University Of Southern Denmark, Odense

Faculty of Engineering

Multipurpose crops drying system for small growers using renewable energy

Product development and innovation Bachelor project

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Delivery date 1/06/2022
Characters excluding spaces: 76327

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Solemn declaration

I hereby solemnly declare that I have personally and independently prepared this paper. All quotations in the text have been marked as such, and the paper or considerable parts of it have not previously been subject to any examination or assessment.

Martin Barron

Abstract

"Engineers Without Borders (IUG) - Denmark is a technical humanitarian organization of volunteers that seek to improve the livelihood for people living in poverty." (IUG 2022)
IUG has a series of engineering challenges for which they are actively looking for people to solve in order to provide humanitarian aid.
This project addresses one of the issues presented in regards to proper handling of crops post-harvest in rural areas within Sierra Leone.
What follows encompasses the process leading up to the creation of a multipurpose crop drying system for small growers at the behest of Engineers Without Borders (IUG) Denmark, as well as the considerations throughout.
This process consists of environment contextualization, idea development and validation as well as implementation.

1.0 Introduccion

Engineers without borders - Denmark (IUG) is a non-profit organization which is financed by contributions from its members, as well as by donors. They work in a variety of fields, providing engineering related solutions while collaborating with local and international aid organizations to provide humanitarian aid wherever possible. Their work covers a wide array of fields, from improving sanitary conditions, to building infrastructures such as schools or health clinics.

IUG has created a liaison with SDU, enabling students to tackle engineering issues relative to specific problems within areas that require humanitarian aid. It is here where this project was born. As a Product Development and Innovation student developing a bachelor project, I was able to take on a challenge presented by IUG.

The challenge revolved around proper handling of crops post-harvest, more specifically their drying process, as the methods currently used were outdated and unsanitary. This will be explored further within the problem definition.

The particular difficulty presented when developing solutions for empoverished environments, are the contrast in user behavior and purchasing power, as well as their perceptions of value. This meant that a strong collaboration with IUG would be necessary to develop a successful solution to the issue presented, as their knowhow in the field would be invaluable.

2.0 Problem definition

A problem definition defines the pre-processing stages by clarifying the client's original problem statement before conceptual design. The client in this case is IUG. In regards to the particular problem to be addressed, IUG shows leniency in regards to possible solutions, as the scope of the presented issue is broad and can be approached in a variety of different manners. Having considered this, it was within the prerogative of the solution developer to define the problem statement.

2.1 Problem as presented

The problem was presented in a simplistic manner, via pictures of the currently employed drying techniques, which clearly lacked efficiency and presented a myriad of issues. Below are a couple of images which were attached to the case description, depicting the issue in question.

Figure 1. Current drying situation

Figure 2. Alternate view of drying setup

Immediately a variety of issues were visible from an efficiency perspective in regards to the methodology of drying, furthermore there were a variety of sanitary concerns detected.
A preliminary meeting was held with IUG's general secretary Dorte Lindegaard Madsen, where a variety of the elements surrounding a possible solution development were clarified. It is from the information obtained within that meeting, together with the pictures which are referenced above that the problem statement is defined.

2.2 Problem Statement

"There is a need to develop an efficient drying process to increase the shelf life and quality of grains for small farmers in Sierra Leone, which is a vital process for incentivizing the growth and development of the agriculture sector"
IUG has defined some general guidelines in regards to the expectations of the final product. Together with the expectations from a product development perspective, we will determine that a successful solution **must:**

- Be able to be built locally
- Can be operated and serviced by the local producers, the user and or local service providers
- Can operate without the use of an external power supply
- Help to reduce postharvest losses and increase shelf life
- Prioritize an ecologically friendly solution
- Prioritizes promoting hygienics
- Decrease overall drying time for any grain
- Be cost efficient (Benefit must not be outweighed by cost)

3.0 Contextualization of deployment environment

For the development of the required solution, one of the most challenging aspects is obtaining in-depth understanding of the user and the deployment environment, as the economical and cultural difference is vast. This means that appropriate information gathering and research into Sierra Leone will be paramount to developing a solution tailored to the user.

The user itself is nigh inaccessible in terms of information collection, as contact with rural farmers within Sierra Leone is impossible without the appropriate connections.

Having understood the limitations of contextualization in regards to the end-user, we will rely on two main methods to collect the required data:

- Digital research and collection of data
- Expert interview

3.1 Sierra Leone as a country (Digital and paper research)

Figure 3. Map of Africa showing location of Sierra Leone WorldAtlas. (2021, February 24). *Sierra Leone Maps & Facts*. WorldAtlas. Retrieved May 29, 2022, from https://www.worldatlas.com/maps/sierra-leone

Figure 4. Map of Sierra Leone (2021, February 24). *Sierra Leone Maps & Facts*. WorldAtlas. Retrieved May 29, 2022, from https://www.worldatlas.com /maps/sierra-leone

3.1.1 Geographical and administrative structures

Sierra Leone is a country located within the west coast of Africa, it shares borders with Liberia as well as Guinea and the Atlantic Ocean and spans a total of 71.740 KM². The average annual rainfall has been estimated to be 2,746 mm (1961 – 1990) and can sometimes be upwards of 4900 mm's, which makes it one of the wettest countries within west Africa.

It has a tropical climate with two main seasons determining agricultural cycles, these are:

-The Rainy Season: Spanning from May to October

-The Dry Season: Spanning from November to April, Harmattan (Onset of cool and dry winds originating from the Sahara Desert) occurs during this season.

The country comprises five provinces: Eastern, Northern, Southern, Western (Where Freetown, the capital is located) and Northwestern. These regions are then further divided into 16 districts.

3.1.2 Population

The country's population is 8,280,045 (World Population Meter) people with a growth rate of around 2.3%, which places it amongst the highest growth rate countries in the world. Out of the entirety of the population, around 57% resides in rural areas, while 43% lives in urban areas. The most vastly populated area is the capital of Freetown, boasting a population of 802,639 people. However, as can be appreciated in the population density map (Attached in appendix A.1) , the bulk of the population lies scattered throughout rural areas. Life expectancy is low at 55.92 years and infant mortality is extremely high at 70.1 deaths per 1000 births (Live statistic Worldometer).

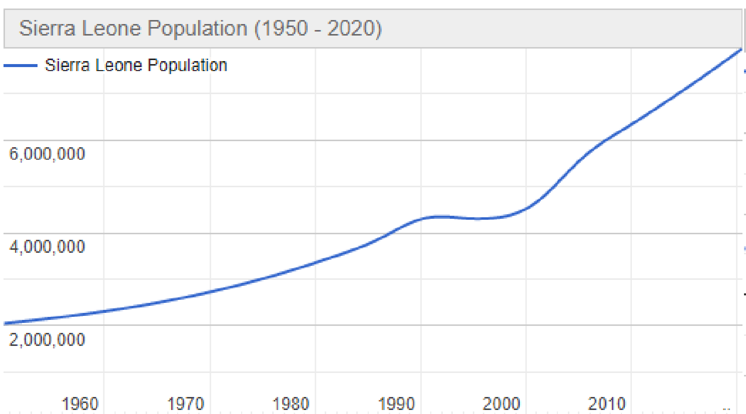


Figure 6. Population density map of Sierra Leone
Sierra Leone population (live). Worldometer. (n.d.). Retrieved May 29, 2022, from https://www.worldometers.info /world-population/sierra-leone-population/

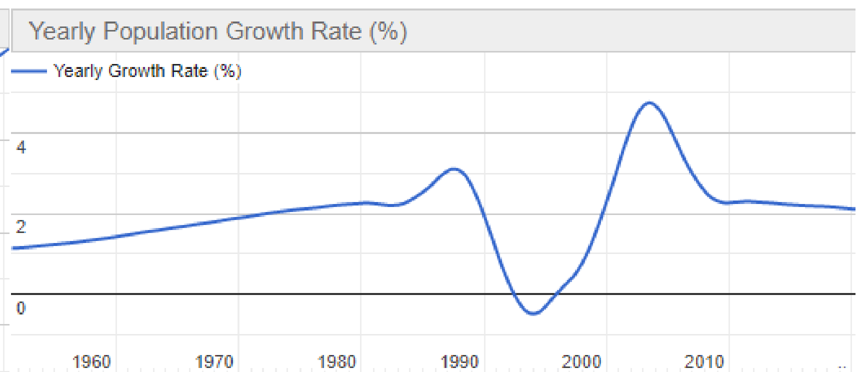


Figure 7. Yearly population growth rate of Sierra Leone
Sierra Leone population (live). Worldometer. (n.d.). Retrieved May 29, 2022, from https://www.worldometers.info /world-population/sierra-leone-population/

The country boasts a largely varied demographic, as it has 16 different ethnic groups, each with its own language. The largest one are the Temne, who make up around 35% of the population, closely followed by the Mende, who make up around 31% of the population. Temne tend to reside within northern Sierra Leone, as well in the vicinity of the capital, while the Mende mostly live in South-Eastern Sierra Leone as well as the Kono District. Although there is no religious affiliation attributed to Sierra Leone, Muslim's are the most common, making up about 78% of the population, followed by Christianity in second place with 21% of the population.

3.1.3 Socio-Economic context

Sierra Leone ranks amongst the least developed countries in the world. It was ranked 182 out of 189 in the latest Human Development Index ranking (UNHDI, 2020). The country's Gross Domestic Product growth percentage has been erratic, mostly due to socio-political conflict related issues. During the past four years it has gone down from 5.3% to -2.7% and back to 5.0% and this paints the landscape of an unstable economic situation.

MAJOR MACRO ECONOMIC INDICATORS

	2019	2020	2021 (e)	2022 (f)
GDP growth (%)	5.3	-2.7	4.0	5.0
Inflation (yearly average, %)	14.8	13.5	10.5	10.0
Budget balance (% GDP)	-2.7	-5.8	-4.0	-3.0
Current account balance (% GDP)	-20.0	-16.0	-14.5	-13.5
Public debt (% GDP)	70.0	73.7	73.0	72.5

Figure 7. Major macro economic indicators for Sierra leone *Sierra Leone. Coface. (n.d.). Retrieved May 30, 2022, from https://www.coface.com/Economic-Studies-and-Country-Risks/Sierra-Leone*

The average Gross National Income per capita is 510 USD. The country’s main economic activity is agriculture, with almost two thirds of the entire country being directly involved in subsistence agriculture. During the past decade, agriculture in Sierra Leone has consistently accounted for approximately 60% of its GDP.

GDP by sector (percentage of GDP at current prices)

	2011	2016
Agriculture, forestry, fishing and hunting	56.7	60.9
of which fishing	10.5	12.4
Mining and quarrying	4.3	2.7
of which oil	...	...
Manufacturing	2.3	1.9
Electricity, gas and water	0.2	0.2
Construction	1.3	1.0
Wholesale and retail trade; Repair of vehicles; Household goods; Restaurants and hotels	10.2	9.9
of which hotels and restaurants	0.4	0.4
Transport, storage and communication	5.6	4.2
Finance, real estate and business services	3.2	2.9
Public administration and defence	4.7	6.9
Other services	11.4	9.4
Gross domestic product at basic prices / factor cost	**100.0**	**100.0**

Source: Data from domestic authorities.

Figure 8. GDP breakdown for Sierra Leone *Publishing, O. E. C. D., & Centre, O. E. C. D. D. (2017). African Economic Outlook 2017 Sierra Leone. Organization for Economic Co-operation and Development.*

The country's troubled history of internal conflict is often pointed out as the main detracting factor from successful economic growth, however, there are a myriad of other issues which directly relate to a stagnant economic environment.

Some of these are:

- Low agricultural productivity
- Low remuneration for all kinds of workers
- Poor investment decision-making
- High unemployment rates
- Corruption
- Failure to adequately use available natural resources
- Poor health status coupled with high fertility rates

In regards to potential of industry, the country has untapped potential, as it boasts large patches of underutilized fertile land, mineral resources, unexploited marine resources and marine trade capabilities.

The manufacturing sector consists mainly of raw material processing, as well as simple manufacturing for domestic market purposes. The service sector has been continually growing as a result of foreign parties entering the market.

3.2 Political Context

3.2.1 Civil War

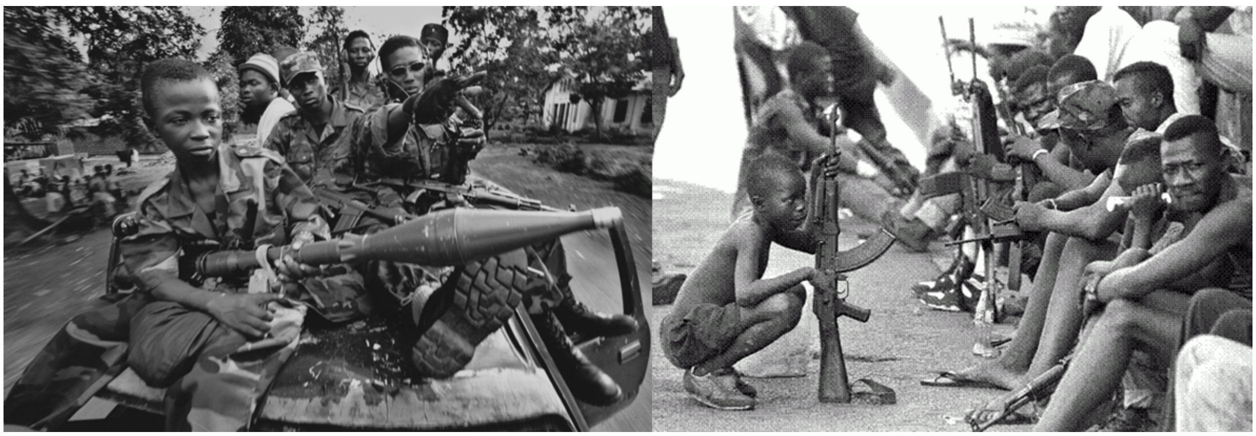


Figure 9 and 10. Pictures of child militia from Sierra Leone civil war *Youth, poverty and blood. Human Rights Watch. (2015, April 29). Retrieved May 30, 2022, from https://www.hrw.org/report/2005/04/13/youth-poverty-and-blood/lethal-legacy-west-africas-regional-warriors*

The recent political context of Sierra Leone has been marred by conflict. In 1991 conflict within the neighboring country of Liberia started to steadily make its way into Sierra Leone, as Liberian rebels known as the National Patriotic Front of Liberia (NPFL) were attempting to seize control of rural areas within the Sierra Leone border. To add to the conflict, the Sierra Leonean army also found itself under attack by the Revolutionary United Front (RUF).

The conflict escalated the following year and a coup led by Capt.Valentine E.M. Strasser led to the president at the time Joseph Saidu Momoh being deposed. Strasser assumed control of the country and during this period the civil war continued its escalation. This period was characterized by the atrocities that took place by both foreign militias, as well as government troops, as both these groups would partake in violation of human rights towards civilians unrelated to the conflict. The coups would continue, with Strasser being ousted in another military coup in 1996, due to speculation that he would be unwilling to relinquish power and General Julius Maada Bio assumed control until elections were held, which were later won by Ahmad Tejan Kabbah. Ahmad would be shortly ousted the following year, as yet another coup took place and Major Johnny Paul Koroma seized power. He stayed in power until 1998 where he was overthrown by the Economic Community of West African States Monitoring Group troops, who intervened by obtaining local community support. President Kabbah's government was then restored, but the battle against militia's continued until 1999, where a peace accord (Lomé Agreement) was signed.

This newfound peace saw itself immediately threatened by the subdivisions within the rebel militia's. It soon became clear that despite the peace accord, several RUF rebels would not comply and would refuse to surrender their weapons, while continuing their assault on civilians, as well a UN mission of peacekeeping troops. This led to a violent battle occurring in the capital of Freetown, during May 2000. In the following years the UN intervention UNAMSIL, had a fair amount of success in disarming a variety of RUF rebel militias by introducing concessions in the Lomé Agreement to suit particular groups of rebels. This led to the UN peacekeeping troops slowly beginning to secure the country and the official end of the civil war was declared in January 2002. The conflict took the lives of over 50,000 people and displaced over 2,000,000 as a result.

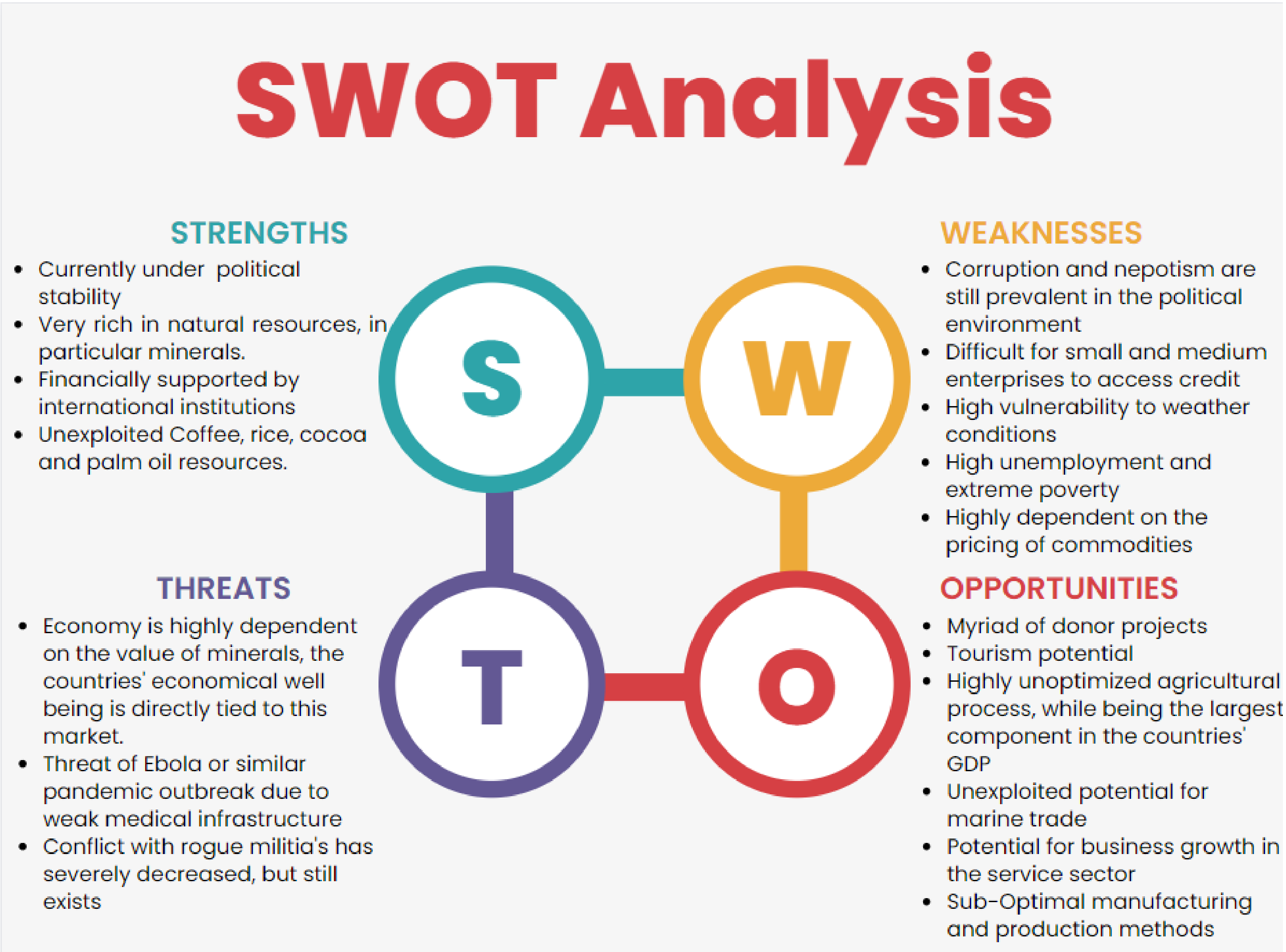
3.2.2 Post-Civil War and Ebola outbreak

Figure 11. Pictures of a child with medical aid during the Ebola outbreak says:, P. R. (2019, June 6). *Lessons from the ebola outbreak in Sierra Leone:* Africa at LSE. Retrieved May 31, 2022, from
https://blogs.lse.ac.uk/africaatlse/2018/08/08/lessons-from-the-ebola-outbreak-in-sierra-leone/

The first elections once the war had ended were held in May 2002, Kabbah would be re-elected and his administration would focus mainly on conciliating territories, increasing population security, as well as promoting reform and economic recovery. The path to recovery saw aid from the reopening of rich ore mines, however, during the coming years Sierra Leone would consistently rank among the world's poorest countries. The coming years would see a steady trend of economic growth and general quality of life improvements as the country continued its recovery.

This slow and steady progress would be halted abruptly in 2014, due to a deadly outbreak of the Ebola virus. This outburst would be severely detrimental to the country, as it was already struggling with the limitations of its poor public health infrastructure. The outbreak was first contained in 2016 and by then more than 14,000 Sierra Leoneans had been infected, with around 4000 dying as a result. Since then, the country has focused on revitalizing its governmental infrastructures, as well as institutional ones. The road to recovery has been long after the myriad of difficulties the country has faced within the last decades and it now faces the issues associated with Covid-19.

3.3 SWOT Analysis on Sierra Leone



The country currently finds itself in a phase of relative political and economic stability. The scope of business opportunities is on the rise again and with it the propensity for individual entrepreneurs to begin business in Freetown. Despite this, the small market makes it not lucrative enough for most internationally operating companies; furthermore the high levels of corruption mean a multitude of compliance issues. There are however interesting business opportunities for entrepreneurs, due to the high margins offered by an undersupplied market. Opportunities for goods import are always good due to the high demand for consumer goods in Sierra Leone. In Sierra Leone almost everything is imported, examples of this are: Rice from Asia, chicken from Brazil, onions from the Netherlands, as well as random mass produced goods and high-end products for the wealthy inhabitants of Freetown.

The country's main activities are agriculture and mining, as these two activities make up the bulk of the country's GDP, without considering the wholesale and retail sector. Germany has been making active investments within the mining sector, as well as providing expertise and technology. However, the largest GDP component which is agriculture is extremely underdeveloped and lacking infrastructure as well as expertise.

Opportunities are also presented for supply and consulting within the infrastructure sector, as it has some particularly profitable areas. There are scores of privately financed projects which are ongoing that lack proper expertise; furthermore, there are also plenty of donor backed projects. It is important to note that due to the current political landscape, a good relationship with local authorities is paramount to the success of entrepreneurships.

3.4 Agricultural sector in-depth analysis

Figure 12. Women harvesting fields in Sierra Leone *Fao.org*. Strengthening Women's Cooperatives in Sierra Leone | Mobilization des ressources | Organisation des Nations Unies pour l'alimentation et l'agriculture. (n.d.). Retrieved May 30, 2022, from https://www.fao.org/partnerships/resource-partners/investing-for-results/news-article/fr/c/1148510/

The nature of the project calls for a deeper analysis of the agricultural sector within Sierra Leone.

The agriculture sector, as has been touched upon previously, is the largest component of the Sierra Leonean economy, employing approximately two thirds of the country's labor force and according to the previously presented data, consistently accounting for roughly 60% of the countries GDP. The country has been blessed with extremely favorable agricultural conditions in the form of vast arable land, abundant water supply, favorable climate and a strong irrigation network due to its abundance of rivers. In theory, Sierra Leone should be able to produce enough food to meet local consumption and for export.

It's interesting to note that 80% of foodstuffs consumed within Sierra Leone are imported, meaning that there is a very low percentage of agricultural activity which is not for export.

Out of the estimated 5.4 million hectares of arable, fertile land, a whopping 75% remains uncultivated.

The sector is primarily made up of small subsistence farmers who utilize local tools and outdated methods, severely limiting their output production. There are however a few agricultural companies which operate in the production of a wide array of products and on occasion provide agricultural machinery contracting services.

The staple food for Sierra Leoneans is rice and it is the main agricultural product of the rural population. Despite the fact that it is consumed on a daily basis by almost every household, the country has consistently been unable to produce enough rice to meet the local demand. As a result, the country spends a considerable sum on rice imports annually. Consequently one of the main goals within the agricultural sector is improving domestic rice production in order to reduce import fees and create more jobs, as was stated within the country's latest national development plan. The rice market has also been identified as a key factor in stimulating economic growth as well as increasing income within rural communities.

The country has an extremely rich fishing ground, which boasts more than 500 kilometers of coastline, as well as a continental shelf with an area of 30,000 square kilometers. Fishing has a potential to become a viable economical cornerstone for Sierra Leone, but in its current state it is challenged severely by incompetent management and governance, a weak infrastructure as well as support services and unregulated fishing practices which lead to overfishing and illegal activity.

Sierra Leone has introduced policies in its Medium Term National Development Plan (2019-2023), which promote diversification within the agricultural sector and fishing sector. The current government is attempting to make these sectors more attractive by revisiting existing policies and legal paradigms, as well as giving incentives to entrepreneurs within the agriculture sector. Some of these policies involve increasing the amount of arable land being currently used for agricultural purposes, as well as introducing machinery into the process.

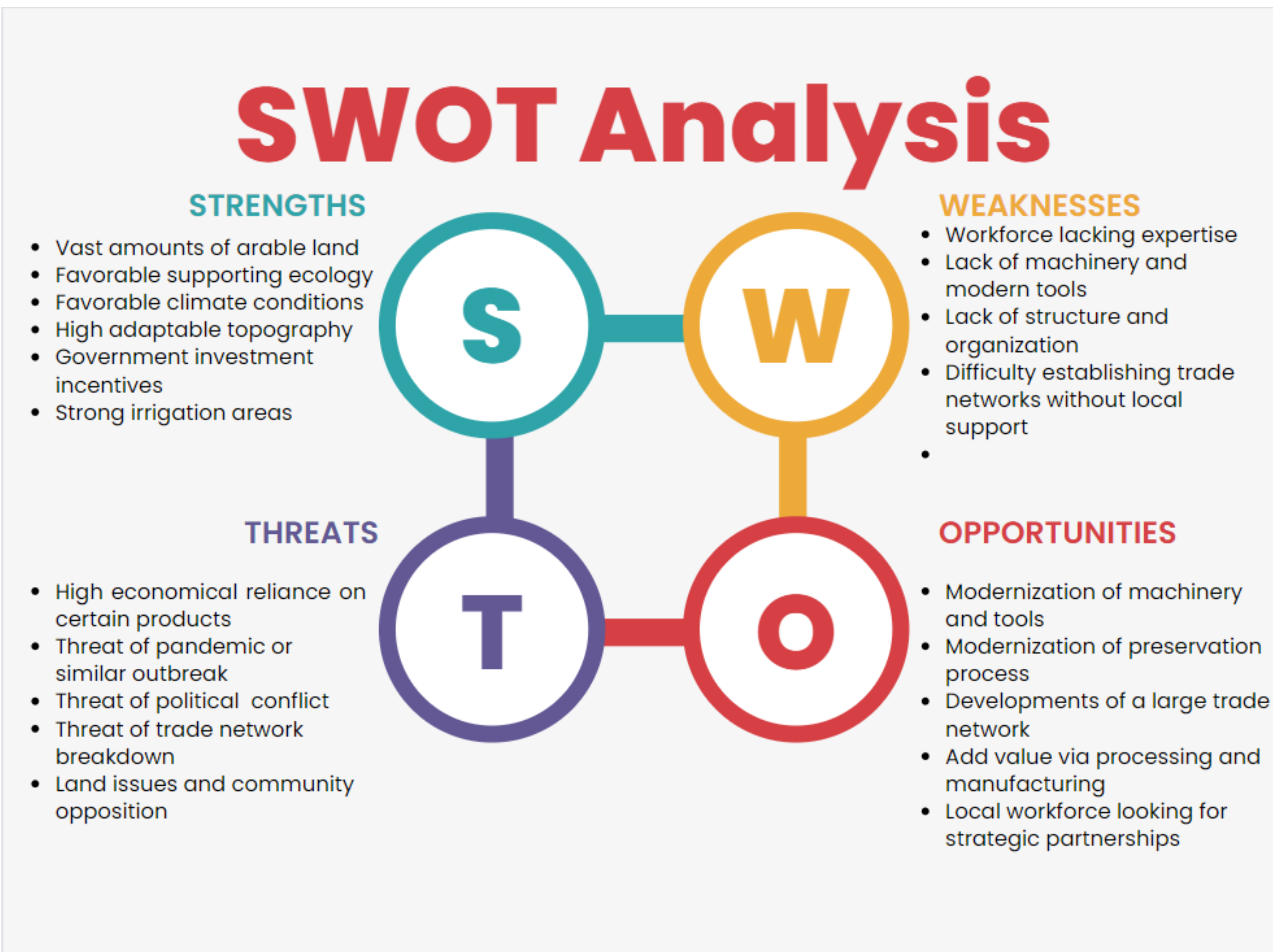
3.4.1 Agricultural Sub-sectors

The leading sub-sectors for agriculture in Sierra Leone are: Rice, palm oil, cocoa beans, coffee, cassava, groundnut, vegetables, fruits and livestock. The government is actively seeking investors in order to boost rice production, as to meet the country's quota. Cassava is of great importance, as it enables the production of flour, which reduces the need for importing goods. In the past USA based investors have ventured into coffee and cocoa plantations, by establishing their own, or purchasing unsuccessful ones with the intent to introduce the necessary expertise to achieve successful business practices.

For any sub-sector partnerships with local workforce is paramount in order to be able to expand cultivation as well as have adequate preservation facilities.

For all sub-sectors domestic production is not sufficient to satisfy local demand.

3.4.2 Agricultural Sector SWOT analysis



4.0 Research on existing drying solutions and technology

4.1 Introduction

Humans have been consuming grains for thousands of years and for as long as they have been doing it, they have been searching for ways to optimize their end product. One of the earliest forms of increasing product quality and longevity came in the form of grain drying and has been referred to in the bible, more precisely Leviticus 11, 14 " Thou shalt offer for the meat offering of thy first fruits green ears of corn dried by the fire". As a consequence dehydration of grain is amongst the earliest recorded drying processes in history.

Grain drying plays a crucial role in ensuring food safety, as it helps prevent the growth of microbes and myotoxins. According to the Food and Agricultural Organization (FAO), around 25% of the world's agricultural products are contaminated by myotoxins due to inadequate storage.

It is important to note that there is a distinction between crops. Durable crops (Grains and legumes) naturally contain relatively low amounts of water, whilst perishable crops (Fruits, and vegetables) contain a high amount. This means that durable crops can be stored for much longer than perishable ones. However, they need to have sufficiently low moisture content before being able to be sent off to the store for sale or long term storage.

We will define the concept of "equilibrium moisture content", as the level of moisture content at which the grain is neither gaining nor losing moisture. Having understood this, grain drying can be defined as: "The removal of excess moisture within a grain, in order to achieve equilibrium". In the developed world, this implies the reduction of moisture from somewhere around 17-30% to values lying within 8-15%, this depends entirely on local regulation surrounding handling of foods, as well the type of grain that is being dried and for what purpose. In general terms, the higher the oil content is for a particular grain, the lower the moisture percentage for storage will be.

4.2 Benefits of grain drying

- Reduction of moisture content, which is the most critical physiological factor for successful grain storage
- Reduce post-harvest loss (Head shattering and cracked kernels for example)
- Increases safety of crops for consumption, by preventing microbial growths and mitigate moisture-mediated deterioration
- Reduces the impact produced by environmental conditions on harvest
- Allows for time re-allocation in post-harvest field work
- Increases storage life by reducing the possibility of germination and degradation
- Reduce insect activity
- Earlier harvest is possible due to reduced drying periods, consequently lengthens the harvesting period
- Increased financial returns as a result of crop quality increase and reduction of post-harvest loss

4.3 Key concepts

- **Moisture content (Mc):** The amount of water contained within a grain kernel. Usually expressed as a percentage value relative to the grains weight. In the modern era this is determined via the use of moisture meters. However it is possible to calculate given both the wet and dry weight are known and it is given by the following formula:

  Mc = 100 x (wet weight - dry weight) / (wet weight)

  It is important to note that this method suffers from certain reliability issues.

- **Moisture Shrink:** While ideally all the weight loss while drying would come from water loss, there is dry weight loss associated with drying of crops (Example: Detached kernels from corn). Moisture shrink refers specifically to the shrinkage that occurs as a consequence of moisture loss. It can be calculate as follows

  Moisture Shrink = 100 x (Mo - Mf)/(100 - Mf)

  - Mo = original moisture content
  - Mf = final moisture content

- **Airflow:** Generally speaking most grain drying techniques revolve around circulating warm air around damp crops, the methods to achieve this vary greatly, but we will determine airflow to be the air which is being made to move through the grain mass in order to absorb and carry moisture away from it.

- **Heat source:** In order to circulate warm air, it is necessary to have a source that generates heat to warm up the air. In its simplest form, this is achieved by convection generated by solar rays, while in more modern equipment the heat source is generally powered by fuel sources.
- **Drying capacity:** Also known as grain flow, commonly expressed in bushels per hour dried over a specific moisture range.
- **Energy efficiency:** Energy efficiency in regards to grain drying is the required energy per pound of evaporated water. This efficiency is influenced by several factors, such as: Dryer design, moisture content removed, environmental conditions. We can calculate energy efficiency as follows:

  Energy Efficiency = (100 x Fuel Consumption x AE) / (Moisture Shrink x Wbd x 56 lb/bu)

    - Wbd = Wet bushels dried
    - Ae = constant

- **Grain quality:** Grain quality is a complicated term, due to it's subjective nature. Depending on the location or even individual perception, grain quality might differ. This is mostly due to the amount of contributing factors to high quality grain (tested weight, moisture content, fissuring, stress cracking, discoloration, breakage susceptibility, mold presence, insect damage, myotoxin count, pesticide residue, milling yield, baking quality, oil recovery, etc…). These characteristics are affected by the genetic predisposition of the seed, growth environment, agronomic practices, post-harvest handling and drying treatment among others. Despite only a few of these factors being measured and standardized in the food production industry, they all contribute to the overall quality of the grain.
- **Grain kernel temperature:** There is a difference between the temperature achieved inside the drying environment and the temperature of each individual kernel. It is important to know this distinction when measuring temperatures, as higher temperatures than required in the drying process could result in grain damage.
- **Breakage susceptibility and stress induced cracks:** Stress cracks occur when a kernel is submitted to viscoelastic property changes, which leads to internal failure and the formation of fissures. Viscoelasticity is directly linked to moisture content and temperature and it refers to a material that displays the behavior of an elastic solid as well as a viscous fluid.

4.4 Types of drying

Active drying: The advances made in technology now allow us to harvest large amounts of crop and dry it quickly, with the use of mechanized agricultural machines. We will understand active drying, as the introduction of mechanized components into the grain drying process. This method consists of exposing grain to forced airflow, which is heated via an artificial source. All modern day grain drying equipment falls under this category.

Passive Drying: Passive drying refers to the use of natural warm air movement to achieve grain drying. It involved no mechanical or digital components and is characterized by the low cost associated. Passive drying machines can usually be set up with local materials, such as wood pallets, which make it ideal for small farms.

4.4.1 Active grain dryers

Due to the nature of a grain dryer's functionality (circulation of warm air), there are a myriad of iterations which achieve this function in an unimaginable amount of ways. However, the agricultural industry in the modern world has established tried and tested drying machinery throughout its history. This is a short review of the most effective and popular methods used globally for grain dryers.

Batch grain dryers: One of the simplest grain drying methods, it is comprised of a storage unit, which holds all the grain in a stationary position throughout the drying period. The components which are usually found in these systems are: Perforated flooring, grain spreader, air circulation system (fan), heat source and sometimes a stirring device.

Benefits:

- Low-effort setup
- Low supervision requirements
- Bin doubles as storage
- Can take variable load sizes

· Disadvantage:

- High initial investment
- Careful management of system is required to achieve uniform heat distribution
- Requires loading and unloading equipment

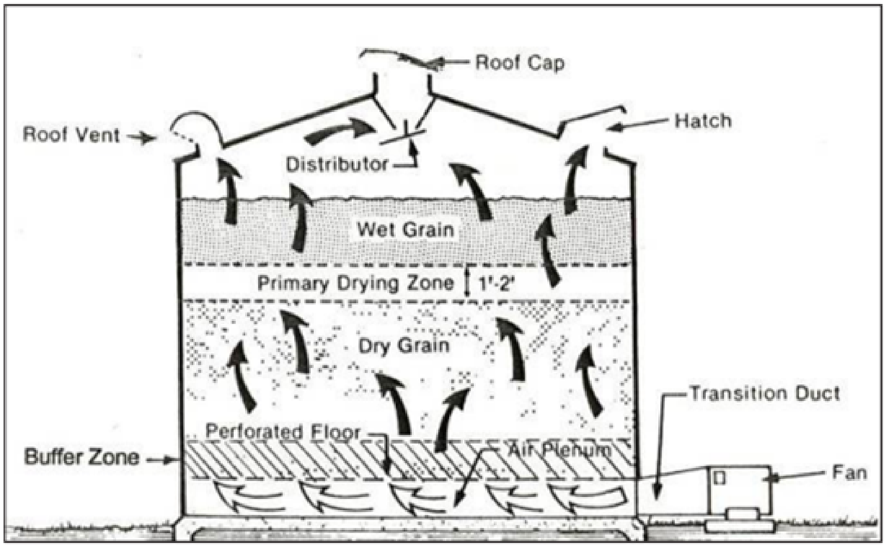


Figure 13. Batch grain dryer schematic *Encon 2.3. 2012). Improving Energy Efficiency in Grain Drying.*

<u>Types of batch grain dryers:</u>

Bin dryer: Simplest iteration uses no external heat source and relies on airflow for drying.

High temperature bin dryer: Exactly the same as a standard bin dryer, but with the addition of flammable gas to generate heat.

Roof Dryer: The dryer section is located in the "roof" of the bin, once the grain has been dried it drops down to the bin floor. The dropped grain cools, while a new batch enters the roof.

Recirculating batch dryers: In recirculating batch dryers, the grain is in constant motion, moving through the differently purposed sections of the bin.

Continuous flow dryers: As the name suggests, in these dryers there is a continuously flowing mass of grain. This means the drying process proceeds uninterrupted, this is to say, the product enters with a high humidity content and exits at the desired content. It is generally used in scenarios that require constant production.·

Benefits:

- Large quantities of grain can be processed with no loading/unloading downtimes
- Optimization of manufacturing process for large scale production

Disadvantages:

- Large initial investment
- Required careful management
- Requirements of loading/unloading equipment

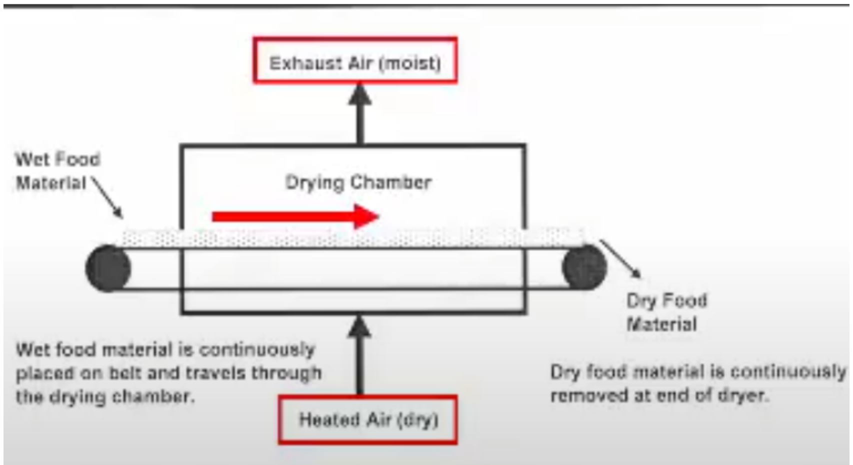


Figure 13. Batch grain dryer schematic Mercer, D. G. (2017, August 1). *Types of dryers*. YouTube. Retrieved May 30, 2022 https://www.youtube.com/watch?v=62_WIhwcfQo&t=368s

Types of continuous flow dryers:

Cross-flow dryers: Most popular iteration of continuous flow dryers. In this type of dryer, airflow is perpendicular to grain flow and grain flow is controlled by gravity. It is interesting to note that as a result, there is a variation of moisture content between both sides of the grain.

Counter-flow dryers: In this type of dryer, grain flow is opposing airflow. This means the hottest air is in contact with the driest grain. One advantage of this system is the ability to stack moist grain on top of drying grain, which eliminates the need for a wet grain container.

Mixed-Flow dryers: As the name suggests, these kinds of dryers possess airflow in both previously mentioned directions. Cross-flow enables the use of higher temperatures without damaging the grain.

4.4.2 Passive grain dryers

Due to the nature of passive drying, the system will always rely entirely on natural air movement to achieve drying. This does not mean that airflow cannot be incentivized. In almost all passive dryers, this is achieved by convection of currents brought forth by solar energy. It is important to note that a passive solar dryer can be quickly modified into an active dryer, via the addition of a fan, which would artificially increase airflow.

Because of the usual applications for passive dryers, they are of particular interest to the project.

There are two main types of solar dryers we will consider, direct solar drying and indirect solar drying:

Direct solar dryer: Usually found in the form of a "cabinet dryer", where there is a separating membrane, usually plastic or glass, which is exposed to sunlight. The sunlight heats up the inside of the cabinet dryer (Usually colored black) and the warm air causes convection of currents, which results in the drying of the grain inside.

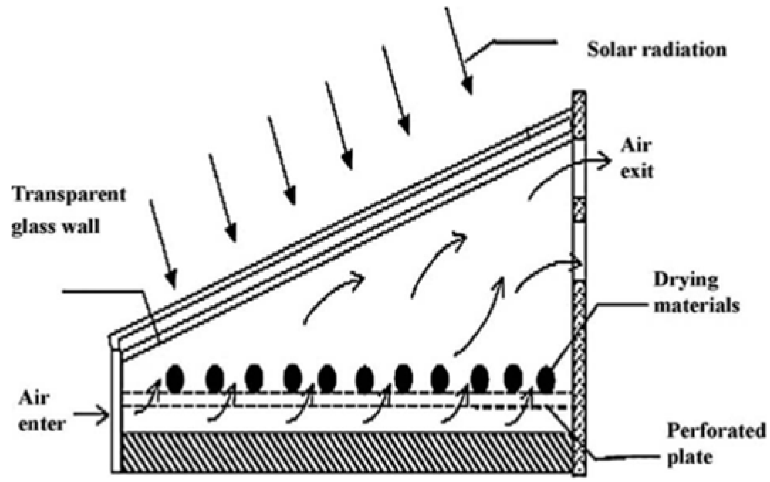


Figure 14. ***Direct solar dryer schematic*** *Om Prakash & Anil Kumar (2013) Historical Review and Recent Trends in Solar Drying Systems, International Journal of Green Energy, 10:7, 690-738*

Indirect solar dryer: As opposed to direct solar drying, the exposure of the crop to solar radiation is limited. The gran is only exposed to air heated as a result of exposure to solar radiation, but does not get direct exposure to sunlight. This has certain benefits, such as reducing discoloration of grain.

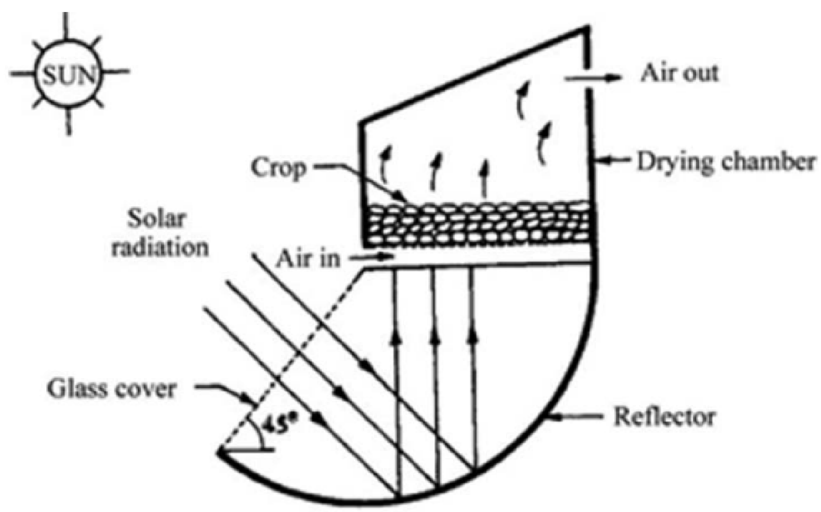


Figure 14. Indirect solar dryer schematic *Om Prakash & Anil Kumar (2013)Historical Review and Recent Trends in Solar Drying Systems, International Journal of Green Energy, 10:7, 690-738*

Mixed mode solar dryer: As the name suggests, this type of dryer combines both indirect and direct drying into one system.

All of these designs are based on very simple physical concepts that ensure their functionality, due to this, there is an almost endless array of possible configurations that can achieve solar drying. In the following section we will review some of these, while placing special focus to existing designs that have been used for similar purposes as the ones that drive this project (Humanitarian aid).

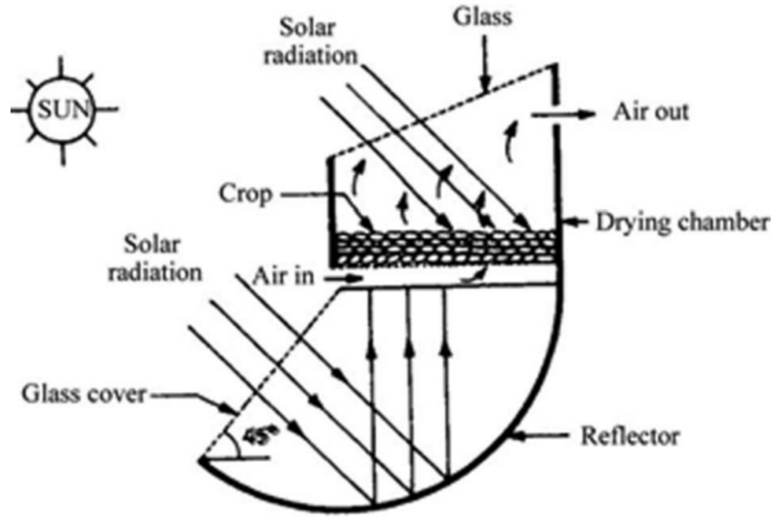
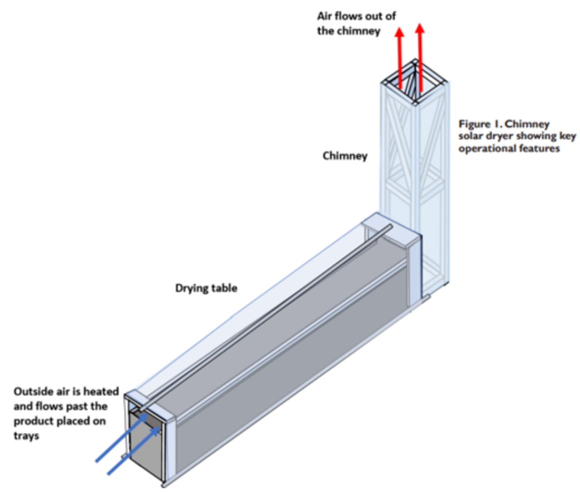


***Figure 15. Mixed Mode solar dryer schematic** Om Prakash & Anil Kumar (2013)Historical Review and Recent Trends in Solar Drying Systems, International Journal of Green Energy, 10:7, 690-738*

4.5 Existing low-cost grain dryers for small farmers

This section is focused around reviewing grain drying solutions that are of particular interest to the project at hand, this is to say, low-cost solutions which have been specifically designed for small farmers.

Feed the future: This organization is the U.S Government's Global Hunger & Food Security Initiative; the organization states "Feed the Future works to give families and communities in some of the world's poorest countries the freedom and opportunity to lift themselves out of food insecurity and malnutrition. By equipping people with the knowledge and tools they need to feed themselves, we are addressing the root causes of poverty and hunger, helping people end their reliance on aid, and creating important opportunities for a new generation of young people". It goes about achieving its mission with a strategy based around a strong partner network that draws upon expertise from a diversity of fields to accomplish its goal. It has spawned many initiatives that have helped a variety of poverty areas around the world (12 in total, Sierra Leone not included).



Among those initiatives they have outlined a proposition in collaboration with the University of California for the design of a low-cost direct solar dryer. The introduction for the assembly manual of said dryer states "Solar dryer was designed to provide efficient drying even in hazy or partially cloudy conditions. Constructing the dryer is simple and can be built from low-cost materials found locally in markets and shops around the world".

It is worth noting that the main points that are brought forth when introducing the design are the low-cost and ease of use, we can understand from this that when producing the design, these were the main considerations.

Figure 16 and 17. Feed the Future solar grain dryer *Feed the future innovation lab for Horticulture. Chimney solar dryer | Feed the Future Innovation Lab for Horticulture (n.d.). Retrieved May 30 , 2022, from https://horticulture.ucdavis.edu/chimney-solar-dryer*

University of Dhaka, "Design, Construction and Performance Study of a Low Cost Solar Dryer for Food Preservation in Bangladesh":

Amongst many relevant papers attached in the appendix, we find a project carried out at the University of Dhaka during 2017. We again see the focus of the project being oriented towards low-cost, easy to assemble and replicate systems with low complexity

Figure 17 and 18. Solar Grain dryer university of Dhaka
Biswas, P. K., Milon Uddin, Huque, S., & Nasif Shams. (2017). Design, Construction and Performance Study of a Low Cost Solar Dryer for Food Preservation in Bangladesh. Institute of Energy, University of Dhaka.

University of Rajasthan, Department of Physics "Fabrication and testing of a low cost passive solar dryer":

In similar fashion to the above intervention, members from the University of Rajashthan's physics department constructed their own variant of a solar grain dryer for small farmers. Again we see the emphasis on low-cost and use of locally available materials.

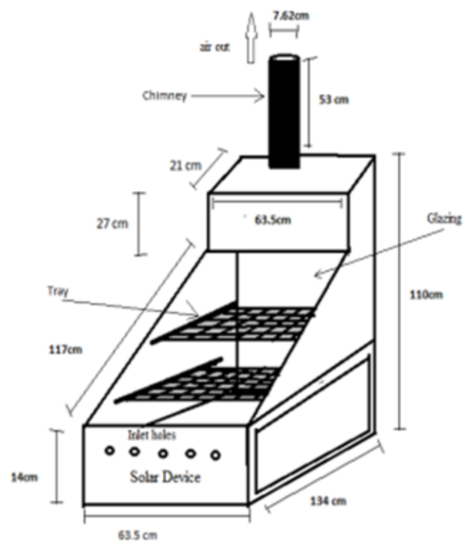


Figure 19 and 20. Solar Grain dryer University of Dhaka
Khan, M., Sengar, N., & Mahavar, S. (n.d.). Fabrication and testing of a low cost passive solar dryer.

5.0 Expert interview and collaboration

The nature of the desired deployment environment calls for local expertise in order to be able to properly understand the end user. This is due to the fact that, despite there being abundant information on Sierra Leone as a country, truly understanding the challenges associated with a successful entrepreneurship or project within the rural community proves itself to be the most challenging aspect.

To this end, contact was made with Alfred Mbayoh, a Sierra Leonean engineer with expertise in project deployment within rural communities, residing in the capital of Freetown. Furthermore, he has a background in rural community farming, as he grew up in this environment and participated in it daily.

Name: Alfred Mbayoh

- **Age:** 28 Years old
- **Nationality:** Sierra Leonean
- **Educational Degree:** Mechanical and maintenance engineer/ University of Sierra Leone

- **Relevant work:**

    o **February 2020-December 2020 :** Student intern at United Nations Office for project services. Report submitted on "Efficiency of operation and disposal of lead batteries for rural electrification systems".

    o **June 2021-September 2021:** Student intern at Water4Ever, worked in the development and deployment of submerged water pumps, purification systems, solar pumping systems and elevated storage.

    o **December 2021:** Began work as engineer in charge of machine part inventory at the Sierra Leone Brewery.

Upon contacting Alfred regarding the project, he was eager to help and share his expertise. We then decided on some ways we would be able to use his knowledge and how he could collaborate in the project in the best way possible. The points we decided upon were as follows:

1: Hold an informal general conversation surrounding the deployment environment and possible solutions, mostly aimed at gaining a general oversight of the rural population which will be targeted with the solution.

2: Focused interviews surrounding specific topics of interest identified throughout digital research, as well as previous conversations.

3: Establishing a line of direct communications, to enable the discussion of ideas or concepts as they become relevant.

4: Provide feedback on design ideas.

5: Help with data gathering when relevant.

5.1 Key knowledge obtained from interviews

Interviews were conducted with the goal of obtaining as much information surrounding the end-user as possible in order to create a solution which is tailored to the environment. To this end, these were held after the digital contextualization was complete, in order to enable assumptions made during this phase to be validated or dismissed by the expert.

The key points which were touched upon in the interviews as well as throughout the whole collaboration process are outlined below.

- **Main challenges identified:**

    - Rain: Farmers leave their crops to dry exposed to the elements, this means they are highly susceptible to rainfall. When rain begins falling, people will rush out to protect their crops.

    - Animals: Much like the exposure to rain, unprotected drying crops are constantly under threat from animals who roam the premises. It is not uncommon for animals to urinate or defecate on drying crops.

    - Energy supply: Most rural areas within Sierra Leone do not have access to a power grid, this means that electricity, as well as other power sources cannot be relied upon when designing a solution, unless they are part of it.

- **Most important considerations when developing solutions:**

    - Farmers must be able to understand the technology in use for them **to** properly integrate it into their process. Local workforce is quick to dismiss that which escapes their understanding.

    - Introduction of technology such as humidity sensors might seem like an appealing idea, but it enhances complexity of the build and lowers ability to replicate.

- **Key factors to ensure a successful integration of solution into everyday life:**

    - Solution must be very inexpensive

    - Ability to handle variety of crops

    - Simplistic approach

- **Rural farmer production:**

    - Size of production is extremely varied and is to be analyzed on a case to case basis, this makes designing a one fits all solution complex.

    - Workers are usually family members or extended family, working for no salary and under no contract.

    - Income per harvest season does not exceed $1000 USD in any case and is around $700 USD for a large farm.

- Largest rural farms will not have produce in excess of 1 ton, most small farmers will be nowhere near this and will usually produce around 400kg. Again, the size of production is extremely varied.

- **Crops:**
  - No standards as to the final state of the crops, their quality is completely up to the discretion of the buyer, but there is a general consensus about what good quality crops are.

The interviews with Alfred helped validate a lot of the assumptions that arose from the digital contextualization and he was able to give strong feedback in regards to the direction the solution should take. It was agreed that a simplistic solution, which used the minimum amount of technology possible, would be ideal, as it would be easy for farmers to understand and incorporate, as well as allow them the possibility of constructing their own. Modularity was also another big component which was discussed, since the size of farms is extremely varied, it makes sense to develop a solution which can simply be replicated or expanded upon as production increases and the need arises.

6.0 Conclusions drawn from research

Market research and contextualization was arguably the hardest challenge surrounding the development of a solution for the presented problem. Having said this, the information gathered through digital research, review of existing interventions and expert interviews, has cemented the grounds for a strong ideation phase, by revealing the most important considerations surrounding a design targeted for rural farmers within Sierra Leone.

There are innumerable ways that the effective research phase would affect ideation for this project, but for the purpose of conciseness, we will talk about the key elements identified which are important to consider when developing a solution.

Low-cost: The nature of all reviewed solutions for solar grain drying, which were targeted to similar environments, were all categorized by being low-cost. This has to do with the economic status of the end-user as well as the role it plays in being appealing enough for the user to want to integrate it. Considering Sierra Leone's country situation it would only make sense that low-cost is one of the main focuses while developing a solution.

Ease of use/understanding: Interviews with our expert revealed that within rural communities, users are quick to dismiss technology they don't understand/aren't used to. In fact, one of the main failure causes for aid interventions is the inability of the user to take care of a project after its deployment. Realizing this and discussing it with our expert, we concluded that a solution which approaches the issue in a manner which is most similar to the users current practices would be optimal.

Local material use: The use of local materials, aside from incentivizing local market growth, plays a crucial role in the user's ability to interact with the product. When coupled with a design that the user can understand and is simple enough to replicate, we enable the sharing of knowledge between potential users and the ability to replicate the existing design.

Replicability/modularity: Because of the lack of production standards within Sierra Leone, there is no one fits all design which would satisfy our users. Therefore, the design of a solution which is easy to replicate adds great value. This is because if a user has a greater production than another, they can simply increase the amount of dryers in use. This could also be achieved via a modular design, which can be retrofitted to hold more crops.

7.0 Solution Development

7.1 Idea generation

Having concluded the necessary research in regards to technologies available, as well as the environment and while taking into consideration the specific constraints that have been defined based on this, as well as the initial project constraints, we can begin the ideation process for our solution.

The solution development phase will cover the main methods used when developing ideas, as well as the thought process alignment of decision making throughout, arriving at the final prototype.

7.1.1Mind mapping

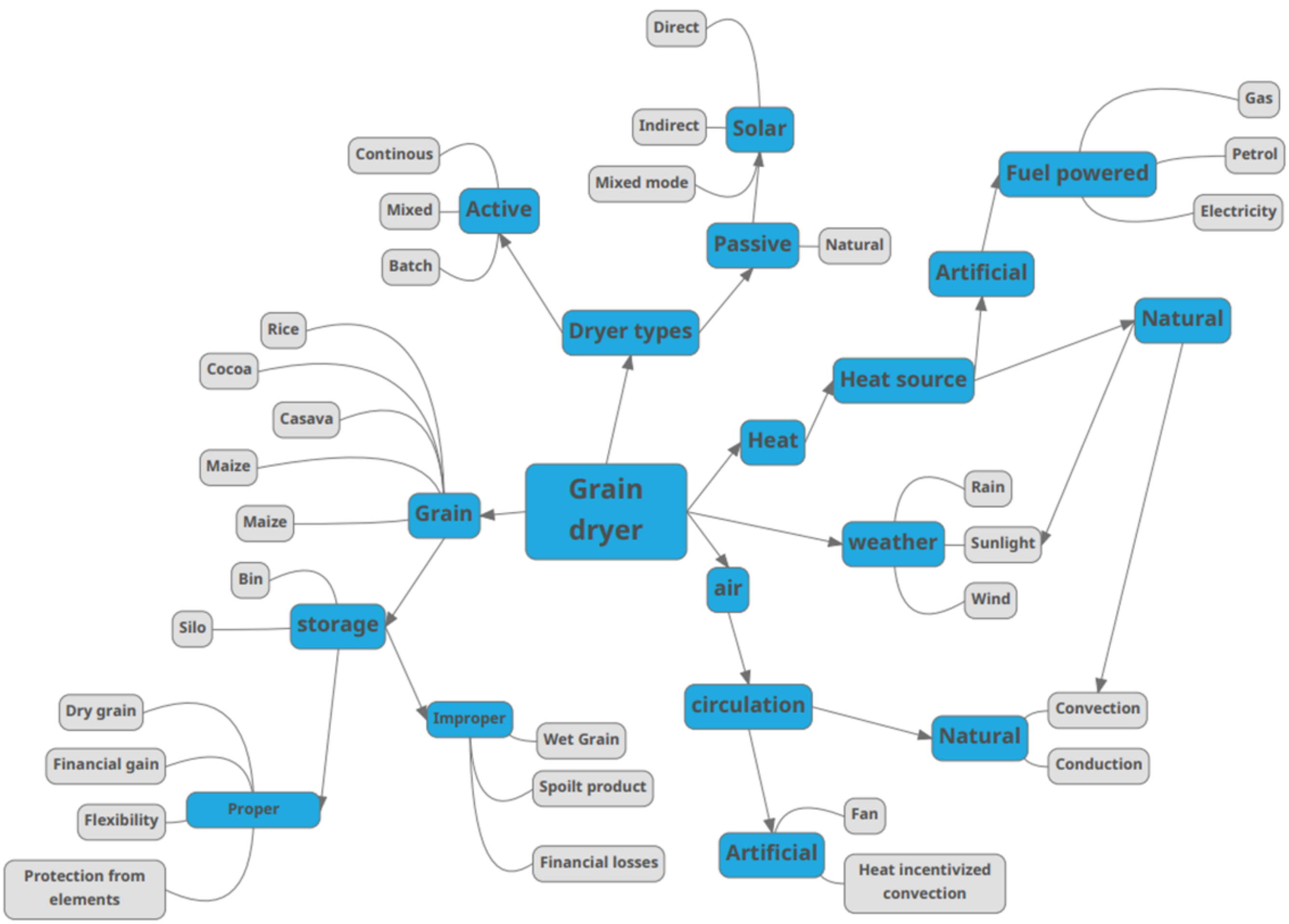


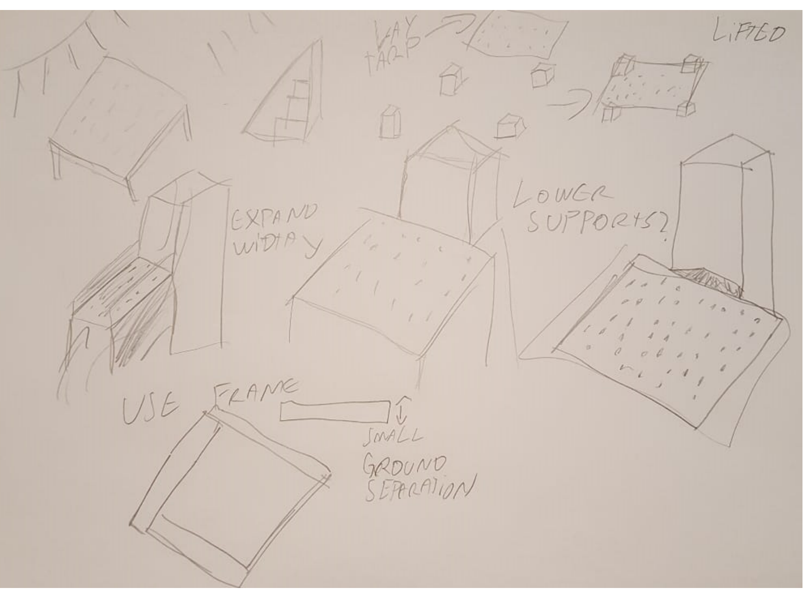
Figure 21. Developed mind map for grain dryers

Mind mapping was the first step of the ideation phase, this was to deconstruct the notion of a grain dryer and uncover possible connections that might not be immediately apparent. Mind mapping is very valuable when trying to deconstruct the makeup of a product and understanding individual components as well as interactions between them.

The mindmap which was constructed would prove to be a valuable addition to the ideation process, as It would be referred to frequently in the sketching portion of idea development.

7.1.2 Sketch Storming

Sketch storming was initially carried out with a specific focus on sketching a variety of possible solutions and ideas surrounding the development of these. However, as ideas began developing the sketching ideation became more specific in regards to particular details and these details were explored in further sketches. It is important to note that the mind map generated previously played a key role in organizing ideas to be translated into sketches, since the visual representation of component interaction helped organize the idea development process. Below are a couple of key examples from this stage; however the bulk of these will be attached in the appendix.



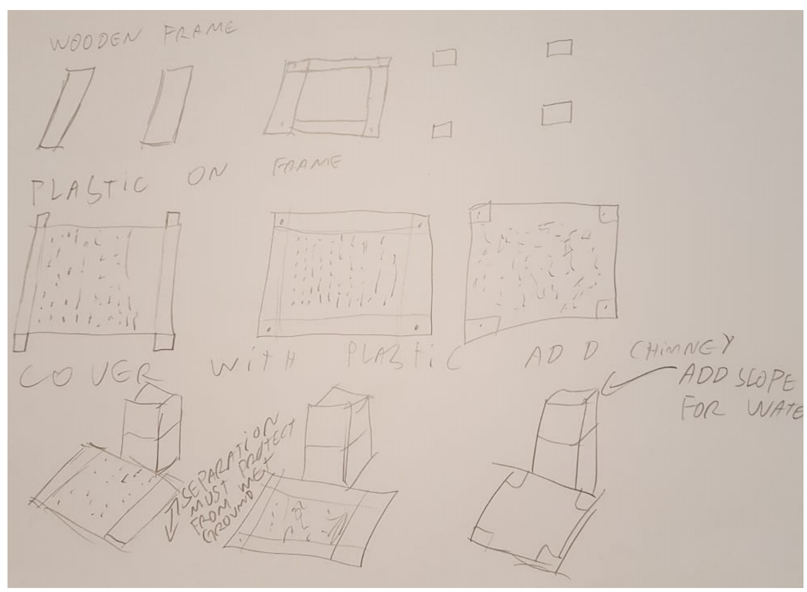


Figure 22 and 23. Sketches developed during sketstorming

7.2 Conclusion of idea generation

Ideation was deemed to be concluded once the framework of the desired solution had been established to a degree that encompassed its main functionalities, as well as it's form; this idea would then later be developed into technical drawings, where the design could be further refined and optimized. Below is the final ideation sketch, selected to be the driving force behind the proposed solution.

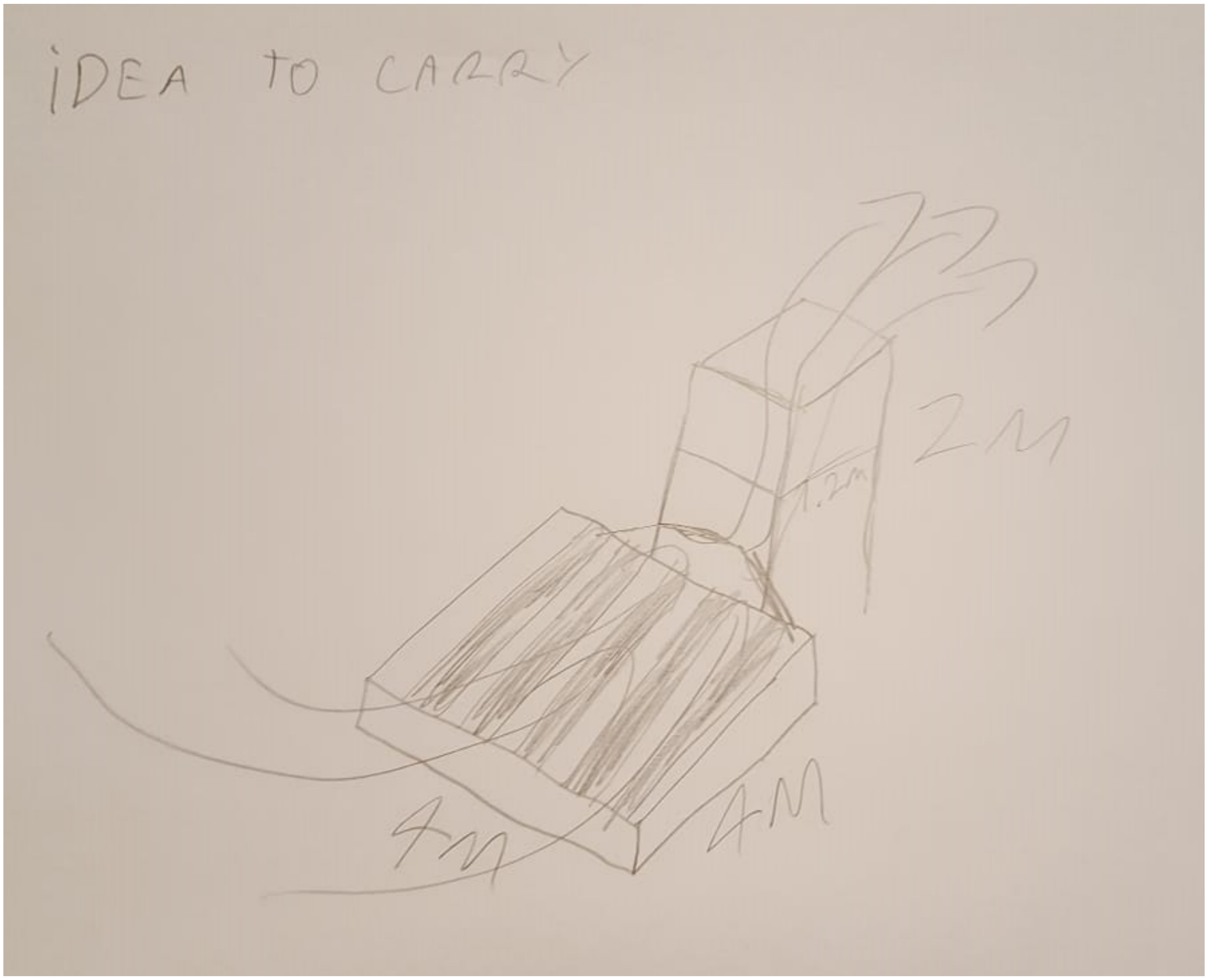


Figure 24. Final concept rough sketch

7.3 Idea refinement

7.3.1 Technical drawing

Once the idea had been refined to the point where it was possible to develop a technical drawing outlining key features of the device, this was the natural step in the product development progression. Technical drawings would serve to expand understanding of the developed solution, as well as present the solution's key features in a manner which allows for a digital prototype to be constructed and further improved upon.

Below is the developed technical drawing for the first iteration of the solution:

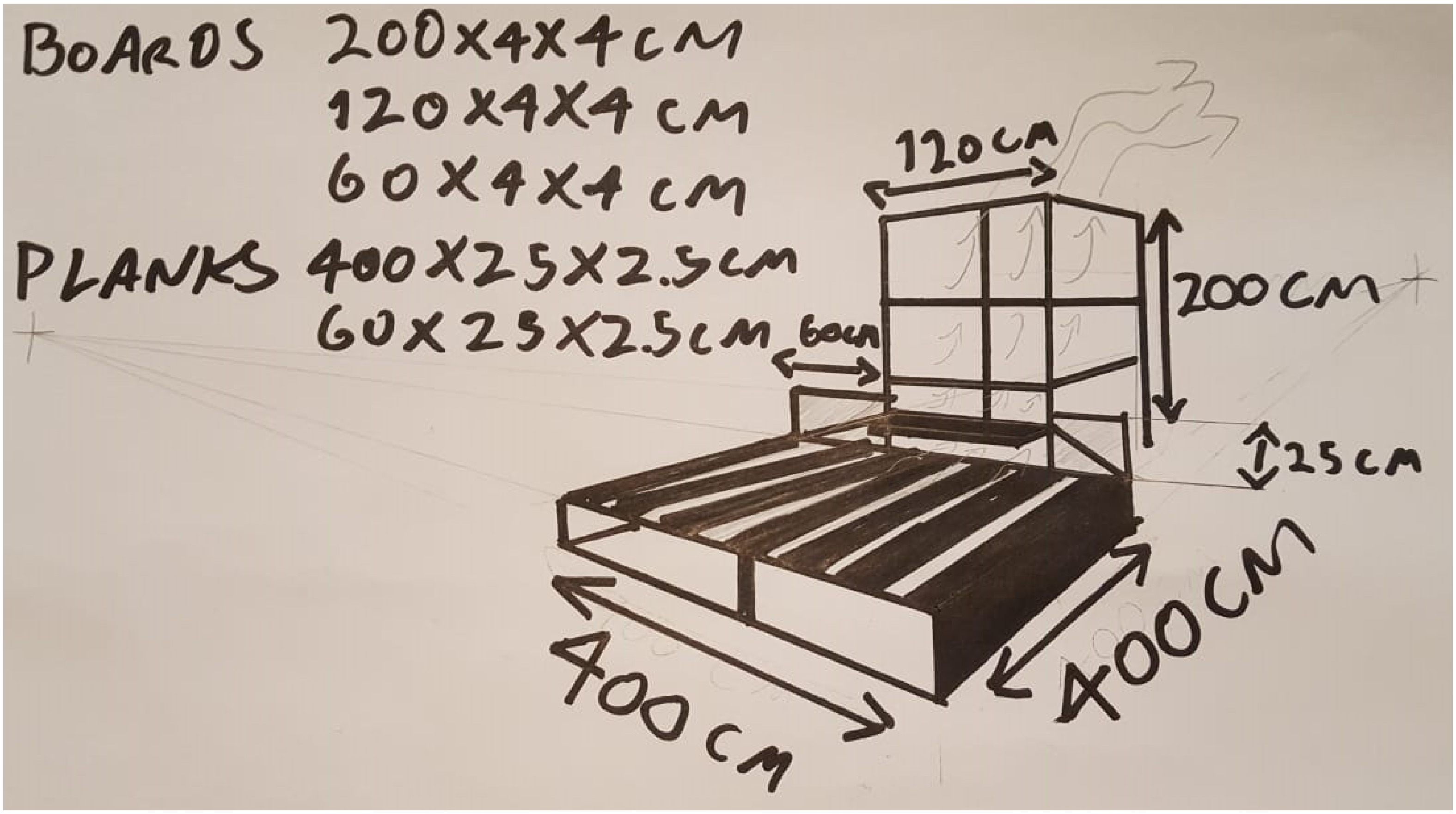


Figure 25. Technical drawing of initial solution

7.4 Digital prototype design

7.4.1 First digital prototype

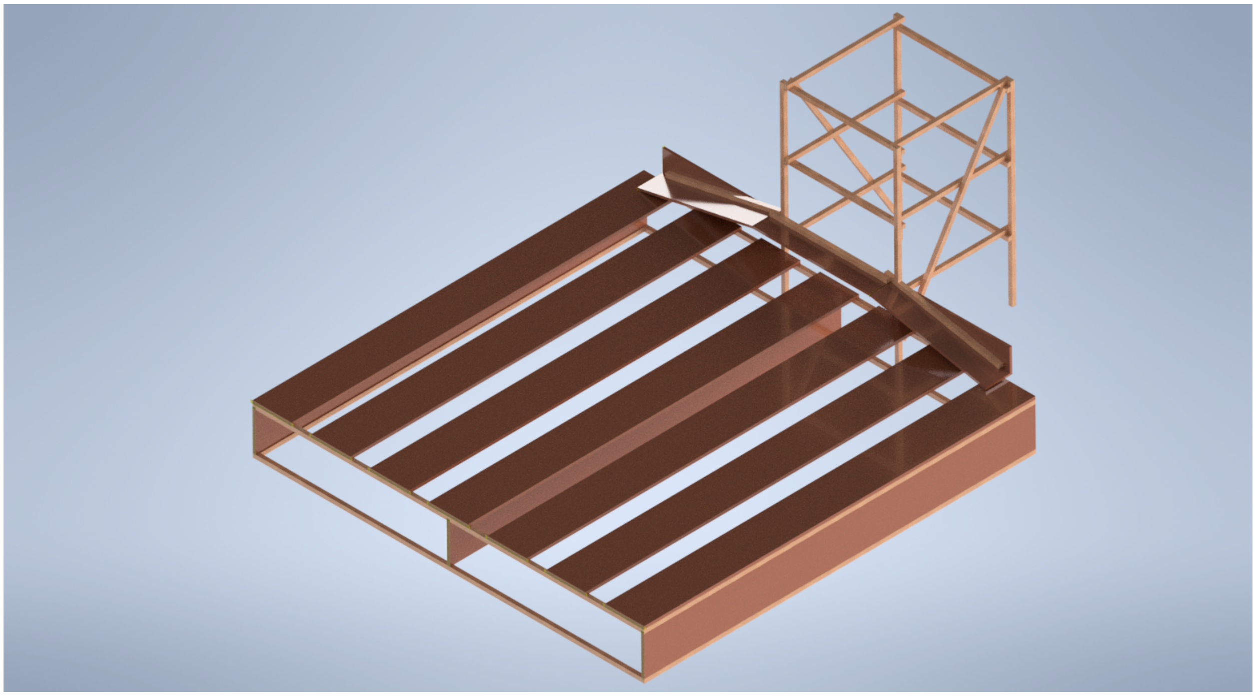


Figure 26. First digital prototype

With the specifications that were previously defined in the technical drawing, construction of the first digital prototype began, the main purpose this digital design sought to achieve was to serve as a demonstrative of the key concepts which would be part of the final solution. This was because it was contemplated that a representative from IUG would give feedback on this prototype, in order to guide possible optimizations in later iterations. Furthermore, this prototype would also be screened with our field expert Alfred Mbayoh.

7.4.2 Second iteration of design prototype

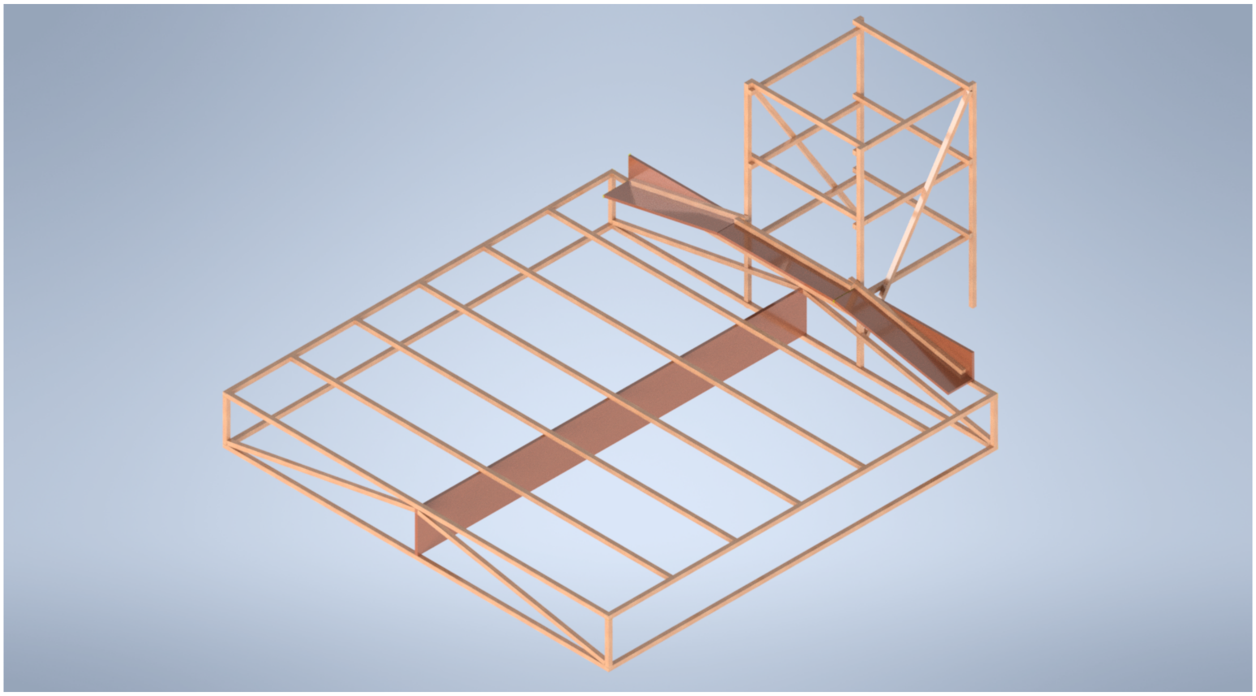


Figure 27. Second digital prototype

The second iteration focused greatly on improving the main issue that the first prototype had and this was excess material use. The base had not been optimized as the prototype was only meant to be an outline of the key design characteristics of the solution. This iteration focused entirely on diminishing material use in the base.

This iteration was successful in reducing the amount of material used, by replacing major structural components with smaller ones. However, concerns arose based on the user's ability to properly distribute grain over a surface so large, as they would be unable to reach the center of the base without stepping on the structure itself or in between its beams. It became apparent that the base had to be reduced in size in order to allow the user to properly utilize it.

7.4.3 Third iteration of design prototype

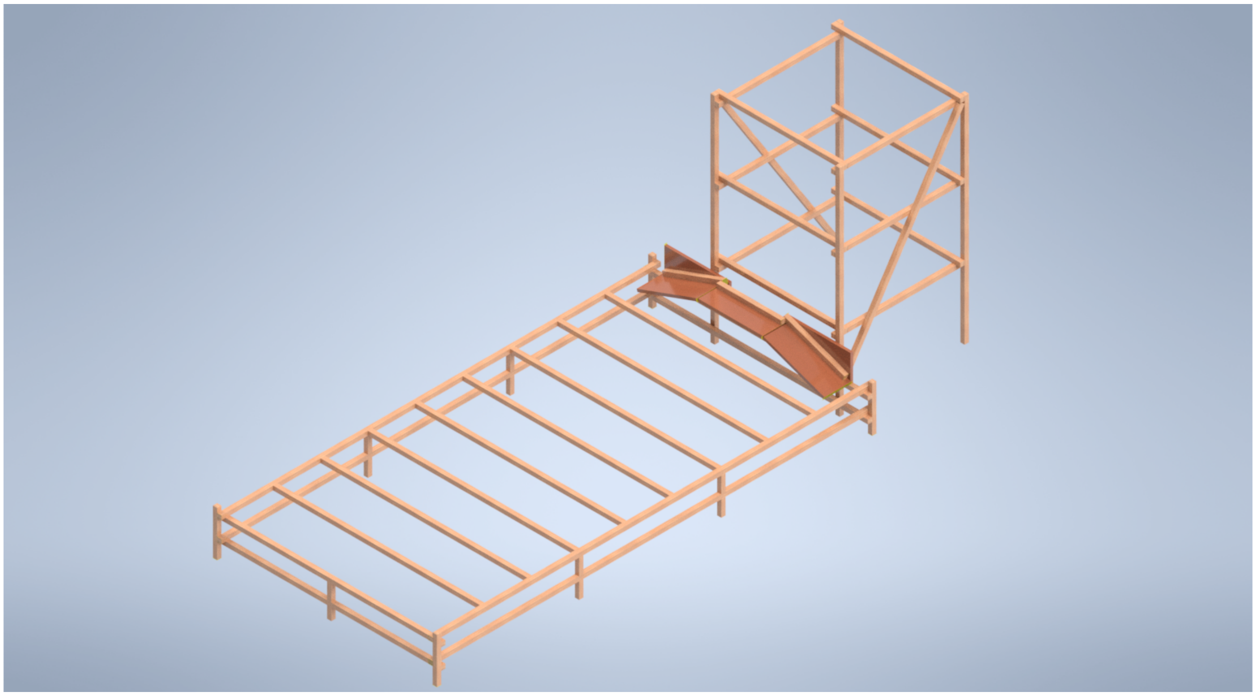


Figure 28. Third digital prototype

A reduction in size to the base meant a reduction in size to the air outlet chimney. It is important to note, that during the optimization of the base reduction heavy inspiration was drawn from IKEA's ease of assembly styled structures.

7.4.4 Fourth iteration of design prototype

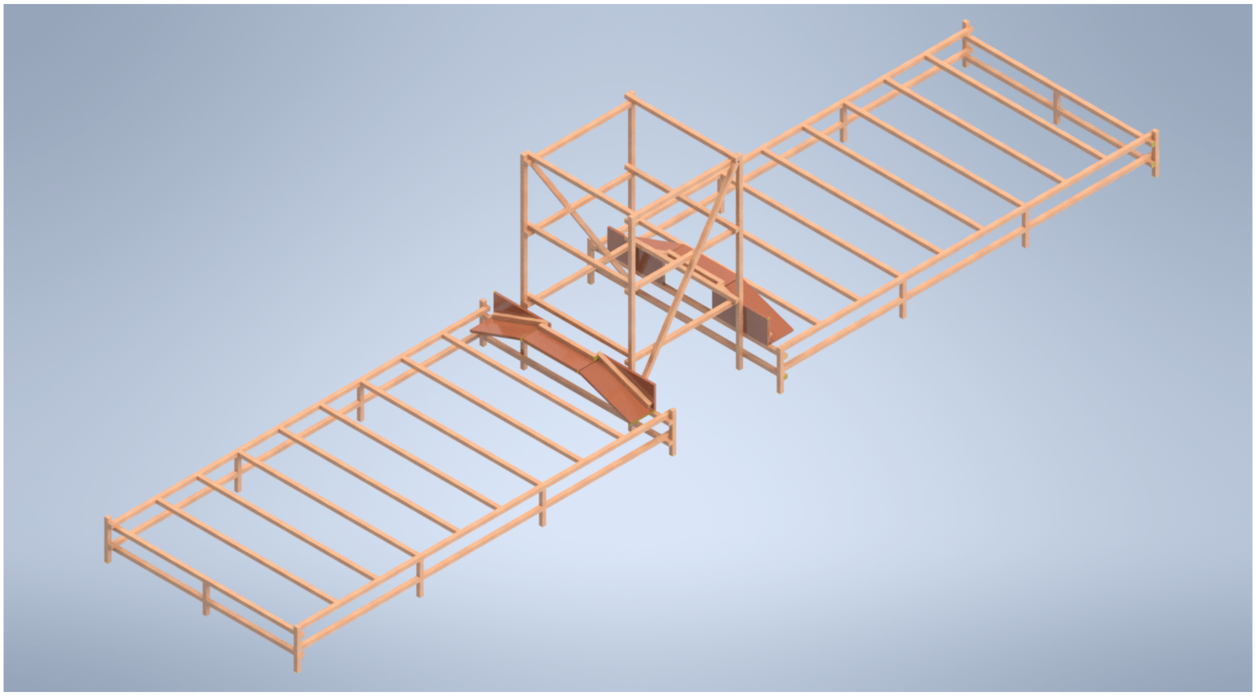


Figure 29. Fourth digital prototype

Considerations had to be made in regards to the chimney, since the current size was providing twice the required airflow for the drying surface area. However, this presented the perfect opportunity for a modular design in which a second drying bed can be attached to the chimney in a fashion which would not impede the user from spreading grain appropriately.

At this point in the digital design phase, the solar powered grain dryer was almost completed to a degree where a physical prototype could be assembled, however certain improvements were made based upon review by comments by Dorte Lindegaard Madsen (IUG Secretary general), as well as our field expert.

7.4.5 Fifth and final iteration of design prototype

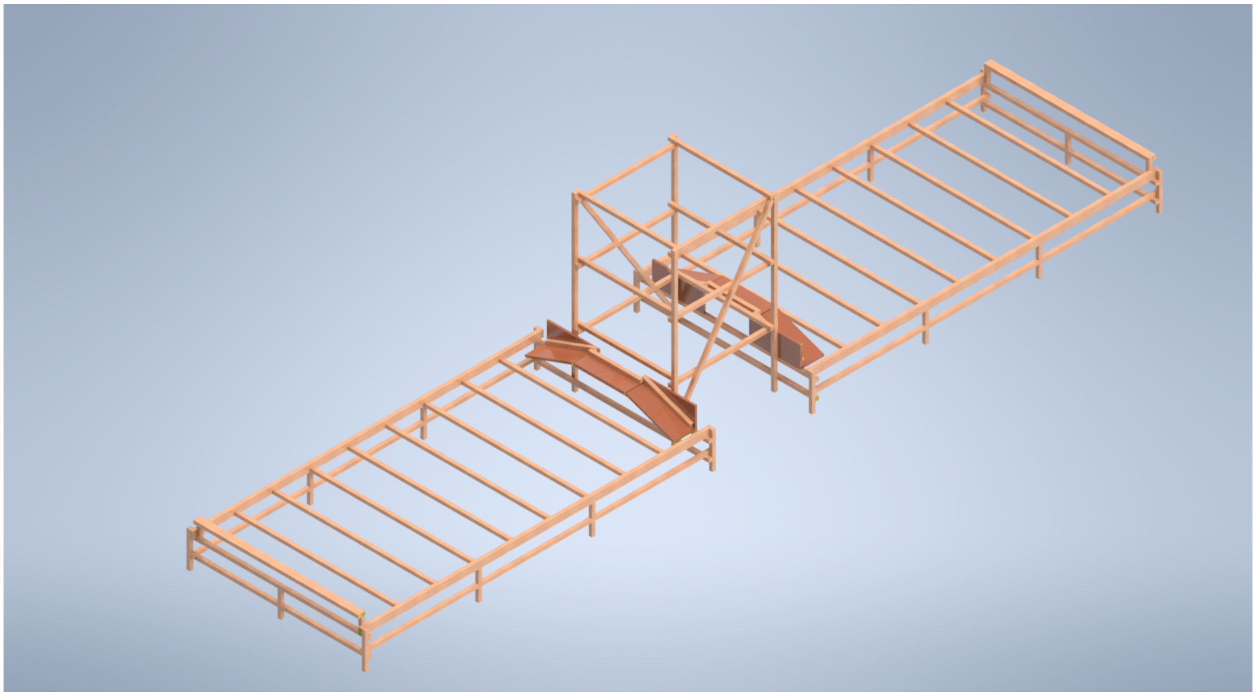


Figure 30. Final digital prototype

The final iteration of the design was very similar to the fourth, except for a couple of key differences. The first of which is the addition of a wooden frame at the end of each drying platform; this was added to ensure airflow stability, as well as protect against the possibility of rain entering the grain drying platform.

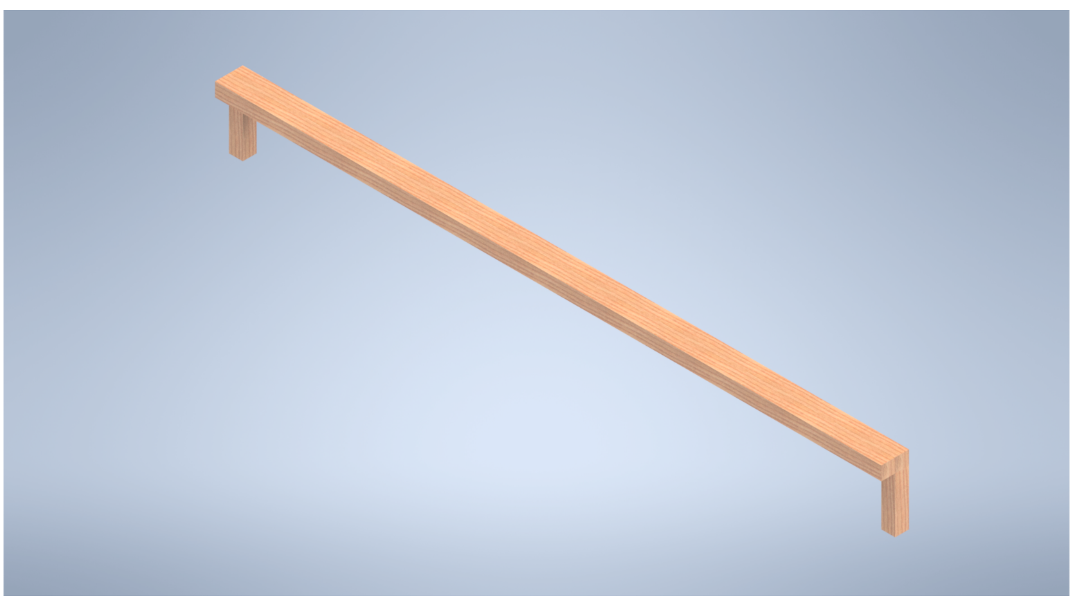


Figure 31. Separator attachment

The second improvement is the addition of a "rail" on each side of the drying platform; this is to prevent grain from rolling off the sides of the drying platform.

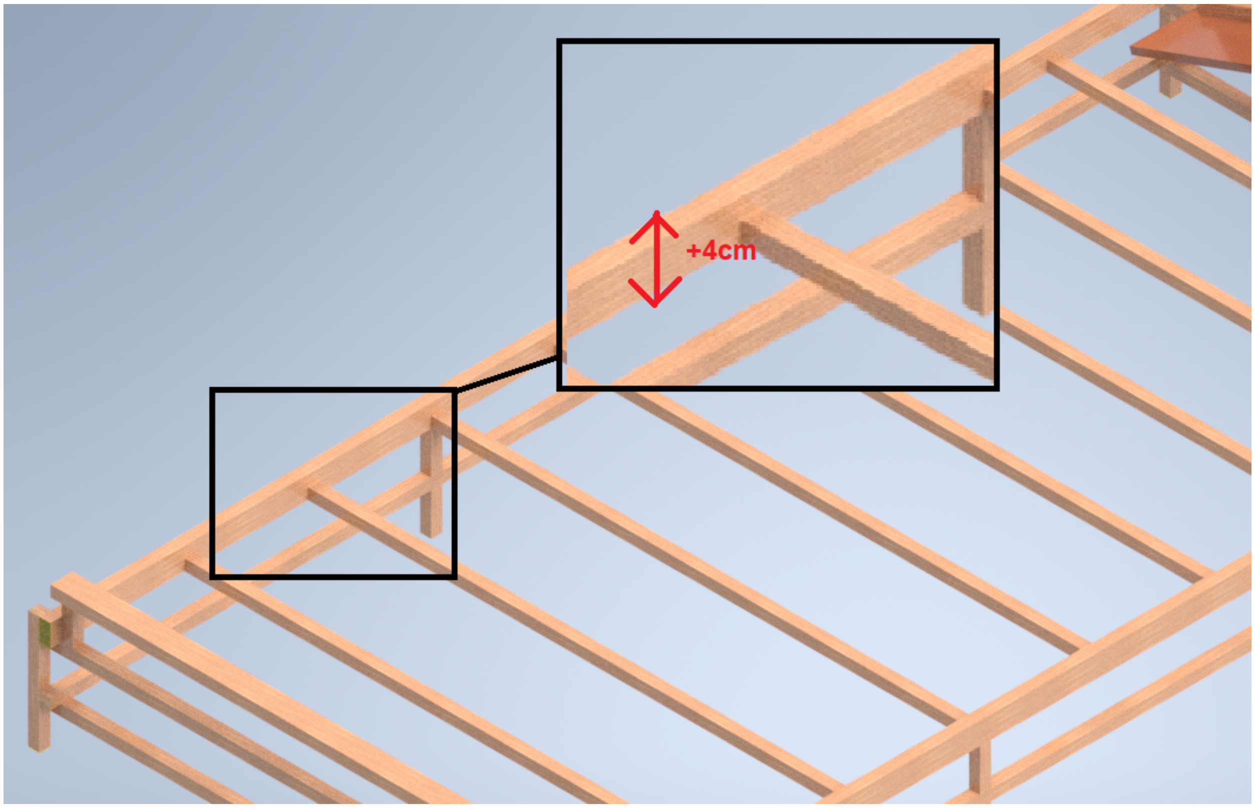


Figure 32. Edge increase

7.5 Material selection

Although it was clear from the research and previous developments that wood was the strongest contender for material selected, a search was carried out in Granta Edupack, in regards to material alternatives. Materials were selected from within the natural material alternatives, and plotted in a cost v/s yield strength table.

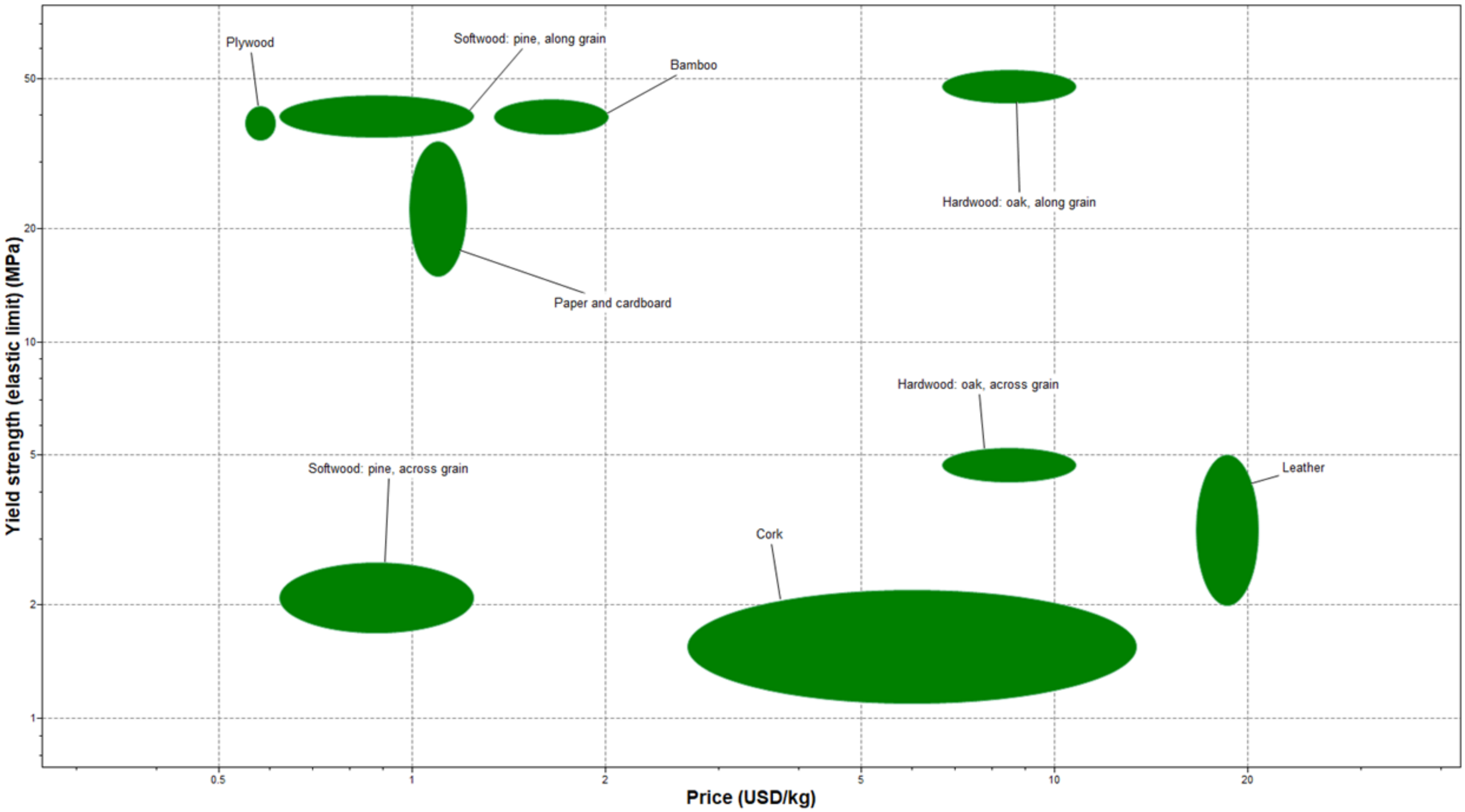


Figure 33. Ces Search result

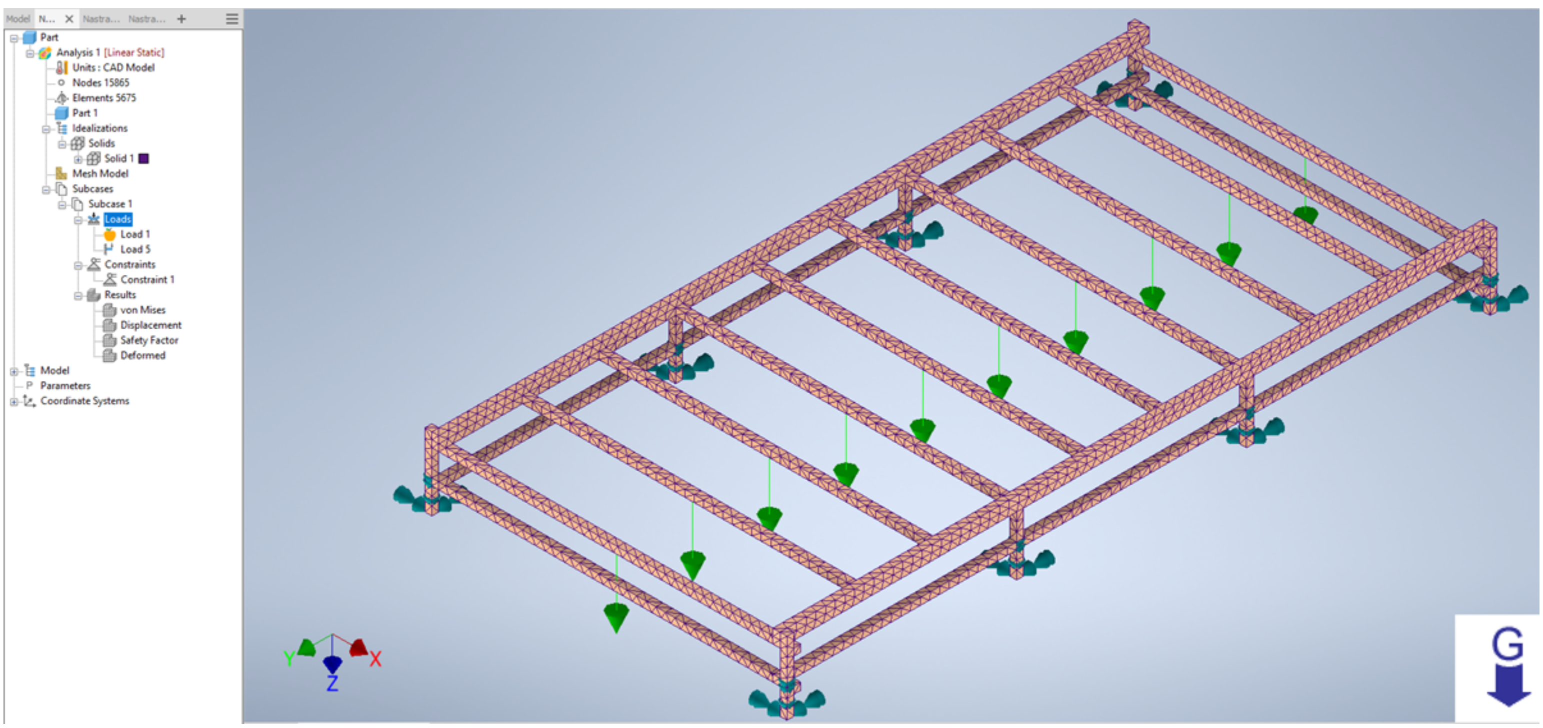
Immediately plywood stood out as a candidate, along with softwood pine, along its grain, as they offered high yield strength at a low cost. It is important to note the mechanical properties of both, when considering the decision, as well as their particular mechanical properties (attached in appendix A.2, A.3)

In this regard, they are fairly similar, pine being slightly superior in all aspects. We can determine that they are both viable options and decisions will be made on local supplier availability.

7.6 Structural validation of base

Due to the load-bearing nature of the base, it was necessary to assess its structural integrity. To do this, the Nastran environment within Inventor was utilized. It was mentioned by our expert that a normal weight load for a season's harvest of grain in rural areas would be around 400 kg. We will use double this weight, to simulate for a situation in which the system is loaded improperly, as if it was able to withstand this weight, we could be sure it would be able to satisfy the users need. (It is worth noting that since one unit has two drying beds, the capacity is double the weight being assessed, since drying beds are assessed individually, as they are their own structure). For the purpose of analysis, we will assume the grain load to be uniformly distributed and to add leniency in regards to construction materials, we will use material properties of plywood, which was the weaker of our viable selections.

Figure 34. Simulation environment



7.6.1 Results

Displacement

In regards to displacement we can see that we are within normal recommended construction ranges (Length/360) for the wooden boards. As the maximum allowable displacement for our board is 5.5mm and the maximum deflection at two times the design load is 1.92mm. This suggests that the design might actually be too solid and further materials could be shaved off, while still maintaining a safety margin; this is important to keep in mind when developing a physical prototype.

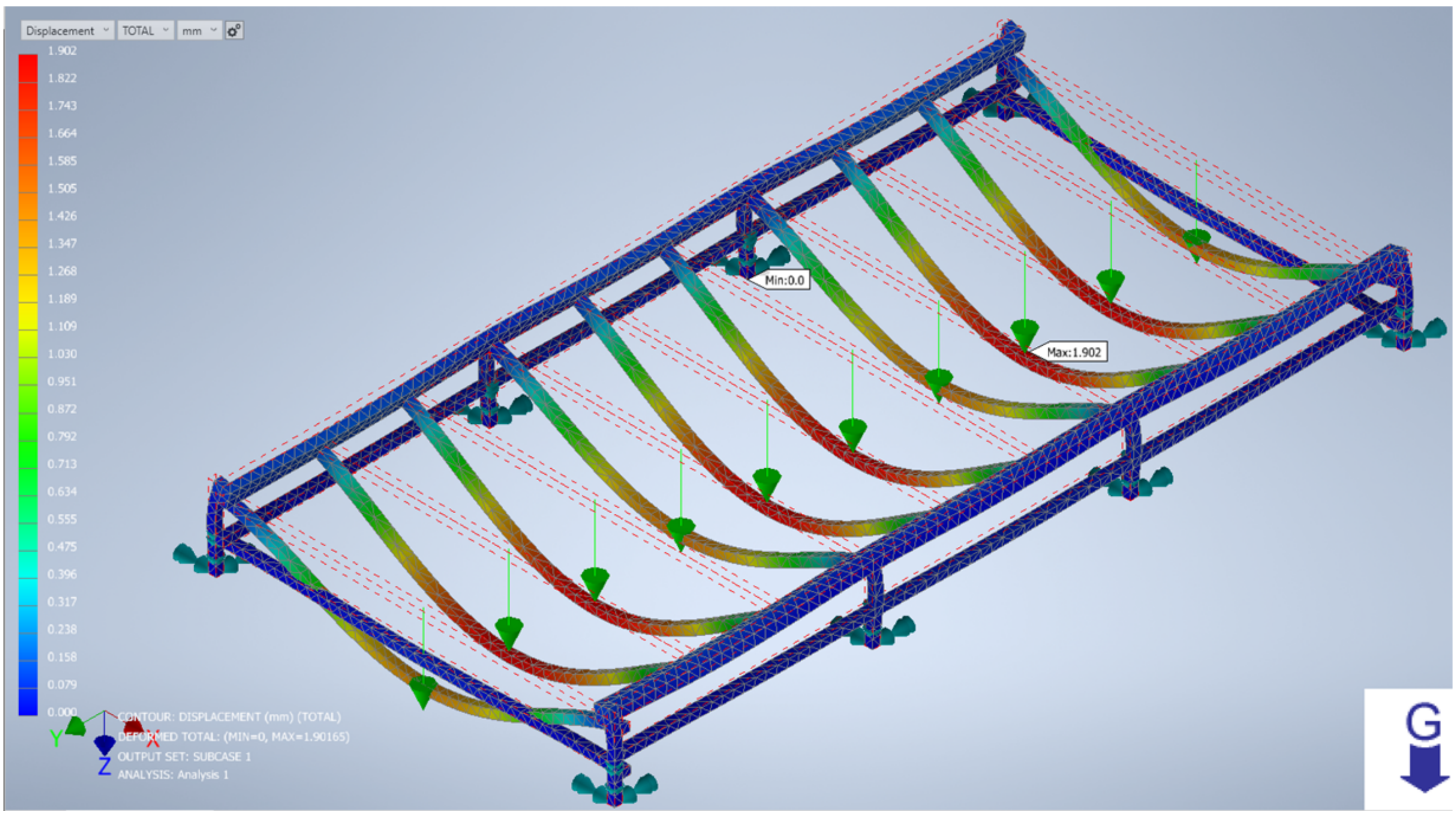


Figure 35. Displacement simulation results

Stress

As was the case with displacement, stress is within the acceptable parameters for plywood and further validated the conclusion that the structure could perhaps lose material weight for the purpose of price optimization.

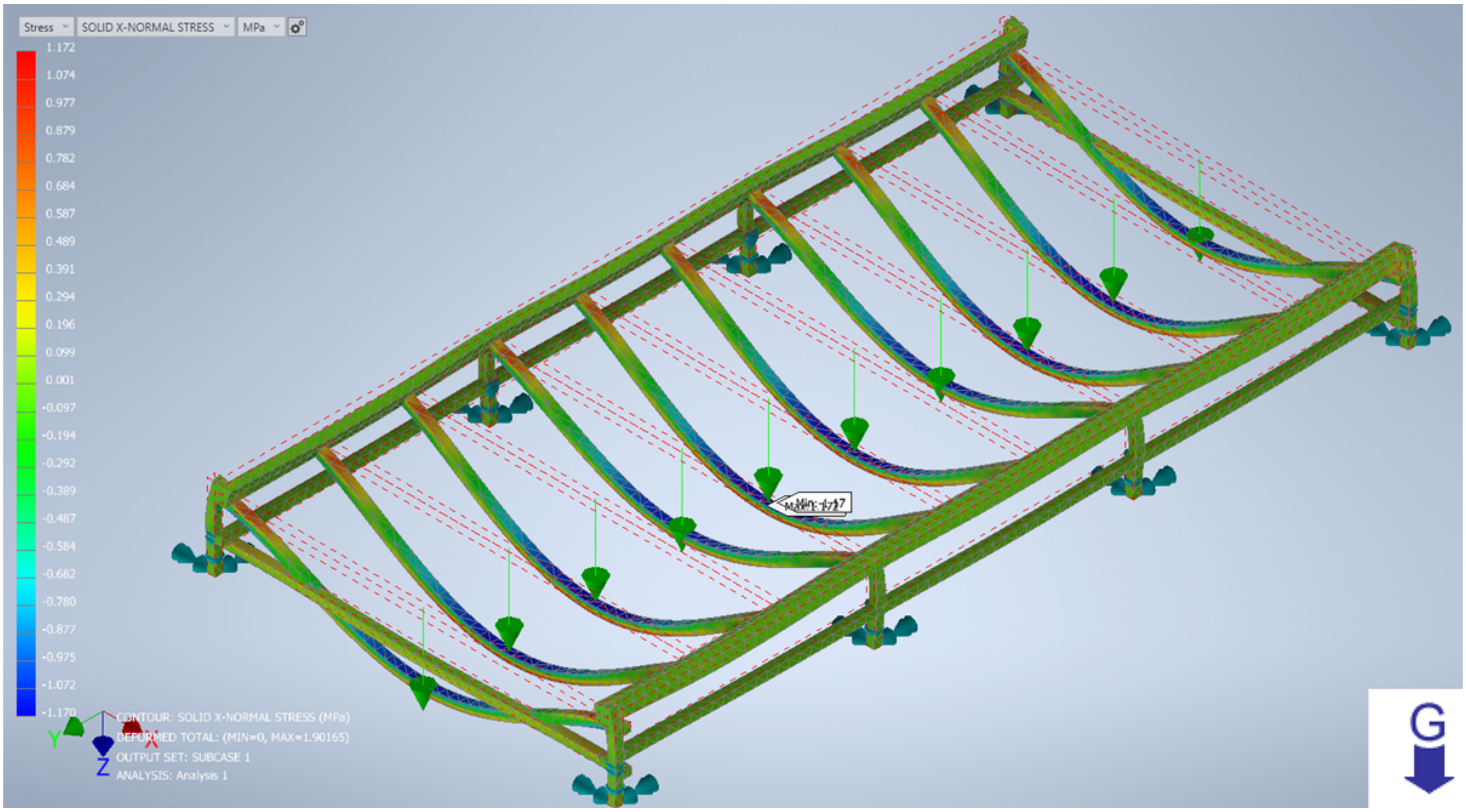


Figure 36. Stress simulation results

7.6.2 Conclusion

We can conclude the drying bed can effectively hold almost twice the load that it is designed for and therefore it is validated from a structural perspective. However, when physical prototyping begins, this information will shape the process, as certain structural components can be shaved off, further reducing costs.

8.0 Solution breakdown

8.1 Proposed solution

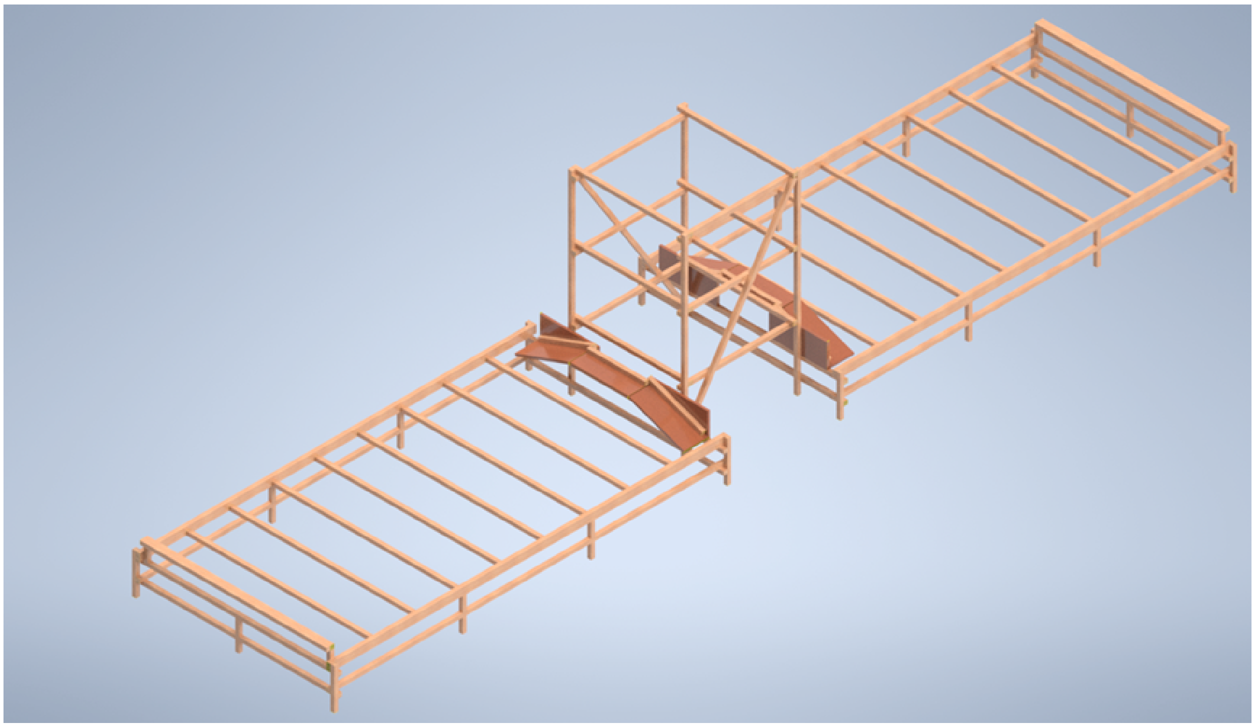


Figure 37. Proposed solution

The proposed solution is a solar powered grain dryer, which will utilize air convection principles in order to generate airflow in the membrane between two plastic sheets which contains the grain. The functioning principles are better explained with visual aid (Note: For explanation of governing principles, a single drying bed model will be used).

8.2 Proposed solution explanation

A plastic sheet which is dark in coloration, usually dark blue, dark green or black (Exactly the kind which is currently used in Sierra Leone) is placed on the drying bed and secured via metal grommets.

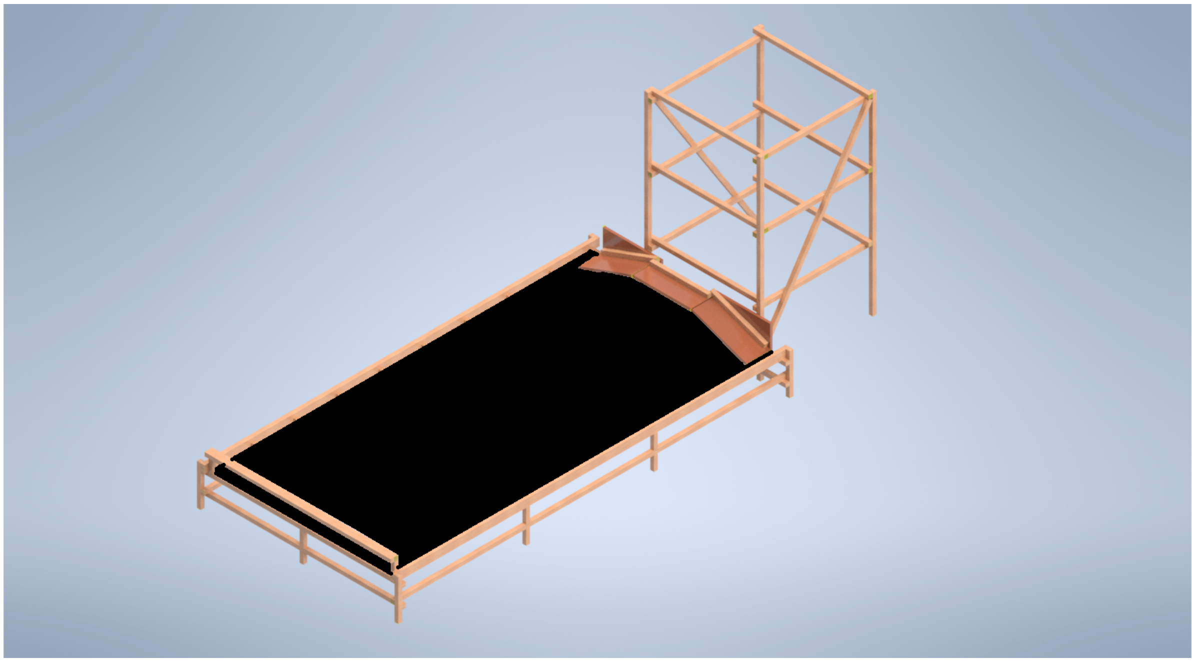
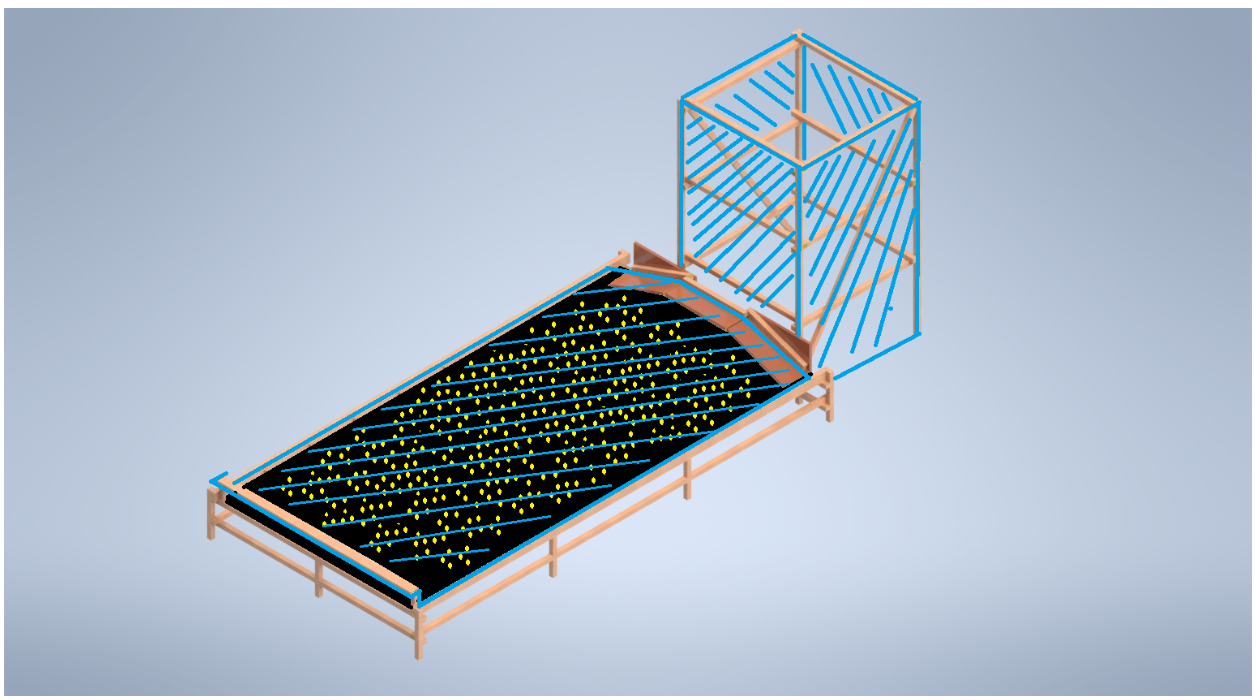


Figure 38. Dark plastic sheet on dryer

The grain is then placed on the dark plastic bed and covered with a transparent plastic film, making sure it is attached properly via metal grommets on both ends and that it is mounted on top of the chimney attachment. The chimney must also be covered in transparent plastic, with the exclusion of the top.For display purposes, transparent plastic will be represented as a light blue hatched region.

Figure 39. Transparent plastic film and grain



Due to the layout and construction, an air pocket will be formed in between both plastic membranes and due to the fact that the dark plastic is absorbing solar radiation in the form of heat, the air contained within this pocket will begin to warm up.

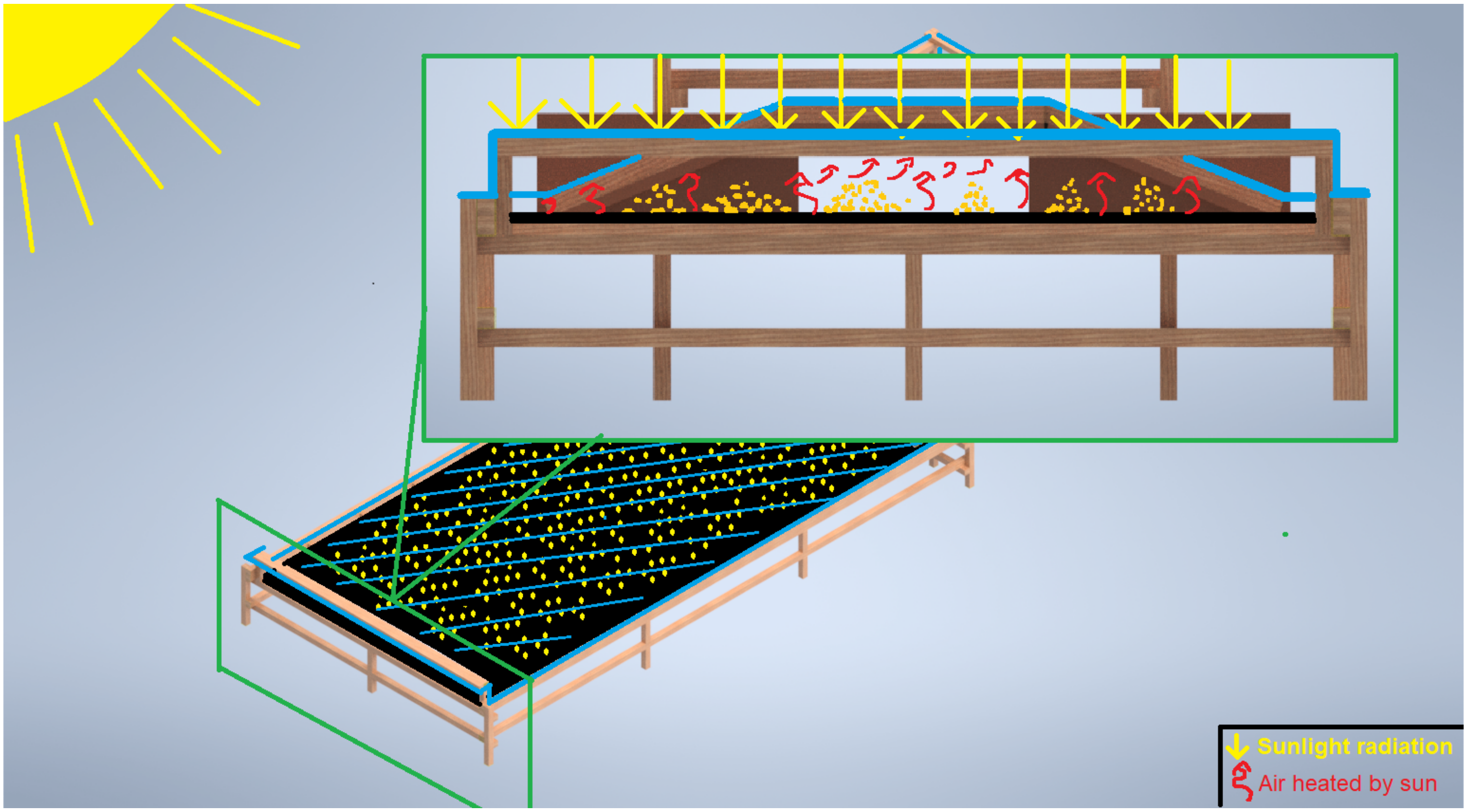


Figure 40. Heated air pocket

Once the air inside the chamber warms up, it will begin to attempt to rise, as warm air does, this will lead it to exit through the chimney and create negative pressure inside the air pocket, which will in turn suck in fresh air from the environment and repeat the cycle.

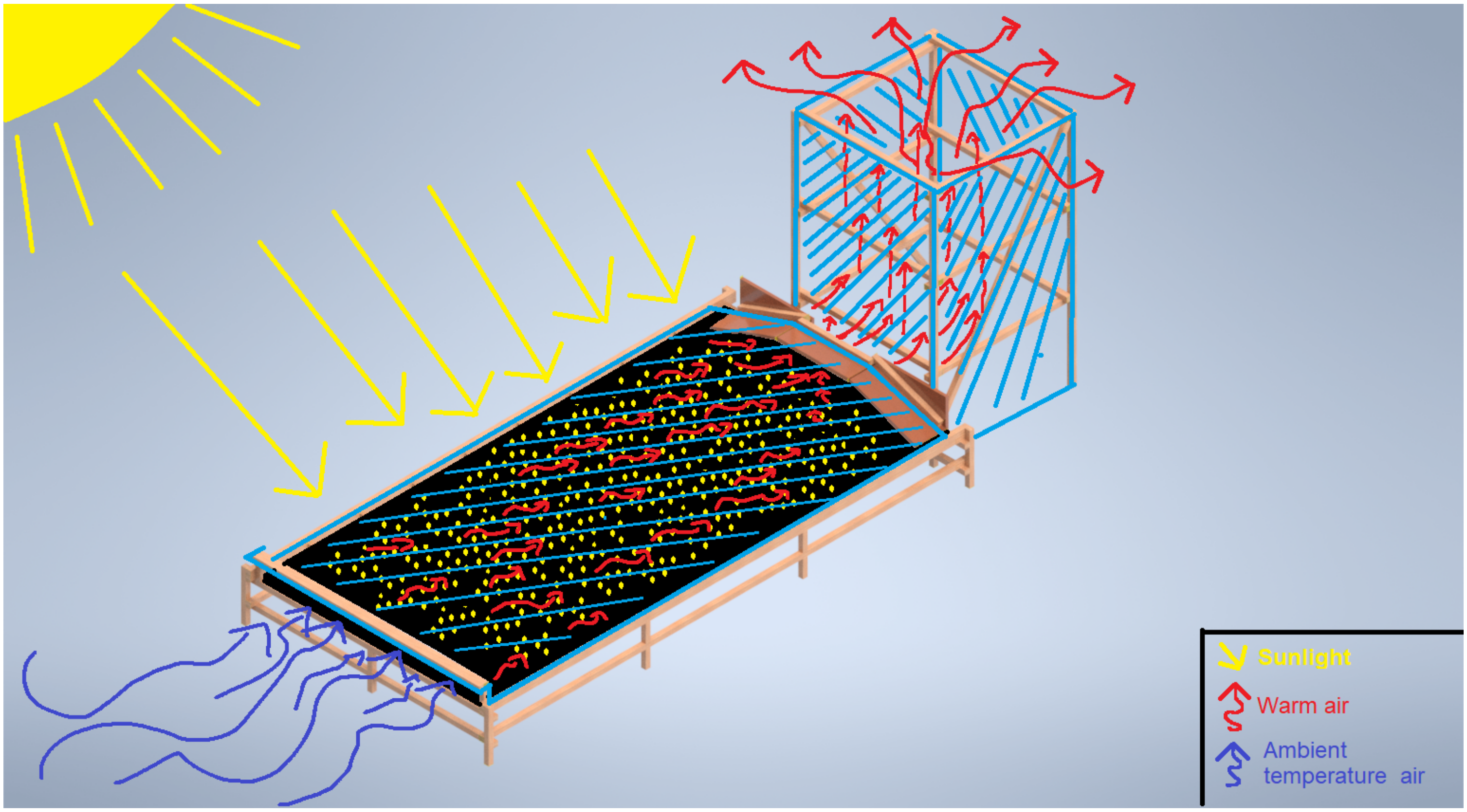


Figure 41. Conveccion of currents in dryer

The principles that govern the functionality of this design are tried and tested, in particular the chimney-styled solar grain dryer design has proven to be amongst the most reliable low-cost principles that can be relied upon for great improvement in the drying process.

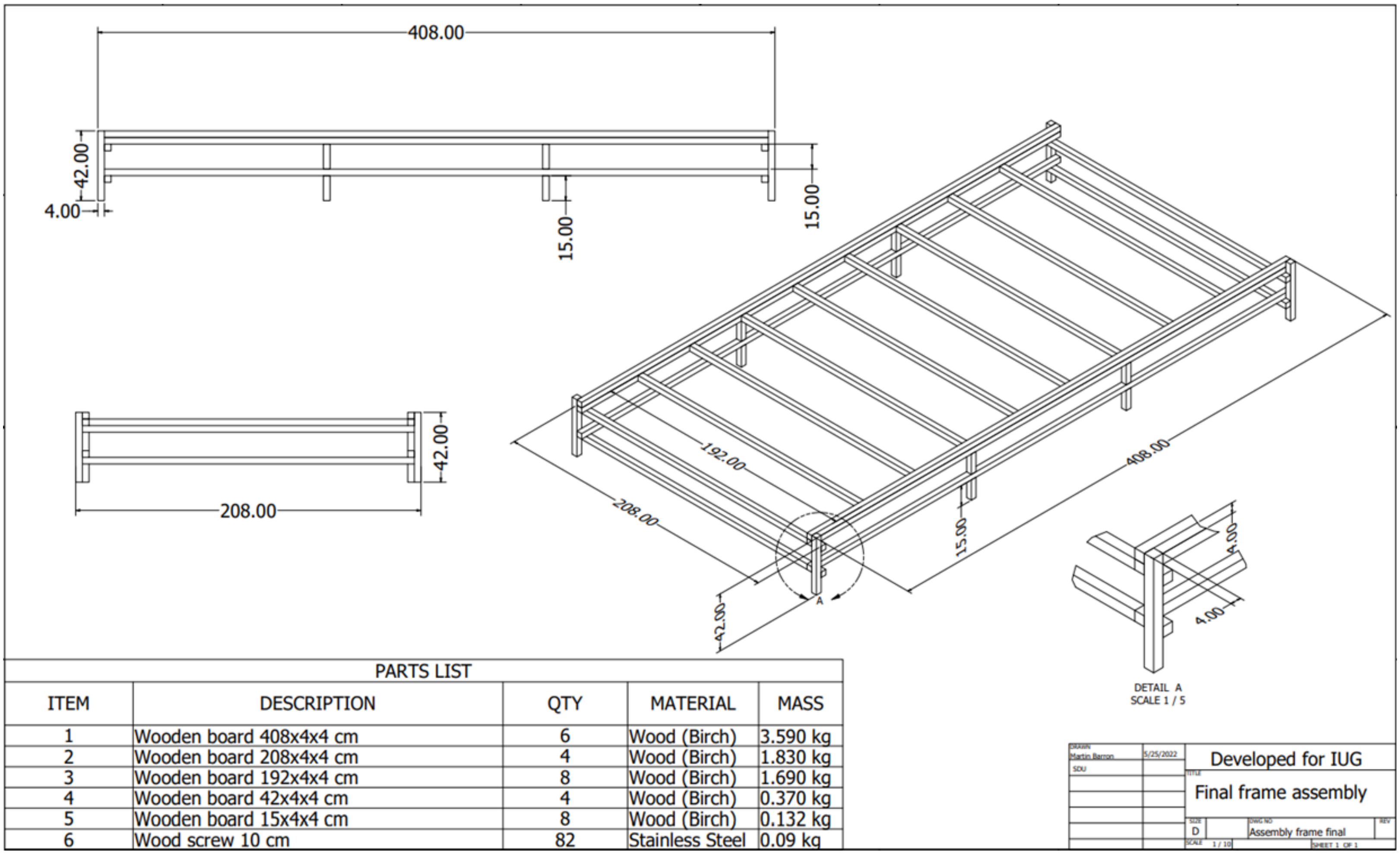
8.3 Design components and assembly

The design has been oriented around ease of assembly, in order to allow local workforce to replicate it, if they had a desire to. To this end, the assembly is broken down into 4 main components.

8.3.1 Drying bed

The drying bed is the raised structure which will serve as the base which the grain will lay upon. In theory this part is not required to construct a solar dryer and we will explore this idea within the alternative design section. However, due to the nature of our deployment environment, it is paramount in protecting the grain from rainfall.

The construction of the frame was focused on optimization of material use, in order to reduce cost, as well as ease of assembly. Furthermore, given its nature it was important to build a structure which would be able to support the weight of the grain. (Base can be retrofitted with heating element).

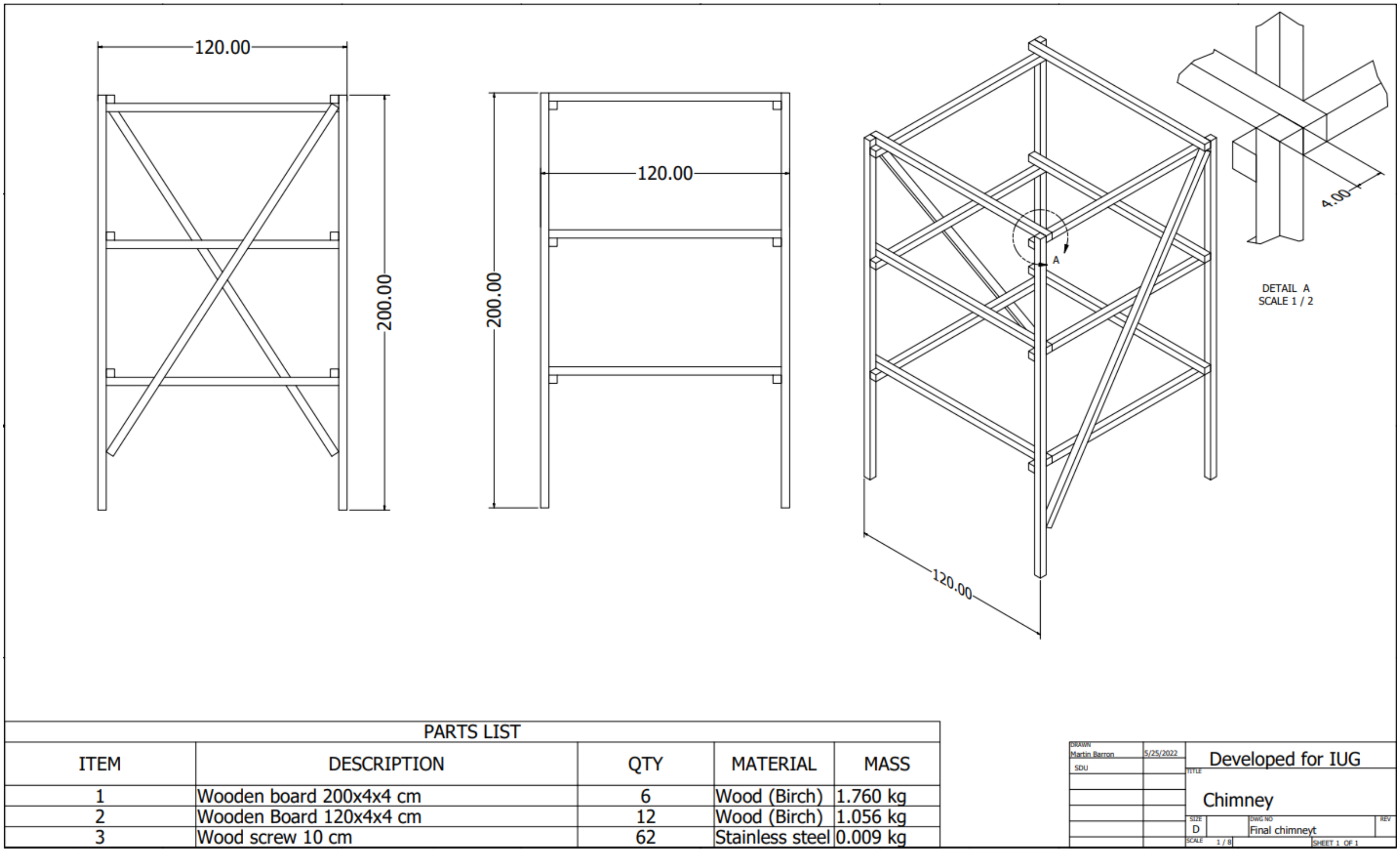


PARTS LIST				
ITEM	DESCRIPTION	QTY	MATERIAL	MASS
1	Wooden board 408x4x4 cm	6	Wood (Birch)	3.590 kg
2	Wooden board 208x4x4 cm	4	Wood (Birch)	1.830 kg
3	Wooden board 192x4x4 cm	8	Wood (Birch)	1.690 kg
4	Wooden board 42x4x4 cm	4	Wood (Birch)	0.370 kg
5	Wooden board 15x4x4 cm	8	Wood (Birch)	0.132 kg
6	Wood screw 10 cm	82	Stainless Steel	0.09 kg

Figure 42. Drying bed Schematics

8.3.2 Chimney

The chimney is what grants the solar dryer its airflow capacity. By enabling warm air to rise and flow out of the air pocket, it creates the needed convection of currents, which results in warm air flow to the grain. The considerations for the development of the chimney were the same as those for the drying bed, with more leniencies on structural capacity, given the fact that it won't be a load-bearing structure. The chimney is capable of having a fan retrofitted to increase drying capacity.



PARTS LIST

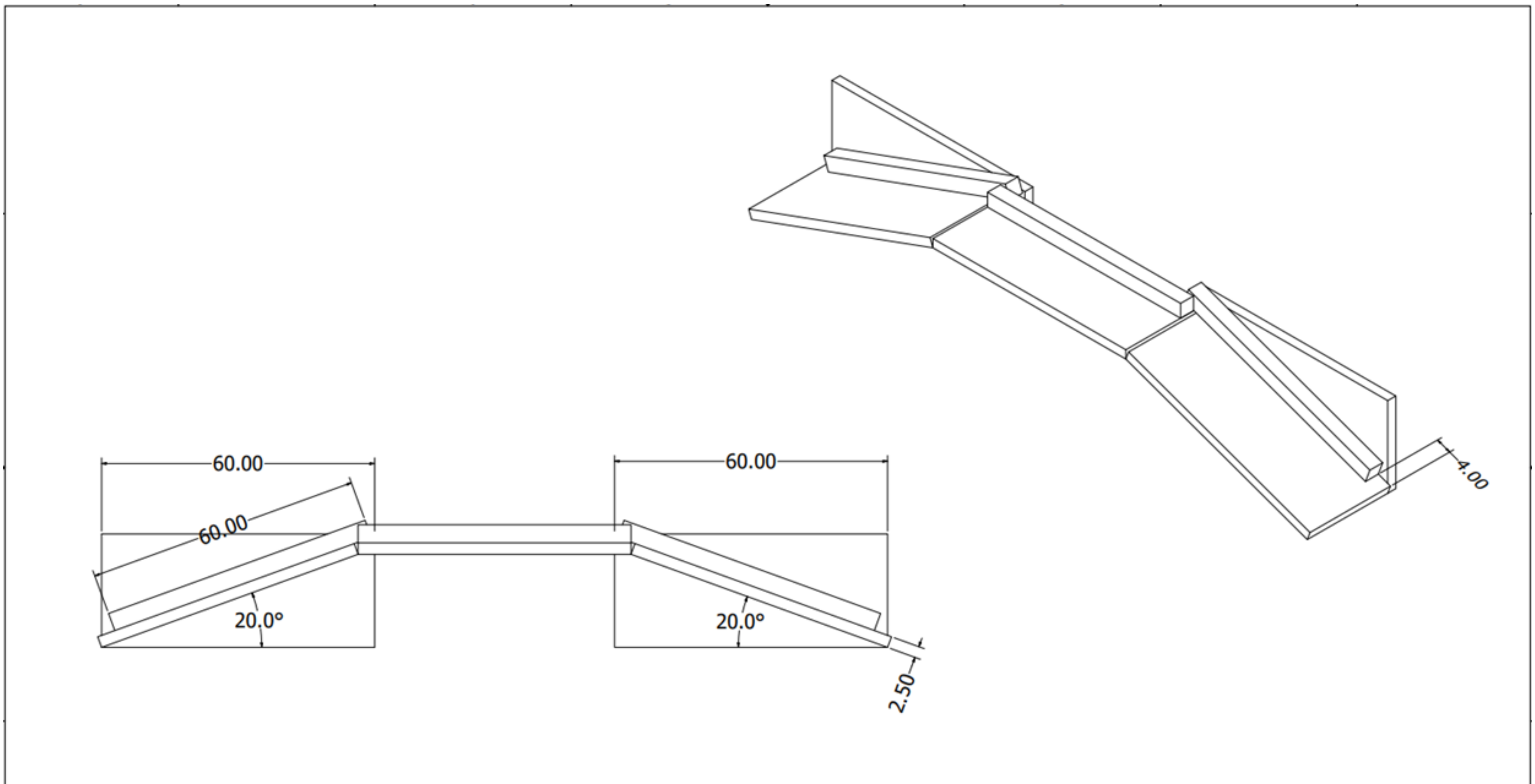
ITEM	DESCRIPTION	QTY	MATERIAL	MASS
1	Wooden board 200x4x4 cm	6	Wood (Birch)	1.760 kg
2	Wooden Board 120x4x4 cm	12	Wood (Birch)	1.056 kg
3	Wood screw 10 cm	62	Stainless steel	0.009 kg

Figure 42. Chimney schematics

8.3.3 Chimney Opening

The chimney opening attachment ensures airflow from the air pocket between the plastic membranes into the chimney. Furthermore, it helps ensure the existence of the air pocket by increasing the separation between plastic membranes. Considerations were the same in regards to material cost and assembly, but as with the chimney structural integrity was not an issue, due to the low strain this component would be under.

It is important to note that the chimney is the only part which does not utilize varying lengths of 4x4cm wood. This means that there is a possibility to optimize the chimney by constructing it with said lengths, as this would enable the entire structure to be assembled with the same type of wooden boards.



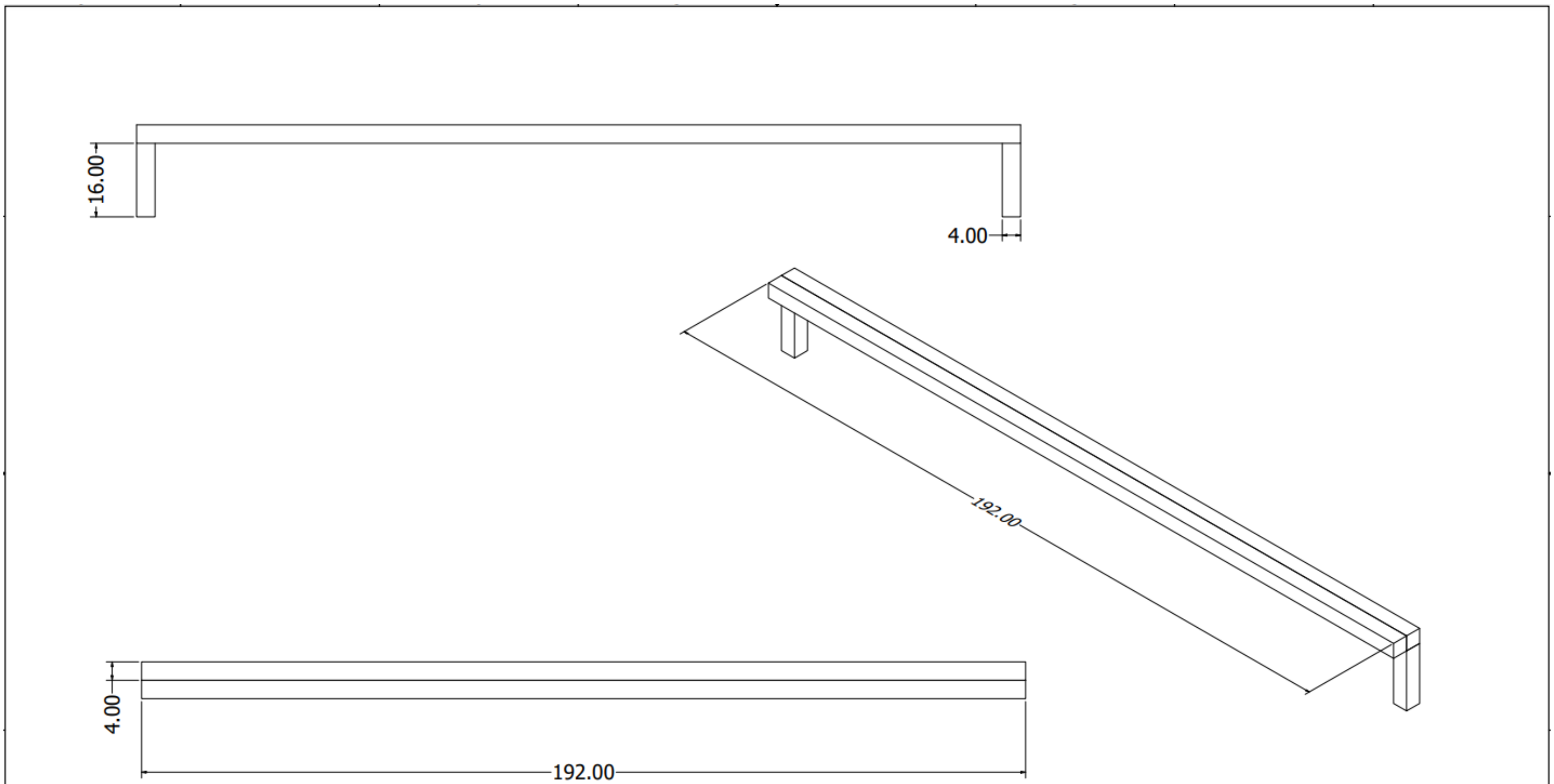
PARTS LIST				
ITEM	DESCRIPTION	QTY	MATERIAL	MASS
1	Wood plank 60x25x2.5 cm	5	Wood (Walnut)	2.063 kg
2	Wood board 60x4x4 cm	3	Wood (Birch)	0.528 kg
3	Wood screw 10 cm	14	Stainless Steel	0.009 kg

Developed for IUG
Chimney opening

Figure 42. Chimney opening schematics

8.3.4 Separator

The separator was added to ensure the plastic cover remains at an adequate distance to maintain the air pocket between the plastic membranes. It also serves to keep the plastic taught, by giving it an anchoring point at the end of the design and ensures rainfall will not enter the drying bed.



PARTS LIST				
ITEM	DESCRIPTION	QTY	MATERIAL	MASS
1	Wooden board 192x4x4 cm	2	Wood (Birch)	1.690 kg
2	Wooden board 16x4x4 cm	2	Wood (Birch)	0.141 kg
3	Wood screw 10 cm	6	Stainless Steel	0.009 kg

Figure 43. Separator schematics

8.4 Alternative designs

The double bed modularity aspect of the design has been touched upon and therefore it will not be considered an alternate design.

We will define alternate design as options which are viable, but were not selected for specific reasons; these will be discussed alongside the alternate designs.

8.4.1 No drying bed alternative

In theory, the system could be assembled in a manner which does not require the construction of the drying bed. This would severely decrease material costs, but it would do so sacrificing some key functionalities. The design would no longer be able to protect from rainfall, or from animals interacting directly with it.

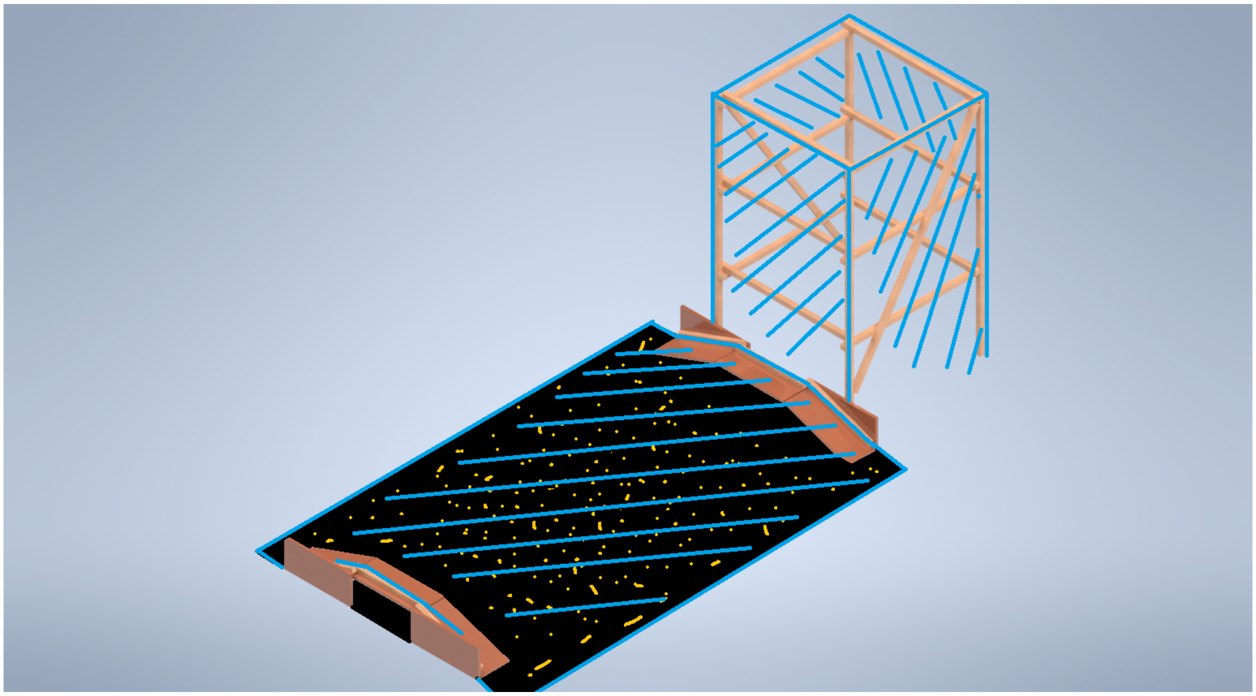


Figure 44. No drying bed unit

This alternative is of particular interest, as it gives a functional dryer design which can be setup even quicker than our presented solution, while being able to be quickly adapted into our solution, via the addition of a dryer bed.

8.4.2 Large unit alternative

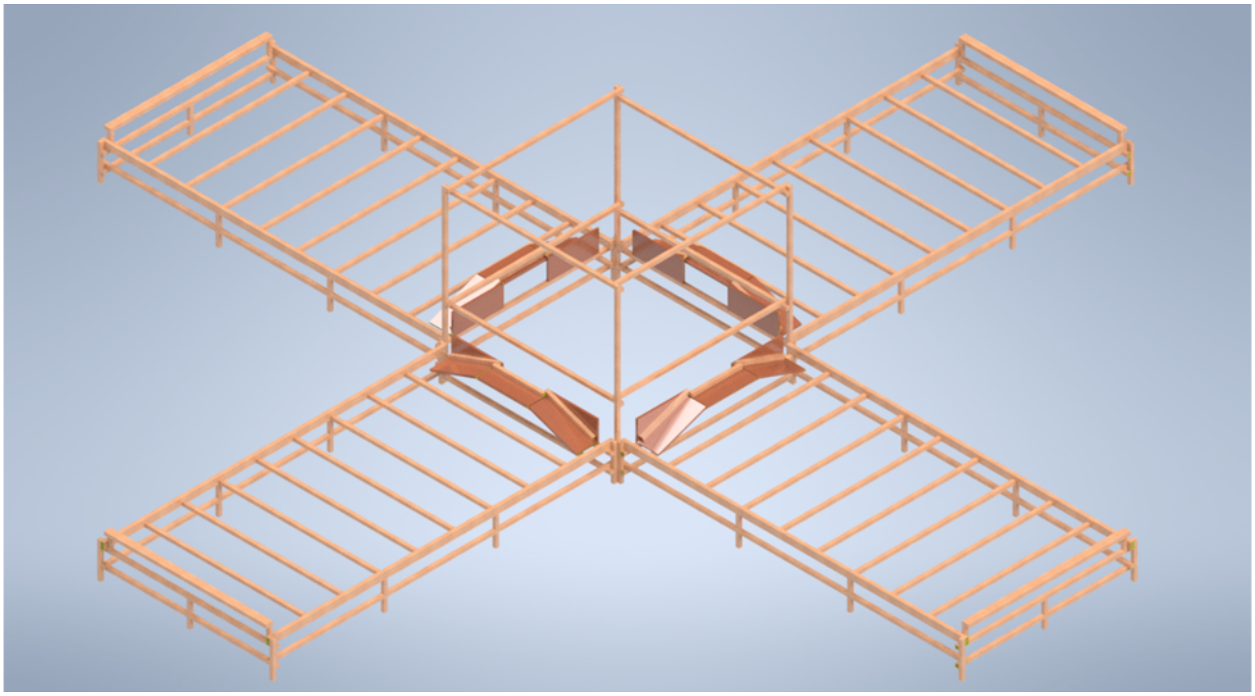


Figure 45. Large unit assembly

The large unit assembly included a larger chimney, with enough surface area for 4 drying beds. This idea, although initially appealing, was not selected due to the inability to place drying setups side by side. Furthermore, financial commitment is greater and if the chimney is developed initially with the thought of adding more units retroactively, there is the threat of units not being added and the chimney increase being a waste, in most cases a double bed, smaller chimney solution will be the better alternative.

9.0 Business case

9.1 Introduction

The business case for this particular project differs greatly from standard product development endeavors. In general terms, financial incentives are the main aspects to be evaluated, as this will be the most important factor to consider when analyzing the value of a product or proposition, as well as its potential for success.

This project was laid out with the main goal of providing life quality improvements for people in poverty and in the case of this solution, addressing a specific problem for a defined set of individuals.

IUG presented the issue, looking for engineers who were willing to work on a solution with no monetary incentive.

When development of the solution was discussed with IUG's general secretary, guidelines were established in regards to what the solution needed to offer in order to receive funding by IUG to be deployed as a humanitarian aid intervention within Sierra Leone.

We will understand the business case, as the products ability to comply with the requirements set forth by IUG in order to fund a humanitarian aid intervention relating to the solution, since this is what will be needed in order for the product to be successfully deployed in the market.

9.2 IUG project funding requirements

9.2.1 Appropriate efficiency/price calibration

"Solution must be adequately calibrated between impact outcome and price" Dorte Lindegaard Madsen.

IUG has made it clear that for a solution to be suitable for financing and deployment, it must be accurately calibrated in the aforementioned aspects. This implies a couple things:

- The benefit provided by the solution must be greater than its cost
- Solution is capable of creating relevant "impact" or change within the users lives
- Solution must be able to perform the task it is set out to efficiently
- Performance offered by the solution is sound in regards to it cost, moreover it is an attractive element of it

Given the tried and tested nature of the implemented grain drying method, benefit weighed against cost is not a concern, as even the simplest convection based solar grain dryer will reduce drying time approximately by half. It was discussed with IUG's representative that validation of the performance is required and there was no issue in regards to the creation of a prototype for IUG which would serve as a benchmark to provide the data which is required in this aspect. Furthermore, Dorte validated the primary prototype and determined that the proposed steps regarding to this aspect of the solution were adequate.

9.2.2 Incentivizing farmer organization

For projects that relate to farming solutions/farming oriented aid, IUG has set more specific constraints in regards to the kinds of solutions they are seeking. The main points are as follows:

- Solutions with community driven aspects are prioritized in all instances
- Given the history of Danish agriculture and farming, promoting organizations between different farmers is a key aspect of any solution or project that tackles farming related issues
- Solution must offer a collaboration framework which encompasses how the users could organize around the use of the product

In order to address this aspect of the project, communal collaboration strategies have been laid out regarding the use of the product.

Premium product based market growth strategy

As our expert pointed out, the produce from each season is subject to “haggling” with the buyer. This is mainly due to the wide variation in quality of the finished product, which is evaluated at the discretion of the produce purchasing merchant. However, he has also stated that there is a fair level of objectivity in regards to the produce.

By taking this into consideration, a collaboration strategy which introduces the concept of “premium produce” while installing the virtues of more effective grain drying into the user has been developed.

By introducing one or multiple solar grain dryers into a community (At the discretion of IUG) a collaboration strategy surrounding use of the dryer should be fairly simple, as grain drying times in solar dryers have been shown to be reliable. The strategy would revolve around allowing the use of the dryer to the local farming community in turns. This would mean that a certain time-frame of the grain drying process for every individual involved would be assigned to the dryer. It is assumed that not all produce in the community will initially be able to go through the solar grain dryer. We will then instill on the local farm hands that the produce they have managed to try via the solar drying solution, should be cataloged as premium produce and sold separately. This is because the produce will have a higher level of quality as compared to produce dried without the use of the solution. The community would then pool their premium produce and sell it in bulk. This would promote organization of labor and financials. The premium grain would naturally have greater returns than their usual produce and this excess in gains produced by the grain dryer can then be pooled into the construction of another unit, furthering their capacity production, until their entire product is high-quality or "premium".

Process flow-diagram

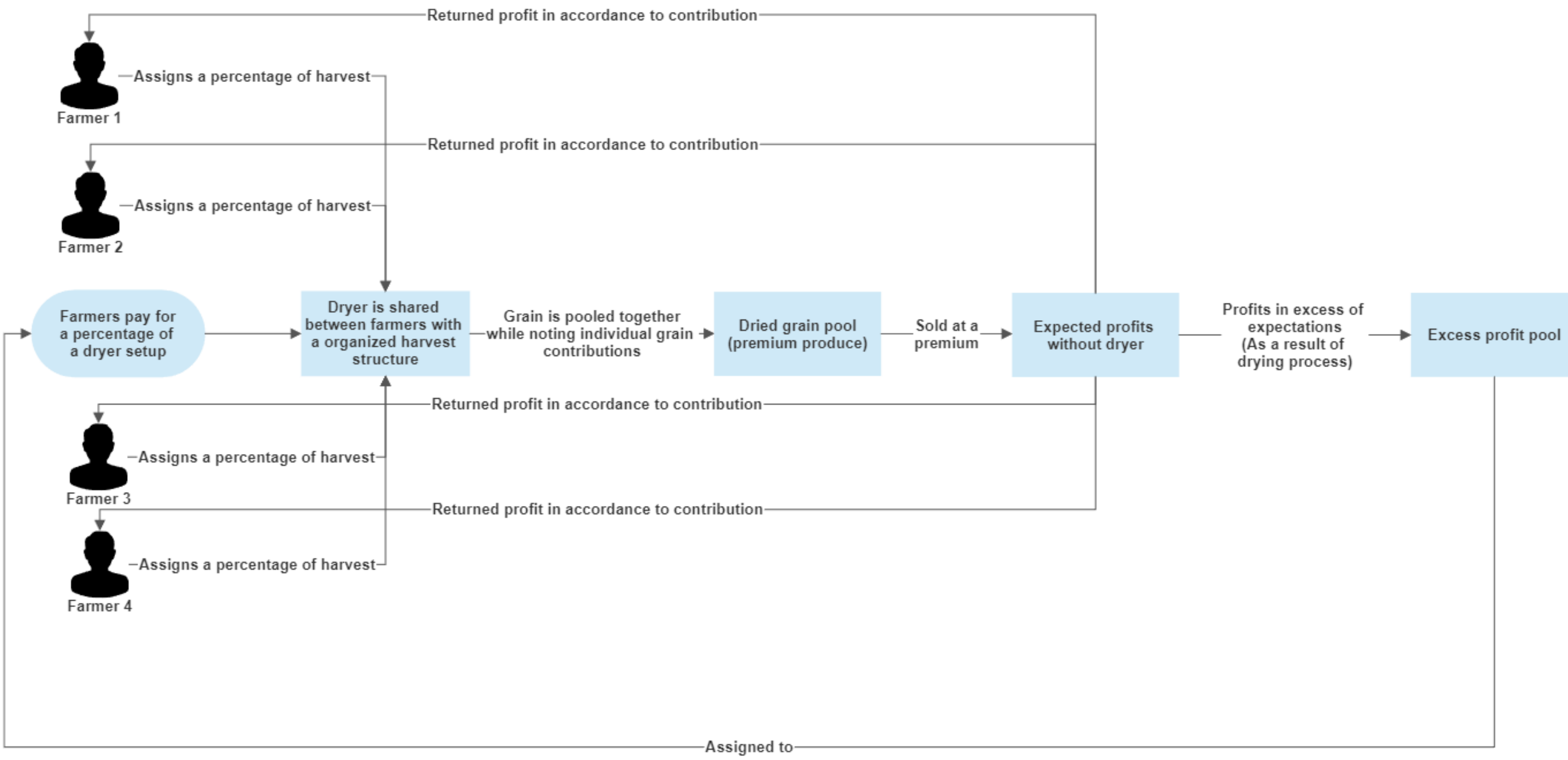


Figure 46. Premium produce strategy process diagram

9.3 Preliminary cost calculations

Costs for the final design were calculated, in order to present cost data to IUG and seek funding for the possibility of a prototype design.

Calculations were carried out for both the single bed unit, as well as the double bed unit, while also taking into consideration the retrofit fan option.

Single bed unit

Material cost calculation Single unit

ITEM N°	Material Description	Unit	Quantity	Unit Price USD	Total Cost USD
1	Plywood for drying bed	Kg	45	0.58	26.1
2	Plywood for chimney	Kg	23	0.58	13.3
3	Plywood for chimney opening	Kg	12	0.58	7.0
4	Plywood for separator	Kg	3.7	0.58	2.1
5	Plastic sheet	M^2	15	0.35	5.3
6	Dark Plastic sheet	M^2	7.5	0.35	2.6
7	Stainless steel Screws	Kg	1.48	2.92	4.3

Total Material Cost USD 60.7

Labor cost calculation

ITEM N°	Labor Description	Unit	Quantity	Labor Pice	Total Labor Cost
1	Carpenter Technician	Day	2	4	8.0
2	Assistant for Carpenter	Day	2	3.2	6.4

Total Labor Cost USD 14.4

Total Material and Labor Cost USD 75.1

Retrofitted fan option

ITEM N°	Item Description	Unit Price USD	Total cost
1	Low capacity air-fan	32	32.0

Total cost with retroffited fan 107.1

Notes:

* For Plywood we have use the average price prices that we have from CES 0.55 -0.61 USD/Kg
* For Plastic sheet we have used reference prices
* For Stainless steel screws values were obtained from CES
* Local workforce cost estimated by using digital research and expert opinion
* Labor times have been exaggerated to account for labor inexperience, however assembly times could be reduced considerably

Double bed unit

Material cost calculation Double unit

ITEM N°	Material Description	Unit	Quantity	Unit Price USD	Total Cost USD
1	Plywood for drying bed	Kg	90	0.58	52.2
2	Plywood for chimney	Kg	23	0.58	13.3
3	Plywood for chimney opening	Kg	24	0.58	13.9
4	Plywood for separator	Kg	7.4	0.58	4.3
5	Plastic sheet	M^2	25	0.35	8.8
6	Dark Plastic sheet	M^2	15	0.35	5.3
6	Stainless steel Screws	Kg	2	2.92	5.8

Total Material Cost USD 103.6

Labor cost calculation

ITEM N°	Labor Description	Unit	Quantity	Labor Pice	Total Labor Cost
1	Carpenter Technician	Day	3	4	12.0
2	Assistant for Carpenter	Day	3	3.2	9.6

Total Labor Cost USD 21.6

Total Material and Labor Cost USD 125.2

Retrofitted fan option

ITEM N°	Item Description	Unit Price USD	Total cost
1	Low capacity air-fan	32	32.0

Total cost with retroffited fan 157.2

Notes:

* For Plywood we have use the average price prices that we have from CES 0.55 -0.61 USD/Kg
* For Plastic sheet we have used reference prices
* For Stainless steel screws values were obtained from CES
* Local workforce cost estimated by using digital research and expert opinion
* Labor times have been exaggerated to account for labor inexperience, however assembly times could be reduced considerably

These are encouraging financials, as the feed the future initiative in conjunction with UCDavis had a cost of 150 USD in 2006, which by today's standards would be 190 USD.

10.0 Future steps

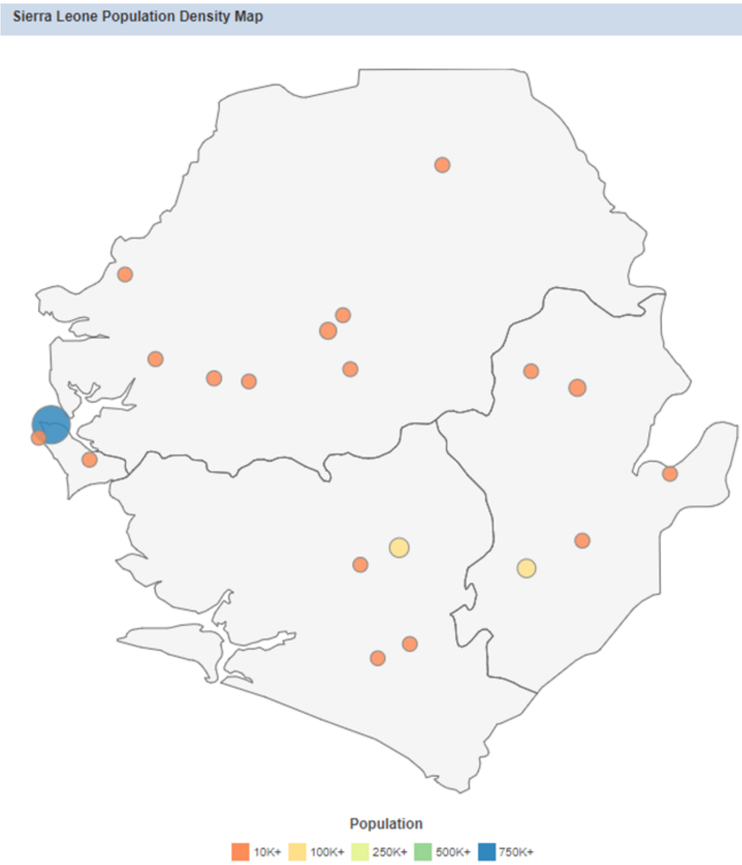
Having maintained a working relationship with IUG and having open discourse surrounding the development of the product, it is of mutual agreement that the next step is the development of a physical prototype in order to collect performance data and reference it with other available data sources.
It is also important to create contacts with local suppliers in order to ensure the availability of materials, as well as train the local staff in the assembly of the grain dryer.

11.0 Conclusion

The liaison between SDU and IUG allows for a phenomenal opportunity for the application of innovation in product development to impact and benefit underprivileged communities throughout the world and in turn gain real world experience for our class of students.
In the particular case of this bachelor project, we are proud to be able to provide our grain of salt for the support of the rural agricultural communities of Sierra Leone, which have been deeply affected for decades with political instability, lack of expertise and technology to overcome the internal demand for agricultural supply, and allow for better profits, quality of grain and improved sanitary standards.
Special gratitude is due to Alfred Mbayoh for allowing the access to real life information regarding Sierra Leone's rural agricultural communities, which was identified as the most limiting factor for the reliable design for real-life use of the product. As such, simplicity, inexpensiveness, ease of local manufacturing and servicing by the producers were the core pillars for the project design.
Through multiple iterations, the product succeeds in delivering a solar driven grain drying solution which is tailored to the needs of the end-user, which will greatly increase shelf life and quality of produce for the local farmers, which in turn will increase their profits.
The product can be manufactured with locally available materials, boosting the local economy, and at the same time is sustainable since it relies only on natural solar energy and simple physical principles to function. Furthermore, the design has been created with ease of assembly in mind, and does not require any sort of previous expertise or complex machinery/tools for assembly, as well as being able to be constructed within a variety of configuration -due to its modularity- to accommodate the different needs of the country's agricultural communities. This allows for multiple levels of financial commitment as well as part retrofitting.
The design philosophy allows for ease of replicability, enabling the end-user to create their own variants of the design, or increase the modules for an existing unit. Additionally, a comprehensive strategy which is aimed at boosting local economical activity has been developed around the implementation of the device, which incentivizes organization of farmers and bulk sale, in order to further develop the agricultural sector.

12.0 Appendix

A.1



A.2

Plywood

Datasheet view: All properties | Show/Hide | Find Similar

Mechanical properties

Young's modulus	5	-	8	GPa
Shear modulus	0.2	-	0.3	GPa
Bulk modulus	* 1.63	-	2.45	GPa
Poisson's ratio	0.2	-	0.3	
Yield strength (elastic limit)	* 34.4	-	42.1	MPa
Tensile strength	45	-	70	MPa
Compressive strength	* 25	-	40	MPa
Elongation	* 2.43	-	2.97	% strain
Hardness - Vickers	3	-	9	HV
Fatigue strength at 10^7 cycles	* 22.6	-	27.6	MPa
Fracture toughness	* 0.5	-	1	MPa.m^0.5
Mechanical loss coefficient (tan delta)	* 0.0077	-	0.0104	

A.3

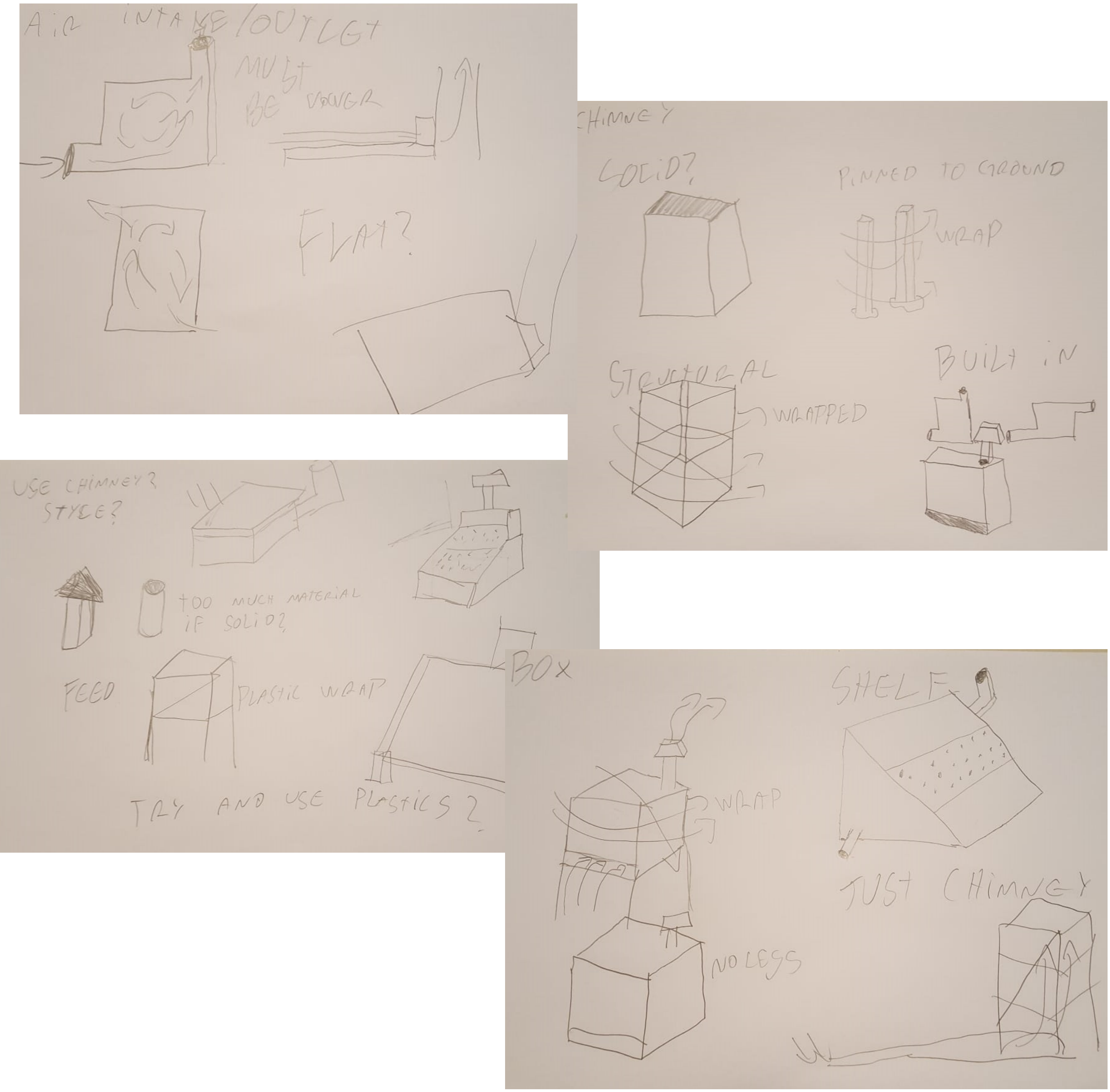
Softwood: pine, along grain

Datasheet view: All properties | Show/Hide | Find Similar

Mechanical properties

Young's modulus	8.4	-	10.3	GPa
Shear modulus	* 0.62	-	0.76	GPa
Bulk modulus	0.37	-	0.41	GPa
Poisson's ratio	* 0.35	-	0.4	
Yield strength (elastic limit)	* 35	-	45	MPa
Tensile strength	* 60	-	100	MPa
Compressive strength	* 35	-	43	MPa
Elongation	* 1.99	-	2.43	% strain
Hardness - Vickers	* 3	-	4	HV
Fatigue strength at 10^7 cycles	* 19	-	23	MPa
Fracture toughness	* 3.4	-	4.1	MPa.m^0.5
Mechanical loss coefficient (tan delta)	* 0.007	-	0.01	

A.4 Sketchstorms



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