Design for Sustainability

Fish Preservation in Tanzania

Project DagUp TU Delft SAGAR ENERGY SOLUTIONS

Project DagUp

Project DagUp

Dagaa : Upgrade
Day : Upepo
: Up

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Table of Contents

01 Preface

I dedicated myself to sustainability for many years by reducing plastic use and participating in charitable activities. Becoming a designer has provided me a new way of dedication. This project showcases the idea of what a designer can do for sustainability.

This project is based on the previous work of a TU Delft student project. The previously developed concept aimed to solve the post-harvest loss for the dagaa fishery in Tanzania by using a greenhouse dryer. The functionality and usability of the concept were partially validated, but the local stakeholders were interested in developing it to a market-ready product. As I saw the opportunities to implement my knowledge of product development, and the potential negative sustainability impact of the concept, I decided to step in for changes.

The methods used in this project provided a systematic way to develop the usability and functionality of a complex product. And, at the same time, the sustainability impact of the product is taken care of. Moreover, through this project, I have developed a structured approach to iterate the design through computer simulation.

This report is not only for demonstrating the acquired knowledge but also for everyone who is interested in developing sustainable products in developing countries, especially for large-scale projects. Moreover, this report provides the necessary information to develop a food preservation solution, particularly in developing countries.

This project could not make it so far without the kind helps from everyone who had provided feedback and suggestions to me, this includes a number of experts in TU Delft, in PMB, in Applied labs, and also outside of TU Delft. Especially, Andreas Ostrovsky-Pereira, founder and CEO of Sagar Energy Solutions, provided the most crucial information that was difficult to access under the COVID-19 circumstance. I would like to give a special thanks to the supervisory team for guidance. The chair Henk Kuipers was very supportive throughout the process. He not only provided professional advice but also mental supports while I was facing difficulties. Last but not the least, I want to thank Student for Sustainability and FAST funding for financial support. Due to the scale of the project, the expense for testing and prototyping was high. Without their help, I might not be able to conduct the same number of tests, which would have posed some financial burden on me.

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02 Summary

In Tanzania, catching dagaa is one of the main activities around Lake Victoria to earn a livelihood. However, the process of dagaa preservation was not entirely secure, which has led to issues of insufficient income and food waste. Therefore, Sagar Energy Solutions (SES) is developing a greenhouse dryer "Upepo" to prevent post-harvest loss and improve the quality.

There were some problems with Upepo needed to be addressed. Consequently, this project was launched to fix its current issue of sustainability, functionality, and business aspects. Besides these aspects, some unexplored topics were also investigated to broaden up the opportunities.

As a result, a greenhouse dryer, "UpWind," was designed. UpWind not only ensures the production of dried dagaa but also aims to improve its performance on drying capability, cost-efficiency, ergonomic, and sustainability and to fulfill the stakeholders' requirements.

This project delivered the result by systematic design methods. The development followed the basic design framework of Double Diamond. First of all, in the Discover phase, research and analyses were done based on two topics, drying methods and other preservation methods. Then, the results were concluded and integrated into a Design Vision and a List of Requirements in the Define phase. Next, through performing creative design methods, such as Brainstorming, Morphological Chart, etc., and evaluation methods, eventually, one concept stood out from the crowd. Finally, the concept was developed through Design Iterations. The components were separated into three groups for easier development management. Depending on the attributes of the group, some were developed through simulation, while the others were through prototyping.

As a closure of the project, the List of Requirements, sustainability, and Technology Readiness Level of the final design were evaluated to ensure the goals of this project were met. Moreover, this project provided technical information for future development, such as the Bill of Material, production method, business model, and a design roadmap, at the end of the report.

Figure 1. Upepo Mock-up [illustration]. (2020). Retrieved from Blankendaal et al., 2020, p. 90

03 Project Introduction

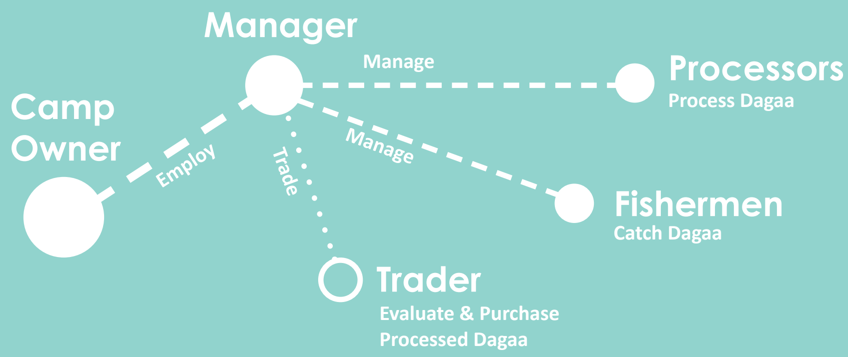

Figure 2. Relations of the Main Stakeholders Concerning Dagaa Processing (adapted from Blankendaal et al., 2020, p. 19).

Figure 3. Dagaa Drying in Tanzania [photograph]. (2020). Retrieved from Blankendaal et al., 2020, p. 1

3.1 Current Situation

In Tanzania, catching dagaa (a sort of sardine) is one of the main activities of the places surrounding Lake Victoria to earn a livelihood. Moreover, dagaa is a vital nutrition source (Ogonda, Muge, Mulaa, & Mbatia, 2014, p. 2) for their people. However, the processes of catching and processing the dagaa catch are not entirely secure, which leads to issues of insufficient income and food waste. And, this project focused on improving the post-harvest processing of dagaa. The main stakeholders concerning dagaa processing and their relations can be seen in Figure 2.

The main way of dagaa post-harvest processing is sun-drying. The main tasks of dagaa drying are, first, spreading dagaa on the ground to dry in the open air (Figure 3). Then, the processors flip sides of the dagaa once in a while. Finally, the processors collect the dried dagaa to sell. In this process, the main reasons for the post-harvest loss are,

1. The contamination caused by sand and animals.
2. Insufficient sunlight during rainy and cloudy days, which leads to dagaa spoilage.

The waste often ends up being chicken food. Moreover, the enormous amount of food waste consequently leads to insufficient income. Apart from the contamination, the quality of the dried dagaa is also evaluated by its intactness and luster, which are affected by the turning process and UV exposure, respectively (Blankendaal et al., 2020, p. 56).

3.2 Current Design

Sagar Energy Solutions (SES) was developing a greenhouse drying solution "Upepo" with Project Dagaa (Figure 4). Upepo protects the fish from sand and animal contamination, rain, and direct UV exposure. Moreover, it provides active ventilation to ensure the dagaa is dried before the trade of the day. However, Upepo was validated only on a limited scale and on an island where sunlight is relatively sufficient. As a consequence, SES is currently planning to install an active heating system and validate it with a prototype. Besides, SES is also considering adding a monitoring system to have better control of the humidity and temperature inside the greenhouse.

Project Dagaa developed Upepo to improve the quality of dried dagaa. However, the design needs further validation and evaluation before being implemented in Tanzania. Therefore, Project DagUp is launched to develop the design based on the previous work of Project Dagaa.

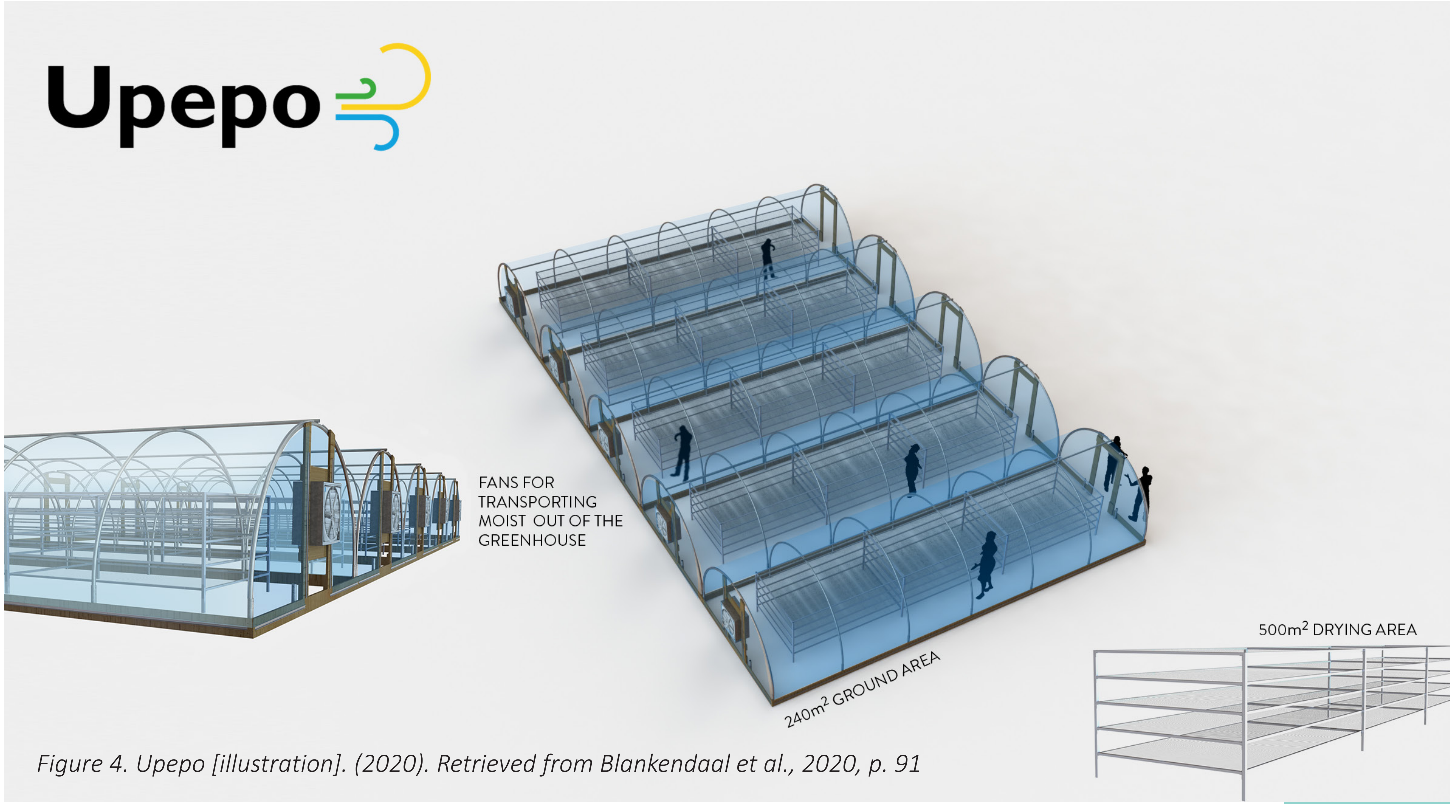

Figure 4. Upepo [illustration]. (2020). Retrieved from Blankendaal et al., 2020, p. 91

3.3 Problem Definition

The current design, Upepo, had resolved the contamination issue. However, its drying capacity during rainy days, sustainability impacts, and cost-effectiveness were still unknown. Moreover, there were some more ways to address the post-harvest loss issues, and yet left unexplored.

Functionality

Upepo was only tested on a smaller scale model, it has not been validated on a full-scale model, which implies the drying effectiveness, usability, and capacity need further validation. Some places often have heavy rain, which lowers the temperature and raises the relative humidity. Under this circumstance, dagaa is less likely to be dried within a day without regulating the relative humidity and temperature.

Sustainability

Upepo is mainly pursuing the social aspects of sustainability, namely "Zero Hunger" and "Decent work and economic growth." For environmental sustainability, its materials are purchased locally, and the fabrication is done locally. Besides, the modularity feature helps reduce waste of resources. However, as adding a heater was the next development of Upepo, the sustainability impact has become an issue.

Business

The cost of the current solution, compared to the income, might place a substantial financial burden on the fishing camps. Therefore, a suitable business model is required for the new solution to secure the profit of the local parties and service providers. Moreover, the current design has no patent and is easy to copy. Therefore, when the competition arises, the service provider might be exposed to potential business loss.

Scope

While developing Upepo, it was mostly focusing on improving the drying system throughout the design process. However, there are some opportunities left unexplored. By looking into the fundamental reason for the problem, the scope can be broadened up, for example, to "design a new solution for fish preservation".

Project Goals

Based on the aspects mentioned above, some goals were defined,

1. *Study the opportunities to reduce the post-harvest loss of dagaa.*
2. *Study the sustainability impact of Upepo and reduce the impact.*
3. *Determine the most suitable solution for reducing post-harvest loss*
4. *Validate the drying effectiveness, usability, and capacity of the (re)design.*
5. *Create a suitable business model/strategy.*

3.4 Partner

This project was in collaboration with Sagar Energy Solutions (SES), a social enterprise located in Tanzania. SES has been working together with the local fishery for years to develop sustainable energy solutions (Figure 5).

Resources

Local Manufacturer

SES does not manufacture. They cooperate with local component and building material suppliers instead.

Foreign Manufacturer

SES has a foreign manufacturing partner, who takes care of the parts that are not yet available in Tanzania, for example, electronics and injection molding.

Assembly

As of now, the assembly is processed in-house. However, SES is planning to build larger-scale assembly and manufacturing plants.

Network

SES is in close cooperation with local fishery and concerned organizations. Besides external networks, their team consists of diverse expertise such as social entrepreneurship, energy and environmental science, finance, regional consultation, and engineering.

Mission

"Our core focus is modernizing the incredibly productive fishing industry of Lake Victoria. Together with our end users, we design and develop solar alternatives to improve their livelihoods and their communities. As a socially driven company, people profit planet is our bottom line."

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Figure 5. The first product of SES: fishing lamp [photograph]. (n.d.). Retrieved from Sagar Energy Solutions, n.d.

Figure 6. Maintenance of the fishing lamp (photo provided by SES)

04 Final Design

4.1 Introduction

UpWind (Figure 7) is a sustainable greenhouse dryer that provides a hygienic and efficient drying environment for freshly caught dagaa in Tanzania. It is a semi-closed system, which allows it to maintain the internal heat level by recirculating the air.

Figure 7. UpWind

[A] Drying Chamber

The chamber provides a suitable environment for drying dagaa. During sunny days, it is heated up by solar radiation.

[B] Air Distributor

The air distributor blows laminar dry air into the drying chamber with a set of fans.

[C] Drying Nets

Drying nets are the platforms to hold the dagaa during the drying process.

[D] Guiding Sheets

The fabric guiding sheet between each drying layer and the PE sheet on top of the drying nets help the laminar airflow maintain its speed and extend its coverage.

[E] Chimney

The chimney design helps to induce internal airflow through the chimney effect.

[F] Wind-driven Fans

The wind-driven fan provides assistance to the chimney effect by enhancing the upward airflow.

[G] Recirculation System

The used air is recirculated through the recirculation system. The top PE guiding sheet [D] not only helps to guide the direction of the airflow but also works as a partition to form a channel for recirculating the exhaust.

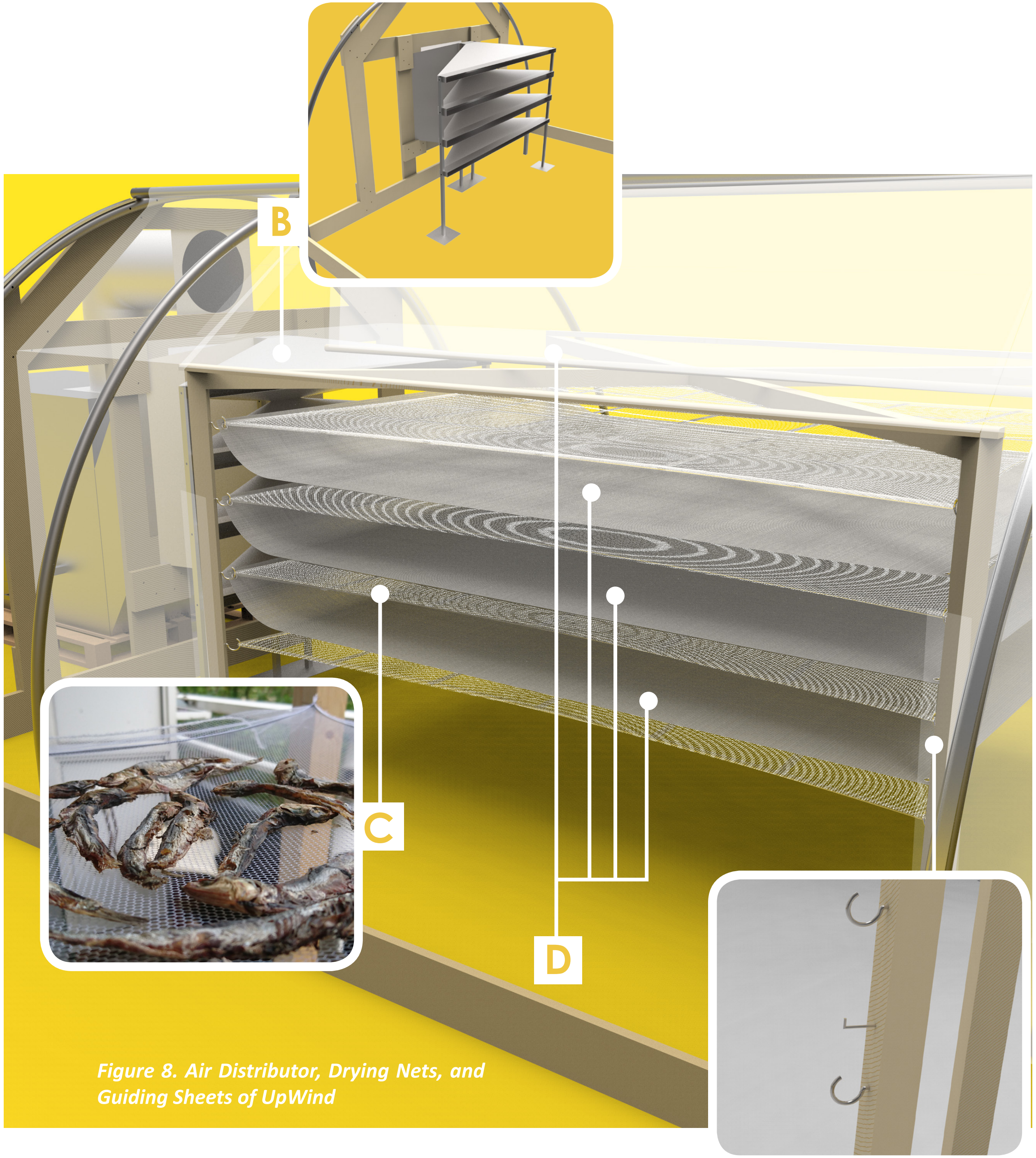


Figure 8. Air Distributor, Drying Nets, and Guiding Sheets of UpWind

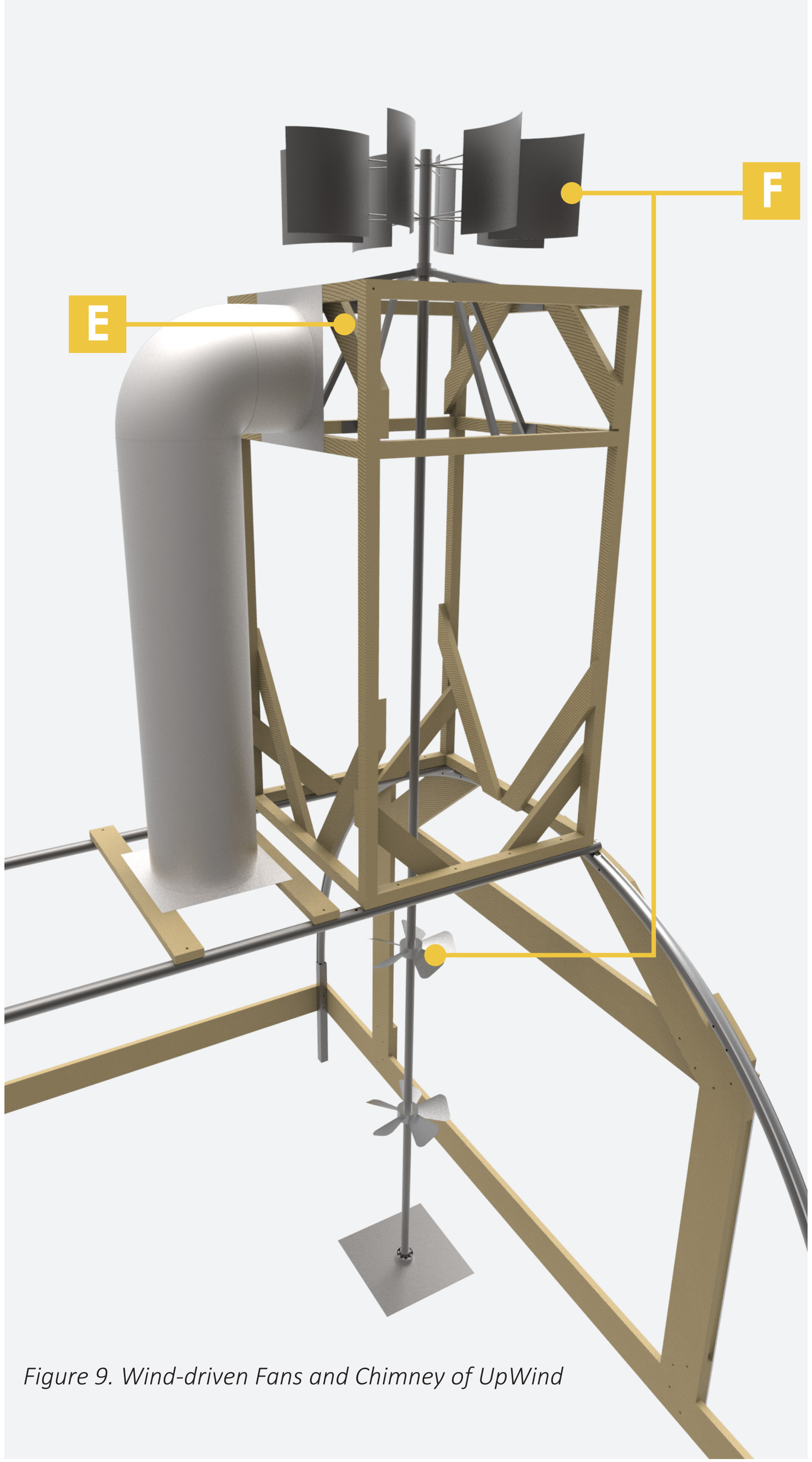


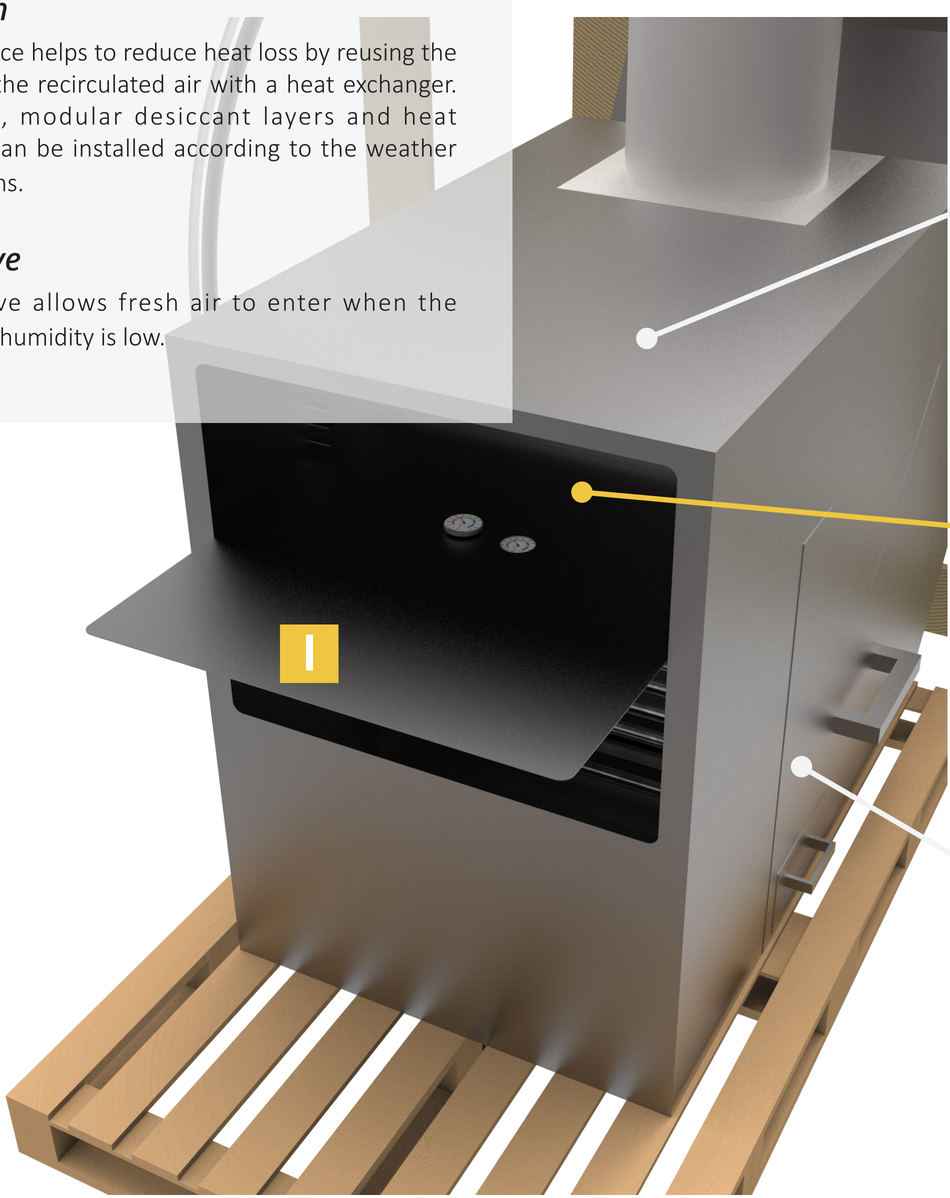
Figure 9. Wind-driven Fans and Chimney of UpWind

[H] Heating and Dehumidification System

This device helps to reduce heat loss by reusing the heat of the recirculated air with a heat exchanger. Besides, modular desiccant layers and heat pumps can be installed according to the weather conditions.

[I] Valve

The valve allows fresh air to enter when the outdoor humidity is low.



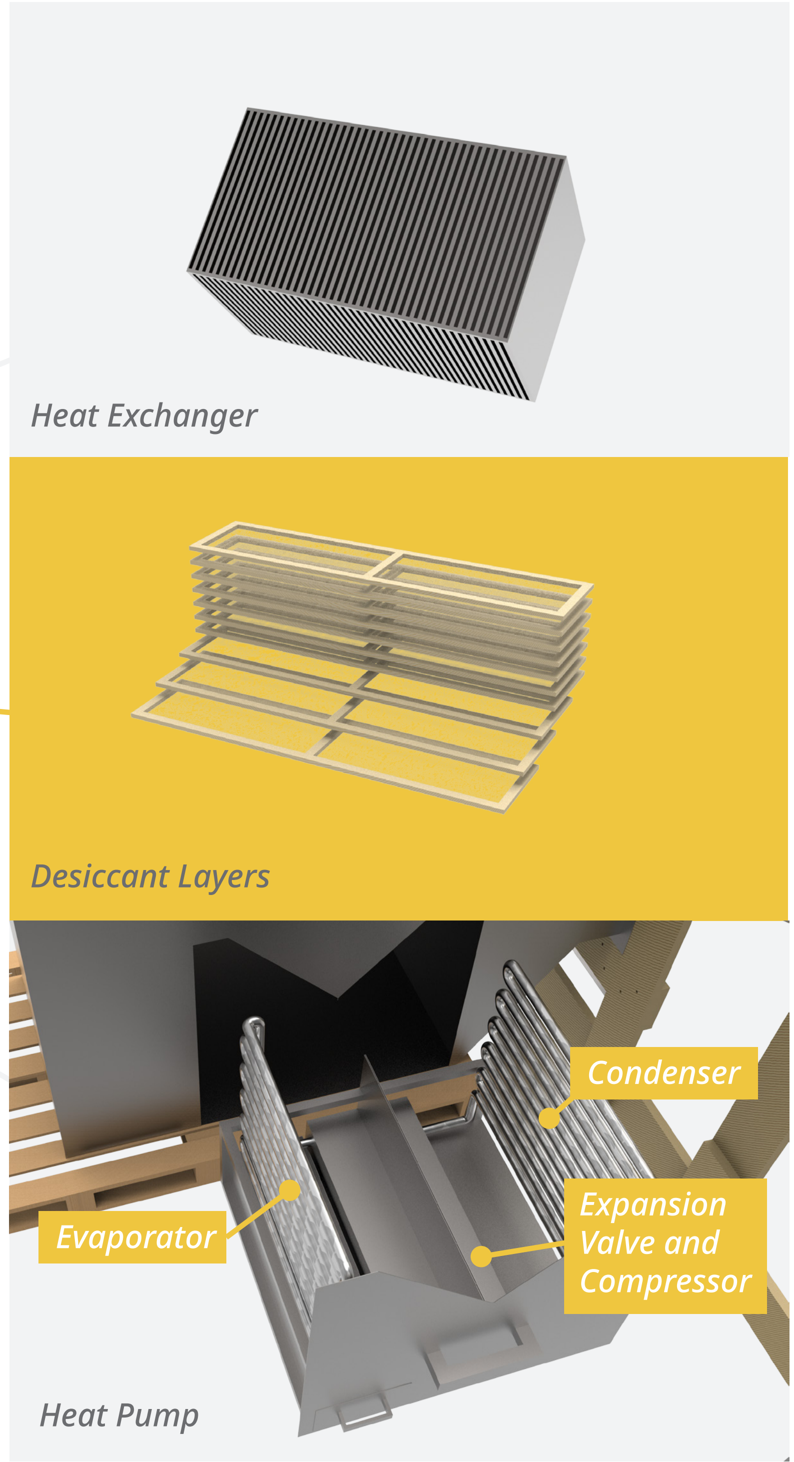


Figure 10. Heating and Dehumidification System of UpWind

[J] Insulation Curtains

The greenhouse is divided into two insulation chambers and a drying chamber by the curtains. They also work as guiding sheets for the internal airflow.

[K] Entrances

The workers can enter through the entrances.

[L] Insulation Chambers

The main function of insulation chambers is to prevent heat loss.

[M] Working Space

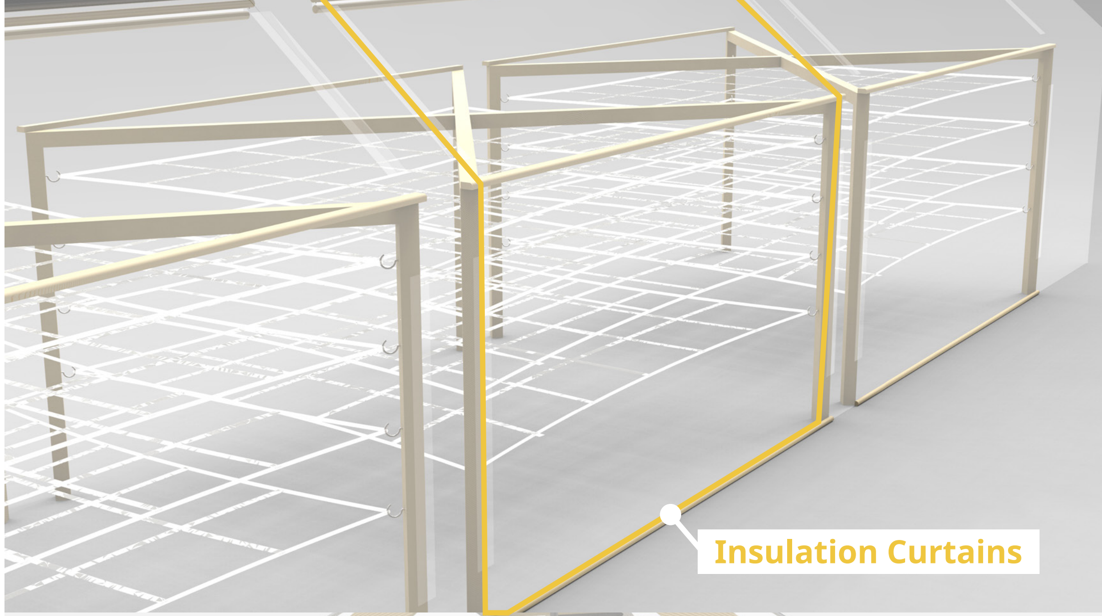
The insulation chambers are also the working space for processors. The processors can access the drying nets by opening up the curtains.

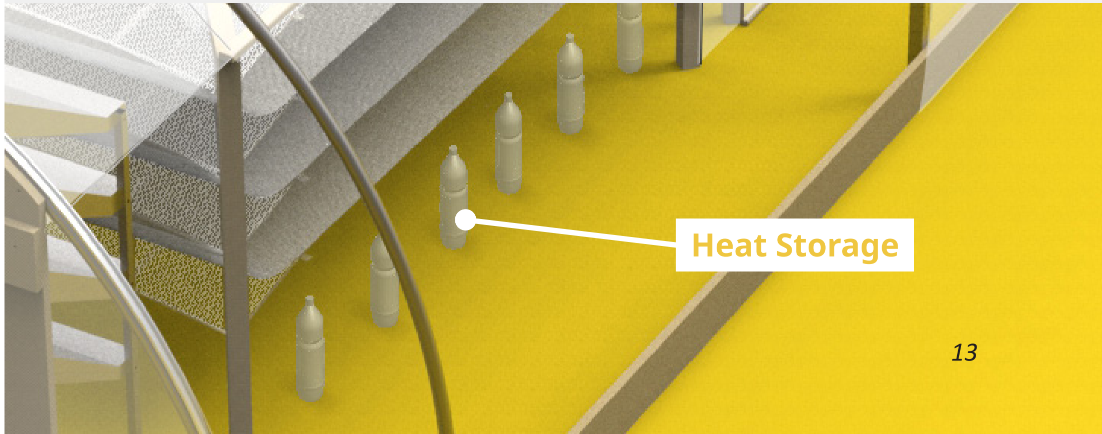
[N] Heat Storage

Water bottles are placed inside the drying chamber to reduce heat loss.

[O] PV Panels and Electricity Storage System

The system supplies energy to the electrical fans and the heat pump.





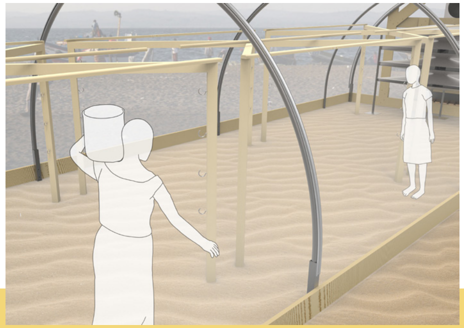
4.2 Use scenario

Transport

1. Transporters collect dagaa from boats

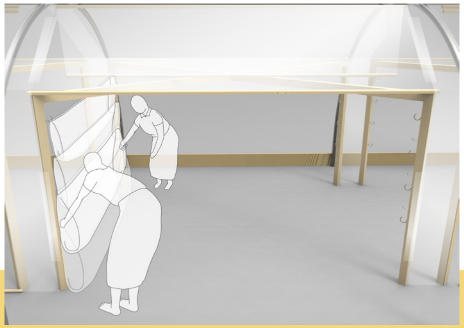
2. Transporters transport the dagaa to UpWind

3. Transporters pass the buckets to the distributors



4. Distributors transport the buckets to designate locations

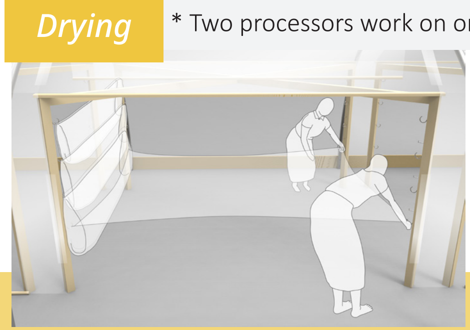
5. Distributors pass the bucket to the processors



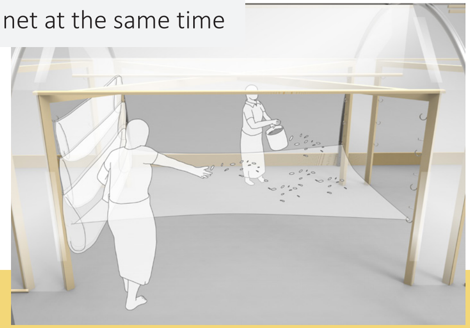
6. Processors start to do the work. And, the transporters and distributors keep doing their work until the catch is fully unloaded.

Drying

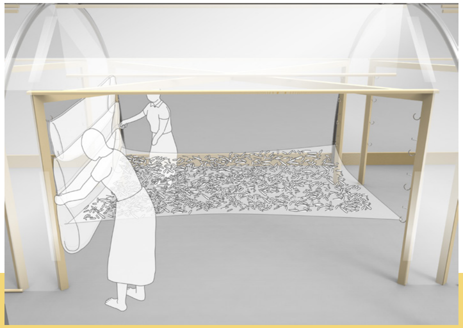
* Two processors work on one net at the same time



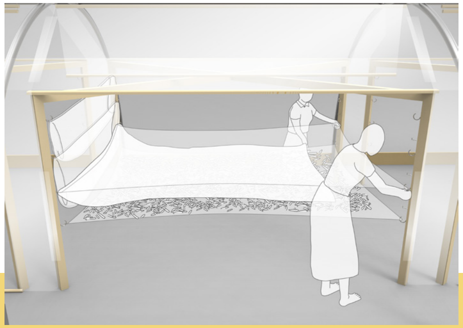
7. Set the bottom net



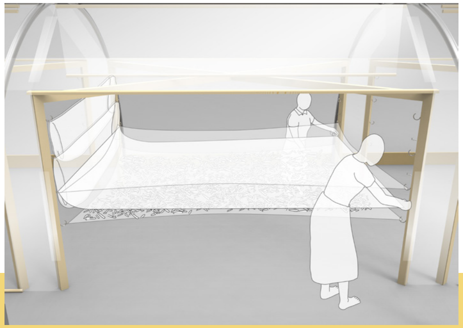
8. Spread the dagaa on the bottom net



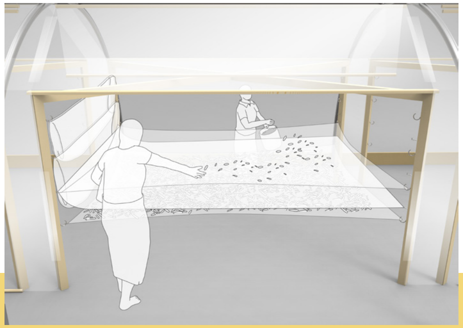
9. prepare the next net and the guiding sheet



10. Hook the net on the poles



11. Hook the guiding sheets on the poles



12. Spread the fish onto the net

13. Repeat step 9-12 until four nets are done

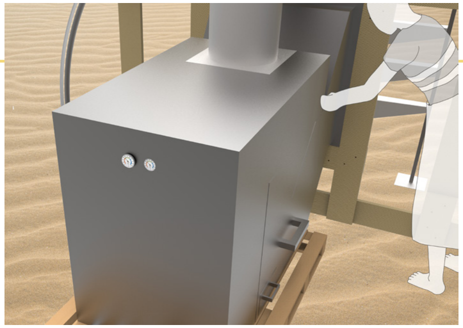
14. Grab the bars of the insulation curtains

15. Pull down the insulation curtains on both sides

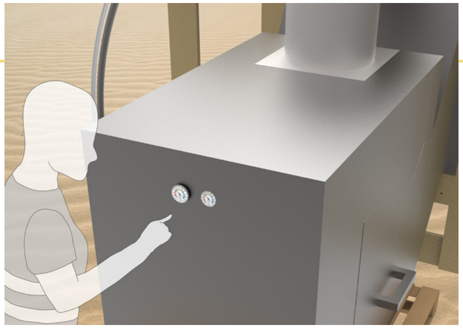
16. Repeat step 7- 15 until three drying racks of the UpWind are done

17. Walk out UpWind and zip the doors

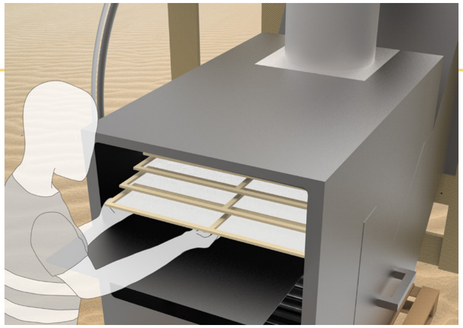
Sunny-day Scenario



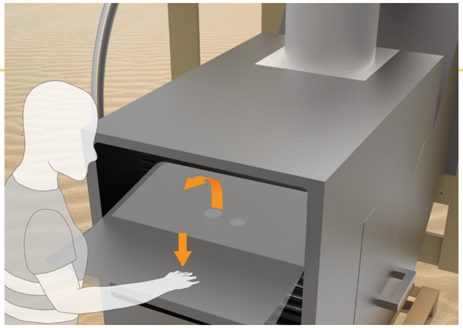
S1. Janitor switches the fans on



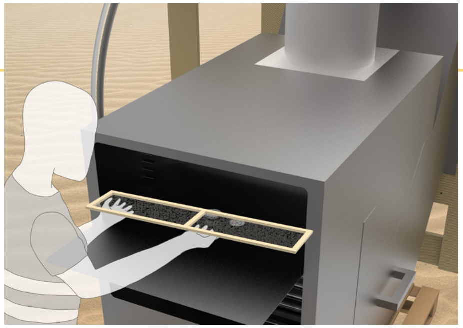
S2. Check the hygrometers



S3. Open the valve and place the dehumidification layers



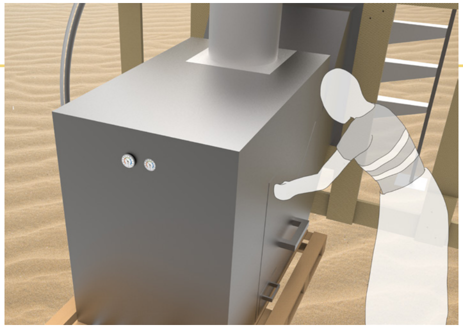
S4. Keep the valve open if the indoor humidity is higher than outdoor.



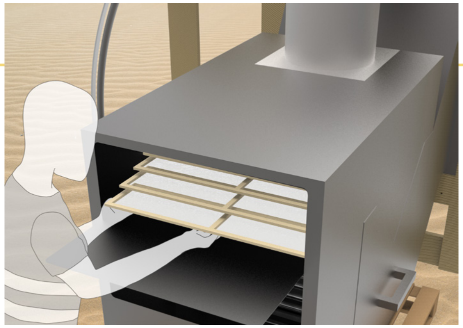
S5. Replace the layers every hour and dry them under the Sun

S5. Repeat Step S2-S5 Regularly until the drying process is finished

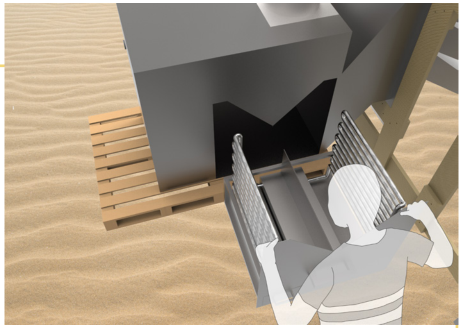
Rainy-day Scenario



R1. Janitors switch the heat pump and the fans on

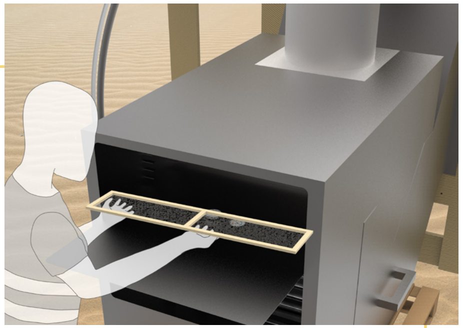


R2. Place the desiccant layers and close the valve

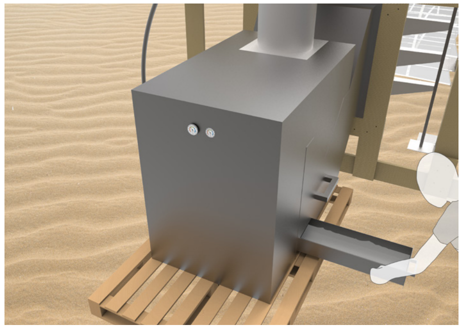


R3. Shift the heat pump between two UpWinds on an hourly basis

R4. While the heat pump is absent, UpWind maintains its temperature through the heat exchanger and heat storage. And, UpWind dehumidifies the recirculated air through the desiccant layers



R5. Replace the layers every hour and dry them when sunny



R6. Empty the water collector once full

Dryness Checking

18. Check the dryness of each layer (Turn the dagaa at the first hour)

19. Close the insulation curtains

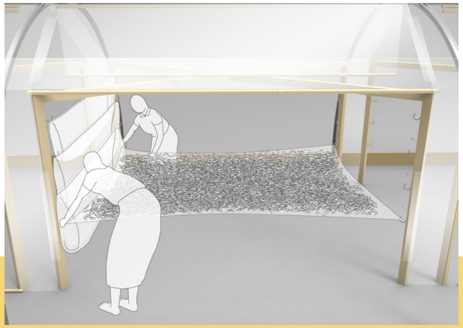
20. Repeat 18-19 every hour for each rack until the drying process is finished

Harvesting

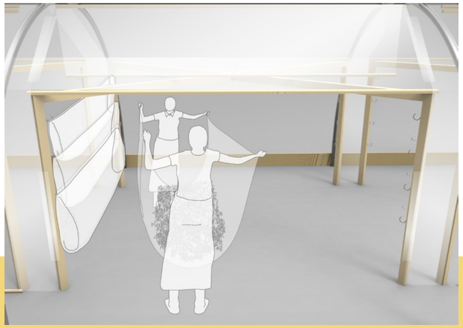
21. Unhook the short side of the top net and the guiding sheet beneath it

22. Pour the dried dagaa to the next layer gradually

23. Hang the net to the closest poles



24. Repeat step 21-23 until the dried dagaa is all at the bottom net



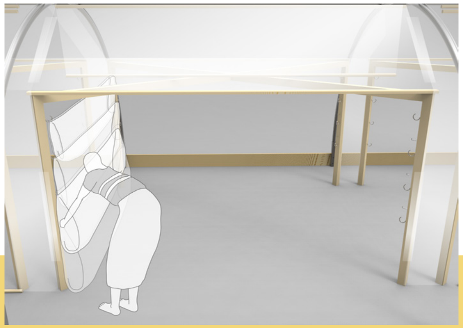
25. Wrap the dried dagaa with the net

26. Pour the dried dagaa into the buckets

27. Transporters transport the dried dagaa to the trading spot

Cleaning

28. Janitors wash the nets in basins



29. Janitors hang the nets back to the poles

* Transporters, distributors, processors can be anyone assigned by the fishing camps
* Janitors are assigned by service providers

4.3 Features

4.3.1 Business

Faster Drying

UpWind will be used by the fishing camps during rainy days as it guarantees the production of dried dagaa. However, during sunny days, dagaa can be dried without UpWind; thus, the fishing camps may not use the service. According to SES, even though quality improvement increases the unit price of the dried dagaa, the customers may still not pay the bill; and, in SES's opinion, a faster drying process is a better selling point than the improvement of drying quality. Therefore, UpWind aimed to shorten the drying time to attract customers.

According to the calculation (Appendix A), UpWind dries dagaa around four hours. Compared to sand-drying, which takes around six hours to dry, UpWind is 33% faster than. It speeds up the process by supplying constant medium heat, dry air, and airflow across the surfaces of the dagaa.

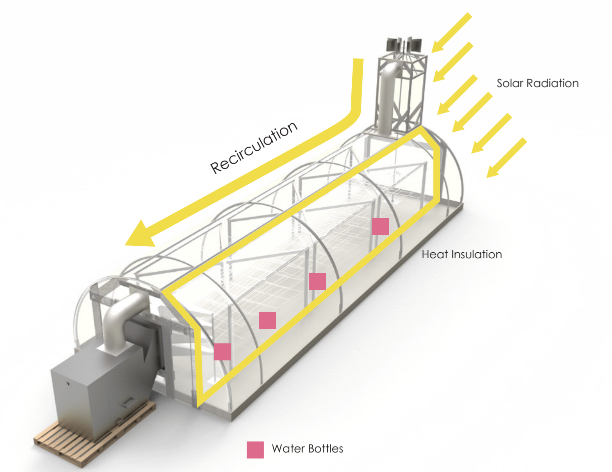


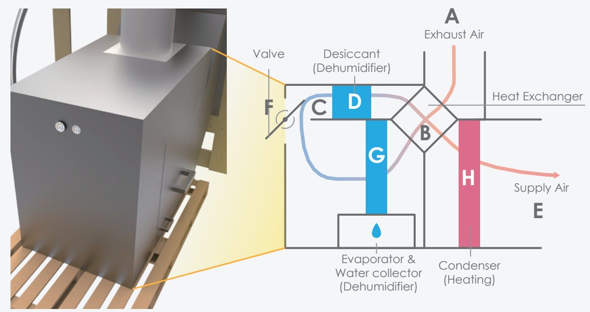
Figure 11. Natrual Heating System of UpWind

Heat and Dry Air Supply

According to the research findings (Chapter 5), the suitable drying temperature range is 35°C to 63°C, and the relative humidity range is 10% to 40%. Therefore, UpWind aims to regulate the air condition of the greenhouse within these ranges with the help of solar radiation, heat pump, recirculation system, heat insulation, heat storage, and desiccant layers.

UpWind gains heat from solar radiation during sunny days and from heat pump on rainy days. The heat loss is prevented in three main ways (Figure 11). First, the waste heat is recovered by a heat exchanger. Second, the insulation chambers help reduce the conduction heat loss. Third, heat storage bottles are placed inside the drying chamber to maintain the temperature. According to the research (Akinjiola & Balachandran, 2012, p. 47), water bottles can be used as heat storage for greenhouse dryers. UpWind dehumidifies the recirculated air by using desiccants and valves during sunny days, and by using the dehumidification effect of the heat pump on rainy days.

How does the Heating and Dehumidification System work?



The wet air enters the device (A) and transmits its heat through the heat exchanger (B). Then, after it passes through the desiccant layers (D) it gains the heat back from the heat exchanger (B). In the end, the dry air is sent back to the drying chamber (E).

During sunny days, when the humidity of the wet air (at position C) is higher than the outside humidity (F), it is more efficient to use the fresh air than dehumidify the wet air. In this case, the valve will be opened to allow the fresh air to enter.

On rainy days, a modular heat pump will be added to provide essential heat for drying. The condenser of the heat pump will be added to position H as a heating element, and the evaporator of the heat pump will be used as a dehumidifier (G).

Airflow Supply

The drying rate is closely related to air velocity over the surface (Rahman, 2006, p. 7). To cover the surface of the fish, UpWind provides laminar horizontal airflow (Figure 12). Moreover, simulations (Subsection 5.4.1) were done to improve the coverage and the overall air velocity of the air distributor. As a result, the air distributor is capable to evenly divide the incoming air into four laminar airflows so that each layer of drying net receives an equal amount of air supply. Furthermore, the coverage of this laminar airflow is extended by the guiding sheets so that 90% of the nets were covered by the laminar airflow.

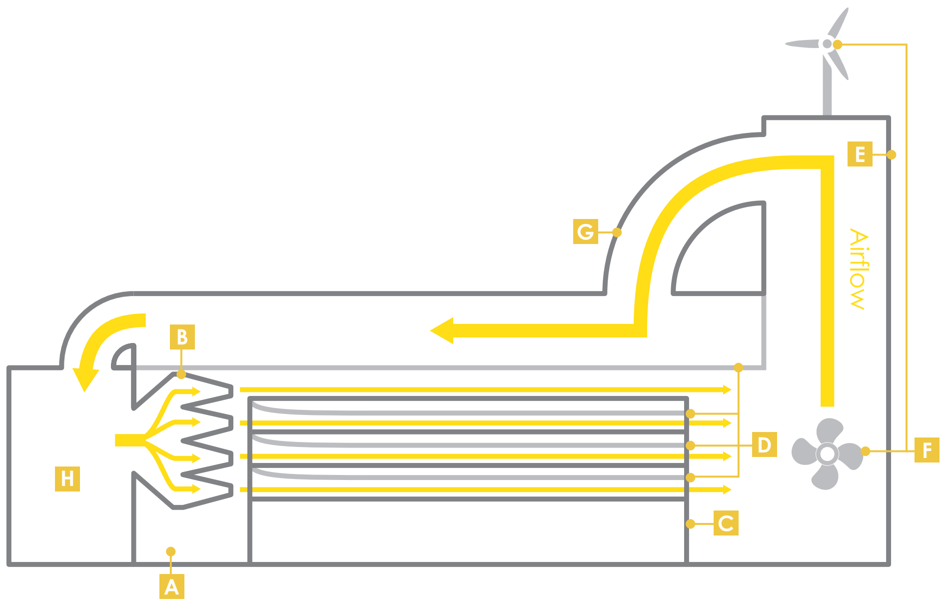


Figure 12. Side View and Internal Airflow of UpWind (Refer the labels to Page 10)

Affordable

Dagaa is a low-cost fish, any slight change in operational cost may influence its price. Therefore, affordability is vital for UpWind. Due to the increased profit of uncontaminated dried dagaa, increased production per unit land area, and a suitable business model, the net profit is increased compared to sand-drying.

Increased Profit

According to Project Dagaa (Blankendaal et al., 2020, p. 59), uncontaminated dried dagaa has roughly 2.5 times higher price than sand-dried dagaa. Moreover, the land used by UpWind is 40% less than sand drying due to the utilization of vertical space (Figure 13). Therefore, the profit per unit of land is increased.

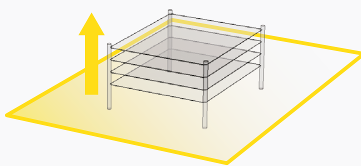


Figure 13. Space Saving of UpWind

Business Model

The business model is a B2B leasing model. The service provider will rent UpWind to fishing camps with a monthly rent round 200 Euros. Based on the cost-profit calculation, the net profit of a fishing camp may increase by 40% compared to sand-drying, and the rent is expected to bring the service provider a margin above 50%.

4.3.2 Ergonomics

The target users are mostly undereducated and some of them are middle-aged or baby-carrying (Figure 14); therefore, the use of UpWind was designed to be intuitive, low-burden, comfortable, and safe. The main activities that involve user interaction with UpWind are spreading, checking, turning, and harvesting dagaa. Among these activities, the longest ones, in terms of time, are spreading and harvesting. The spreading task is done in the early morning and the harvest is done around noon.

Figure 14. Child-carrying processor [photograph]. (2020). Retrieved from Blankendaal et al., 2020, p. 83

Intuitive

According to the user tests (Subsection 5.4.2), in terms of usability, the drying net is a good system (SUS score = 78.75). Moreover, All participants stated that they would imagine that most people would learn to use this system very quickly.

Low-Burden

According to the user test results regarding the interaction of the drying nets and insulation curtains, participants with lower back issues and the participants in different height groups could perform the task without major issues.

UpWind aims to lower the burden of the drying process by four features. First of all, the turning operation was reduced to one time throughout the process. Second, the spreading operation, regardless of which layer, can be done without bending the body or squatting. Third, the harvesting operation of UpWind allows users to harvest the fish in one swift move (Figure 15). Fourth, according to the user test (Page 83), the pulley system of the insulation curtains (Figure 16 and 17) provides a faster opening and closing operations compared to manual rolling operation.

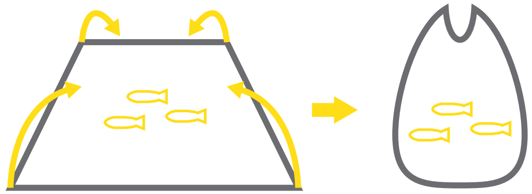


Figure 15. Harvesting operation of UpWind

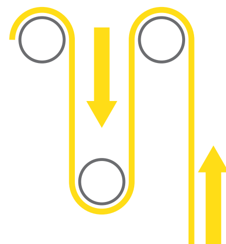
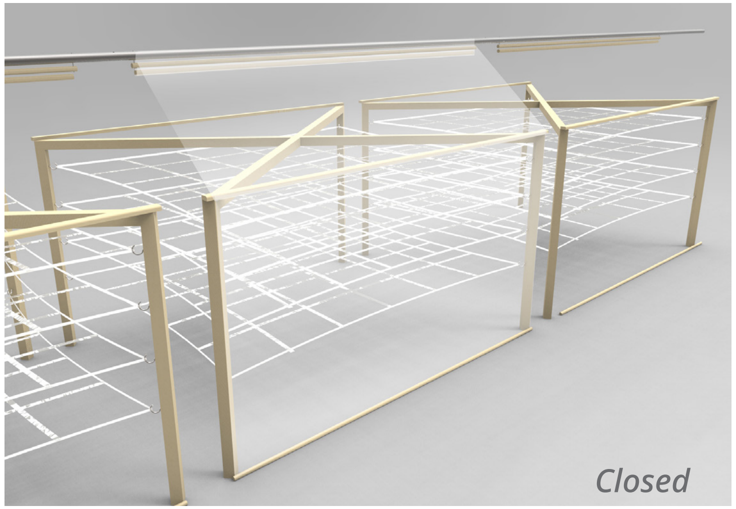


Figure 16. Pulley Mechanism



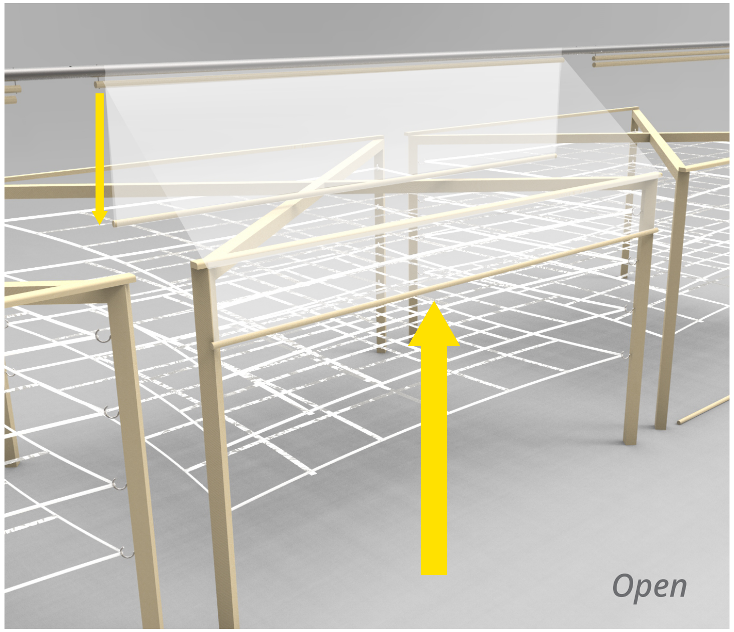


Figure 17. Pulley System of UpWind

Comfortable

According to the user test of the interaction inside the greenhouse setup (Page 81), none of the participants stated that they had perceived any oppression during the test. Some participants even mentioned the brightness of the setup gave them an open-space perception.

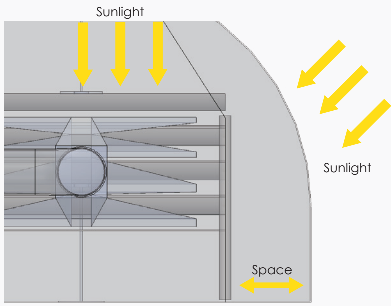


Figure 18. Space and Brightness of UpWind

Safe

UpWind aims to protect users from being cut under regular operation by avoiding sharp edges in the working areas. Moreover, UpWind also aims to reduce the safety hazards for its assembly. The assembly process is expected to be safe due to the simplified procedure. The process is only to connect parts with bolts and screws, i.e., the techniques with higher risk such as welding, cutting, and sawing are not required on-site.

4.3.3 Sustainability

Cheap, short-lived products are sometimes used for short-term problem solving without evaluating the impact on the environment and the people. Moreover, these products sometimes are abandoned or improperly disposed of, then end up becoming an environmental issue. Therefore, choosing and making a durable, suitable, and sustainable design are crucial, especially for those places that are still developing.

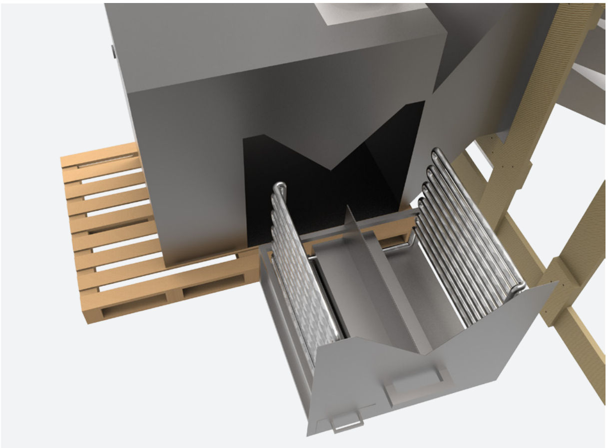


Figure 19. Modular Heat Pump

Lower Sustainability Impacts

UpWind aims to have lower sustainability impact (Section 7.2) than the original design Upepo by inheriting sustainable features from Upepo and reducing the impacts on the material, use, and end of life phases.

Material

Instead of using brand new plastic-coated wire meshes, UpWind opted for reusing retired fishing nets. On one side, it is reusing the wastes; on the other hand, it diminishes the improper disposal of the old fishing nets.

Use

Compared to other common heaters, heat pumps are low-pollution and energy-efficient, which consumes only less than half of the electricity of conventional condenser dryers (Fayose & Huan, 2016, p. 2). Therefore, instead of using a charcoal burner, UpWind uses an electrical heat pump as the heat source.

UpWind also uses PV panels as its green energy supply. However, as the heat pump is needed when sunlights are not available, an electricity storage system is adopted to store electricity during sunny days.

End of Life

The materials used for UpWind are recyclable or biodegradable.

Modularity

The modularity feature for easy repair remained and was further developed for easier adaptability. For example, the heating system was designed as a modular component (Figure 19). When the heat pump is not in use, it can be removed from UpWind and utilized in another place.

Durable

The durability of most of the components and materials is more than 3 years. Many components even have higher lifespans, some are more than 10 years, such as galvanized steel tubes, PV panels, Heat Pumps, steel sheets, etc. Even after 3 years, UpWind is still repairable due to its modularity.

Suitable

UpWind is suitable for Tanzania because it is customized based on the local conditions.

Modularity

The service provider can also decide whether heat pumps should be installed in a certain place, according to the overall weather condition and cost.

Alternatives

For those places where heat pumps are not installed, alternative preservation methods, such as fermentation, salting, and smoke-drying, are recommended to be practiced when drying is not possible.

Self-Sufficient

Due to the fact that electrical grids on the islands are often unavailable. UpWind is completely self-sufficient by using PV panels.

Local Resources

The wind on the fishing islands comes from all directions, but the wind-driven exhaust fans (Figure 20) can make use of the natural wind regardless of the direction.

The sandy ground is used for stabilizing the greenhouse frame and drying racks, and also used for sealing the gaps between the greenhouse and the ground (Figure 21).

Economy

To stimulate the local economy and to lower the sustainability impact, most of the materials and fabrication are locally sourced. Moreover, the drying operation is now a two-worker task; therefore, even though the task is low-burden, the job positions are still kept. Furthermore, the maintenance tasks open up some new job opportunities for locals.

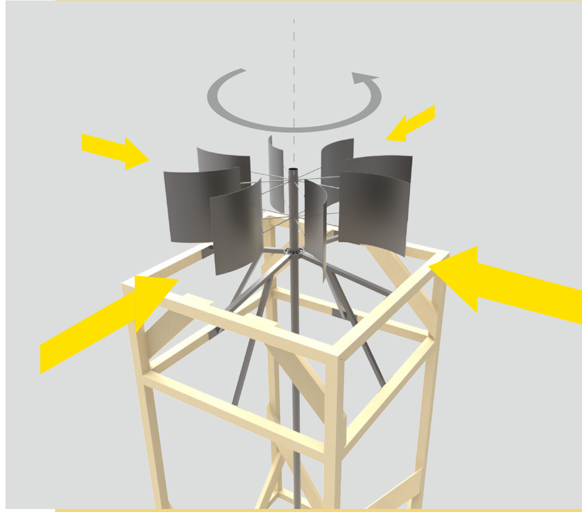


Figure 20. Wind-driven exhaust fan

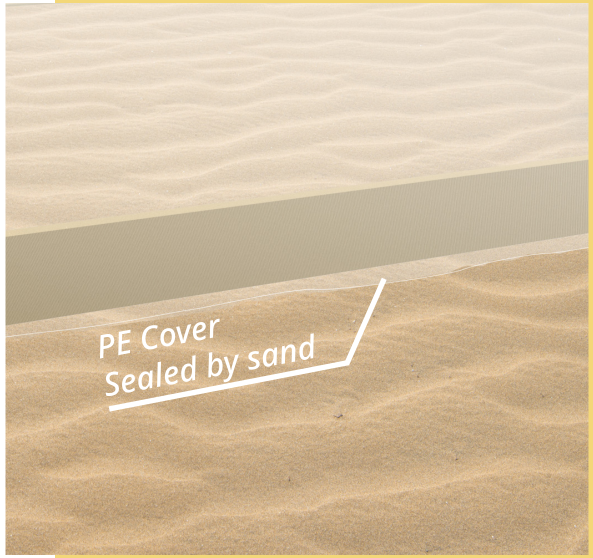
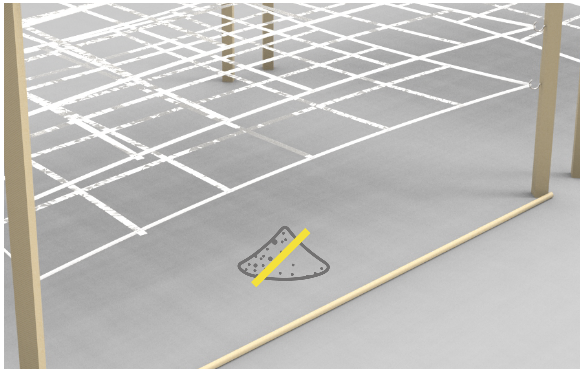


Figure 21. Sand Utilizing Feature

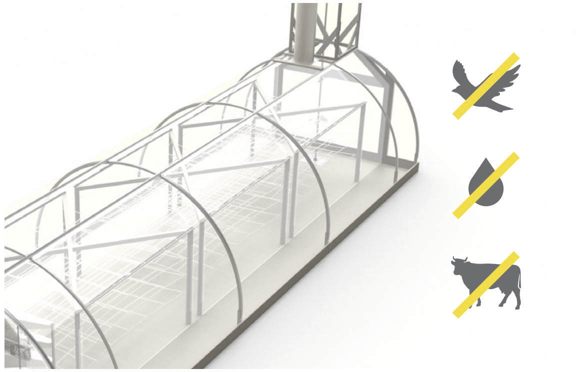
4.3.4 Drying Quality

Dagaa is an affordable and nutritious food source for the people in Tanzania, especially for impoverished families. Still, the poor quality of dried dagaa may cause physical discomfort or even diseases to them. Therefore, the quality should be improved to ensure public health. Apart from that, quality improvement also secures the income of the fishery workers.

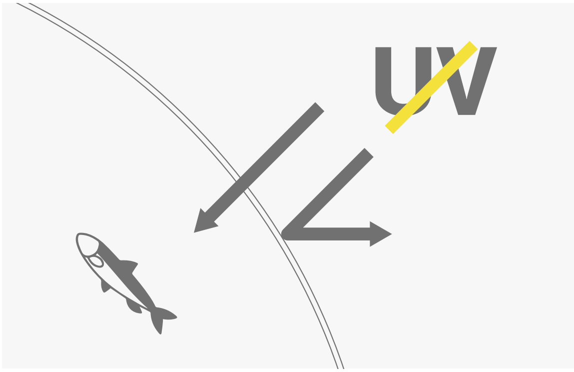
UpWind improves the quality of dagaa by protecting them from contaminations and by drying them properly to avoid spoilage. The dagaa is protected in many ways,



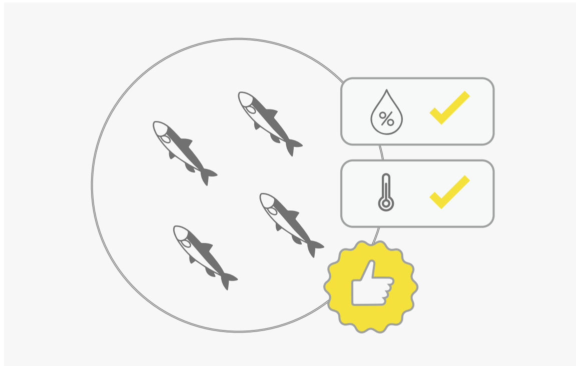
The lifted drying nets keep the dagaa away from sand contamination.



The greenhouse body protects the dagaa from rain and animals.



The greenhouse's covering material limits the dagaa's exposure to UV radiation, which improves the texture of the fish.



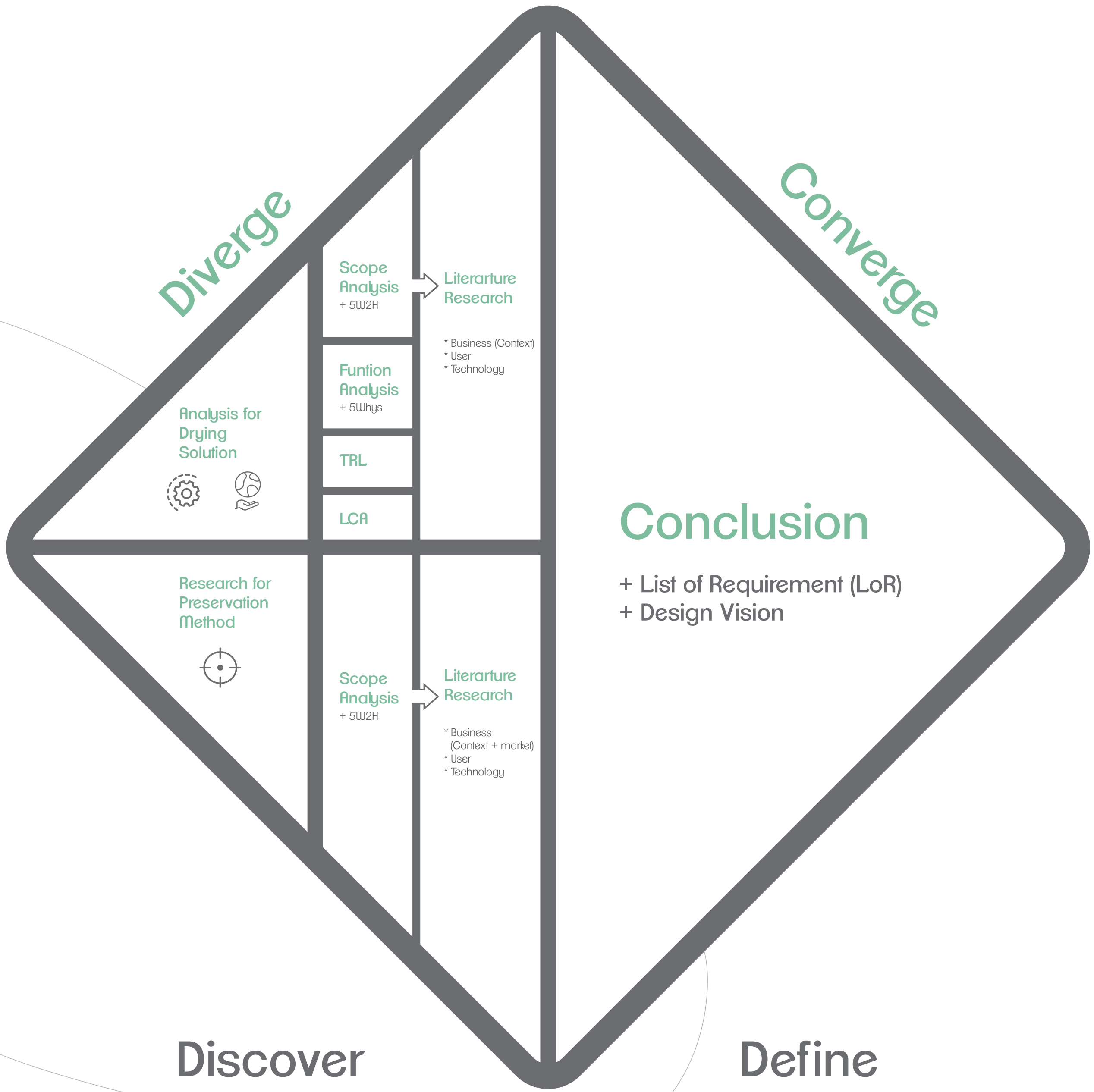
The drying condition is properly controlled within a range that dagaa can be dried without rotting or being scorched.

05 Process/Method

The process follows the framework of Double Diamond, a basic systematic design framework that helps generate designs by integrating a vast amount of information. There are four phases in Double Diamond: Discover, Define, Develop, and Deliver.

In the “Discover” phase, to ensure the study covers enough aspects of the given problem, the research phase was divided into two directions: refinement and exploration. In doing so, undiscussed information regarding drying methods and unexplored information about preservation methods would be included for a more comprehensive overview. Moreover, before the research and analyses started, the scope of each direction was checked to prevent undesirable narrow scope.

In the “Define” phase, the conclusions of refinement and exploration were drawn separately, to yield design direction for ideation.



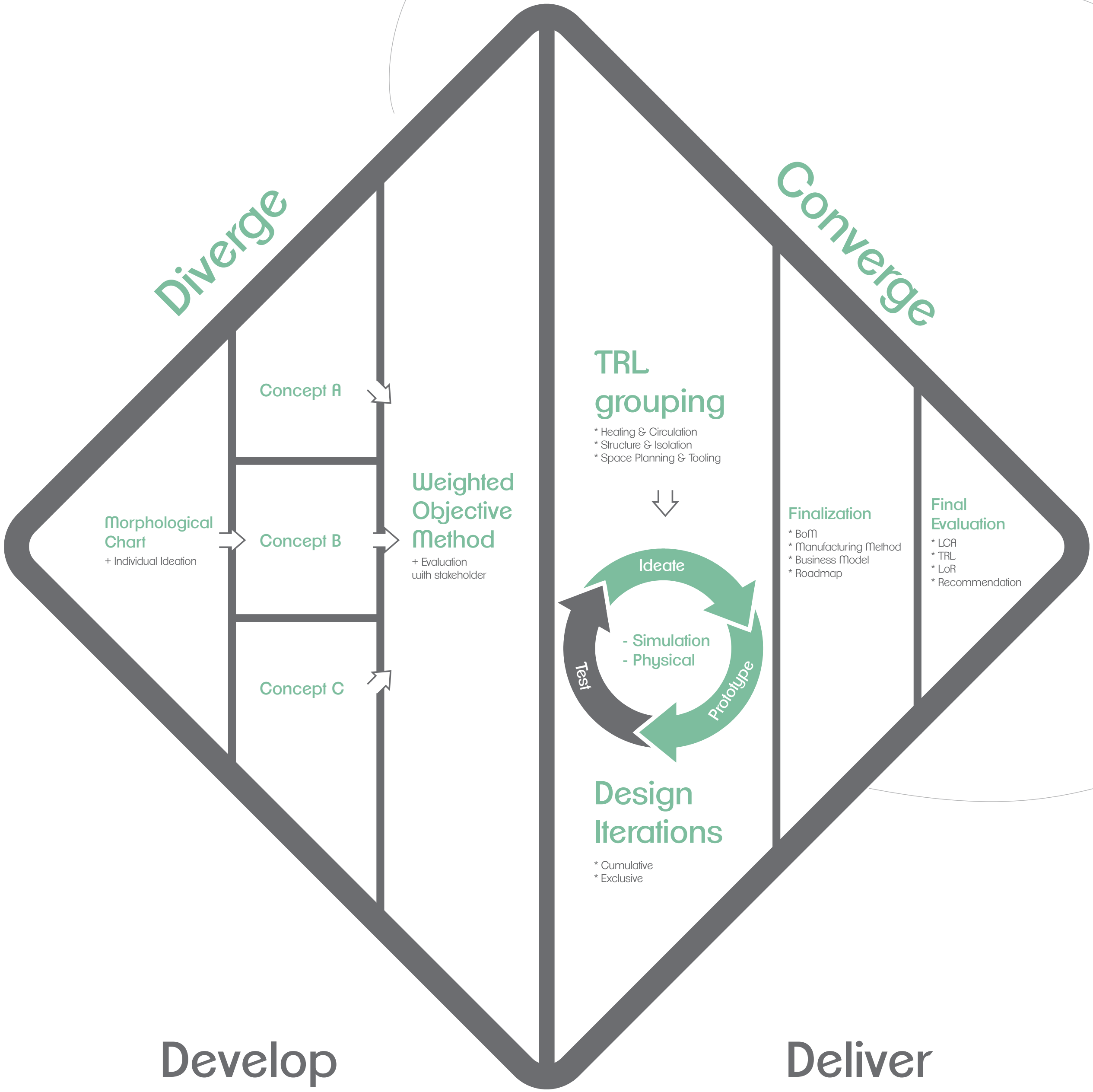


Figure 22. Method Overview

In the “Develop” phase, three concepts were generated and evaluated. The quantity of ideas was achieved by literature research and various design methods. Then, these ideas were filtered and combined into three concepts. Finally, the concepts were evaluated by the crucial criteria and then presented to stakeholders for feedback. Subsequently, one concept was chosen and then adjusted to meet the stakeholders’ expectations.

In the "Deliver" phase, the design was developed through design iterations and evaluated by simulation, user tests and consultation with relevant experts and stakeholders.

After the final iteration, the Bill of Materials, manufacturing methods, business model, and design roadmap were made to finalize the design.

As a closure of this project, the List of Requirements(LoR), Technology Readiness Level (TRL), and Life-Cycle Assessment (LCA) were check to evaluate the achievement and to identify the deficiencies of the project. Then, the development recommendation accordingly.

5.1Discover

The aim of this phase is to identify the problem through literature research and various design research methods.

The primary goals of the research are:

1. **To study the opportunities for reducing the post-harvest loss of dagaa.**
2. **To study the sustainability impact of Upepo**

5.1.1 Refinement

The goal of refinement is to investigate the undiscussed information and identify problems that can be improved from Project Dagaa's previous work.

Scope

The major problem of Upepo is that it does not guarantee the production of dried dagaa during non-sunny days. Through the method 5W2H, numerous questions were listed based on the above-mentioned problem statement, for example, "Why can the production not be guaranteed?". After clarifying those questions, the method HMW was carried out to identify more opportunities. Then, the relations of these opportunities were mapped out (Figure 23) for scope identification. Subsequently, the scope of the refinement was defined as "Drying Solutions" for the following two primary reasons,

01 *The acknowledgment of the difficulty in terms of behavioral change.*

It is safe to follow the original behavior before knowing the acceptance of the stakeholders.

02 *The room for exploration.*

Project Dagaa had discussed some drying methods, heating, and dehumidifying opportunities. However, the research can be further explored since only solar drying and one type of thermal drying method were discussed.

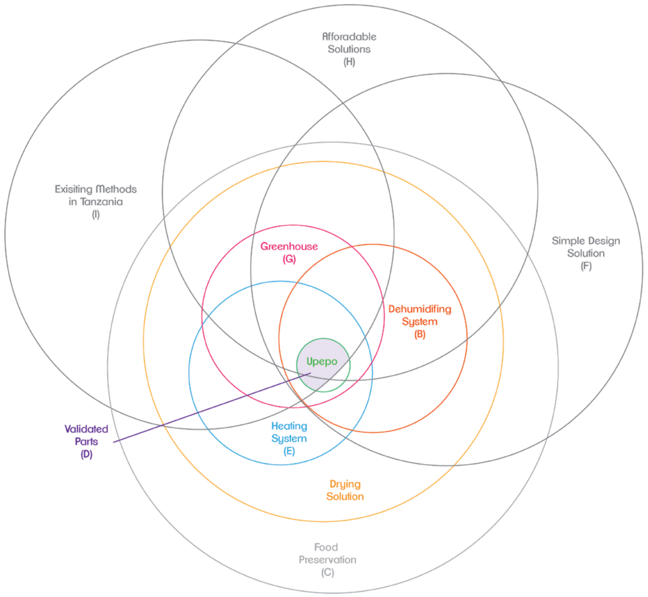


Figure 23. The Scope of Refinement

Overview of Researches and Analyses

Based on the scope, relevant research and analyses were done. Figure 24 shows the overview of the research and analyses. The research purpose was to study the opportunities for dagaa drying by covering the three design aspects: user, technology (included in "Drying Solutions"), and business (included in "Context"), i.e., to provide a comprehensive view for identifying opportunities regarding drying methods.

To identify the existing problem of the current design "Upepo," its functionality was analyzed by two methods: Function Analysis and TRL, and its sustainability was investigated by the method: LCA. However, due to the low overall readiness of Upepo, its user experience was not analyzed.

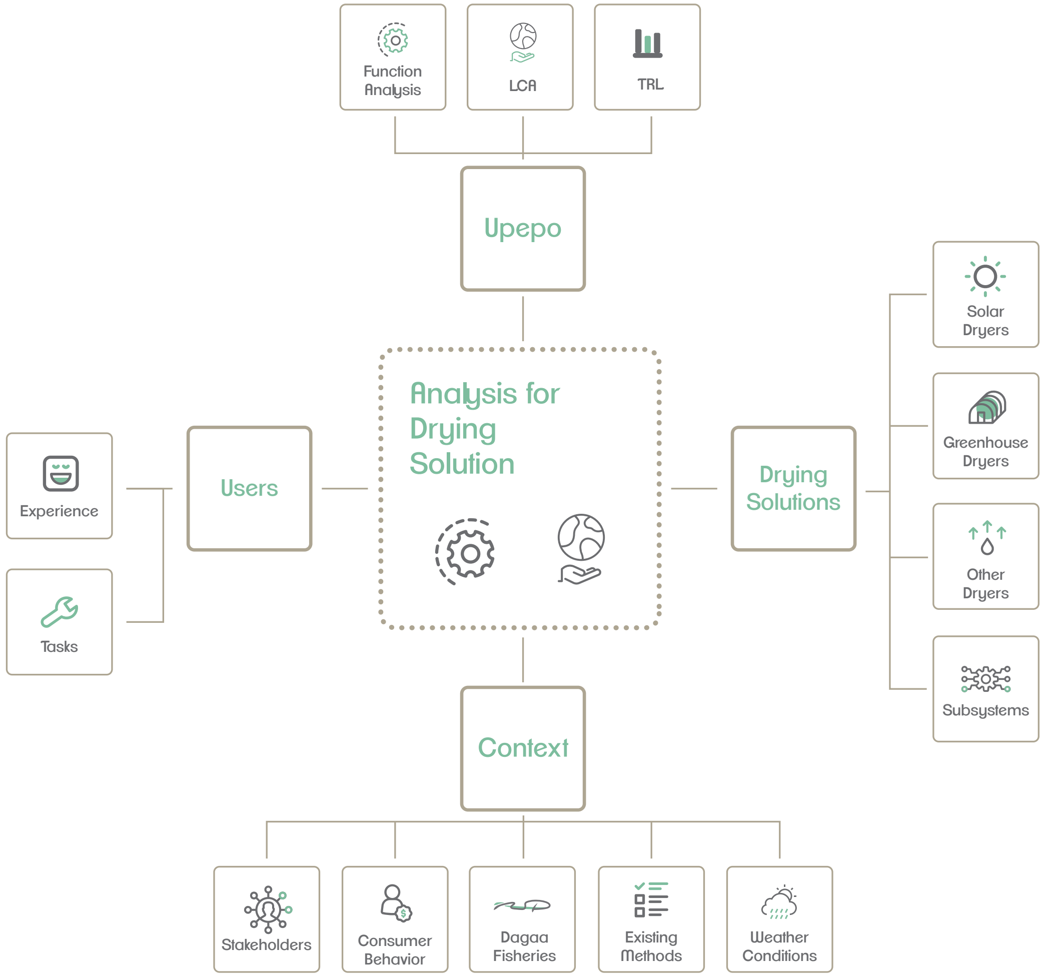


Figure 24. Overview of Analyses and Research for Drying Solutions

Technology Readiness Level (TRL) and Function Analysis

TRL and Function Analysis help clarify the use of each component and their levels of development. Moreover, TRL is a systematic method to keep the development on track by assessing the readiness levels with a set of standards. First, the component breakdown of Upepo was made, and the key function of each component was identified. Then, the components are categorized into subsystems and systems according to their key functions (Upper Figure 25). Finally, the readiness level of each subsystem was marked according to its extent of development compared to the production-ready level (Lower Figure 25).

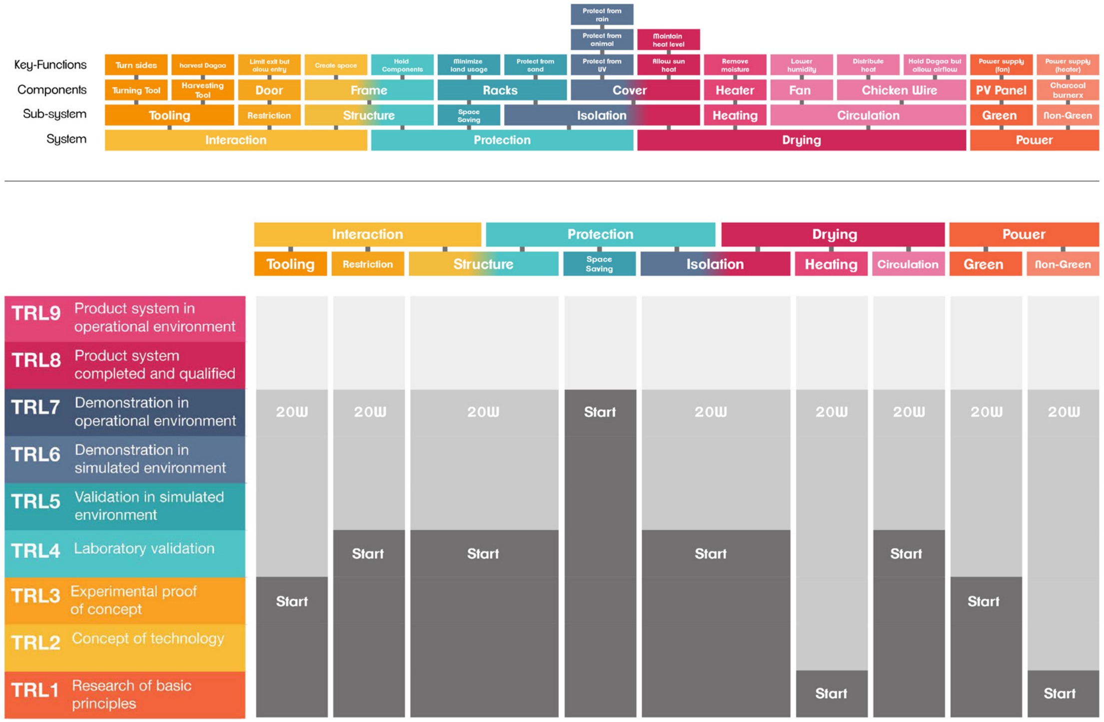


Figure 25. Function Analysis & TRL Analysis of Upepo

The development priority was based on their levels of readiness. According to the chart, the heating subsystem and its power supply, non-green subsystem, had the lowest readiness levels among all subsystems. Thus, these two subsystems were the main focus of the project at the beginning.

The target level of this project was at seven of each subsystem, which implies each subsystem should include a pre-production prototype, Bill of Materials, and assessed suppliers in the final deliverable.

Function analysis not only can be used for TRL analysis but also helps to find the relations between subsystems (Figure 26). It helped identify what subsystems can be developed together and even what subsystems can be merged with another subsystem. Furthermore, the fundamental functions of the subsystems were identified through the method 5Whys to provide a clearer development direction for each subsystem.

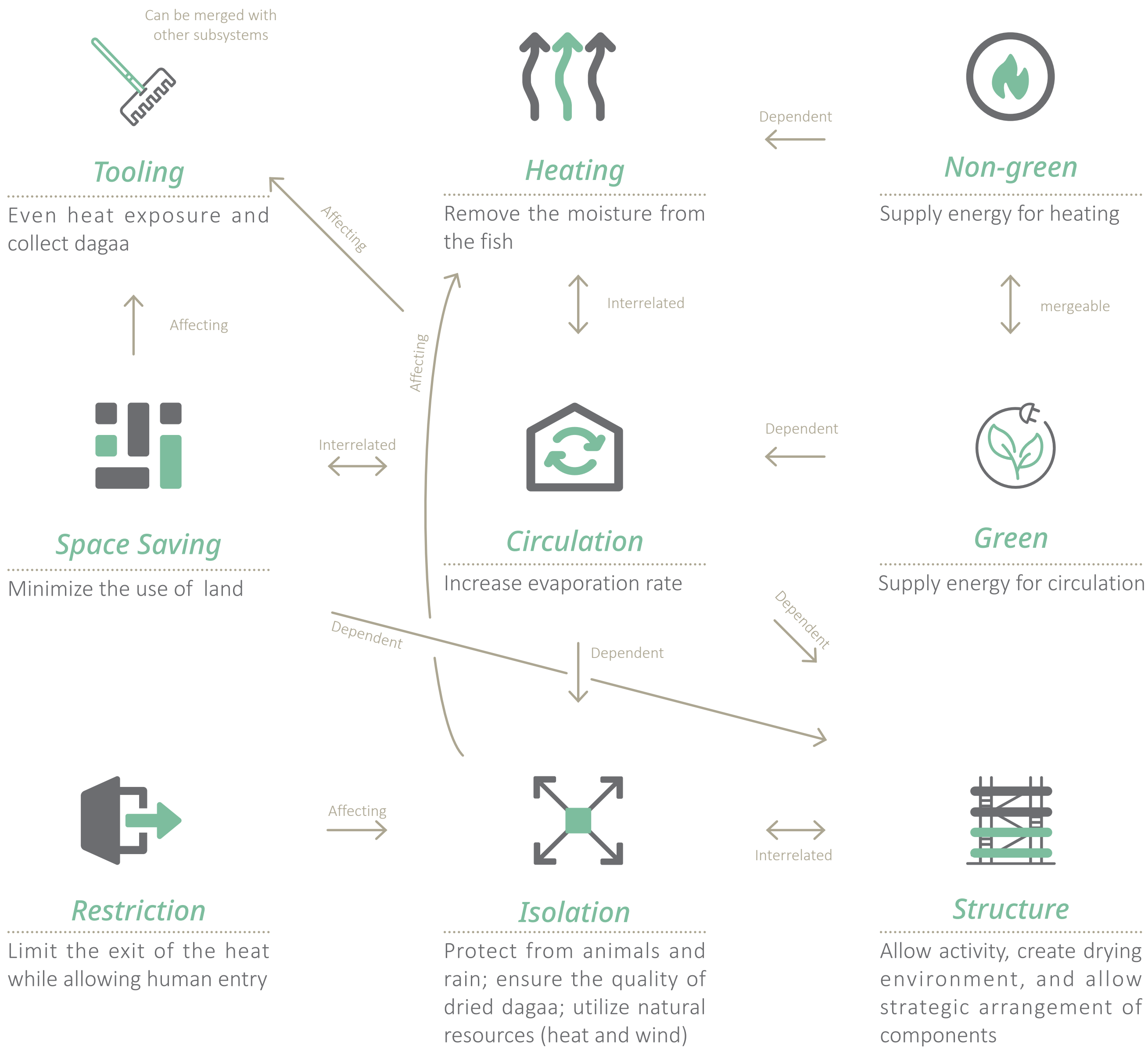


Figure 26. The Fundamental Functions and Relations of the Subsystems

Life-Cycle Assessment (LCA)

The goal of this analysis was to determine the sustainability impacts, namely Carbon Footprint, Cumulative energy demand (CED), ReCiPe Human Health, ReCiPe Ecotoxicity, and ReCiPe Resources of Upepo's material, production, transport, use, and end of life (Figure 27) over a period of one year (280 working days) in order to improve the design. The production of the design was set at a capability of one greenhouse, which processes 390 kg (100m^2) of dagaa, per working day.

Some minor production processes (material weight <1%) were neglected. And some assumptions were made; for example, the materials were assumed to be purchased locally to simplify the analysis. And due to the lack of information, some transport was neglected. When it comes to the lack of information, the recycling system in Tanzania needs to be further investigated. For this analysis, the system was assumed to be complete and accessible so that every recyclable material can be properly recycled at the end of their lives.

The result showed that having charcoal as a material for the heater, using stainless steel wire mesh, and using stainless steel tubes account for the majority of Upepo's negative sustainability impacts. Therefore, when designing a new concept, these factors were taken into consideration to reduce the impact. (see Appendix B for the scope, full list of assumptions and results).

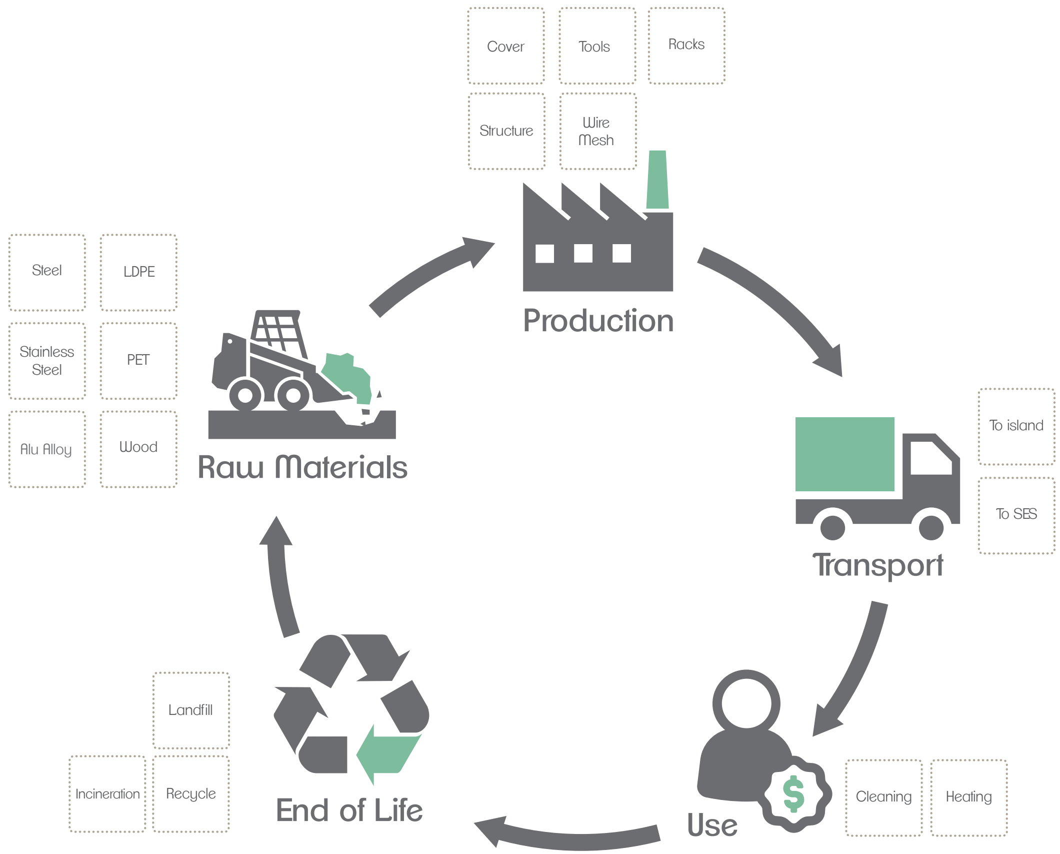


Figure 27. Life Cycle of Upepo

Drying is one of the oldest preservation methods (Tucker, 2016, p. 156). It preserves fish by removing the moisture necessary for microbial growth (Rahman, 2006, p. 6). Drying is a process of applying heat to the surface of desired items in order to evaporate the surface moisture. Furthermore, the surface evaporation leads to the migration of moisture from the central to the surface, which dries the inner flesh (Rahman, 2006, pp. 7-8).

The desired situation for drying preservation is to reduce the moisture level of dagaa from 40~75% to 10~16% (Sablani, Rahman, Haffar, Mahgoub & Al-Marzouqi, 2003, p. 85., Ogongo, 2015, pp. 4-6) with the temperature between 35°C and 63°C and relative humidity between 10% and 40% (Rahman, 2006, p. 6). To achieve this, there are some external factors that affect the drying rates that should be taken care of, namely temperature, humidity, air velocity, and distribution pattern, and air exchange (Rahman, 2006, p. 7). To control these factors, numerous drying solutions can be used. Based on the research (Sharma, Chen, & Vu Lan, 2009, p. 1189) and the review of existing technologies, the drying methods can be categorized into three types: solar drying, active thermal drying, and other technologies (Figure 28).

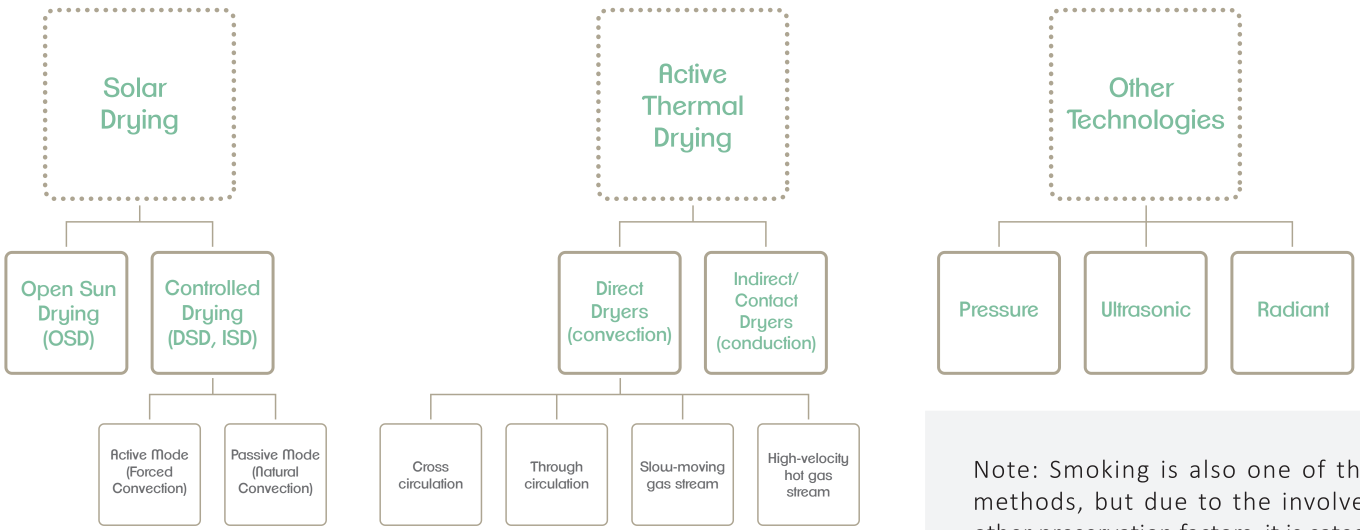
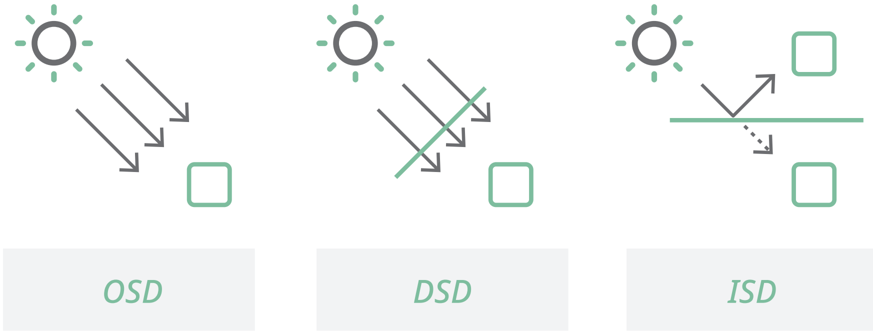


Figure 28. Scheme of Existing Drying Solutions

Note: Smoking is also one of the drying methods, but due to the involvement of other preservation factors, it is categorized as "other preservation methods."

Solar dryers

According to research (Sharma, Chen, & Vu Lan, 2009, p. 1189), there are three modes of solar drying: Open Sun Drying (OSD), Direct solar drying (DSD), and Indirect solar drying (ISD). The ones with a motorized fan or pump are categorized as Active Mode. Among these types, ISD stood out from the crowd as it minimizes discoloration and cracking on the surface (see Appendix C for pros and cons comparison).



Greenhouse dryers

Greenhouses dryers are a type of ISD. It has several benefits to be used in developing countries, such as low-cost, high-capacity, and sanitary, etc. The pros and cons are listed here,

Controllable
Provides controlled environments with desired sunlight, temperature, and humidity (Worley, 2014, p. 3)

Flexible, Simple and Low-cost
Simple, cheap, and flexible for different technology (Akinjiola & Balachandran, 2012, p. 42)

High-capacity
High loading capacity (Sablani et al., 2003, p. 86)

Sanitary
More sanitary compared to open-air sun drying (Akinjiola & Balachandran, 2012, p. 42)

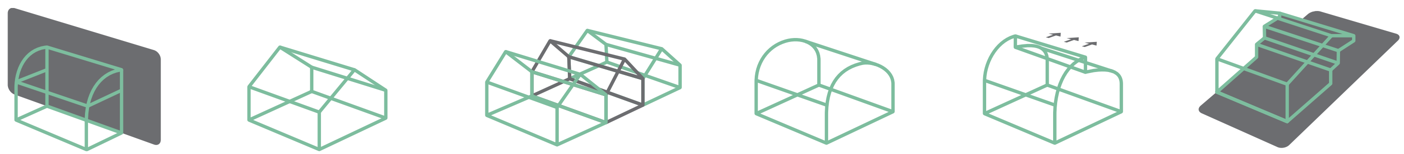
Wind-sensitive
Wind-sensitive (Akinjiola & Balachandran, 2012, p. 44)

Moderate Performance
Moderate drying rates and quality of dried fish, compared to some other sun-dryers (Sablani et al., 2003)

Dependent on Sunlight
Highly dependant on sunlight; should not be built near buildings or trees (Worley, 2014)

Pros/Cons

There are different types of greenhouses; they differ in shapes, constructions, and covering materials (Table 1). Each of them has different stability, suitable circumstances, lifespan, drawbacks, and cost (see Appendix D for full comparison). For developing a greenhouse dryer, in terms of cost and environmental conditions, Quonset and sawtooth are the most suitable shapes. About the construction, both pipe-framed and truss framed are to create a long span greenhouse dryer, but considering the cost and required height, a pipe-frame would be a better choice. However, the span should be less than 12 meters. As for covering material, although using plastic film may seem unsustainable compared to glass, however, considering the accessibility, availability, cost, and maintenance, the impact might be less than using glass.



Shape	Lean-to	Even-span	Ridge and furrow	Quonset	Sawtooth	Uneven-span

Construction	Wooden framed	Pipe framed	Truss framed
	 (Greenhouse Store, n.d.)	 (Laferney, 2008)	
Covering Materials	Glass	Plastic film	Rigid panel

Table 1. Different types of greenhouse (adapted from DMGH, 2013)

To design a greenhouse dryer, some factors (Table 2) that influence its performance should be taken care of (see Appendix D for detailed description of the factors). Some general conclusions were drawn,

1. While designing the structure, wind resistance should be taken into account.

2. The location and orientation should be carefully decided according to the wind direction, shade, and Sun path.

3. The temperature difference can be utilized, and the opening sizes should be taken care of when designing for natural ventilation.

However, some effects differ under different circumstances. Thus, when a certain type of greenhouse is designed, it is suggested to check the parameter to assure the quality of the design.

Size of openings	*Shade*	*Size*
Surface area	*Wind*	*Ventilation*
Height	*Drainage*	*Supplementary Heat*
Layer of stacks	*Covering Materials*	
Temperature difference	*Orientation*	

Table 2. Parameters that influence the performance of a Greenhouse

Other dryers

As technology grows, there are more options to dry food in the absence of sunlight. In this report, suitable solutions were categorized into two types: Active Thermal Drying and Other Technologies. Furthermore, Active Thermal Drying can be split by its types of heat transfer into Direct Dryers, and Indirect Dryers. The categories and corresponding dryers are presented in Appendix E. However, The initial cost and operation costs of these dryers, especially the ones of "Other Technologies," are often high, which may not be suitable for developing countries.

To summarize, the key pros and cons of different drying methods are presented in Table 3.

Open Sun Drying

Pros
- Cost: low

Cons
- Dependent on sunlight
- Space inefficient
- Contamination
- Discoloration

Direct Solar Dying

Pros
- Cost: medium

Cons
- Dependent on sunlight
- Space inefficient
- Discoloration

Indirect Solar Drying

Pros
- Cost: medium
- Discoloration avoided
- Space efficient
- High modularity

Cons
- Dependent on sunlight

Direct Dryers

Pros
- Independent on sunlight
- Fast processing speed

Cons
- Cost: High Initial cost, some even high operational cost

Indirect or Contact Dryers

Pros
- Independent on sunlight
- Fast processing speed

Cons
- Cost: High Initial cost and operational cost

Other Technologies

Pros
- Independent on sunlight

Cons
- Slow processing speed (some)
- Cost: High Initial and operational cost
- Fragile

Table 3. Pros and Cons of different dryers

Subsystems

For developing Upepo, the possible solutions and state of the art of the subsystems were investigated.

Heating Subsystem

Heat is one of the essential elements in the drying process. Figure 29 provides an overview of possible ways of generating heats. For burning, various types of fuel can be chosen depending on the cost, sustainability, and availability: wood, charcoal, biomass, peat, coal, coke, waste (Designing Buildings Ltd., 2019), human waste (Diener et al., 2014), peanut shell (Goodier, 2019) corn cobs, corn stalks, cassava stalk, rice husks, and kernel shells (Akinjiola & Balachandran, 2012, p. 47), mains gas, liquid petroleum gas (LPG), oil (OVO Energy Ltd, n.d.)

The objective of generating heat is to remove moisture from the fish. Besides heating, there are two other main ways to remove moisture content from the fish: osmotic dehydration and mechanical dewatering (Rahman, 2006, p. 7). However, mechanical dewatering is not suitable for drying fish. And, Osmotic dehydration methods involve extra ingredients than heat; therefore, it is not discussed in this subsection.

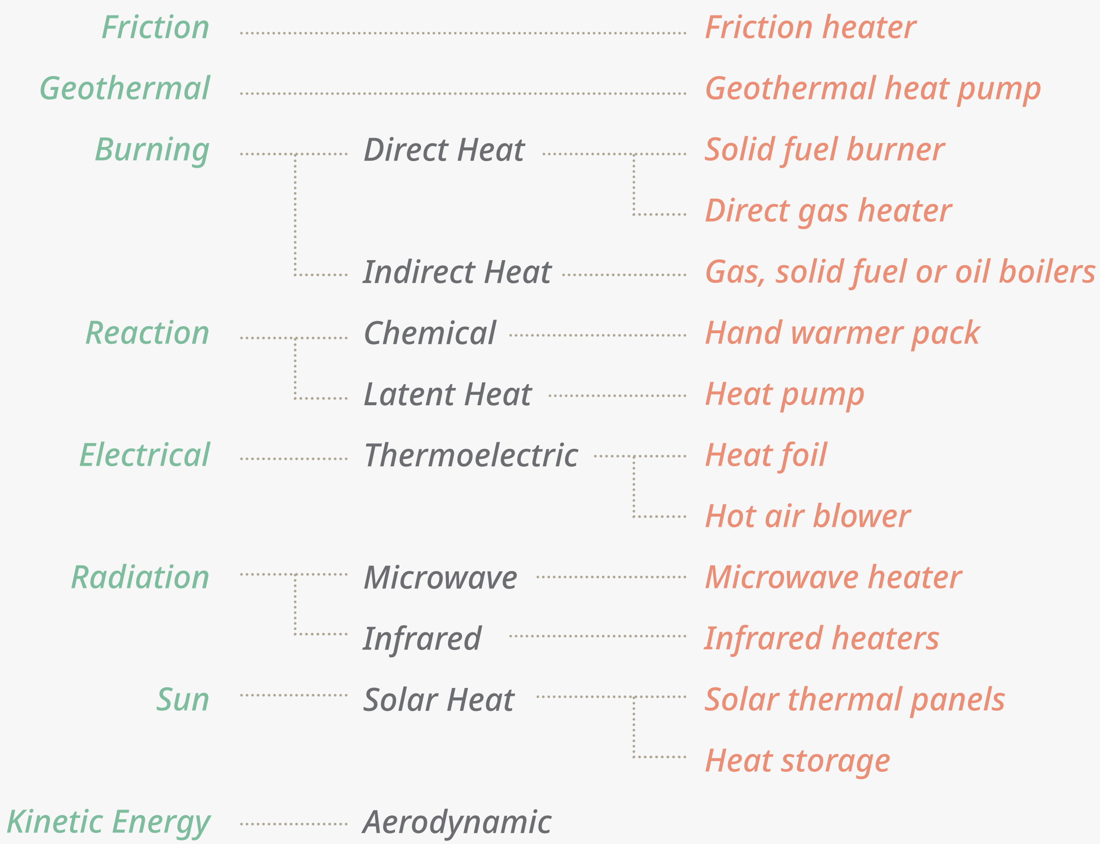


Figure 29. Possible Ways of Generating Heats

Circulation Subsystem

Another factor in the drying process is circulation. In terms of natural ventilation, Table 4 shows the parameters that influence natural ventilation for buildings (see Appendix F-1 for detailed description).

To maintain the desired relative humidity during drying, the minimal volume flow rate should be 6375 m^3/h, which means the air change rate is 59.3 ach when sunny, no added heater, and no dehumidifier is added (see Appendix A for calculation). This can be achieved by utilizing natural or mechanical ventilation. To have a balanced ventilation system and to utilize the natural resource, the characteristics of airflow and types of applications were investigated.

Size of openings	*Stack Pressure*
Building Air-tightness	*Wind Pressure*
Positioning of Openings	

Table 4. Natural Ventilation Factors.

By utilizing the above-mentioned factors, sometimes with the help of mechanical ventilators, several types of existing ventilation strategies were found (Table 5, see Appendix F-2 for descriptions). The existing ventilators for both natural and forced ventilation systems were found and listed in Appendix F-3 for design reference.

The objective to create circulation is to increase the evaporation rate. Besides creating circulation, by adjusting some factors can also increase the evaporation rate, such as decrease humidity, increase temperature (Rahman, 2006, p. 8), add a magnetic field (Farhan, Nada, Aqel &Ahmed, 2013), change mineral contents of the water content, lower pressure, enlarge the surface area, and reduce surface tension (Armenta-Deu, 1997). Appendix F-4 shows some methods to decrease the humidity of the air. Heat pumps and water-absorbing materials are the ones with higher capacity among all dehumidification methods.

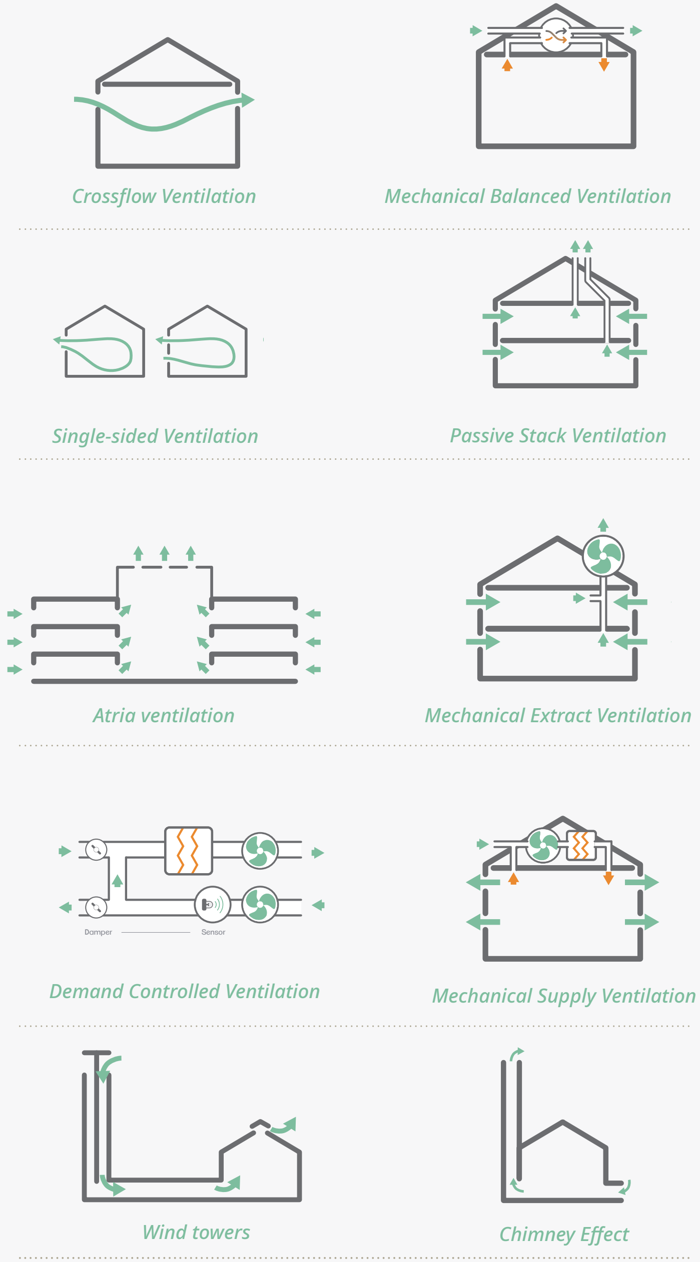


Table 5. Ventilation Strategies (Adapted from Liddament & Air Infiltration and Ventilation Centre, 1996, pp. 87–114)

Isolation Subsystem

The isolation subsystem aims to protect the dagaa from UV damage, animals, and rain. Some methods were researched (Table 6, see Appendix G for detailed list).

UV damage

UV Absorbing Materials
UV Reflective Chemical Coating

Animals

Visual / Olfactory / Auditory / Physical Interference
Physical Barriers
Source Control

Rain

Blocking
Source Control

Table 6. Methods to Protect from UV, Animals and Rain

Structure Subsystem

The objective of this subsystem is to create space for human activities. Possible structures are categorized in Table 7 based on the research (Misirlisoy, 2011) and insights from inspirations materials (see Appendix H for detailed list).

One of the benefits of portable structures is its mobility, while the disadvantage is its negative correlation between durability and space. Enclosure structures give a huge amount of freedom to access desired outdoor elements, while the drawback is the poor protection from undesired outdoor elements. Lastly, the structure for buildings, generally speaking, are durable and protective. The main issue of masonry is its heavyweight and low resistance in tension. Besides all these pros and cons, two other worth-mentioning structures are form active structures and vector active structures. These two have some desirable features for creating a large space. Form active structures are light, flexible, able to create large space, and requiring less internal support (Misirlisoy, 2011, pp. 33-40). And vector active structures are able to transfer loads over long distances without intermediate supports (Misirlisoy, 2011, pp. 40-44).

Portable

Pneumatic / Foldable / Rigid

Enclosure

Partition / Natural barrier

Buildings

Masonry / Form Active / Vector Active /
Section Active / Surface Active

Table 7. Possible Structures for Human Activities

Space Saving Subsystem

To make use of limited space, there are some methods that can be taken such as utilizing vertical space, minimizing spacing, and modularization.

Modularity

Modularity has many advantages, such as customization, enabling upgrades or alterations, and ease of assembly, service, and maintenance (Mascitelli, 2004, p. 119). These advantages may help the new design to be more sustainable and flexible. Thus, the types of modularity were researched and presented in Figure 30.

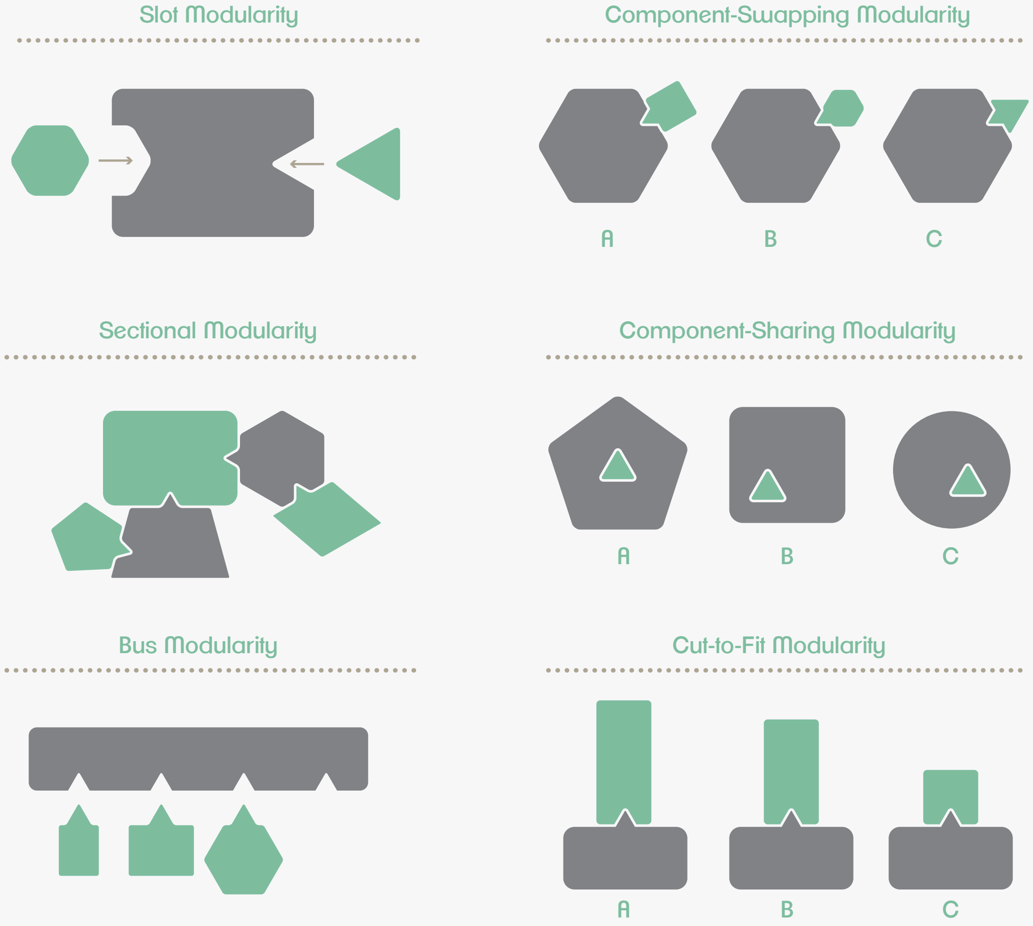


Figure 30. Six Types of Modularity (adapted from Mascitelli, 2004, p. 119)

Context

To understand the influential factors that drive the local dagaa drying methods, contextual studies were done. The study topics included local weather conditions, existing drying methods in developing countries, stakeholders, dagaa fisheries, and consumer behavior.

Local weather conditions

The weather-related factors that affect the drying rate are temperature, humidity, and air velocity (Rahman, 2006, p. 8). The relevant data plays an important role in design decision making and design improvement. Thus, the data of three target islands were collected in Table 8. Some data was not available; therefore, the general observations provided by SES are also presented.

The hourly data, from May 2019 to April 2020 between 6 a.m. to 15 p.m. (excluding the off-cycle periods), of Ukara was analyzed (Appendix I, data retrieved from Time and Date, 2019). Some general patterns were observed:

Humidity

- The daily humidity was between 50% and 85%.
- The humidity started high in the morning, around 85%, and dropped in the afternoon, above 50%.
- However, the trend between November and the next April was less obvious.
- Seldomly, the humidity stayed above 70% throughout the day.

Temperature

- The daily temperature was between 20 °C and 30 °C throughout the year.
- The temperature started low in the morning (20 °C- 23°C).
- However, the trend between November and April was less obvious.
- Sometimes, the temperature stayed below 23°C throughout the day.

Rain

- It normally rained once or twice a month.
- It rained more often between November and April.
- 60% to 85% of the days were sunny.

Wind Speed

- The wind speed was above the breeze level throughout the year.
- It often reached the level of moderate breeze, sometimes fresh breeze, rarely strong breeze.
- No specific patterns were observed.

Wind Direction

- The wind direction changed several times during the day.
- No specific patterns were observed

Although the data of Kasalazi was not available, due to its geographic proximity (Figure 31) and its similar island properties to Ziragula, the data of Ziragula has its referential value to Kasalazi's conditions.

There was a slight difference between the analyzed weather data of Ukara (Figure 32) and the observed rainy season. The reasons might be the accuracy of the data, the climate change in the year 2019/2020, or the sampled hours simply had a different pattern than the overall trend.

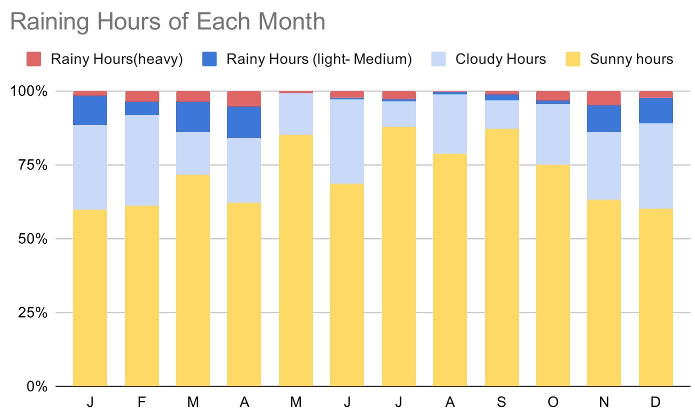


Figure 32. Raining Pattern of Ukara

Figure 31. Location of Ziragula, Kasalazi, and Ukara

	Ziragula*	Kasalazi	Ukara
Sunlight (Dry / Rainy season)	Regularly available / Mostly overcast or cloudy but very bright**		
Wind Velocity	3 m/s	N/A	3-11 m/s
Temperature (Sunny / Rainy)	30 °C /23 °C	N/A	20~30 °C / 20~25 °C
Relative humidity (Sunny / Rainy)	35~70% / 45~80%	N/A	55~75% / 65~85%
Rainy / Dry Season**	Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec		

* The data of Ziragula is retrieved from Blankendaal et al., 2020

** Observation by SES

Dry Half-half Rainy

Table 8. Weather Data of Ziragula, Kasalazi, and Ukara

Dryer	Region
Trays and Mats	Tanzania[a]
Swing Solar Dryer	Tanzania[a]
Box Solar Dryer	Tanzania[a]
Lifted Racks	Tanzania, Kenya[b]
Tunnel Dryer	Tanzania[c]
Greenhouse Dryers	Tanzania[d]
Direct Solar Dryer	Tanzania[e]
Solar Collector	Tanzania[f]
Household Dehydrator	Tanzania[g]
Solar Conduction Dryer	India, Kenya, Sri Lanka, and Vietnam[h]
Forced Air Heating Dryer	Tanzania[i]
Biofuel Dryer	Uganda[j]
Oven Dryer	Cameroon and Ghana[k]
Heat Pump	Potential

Solar   Active Thermal

[a]Makwaia (1985). [b]Ogonda, et al. (2014, p. 3). [c]Nicanuru, Laswai, & Sila (2015). [d]Engineering for Change (2016). [e]Farm Radio International (2017). [f]Lytefire (2020). [g]KinoSol (2020). [h]S4S technology (2019). [i]Karuga (2018). [j]Engineering for Change (2018). [k]DJILEMO (2016).

Table 9. Existing Drying Solutions in Tanzania and Other Developing Countries

Existing drying methods in Tanzania and countries with similar conditions

There are some drying solutions found in countries with similar conditions to Tanzania and listed in Table 9 along with the existing drying solutions in Tanzania. Sometimes, the food is soaked in brine solutions before drying to increase the drying rate (Mbunda, 2015, p. 6). Although a heat pump has a high initial cost, according to the research (Fayose & Huan, 2016), its operating cost compared to electrically heated convective dryers and direct-fired dryers is the lowest. This makes it a potential heating element for developing countries.

The reasons behind the unpopularity of other active thermal dryers in Tanzania might be their high energy consumption (Joardder & Masud, 2019, pp. 145–146), space occupancy (Sokoine University of Agriculture, 2019), fragility, long processing duration (Fayose & Huan, 2016, p. 2), and high capital intensity (Mendoza, 2017). Moreover, according to the research (Onyango et al., 2017, p. 113), in Kenya, over 78% of the fish were preserved by sun-drying, and 90% of them were dried on old fishing nets placed on the ground. The reason for such a choice is its low price and easy-to-use feature.

Stakeholders

Some new stakeholders are identified during the literature research and listed along with the already-identified stakeholders.

Camp owner
Responsible for all the possessions of the fishing camp.

Camp supervisor/manager
Supervises and manages the fishing camp.

Fishermen
Catch the dagaa during night fishing.

Processors
Process the dagaa, take it from the boat and dry it on the sand.

Trader
Buys fish from fishing camps on the fishing island and transport the dried dagaa to the market.

Customer
Buys dried dagaa on the market.

Fishers Union Organization (FUO)
The mediator between governmental organizations and fishing camps. They help in safeguarding and promoting the interests of fishers.

Fisheries Resource Protection (FRP)
Does surveillance, patrol, management, and law enforcement in the fishing industry. They check if the government rules are followed.

Fish Education Training Agency (FETA)
Gives training to men who want to become fishermen or want to work in the fishing industry.

Government & ministry of livestock and fisheries
Has a mandate of overall management and development of livestock and fisheries resources.

National Fish Quality Control Laboratory (NFQCL)
Tests the quality of fish and tries to improve/ maintain the quality of the fishery.

Innovations and Markets for Lake Victoria Fisheries (IMLAF)
Aims to promote nnovations and technologies for the production of high-quality fish products for domestic and international markets in the Lake Victoria basin, Tanzania (IMLAF, n.d.).

Tanzania Food and Nutrition Center, (TFNC)
Aims to play a pivotal role in guiding and catalyzing actions for prevention and control of malnutrition in Tanzania (TFNC, 2020).

Vocational Education and Training Authority (VETA)
Oversees the Vocational Education and Training (VET) system in Tanzania (VETA, 2018). They have access to machinery, materials, and technicians for manufacturing procurement.

Adapted from Blankendaal et al., (2020, p. 19) Newly added

Dagaa fisheries

According to the report (Blankendaal et al., 2020), the fishing activity of Dagaa is executed during the night and ends early in the morning. Then, the processors will perform the drying task until, at most, 18:00 of the same day before the traders come.

In general, according to SES, fishing activities only happen during moon cycles. A moon cycle is the days in a month excluding the 7-to-10-days off-cycle period, which is equivalent to just before, during, and after the full moon. However, in moon cycles, the activity still could be canceled if the weather conditions do not allow (Blankendaal et al., 2020). In contrast to that, the fishing activities will take place if the moonlight is dim during off cycle.

On average, the catch of one boat is 487.5 kg of dagaa, while the best case is 1950 kg per boat (Blankendaal et al., 2020). Upepo set its capacity to the average catch of one small camp, where a small camp consists of 3-4 boats. According to research (Reynolds, 1993, p. 94), the period between July and November has the highest Dagaa catches among the year.

Currently, only 30% of dagaa is for human consumption. The rest is used for animal feeds (Kolding et al., 2019, p. 80). After drying, the dagaa will be packed in plastic bags, sealed, and labeled for sale (Bille & Shemkai, 2011, p. 6). Then, the dagaa will be transported through lorry (Figure 33). Dried dagaa is consumed all over Tanzania and even greatly exported to other countries (Kolding et al., 2019, pp. 79-82). One of the reasons for its popularity is its longer shelf life. It can be easily stored without electricity (Kolding et al., 2019, p. 7), i.e., need not to be refrigerated, and easy transportation (Reynolds, 1993, p. 103., Kolding et al., 2019, p. 4). Nonetheless, the poor transport infrastructure of Tanzania is still a barrier for the fish to be distributed (Reynolds, 1993, p. 103).

Figure 33. Sun-dried dagaa (Rastrineobola argentea) being loaded and readied for regional trade (Kolding, van Zwieten, Marttin, Funge-Smith, & Poulain, 2019)

Figure 34. Dagaa Fishing (photo provided by SES)

Consumer behavior

Consumer behavior of dagaa is an important factor in decision making. Thus, the types of consumers and ways of consuming dried dagaa were investigated.

Dagaa is cheaper than other types of fish; thus, it is described as “the poor man’s food” (Reynolds, 1993, p. 100), which implies the target consumers are from poor families. Sun-dried dagaa is one of the most traded processed dagaa(Kolding et al., 2019, p.83). Dried dagaa can be cooked into different cuisines, including milling into powder for babies or hospital patients (Kolding et al., 2019, p. 80). But, according to Project Dagaa, when the quality of the dried dagaa is low, the consumers used to remove the heads before ingestion. Despite the quality of sand-dried dagaa, some people also believe that sand-dried dagaa has better taste (Reynolds, 1993, p. 94).

Users

The main users of the drying solutions are camp owners, camp managers, fishermen, and processors. The relevant information, such as working time and user experience, was researched.

Regarding drying solutions, the main concern of a camp manager is personnel management. According to the report (Blankendaal et al., 2020), three processors are assigned by the manager to each boat for dagga processing dagaa. To dry the dagaa, the camp owner has to pay a rent of 200,000 to 300,000 THS per moon cycle to the landlord. As for the fishermen, the concerns are the loading time and payment. Every morning after fishing, the fishermen have to unload the catch and hand it over to the processors.

The major users of the drying solution are the processors, the relevant information and concerns are synthesized from the personas, interviews, and Experience Map of the report (Blankendaal et al., 2020) into Table 10.

Figure 35. Sun-drying Processors (photo provided by SES)

Sex	*Female*
Age	*Wide-ranging*
Working time (days)	*Same as fishermen, work on moon cycles (approximately three weeks in a month)*
Working time (hours)	*From unloading the catch in the morning (around 6 a.m.) to waiting for the trader in the evening (around 18 p.m.)*
Main Tasks	*1. Help unload the catch 2. Spread dagaa on the sand 3. Turn the dagaa 3-6 times a day (depending on the sunlight) 4. Harvest the dried dagaa 5. Wait for the traders*
Pain points	*• Heavy physical work • Early starting time • Uncertain income caused by bad weather • Working in the dark • Standing in the water*

Table 10. Information of Processors

5.1.2 Exploration

The goal of exploration was to research new opportunities to tackle post-harvest loss issues. Similar to the research of drying methods, the three aspects were also investigated. However, the change in the preservation method involves more factors in business and user aspects. Therefore, market preference was studied.

Scope

In order to secure the broadness of the discussed scope, the problem statement was further elaborated as: "The solution Upepo does not guarantee the qualitative and quantitative output of dagaa preservation during non-sunny days. As a consequence, it negatively affects the food security and local economy in Tanzania." By analyzing this problem statement with the same method described in Subsection 5.1.1, the relevant areas were identified and mapped in Figure 36. Subsequently, "Food Preservation" was chosen as the scope for exploration, and the two main reasons are,

01 *The urgent need to solve the problem of dagaa.*

Other scopes, such as constructing a stable economy, may also solve the fundamental problem; but it showed little possibilities of solving the problem of dagaa in a short time. Moreover, the involved aspects are unlikely doable within the given time.

02 *Explore the opportunities*

Although it is safe to keep the same preservation method due to market preference and the difficulties of user behavioral change, there is still a chance to find opportunities by conducting market research and user tests. Therefore, the aim was set to find suitable preservation methods that meet the market preference and diminish the difficulty of user behavior change.

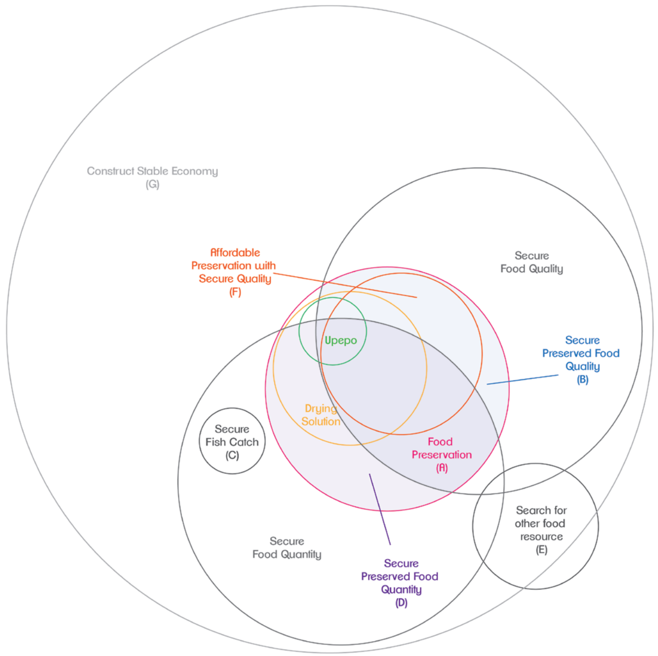


Figure 36. Broadened Scope

Overview of Researches and Analyses

Based on the scope, research and analyses were done. Figure 37 shows the overview of the research that had been done. The research purpose was to study the opportunities for dagaa preservation by covering the three design aspects: user, technology (included in "Preservation Solutions"), and business (included in "Context"), i.e., to provide a comprehensive view for identifying opportunities regarding preservation methods.

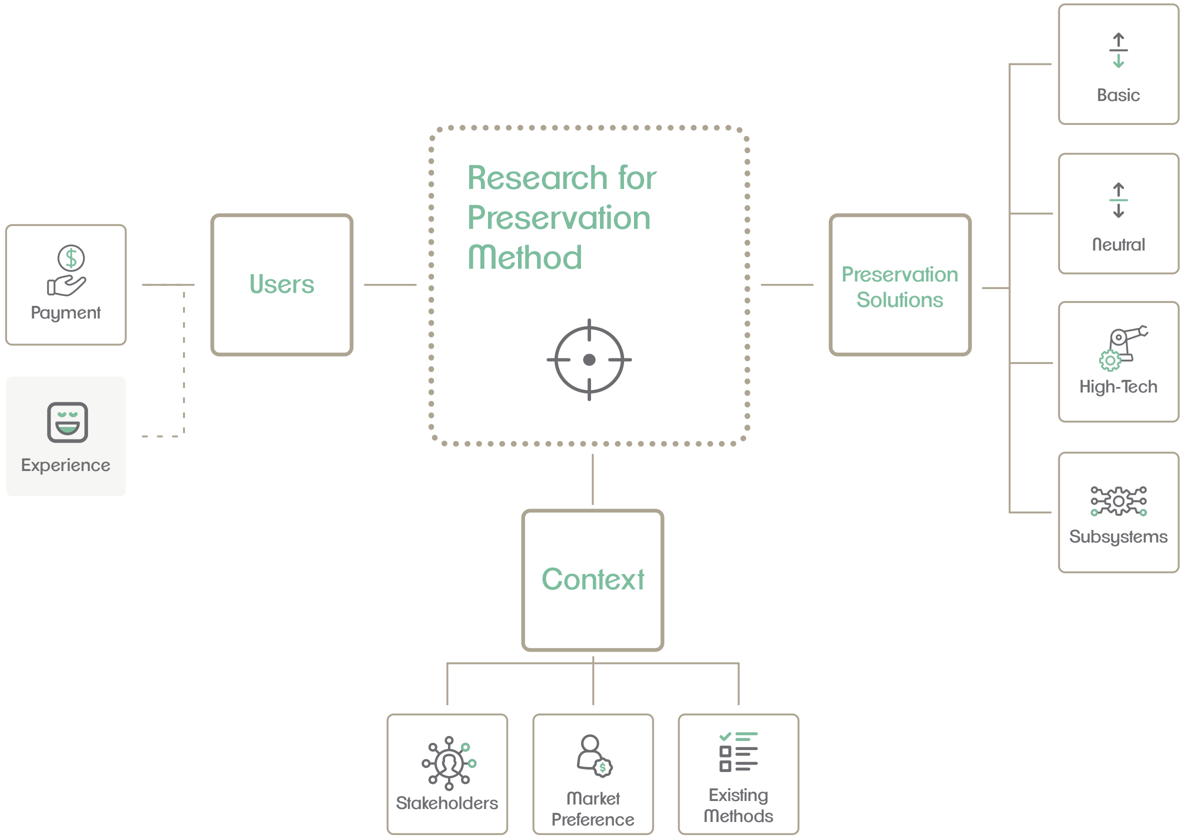


Figure 37. Overview of Analyses and Research for Food Preservation

Preservation Solutions (Technology)

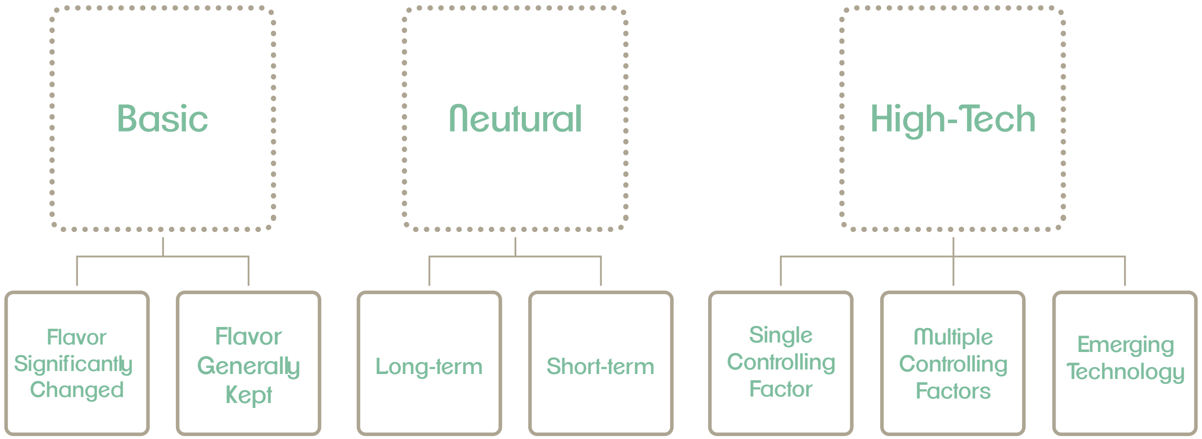


Figure 38. Scheme of Existing Preservation Solutions

There are many kinds of preservation methods that have been practiced in the world. Some have long histories (Joardder & Masud, 2019), while some were developed in the wake of new technologies. By reviewing the existing methods and technologies, the preservation method can be categorized into three types: Basic (normally do not involve electricity consumption), Neutral, and High-Tech (Figure 38).

Generally speaking, Basic methods are cheaper and have a long shelf life, while Neutral and High-Tech methods are expensive and mostly require post-processing chilling or freezing for longer shelf life (Tucker, 2016). Moreover, most High-Tech methods require hermetically sealed packaging unless the moisture is completely removed from the product (Tucker, 2016). However, Basic methods sometimes involve flavor change, e.g., smoking (Mhongole & Mhina, 2012, p.1) and health concern (Ziarati, Shirkhan, Zahedi, Mostafidi, & Hochwimmer, 2018), while Neutral and High-Tech methods significantly keep the original flavor without extra additives (Tucker, 2016). (see Appendix J for the comparison of these methods)

The existing solutions provide many different ways to preserve food, but in principle, it is a selection of applying controlling factors (Table 11) to inhibit or stop microbial growth under certain circumstances with certain types of packaging (if applicable).

Factors	Description
pH level	Most microorganisms can not grow at pH < 4.0.
Moisture content	A water-free environment stops enzyme activity and slows down most chemical reactions.
Water Activity	When the water activity of food is lower than 0.61, nearly all bacteria, molds, and yeasts stop growing.
Temperature	Generally speaking, microbial growth slows down in lower storage temperature.
Humidity of the Environment	When the water activity of food is lower than that of the environment, the food absorbs moisture from the atmosphere.
Availability of Oxygen	Some microorganisms are aerobic and some are anaerobic, thus, this factor must be modified according to the target microorganisms.

Table 11. Factors of Microbial Growth (Adapted from Tucker, 2016)

Context

To understand the factors that drive the use of preservation methods in developing countries, contextual studies were done. The study topics included existing preservation methods in Tanzania and countries with similar conditions, stakeholders, and market preferences.

Existing preservation methods in Tanzania and countries with similar conditions

Some preservation solutions were found in countries with similar conditions and listed in Table 12 along with the existing preservation solutions in Tanzania.

Method	Region
Deep-frying	Tanzania[a]
Hot smoke drying[a]	Tanzania
Spiced-smoking[b]	Tanzania
Chorkor oven and Nyegezi models ovens[c]	Tanzania
Traditional mud-type oven and oil drum kilns	West Africa[d]
Salting	Tanzania[a]
Fermentation	developing countries that are wet and have limited sunlight[e]

[a]Reynolds (1993, pp. 93-94). [b]Bille & Shemkai (2011). [c]Mhongole & Mhina (2012, p. 1). [d]ILO, FAO, & UNEP (1982). [e]Joardder & Masud (2019, pp. 159)

Table 12. Existing Preservation Solutions in Tanzania and Other Developing Countries

The technical causes of other preservation methods' absence can be generalized by the factors shown on the right.

The main reason that some preservation methods were not used for dagaa is mainly because of the cost, e.g., canning (Reynolds, 1993, p. 6.), salting (Isaacs, 2016, p. 8), and freezing (Joardder & Masud, 2019, p. 148), which might influence the pricing of dagaa.

01 **The lack of scientific basis**

Some preservation methods are often processed incorrectly, for example, canning (Joardder & Masud, 2019, p. 130) and salting (Reynolds, 1993, p. 94). Moreover, sometimes processed foodstuffs are stored improperly (Mhongole & Mhina, 2012, pp. 7-8).

02 **High capital intensity**

Due to the cost, igh-tech methods are hard to be implemented (Joardder & Masud, 2019, p. 215).

03 **The lack of available materials**

Salt, sugar (The Citizen, 2020), and fuels for smoking (Reynolds, 1993, p. 93) are sometimes unavailable.

04 **Poor management of facilities**

Freezing and chilling (Reynolds, 1993, p. 93) facilities were poorly managed, therefore, it is not commonly found for domestic markets, although it is often used for exporting (Joardder & Masud, 2019, p. 82)

05 **Dependent on electricity**

Non-traditional methods often require electricity, however, in developing countries, energy often comes from the nature (Joardder & Masud, 2019, p. 69).

Market preference

Some preservation methods involve flavor changes, for example, smoking, salting, and fermentation; thus, to understand the acceptance of these flavor changes, a study of market preference was done (Table 13).

Stakeholders

In the case of changing the preservation method, the stakeholders mostly remain the same as mentioned in Subsection 5.1.1. However, during literature research a stakeholder was found that might be concerned.

Tanzania Fisheries Corporation (TAFICO)

TAFICO runs ice making, freezing and cold storage facilities (Reynolds, 1993, p. 92.). Although it seems not to be running now, the government has its revival planned in 2018 (Further Africa, 2018).

According to the research (Kolding et al., 2019, p. 83), the most traded processed dagaa is sun-dried dagaa (over 70%), the next is deep-fried dagaa. Although sun-dried dagaa is widely traded in the domestic market, the label of "poor man's food" and stereotype of low value may have negatively influenced its market (Kolding et al., 2019, p. 7).

In comparison, the sales of smoked dagaa were not high, even though it has been reported having a high score of market preference (Bille & Shemkai, 2011) and acceptability (Mhongole & Mhina, 2012, p. 1). The reason might be its higher price than sun-dried dagaa (Bille & Shemkai, 2011), poor domestic promotion, and the middlemen traders' preference due to its storage requirements (Mhongole & Mhina, 2012, p. 1).

Besides smoked dagaa, salted dagaa also does not sell well, but the reason was not found. However, salted or fermented fish, not dagaa specifically, do have their market in Africa (FAO & Kofi Manso Essuman, 1992, p. 65) due to its flavor enhancement.

In addition to processed dagaa, according to the research (Reynolds, 1993, p. 101), fresh and bigger fish are the most favorite options in Tanzania. Moreover, according to SES, stewing fresh dagaa is also an observed behavior.

Table 13. Market Preference of Dagaa

Users

Changing preservation methods would be a challenge for the processors to learn. Apart from that, some preservation methods have a lengthy processing period, for example, smoke drying, which may last until the next day; this may affect the payment of the employees. Therefore, the payment details were researched. According to SES, the payment is done at the end of the month and is based on the net profit of the camp (Table 14).

	Fishermen	Processors (camp ladies)	Processors (Freelencers)
Payment Date	*End of the month*	*End of the month*	*End of the case*
Payment Basis	*A share of total net profit*	*A share of total net profit (less than fishermen)*	*Assigned buckets*

Table 14. Payment of the Processors and Fishermen

5.2 Define

In this phase, conclusions were made, based on the information collected, in order to provide a direction for ideation. Two main messages from the conclusion are do's and don'ts, and the design opportunities. To bring the insights into ideation phase, the conclusions were integrated into a Design Vision and a List of Requirements.

5.2.1 Conclusion of Refinement

There are many drying methods existing in the world. But, generally speaking, due to the cost, energy consumption, required space, easiness of the operation, etc., only solar dryers and biofuel dryers were found in countries that have similar conditions to Tanzania. In case that a heater is required, apart from bio-fuel dryers, heat pumps may be adopted with careful calculations. According to the weather conditions of Ukara Island, most of the time, sunlight and wind are available. Based on the factors mentioned above, greenhouses would be a good option due to its attribute of low cost, high space efficiency, high rate of sunlight utilization, and potential of wind utilization.

Based on the TRL analysis, the heating and circulation subsystem have the lowest readiness levels among the subsystems. The challenges of designing these subsystems are to spread the heat and airflow evenly and to keep the main factors, namely humidity, airflow, and temperature, in control. In terms of natural ventilation, stack pressure in Tanzania might not be significant all the time (significant during colder days), but the overall wind velocity is enough to induce wind pressure-driven effects. It means atria ventilation, controllable openings, etc., can be applied to the design. To prevent heat loss from the massive air exchange rate, heat recovery should be considered; for example, mechanical balanced ventilation with a heat exchanger or heat pump with heat recovery could be used.

LCA analysis showed that the fuel of the heater, the material of the frame, and the material of the wire mesh should be wisely chosen and compared to the original design. Thus, while refining Upepo, not only heating and circulation should be considered, the other subsystems should also be taken into account to resolve the concerns.

The weather difference between the target islands is not significant; however, the design might be implemented in some other regions that has different weather conditions. In this case, modularity might be an opportunity, for example, to easily provide a customized greenhouse of different weather conditions.

Many things will be influenced in the case of changing the drying method, such as the cost, which may also influence the price of dried dagaa, the working routine of the users, the quantity and quality of dried dagaa, and environmental impact. Thus, user tests and negotiation with stakeholders, for example, setting acceptable rent with camp owners, setting planning training programs with FETA, discussing overfishing issues with the Ministry of Livestock and Fisheries, etc., are necessary.

5.2.2 Conclusion of Exploration

Most of the non-basic preservation methods have a high initial, maintenance, and operational cost, and are sometimes too complicated to operate. These are huge barriers for developing countries like Tanzania to process. However, if these methods can be cheaper, easier, and energy sufficient, it can still be taken into consideration.

Long-term Basic methods sometimes change flavors; nonetheless, the market preference showed a certain extent of acceptance towards these flavor changes, such as smoked, fermented, and salted fish.

The selection of preservation methods depends on the quality, storage, shelf life, market preference of the processed fish, sustainability, and the cost efficiency of the methods. When these factors are comparable to sun drying solutions, these methods can be substituted for sun-drying. To evaluate cost efficiency, further research is needed. Nevertheless, assuming the energy consumption of an active-drying solution is enormous, and all the factors mentioned above are satisfied, these methods can be applied when the sunlight is not available. In this case, methods such as fermentation, smoking, and salting (if the price of salt is acceptable) has the potential to be suitable choices.

Based on the conclusion, considering the high capital, high risk of failure, the uncertainty of market preference and cost, etc., more research and tests are required in order to understand the feasibility, viability, and desirability. In comparison, producing dried dagaa is less complex in terms of processing and marketing. Therefore, it has been decided only to take other preservation methods as a recommendation when sunlight is not available. Therefore, a preliminary recommendation was made: for the places that are usually sunny, an alternative method such as smoking, fermentation, and salting can be adopted when the weather is insufficient for drying. In this way, these places do not need to afford the initial cost of a heater. However, cost efficiency should be further researched.

5.2.3 Design Vision

"Design a modular indirect solar dryer (product-system combination) for drying dagaa that utilizes natural resources to the utmost. The design should be adjustable according to the weather conditions in Tanzania, i.e., sunny and rainy days. At the same time, the dried dagaa should be protected from contamination. Furthermore, the income of the locals and the business of the service providers must be secured."

5.2.4 List of Requirements

The LoR has been formulated based on the research findings and the former report (see Appendix K for detailed list).

Performance/Functionality

1. *The product maintains the temperature around dagaa constantly between 35°C and 65°C*
2. *The product maintains the humidity around dagaa constantly between 10% and 40%*
3. *The drying solution should fit all different climate types around lake victoria*
4. *The product should utilize available natural resources as much as it is not harming the nature*
5. *The product should be self-sufficient in energy.*
6. *The drying solution must protect the dagaa from the rain*
7. *The fish out of the drying solution may not contain sand or dirt*
8. *The drying solution should not allow animals contact (birds, goats, chickens, etc.)*
9. *The drying solution must dry fish before 18:00 the same day*
10. *All fish harvested from the drying solution should be for human consumption*
11. *The capacity of the drying solution is at least the catch of 200 buckets*

Usability

12. The product must be understandable and usable by users regardless of their educational level
13. The users must be able to place the fish in and take the fish out of the drying solution
14. The operation of the drying solution must cause a lower physical effort per unit of processed fish than the current sand drying method.
15. The product should not contain sharp edges, which could lead to injuries

Sustainability

16. The number of components should be reduced by merging components with similar functions
17. The impact of the product should not be more than Upepo

Business

18. The product should be hard to copy for competition

5.3 Develop

5.3.1 Ideation

In this phase, the research findings were developed into concepts through a morphological chart (Figure 39). Morphological Chart is a method that generates concepts by combining ideas from separate parts. In this project, these separate parts refer to the subsystems of Upepo. Each part gained its inputs from the findings in the discovery phase and through performing various design methods (Figure 40), e.g., brainstorming, analogy, etc., based on its key function. The tooling subsystem was removed for two reasons. First, constant heat and airflow are constantly applied to both sides of the fish; as a result, turning were considered unnecessary because two sides would be dried equally. Second, the harvesting tools were excluded by integrating harvesting movement into the Space Saving subsystem. In the end, the parts were combined to form three concepts by sketching (Figure 41).

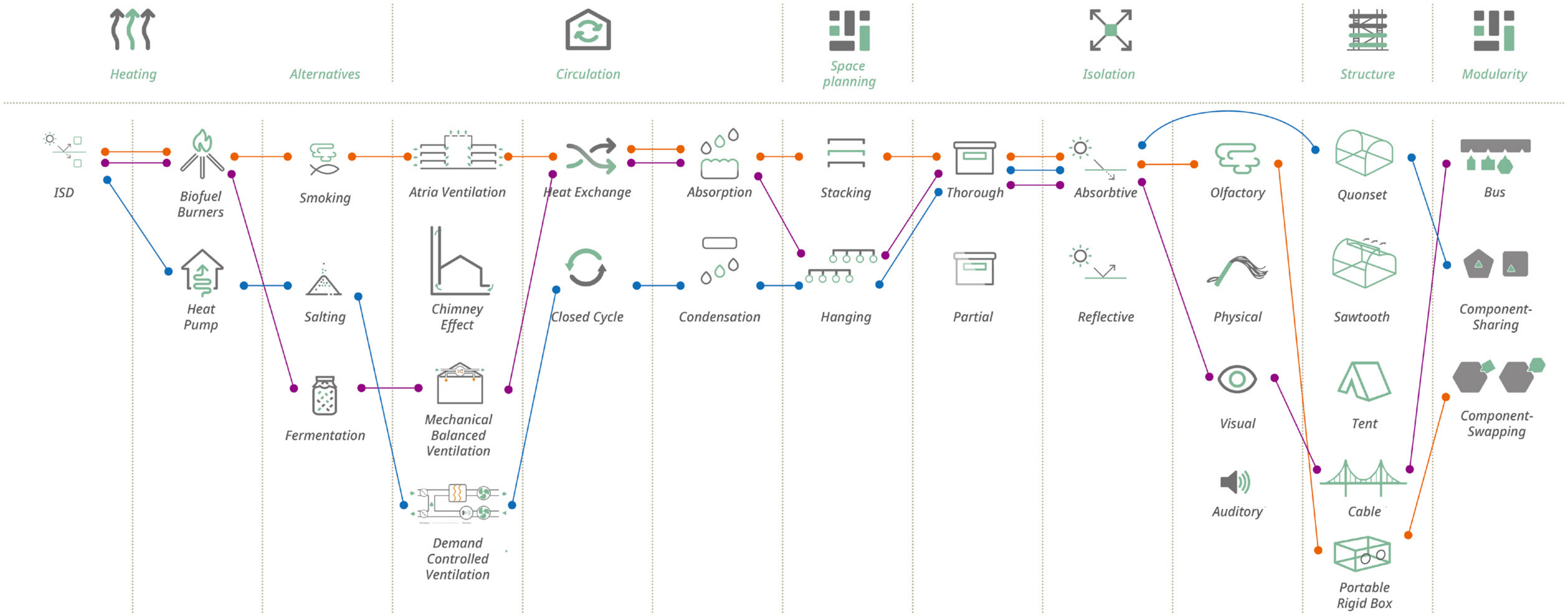
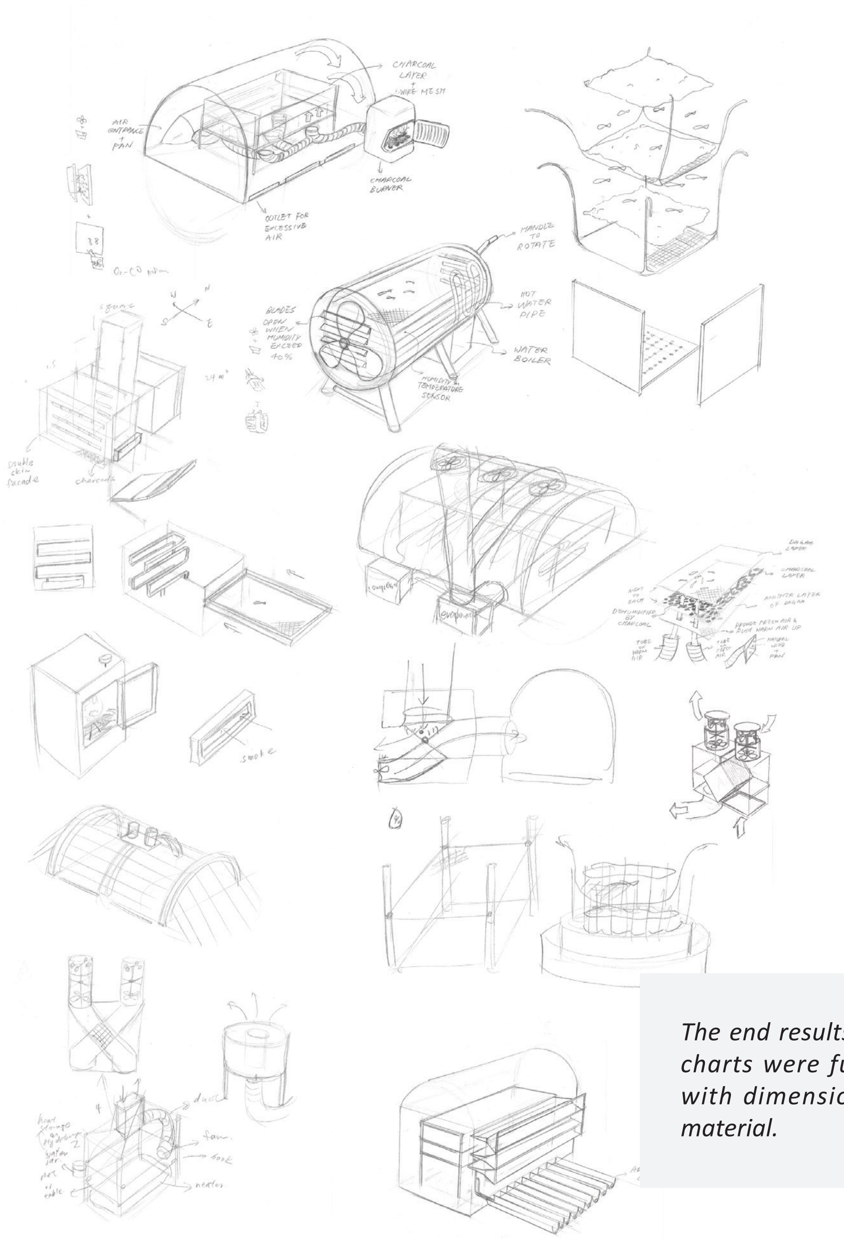


Figure 39. Morphological Chart (linked)

Figure 40. Brainstorming Results Based on Key Functions



The end results of the morphological charts were further conceptualized with dimension, use scenario, and material.

Figure 41. Concept Sketches

Concept Oven

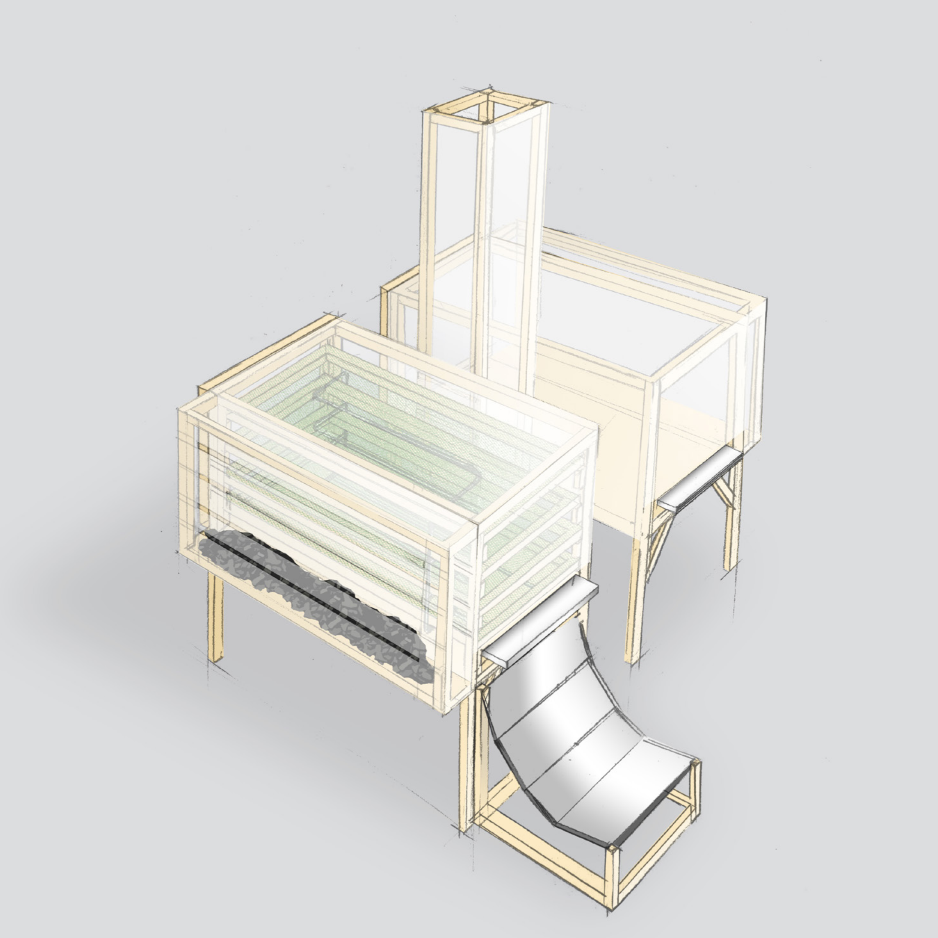


Figure 42. Concept Oven

Dimensions: *W 3.9 m x L 2.1m x H 1.6 m (extra 1.4m high for chimney)*
Capacity: *24 m^2 (1 set, i.e., 2 ovens, 16 trays)*
Materials: *Wood (Structure), PE film (Covering), reused old nets (Tray), Aluminium (Conduction Pieces), Reused metal oil drum (Heater) (see Appendix L for detailed specification).*
Use scenario: *(see Appendix M)*

Concept Oven is a tray dryer with chimneys (Figure 42) that dries dagaa by solar radiation on sunny days, and by wood burners on rainy days. The recommended alternative preservation method for Concept Oven is smoke drying. The airflow source of Concept Oven is relying on chimney effect and atria ventilation. Due to the temperature difference between the chimney top and the oven body, the air is brought into the oven through the openings of the facade. To prevent heat loss, the atria facades trap heat inside and transmit heat to the incoming air.

The main feature of this concept is component-sharing. During sunny days Concept Oven dries dagaa with the help of radiation reflectors and internal conductive coils (Figure 43). During rainy days, the reflectors will be replaced by wood burners (Figure 44). The wood burners use the same conductive coils for conducting heat to the ovens. The woods are partially anaerobically burned; thus, some charcoals will be produced at the end of the combustion. These charcoal can be placed in the atria facade to absorb the humidity of the incoming air, or used for smoke-drying. To smoke-dry dagaa, the conduction pieces should be changed to smoke inlets (Figure 45), and then use the same burners to burn charcoal.

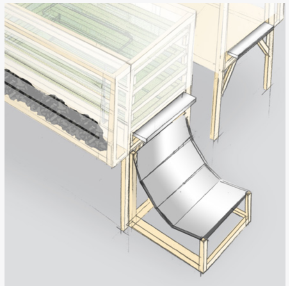


Figure 43.
Sunny day setting
(Concept Oven)

Figure 44.
Rainy day setting
(Concept Oven)

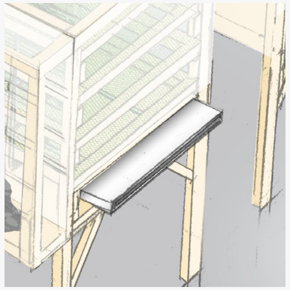


Figure 45.
Smoke inlet
(Concept Oven)

Concept Cable

Figure 46. Concept Cable

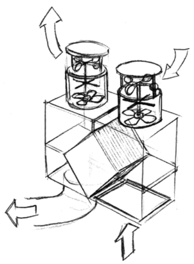


Figure 47.
Heat exchanger
(Concept Cable)

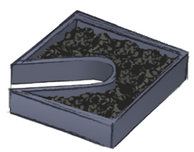


Figure 48.
Charcoal Dehumidifier
(Concept Cable)

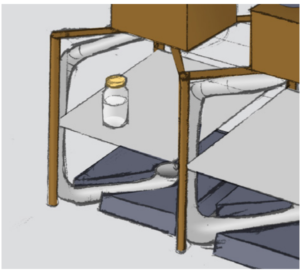


Figure 49.
Fermentation
(Concept Cable)

Concept Cable is a greenhouse dryer (Figure 46) that dries dagaa by solar radiation on sunny days, and by wood burners on rainy days. The recommended alternative preservation method for Concept Cable is fermentation. The airflow source of Concept Cable is relying on fans at the bottom of each rack and natural upward airflow due to temperature difference. To prevent heat loss, heat exchangers are installed at the top of each rack. When waste air passes through the exchanger, the heat will be transmitted to the incoming air (Figure 47).

The main features of this concept are wind-driven exhaust fans, reduced structural materials, and upward airflows. Irregular wind direction makes it harder to utilize natural wind in a greenhouse setting, however, a wind-driven exhaust fan is a suitable solution for it as it catches wind from all directions. Cable structure reduces the structural materials by decreasing support arches. As for upward airflow, it helps reduce the drying rate difference between the top layer and the bottom layer.

During sunny days Concept Cable dries dagaa simply through solar radiation, constant airflow, and charcoal dehumidifiers (Figure 48). During rainy days, the containers of charcoal dehumidifiers will be used for wood burning to generate heat. The woods are partially anaerobically burned; thus, some charcoals will be produced at the end of the combustion. The hanging net can be changed to rigid working tables for fermentation preparation works (Figure 49).

Dimensions:	*W 4m x L 12m x H 3m*
Capacity:	*100 m^2*
Materials:	*Steel tubes and wires (structure), PE film (covering), bamboo (rack pole), reused old nets (rack layer), fan and PV panel (circulation system), aluminium and wood (heat exchanger), Reused metal oil drum (heater) (see Appendix L for detailed specification).*
Use scenario:	*(see Appendix M)*

Concept Heat Pump

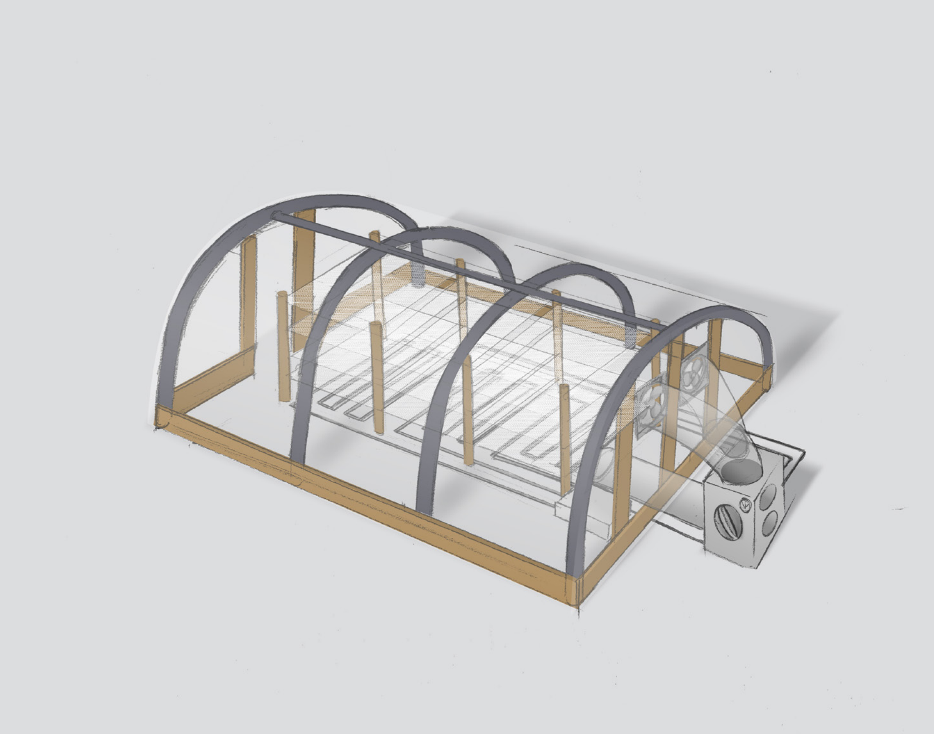


Figure 50. Concept Heat Pump

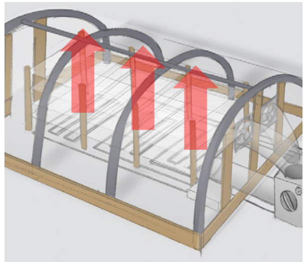


Figure 51.
Upward airflow
(Concept Heat Pump)

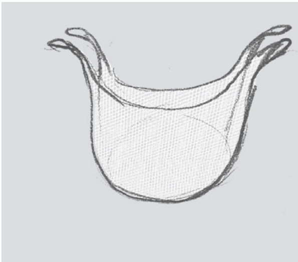


Figure 52.
Easy-to-harvest drying net
(Concept Heat Pump)

Figure 53.
Salting
(Concept Heat Pump)

Concept Heat Pump is a greenhouse dryer (Figure 50) that dries dagaa by solar radiation on sunny days, and by a heat pump on rainy days. The recommended alternative preservation method for Concept Heat Pump is salting. The airflow source of Concept Heat pump is relying on the exhaust fan of the heat pump and two outlet fans at around ceiling height. The heating pipes are located at the bottom of each rack to create upward airflow (Figure 51). Concept Heat Pump is a closed system, and this system prevents heat loss by recirculating the dehumidified warm air.

The main features of this concept are the semi-closed system and the hanging racks. The heat recycling system and dehumidifying system improve the drying performance; at the same time, it still allows natural heat from solar radiation to enter. The hanging racks reduce the building materials and reuse the old fishing nets. Moreover, the harvesting tool is no longer required due to the easy harvesting procedure of this system (Figure 52).

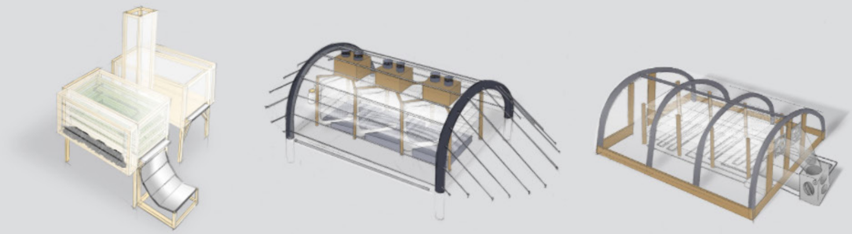
During sunny days, Concept Heat Pump dries dagaa through solar radiation, constant airflow, and desiccant; during rainy days, the heat pump provides heat and dehumidifies the recirculated air. For salting preservation, the rack poles can be rearranged into a container for it (Figure 53).

Dimensions: *W 4m x L 12m x H 3m*
Capacity: *100 m^2*
Materials: *Steel tubes (structure), PE film (covering), bamboo (rack pole), reused old nets (rack layer), fan and PV panel (circulation system), heat pump (heating system) (see Appendix L for detailed specification).*
Use scenario: *(see Appendix M)*

5.3.2 Evaluation

Then, the concepts were evaluated and presented to stakeholders for feedback on acceptability. Subsequently, one concept was chosen and adjusted to meet the stakeholders' expectations.

By evaluating the concepts with the vital criteria (Appendix L), Concept Oven stood out from the crowd (Table 15). Moreover, the result showed that Concept Oven is a sustainable and affordable solution.



	Oven	Cable	Heat Pump
Affordability (5)	8	7.5	7
Availability (3)	7.5	6.5	5.5
Reliability (4)	7	8	7.5
Sustainability (3)	8.5	8	8
Acceptability (1)	7	5	9

Table 15. Concept Evaluation

However, SES mentioned, from a local service provider's point of view, that quality improvement is not an intuitive attraction to the locals since it is more expensive than sand drying. In comparison, shortened working hours would be considered worth the money for them.

Therefore, to achieve the maximum value of all aspects, namely people, business, and environment, another evaluation and integration were made. First, all ideas of each subsystem were reevaluated (Appendix N). The results showed that some ideas from Concept Oven had significantly lower scores than the others (Figure 54). Moreover, the sustainability analysis was on the basis of one-year usage, which was not representing the result for long-term usage. As the impact of renewable energy will decrease year after year, it is believed that the impact will be much lower than that of non-renewable energy. Consequently, Concept Heat Pump was chosen. And, in order to have a better result, the following high-score features of other concepts were recommended to be added to the Concept Heat Pump during development,

1. Provide another modular component: humidity absorber for those places that do not need a heater
2. Make use of chimney effect and natural ventilation.
3. Reduce structural material

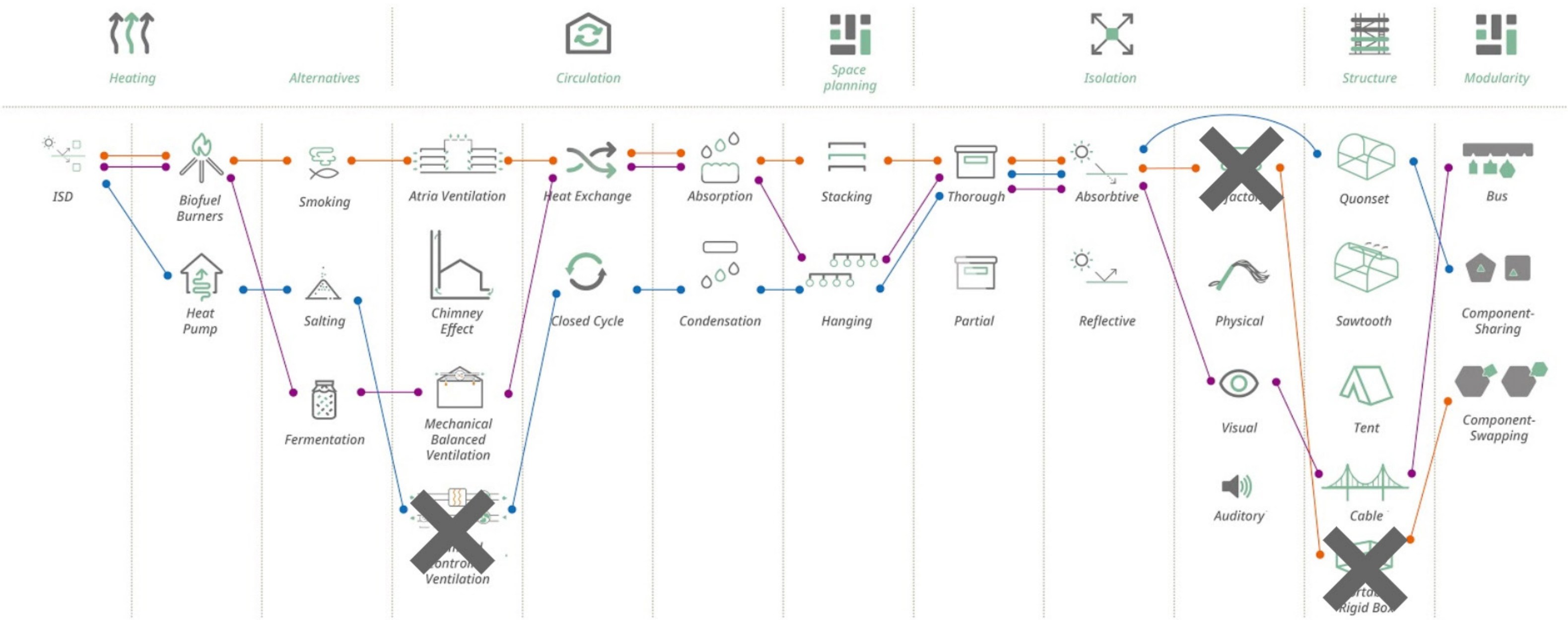


Figure 54. Morphological Chart Reevaluation

5.4 Deliver

The goal of this phase was to develop the chosen concept to a desired level of readiness through design iterations. As the chosen concept was created on the basis of Upepo, the TRL results were used for developing the new concept. However, tooling and non-green subsystems were removed since it is no longer applicable. Based on the readiness levels, the first step was to develop the heating subsystem to level four before working on the other subsystems.

One benefit of TRL is that it helps to manage the development of complex projects. This advantage allows developers to work on different parts of the design at the same time; therefore, the design was separated into three groups for development to save some time. These groups were arranged based on the relations between group members. Group members are mostly interrelated to each other, while all groups are partially independent of each other. These three groups are presented in Figure 55 by color coding.

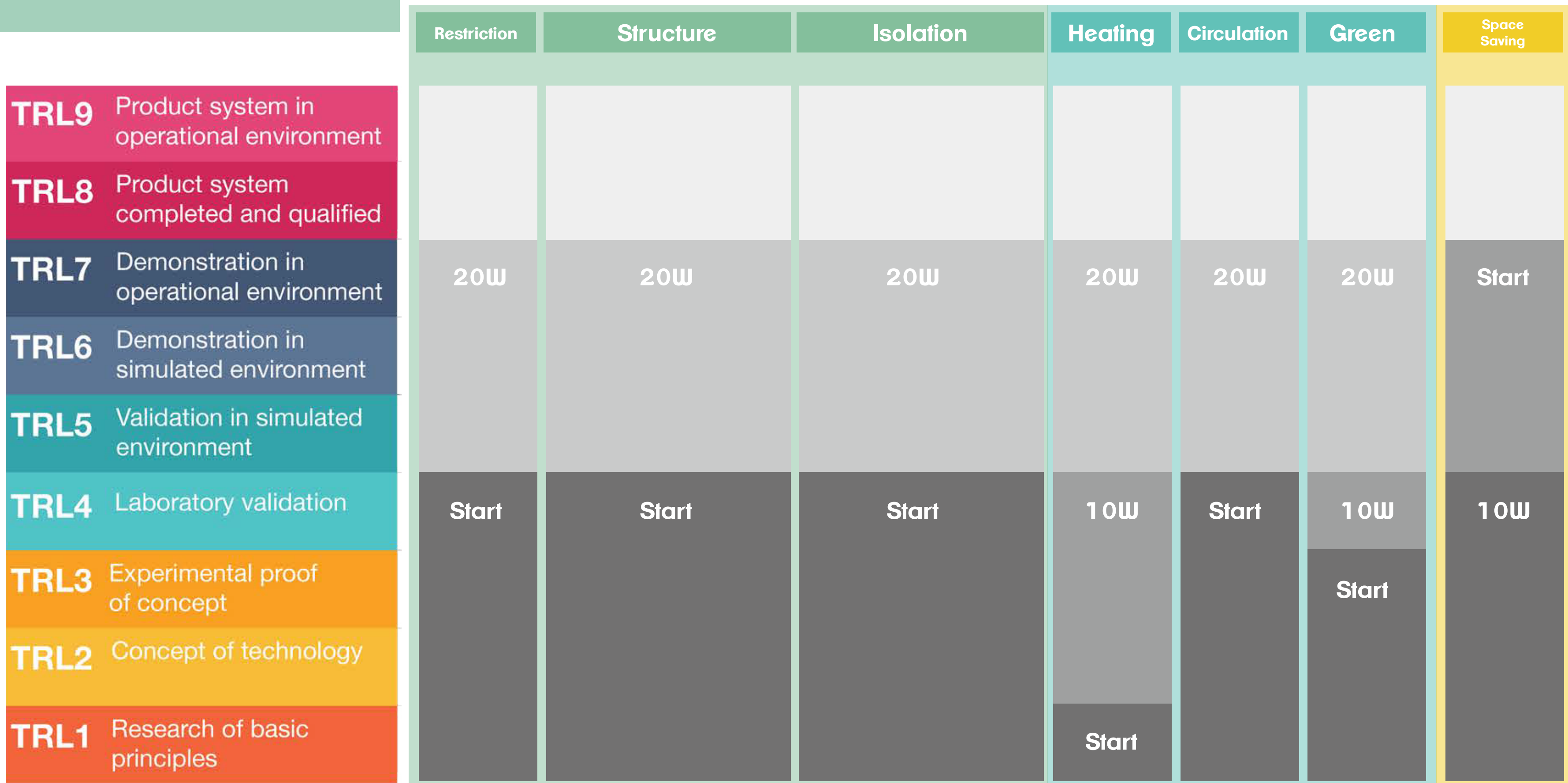


Figure 55. Revised TRL and groups for development.

5.4.1
Heating and Circulation Subsystems

Most of the iterations of this group were done through Solidworks flow simulation. Due to the fast and material-free attribute of building a 3D model for digital iterations, it was possible to test several ideas from each goal before picking one. But as a result, there were quite some numbers of testing results in one iteration. To integrate the results, two approaches were used, namely the cumulative approach and the exclusive approach. And, these two approaches were developed during the iterations.

Every iteration in this group started with a set of problems(goals) to achieve. The problems(goals) that were considered influential to airflow were categorized to the simulation group (Problem A and B in Figure 56), otherwise, to the concept group (Problem C in Figure 56). Then, each problem(goal) had its separate ideation(s). For idea generation, besides frequently used design methods, such as brainstorming and mindmapping, the simulation group also generated ideas through checking the parameters, e.g., the opening size of the inlets, the height of the fans, etc. In addition to the generated ideas, feedback from experts and stakeholders were also simulated.

To generate the outcome, the iterations either implemented the cumulative approach or the exclusive approach. For the cumulative approach, multiple ideas from a problem were evaluated with certain criteria to select the best idea. Then, the model of this idea was used as the basis for the next problem, i.e., the ideas from the next problem were built upon this model. Then, the procedure repeated until all ideas were tested. As for the exclusive approach, the models of different goals were tested and evaluated separately. Then, the models were combined and compared to the original design after all tests had finished. In the end, no matter which approach was taken, the results of the simulation group and the concept group were combined as the outcome of that iteration.

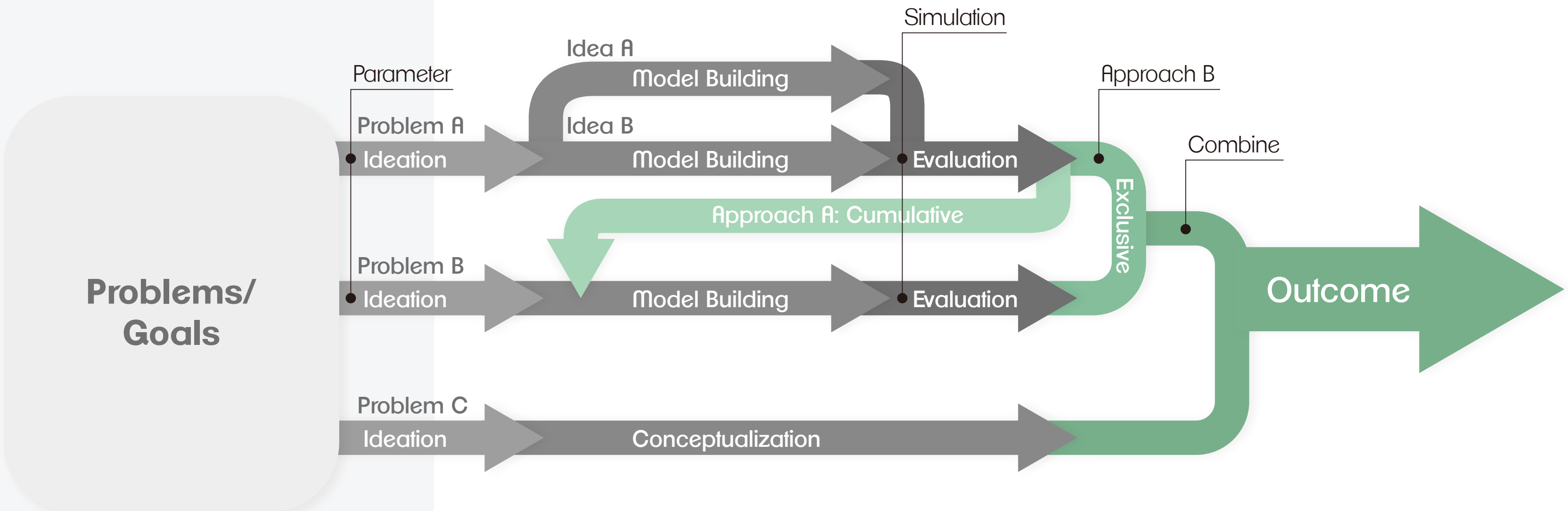


Figure 56. Overview of the Methods used in Heating and Circulation Subsystems

Goals

The results of the concept evaluation suggested combining the advantages of other concepts. Therefore the goals of this iteration were set as below,

1. Add features to create natural ventilation
2. Add a modular component: humidity absorber
3. Add features to decrease the heat loss

Evaluation

Three goals were ideated and the ideas of goal one were simulated and evaluated with the following criteria.

Distribution
The distributed air at the desired locations.

Velocity
The overall velocity at the desired locations.

Reach
The distance that the supply air could reach.

Then, the ideas that were observed to have the best performance on these criteria were combined by the cumulative approach (see Appendix O for detailed evaluation process and ideas).

Results

After the evaluation, the ideas from three goals were merged as the outcome of this iteration. Two designs were generated, one with horizontal airflow (Figure 57) and another with vertical airflow (Figure 58). The advantage of the horizontal airflow is that only a thin layer of airflow is required, while the vertical airflow has the need for wide coverage. The advantage of the vertical airflow is that the drying rate of every rack and layer is more even than that of the horizontal airflow. These two designs had their own advantage, and their performances still had some room for improvement. Therefore, these two designs were both kept until mature enough to be compared.

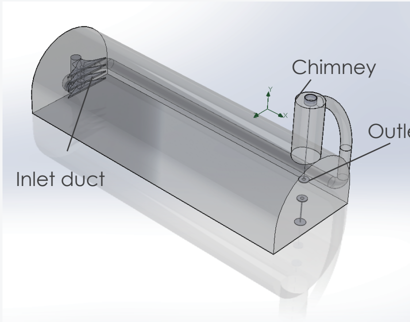


Figure 57. Design for Horizontal Airflow

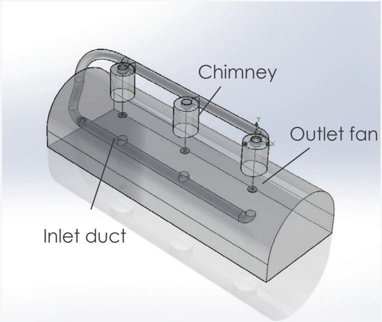


Figure 58. Design for Vertical Airflow

To create natural ventilation, a wind-driven fan was added to the design. The wind-driven fan (Figure 59) is principally the same as the ones used in Concept Cable. To decrease heat loss and dehumidify the air, a heat exchanger and desiccant layers were added to the design (Figure 60).

Figure 59. Wind-driven Fan

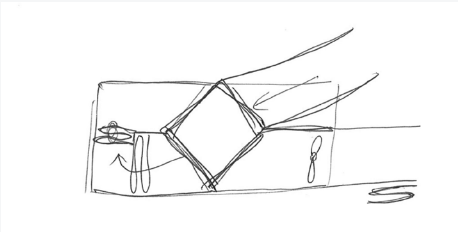


Figure 60. Heating & Dehumidification System

Second Iteration

Goals

The first iteration yielded two designs, but their performance on air velocity and air distribution required some improvement. Furthermore, after consulting a heat pump expert, it was suggested that a heat pump system should be heat-insulated to prevent heat loss. Therefore four goals were generated for the second iteration.

1. Reduce the speed loss wind redirection
2. Increase the coverage of the vertical airflow
3. Diminish the speed difference between the openings
4. Reduce heat loss by adding a insulated layer

Evaluation

Four goals were ideated, simulated, and evaluated with the following criteria.

Distribution
The distributed air at the desired locations.

Velocity
The overall velocity at the desired locations.

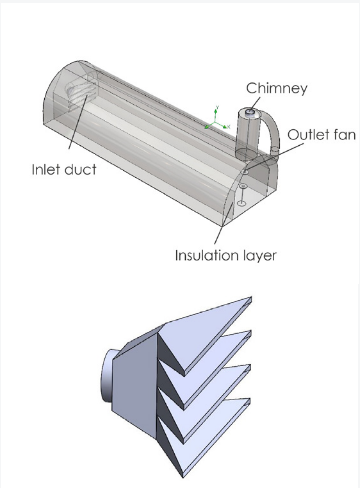
Reach
The distance that the supply air could reach.

Then, the ideas that were observed to have the best performance on these criteria were combined by the cumulative approach (see Appendix P for detailed evaluation process and ideas).

Results

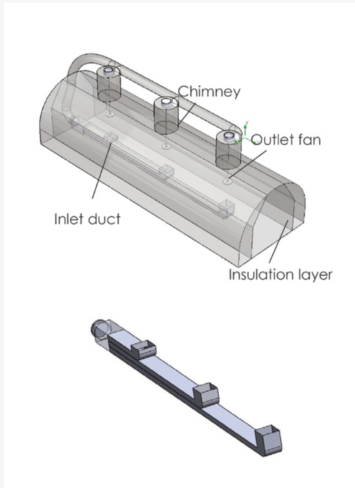
The heat pump system, dehumidifier system, and wind-driven exhaust fan remained the same. The results of two design, horizontal and vertical, are presented on the right,

Horizontal



The incoming air is first flattened by a funnel-shaped duct so that the air can be evenly distributed to each opening. Then, the airflow of each opening is flattened by another funnel-shaped duct before being blown into the greenhouse, so that a flat and wide airflow can be created.

Vertical



The incoming airflow is divided by a three-layered duct. At the end of each duct the air is redirected to form a vertical airflow.

Third Iteration

Goals

The results of the previous iteration were positive; however, it still had some room to improve before making a selection between two designs. Therefore, after the discussion with stakeholders, some goals and ideas were generated to improve the performance.

1. Vertical: Increase the coverage
2. Horizontal: Increase the width of the airflow
3. Reduce the speed loss
4. Solve the slightly uneven air distribution of the openings

Evaluation

The goals were brainstormed with the inputs from the stakeholders, a greenhouse expert, and an airflow expert to get some ideas. Then the ideas were simulated and evaluated with the following criteria.

Distribution
The distributed air at the desired locations.

Velocity
The overall velocity at the desired locations.

Coverage
The area covered by the supply air at the desired surfaces.

Different from the previous iterations, the results were difficult to be compared by observation. Therefore, quantitative comparisons were adopted (Table 16). Then, the ones that have the best performance on these criteria were combined through the exclusive approach (see Appendix Q for detailed evaluation process and ideas).

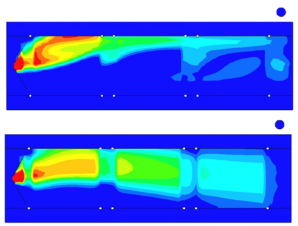


Figure 61. Simulation Results of two ideas of Horizontal Airflow

	Velocity	Coverage
Horizontal Airflow	The average velocity was measured at a certain height of each layer. Then, the velocities of all four layers were averaged to compare to that of the other ideas.	The area covered by the supply air (velocity > 1 m/s) of each layer was measured. Then, the areas of all four layers were summed up to compare to that of the other ideas.
Vertical Airflow	Same as horizontal airflow, except that the average velocity and covered area was only measured at the top layer.	

Table 16. Quantitative Evaluation of Velocity and Coverage

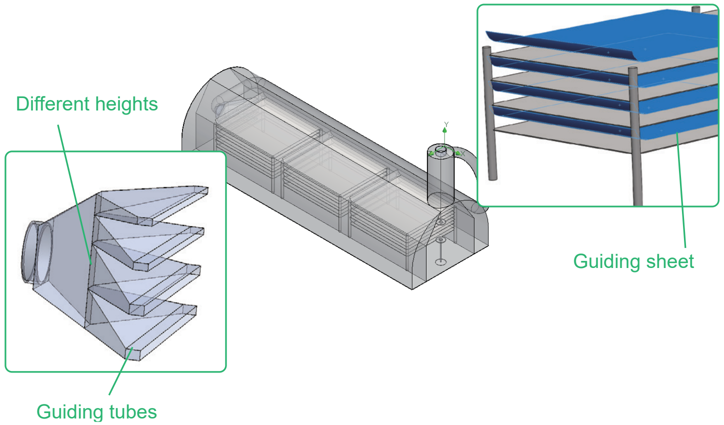
Results

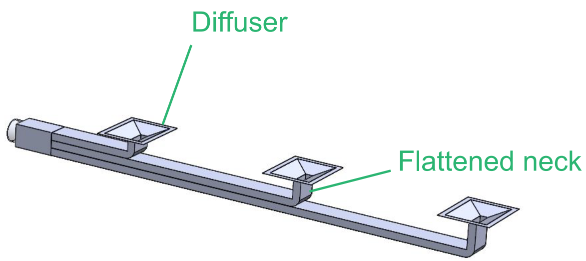
Horizontal

The design works in the same principle as the previous version. The differences are that some sheets were added on the racks to guide the airflow and increase the airflow velocity; As for the inlet duct, the opening sizes were adjusted to balance the air distribution of each opening, and guiding tubes were added at the ends of the openings to stabilize the airflow.

Vertical

The design works in the same principle as the previous version. The differences are that the opening sizes were adjusted to increase speed; and the diffusers were added at the openings to increase the coverage.





After three iterations, the results showed that both horizontal and vertical designs were possible to reach the desired conditions. Thus, the drying test was carried out to determine which design to choose.

Goals

Normally, the top layer dries faster than the bottom layer. Thus, theoretically, vertical airflow is more desirable as it provides faster airflow at the bottom, which evens out the drying rate differences. Moreover, due to the balanced air distribution, each rack would have the same drying rate. On the contrary, horizontal airflow often dries the fish at the closer end faster than the other end. Thus, one of the goals of this test was to validate this theory.

And another goal was to validate whether turning can be withdrawn from the drying process.

Method

It was supposed to be two tests, one for horizontal airflow and another one for vertical airflow; however, due to the weather conditions in the Netherlands and the hassles of getting fresh small fishes, only vertical airflow was tested in the end.

