Plastic building blocks in Watamu

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Master Thesis

Integrated Product Design

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A minimal viable brick production process

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Preface

It all started with one man I met, Floris Koumans. He is an entrepreneur who started his career as a fisherman in Greece, and has since build and invested in multiple companies. We share personal passions such as surfing, nature and our love for Africa. He told me about one of his initiatives called Upstream, a project facilitating students to find plastic waste solutions in Kenya. I was lucky to become one of those students.

One thing left to do: find a local company in Kenya that I can do this project for. Through a friend I got to hear about EcoWord, a plastic waste recycling company in coastal Kenya. It felt immediately as if this was the right company, so I contacted them. A few days later I had a zoom call with Steve, the initiator and director of EcoWorld. Our meetup was faith. Apparently Steve was eagerly looking for an engineering student to do a project on making building material from plastic waste. It couldn't be a better match.

The kick-off meeting with my supervisory team Jan-Carel and Caroline followed. With great enthusiasm they encouraged the project, which made me very motivated. The supervisory team was suiting the project greatly. JC as Bottom of the Pyramid design expert and Caroline as sustainability expert.

During my project Floris gave me the opportunity to make a field trip to Kenya, which I am incredibly thankful for. Not only was it a crucial part for the quality of the project, but also for my personal lessons and growth.

I alway had an ambition to contribute to plastic waste solutions. I feel that with my studies, Product design, I can really do something about the plastic waste pollution. Plastic utilizations are so much focused on consumer products and interaction. Considering my love for surfing and nature I really feel eager to do something about the plastic in the environment. Being able to combine my ambition with my love for Africa was incredible. By actually being able to work together with locals in a Base of the Pyramid country I learned so much from how they approach things. The Kenyan's really have a practical approach,which I love.

I want to express my gratitude to the EcoWorld team for this opportunity. Steve, thanks for being so enthusiastic and driven. That really inspires me. You have a vision and you really go for it. You've been at my sight and a great sparring partner throughout this project. Also thank you so much for opening up a budget to make prototypes locally.

Karen, Morris and Helen, office team of Ecoworld, thank you guys so much for supporting me every day when I was at EcoWorld. With our morning rides in the TukTuk the day already started with a laugh. Your interest and curiosity in the project was really inspiring and motivational.

Then, Willy, my friend. The man who stood by me every day. Firing up the pot, making bricks, co-designing the mould. Without you this project wouldn't have been so wonderful and I could never have accomplish all that we have together. You taught me a lot about life in Kenya and we had so much fun together. I miss your laugh already.

To the other team members of EcoWorld, Balusi, