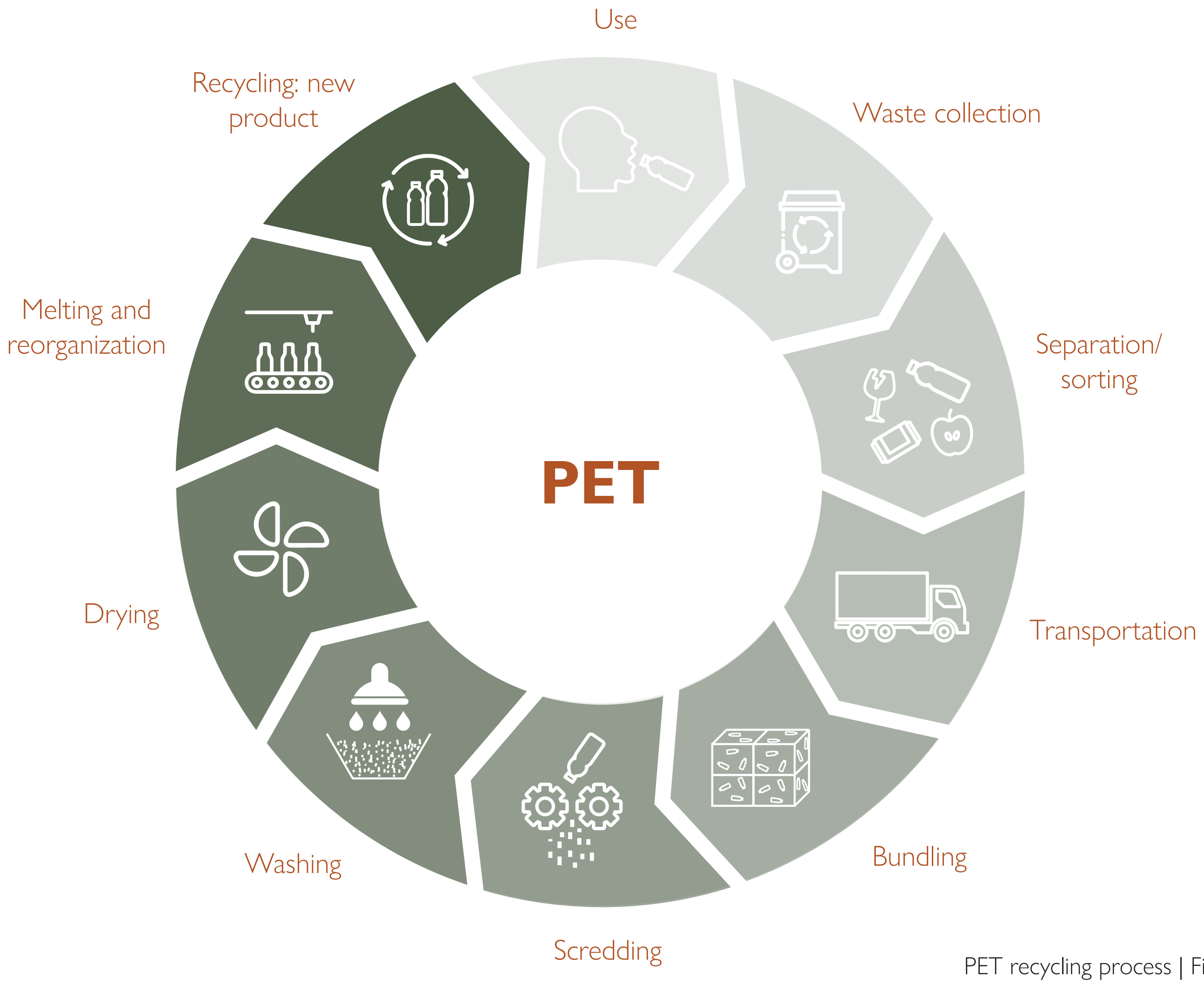
90% of the marine waste consists of plastic waste. Due to the increase of plastic consumption, there will likely also be an increase of the amount of marine plastics. (Kumartasli & Avinc, 2020)
Marine waste consists of multiple types of plastic. One of the most commonly used plastics and easiest to recycle is polyethylene terephthalate, also known as PET.
Approximately 31% of the collected marine PET plastic is non-PET waste items. (Moore & Staub, 2020) Plastic waste mainly comes from packaging, development and tourism. Everything imported contains packaging, due to the high dependency on import this is a large issue and contributor to the plastic waste generation. The annual estimations in the Maldives show that more than 23,395 tonnes of plastic is produced each year. Unfortunately only 5% of this plastic is being recycled. (Board, 2022)
Most plastic waste which is being recycled are thermoplastics. These types of plastic are easy to recycle as they can be reshaped by applying high temperatures. (Ceurstemont, 2020)

According to the software GRANTA Edupack has PET plastic good mechanical properties to temperatures up to 175°C. The material is crystal clear and almost completely impenetrable to water and CO2.
PET is easy to shape and simultaneously very strong and durable. However, the most interesting aspect of PET is that it allows reuse. At the end of a PET products first life, the material can be treated and recycled into new products.

To ensure a strong and resilient structure in using PET plastic, certain design decisions have been made. The elements for the structure will be made out of solid PET. Enabling the recycling and processing of a much larger amount of plastic waste. The weight of PET plastic (1.38 kg/dm3) is greater than the weight of seawater (1.021 kg/dm3). This results in solid PET sinking to the bottom of the sea.
Another reason for the application of PET is that the whole design becomes completely recyclable.
Taking into account the effects of wave energy and currents, it is crucial to ensure that the structure is secured in place by fastening it to the anchored columns of the walking deck.
Examining the degradation of PET, it degrades very quickly when exposed to UV light and heat. The presences of water significantly decreases the degradation. (Dimassi et al., 2022)
PET does not degrade naturally, but it does weather over time. However, plastics of small sizes with high surface areas, a high surface-to-volume ratio, are more susceptible to degradation. Using larger plastics with little surface area, a very low surface-to-volume ratio, we try to deliver the opposite leading to low rates of degradation.
Stabilizers can be added to the PET plastic to improve the polymer’s resistance to degradation. (Dimassi et al., 2022)

Additional information about PET properties, retrieved from the GRANTA EduPack software, and example applications of recycled plastic in the built environment, can be found in appendix F.

# Recycling process | *PET plastic*




PET recycling process | Fig. 16

84% of plastic recycling is being recycled by the mechanical recycling process. The process includes collection, sorting, washing and shredding. (Sadeghi et al., 2021) When the plastic is shredded into small flakes, the material is dried and ready for the production processes.

Many items are made out of different types of plastic. The most critical phase is the sorting phase as some types of plastic don't mix and will not blend into a homogenous material later in the process. (Ceurstemont, 2020) resulting in a new material with very poor properties.

The plastic flakes can be recycled into varies products through different processes. The products vary from bottles, to carpets, to textiles or even insulation. (Ceurstemont, 2020) Looking at the use of recycled PET plastic in buildings it ranges from pipes, façade panels, flooring to decking. An important aspect to take into account is the fact that the quality of plastic degrades every time it is being recycled. (Ceurstemont, 2020)

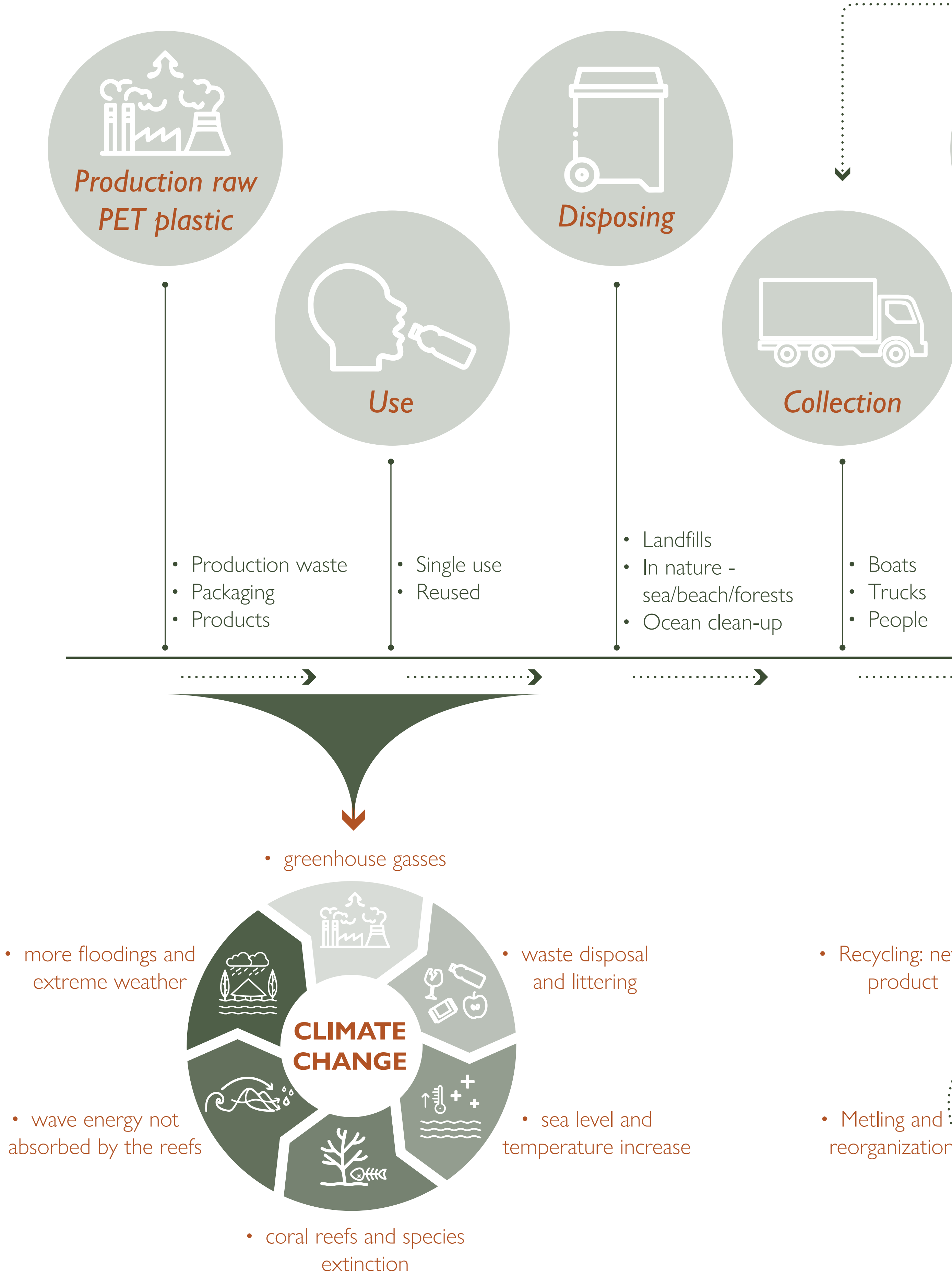
The entire recycling process of plastic is of course also contributing to greenhouse gasses. The waste needs to be transported and the facilities need energy for sorting, melting and producing. However considering the complete life cycle of the material, the greenhouse emissions generated during recycling are almost negligible, as it is only 9% of the total emissions generated throughout its lifespan. (Ceurstemont, 2020) Incorporating renewable energy sources can actually lead to a reduction in the environmental footprint of recycling.

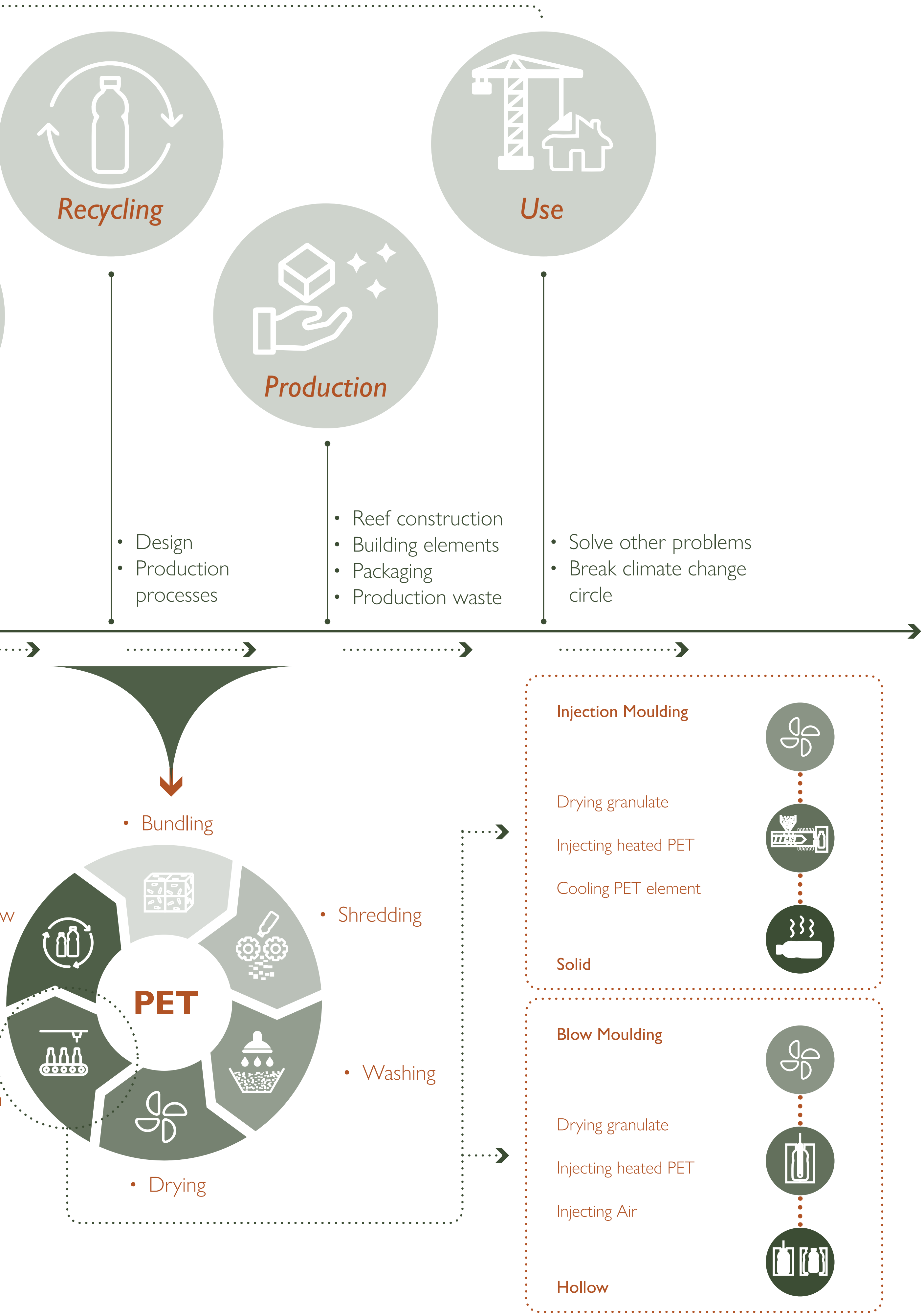
# Reproduction processes | *PET plastic*


PET reproduction processes | Fig. 17

The reproduction processes of PET plastics can differ depending on the desired outcome. For example is the injection moulding process, is a very accessible reproduction process which is only requiring minimal energy to create solid new products. (3devo, 2021) The granulate enters an extruder, where it is heated until it melts. The rotating movement of the extruder then presses the molten plastic into a mould of the desired shape.
The blow moulding process is commonly used in the production of bottles and containers. In the recycling process the PET material is melted and extruded into a hollow tube which is placed in a mould. Pressurized air is blown in, causing the molten plastic to expand and take the shape of the mould. This process is also an energy efficient way of reproducing products from recycled plastic. (3devo, 2021)
3D printing with recycled PET requires and additional step before completing the final product. Firstly, the recycled PET filament needs to be created. Afterwards the filament can be used to print the desired products. The whole process is consuming a lot of energy. However, 3D printing offers endless possibilities for creativity and design. (3devo, 2021)

# Recycling process | *start to finish*

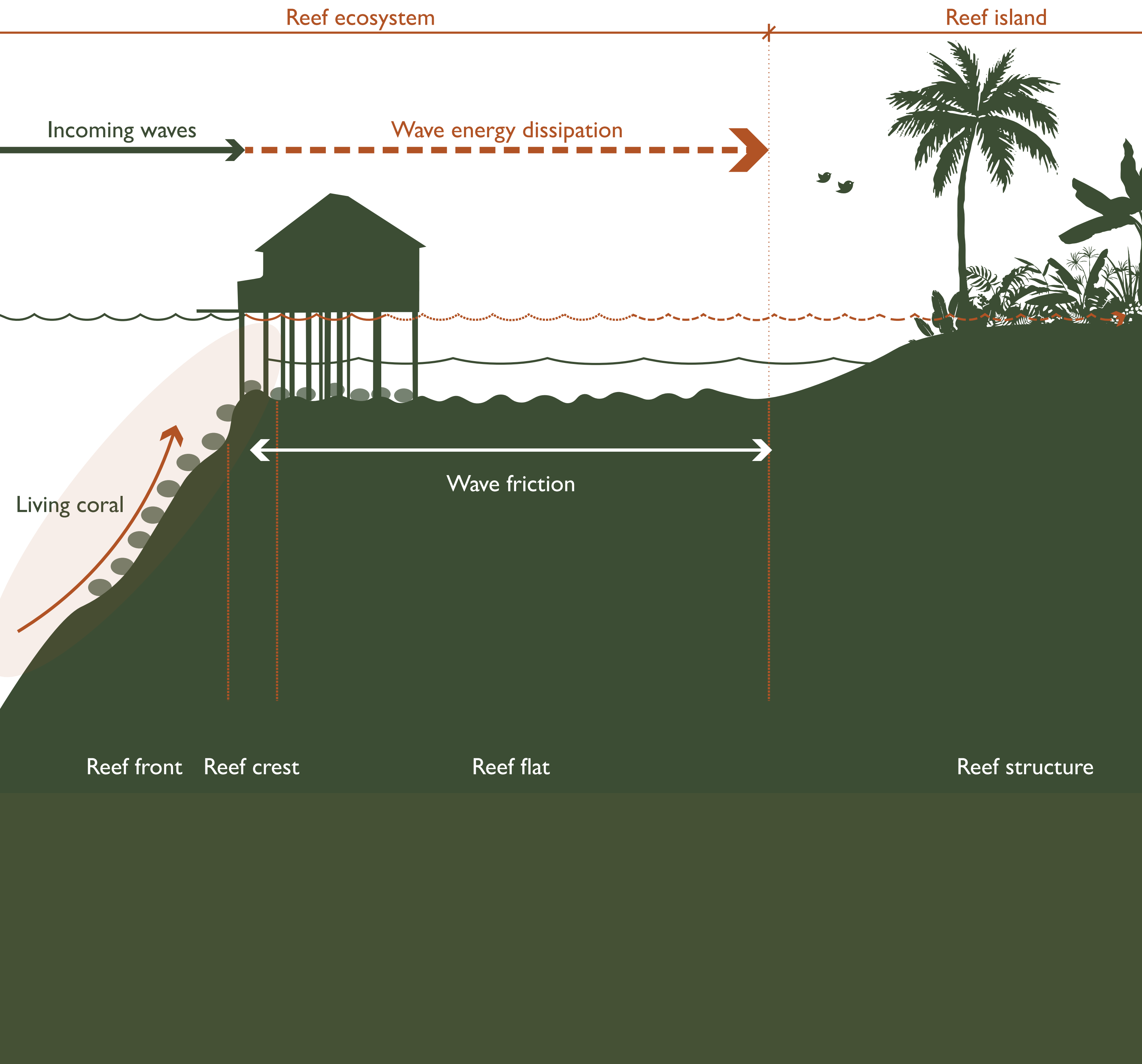



Recycling
Use
Production
Design
Production processes
Reef construction
Building elements
Packaging
Production waste
Solve other problems
Break climate change circle
Bundling
Shredding
PET
Washing
Drying
Injection Moulding
Drying granulate
Injecting heated PET
Cooling PET element
Solid
Blow Moulding
Drying granulate
Injecting heated PET
Injecting Air
Hollow

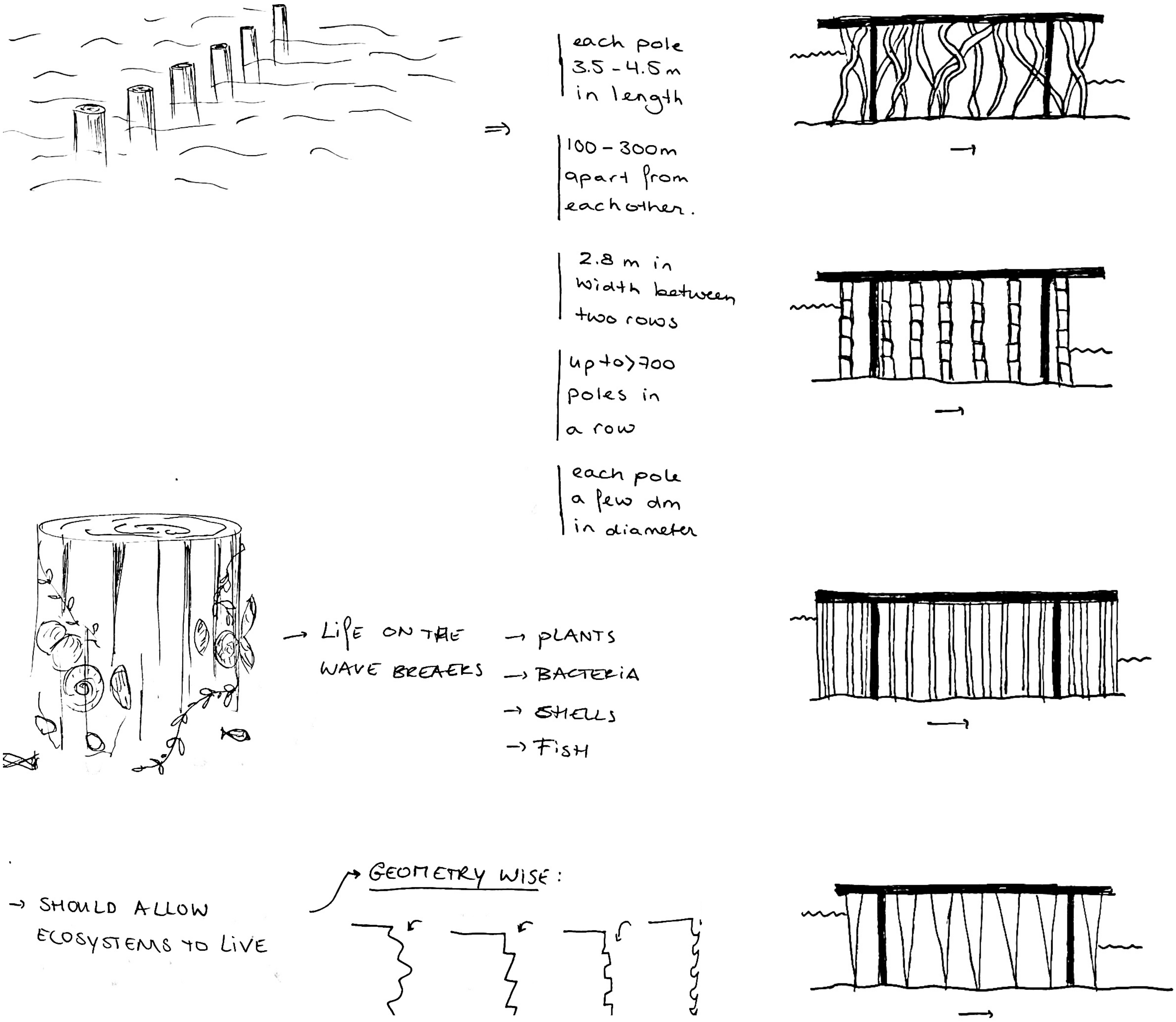
# 8. | Wave breaking reef |

*Coral reef explanation*
*Wave breaking structure | exploration*
*Wave breaking structure | model tests*
*Wave breaking structure | building on top of structur*
*Wave breaking structure | geometry*
*Wave breaking structure | output and location*
*Wave breaking PET reef | positioning*
*Wave breaking PET reef | elements & assembly*
*Wave breaking PET reef | dimensions*
*Wave breaking PET reef | calculation*
*Extra PET collection*
*Sea level changes*

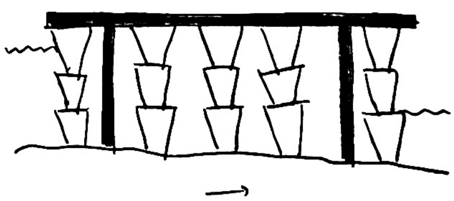
# Coral reefs | *conceptual explanation*

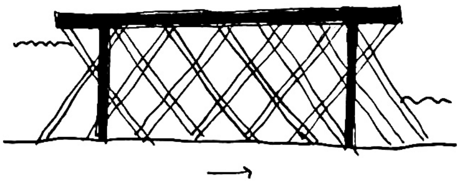


# Wave breaking structure | *exploration*

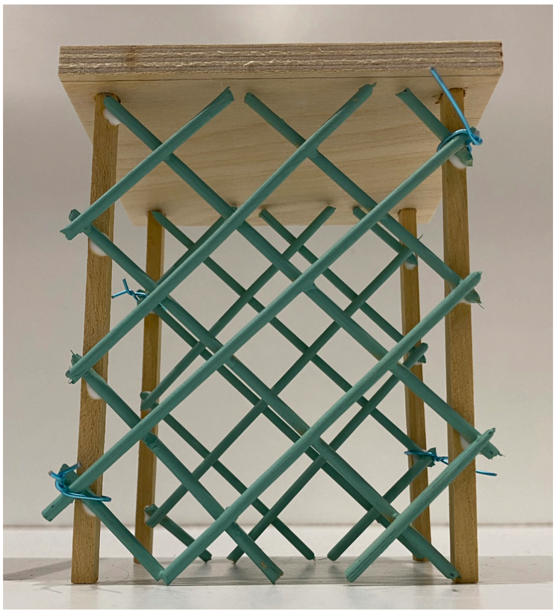


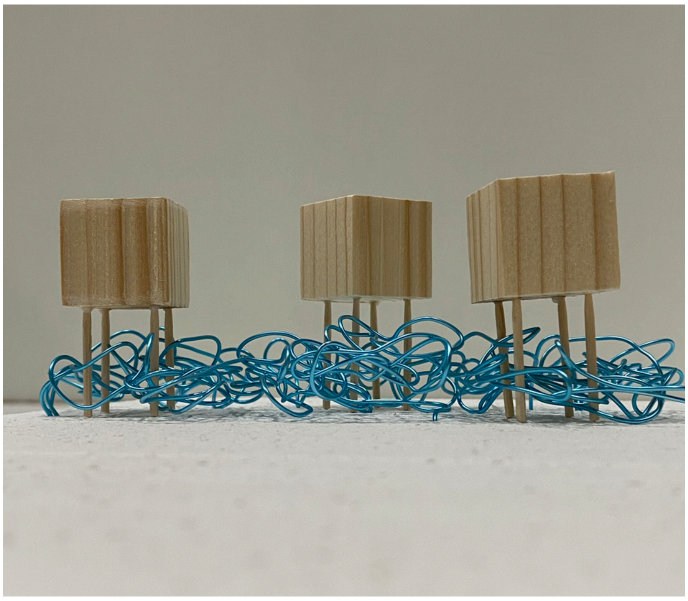

A solution to and restoration of damaged and extinct reefs is a high priority.
To make sure the islands will not erode away, a design is needed to take over the function of the extinct coral reefs. As the coral reefs used to defend the islands from high wave energy impacts, a new coastal defense design is required to prevent the coastal erosion from occuring. (Amores et al., 2021)
First of all, the geometry of wave breakers is researched in the following hand drawings. These wave geometries are located in the water and are based on the coastal defenses and wave breakers of the Netherlands.

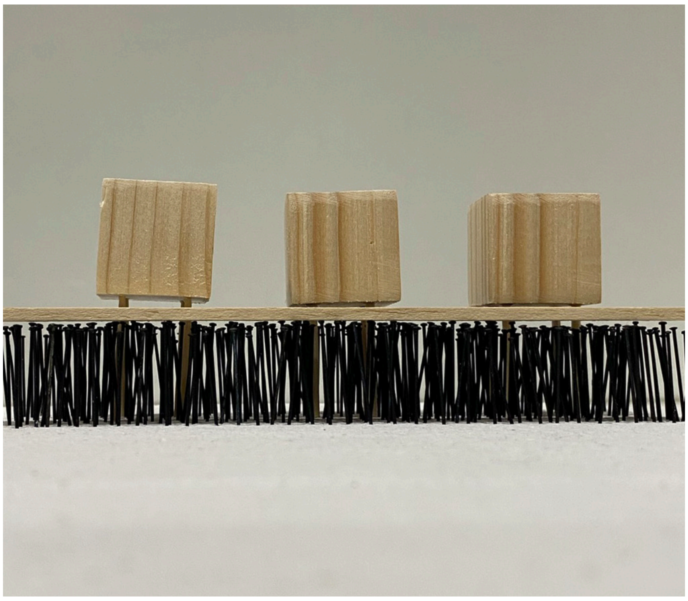




# Wave breaking structure | *model tests on geometry*







The visual research has been further developed by a number of model studies, as visible in the photos above. With the addition of platforms and volumes, the possibilities of building in the water, next to the wave breaking structure, or on top of the structure is included.

Wave breaking structure | *building on top of structure*

# Wave breaking structure | *geometry and material*

Applying coral samples to artificial reef by Coastruction | Fig. 18 (Piciocchi, 2019)

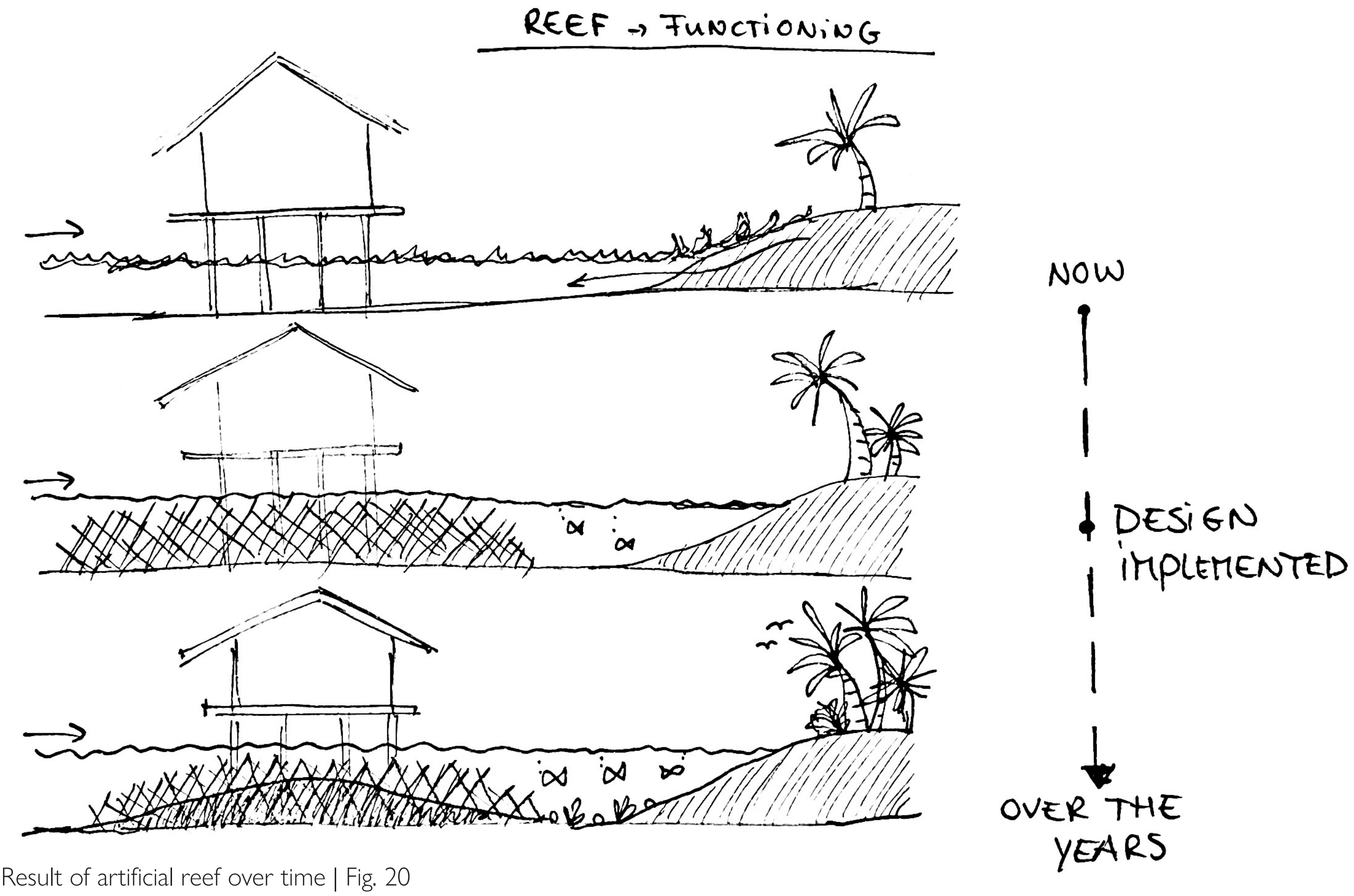
Artificial reef by Coastruction | Fig. 19 (Piciocchi, 2019)

The members of the Coastruction company have designed artificial reefs for reef restoration and coastal protection. The reefs are 3D printed concrete elements filled with sand for extra weight and stability underwater. The image above shows the assembled concrete elements and the applied coral samples to stimulate coral growth and ecosystems. The naturally shaped reef is designed to be produced easily and onsite. It provides easy and accessible technology. (Koetsier, 2022)

Using the geometry of the existing artificial reef design and adjusting it in such a way that another problem can be solved, can be done by creating this geometry out of recycled plastic waste.
A higher amount of waste can be recycled and processed when the structure elements are solid PET material. The weight of PET plastic is heavier than the weight of seawater. Meaning solid PET will sink to the bottom of the sea.
The entire element also becomes completely recyclable when it is fully made out of PET plastic.
With the impact of wave energy and streams we want to make sure that the structure will be held in place by fixating it to the anchored columns of the walking deck.

Looking at the degradation of PET. PET degrades very quickly when exposed to UV light and heat. Water is decreasing the degradation tremendously. (Dimassi et al., 2022)
PET does not degrade naturally. It does weather over time. However plastics of small sizes with high surface areas, a high surface-to-volume ratio, are more susceptible to degradation. (Dimassi et al., 2022) Using larger plastics with little surface area, a very low surface-to-volume ratio, we try to deliver the opposite leading to low rates of degradation.
Stabilizers can be added to the PET plastic to improve the resistance of the polymers to degradation. (Dimassi et al., 2022)

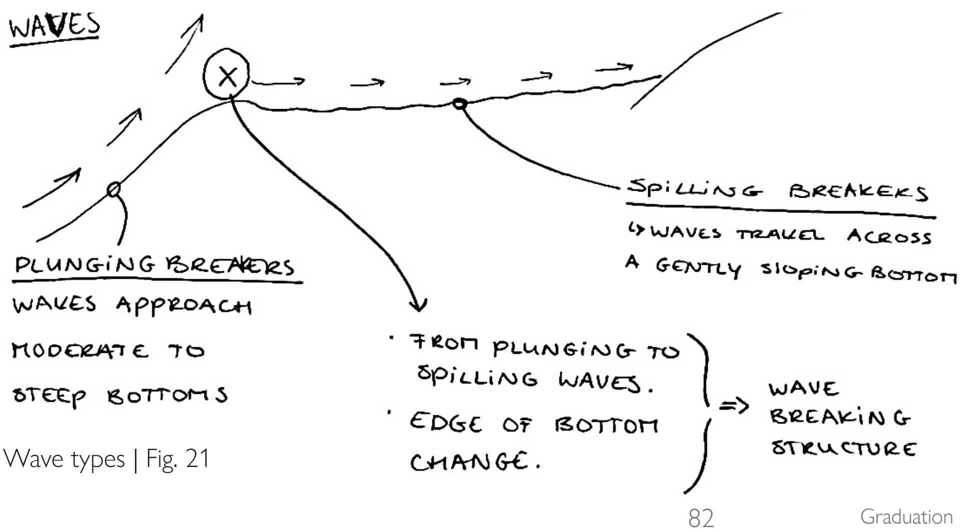
# Wave breaking structure | *output and location*




Result of artificial reef over time | Fig. 20

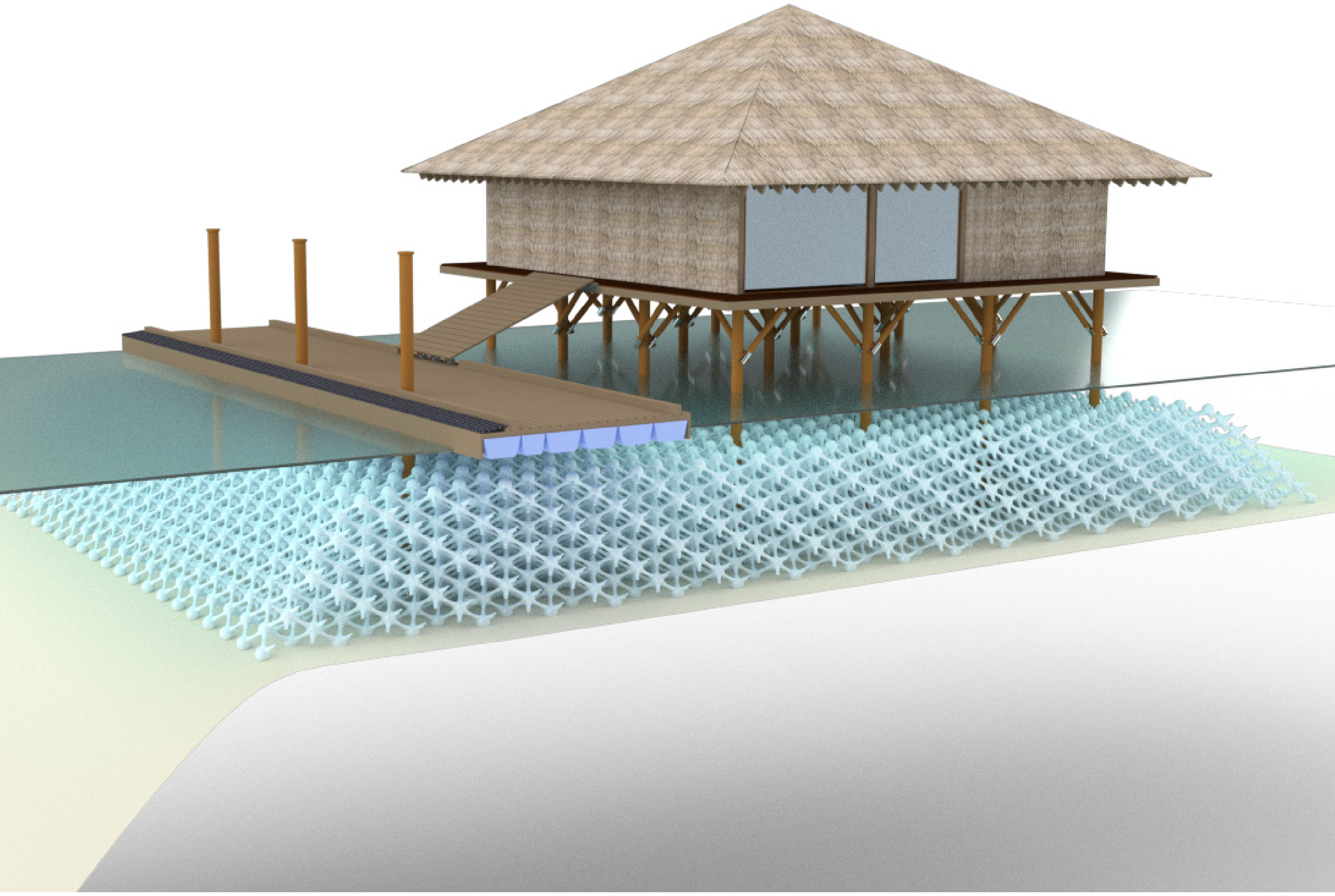
The goal of applying this artificial reef is to stop coastal erosion on the Maldivian islands and to create a new barrier over time. Decreasing the wave energy by the artificial reef can lead to significant turbulence at the base of the structure. The desired result is for the sand to be carried upwards with the stream from the deep ocean. Underwater dunes are created by the accumulated sand as it is unable to pass any further than the artificial reef. The energy of the waves will not pass the reef resulting in coastline preservation. (Koetsier, 2022) Next to that a a quiet and pleasant lagoon is created forming a safe habitat for at-risk ocean species and on land species as the islands will not get flooded.

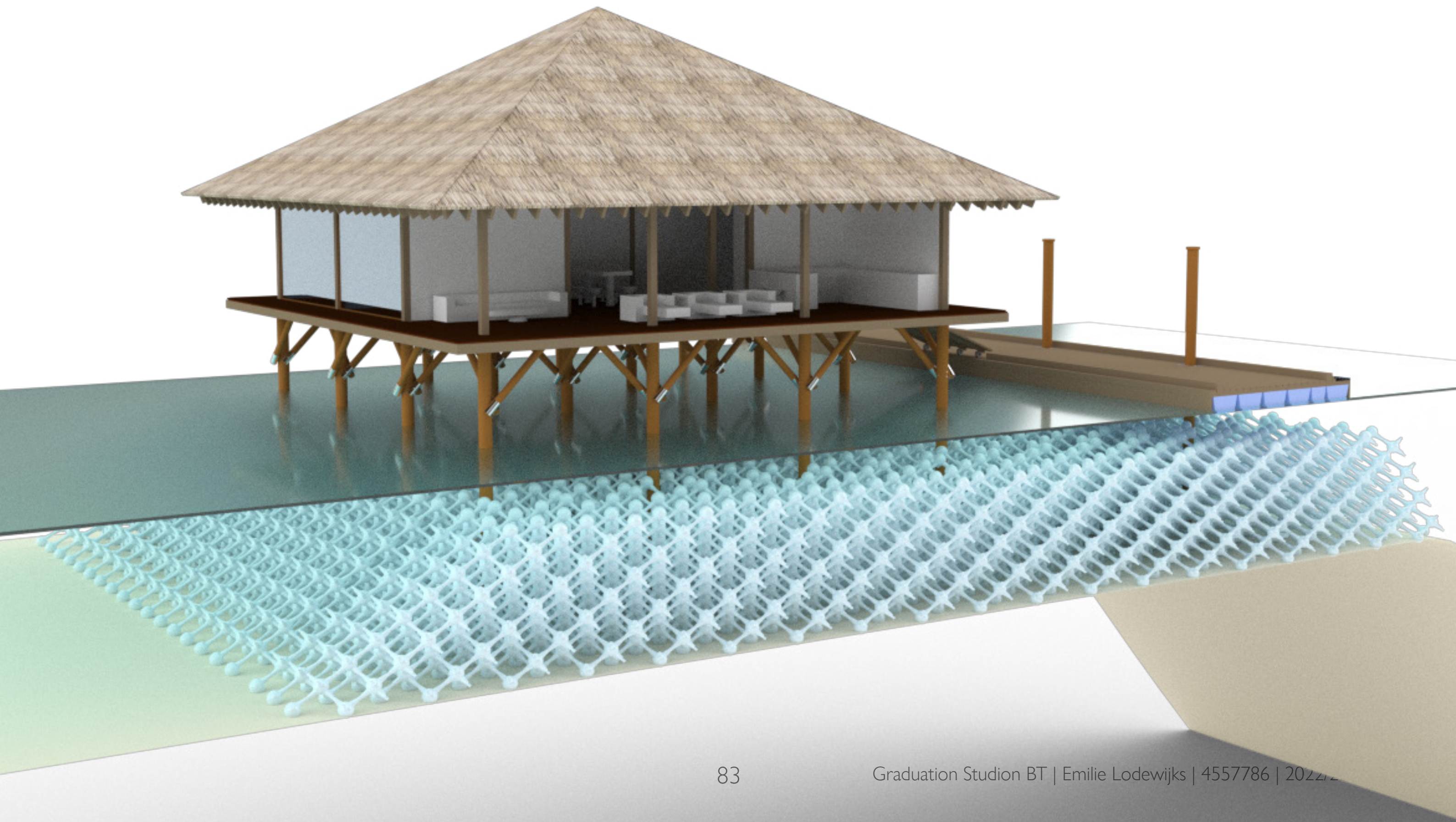
The location of the new artificial reef should be on the same as the coral reefs used to be. At this particular area the plunging waves, large waves with a lot of wave energy, can be turned into quiet and easy spilling waves by the artificial reef. A calm lagoon is created within the reef structure.



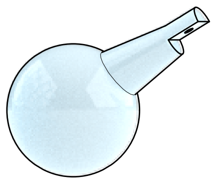

Wave types | Fig. 21

# Wave breaking PET reef | reef *positioning*

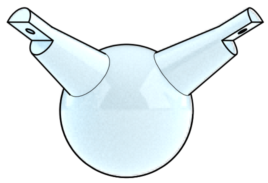




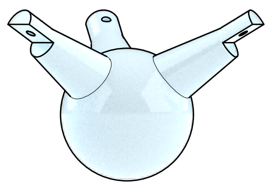
# Wave breaking PET reef | *elements and assembly*



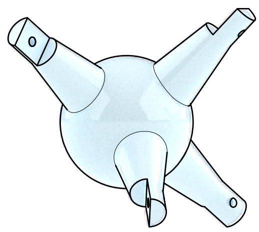
1 leg
13.9 dm3



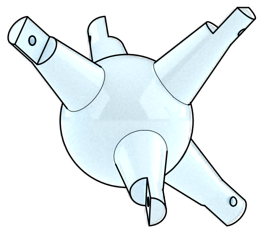
2 legs
15.1 dm3



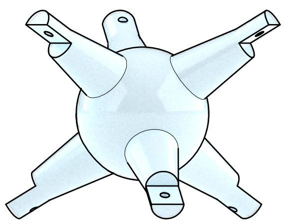
3 legs
16.3 dm3



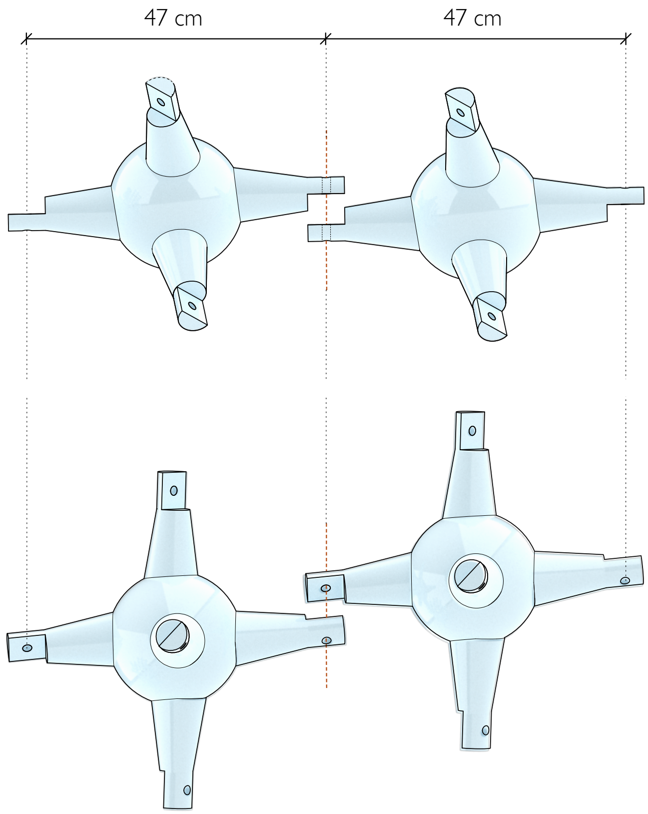
4 legs
17.5 dm3

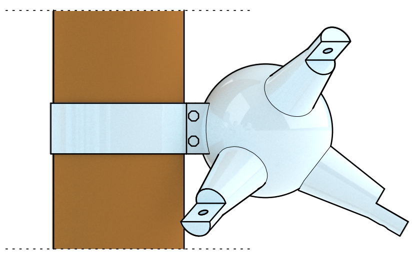


5 legs
18.7 dm3

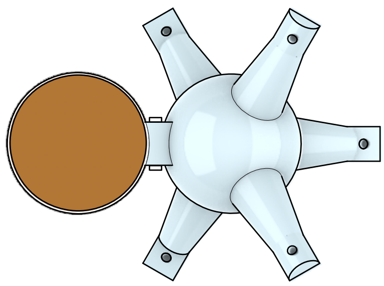


6 legs
19.9 dm3

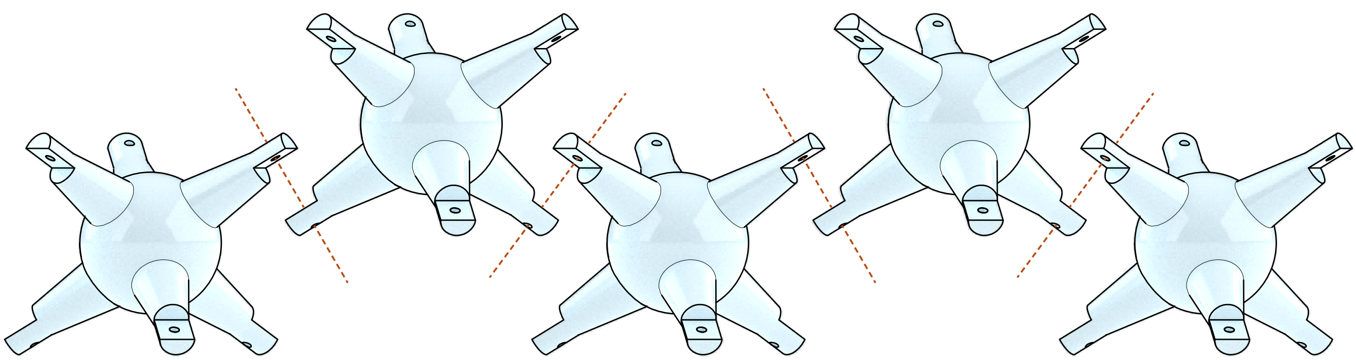


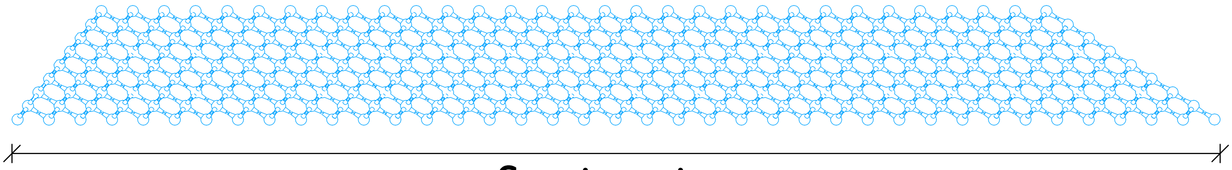
side view connection



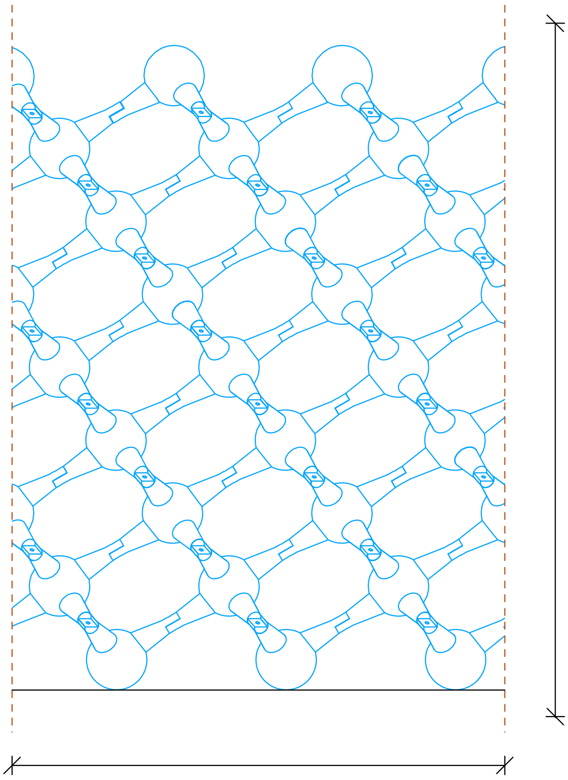
top view connection



# Wave breaking PET reef | *dimensions*

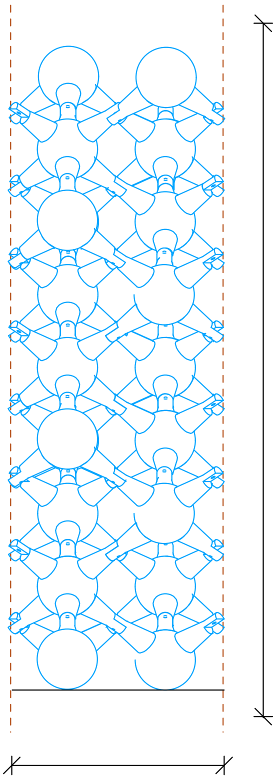


**Section view**
*width ~ 30 m*



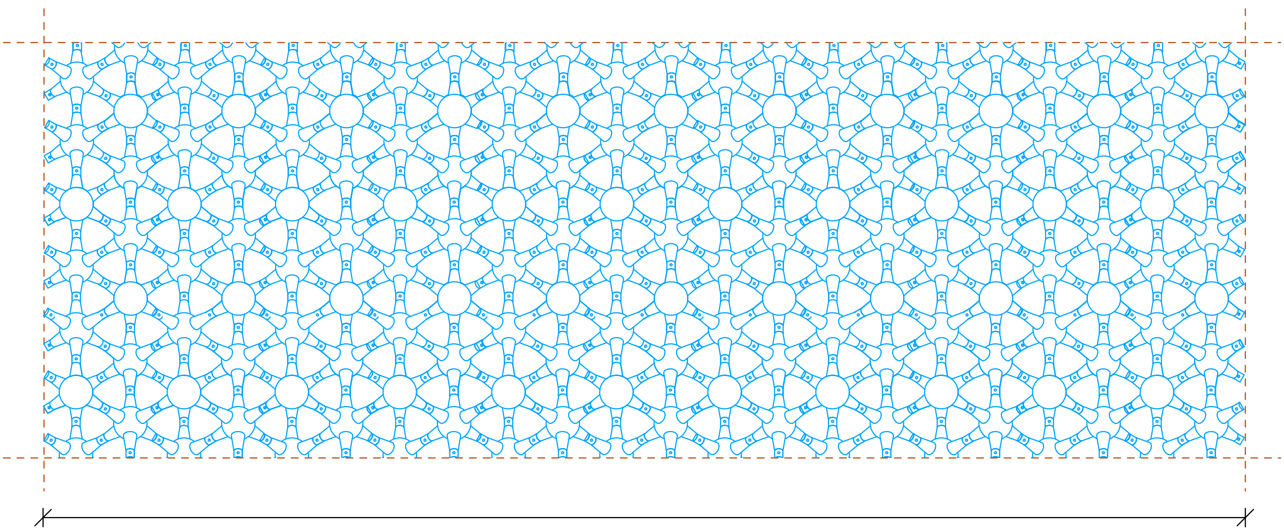
**Section view**
*height ~ 3.0 m*

**Section view**
*length ~ 10 m*



**Front view**
*height ~ 3.0 m*

**Front view**
*length ~ 1 m*



**Top view**
*length ~ 10 m*

# Wave breaking PET reef | *calculations*

The following calculation shows a rough estimation of the amount of PET plastic needed to create 10 m of PET reef.

*Volume of the PET Reef:*

- *22x 1 leg element: 306 dm3*
- *750x 3 legs element: 12,225 dm3*
- *77x 4 legs element: 1,348 dm3*
- *66x 5 legs element: 1,234 dm3*
- *2897x 6 legs element: 57,650 dm3*

*Total: 72,763 dm3 PET plastic is needed to create per 10 linear metres of structure.*

The following calculation shows an approximation of the possible length of the PET reef when only annually disposed plastic waste is recycled and reused.

- *PET waste of the Maldives per year: 24,000 tonnes = 24,000,000 kg*
- *Non-PET waste items: 31%*

- *Pure PET waste per year: 24,000 * 0.67 = 16,560,000 kg*

- *10 linear metre structure 30mx10mx3m: 3,812 elements in total*
- *10 linear metre structure = 72,763 dm3*

- *Weight of PET = 1.38 kg/dm3*
- *10 linear metre recycled PET = 72,763 * 1.38 = 100,413 kg*
- *1 linear metre recycled PET = 10,041 kg*

- *Rough estimation of area m2 recycled PET structure per year possible: 16,560,000 / 10,041 = 1,649 linear metres*

Plastic amounts retrieved from (Moosa, 2021)

- Average periphery of the centre of the PET structure decking walkway: ~ 4000 m

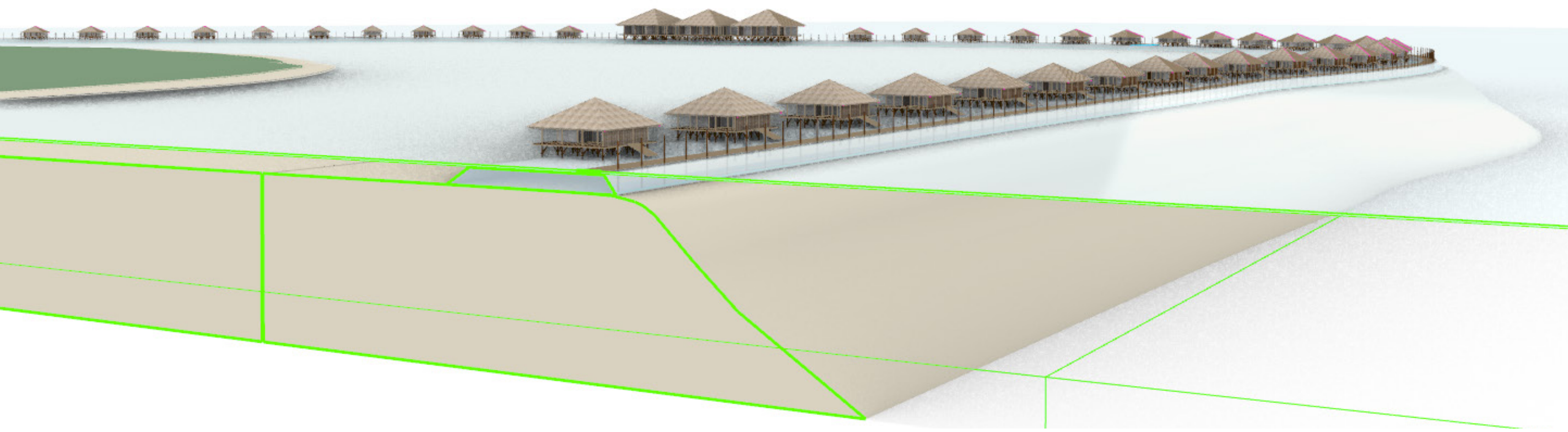
- Amount of recycled PET needed: ~ 10,041 kg/m x 4000 m = 40,164,000 kg = 40,164 tonnes

- Annual PET waste can create (16,560/40,164) * 100% = 41.1% of the PET reef around islands of similar size as Vangaaru.

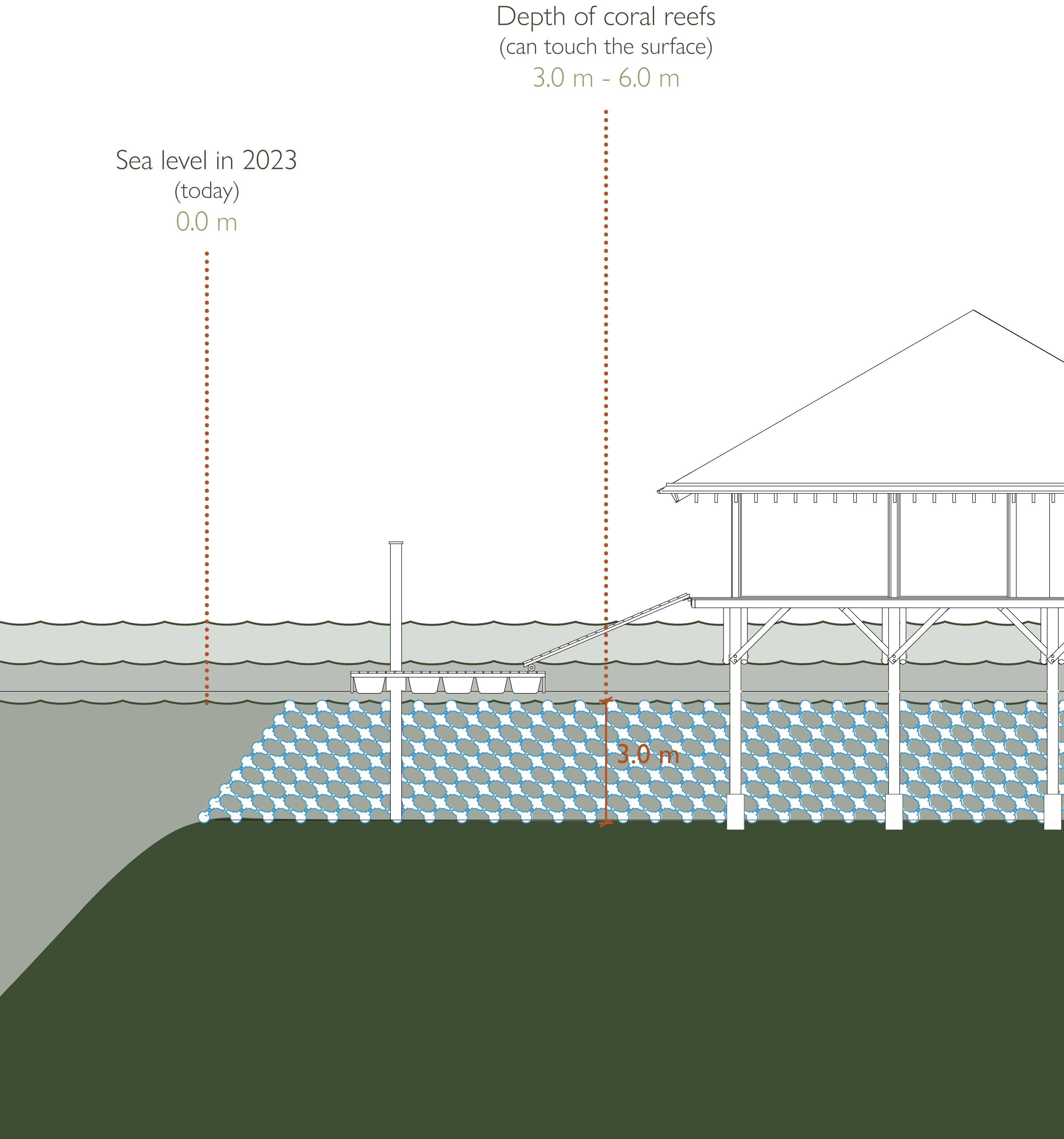
The tonnes of plastic waste from Thilafushi island can also be treated and processed into the PET reef.
Tonnes of plastic waste is also accumulated in the oceans in gigantic patches all over the world, covering thousands of square metres. There are five areas worldwide where the waste accumulates due to the currents. One of these five areas is relatively near the Maldives and is created because of the South Indian Gyre. Plastic collected by the OceanCleanUp can also be processed and recycled in the wave breaking PET reefs.

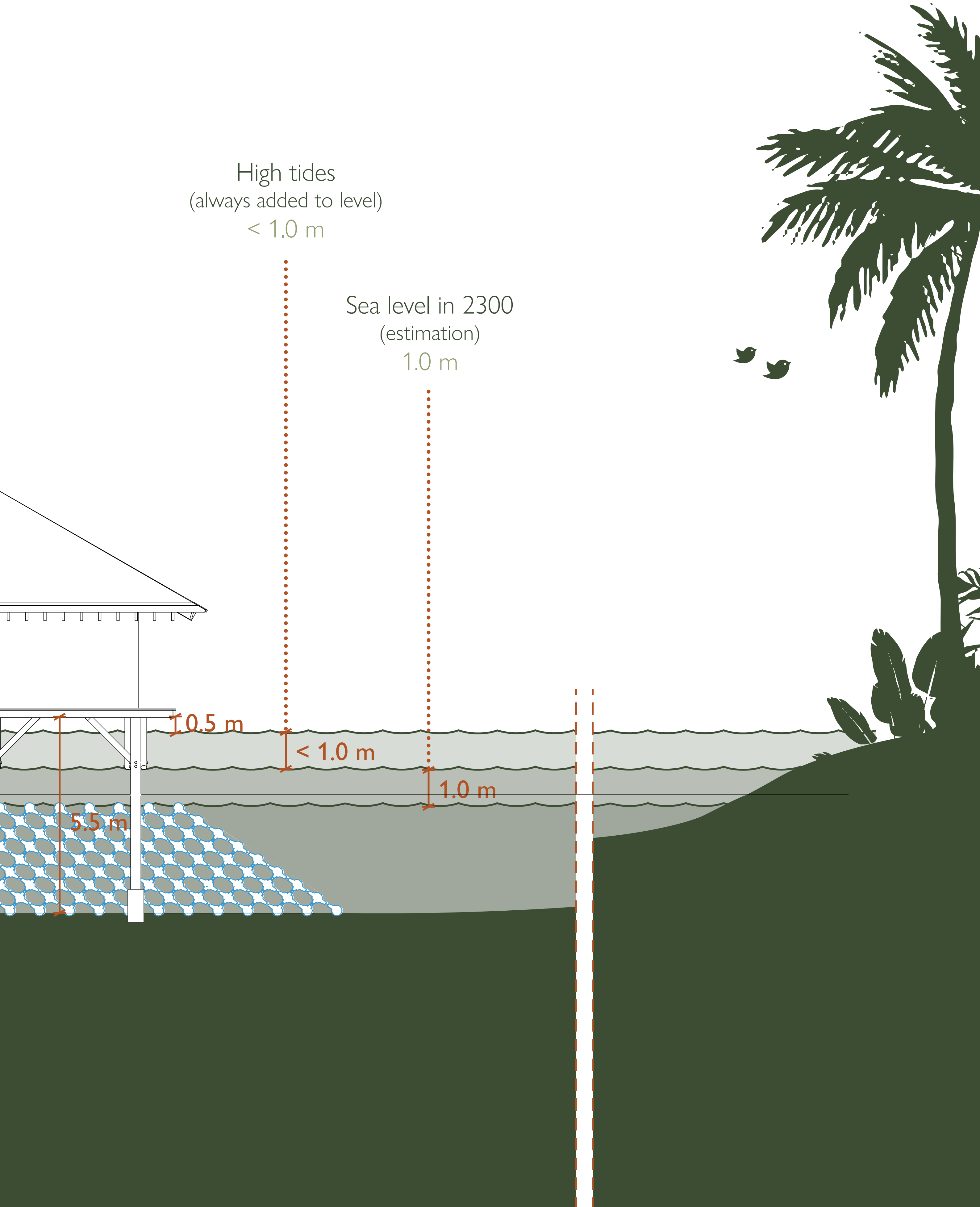
# Extra PET collection | *plastic soup patches in the world*


# Wave breaking PET reef | *positioning and calculation*



# Sea level changes | *approximation and predictions*

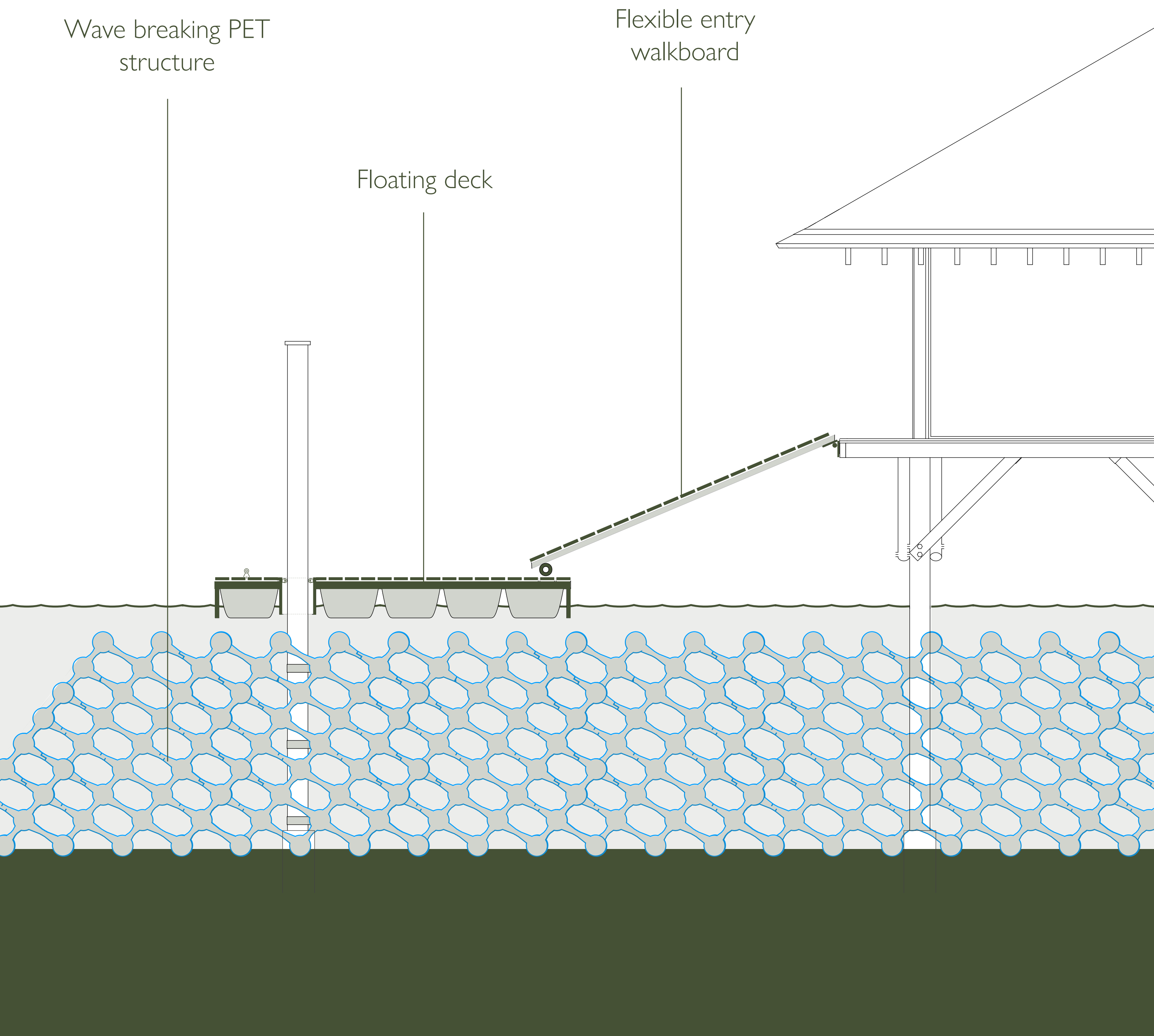



High tides
(always added to level)
< 1.0 m
Sea level in 2300
(estimation)
1.0 m
0.5 m
< 1.0 m
1.0 m
5.5 m

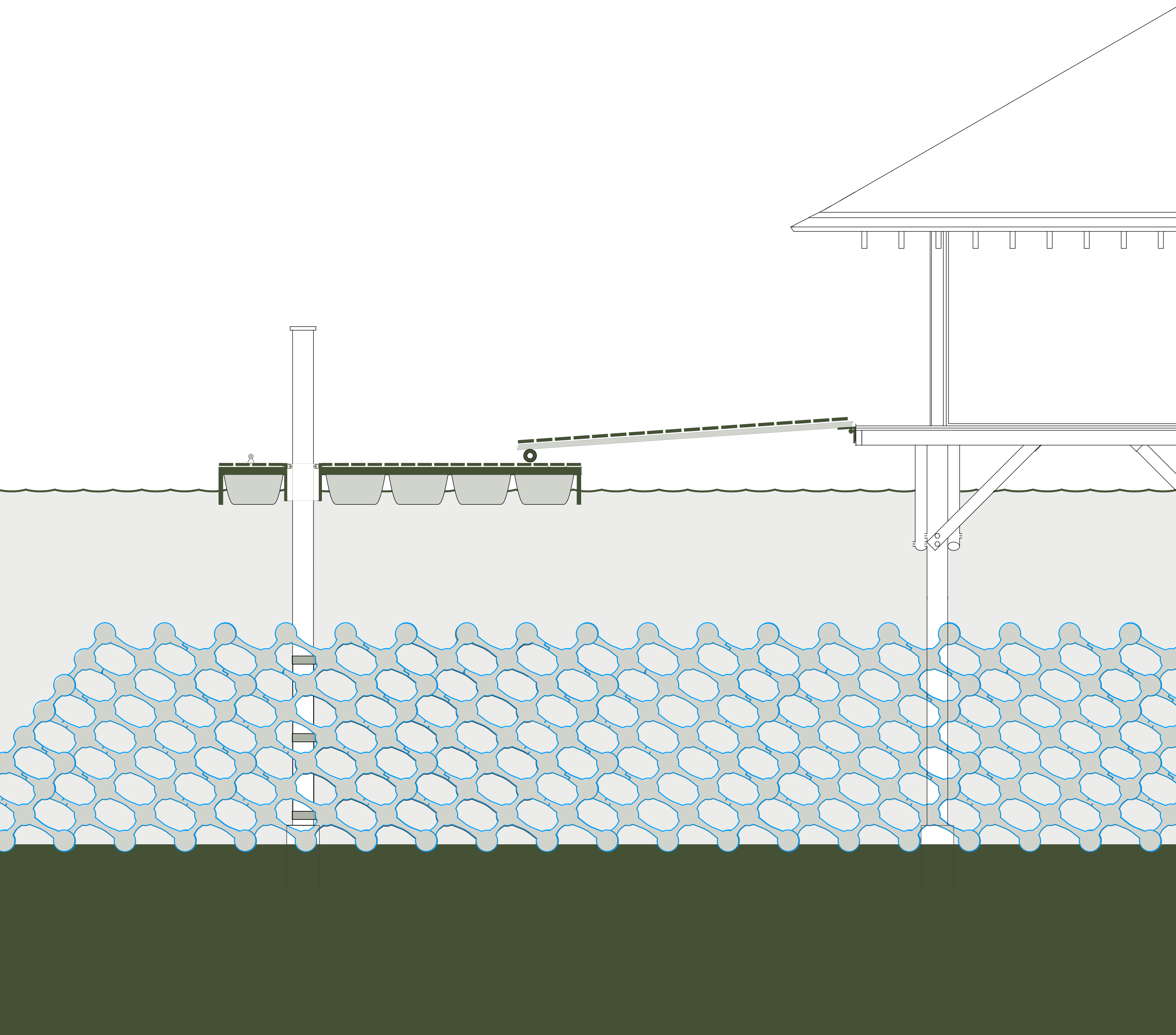
# 9. | Adaptability & applicability |

*Floating deck*
*Future proofing*
*Applicability | applying to other islands*
*Applicability | example island Hibalhidhoo*
*Applicability | build-up*

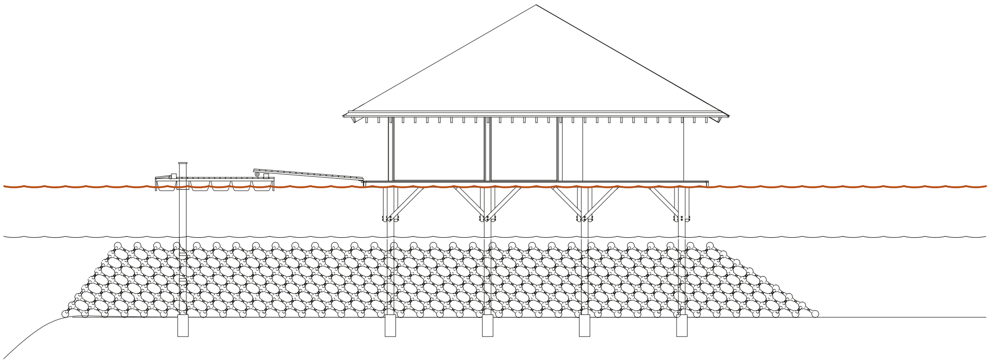
# Floating deck | *low tides today*



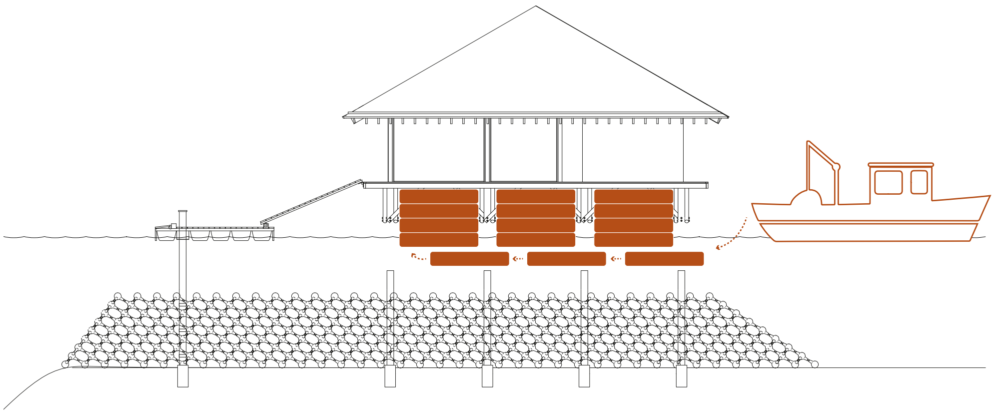
# Floating deck | *high tides in the future*



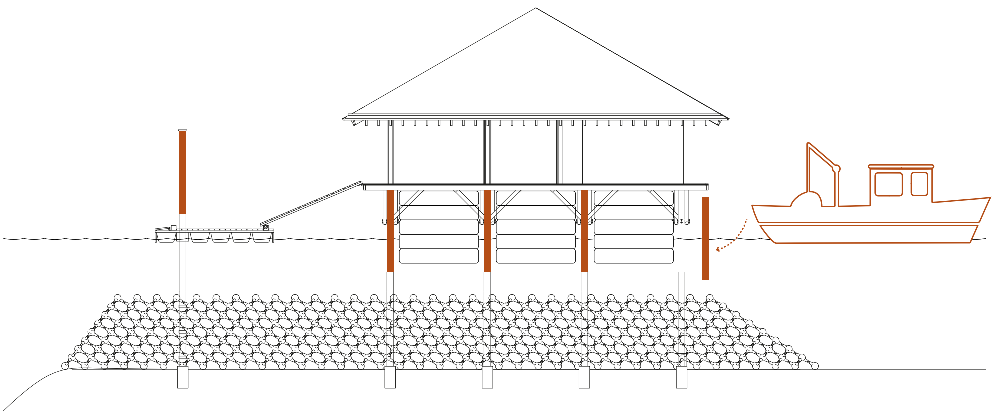
# Future proofing | *jack up the floor to add height to columns*



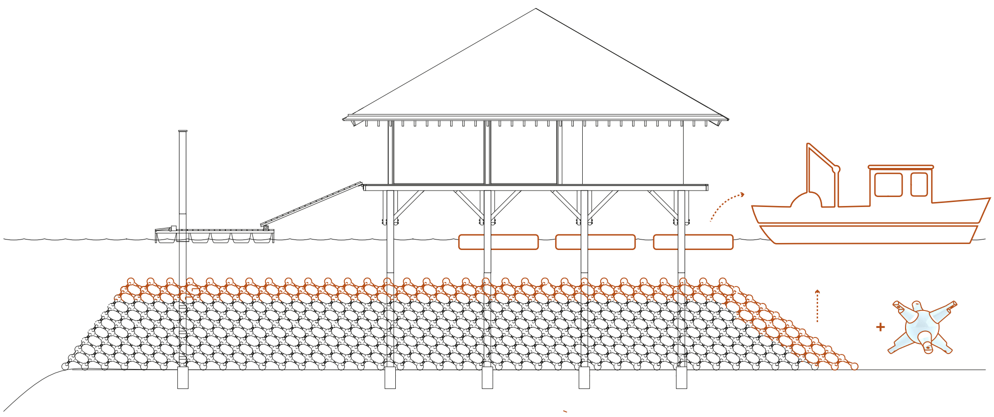
1. Increased water level



2. Floor and total lightweight goathi lifted by inflated floating elements applied from underneath

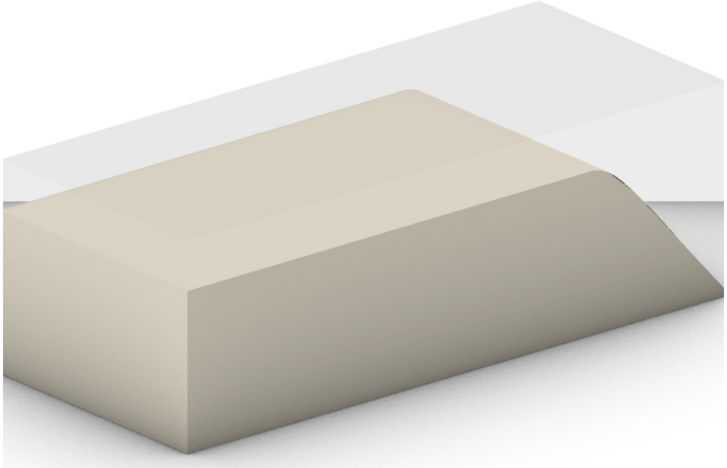


3. Additional height part connected to existing column, floor of the goathi and bracing

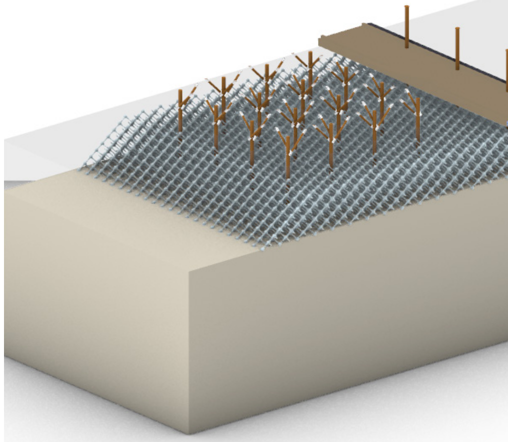


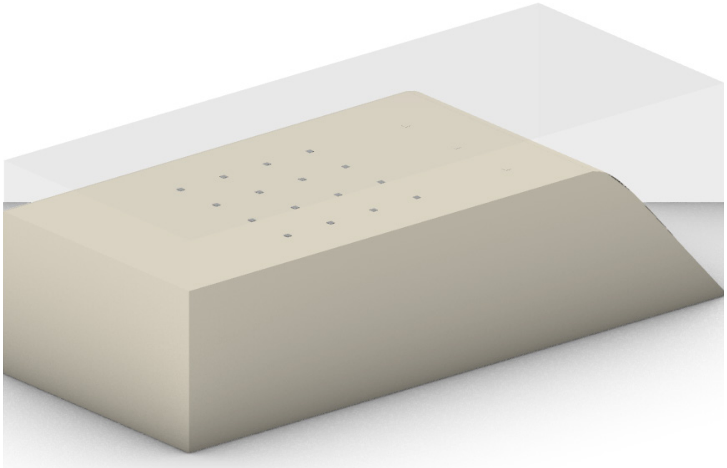
4. Floating elements can be taken away and extra PET elements can be added increasing the height of the barrier

# Build-up sequences | *all construction phases*

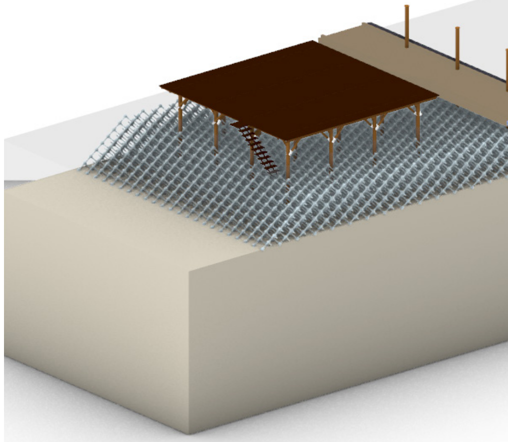


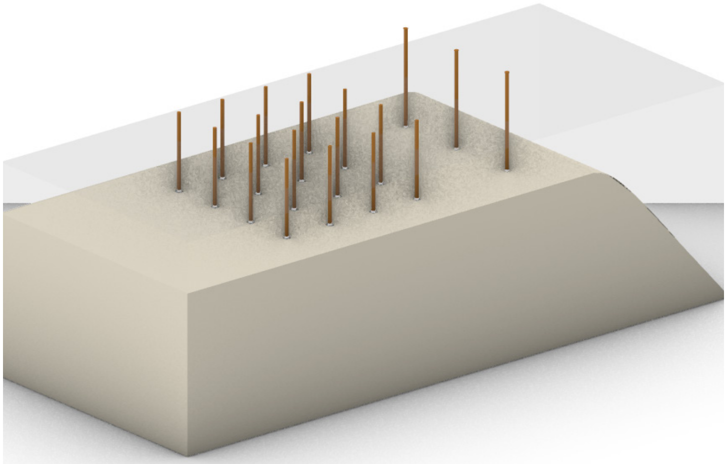
1. Prepare and clean up the sea bottom before construction phase



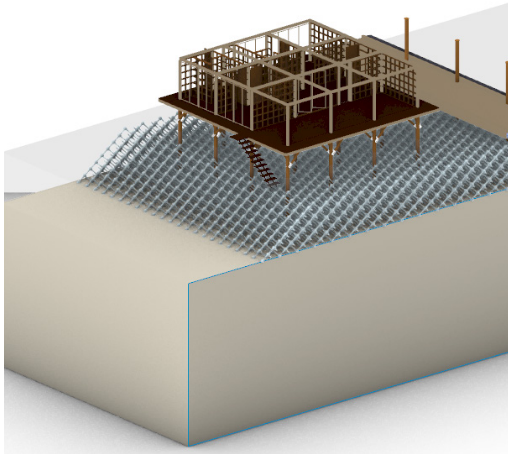


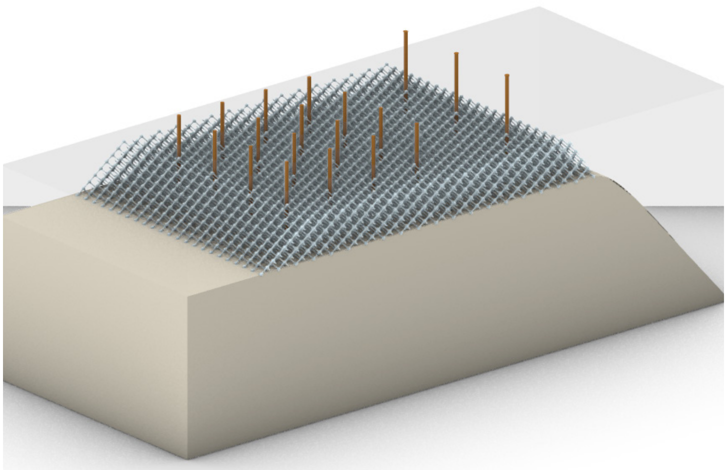
2. Add foundations to the seabottom



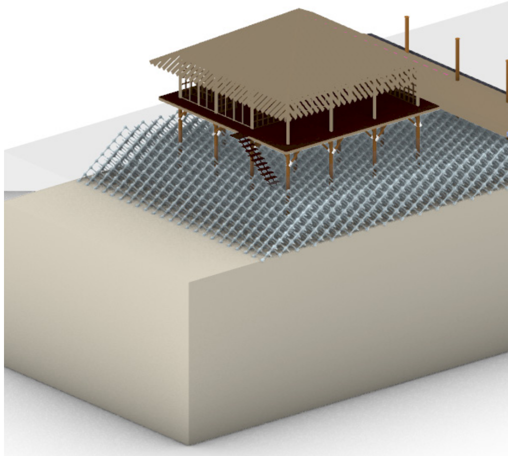


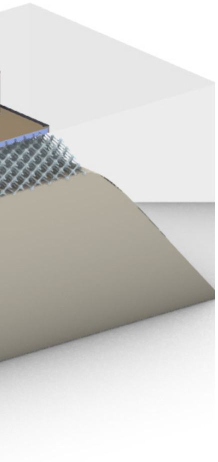
3. Columns are placed on the new foundations



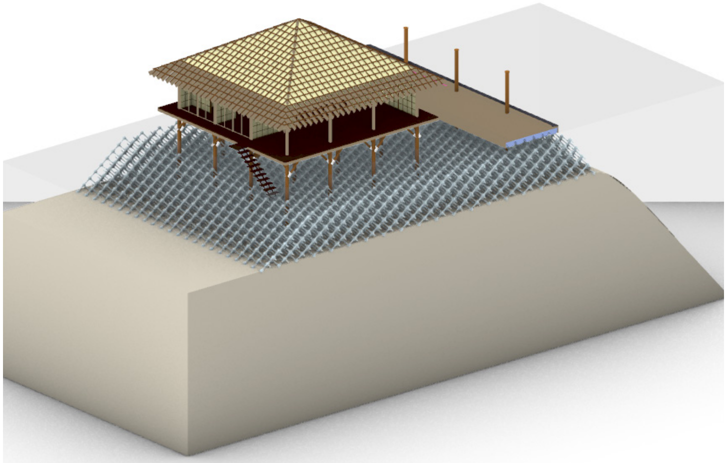


4. Build entire PET reef around the island and attach to columns

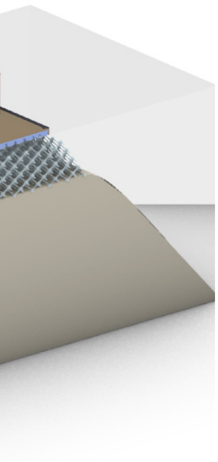




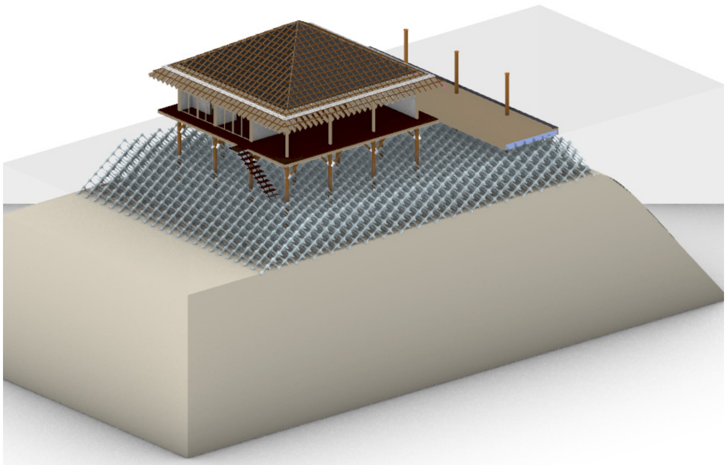
5. Apply stability bracing to columns and add deck



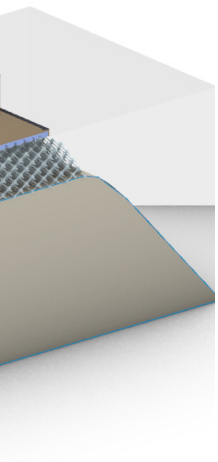
9. Apply insulation in roof and walls



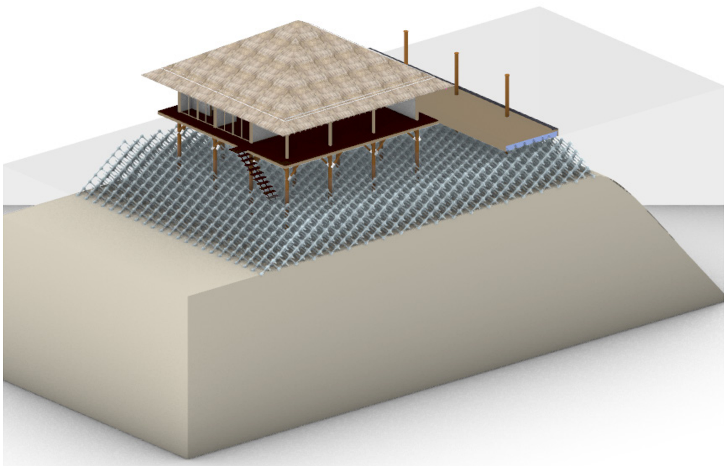
6. Connect floor construction to the columns and stability bracing



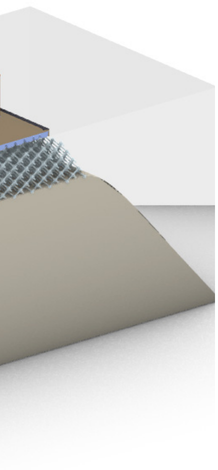
10. Add water drainage in the roof. Add water resistant and moisture blocking foils. Add plasterboard



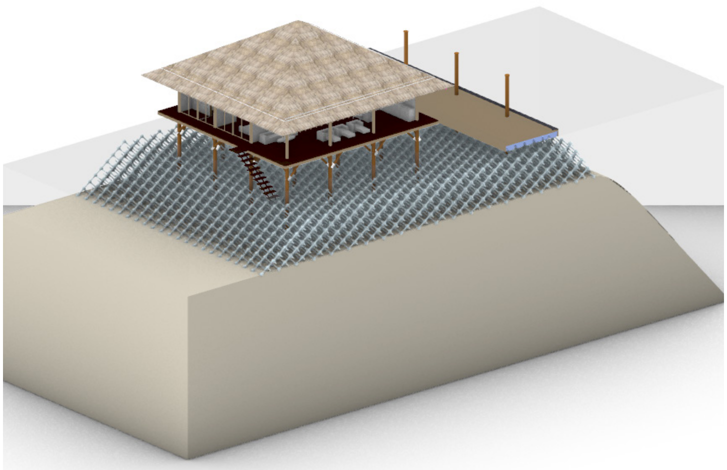
7. Place timber loadbearing wall construction



11. Finish roof and facades with palm fronds



8. Add the timber roof construction



12. Add glazing and furniture

# Applicability | *design system applied to other islands*

To ensure the viability of the designed system on other islands, it is important to set specific requirements. Requirements outline criteria other islands need to meet for an optimal results after the implementation of the design.

The design contains flexibility as it is able to be applied in different shapes of the islands.

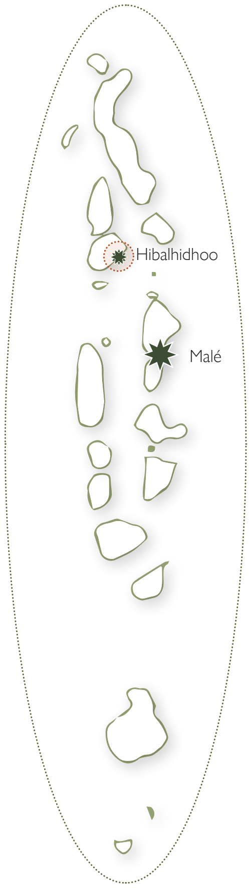
***Requirements:***

- *Islands located on the edges of atolls*
- *Built on coral stone/ coral reef location*
- *Depth of the coral reef location between 3 to 10 meters*
- *Water depth enough/ not too deep*
- *Island shows coastal erosion*
- *Islands where ecosystems are struggling (on and off shore)*
- *Sea currents dependent*
- *Facility islands nearby or possibilities to create*
- *Sizes of islands and reefs need to be comparable to the example island of the design*

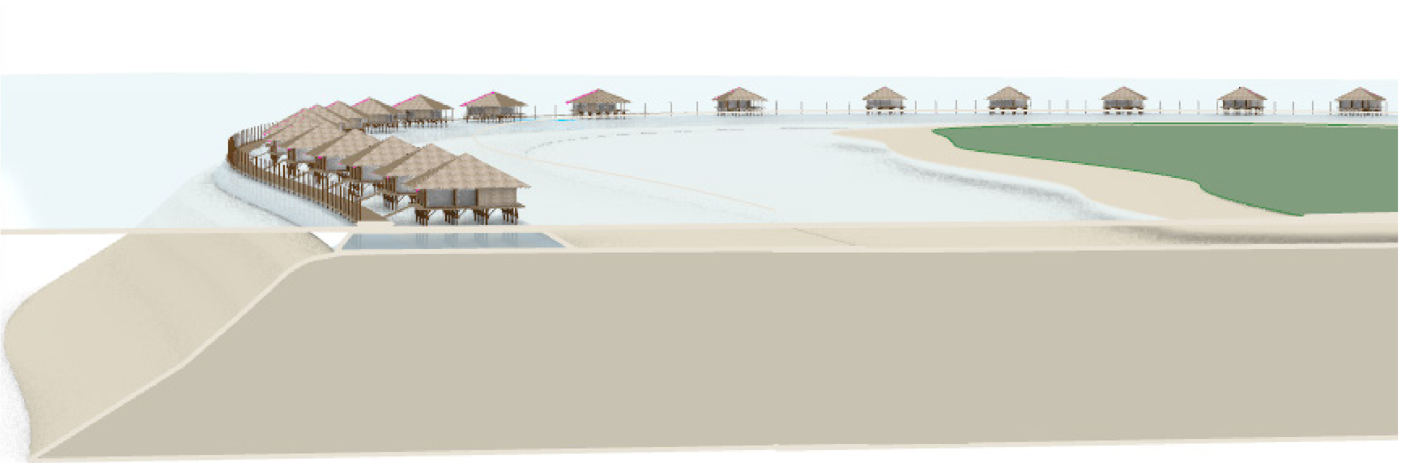
When it is desired to apply this system to other islands in different zones on the planet, it is important to take different climates, different severe weather types, and conditions into account. It needs to be adjusted to be able to cope with the changed circumstances and conditions.

Regarding the future, the design is flexible to transform and adapt into a system designed for local inhabitants instead of tourists. Simple adjustments in building functions, such as converting the spa into a school or repurposing the lobby as a community centre or grocery shop, will create a living environment that addresses the needs of the local population.
The concept of the goathi is already incorporates elements of the traditional architecture of the Maldives. Additionally, the goathi's are partly self-sufficient and utilize low tech solutions.
Having the local population living in a system such as this, the awareness of sustainability will be raised and will be playing an important role in the daily lives.

# Applicability | *design system applied to other island - Hibalhidhoo*

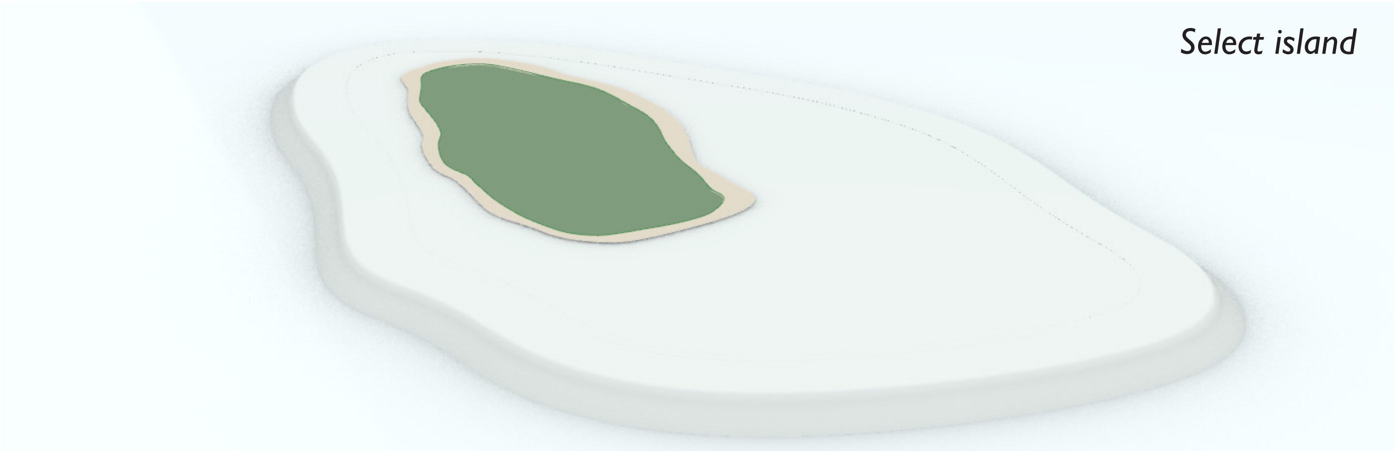

Google Maps image of Hibalhidhoo | Fig. 22

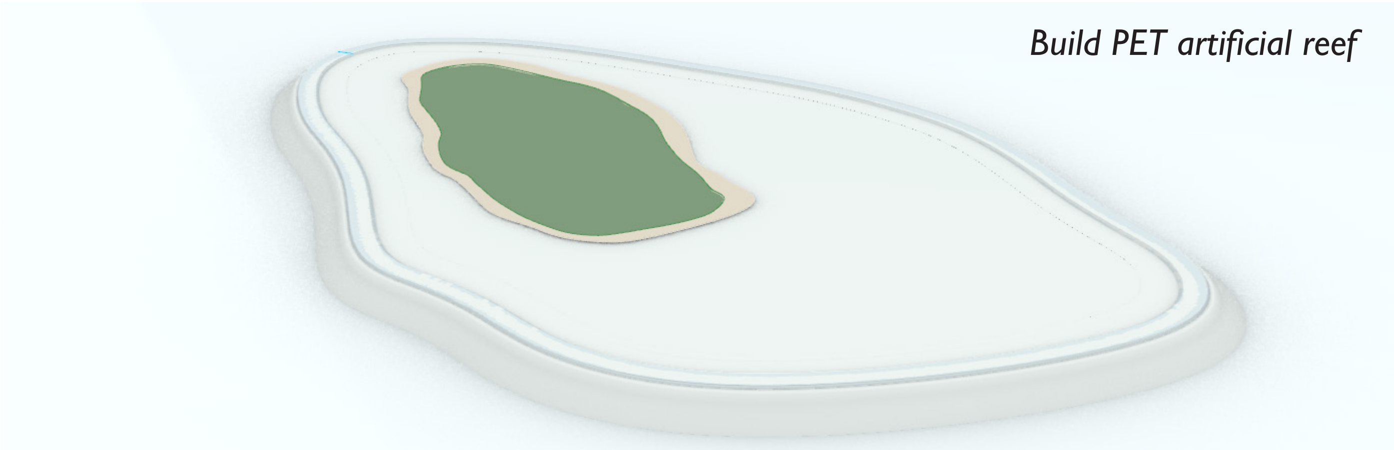


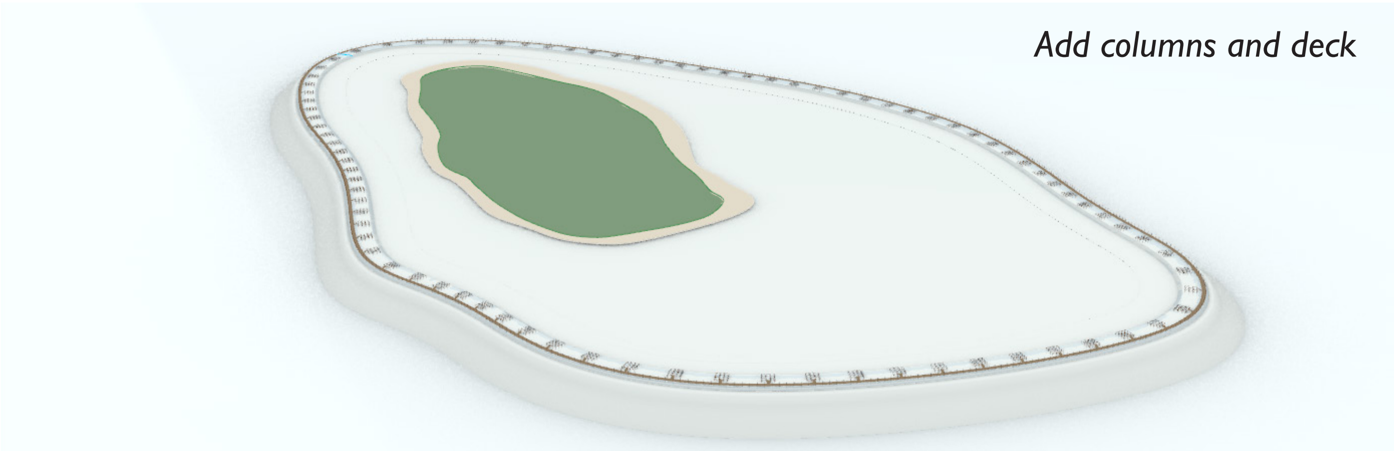
Section with applied system on Hibalhidhoo | Fig. 23

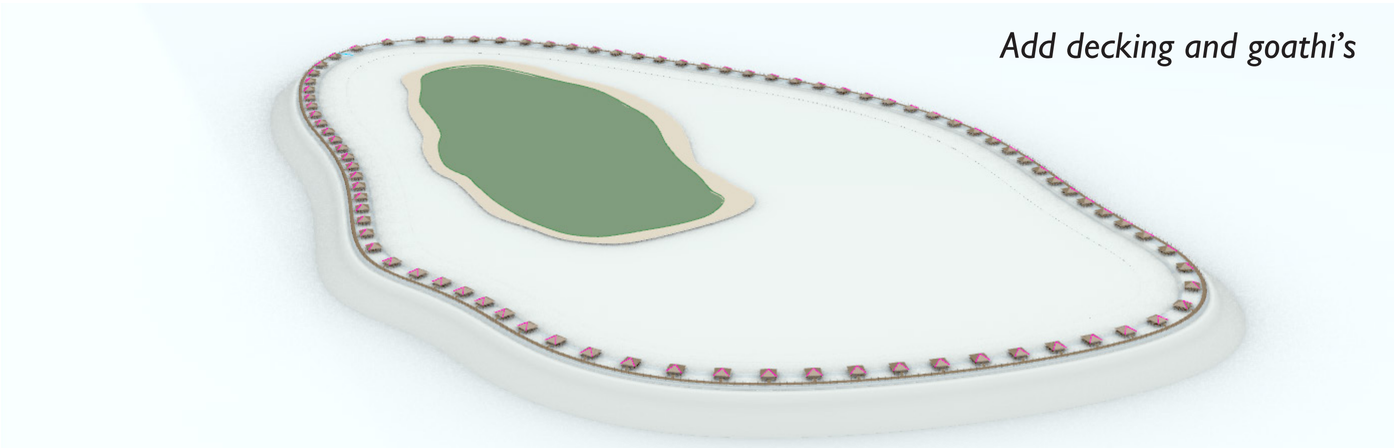
***Requirements met:***
- Island located on the edges of atolls
- Built on coral stone/coral reef location
- Depth of the coral reef location between 3 to 10 meters
- Water depth enough/ not too deep
- Island shows coastal erosion
- Sea currents dependent
- Facility islands nearby or possibilities to create
- Shape of the islands do not matter
- Sizes of islands and reefs need to be comparable to the example island of the design

# Applicability | *Hibalhidhoo build-up*



# 10. | Tourism |

*Eco-tourism & taxes*
*Resort pricing rates*
*iMaldives*
*Nature as selling point*
*Safety*

# Eco-tourism & taxes | *the basic definition and concept*

### *Eco tourism*

The definition of ecotourism is defined as follows: “responsible travel to natural areas that conserves the environment, sustains the well-being of the local people, and involves interpretation and education” (TIES, 2015). (TIES, 2019) With education staff and guests both included.

The key ingredients of ecotourism are conservation, communities and sustainable travel. Guidelines are set to uphold the principles of ecotourism and now only need to be implemented, participated in and promoted.

Conservation is based on long term solutions offering economic incentives for the conservation and enhancement of bio-cultural diversity. By promoting sustainable travel the natural and cultural heritage is preserved and protected while simultaneously benefiting local economies and communities. (TIES, 2019) Worldwide local communities are empowered by ecotourism in their fight against poverty and to pursue sustainable development. Communities are able to actively participate in and benefit from ecotourism as it increases local capacity building and opportunities in employment. (TIES, 2019)

Creating environmental awareness and enriching personal experiences through interpretation is what ecotourism strongly emphasizes. By connecting with nature, local society, and culture, ecotourism encourages a deeper understanding and appreciation. (TIES, 2019)

### *Eco/green tax*

Increasing the green tax for tourists can be an effective way to cover external costs and promote sustainable practices. By incorporating the costs of environmental services and damages into the price of activities, services and goods. These taxes can be used as incentives to encourage tourists administrators to adapt towards a more eco-efficient mindset and to stimulate innovation. (EcoTaxes, EcoCharges, Fees, z.d.) In addition to that, the profit from these taxes can be specifically allocated to improve environmental quality and expand the basic offerings of tourist destinations. Funds can be utilized for activities such as beach and coastal area clean-up, sea and water quality control, municipal waste management, preservation of natural resources, and protection of marine and shallow waters. In the end the implementation of eco-taxes creates incentives for responsible tourism and contributes to the conservation of the natural environment. (EcoTaxes, EcoCharges, Fees, z.d.)

# Resort pricing rates | *quick insight of the expenses and taxes*

***JA Manafaru Maldives***
***Eco-resort:***
Water villa for 2 persons
Average price/night:

- Jun: $ 340
- July: $ 340
- Aug: $ 340
- Sept: $ 370
- Oct: $ 660-750
- Nov: $ 750
- Dec: $ 710-2380
- Jan: $ 980-1700
- Feb: $ 900-1020
- Mar: $ 870-1000
- Apr: $ 790-910
- May: $ 370-710

***Fairmont Maldives - Sirru Fen Fushi***
***Resort:***
Water villa for 2 persons
Average price/night:

- Jun: $ 640
- July: $ 640
- Aug: $ 640
- Sept: $ 640
- Oct: $ 680
- Nov: $ 680
- Dec: $ 680 - 2550
- Jan: $ 1460-2260
- Feb: $ 1460
- Mar: $ 1400
- Apr: $ 1400
- May: $ 1400

The price range of 5 star resorts and 5 star eco-resorts in the Maldives, differ a lot throughout the year. Both the resorts meet similar price per night rates during holiday season.

It does come across as counterintuitive that eco-resorts often charge lower rates compared to conventional resorts as they are both 5 star ranked resorts. This pricing structure is designed to incentivize and reward sustainable choices. The lower costs reflect the commitment of eco-resorts to prioritize sustainability over excessive profits. While tourists are paying less, tourists are making a more sustainable choice.

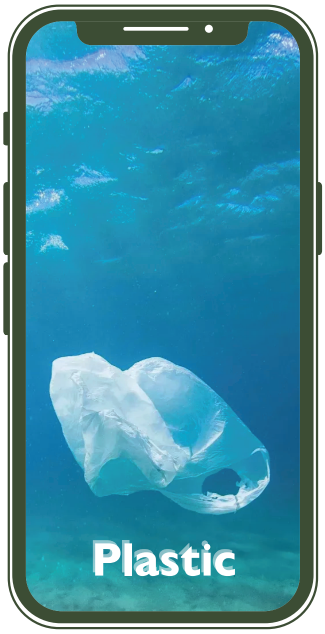
Despite the large price ranges, the green tax stays for both type of resorts the same throughout the year; only $ 84 per week, per villa. Unfortunately this tax amount is a tiny fraction of the entire expenditures of tourists. This needs to be changed.

To ensure long-term sustainability and future proofing, a suggestion would be increasing the costs of the eco-resorts and a green tax difference depending on the type of resort. The profit balance of the eco-resorts needs to be kept the same as the excessive money can be used in important initiatives such as extra waste treatment and recycling facilities, the construction of goathi's and the artificial reef around the islands, and all other sustainability related activities. This approach allows tourist to see first-hand where their money is being invested and that they take part in the preservation of the Maldivian islands and holiday destinations. It offers a sense of engagement and awareness of the impact one can make as an eco-tourist while fully enjoying their stay on the beautiful and cultural Maldivian islands.

# iMaldives | *application design with all information for tourists*


## *Goathi*

- *All info about the goathi*
- *Traditional features*
- *Indoor climate*
- *Water consumption*
- *Water collection*
- *Electricity consumption*
- *Electricity generation*
- *Nature inclusive design*




## *Plastic*

- *Consumption per day*
- *Waste per year Maldives*
- *Recycling facilities*
- *PET reef construction and production*
- *Average footprint*
- *Timeline/live stream of a new recycled reef*


## *Weather/climate*

- *Daily weather forecast*
- *UV intensity*
- *Climate*
- *Sea water temperature*
- *Changed climates*


## *History*

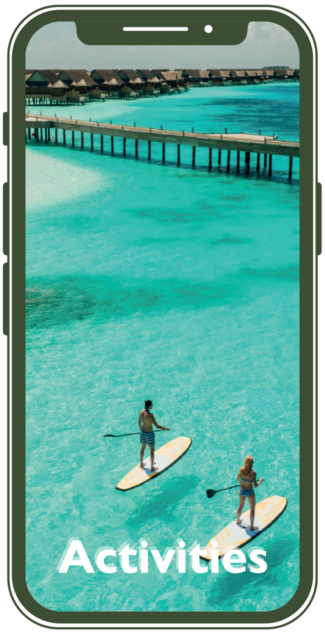
- *Changed waterlevels*
- *Extinct species*
- *Coastal erosion impact*
- *Untouched nature*
- *Maldivian culture*
- *Maldivian architecture*


## Delivery service

- Food delivery
- Room service
- Wake up calls

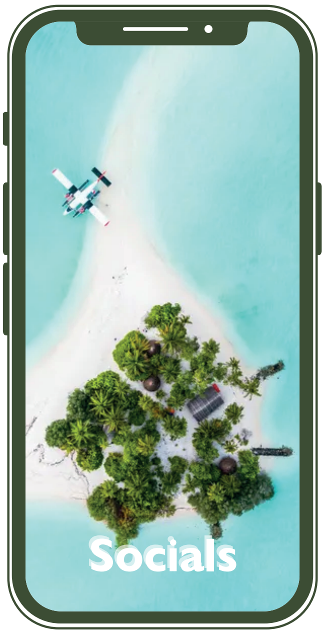

## Maldives

- Island information
- Effects on worldlevel
- Flora and fauna
- How to help recovery?




## Activities

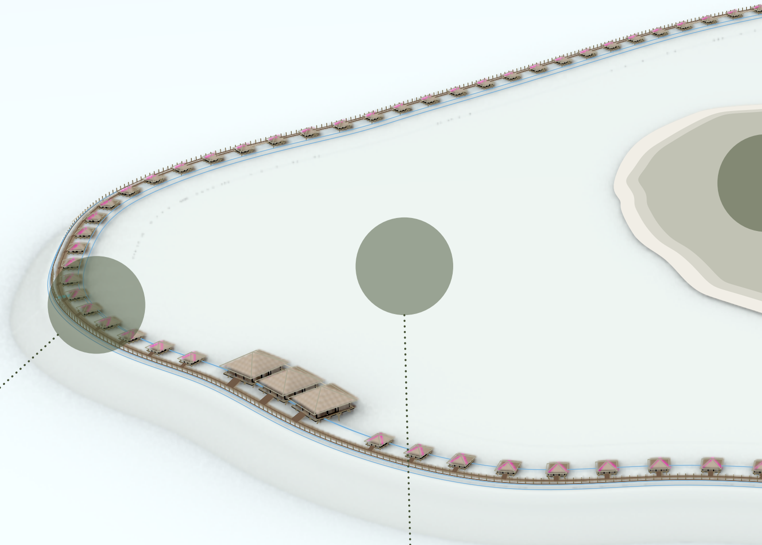
- Daytrips
- Educational trips
- Relaxing
- Work-outs
- Watersports
- Food experiences
- Special Maldivian experience




## Socials

- Instagram
- LinkedIn
- Facebook
- TripAdvisor
- Tiktok

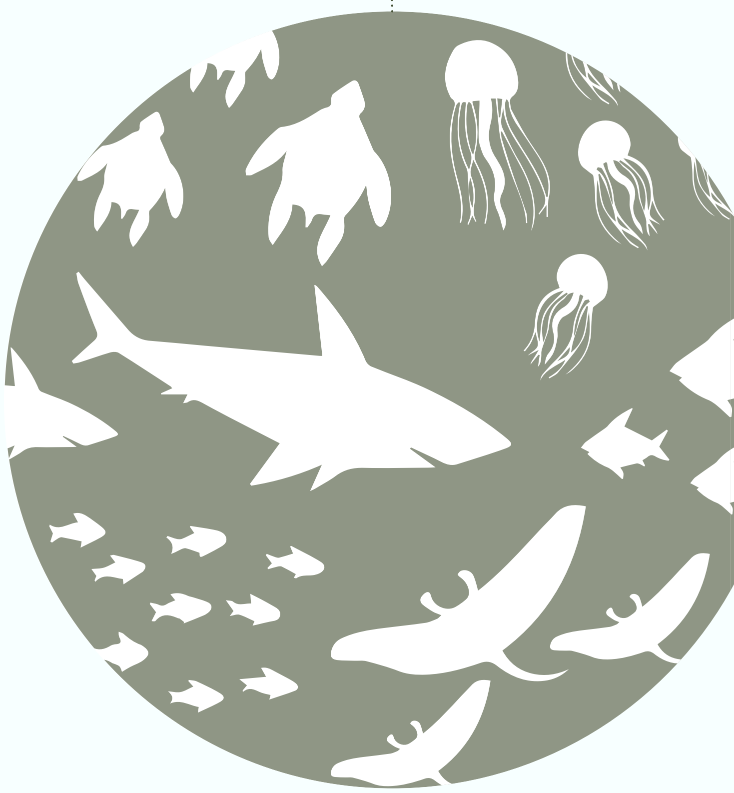
# Nature as selling point | *boosting recovery of different ecosystems*



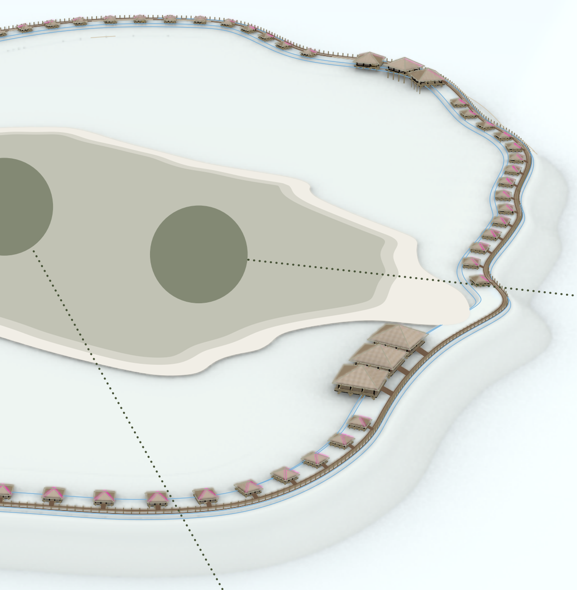
## Artificial coral reef

*Underwater ecosystem - flora*
*| Corals and plants |*

## Lagoon



*Underwater ecosystem - fauna*
*| Sealife and living creatures |*



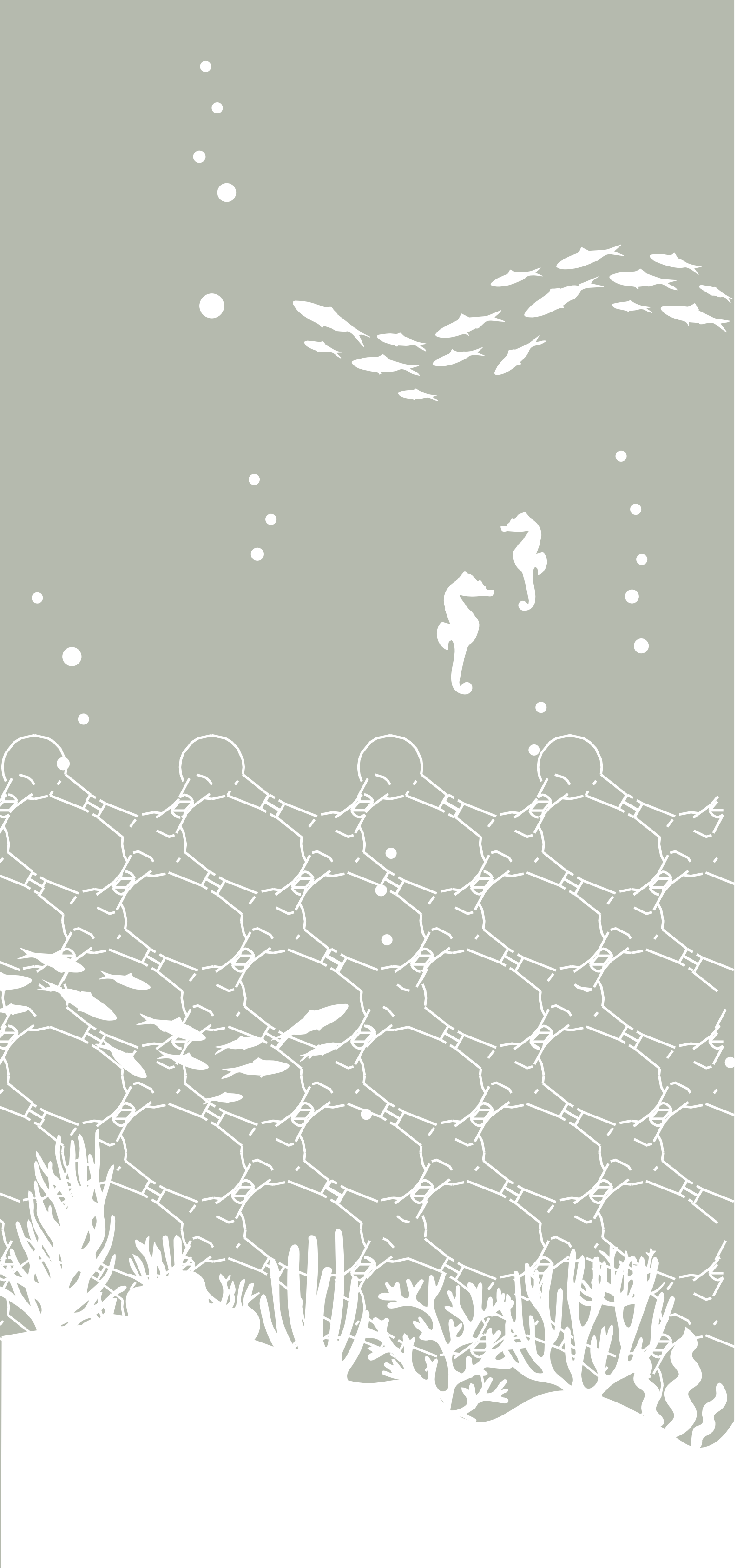
## On the island

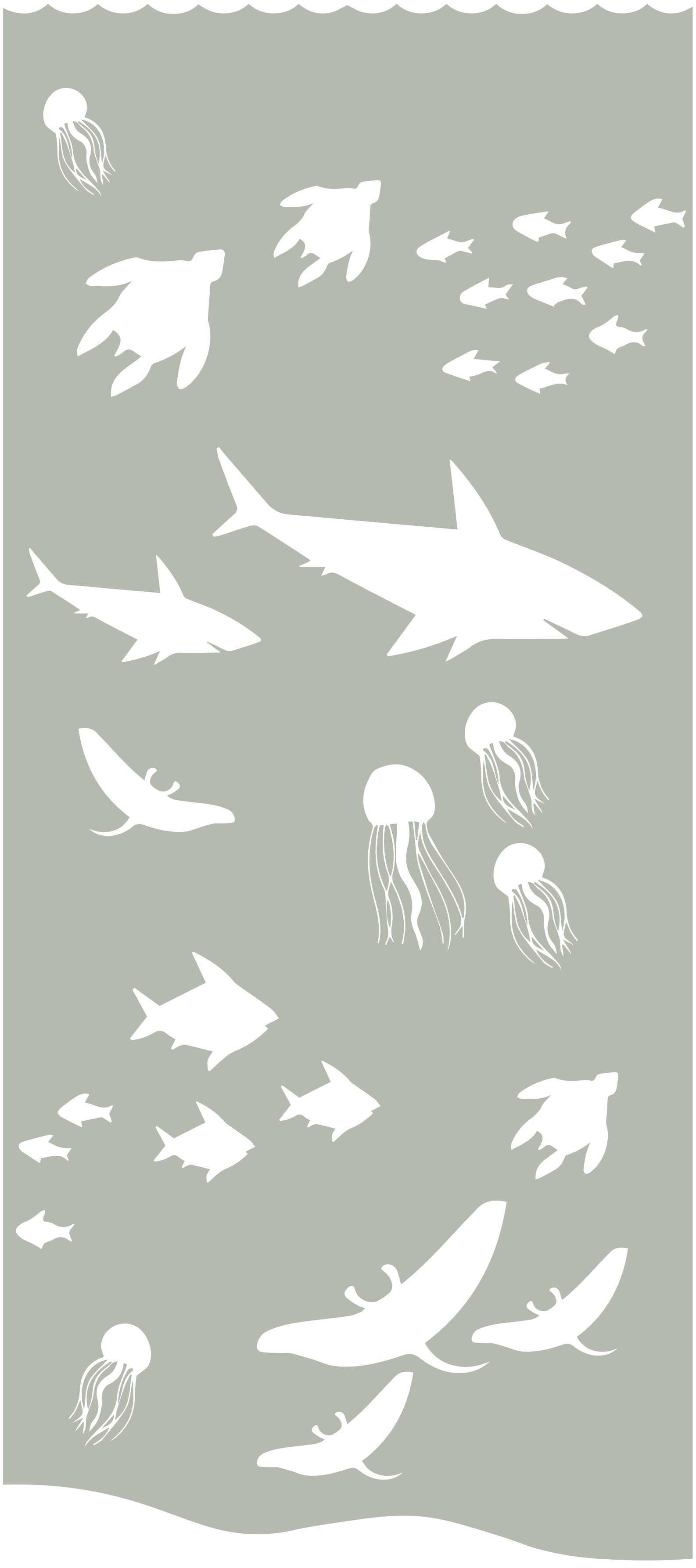
*Onland ecosystem - flora*
*| Plants and trees |*

## On the island

*Onland ecosystem - fauna*
*| Tropical animals and living creatures |*

# Nature as selling point | *underwater and onland world*





***Underwater ecosystem - flora***
***| Corals and plants |***

***Underwater ecosystem - fauna***
***| Sealife and living creatures |***

***Onland ecosystem - fauna***
***| Tropical animals and living creatures |***

***Onland ecosystem - flora***
***| Plants and trees |***

# Safety | *evacuation plan outlines*

An evacuation plan is required when an extreme circumstance or weather conditions are approaching the island. The most effective way to protect the people, buildings and island itself as much as possible is by understanding how the extreme circumstance is detected, how the information is communicated to people, and by what guidelines or instructions need to be followed.

Starting with becoming and staying informed. Next to keeping track of the local weather, temperatures and currents, are storm surges and high waves also monitored constantly. However, these can only be accurately predicted a few hours in advance. The National Weather Service, local authorities or emergency management agencies stay alert for warnings in the area.

Once the emergency alert is received on the island, all tourists and all staff need to be notified and updated with the forecasted conditions. This can be done by a mobile phone alert, via the app, or by activating sirens. All people will be instructed depending on the severity level of the upcoming event. When the risk level is high, everyone will be instructed to go to their goathi and gather essentials such as important documents, medication and any other necessary items. Time is of the essence, there must be acted quickly.

To protect the goathi and the resort as much as possible, all loose objects and belongings outside the goathi's need to be secured or brought inside. This way the risk of damage and loss is decreased. Additionally, all doors and windows need to be closed and locked.

Again, depending on the level of severity of the upcoming event, people can go and stay inside the goathi's. If this would be too dangerous, people can follow the designated evacuation routes along the walk deck or can be transported by boat to be brought to a safer space on the island, to the facility buildings or even to other nearby islands with a lower risk. Sufficient boats need to be available to transport all people present in the resort to a safe site.

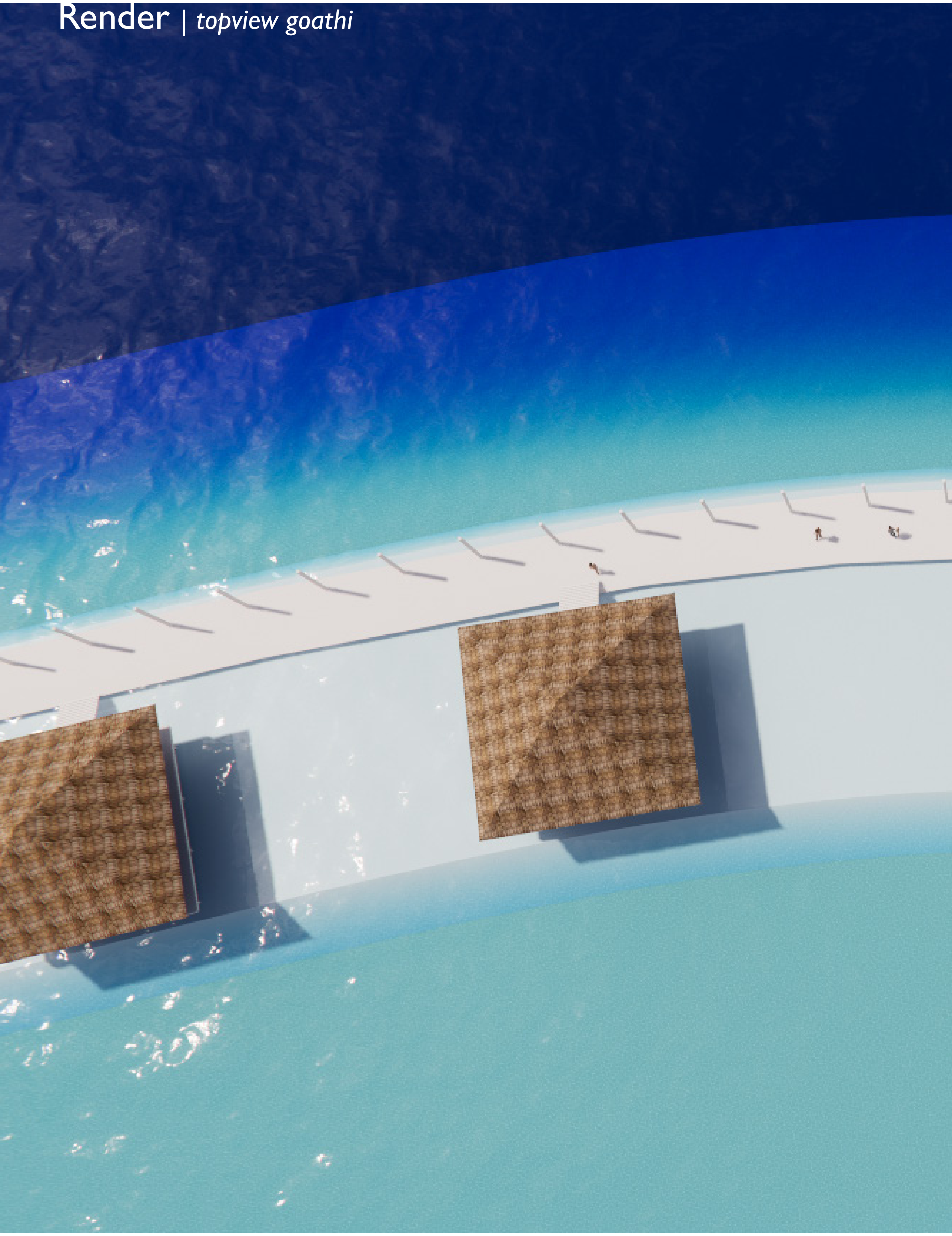
At the emergency assembly point, which is well-equipped with provisions, medical care, and communication devices, a headcount should be conducted to ensure that everyone is safely evacuated.

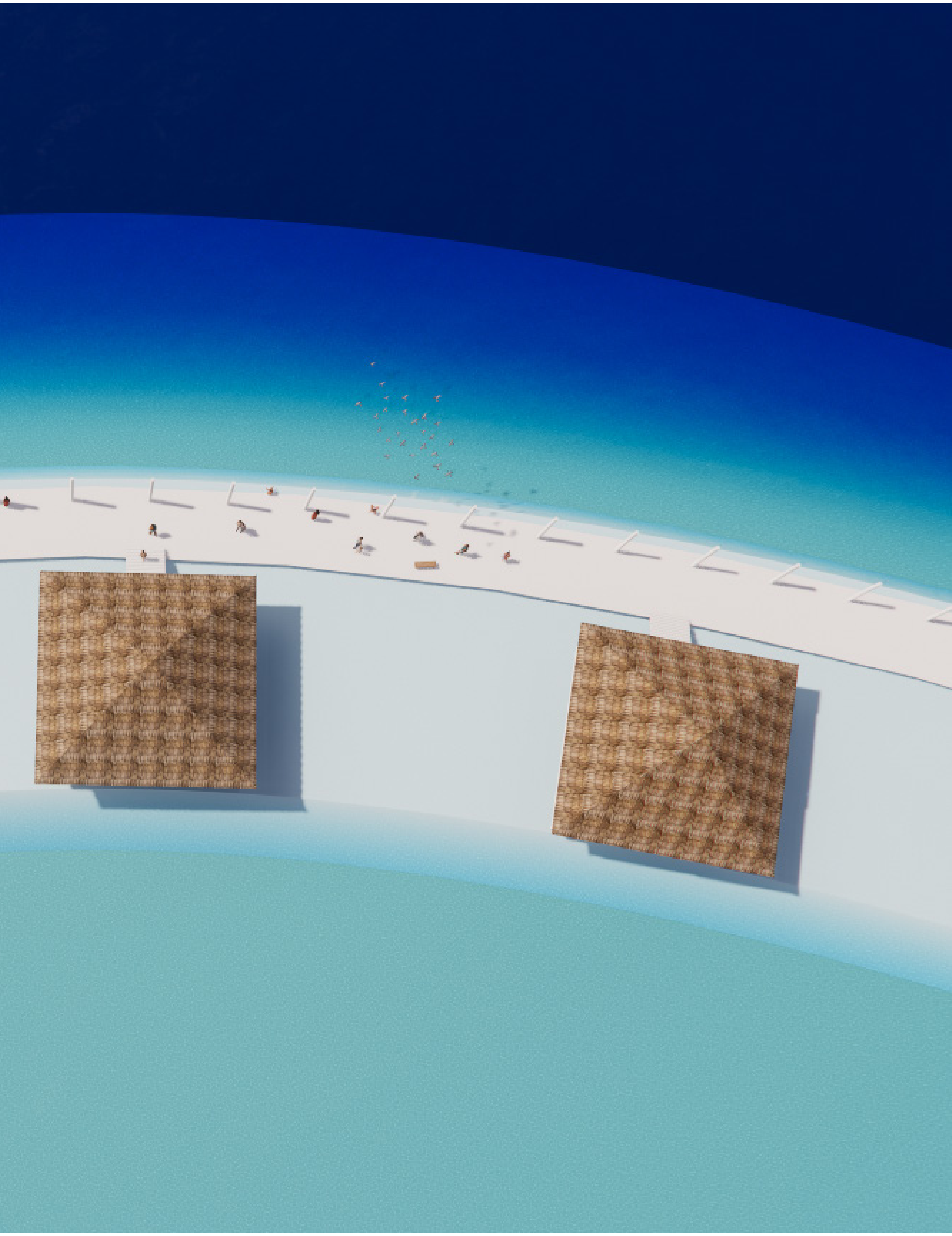
# 11. | Visualisation |

*Island Vangaaru*
*Goathi topview*
*Walking deck*
*View from goathi*
*Island view*

# Render | *island Vangaaru*

# Render | *topview goathi*

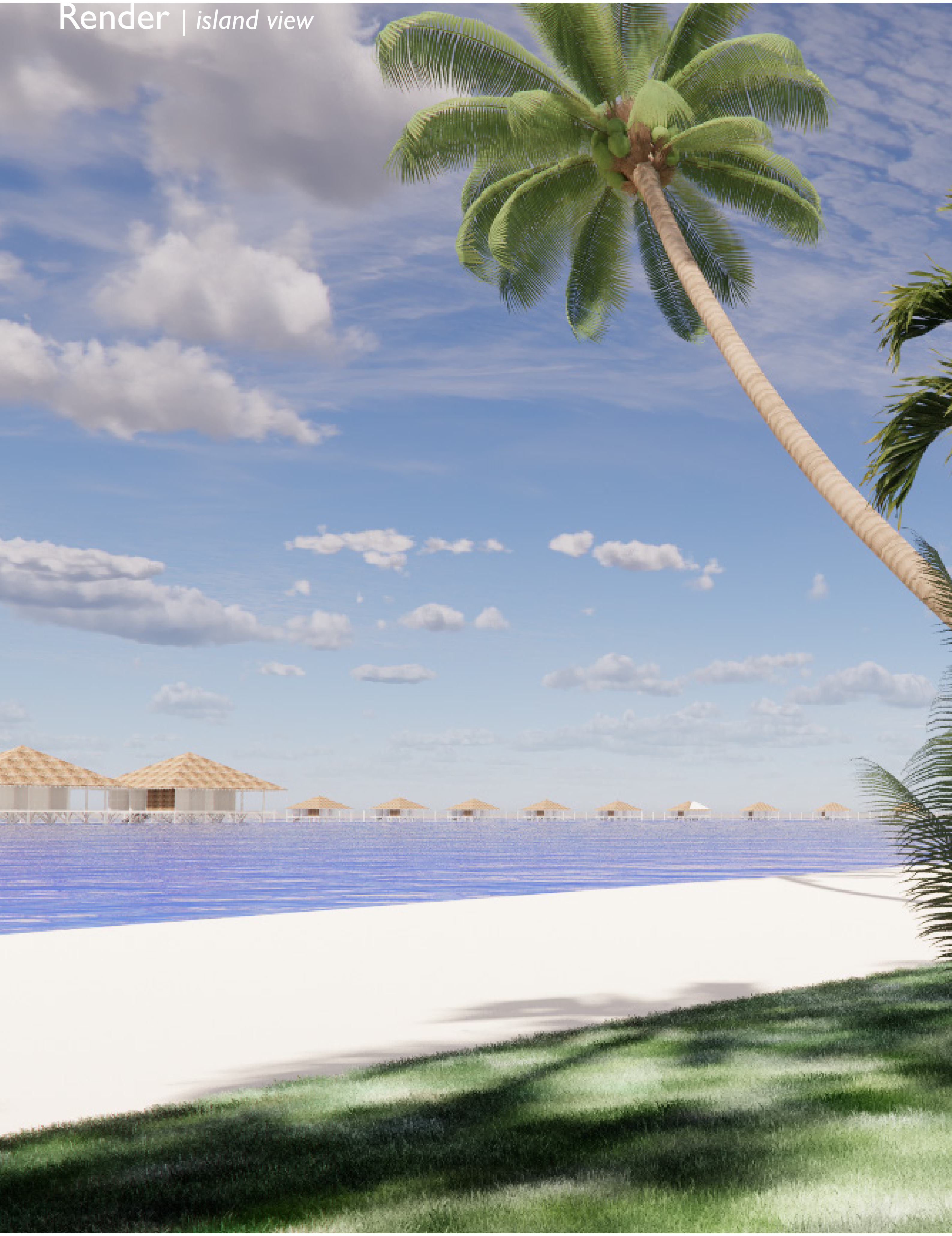


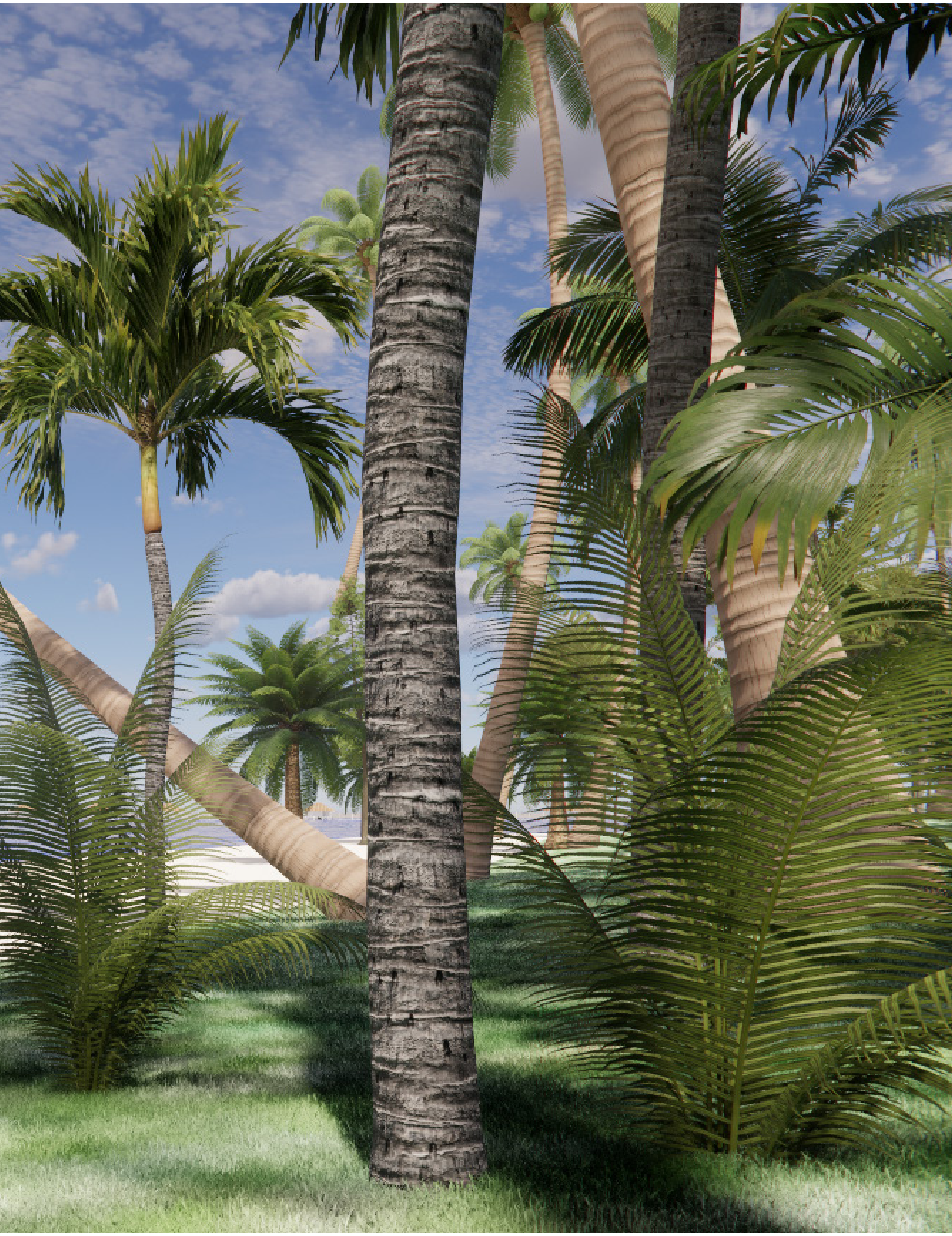


# Render | *walking deck*

# Render | *view from goathi*

# Render | *island view*





# 12. | The end |

*Sustainable development goals*
*Timeline*
*Conclusion*
*Recommendation*
*Reflection*

# Sustainable development goals | *addressed by the design*


# Timeline | *design prognose and time estimations*

2023

***All ecosystems disturbed because of:***
- Waste
- Pollution
- Overfishing
- Floods

***Ocean ecosysten***
- 10 years to cor

G

***Government - client***
- Solutions to problems
- Preservation
- Future proofing
- Economic benefits
- Plastic waste recycling plan
- Job opportunities for population
- Example for the country
- Awareness population/tourism

B

***Building Engineer - designer***
- Create the solutions
- Design decisions
- PET explanation
- Future proofing concept
- Applicability

2020 — 2021 — 2022 — 2023

L

***Locals - requirements***
- Job opportunities
- Preservation of islands, culture and tradition
- Pilot design nearby living area

L

***Locals - jobs***
- Hospitality
- Transportatic
- Management
- Environment
- Farming
- Wildlife keep
- Maintenance

***Set plan in pro***
- New treatme
- Waste collec
- Building site p
- Island farms a

***Onland ecosystems:***

- 42 years to complete recovery

2065

2033

*"If the source of damage is completely removed"*

ns:

nplete recovery

E

***Ecologist - conservation***

- Protect environment and wildlife
- Experiments and lab research
- Fieldwork and research
- Monitor waste in resort
- Monitor the artificial reef weathering
- Inform the public

***"Prepare new islands to apply this system to"***

2025

Future

2025

T

***Tourist - experiencer***

- Eco-tourism
- Activities
- Experiencing culture
- Create awareness

on

al conservation

er

gress

ent facilities

tion

preparation

and greenhouses

***Jobs before resort is finished***

- Construction workers
- Workers at facilities
- Transportation
- Farmers

Future

# Conclusion |

In conclusion, the exploration of creating a future-proof system from recycled plastic waste for the preservation of Maldivian islands has brought remarkable results and outcomes.
The developed system has become a sustainable solution for a resilient future, capable of withstanding increasing extreme circumstances. It includes a design of an artificial reef, acting as a wave-breaking structure, engineered to withstand predicted extreme future circumstances faced by the Maldivian islands. This approach creates resilience to climate change impacts, protection of coastal areas and ecosystems.
The future-proof system has exceeded expectations becoming the solution to multiple problems, addressing not only waste management, but also challenges such as coastal erosion, frequent floods, the influx of tourism and raising awareness among tourists and the local population.
Each aspect of this research is based on a concept and is open for the interpretation and opinions of experts on the specific matter. The design components are suggestions for what is needed in order to accomplish a functional system. It is important to note that modifying one aspect will affect the rest of the system as well.
The material scarcity in the Maldives creates opportunities on innovative solutions. That is why the excessive waste problem has become the solution to the material shortage. A strategy on how to create the wave breaking structure out of recycled PET has been developed and turned into one of the most impactful adjustments.
As the system is a pilot version, its adaptability and applicability to other islands offers a multi-applicable and sustainable island development. Next to that, by promoting ecotourism, the system can attract environmentally conscious tourists, leading to economic benefits and job opportunities, while raising awareness about waste management and environmental conservation.
By including the traditional Maldivian architecture and culture into the design, opportunities are created to house changing users in the future. When circumstances change, the possibilities in adjustments to the goathi construction show future-proofing on a more detailed level.
This research provides a strong foundation for the development and implementation of a future-proof system that contributes to the preservation and protection of the Maldivian islands. The potential of recycled plastic waste and integrating it into a design creates a step to a more sustainable and resilient future for these vulnerable islands and its communities.

# Recommendation |

This research project primarily focusses on a swift solution that should also have the ability to function in the future. It is a short-term solution that is intended to naturally develop into a long-term solution.

Further research can be done to expand the pilot version to other islands. When implementing the system on another island, it needs to be adjusted to meet the required and preferred needs of the new users. Example, When  the type of users is being changed from tourist to local population, facilities such as schools are required.

Regarding the PET reef development and durability, additional research is necessary to examine the  degradation of the recycled PET plastic in these specific shapes and marine conditions. The larger the objects and lower exposure to UV radiation, the PET will barely experience degradation.
Addtionally, when looking on a 50 year timeframe, what will the reef look like? Has nature taken over creating a protection film of algea around the structure? If the degration level proves to be too severe, should new protection measures be implemented?

The impact of the large wave energy on the PET reef should also be researched and tested. What will the sea bottom look like in several years after installing the reef around an island?  Will there be increased erosion on the bottom of the reef? Will sand accumulate within the structure, forming underwater dunes?

Lastly, as previously mentioned, this system serves as an example, including concepts on multiple topics. Each concept remains open to the knowledge and research of experts on the specific matter.

# Reflection |

*1. What is the relation between your graduation project topic, your master track (Arch, Urb, BT, LA, MBE), and your master programme (MSc AUBS)?*

The relation between the final output of this research project and the Building Technology master track is present throughout the entire research. It addresses to multiple disciplines levels of detail in solving building technology related problems.

The graduation topic is a mix of different courses, which were on the curriculum of the Building Technology master. Examples included the Buckylab and Extreme technology and the SWAT course. The whole island system can be seen as a product which can be applied and can solve an even broader range problems. The product related development touches the workflow and mindset of the Buckylab course. It addresses to technical and architectural aspects. The optimization of the design was found in detailing and in the fabrication of models. Additionally, dealing with extreme circumstances as excess waste and climate change effects is not an easy task to solve. It requires thorough research and common human sense. The design has an end-goal of future proofing and becoming a solution to multiple problems.

**2. How did your research influence your design/recommendations and how did the design/recommendations influence your research?**

At a certain point, there is no more time left to research deeper into every aspect of the project. I believe that time has a large influence on either the design as well as the recommendations. Given the broad scope of the research, it has created lots of opportunities for further research.

However, due to research, I found out there is all these different problems on the Maldives. Problems which later on became solutions in the design. Because this research is focused on one location, the Maldives, the country that needs solutions to their problems as there is no solution available, it is understandable that extensive research beyond my research is necessary in handling these life and country threatening problems.

During my research, I came across some other interesting graduation/PhD topics or topics in departments other than architecture and the built environment, such as civil engineering. These topics include investigating the effect of the seawater on PET plastics, the effect of the wave energy on the PET reef in its resistance, or the accumulation of sand on the sea bottom. Questions that erose; are under water dunes created over time? How is the material weathering in these conditions? are extra measures necessary to make sure the material does not degrade into microplastics? As there is only limited time on the graduation studio, I have to add these research topics to the recommendations.

*3. How do you assess the value of your way of working (your approach, your used methods, used methodology)?*

In the beginning of the graduation studio I was struggling to find the right scope. Further in the research I found out that the Maldives are struggling with much more than just floods. By making some 'dramatic' design decisions, even more solutions arose. From the moment I found out that there was a strong need in finding new solutions to prevent the Maldivian Islands from disappearing, I started researching and designing on live changing solutions.

The approach went from literature research to designing. While designing information was missing, so I went back into the literature again. By going back and forth between designing and literature research I created a solid and

reliable base to build further research on and open up design solutions and possibilities.
Keeping the research relatively broad, rather than very specific, has made it possible to create an comprehensive system for an entire island. Additionally, a broader scope has allowed for thorough exploration of various aspects on different detailed levels.
The system is based on literature research and research by design. The designed concepts together form the system/strategy which is open to the expertise of specialists on the specific matter.
The overall design is providing an example system and strategy for Maldivian Islands. It is addressing as much as possible to problems the islands are facing. Additionally, the design decisions are specifically made to create multi-applicability to other islands. This has been done intentionally for expanding the research to different locations of the country.
Some well thought out choices or assumptions had to be made. This has only been done after thorough research and through reliable sources. Regarding future predictions, there is always a lot of data available. The data is evaluated, selected and used in the design.
What would have been interesting is, to be able to visit the islands, talk to the local population and government to hear all of their different opinions. In this research, the opinions and ideas of these stakeholders are retrieved from existing interviews. It would have been valuable to obtain the information first hand.
However, this system is ready to be passed onto the next specialist.

***4. How do you assess the academic and societal value, scope and implication of your graduation project, including ethical aspects?***

The overall design also has its effects on different scale. The entire system ensures that the islands of the Maldives remain habitable. The local population will not have to move or flee from their living environment because of global warming any time soon. The design respectfully considers the local population, culture, tradition and ecosystems and ensuring their welfare. Benefitting in job opportunities, the promotion of sustainable tourism, and the conservation of cultural heritage. All resulting in a positive environmental impact.
The research gap that I came across is the fact that, lots of research is about flood proofing, but is not location specific, nor has it possible solutions to the other problems the Maldives are facing. Existing research fails to provide viable solutions. The problems on the Maldives are pressing, the circumstances are changing very quickly, we need a solution right now and not waiting for a distant future as it could be too late. Consequently, the research scope is specifically focussed on the Maldivian islands.

***5. How do you assess the value of the transferability of your project results?***

The output is are designs on a broader level, by implementing a coastal defence construction out of local waste material, the problems of waste, coastal erosion, and frequent floods are all tackled at once.
Looking at a building level, the preservation of traditional architecture, tourism, and the ability of maintaining a living environment for the local population is incorporated and secured. The houses (goathis) are built according to vernacular principles and make use of some technology to become as self-sustaining as possible.
The combination of designing through multiple scales and levels shows that there is dependence and cooperation between each level and needs to be thoroughly researched and designed to ensure optimal efficiency of the system

# Reflection |

This research provides a solid foundation for the development and implementation of a future-proof system that can contribute to the preservation and protection of the Maldivian Islands. As said before, it is ready to hand this research over to the next specialists whom can elaborate further on the design and implement their expertise.

***6. How did your research incorporate sustainability?***

The main focus within this research is addressing to are reuse and preservation. The steps to go from collecting to the processes of recycling. The most suitable reproduction process is investigated and included in the research. The carbon footprint is kept as low as possible by reusing local waste, recycle it locally, and applying the newly reproduced products locally.

The target group is promoting sustainable tourism. The system is a way of creating sustainability awareness among tourists and local population.

In the architecture the principles of self-sustaining buildings are integrated. Solar energy, water collection and filtering, as little energy consuming installations. The focus was on the passive side of buildings. Incorporating the vernacular principles in the design of the buildings, the buildings are as passive as possible in this type of climate.

***7. How has the research project and graduation studio impacted the progression of the research and personal development?***

My seven-year journey in the study of architecture and the built environment has been filled with challenges, highlights, confrontations and passion. I found out what my strength, weaknesses, opportunities and threats are. Especially during the Building Technology masters I found out where my preferences lie. Through the courses of Buckylab and Extreme I learned that being challenged in thinking out of the box and knowing that your design can make an enormous difference to the people who are in need of help. The idea of translating my findings into concrete applications, excites and motivates me in exploring further.

In the beginning of the research process, my enthusiasm caused my mind to overflow. I started sprinting through tons of research, not specifically knowing what I was researching on or what direction I was going for. This enthusiasm turned quite quickly in to my downfall as it was difficult to settle on one specific topic. I struggled to find the right focus and took my time finding out that working on a research project is not a sprint race, it is like a marathon.

My mentors, Marcello and Job, were the ones who challenged me, pushed me and engaged in some fruitful discussions. They both possess a great and similar amount of enthusiasm and creativity. I am thankful for their feedback and support they provided during the past months. They were the ones challenging me in thinking even bigger, more out of the box and throughout many layers of detailing. After every consult I was able to investigate deeper into some topics and find the limits and opportunities. From which I learned to not be afraid to go deep into research and explore as much as possible. And to not make assumptions to easily, but first find viable research.

Throughout my research project, I have learned tremendously. Not only have I gained academic knowledge, but I have also developed skills that will be valuable in my future career. This year has shown me the hard way, that it takes and creates a great deal of discipline, motivation and solution based thinking. I strongly believe that I have grown as

# Reflection |

a person. I discovered that perseverance and the right support are crucial in overcoming setbacks and achieving success. Working independently for eight months has proven to be challenging.
With my building technology background and my enthusiasm as my driving force, I am going to utilize my knowledge and skillset in the future to make a positive impact in this world.

# 13. | Literature |

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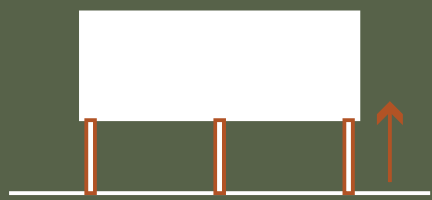
# 14. | Appendix |

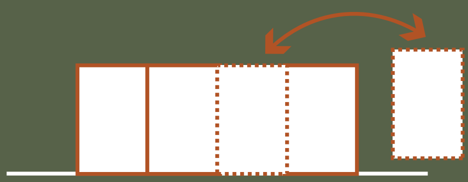
# Appendix A | *Vernacular flood resilience interventions*


basic building example


massive walls, lightweight construction on top

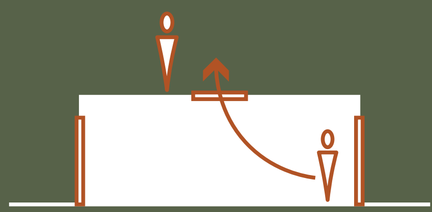

lift foundations to prevent construction rot


build on stilts, when available

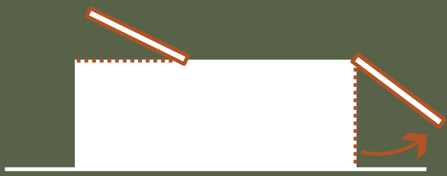

small annual adjustments, constant building repair


raising ground level


create floodwalls or use sandbags


escape/access route to next level or roof

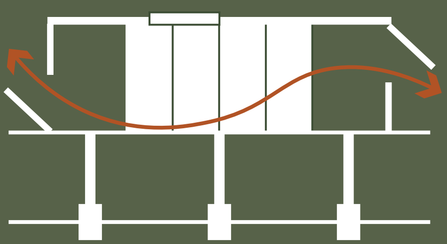
# Appendix A | *Vernacular flood resilience interventions*



moveable parts or functions

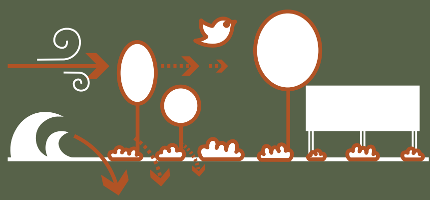
deep porches/overhangs, natural ventilation


one story design

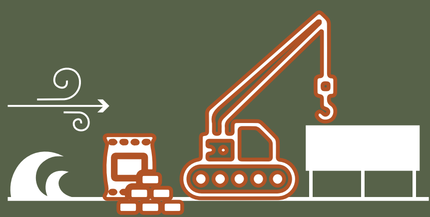


everything combined

basic floodplain example



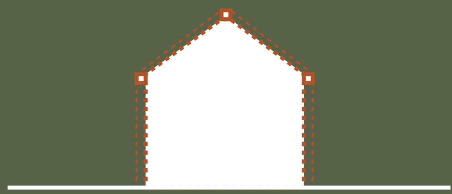
restore floodplain ecosystems, acts like a sponge that retains water and absorbs it into the ground



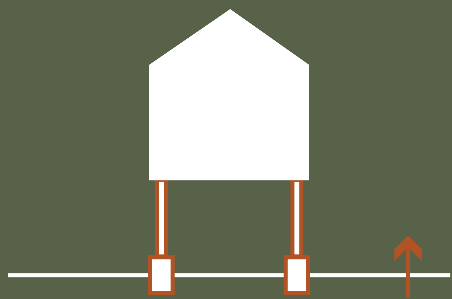
building materials properly chosen and matched to site conditions, will help the buildings stay drier

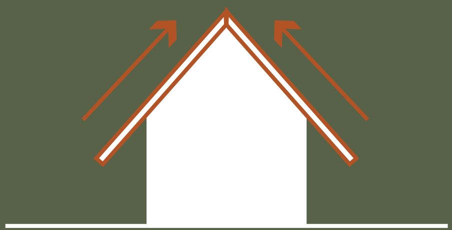
# Appendix A | *Vernacular heat & humidity resilience interventions*


basic building example

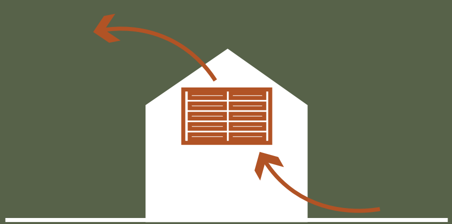

open skeletal frame construction


extensive roofs


stone foundation to elevate posts above damp soil

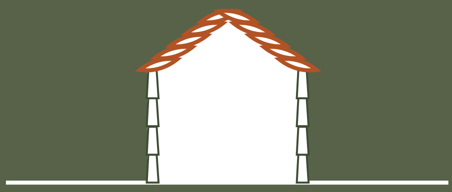

well sloped roofs


raised floors

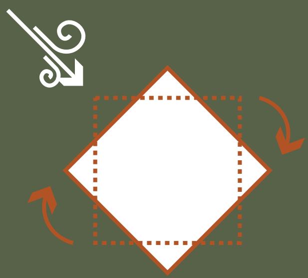

hooded gable vents


louvres, jalousies, shutters

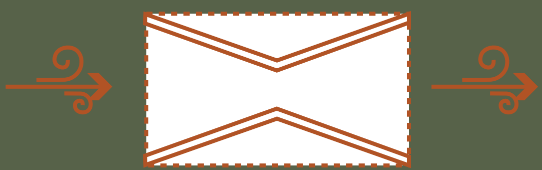
# Appendix A | *Vernacular heat & humidity resilience interventions*



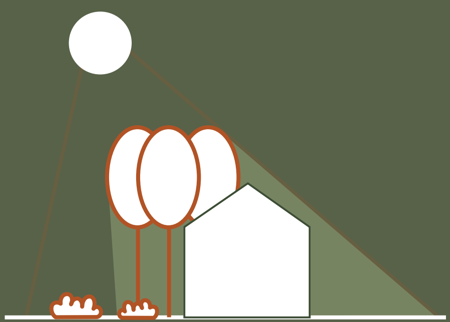
bamboo frames and leaves woven into the roofs



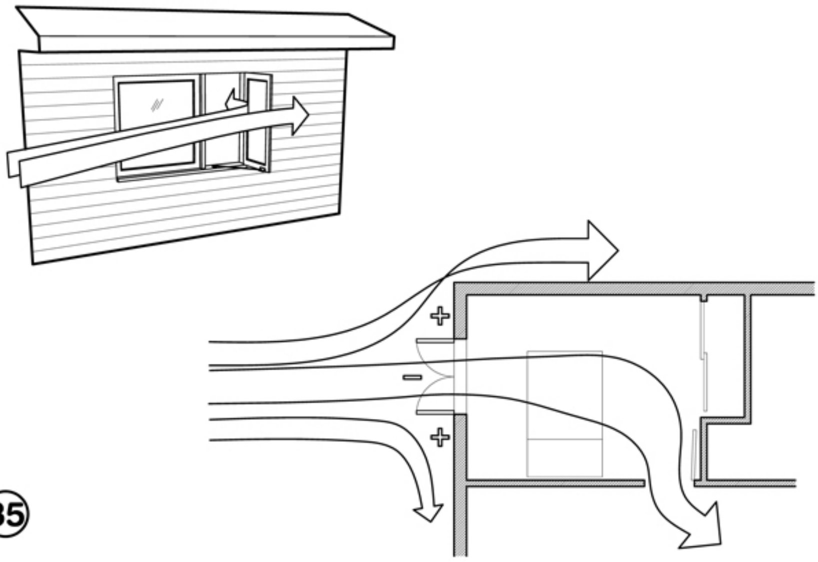
position buildings to capture the winds



outer walls built to channel cooling breezes indoors

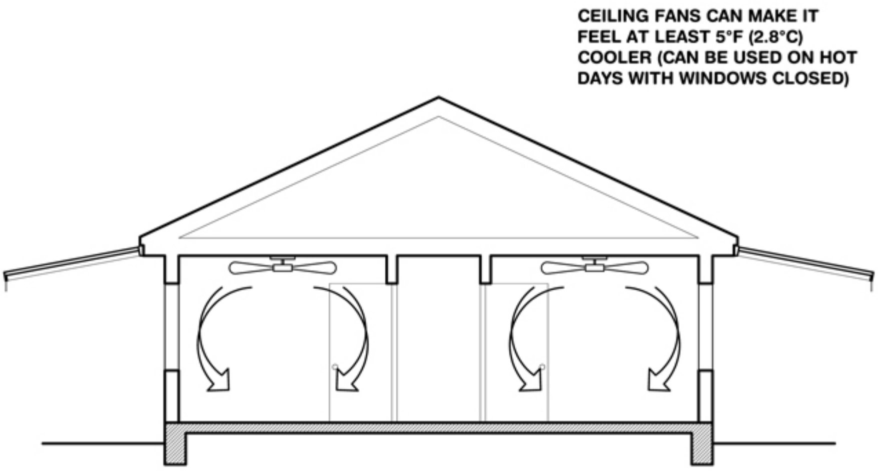


plants grown around a building to provide shade



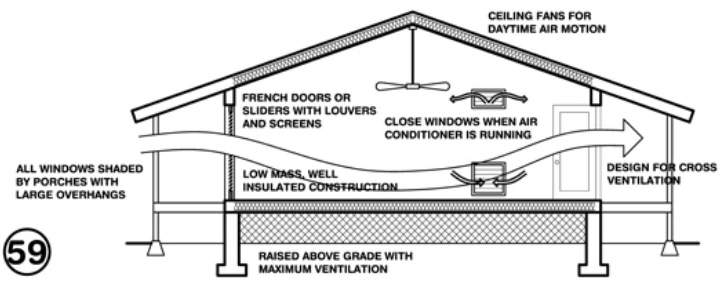
35

**Good natural ventilation can reduce or eliminate air conditioning in warm weather, if windows are well shaded and oriented to prevailing breezes**




42

**On hot days ceiling fans or indoor air motion can make it seem cooler by 5 degrees F (2.8C) or more, thus less air conditioning is needed**

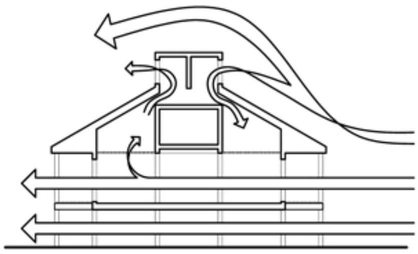


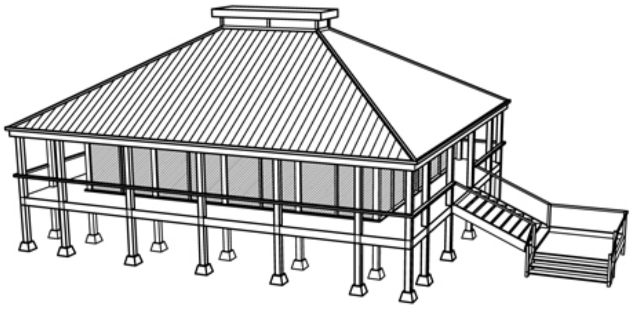

59

**IN HOT/HUMID CLIMATES**

**In this climate air conditioning will always be needed, but can be greatly reduced if building design minimizes overheating**

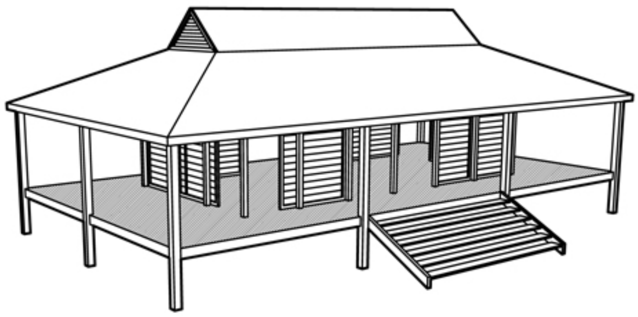
# Appendix B | *Climate Consultant 6.0 | Design guidelines tropical climate*





**27**

**If soil is moist, raise the building high above ground to minimize dampness and maximize natural ventilation underneath the building**



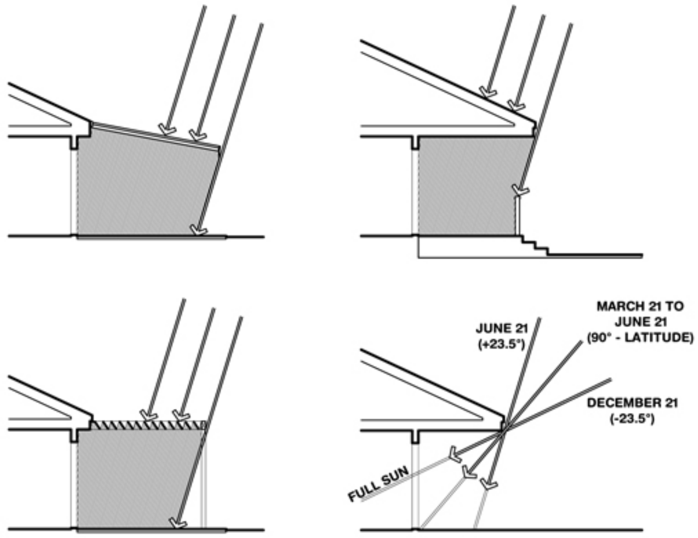
**68**

**Traditional passive homes in hot humid climates used light weight construction with openable walls and shaded outdoor porches, raised above ground**

**56**

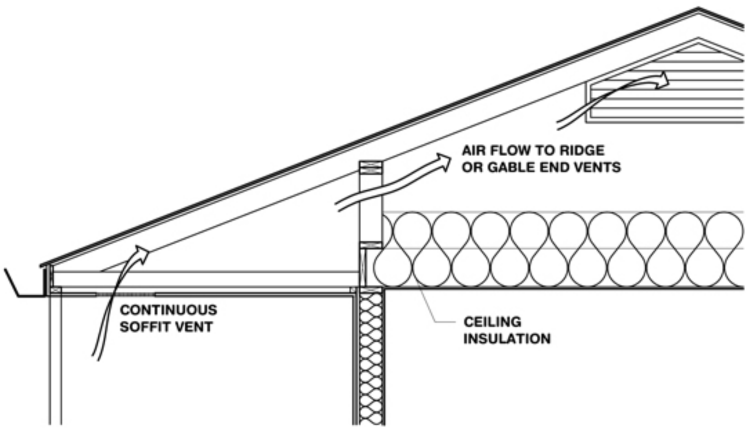
**Screened porches and patios can provide passive comfort cooling by ventilation in warm weather and can prevent insect problems**

# Appendix B | *Climate Consultant 6.0 | Design guidelines tropical climate*



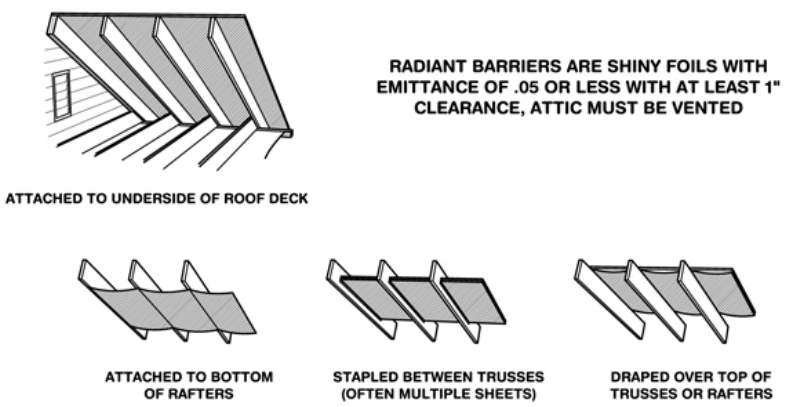

37

**Window overhangs (designed for this latitude) or operable sunshades (awnings that extend in summer) can reduce or eliminate air conditioning**



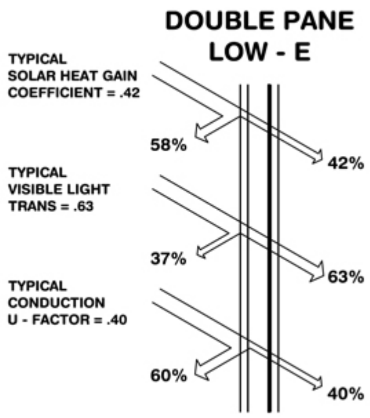

25

**In wet climates well ventilated attics with pitched roofs work well to shed rain and can be extended to protect entries, porches, verandas, outdoor work areas**



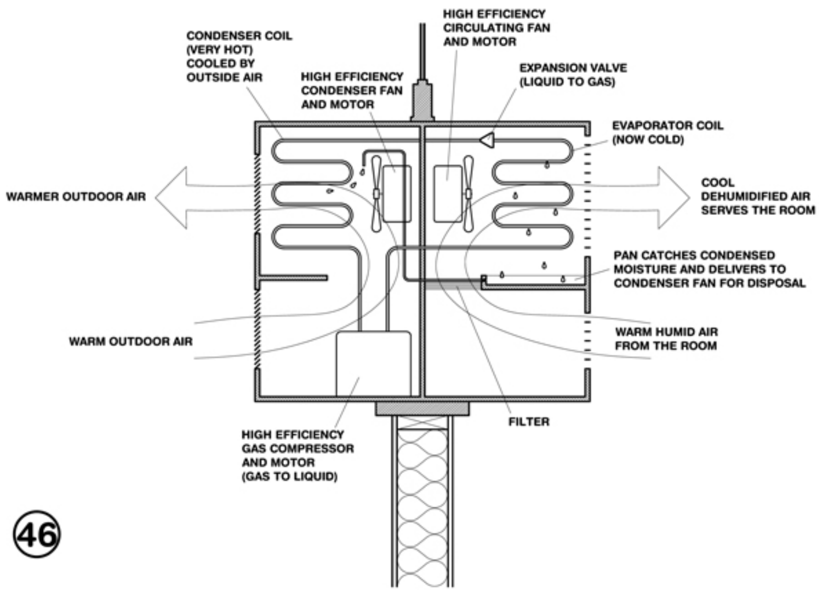

26

**A radiant barrier (shiny foil) will help reduce radiated heat gain through the roof in hot climates**




**30**

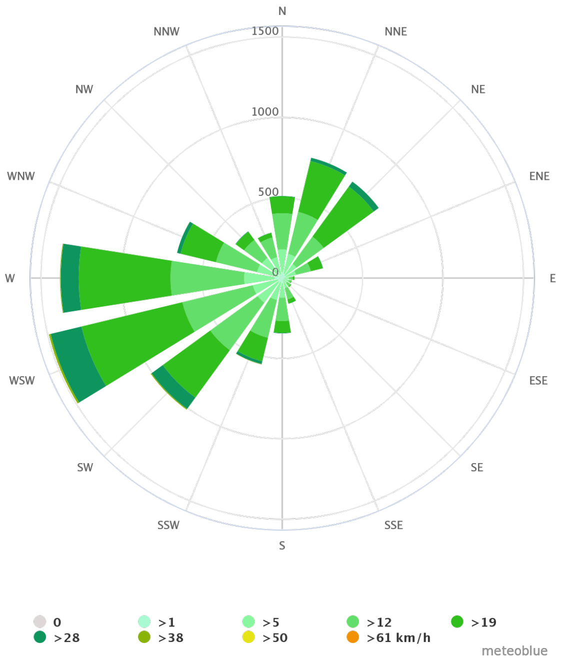
**High performance glazing on all orientations should prove cost effective (Low-E, insulated frames) in hot clear summers or dark overcast winters**

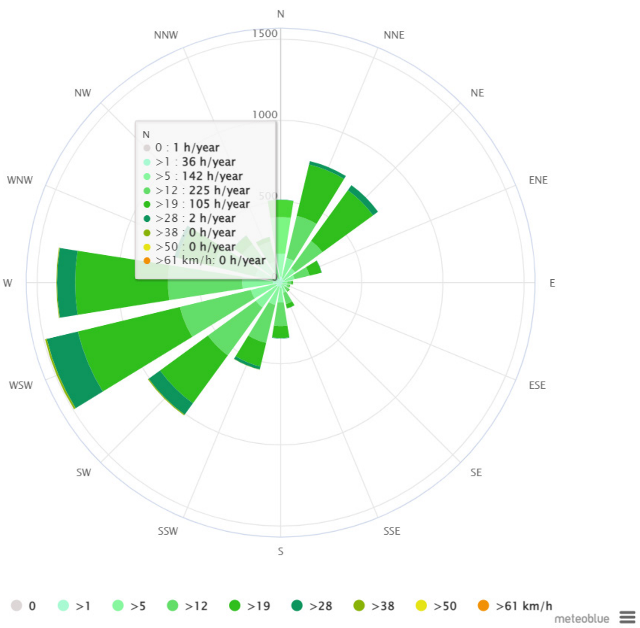


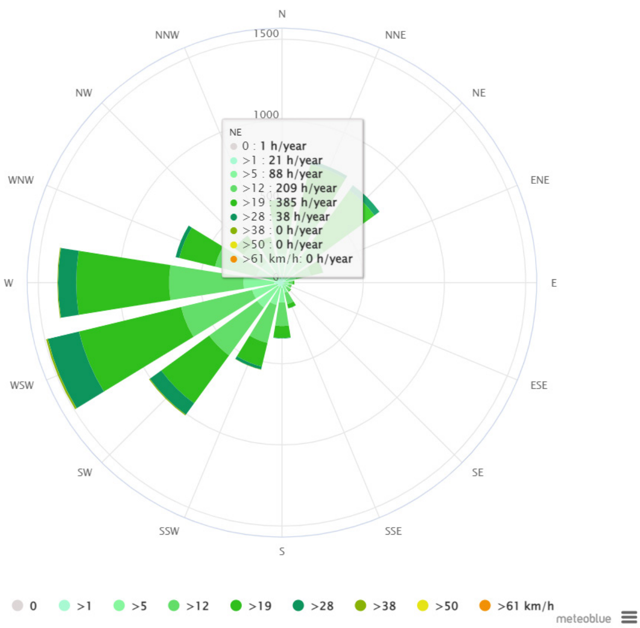

**46**

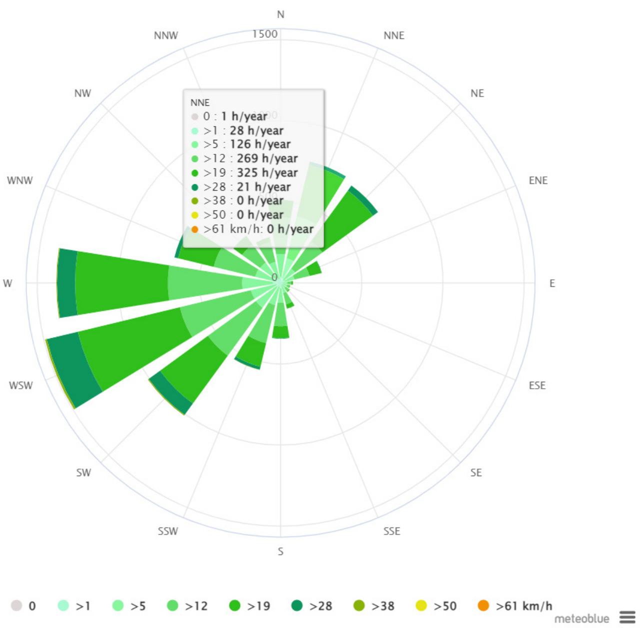
**High Efficiency air conditioner or heat pump (at least Energy Star) should prove cost effective in this climate**

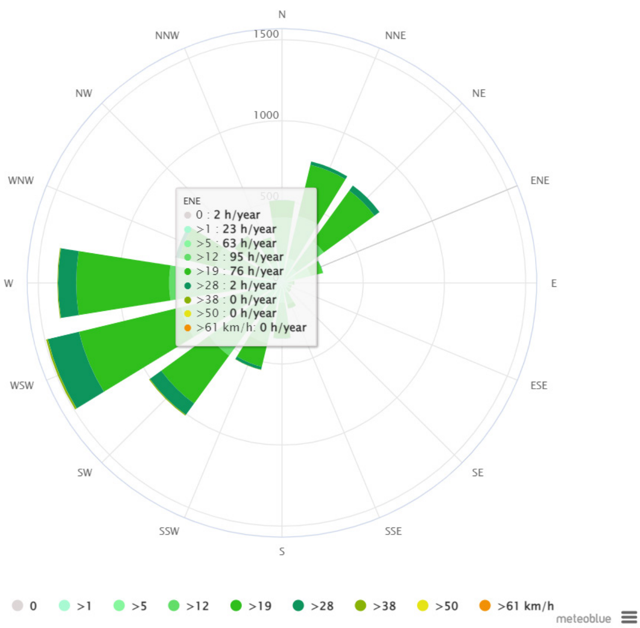
# Appendix C | *Wind direction throughout the year diagrams*



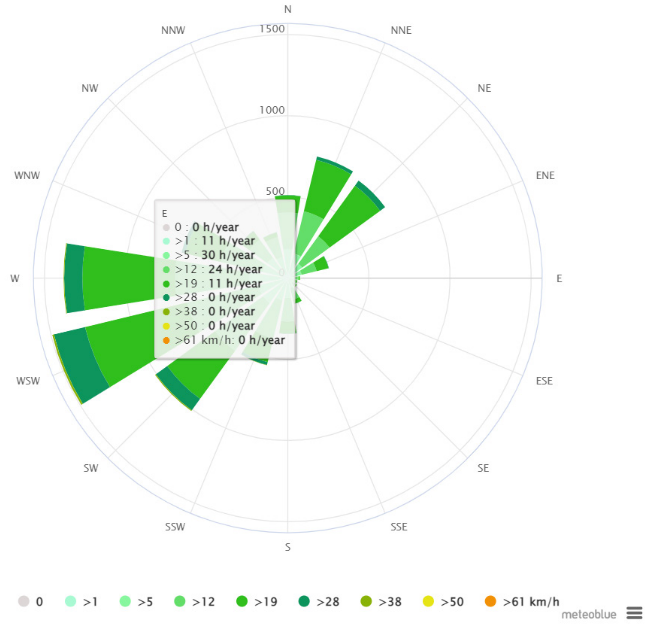



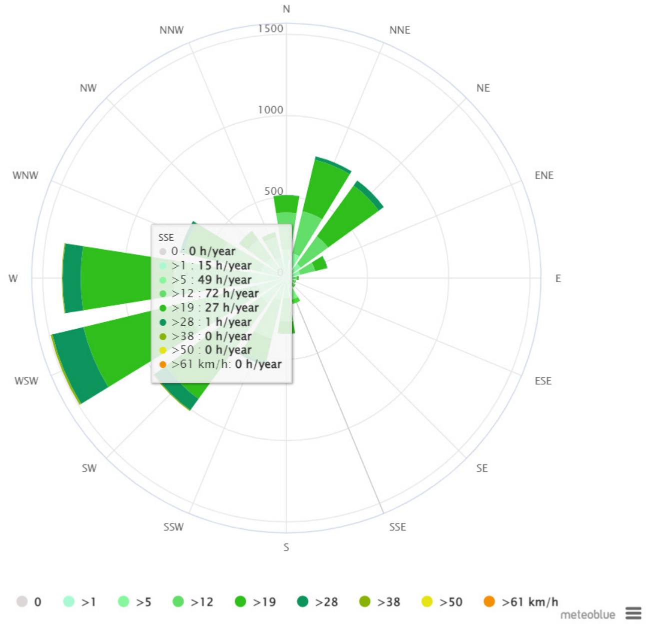



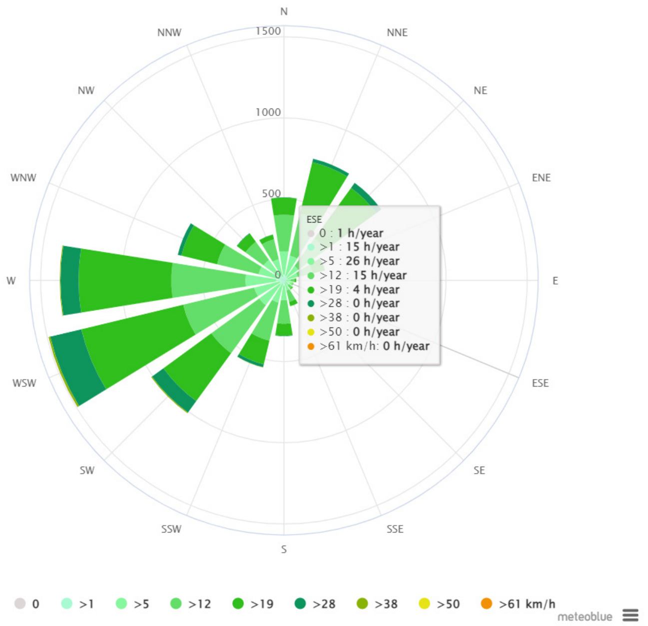



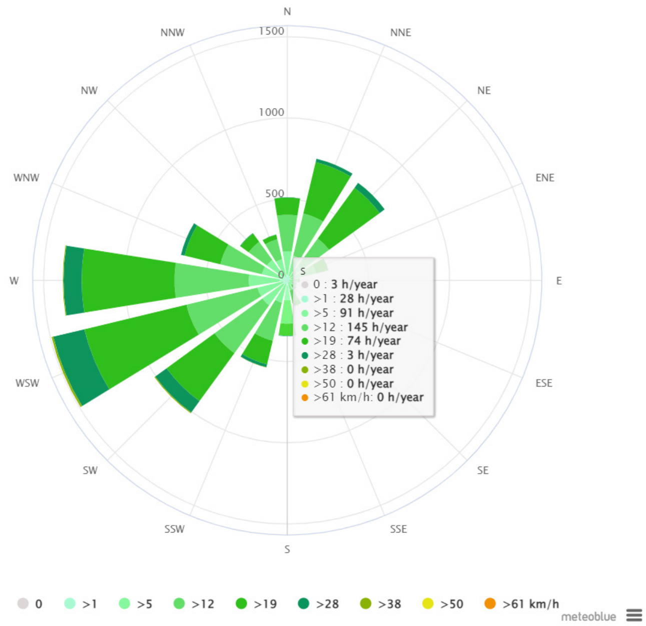



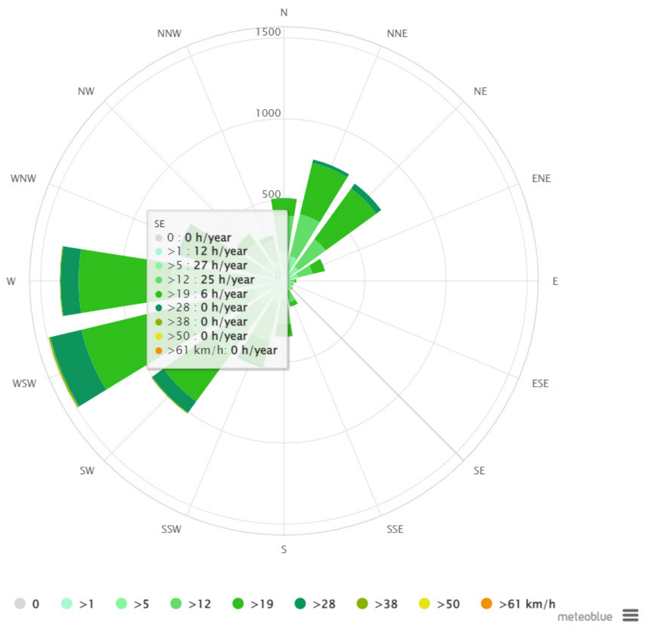
# Appendix C | *Wind direction throughout the year diagrams*

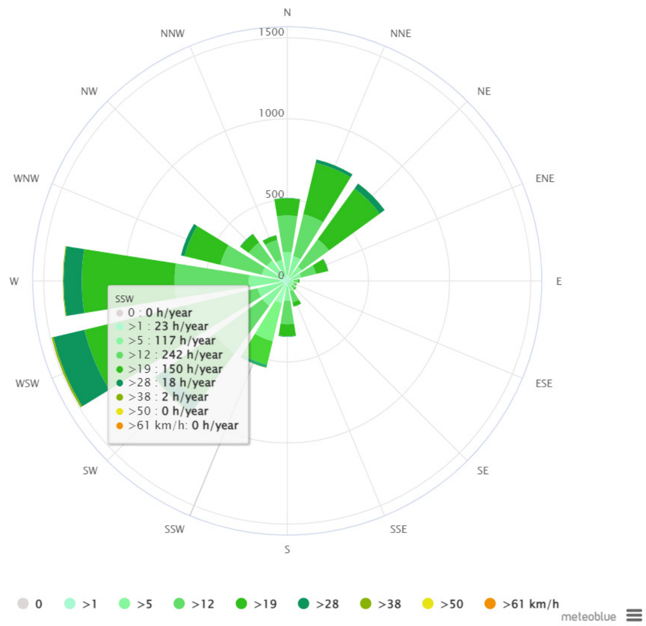


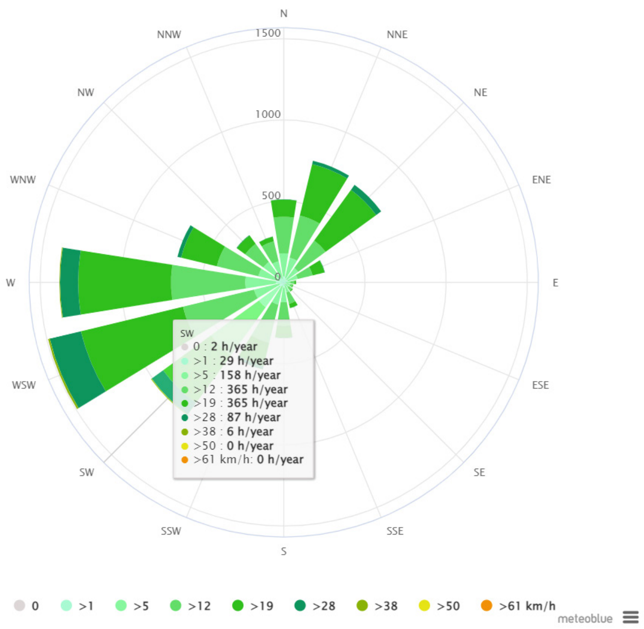



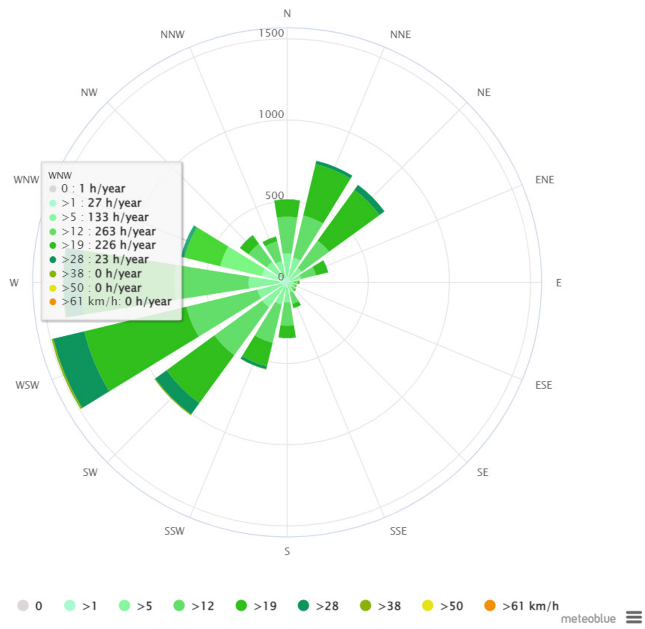



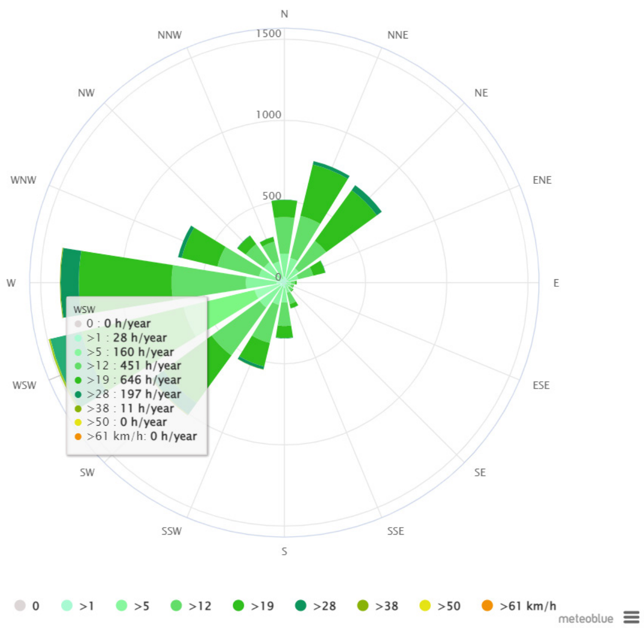



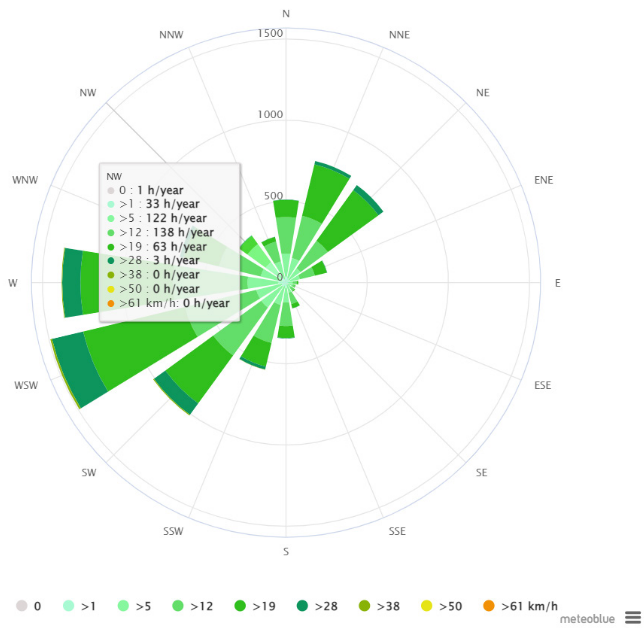



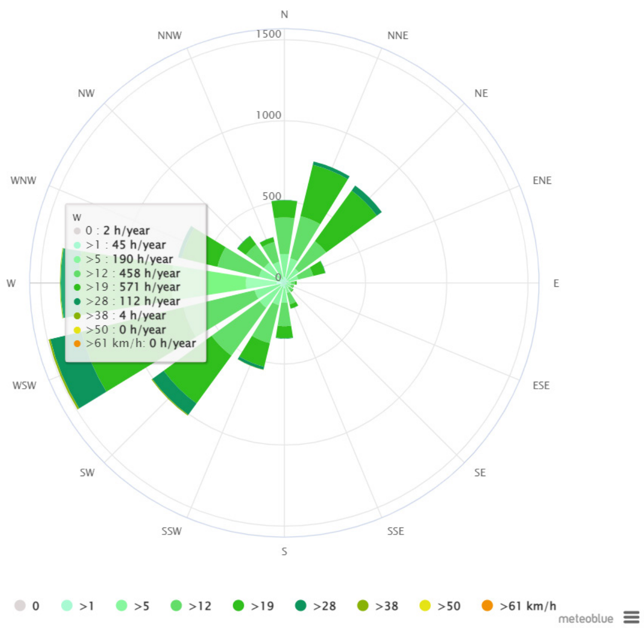
# Appendix C | *Wind direction throughout the year diagrams*

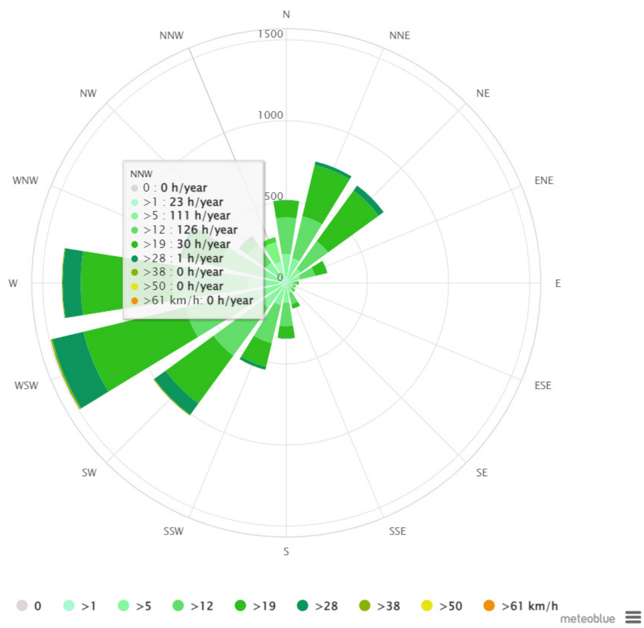


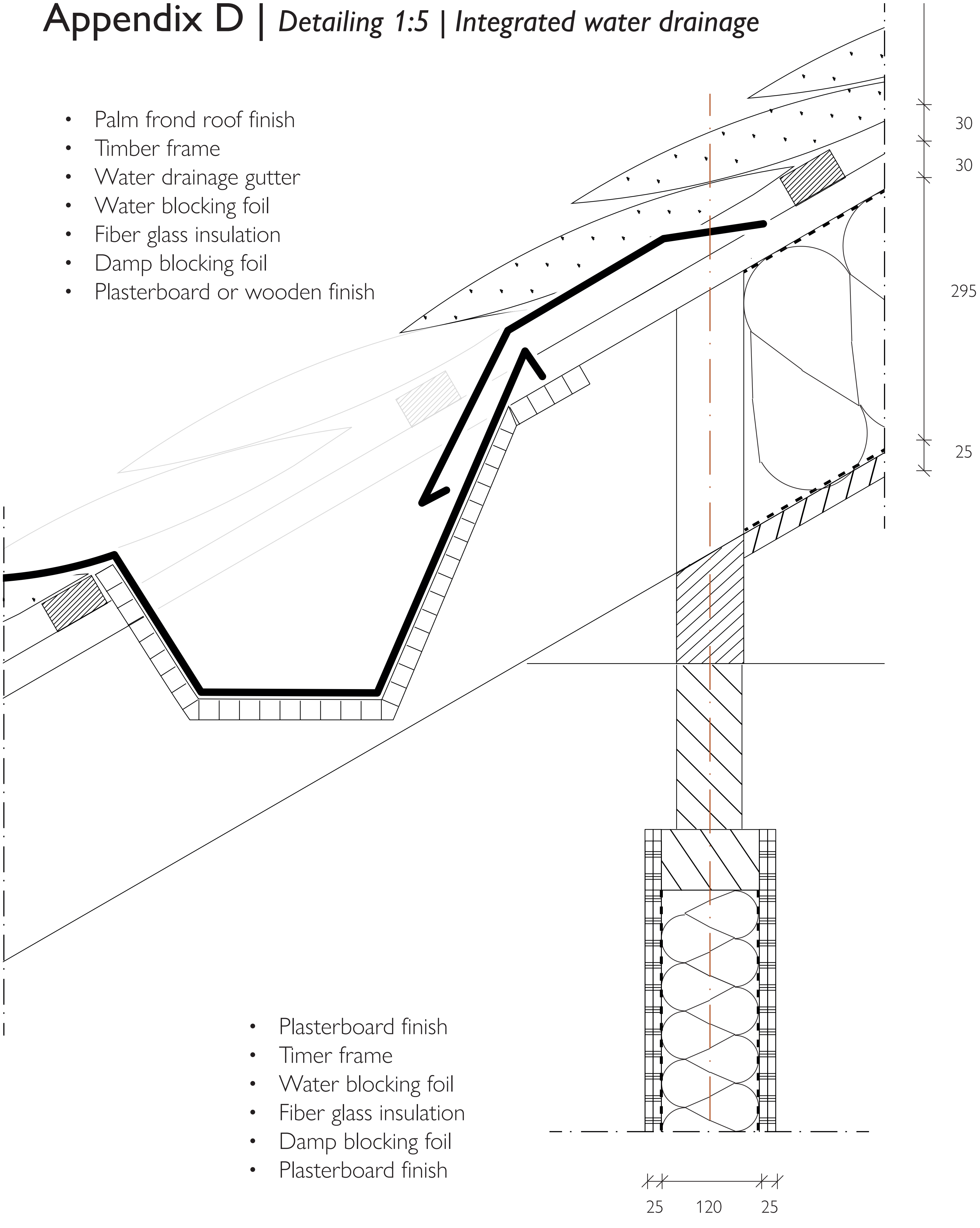



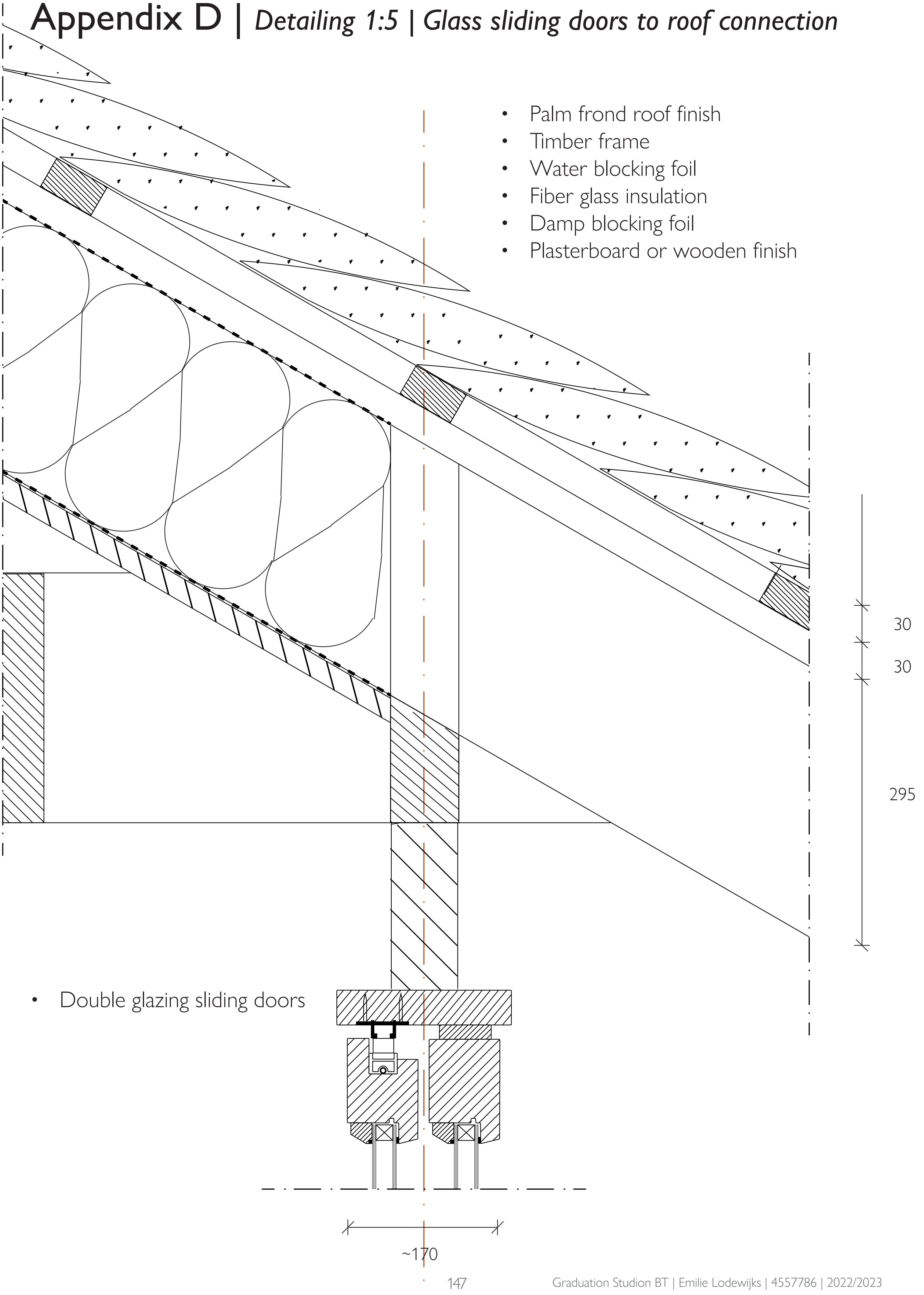
# Appendix D | *Detailing 1:5 | Integrated water drainage*

- Palm frond roof finish
- Timber frame
- Water drainage gutter
- Water blocking foil
- Fiber glass insulation
- Damp blocking foil
- Plasterboard or wooden finish

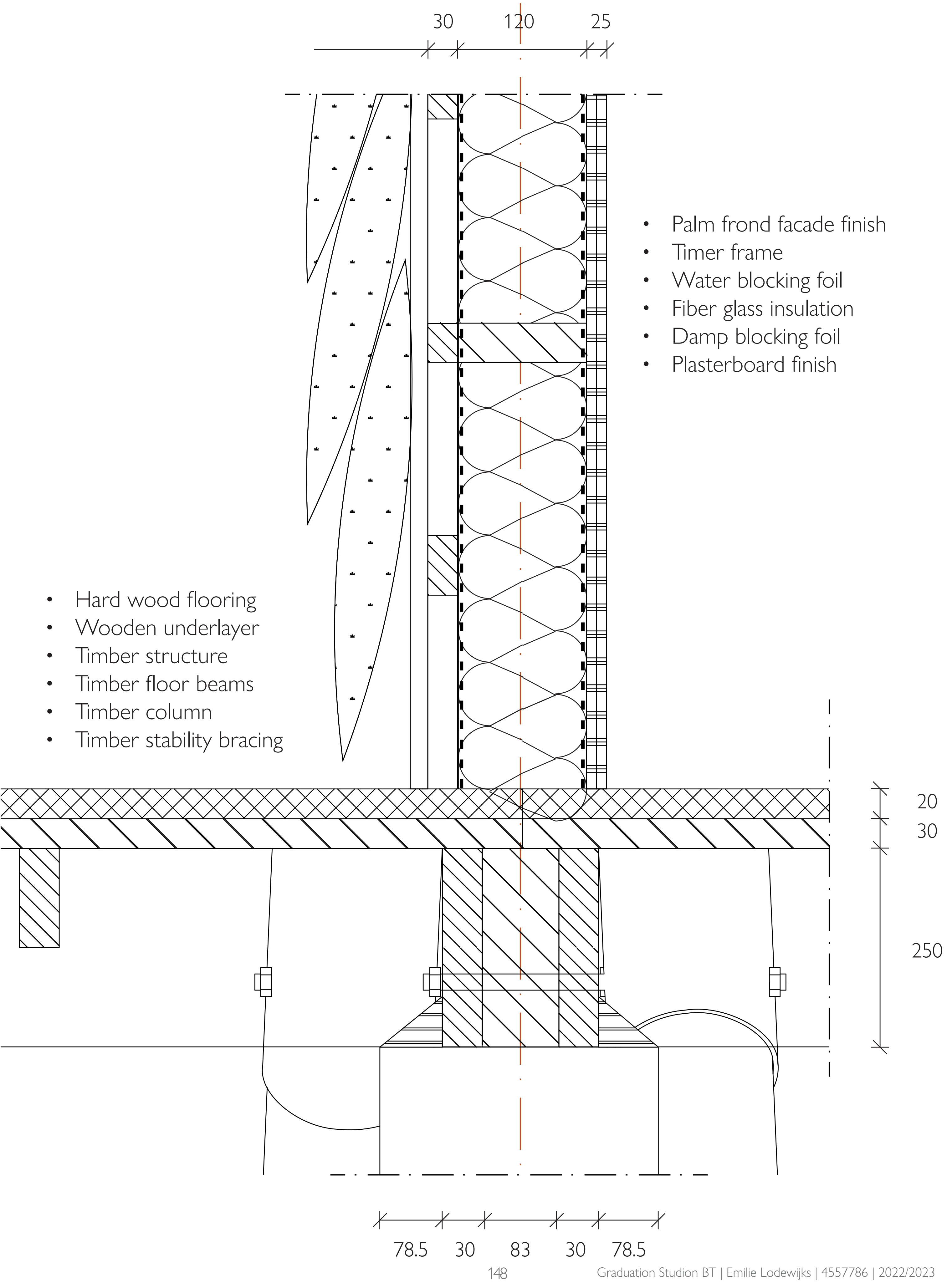



- Plasterboard finish
- Timer frame
- Water blocking foil
- Fiber glass insulation
- Damp blocking foil
- Plasterboard finish