The test setup included a fan (Dia. 50cm), a wooden frame with a PE cover, three layers of drying nets (50cm x 50cm, mesh size 2mm) (Figure 62). The initial air velocities at A, B, C, and D were 4.26, 3.78, 2.65, and 2.10 m/s, respectively. Each layer held 4 wet small fish at the corners. The temperature and air velocity of each layer was measured every hour at the center (A, B, C, and D). The weights of the fish were measured every hour from the beginning. The test lasted for 5 hours and the fish were further dried with an oven to measure their weight of dry matters (see Appendix R-1 for detailed procedure).

Figure 62. Drying Test Setup

Results

Drying Rates

The test results (Appendix R-2) showed that, even though the bottom layer dried faster than the top layer at the first hour, in the end, three layers reached a certain dryness level at the same hour (Figure 63). Based on this fact, the assumption, that horizontal airflow dries every layer with approximately equal speed, was validated. However, through observation, the upper side of the fish seemed to be thicker than the bottom side (Figure 64). The reason might be that the airflow rarely flew to the top surface (Figure 65) so that the bottom side dried faster.

Another test should be conducted to validate the assumption. However, the weather in the Netherlands was unpredictable; thus, it has been decided to accept this assumption for now. As the vertical airflow had some unexpected side effect, which makes less desirable. Considering this and the fact that the design for vertical airflow involves more building materials, the horizontal design was chosen to be the final design for this project.

Side Turning

The other objective of this test is to determine whether the turning operation can be omitted. The original objective of the test was to see whether the fish can be fully dried without turning sides. In this perspective, the test result showed that most likely the fish can be dried without turning. However, when the fish was taken for weight measurement, it was observed that some flesh and skin were stuck on the nets. The sticking situation at the lower layers seemed to be more severe than the higher layers (Figure 66), where the lower layers had faster drying rates at the beginning (Figure 63). According to the test observation, after the first removal at the first hour, the fish no longer had sticking issues. Therefore, it was assumed that flipping the fish before a certain dryness level can avoid the sticking situation. In this case, turning is still required, but only once at the beginning.

Other Insights

1. During the test, the fish attracted many flies, mostly at the top layer. The airflow at the top layer does not seem to affect the flies. According to the article (Kolbe, 2013), airflow can repel flies. Comparing this finding to the result, applying fast airflow, above 2.65 m/s may have an effect on repelling flies.
2. The cleaning of the net was easy. By lightly rubbing the nets in a bowl of water, the stains came off without using soap.

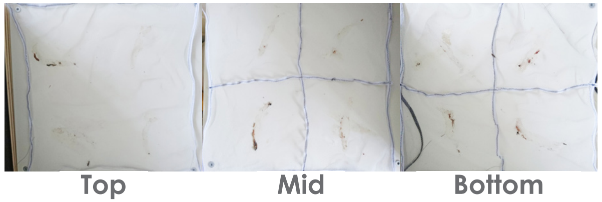


Figure 66. Sticking Situation of Three Layers

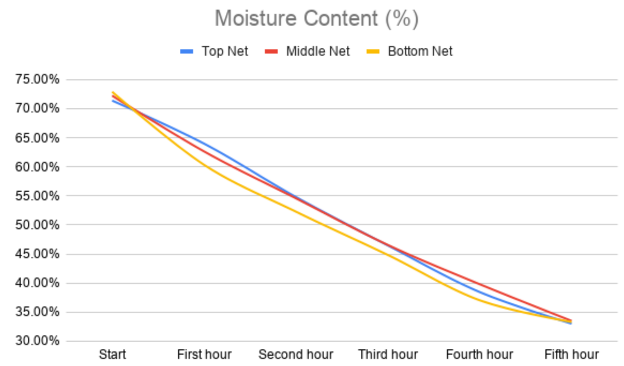


Figure 63. Drying Rate of Three Drying Nets

Figure 64. Dryness Difference on Two Sides

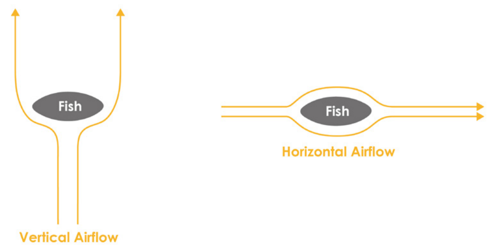


Figure 65. Vertical Airflow and Horizontal Airflow

Fourth Iteration

Goals

In the previous iterations, the fan used was one single powerful fan. According to SES, the availability of powerful industrial fans is limited. Therefore, in the actual situation, several small fans would be used to achieve the same effect. Therefore, one of the goals was to determine a suitable rearrangement of the fans. Another goal of this iteration was to rearrange the recirculation ducting system, because the a greenhouse expert pointed out that the current setting may block the sunlight. Other than these two goals, a general improvement goal of the performance was also set for this iteration.

1. Increase the velocity and balance the distribution
2. Rearrange the fans and test the performance
3. Rearrange the chimney and ducting system

Evaluation

The goals were brainstormed and goals one and two were simulated and evaluated with the following criteria.

Distribution
The distributed air at the desired locations.

Velocity
The overall velocity at the desired locations.

Reach
The distance that the supply air could reach.

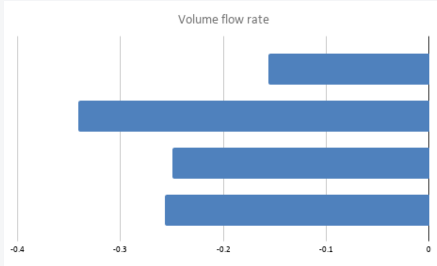


Figure 67. Air Distribution of the Openings

In this iteration, the cumulative method was used. The measuring method of velocity and coverage was the same as the previous iteration. For air distribution, each opening's volume flow rate was first sampled (Figure 67), then the standard deviation of the sampled data was calculated. Subsequently, the standard deviations of the designs were compared to evaluate the distribution (see Appendix S for detailed evaluation process and ideas).

Results

The heat pump system, dehumidification system, and wind-driven exhaust fan remained the same. The ducting system was integrated to the top of the drying chamber to reduce building material and to avoid shades (Figure 68).

As for the inlet duct (Figure 69), a guiding neck was added to help the performance of air distribution. Moreover, a two-by-two fan arrangement showed the closest result on air distribution, air velocity, and airflow coverage to the original one-fan design; therefore, a powerful fan was replaced by this arrangement.

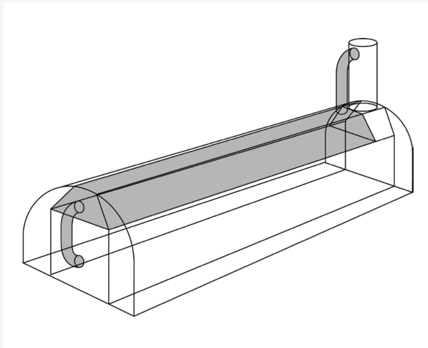


Figure 68. Integrated Chimney

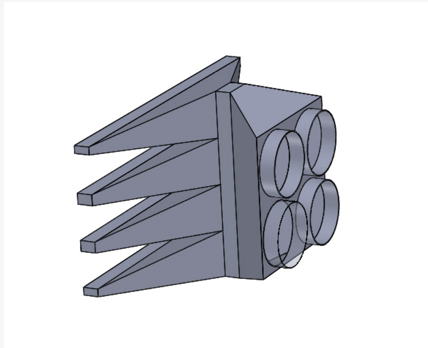


Figure 69. Revised Inlet Duct

5.4.2 Space Saving and Tooling Subsystems

This group was developed through physical prototyping. The iterations also started with some goals to achieve. However, due to the difficulties of building prototypes, just a limited amount of ideas can be tested in one iteration. Sometimes even only one idea was prototyped. Once the idea had been conceptualized, the prototype building plan would be subsequently drawn up in consultation with model building experts. Soon after prototype building, tests were conducted for evaluation.

First Iteration

The first iteration was intended to validate the concept; thus, no additional ideation was made.

Goals

1. Test the usability (the operation: spreading & collecting)
2. Test the structure strength

Method

The test setup was a one-to-one scale model. It consisted of four 180-cm-tall wooden poles with steel plate bases and two wooden top support beams, four metal hooks on each pole with 30 cm spacing starting from 60 cm high, four (reused) mosquito nets with hemp ropes (Figure 70), and a bucket of paper rolls in dagaa size.

For the usability test, it was aimed to recruit 3-5 participants in different age groups and different heights. According to the research (Akachi & Canning, 2007, p. 403), the average height of Sub-Saharan African females was around 160 cm and the standard deviation was around 6 cm. Thus, the heights of the participants were aimed at the range between 154 cm to 166cm (68% of the target group). The participants were asked to perform dagaa spreading, checking, and harvesting (Figure 71). The operations were recorded for observation. After the test, the participants were asked to fill in a System Usability Scale (SUS) survey. And then, the follow-up discussions were proceeded after the survey (see Appendix T-1 for detailed procedure).

To test the structure strength, multiple items were placed onto one net for 4 hours (Figure 71).

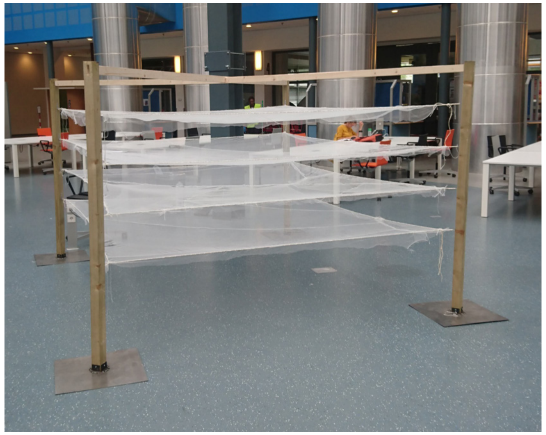


Figure 70. Test setup (first iteration)

Figure 71. User Test and strength test (first iteration)

Results

Four participants of the age ranged from 20 to 30, and the height ranged from 155 cm to 165 cm were recruited. The usability score of this design was 78.75, which indicated that this system was a “Good” system in terms of usability (T, 2020). The quantity of the participants was not enough to show quantitative results, but it was still of some referential value. The follow-up discussion gave some insights to the concept. The general feedbacks for the concept were,

1. There were confusions of long and short sides.
2. The harvesting was helpful, but the procedure could be optimized.
3. The nets were too wide that made it hard to check the center at the top layer.
4. Fish sometimes got stuck on the net while harvesting.
5. The design was bright, which gave a positive perception to some participants.
6. The tasks were skill-free and easy to understand.

The review with stakeholder pointed out another issue of the design:

1. The nets were sagging too much, which might influence the airflow and create dagaa clusters on the nets.

Because the materials were not completely the same as intended, the strength test was only tested for reference. The result showed that one layer was able to hold at least 10 kg for 4 hours.

Second Iteration

The sagging issue may lead to a slower drying rate due to the clustering situation. Thus, it was decided to solve the sagging issue before another usability test. There were two ways to deal with this issue, one is to adjust the airflow according to the sagging situation, the other is to improve the design of the nets. As improving the nets seems faster and easier, it was chosen as the goal of this iteration. The solutions to the sagging issue were either to change to a stiffer material or improve the stiffness by sewing techniques. Owing to the feature of reusing old fishing nets, it was decided to improve by sewing techniques first.

Goals

1. Improve the sagging issue of the nets.

Method

A textile expert was consulted for advice on improving the stiffness of elastic materials. Those techniques were applied to six pieces of square nets (50 cm x 50cm) for stiffness comparison (Figure 72).

The setups were hung on the poles and tested by placing a weight (~ 380g) on top of each net (Figure 73). The sagging extent was recorded by measuring the length from the horizontal line at where the nets were hung and the lowest point of the sag. Furthermore, wooden clips were spread on top of each net to observe the clustering situations.

Test Setup 1
Hemp Rope with no Ribs

Test Setup 2
Hemp Rope with 1x1 Ribs

Test Setup 3
Hemp Rope with 2x2 Ribs

Test Setup 4
Elastic bands with no Ribs

Test Setup 5
Elastic bands with 1x1 Ribs

Test Setup 6
Elastic bands with 1x1 Ribs and support ropes on the sides

Figure 72. Test setup (Second iteration)

Results

The results (Table 17) showed that ribs help to improve the sagging situation. Through comparing the sagging depth, the test setup five had the best result. As for the clustering situation, through observation, test setup five and six had similar results and were the best results among six of them. However, two other insights were observed. First, test setup four to six were bouncy, this may lead to some difficulties for the spreading task. Second, test setup one to three had larger surfaces to load more fish.

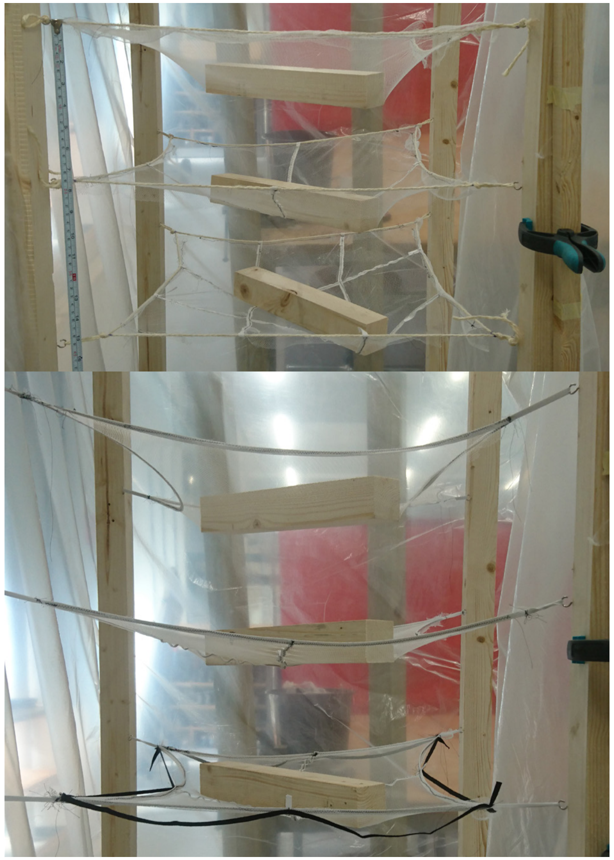


Figure 73. Sagging Situation test

Test Setup 1	Test Setup 2	Test Setup 3
Sagging Depth 8.5 cm	*Sagging Depth* 7.8 cm	*Sagging Depth* 7.1cm
Clustering Situation	*Clustering Situation*	*Clustering Situation*
		

Test Setup 4	Test Setup 5	Test Setup 6
Sagging Depth 7.3 cm	*Sagging Depth* 5.1cm	*Sagging Depth* 5.3 cm
Clustering Situation	*Clustering Situation*	*Clustering Situation*
		

Table 17. Test Results

5.4.3 Structure and Isolation Subsystems

This group was also developed through physical prototyping, and followed the same principle as the Space Saving and Tooling Subsystems.

First Iteration

The first iteration was intended to validate the concept; thus, no additional ideation was made.

Goals

1. Test usability of the space inside the structure
2. Test usability of the insulation layer

Method

The test setup was a one-to-one scale model (Figure 74). It consisted of the setup from the first iteration of Space Saving and Tooling subsystems (A), half side of the greenhouse dome (B), and an insulation layer between the rack and the dome (C).

The participant requirements were the same as the first iteration of Space Saving and Tooling subsystems. The participants were asked to perform dagaa spreading, checking, and harvesting inside the greenhouse setup (Figure 75). The operations were recorded for observation. After the test, the participants were asked to fill in a System Usability Scale (SUS) survey, and follow-up discussions were proceeded afterwards (see Appendix U-1 for detailed procedure).

Figure 74. Test setup (first iteration)

Results

Five participants of the age ranged from 20 to 35 and the height ranged from 150 cm to more than 170 cm. The usability score of this design was 83, which indicated that this system was a “good” system in terms of usability. The follow-up discussion gave some insights to the concept. The general feedbacks for the concept were,

1. The working space was enough, none of the participants perceived oppression or was hindered while working inside the aisle.
2. The rolling movement of the layer was intuitive but cumbersome for every participant, especially when rolling above chest height.
3. The beam was too high to reach for shorter participants.
4. Some participants would choose not to roll up the layer for dryness checking.

Figure 75. User Test (first iteration)

Goal

The rolling task was the main pain point, thus the goal of this iteration was to improve the opening mechanism of the insulation layer.

Method

Mindmap was done to generate Ideas. Then, the test setup was adjusted according to the chosen idea.

The new opening mechanism was a pulley system. One end of the layer was fixed on a wood stick on the roof (A). The other end was tucked through the top support of the greenhouse (B) and then connect to a wooden stick (C). Between (A) and (B), a weight was added in to create the pulley system (Figure 76).

The participant requirements were the same as the previous iteration. The participants were asked to perform dagaa spreading and checking but only at the top layer. The operations were recorded for observation. After the test, the participants were asked to fill in a System Usability Scale (SUS) survey and follow-up discussions were proceeded afterwards (see Appendix V-1 for detailed procedure).

Moreover, to determine the progress of this design, the opening and closing times were measured to compare to the previous design.

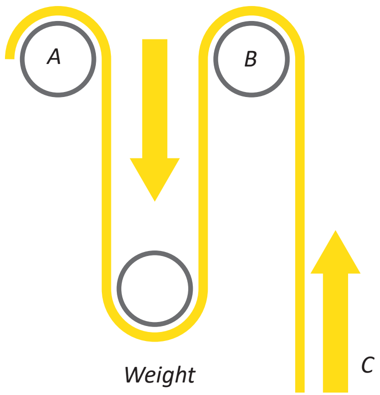


Figure 76. Test setup-Pulley system (second iteration)

Results

Five participants of the age ranged from 20 to 35, and the height ranged from 150 cm to more than 170 cm were recruited. Most of the participants were the same as that of the previous iteration. The usability score of this design was 93, which indicated that this system was an "Excellent" system in terms of usability. The follow-up discussion gave some insights into the concept. The general feedback for the concept was,

1. The smoothness of the pulley system can be improved
2. It saved a lot of effort compared to the previous design
3. It would be better if the system can bring the layer all the way up to the top.
4. Due to the squatting movement, some participants still think that it is cumbersome
5. The beam to rest the bar was too high for short participants

The measured rolling time showed that the new opening mechanism (12 seconds) was 64% faster than the original design (34 seconds) in terms of opening. The closing time remained the same as the previous design, which was 11 seconds.

Figure 77. User Test (second iteration)

06 Finalization

6.1 Bill of Materials

The Bill of Materials was established based on various sources, e.g., literature research and commercial products. While selecting the materials, the following aspects were taken into account,

Availability

Most of the materials are locally available. The metal frames, covering film, wood planks, and small fans can be purchased from local suppliers, according to SES. Moreover, the wood used in UpWind is pine as it is the most common wood in Tanzanian plantations (Held et al., 2017).

Durability

The durabilities of the materials were preliminary researched, e.g., by checking general information of the material and referencing commercial products. Most of them have lifespans more than 3 years under regular use, some even have up to 20 years of lifespan.

The materials of UpWind are shown in Figure 78 (see Appendix W for detailed Bill of Materials)

[A] Greenhouse Base
Pinewood planks

[B] Greenhouse Frame (1)Ground tubes (2)Hoops (3) Purlins (4) Wiggle wire rails
(1) Galvanised steel square tubes
(2&3) Galvanised steel round tubes (4) Aluminum

[C] Greenhouse Facades
Pinewood planks

[D] Chimney
Pinewood sticks and L-shaped brackets

[E] Greenhouse Cover
HDPE film, greenhouse tapes

[F] Wind-driven Fans
Steel tubes, steel sheets, bearings, and fan blades.

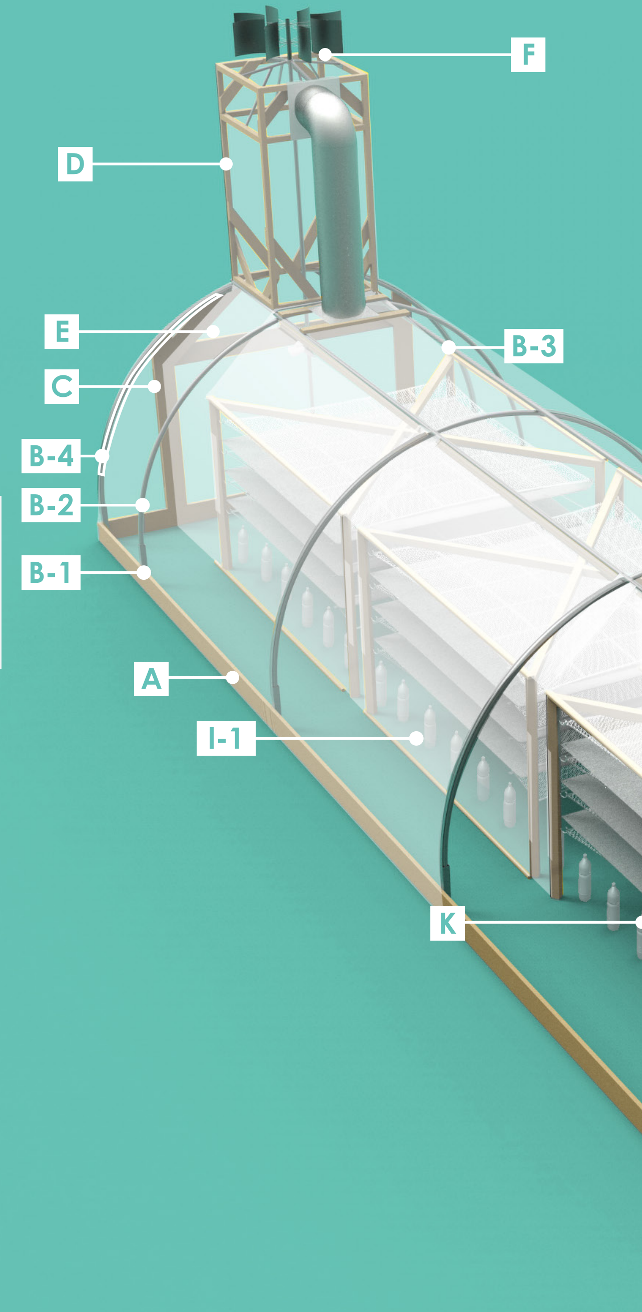
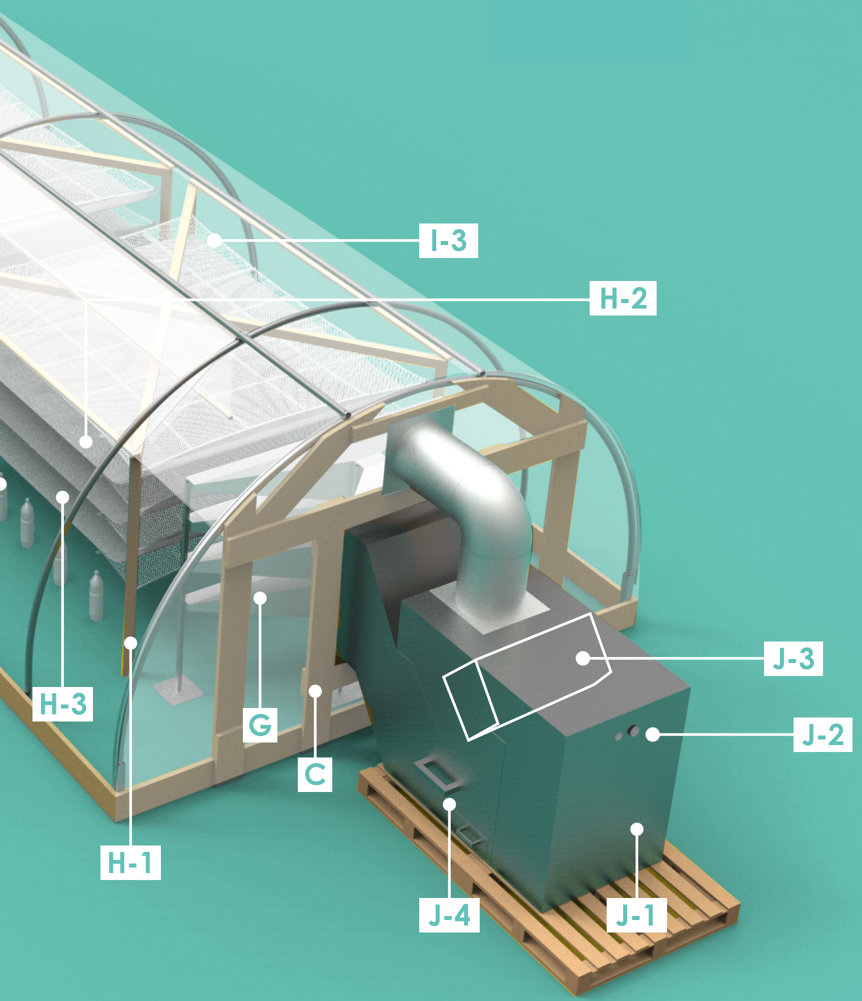


Figure 78. Materials of UpWind



[G] Air Distributor
Steel sheet and steel tubes

[H] Drying Nets (1) Poles (2) Nets (3) Guiding Sheets
(1)Pine, stainless steel (hooks), steel, nd L-shaped brackets (2) Retired fishing nets and elastic bands (3) Fabrics

[I] Internal partitions (1) Insulation Curtains (2) Intermediate walls (3) Top guiding sheet (Integrated ducting system)
(1) HDPE and wooden sticks (2&3) HDPE

[J] Heating and Dehumidification System (1) Casing (2) Desiccant layers (3)Heat exchanger (4) Heat Pump
(1) Stainless steel sheets, brackets, and sticks; hygrometers; rubber strips and washers (2) Silica gel, wooden sticks, cotton nets, and u-shaped nails (3) Steel sheets and wood strips (4) refrigerant, stainless steel pipes, an expansion valve, and a compressor

[K] Heat Storage
Any reused bottles and water

[L] Power supply
PV Panels, inverters, batteries, and cables

6.2 Manufacturing Methods

Due to the limitation of manufacturing methods in developing countries, the easier to produce the better. Moreover, aesthetics is not the priority of UpWind; therefore, the design does not contain curvatures or complex mechanisms that are difficult to produce (see Appendix X for technical drawings). Moreover, the manufacturing methods are frequently used methods which are expected to be available in Tanzania (Table 18).

The specifications and the manufacturing methods of the heat pump should be discussed with a refrigeration company. It is recommended to adapt the design based on the available heat pumps to avoid extra costs due to customization.

The steel parts are recommended to be painted to prevent them from rusting. The bolts on top of the purlins should be covered by taps to avoid frictional damage to the covering.

[A] Greenhouse Base Sawing and drilling (for bolts)	**[B] Greenhouse Frame (1)Ground tubes (2)Hoops (3) Purlins (4) Wiggle wire rails** Tube Bending, cutting, and drilling (for bolts)
[C] Greenhouse Facades Sawing and drilling (for bolts)	**[D] Chimney** Sawing and drilling (for bolts and screws)
[E] Greenhouse Cover Film cutting, taping, and sewing	**[F] Wind-driven Fans** Roll bending, metal cutting, and welding
[G] Air Distributor Bending, welding, and metal cutting	**[H] Drying Nets (1)Poles (2)Nets** (1) Metal cutting, welding, drilling, and wood sawing. (2) Sewing
[J] Heating and Dehumidification System (1) Casing (2) Desiccant layers (3)Heat exchanger (4) Heat Pump (1) Metal cutting, welding, and piercing. (2) wood sawing (3) metal cutting, wood sawing, and gluing (4) consult a refrigeration company	**[I] Internal partitions (1) Insulation Curtains (2) Intermediate walls (3) Top guiding sheet (Integrated ducting system)** Film cutting, wood sawing, and drilling

Table 18. Manufacturing Methods of UpWind

6.3 Assembly

UpWind was designed to be able to assemble onsite. Most of the parts are manufactured with pre-drilled holes for bolts to reduce the assembly hassles. Moreover, the assembly steps were specified (Appendix Y) so that the workers can build UpWind by following the instructions.

The orientation of UpWind should be north-south to receive maximum sunlight in Tanzania.

6.4 Cost Estimation

The cost was difficult to estimate without visiting and discussing with the local producer, especially for the cost of labor and manufacturing; therefore, the estimated cost may not be accurate. However, it gives a general idea of the proportions of each part's cost. Moreover, it helped to evaluate whether UpWind is profitable (will be discussed in Section 6.5).

The costs were estimated by referencing the expense of SES, the prices in the Netherlands, and online reference of Tanzanian websites. Due to the component-sharing feature of UpWind, the initial cost was reduced. The heat pump is shared by two UpWinds and is used for another purpose during sunny days (60% of the time); therefore, the cost of the heat pump and its power supply system for one UpWind is reduced to 20% of the original cost (see Appendix W).

6.5 Business Model

UpWind adopts a leasing business model. The principle is that the service provider produces and leases UpWinds to fishing camps. The service provider has the responsibilities of maintenance, including cleaning, repairing, recycling, and monitoring the drying condition, i.e. humidity and temperature. Another feature of UpWind is the modular heat pump. The heat pump is shared by two UpWinds and it can be used for other purposes, e.g., refrigeration, during sunny days. This feature has lowered the cost of the heat pump and its power supply.

Based on the yearly and monthly cost estimation of the fixed costs and the variable cost (Table 19), the monthly rent of an UpWind should be set around 200 Euros (see the second sheet Appendix W for calculation). The estimated rent is expected to bring the service provider a margin above 50%, and the fishing camps are expected to earn around 130% more than sand drying (Net profit: 40% more) (Table 20). The rent covers the monthly variable cost and fixed cost, which implies that if the service provider keeps UpWinds running, the rent will be able to cover the salary of its employees and other expenses caused by UpWinds. However, the high fixed cost of UpWind and the low price of rent will lead to a long payback period, approximately four to five years. The service provider should seek low-interest loans, governmental subsidies, or lower the fixed cost, to relieve the financial burden and shorten the payback period.

Category	Subcategory	Item	Price	Note
Fixed Costs (Yearly)	Depreciation	Heat pump Battery PV panels Heat exchanger Circulation Greenhouse and drying nets	~€ 620	1. Assuming after the maximal duration of the product, it will not be able to operate anymore. Instead of repairing it, a new product will have to be purchased. This assumption is to simplify the calculation by omitting the maintenance fee. 2. Taxes and transportation are not included
Variable Costs (Yearly)	Rent	Land use	~ €145	60 m2
	Salary	Cleaner	~ €520	One person takes care of 5 UpWinds
		Maintenance	~ €160	Inspect once in a month
		Manager	~ €70	Manage up to 100 UpWinds
	Utilities	Water	~ €5	50L per day
		Soap	~ €5	Wash everyday
		Yearly cost	~ €1,525	Rounded-up Estimation
		Monthly cost	~ €130	Rounded-up Estimation

Table 19. Yearly and monthly cost estimation

	Cost (Rent)	Revenue	Net Profit
Sand Drying	~€ 20	~€ 195	~€ 175
UpWind	€ 200	~€ 450	~€ 250

Table 20. Cost-Profit Estimation for Fishing Camps

6.6 Roadmap

Before being produced, UpWind still has some functionalities and usabilities to be validated, e.g., the function of the air distributor and the heat pump, and the interaction of the new drying nets (the development details will be discussed in Chapter 7); and some manufacturing details should be discussed with the suppliers. The timeline of these developments can be found in Figure 82. Moreover, due to the heat pump's availability in Tanzania, its requirement of well-insulated chambers, the increased need for PV panels caused by heat pumps, and the fragility of these components, it may not be the most suitable long term heating solution.

Therefore, a three-phased plan was made for improving its long-term performance. The goal of phase one is to develop and manufacture the current design of UpWind. Then, in phase two, the goal is to substitute the heat pump by another heat source. According to the research (Masud, Karim, Ananno, & Ahmed, 2020, pp. 135-141), some waste heat can be utilized as the heat source for drying. According to SES, there are factories available on the coast of the mainland, but not on the islands. The main heat source on the islands is the local home kitchens. Therefore, the second phase of the design roadmap was divided into two directions. First, replace the heat pump by utilizing local factory exhaust on the mainland. Second, convert Upwind to a compound of a kitchen and a greenhouse dryer for the islands. The benefit of these transitions is that it removes the initial cost and maintenance fee of the heat pump and its PV panels while the other components are still effective in the new design. For these transitions, only the heat pump will be removed from the heating and dehumidification system. UpWind will not use the exhaust directly, instead, the heat exchanger will transmit the heat from the exhaust to the supply air. In this way, the air supply will not be contaminated by the exhaust. As for the third phase, since the fishing camps are right next to the shores, UpWinds will also be located close by. Therefore, instead of using silica gels for dehumidification, a sea-cooling system might be utilized as a renewable dehumidification system for UpWind.

The implementation of these transitions were set after five years not only for the time reserved for redesigning and negotiation with local factories but also for the payback period of current UpWind. It is recommended to run the business until the break-even point so that it will not pose a financial burden to the service provider. As for the retired heat pump, generally speaking, it has a lifespan of fifteen years, therefore, after its retirement, it can be used for other purposes or assisting the drying process until the end of its life.

Figure 79. Heat Source of Upwind Phase 2.0 (Mainland)

Figure 80. Heat Source of Upwind Phase 2.0 (Islands)

Figure 81. Condensation cooling source of Upwind Phase 3.0

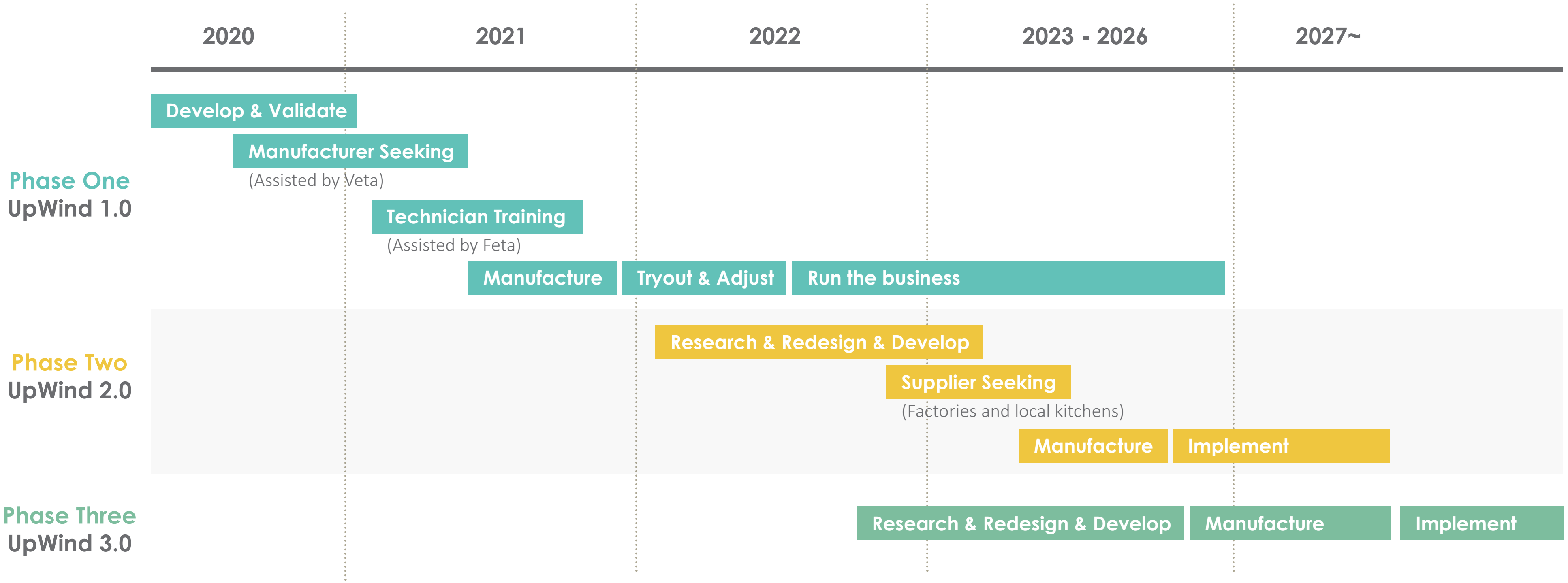


Figure 82. Design Roadmap of UpWind

07 Final Evaluation

7.1 List of Requirements

The List of Requirements (LoR) with a total of forty-six requirements and twenty-three wishes was generated based on the research finding and the list created by Project Dagaa. To evaluate the achievement of this project, the requirements were examined one by one. As a result, 80% of the requirements were fulfilled 11% of the requirements were partially fulfilled. Some of the requirements were theoretically fulfilled, however, it still needs to be validated in the actual environment. The essential ones are listed below, for the detailed list see the fourth sheet of Appendix K.

Performance

- *The drying solution must dry fish before 18:00 the same day*

  As described in Section 4.2.1

- *The drying solution must protect the dagaa from the rain, animals, and sand*
- *The quality of the fish should be better than sand drying*

  As described in Section 4.2.4

- *The product maintains the temperature around dagaa constantly between 35°C and 65°C and the humidity constantly between 10% and 40%.*

  According to the simulation, the temperature stays above 35 degree Celsius during sunny days. When the temperature is raised to 35 degree, the humidity would be lower than 40%. And the humidity will be maintained at this level through dehumidification and air exchanging with outdoor air when needed. During rainy days, the temperature and humidity will be controlled by the heat pump and the desiccant layers. However, the effect should be tested.

- *The product must be self-sufficient in energy*

  UpWind is completely powered by PV panels.

- *The product must be good for the climate on island Ziragula, Kasalazi, and Ukara*

  The heat pump provides heat on rainy days; therefore, UpWind should be suitable for different climates. However, the more the heat pump is used, the higher cost it will be.

- *The product should utilize available natural resources as much as it is not harming the nature*

  UpWind utilizes the heat, wind, and sand of the islands. And utilizes the air during sunny days.

- *Using the drying solution will pay out more than using the current sand drying*

  As described in Section 4.2.1

Usability

- *The product must be understandable and usable by users regardless of their educational level*

  According to the user test, the drying process is a skill-less task. It is expected to be easy for the actual users as well.

- *The user must be able to place the fish in and take the fish out of the drying solution*

  According to the user test, all users of different height group can perform the task.

- *The operation of the drying solution must cause a lower physical effort per unit of processed fish than the current sand drying method*

  According to the user test, it is not a heavy task. However, it was marked unknown without testing with actual users

- *Risks of injury should be low while assembling the drying solution*

  Only bolting and screwing is required for assembly, which means welding, cutting, and sawing is involved.

- *The product should not contain sharp edges which could lead to injuries*

  The working areas do not have sharp edges. However, the blades of the wind-driven fans might pose a threat to the users if trespassed to the non-working areas.

Fulfilled   Partially Fulfilled   Unknown

7.2 Sustainability

The sustainability of UpWind is evaluated by the Sustainable Development Goals (SDG) of the United Nations (UN) (the United Nations, 2020). The overall achievement of UpWind is displayed in Figure 83.

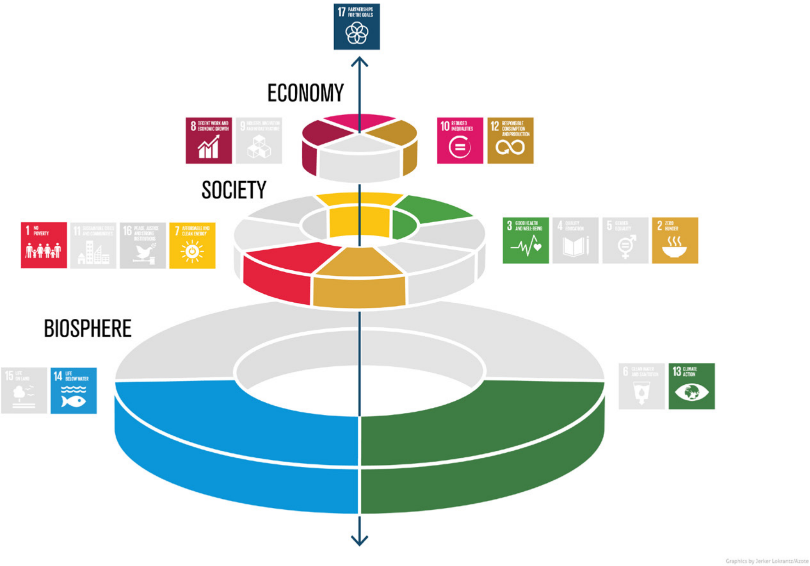


Figure 83. Achieved Goals (adapted from Stockholm Resilience Centre, 2016)

No Poverty

According to the research (Blankendaal et al., 2020, pp. 21-25), the current drying process is insecure. This has led to unstable incomes, sometimes even no income. By providing proper drying conditions, UpWind ensure the production of human consumable dried dagaa. This will not only secure the income of the fishing camps but also increase their profit by 40% compared to sand-drying.

Zero Hunger

Dried dagaa is a cheap and nutritious food that is affordable for poor people. Its long shelf life feature makes it possible to reach the poor inland families. UpWind is expected to contribute to the famine issues in Tanzania by decreasing post-harvest loss of dagaa, i.e., increasing the production of dried dagaa.

Good Health and Well-Being

The proper drying process of UpWind protects processed dagaa from contamination. This quality improvement is expected to eliminate the health hazards caused by contamination. Moreover, as dagaa is a nutritious food, the increased quantity is also expected to benefit more poor families' health.

Affordable and Clean Energy

UpWind is completely powered by solar panels. Moreover, when UpWind is not in use, the PV panel can be used for other purposes, e.g., provide electricity for the islands, where the power grid is not available.

Decent Work and Economic Growth

Most of the materials purchase and manufacturing of UpWind will take place locally, e.g., provided by local suppliers (fundi). This is expected to stimulate the local economy. Moreover, the salaries of the job opportunities opened up by UpWinds were estimated by the average salary of the specific job to ensure the workers will be fairly paid.

Reduced Inequalities

UpWind aims to be low-burden and skill-less for processors, so that undereducated, mid-aged, and child-carrying ladies can still perform the drying tasks. Moreover, technician training will be provided so that the threshold of the technician position can be lowered.

Responsible Consumption and Production

The materials of UpWinds are recyclable or biodegradable. Some of the materials are even reused, such as the drying nets and the heat storage bottles. Besides, the service provider will take the responsibility for the disposal and recycling of the retired parts. In this way, the improper disposal of fishing nets and water bottles are expected to be addressed.

Climate Action

A high percentage of Upepo's carbon emission came from the charcoal heater, wire mesh, and the steel frame. Therefore, one goal of this project was to reduce the impacts by focusing on these three elements. Subsequently, the charcoal heater was replaced by a solar-powered heat pump; and the steel wire meshes were replaced by retired fishing nets. As for the steel frame, considering its stability, long lifetime, and carbon emission compared to other materials*, it was not replaced.

*Wooden frames have a shorter lifespan in such warm and humid conditions. Moreover, wooden frames are not suitable for the desired greenhouse length; other materials such as PVC tubes aluminum has higher impacts than steel.

Life Below Water

The amount of UpWind is limited to the current catch of each fishing camp; therefore, it does not encourage overfishing. Moreover, it is recommended to have further discussion with concerned governmental institutions to formulate regulations based on the capacity of UpWind for more comprehensive fishing control.

Partnerships

SES is in close corporations with local NGOs and governmental Institutions. It is expected that these corporations will make the implementation of sustainable solutions easier, and at the same time, will help to monitor the sustainability of UpWind.

7.3 Technology Readiness Level

Due to COVID-19, it was not allowed to travel to Tanzania for field tests. Considering the given amount of time, to reach the desired levels by conducting remote tests seem time-inefficient. Therefore, the focus of the project was on developing the function through simulation and testing the usability of the most crucial parts in terms of user interaction, i.e., the drying nets and the working space. As a result, the TRLs did not reach the desired levels (Figure 84).

Heating

The heat pump used is available on the market and the material and specifications were preliminary specified; the natural heating by solar radiation was preliminarily validated through simulation; and the heat exchanger and heat storage were proofed by other researches, which means they can be considered as a validated product. Because the effect of the subsystem was only validated by simulation, it only has an overall level of three.

Circulation

This subsystem incorporates several new concepts, such as the air distributor and the wind-driven fan. And these components are not yet built nor validated. Therefore, although the airflow was designed based on commercial drying solutions and simulated, the overall level of this subsystem is still two.

Green

PV panels are market available products, therefore its TRL is nine.

Isolation

The PE film used is a standard material for greenhouses. However, the insulation performance of the insulation curtains was only validated in simulation. Therefore, the overall TRL is three.

Structure

The structure is based on a standard structure of commercial greenhouses. Although the distance of the hoops does not follow the standard length, due to incorporate the installation of the insulation curtains, an extra purlin, and some wiggle wires were added to enhance the stability of the structure (High Tunnels, 2010). However, the chimney is not a commercial product, the stability was only tested in a laboratory environment. Therefore, the overall level of this subsystem is four.

Restriction

The zipper used is available on the market and the material and specs are specified. Therefore, it has a level of nine.

Space-Saving

The racks, including drying nets and the frame, were demonstrated and tested by a 1:1 working prototype, which gave it a level of six; however, the drying nets were further developed and but only tested with a scaled prototype. Therefore, the overall level of this subsystem is five.

Nonetheless, the BoM and manufacturing methods have already been established, after validating the stability and function in Tanzania, the subsystems will reach TRL seven*.

*Some validation steps are skipped since the unvalidated components were mostly designed based on commercial products.

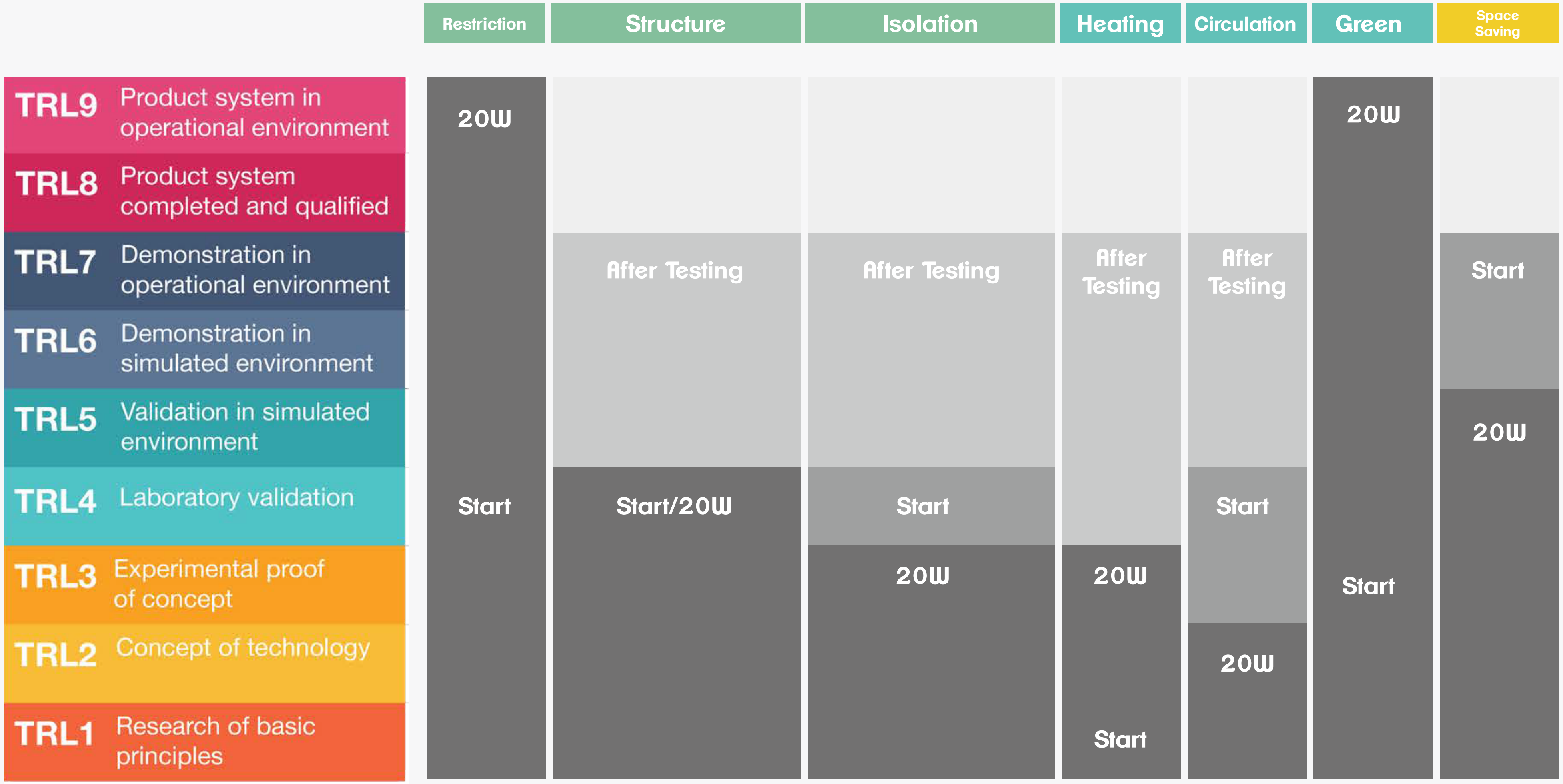


Figure 84. Technology Readiness Levels of UpWind

* The evaluations of the subsystems were based on the established Bill of Materials, manufacturing methods, and assembly steps in Appendix W, X, and Y, respectively.

7.4 Project Goals

- Study the opportunities to reduce the post-harvest loss of dagaa.
- Study the sustainability impact of Upepo and reduce the impact.
- Determine the most suitable solution for reducing post-harvest loss
- Validate the drying effectiveness, usability, and capacity of the (re)design.
- Create a suitable business model/strategy.

Fulfilled   Partially Fulfilled

In Subsection 5.1.1 and 5.1.2, various preservation methods and their implementations in developing countries were studied to understand the possible opportunities and the limitations of these methods. Moreover, the context, e.g., weather condition and market preference, was studied to help analyze the feasibility of certain methods and their desirability in Tanzania.

Besides exploring new methods, the research for possible modifications of the current design Upepo was also done in parallel. The life-cycle of Upepo was analyzed to determine the parts that have significant impacts so that it could be avoided in the development phase.

The functionality and usability of UpWind were validated through simulation, calculation, and user tests. However, the given circumstance of COVID-19 has posed some difficulties in validating the functionality; therefore, to fully validate the design, further tests should be conducted.

The business model and cost-profit calculation were made to ensure that the profit for both fishing camps and the service provider will be sustainable. The profit for fishing camps is expected to be always more than that of sand-drying. Moreover, the design roadmap was also made to indicate the possible design directions for UpWind.

7.5 Recommendations

This section provides an overview of recommendations based on the to-be-fulfilled requirements, other sustainability goals to work on, and the future development of each subsystem.

To-be-fulfilled requirements/wishes

1. *The solution should meet governmental demands*

   The regulation should be discussed with the government to avoid overfishing. Other regulations should also be studied or discussed with the government.

2. *The product must be fire-retardant*

   The PE film and wood are not fire-retardant. There are two recommendations for addressing this requirement. First of all, look for fire-retardant materials to replace with, but the sustainability, functionality, and usability of the materials should be taken into consideration while choosing substitutes. Second, instead of replacing the material, a standard escape procedure and fire extinguishing procedure can be established for the users, to ensure their safety and to minimize the loss and toxic emission due to the fire.

3. *(Wish) breakeven time of the drying solution should be under 1 year*

   The payback period is about 5 years due to the high initial cost of PV panels and the heat pump. To shorten the period, it is recommended to re-estimate the cost first. Then, try to lower the cost either by replacing the materials with cheaper-and-suitable materials, negotiate the price with the supplier or acquire subsidies.

   While decreasing the cost of UpWind, it might be helpful to decrease the cost by re-evaluating the workload of the technician, manager, and janitors, i.e. increase the workload in a reasonable range. However, this process is to match the workload to the salary, not to impose extra workload or underpay the workers.

4. *With perfect weather circumstances, the fishermen still want to use the drying solution*

   Although it is assumed that the faster-drying and profit-increasing features of UpWind will be attractive to the customers, the huge increase in rent may still deter the costumers. According to the Transtheoretical Model of Behavior Change (Prochaska, 2018), it requires some time for people to understand the benefits and get ready for the behavior change. Therefore, the benefits of UpWind, such as increased profit, quality, and decreased drying time, should be well conveyed to the costumers. Moreover, a period of tryout should be given to help them experience the benefits.

Sustainability

The sustainability impact of UpWind is expected to be reduced by replacing the charcoal heater and wire meshes with a heat pump and retired fishing nets, respectively. Due to the long lifespan of a heat pump, it was assumed that the impacts caused by the additional material of the heat pump and its power supply are lower than that of the continuous emission from charcoals. However, it is recommended to perform a thorough LCA analysis on UpWind and compare it to the impacts of Upepo. Other than this, in terms of improving UpWind's sustainability performance, some aspects might be worth-investigating to achieve more SDGs.

Clean Water And Sanitation

The heat pump dehumidifies the air through condensation, the condensed water may be used for sanitation, e.g., hand-washing. Theoretically, condensed water should be clean and comparable to distilled water (Schwarcz, 2018). However, the level of bacteria and molds of the water depends on the hygiene of the tank and the coil. It is not recommended for drinking; however, if the available water on the islands is less clean, then, it can be used for at least other sanitation purposes.

Industry, Innovation, and Infrastructure

Power grids are not available on the small islands. Therefore, since the PV panels of the fans will only be used for half of the day, it can be used as the electrical infrastructure when not in use.

Development Suggestions

Due to the time constraint of this project, the number of design iterations was limited. Therefore, the readiness level of each subsystem still varies. Nonetheless, the specifications of UpWind were defined for manufacturing. In this paragraph, the recommendations for each subsystem's development were provided.

Heating

Functionality:

First of all, the specification of the heat pump should be discussed with a refrigeration company to select a suitable model for the desired temperature range. Then, the heat recovery rate of the heat exchanger, the effectiveness of the heat storage, and the effectiveness of the desiccant layers and the heat pump should be tested to determine the actual amount of the desiccant needed and the interval of shifting the heat pump between two UpWinds.

Design refinement:

To reduce the cost, the heat pump was designed as a shared component. The other use of the heat pump during sunny days still needs to be ideated. As for the rainy-day sharing feature, it might be risky to move the heat pump frequently, especially in the rain. This idea was generated after the cost estimation, therefore, the design of the case did not take the hourly shifting into account. A redesign of the casing should be done to incorporate this feature in a safer way, e.g., an easier and safer transporting mechanism or a switchable ducting system that allows the heat pump to serve two drying chambers without being moved.

Circulation

Functionality:

The air distributor can be built with materials that are easy to adjust first e.g., cardboards, to validate and improve the air distribution of each layer. Then, the whole subsystem, including the air distributor, guiding sheets, and wind-driven fans, should be tested with the greenhouse body, including covering, insulation curtains, chimney, and the top guiding sheet, to validate the airflow inside the UpWind. The wind-driven fans can be replaced by small fans first to test the effect.

Structure

Functionality:

Test the stability of the structure, including the greenhouse frame and the chimney, together with the isolation subsystem.

Usability:

The type, shape, and the way of holding the bucket in the user tests might be different from the actual situation. Moreover, the temperature difference might also affect the perception of comfort; therefore, usability tests should be conducted to validate the comfort of the working space.

Isolation

Functionality:

The insulation effect of the curtains should be validated during sunny days and rainy days. The crucial function to validate on sunny days is whether the drying chamber can be heated to the desired temperature. The function to validate on rainy days is whether the heat loss is reduced by the insulation layers. Another factor to take in to consideration is the air infiltration. The flaps between the curtains and the walls are made to decrease air infiltration from the drying chamber to the insulation chambers. However, the effect still need to be tested.

Restriction

Functionality:

Test the durability of the zipper and the PE film that holds it.

Usability:

Test user experience of opening and entering through the door.

Space-Saving

Usability:

Interaction of the second version of the drying nets is not tested yet. However, before testing, the interaction feedback from the first iteration should be involved in the design. Such as the confusion of long side and short sides. Some shorter participants reported that it was hard to check the dryness of the dagaa in the middle of the top layer. This can be resolved by shortening the width; however, it should be taken into account that this change will involve more changes to the other components, e.g., the insulation curtain and the space of the working area.

Functionality:

The design was made without turning tools, however, the drying test has proven at least one turning is still required. Before designing a new tool, some simple tools can be tested, for example, a wooden stick. Tip: While ideating for the tools, the bouncing feature of the stretched fishing net may also be a worth-investigating idea.

Green

This subsystem involves extensive knowledge of PV panels. For cost estimation, a simplified method of calculating the needed PV panels was adopted. It is recommended to evaluate the PV panels and electricity storage system after the actual specifications of the heat pump are discussed and defined.

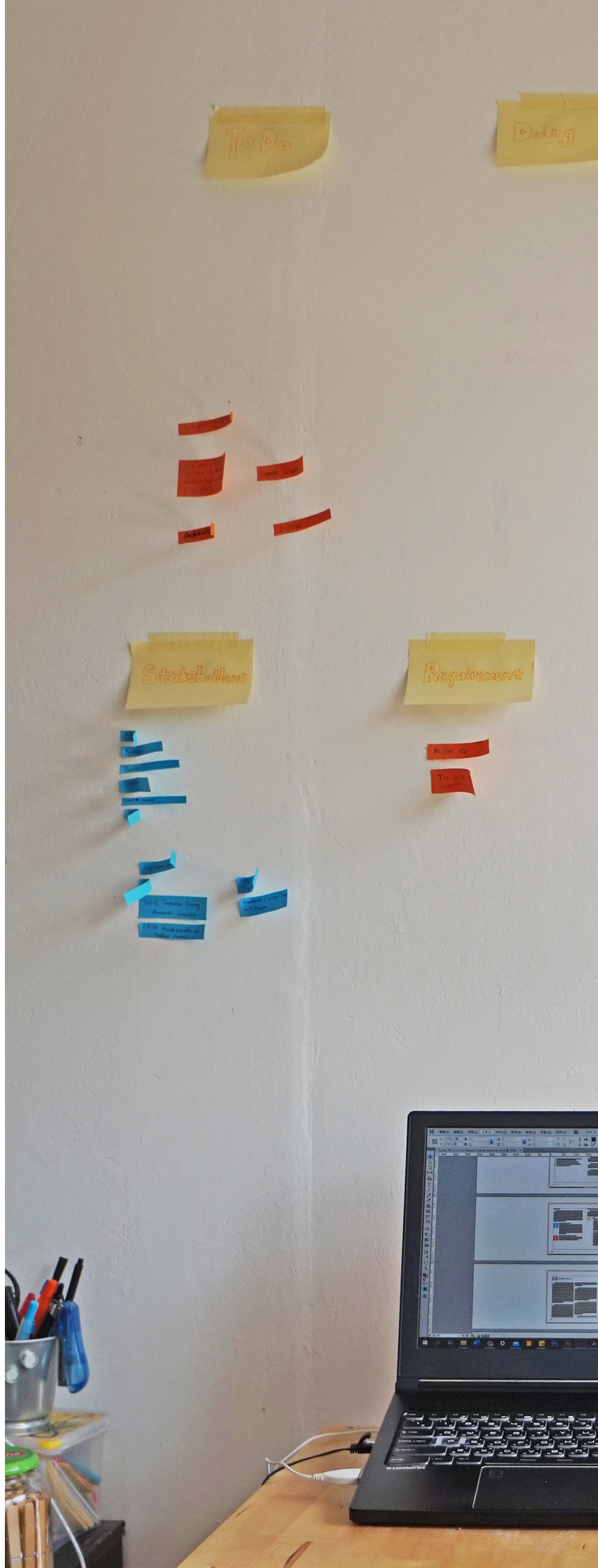
08 Reflection

The methods used in this project followed the basic design framework, double diamond, which helped to guide the project to stay on the right track. Under this framework, a management method, scrum board for one person, was adopted to keep track of the process; and a product development method, Technology Readiness Level, was used to handle the complexity of this project. Within the framework, some design methods were used for the discover, define, develop, and deliver phases to ensure the quality of the outcome. These methodologies were obtained from the IPD master program from TU Delft. However, there were some adjustments and difficulties experienced while implementing this project. Therefore, the reflections on the methodology used were discussed and presented in this chapter for readers to understand the rationales behind the decisions and the limitations due to the difficulties.

In the beginning, the problems were defined based on the former design. Then, a design vision was formulated to summarize the problems as the starting point for this project. Throughout the discover phase, the research topics followed the problems instead of the vision, therefore, the directions of the researches were accurate. However, it was found difficult to manage the research due to the lack of problem overview. At a later stage, the difficulty was identified, subsequently, the design vision was transformed into multiple project goals. As a result, this transformation helped clarify the purposes of the studies. If this was done at an earlier stage, in my opinion, it would help to communicate the purposes of the research and analyses more easily.

The idea generation was done through a morphological chart. However, it may have limited the form of the design. The other drying methods and the refinement of Upepo were researched at the same time. Subsequently, the findings of the research from both topics were filled into one morphological chart. This step may have influenced and limited the outcome of the ideation for drying methods. In other words, it may have confined the result to a greenhouse or enclosed solution. To lower the influence, the ideation of other drying methods should be separated from the refinement of Upepo.

The weighted objective method was used for concept evaluation. The criteria chosen were tailored for the design for the Base of the Pyramid, which includes affordability, accessibility, availability, reliability, sustainability, and acceptability. Although after re-evaluating the concepts in-depth, the outcome was accepted, the initial result of this method did not align with the wish of the stakeholders. After reflecting on the process, I have observed that effectiveness should also be added to the criteria due to the commercial attribute of this project.



In the deliver phase, the product was developed by design iterations in small groups The heating and circulation subsystems were developed through simulations. Because 3D models are easy to modify and simulation yields results relatively faster than physical prototyping, it was decided to alter the design iteration method slightly so that more possibilities can be evaluated in one iteration. However, this adjustment had also increased the amount of data to process. It became a pressure to process all the data within the planned time. Therefore, as a reflection, to practice the same method, a longer period should be planned. Otherwise, focusing on the ideation of each iteration would be more time-efficient.

In terms of project management, the schedule and planned activities were mostly followed. Although the project was influenced by the pandemic that the planned activities and remote testing in Tanzania were not implemented, however, the time was used to spend on testing in the Netherlands, e.g., functionality simulation and basic user experience test (Because the target users are very specific, the user tests conducted were only some basic usability tests to avoid biased results). Moreover, more time was spent on consulting experts on various topics, e.g., greenhouse, heat pump, and PV panels. Another difficulty experienced in project management was the lack of human resources. The graduation project was an individual project, there were no engineers involved in the project from the client's side. This has led to difficulties in design decision making. The only two approaches that came into my mind while facing these difficulties were to perform research and consult experts. However, research has its limitations and the experts were often not available for providing information in-depth.

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10 Appendix

A Calculations

B Life-Cycle Assessment of Upepo

- B-1 LCA Analysis
- B-2 LCA Datasheet

C Comparison of Solar Dryers

D Greenhouse Information

E List of Other Dryers

F Circulation Subsystem

- F-1 List of Ventilation Parameters
- F-2 Descriptions of Ventilation Strategies
- F-3 List of Ventilators
- F-4 List of Dehumidification Methods

G List of Protection Methods for UV/Animal/Rain

H List of Strutures for Human Activities

I Weather Data of Ukara

J Comparison of Preservation Methods

K List of Requirements

L Specifications and Evaluation of Three Concepts

M Use Scenarios of Three Concepts

N Re-Evaluation of Morphological Chart

O Heating and Circulation Iteration 01

P Heating and Circulation Iteration 02

Q Heating and Circulation Iteration 03

R Drying Test

- R-1 Procedure of Drying Test
- R-2 Drying Test Data

S Heating and Circulation Iteration 04

T Space Saving and Tooling Iteration 01

- T-1 Test Plan of Space Saving and Tooling Iteration 01
- T-2 Survey Responses of Space Saving and Tooling Iteration 01

U Structure and Isolation Iteration 01

- U-1 Test Plan of Structure and Isolation Iteration 01
- U-2 Survey Responses of Structure and Isolation Iteration 01

V Structure and Isolation Iteration 02

- V-1 Test Plan of Structure and Isolation Iteration 02
- V-2 Survey Responses of Structure and Isolation Iteration 02

W Bill of Materials and Cost-Profit Analysis of UpWind

X Technical Drawings of UpWind

Y Assembly Steps of UpWind

Z Graduation Project Brief