# Appendix D | *Detailing 1:5 | Glass sliding doors to roof connection*



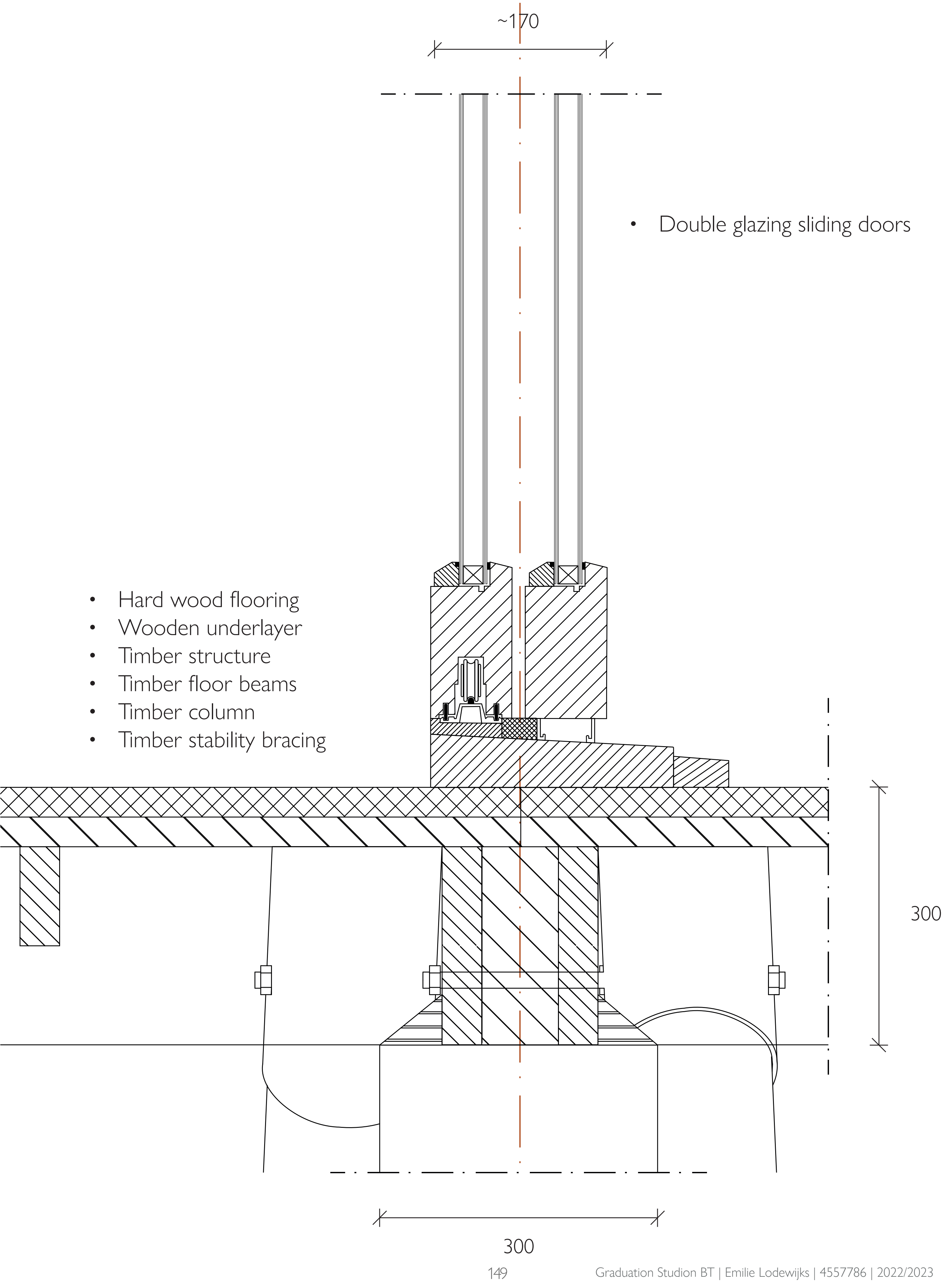
# Appendix D | *Detailing 1:5 | Exterior wall to floor and column connection*




- Palm frond facade finish
- Timer frame
- Water blocking foil
- Fiber glass insulation
- Damp blocking foil
- Plasterboard finish

- Hard wood flooring
- Wooden underlayer
- Timber structure
- Timber floor beams
- Timber column
- Timber stability bracing

# Appendix D | *Detailing 1:5 | Glass sliding doors to floor connection*

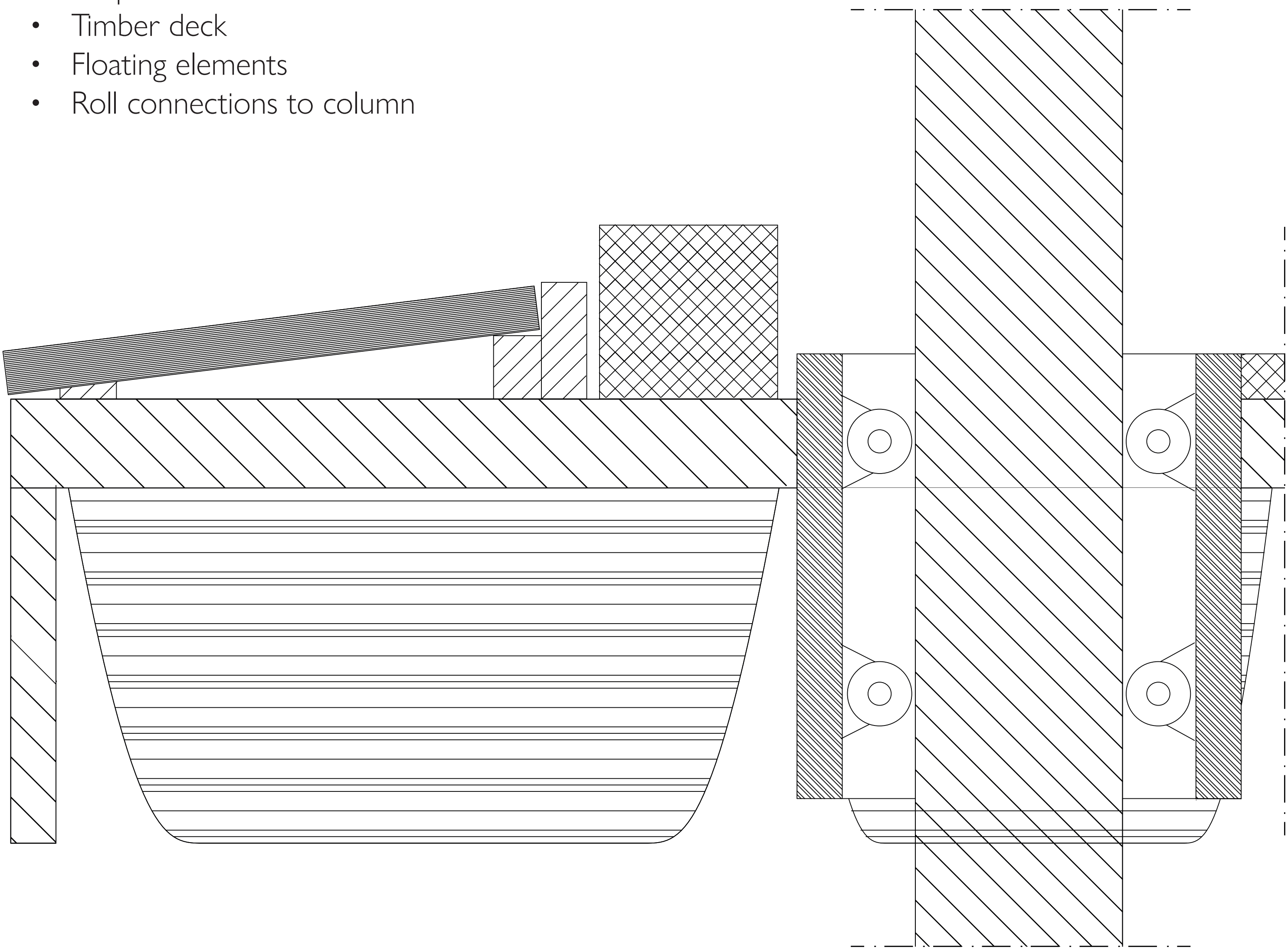



- Double glazing sliding doors

- Hard wood flooring
- Wooden underlayer
- Timber structure
- Timber floor beams
- Timber column
- Timber stability bracing

# Appendix D | *Detailing 1:5 | PV on deck | Deck along column*

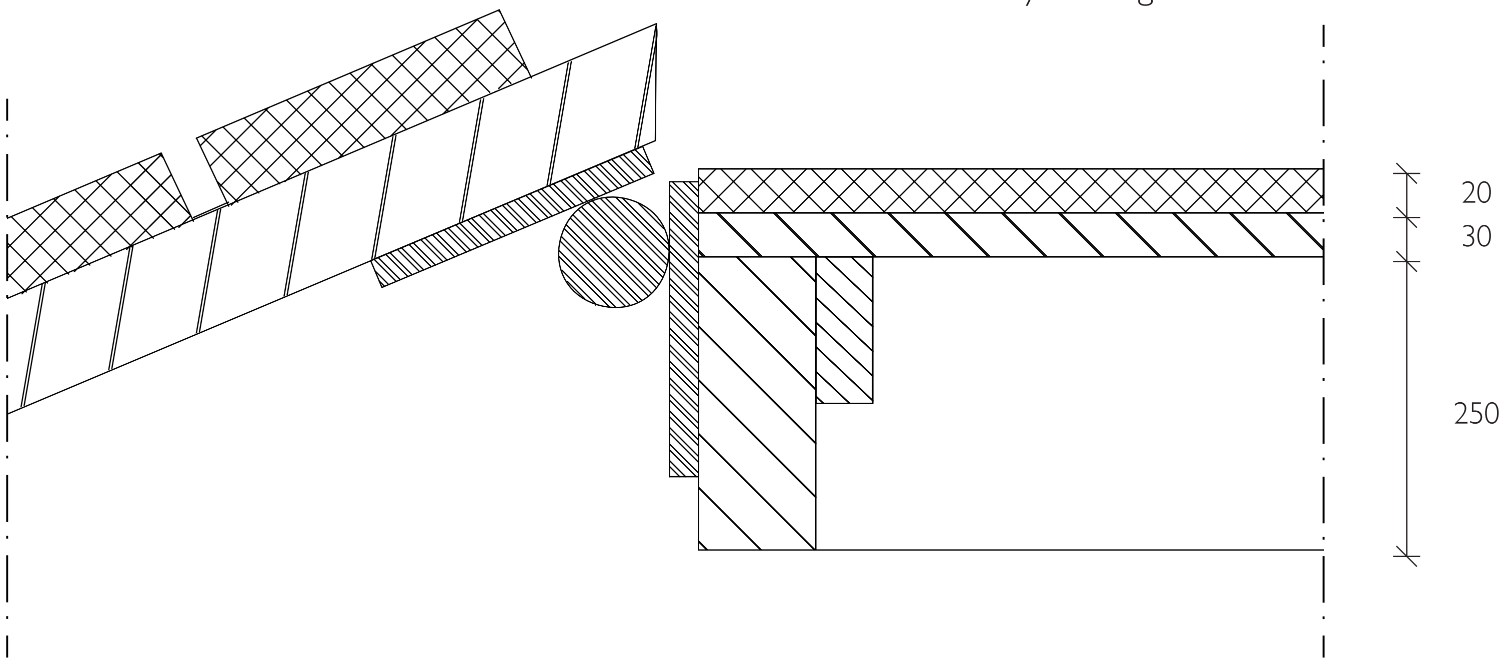
- PV panel
- Timber deck
- Floating elements
- Roll connections to column



Scaled to fit

# Appendix D | *Detailing 1:5 | Hinging walk board to Goathi floor*

- Timber walk board
- Hinge
- Hard wood flooring
- Wooden underlayer
- Timber structure
- Timber floor beams
- Timber column
- Timber stability bracing



# Appendix E | *Temperature data*

**Table 3.1:** Monthly averages and average minima and maxima of air-temperature at 2 m at 4 sites

| Month | Temperature [°C] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hanimaadhoo | | | Hulhulé | | | Kadhdhoo | | | Gan | | |
| | Average | Min | Max | Average | Min | Max | Average | Min | Max | Average | Min | Max |
| January | **27.3** | 26.8 | 27.6 | **27.5** | 27.1 | 27.8 | **27.7** | 27.3 | 27.9 | **27.7** | 27.3 | 28.0 |
| February | **27.5** | 27.0 | 27.8 | **27.6** | 27.2 | 27.9 | **27.9** | 27.4 | 28.2 | **28.0** | 27.6 | 28.3 |
| March | **28.2** | 27.7 | 28.5 | **28.2** | 27.7 | 28.5 | **28.3** | 27.8 | 28.6 | **28.3** | 27.9 | 28.7 |
| April | **28.9** | 28.5 | 29.2 | **28.7** | 28.3 | 29.0 | **28.6** | 28.1 | 28.9 | **28.7** | 28.2 | 29.0 |
| May | **29.0** | 28.5 | 29.3 | **28.7** | 28.2 | 29.1 | **28.6** | 28.2 | 29.0 | **28.7** | 28.2 | 29.0 |
| June | **28.4** | 27.9 | 28.8 | **28.4** | 27.9 | 28.7 | **28.4** | 28.0 | 28.7 | **28.3** | 27.9 | 28.7 |
| July | **28.0** | 27.5 | 28.4 | **28.2** | 27.7 | 28.5 | **28.2** | 27.7 | 28.5 | **28.1** | 27.6 | 28.4 |
| August | **27.9** | 27.4 | 28.3 | **28.0** | 27.5 | 28.3 | **28.0** | 27.5 | 28.3 | **27.9** | 27.5 | 28.3 |
| September | **27.8** | 27.4 | 28.2 | **27.9** | 27.4 | 28.3 | **28.0** | 27.5 | 28.4 | **27.9** | 27.4 | 28.3 |
| October | **27.9** | 27.5 | 28.2 | **27.9** | 27.5 | 28.3 | **27.9** | 27.4 | 28.3 | **27.9** | 27.4 | 28.3 |
| November | **27.8** | 27.3 | 28.1 | **27.7** | 27.3 | 28.1 | **27.8** | 27.3 | 28.2 | **27.8** | 27.3 | 28.2 |
| December | **27.5** | 27.1 | 27.9 | **27.5** | 27.1 | 27.9 | **27.6** | 27.2 | 28.0 | **27.8** | 27.3 | 28.1 |
| **YEAR** | **28.0** | | | **28.0** | | | **28.1** | | | **28.1** | | |

Table 3.1 shows monthly characteristics of air temperature at four selected sites; they represent statistics calculated over a 24-hour diurnal cycle. Minimum and maximum air temperatures are calculated as an average of minimum and maximum values of temperature during each day (assuming full diurnal cycle - 24 hours) of the given month.

**Table 3.2:** Daily averages and average minima and maxima of Global Horizontal Irradiation at 4 sites

| Month | Global Horizontal Irradiation [kWh/m²] | | | | | | | | | | | | Variability between sites [%] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hanimaadhoo | | | Hulhulé | | | Kadhdhoo | | | Gan | | | |
| | Average | Min | Max | Average | Min | Max | Average | Min | Max | Average | Min | Max | |
| January | **5.62** | 5.11 | 5.96 | **5.68** | 4.84 | 6.15 | **5.75** | 5.01 | 6.35 | **5.76** | 4.82 | 6.54 | **1.1** |
| February | **6.16** | 5.34 | 6.59 | **6.36** | 5.93 | 6.79 | **6.28** | 5.61 | 6.79 | **6.33** | 5.70 | 6.79 | **1.4** |
| March | **6.59** | 5.49 | 6.93 | **6.59** | 5.74 | 7.12 | **6.56** | 5.91 | 7.05 | **6.49** | 5.55 | 7.05 | **0.7** |
| April | **6.20** | 5.74 | 6.79 | **6.06** | 5.48 | 6.66 | **5.91** | 5.35 | 6.62 | **5.90** | 5.32 | 6.52 | **2.4** |
| May | **5.22** | 4.43 | 6.15 | **5.29** | 4.40 | 5.80 | **5.36** | 4.82 | 5.81 | **5.40** | 5.01 | 5.92 | **1.5** |
| June | **4.89** | 4.16 | 5.75 | **5.14** | 4.38 | 5.75 | **5.27** | 4.63 | 6.05 | **5.13** | 4.13 | 5.96 | **3.1** |
| July | **5.02** | 4.32 | 5.75 | **5.10** | 4.50 | 5.59 | **5.08** | 4.53 | 5.60 | **4.92** | 4.36 | 5.68 | **1.6** |
| August | **5.37** | 4.72 | 6.02 | **5.40** | 4.54 | 5.99 | **5.27** | 4.61 | 5.75 | **5.26** | 4.53 | 5.83 | **1.4** |
| September | **5.54** | 4.90 | 6.53 | **5.39** | 4.73 | 6.57 | **5.56** | 5.07 | 6.43 | **5.59** | 4.72 | 6.08 | **1.6** |
| October | **5.53** | 4.60 | 6.30 | **5.65** | 5.07 | 6.44 | **5.58** | 4.88 | 6.20 | **5.64** | 4.92 | 6.63 | **1.0** |
| November | **4.97** | 3.90 | 5.75 | **5.02** | 4.07 | 5.86 | **5.19** | 4.21 | 6.45 | **5.50** | 4.63 | 6.59 | **4.6** |
| December | **5.02** | 4.25 | 5.84 | **4.95** | 3.69 | 5.79 | **5.11** | 3.97 | 5.87 | **5.55** | 4.55 | 6.31 | **5.2** |
| **YEAR** | **5.51** | **5.32** | **5.63** | **5.55** | **5.33** | **5.67** | **5.57** | **5.30** | **5.74** | **5.62** | **5.31** | **5.75** | **0.8** |

# Appendix E | *Tilted irradiation data*

**Table 3.4:** Daily averages and average minima and maxima of Global Tilted Irradiation at 4 sites

| Month | Global Tilted Irradiation [kWh/m$^2$] | | | | | | | | | | | | Variability between sites [%] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hanimaadhoo | | | Hulhulé | | | Kadhdhoo | | | Gan | | | |
| | Average | Min | Max | Average | Min | Max | Average | Min | Max | Average | Min | Max | |
| January | **5.94** | 5.37 | 6.32 | **5.97** | 5.08 | 6.49 | **6.02** | 5.22 | 6.67 | **5.48** | 4.62 | 6.21 | **4.3** |
| February | **6.39** | 5.52 | 6.85 | **6.58** | 6.12 | 7.04 | **6.47** | 5.76 | 7.00 | **6.14** | 5.54 | 6.59 | **2.9** |
| March | **6.68** | 5.54 | 7.02 | **6.65** | 5.78 | 7.19 | **6.60** | 5.93 | 7.09 | **6.46** | 5.53 | 7.02 | **1.5** |
| April | **6.13** | 5.68 | 6.71 | **5.96** | 5.40 | 6.54 | **5.79** | 5.25 | 6.48 | **6.03** | 5.42 | 6.67 | **2.4** |
| May | **5.07** | 4.32 | 5.97 | **5.11** | 4.26 | 5.58 | **5.15** | 4.63 | 5.57 | **5.62** | 5.21 | 6.18 | **4.9** |
| June | **4.72** | 4.02 | 5.53 | **4.93** | 4.21 | 5.50 | **5.02** | 4.42 | 5.74 | **5.38** | 4.30 | 6.29 | **5.5** |
| July | **4.86** | 4.20 | 5.57 | **4.92** | 4.35 | 5.38 | **4.87** | 4.36 | 5.36 | **5.13** | 4.53 | 5.94 | **2.5** |
| August | **5.28** | 4.64 | 5.90 | **5.28** | 4.44 | 5.86 | **5.13** | 4.49 | 5.60 | **5.40** | 4.64 | 6.00 | **2.1** |
| September | **5.56** | 4.92 | 6.55 | **5.39** | 4.72 | 6.57 | **5.53** | 5.05 | 6.40 | **5.61** | 4.73 | 6.11 | **1.7** |
| October | **5.69** | 4.72 | 6.49 | **5.79** | 5.18 | 6.60 | **5.69** | 4.97 | 6.35 | **5.53** | 4.83 | 6.49 | **1.8** |
| November | **5.21** | 4.06 | 6.06 | **5.23** | 4.21 | 6.14 | **5.40** | 4.36 | 6.74 | **5.27** | 4.47 | 6.29 | **1.6** |
| December | **5.33** | 4.47 | 6.24 | **5.22** | 3.84 | 6.14 | **5.37** | 4.13 | 6.20 | **5.25** | 4.34 | 5.96 | **1.3** |
| **YEAR** | **5.57** | **5.39** | **5.68** | **5.58** | **5.35** | **5.71** | **5.58** | **5.30** | **5.74** | **5.61** | **5.30** | **5.75** | **0.3** |

# Appendix E | *PV related data*

**Table 3.5:** Annual performance parameters of a PV system with modules fixed at 7° tilt towards equator

| | Hanimaadhoo | Hulhulé | Kadhdhoo | Gan |
|---|---|---|---|---|
| PVOUT<br>Average daily total [kWh/kWp] | 4.37 | 4.38 | 4.38 | 4.40 |
| PVOUT<br>Yearly total [kWh/kWp] | 1595 | 1598 | 1599 | 1606 |
| Annual ratio of DIF/GHI | 46.6% | 45.1% | 43.3% | 42.3% |
| System PR | 78.4% | 78.4% | 78.4% | 78.4% |

PVOUT - PV electricity yield for fixed-mounted modules at 7° tilt towards equator; DIF/GHI – Ratio of Diffuse/Global horizontal irradiation; PR - Performance ratio for fixed-mounted PV

**Table 3.6:** Average daily sums of PV electricity output from an open-space fixed PV system with a nominal peak power of 1 kW [kWh/kWp]

| Site | Average daily sum of electricity production [kWh/kWp] | | | | | | | | | | | | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | |
| Hanimaadhoo | 4.68 | 5.02 | 5.21 | 4.78 | 3.96 | 3.70 | 3.82 | 4.15 | 4.36 | 4.45 | 4.09 | 4.20 | 4.37 |
| Hulhulé | 4.69 | 5.15 | 5.19 | 4.66 | 4.01 | 3.87 | 3.87 | 4.15 | 4.23 | 4.53 | 4.11 | 4.10 | 4.38 |
| Kadhdhoo | 4.73 | 5.06 | 5.15 | 4.53 | 4.04 | 3.95 | 3.83 | 4.03 | 4.34 | 4.46 | 4.23 | 4.22 | 4.38 |
| Gan | 4.30 | 4.81 | 5.04 | 4.71 | 4.41 | 4.23 | 4.04 | 4.24 | 4.40 | 4.34 | 4.14 | 4.13 | 4.40 |

**Manadhoo, Maldives - Solar energy and surface meteorology**

| Variable | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Insolation, kWh/m²/day** | 5.83 | 6.49 | 6.94 | 6.40 | 5.54 | 4.84 | 5.11 | 5.63 | 5.84 | 5.87 | 5.29 | 5.42 |
| **Clearness, 0 - 1** | 0.63 | 0.66 | 0.67 | 0.62 | 0.55 | 0.49 | 0.51 | 0.55 | 0.57 | 0.59 | 0.56 | 0.60 |
| **Temperature, °C** | 26.98 | 26.79 | 27.18 | 27.56 | 27.99 | 27.64 | 27.01 | 26.77 | 26.89 | 26.80 | 26.74 | 27.06 |
| **Wind speed, m/s** | 4.76 | 3.99 | 3.43 | 3.68 | 5.71 | 7.09 | 5.56 | 5.43 | 5.40 | 4.90 | 3.88 | 4.53 |
| **Precipitation, mm** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Wet days, d** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |

These data were obtained from the NASA Langley Research Center Atmospheric Science Data Center; New et al. 2002
**Notes:** Help. Change preferences.

Gaisma Planet - Interactive Climate and Environment Imagery Viewer

# Appendix F | *PET properties*

### General properties

| | | | | | |
|---|---|---|---|---|---|
| Density | ⓘ | 1,29e3 | - | 1,39e3 | kg/m^3 |
| Price | ⓘ | * 0,614 | - | 1,08 | EUR/kg |

### Mechanical properties

| | | | | | |
|---|---|---|---|---|---|
| Young's modulus | ⓘ | * 2,8 | - | 3 | GPa |
| Yield strength (elastic limit) | ⓘ | * 50 | - | 55 | MPa |
| Tensile strength | ⓘ | 55 | - | 60 | MPa |
| Elongation | ⓘ | 280 | - | 320 | % strain |
| Hardness - Vickers | ⓘ | * 2 | - | 5 | HV |
| Fatigue strength at 10^7 cycles | ⓘ | * 19,3 | - | 29 | MPa |
| Fracture toughness | ⓘ | * 4,75 | - | 5,25 | MPa.m^0.5 |

### Thermal properties

| | | | | | |
|---|---|---|---|---|---|
| Melting point | ⓘ | 237 | - | 277 | °C |
| Maximum service temperature | ⓘ | * 54,9 | - | 64,9 | °C |
| Thermal conductor or insulator? | ⓘ | Good insulator | | | |
| Thermal conductivity | ⓘ | 0,138 | - | 0,24 | W/m.°C |
| Specific heat capacity | ⓘ | 1,15e3 | - | 1,25e3 | J/kg.°C |
| Thermal expansion coefficient | ⓘ | 115 | - | 119 | µstrain/°C |

### Electrical properties

| | | | | | |
|---|---|---|---|---|---|
| Electrical conductor or insulator? | ⓘ | Good insulator | | | |

### Optical properties

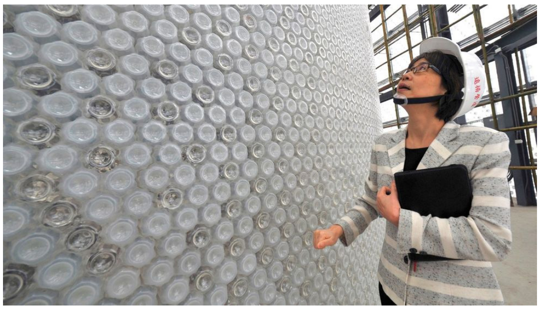
| | | | | | |
|---|---|---|---|---|---|
| Transparency | ⓘ | Optical Quality | | | |

### Eco properties

| | | | | | |
|---|---|---|---|---|---|
| Embodied energy, primary production | ⓘ | * 68,7 | - | 76,8 | MJ/kg |
| CO2 footprint, primary production | ⓘ | * 2,54 | - | 2,82 | kg/kg |
| Recycle | ⓘ | ✓ | | | |
| **Recycle mark** | ⓘ | | | | |

GRANTA EduPack (22.1.2) [ANSYS]. (2022).Retrieved from software.tudelft.nl

# Appendix F | Recycled plastic *application examples*


(Credit: Getty Images)


https://theconstructor.org/building/plastics-construction-material/12438/


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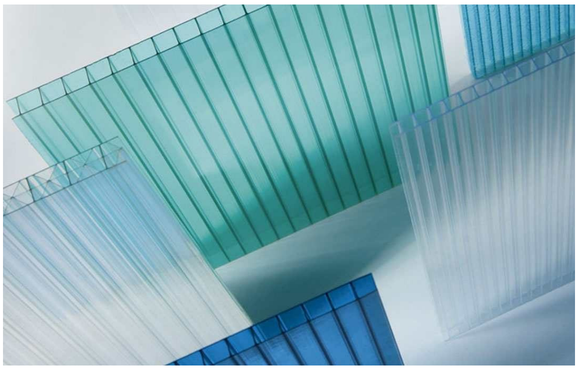
Photo: Issouf Sanogo/AFP via Getty Images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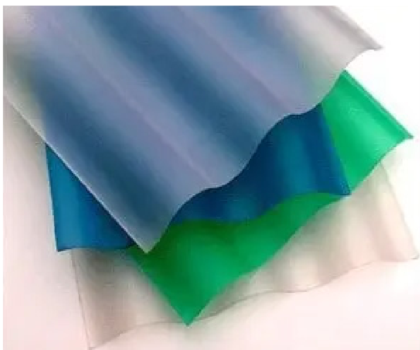
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# | PET Paradise |

## Turning a waste problem into a source to preserve the Maldivian Islands


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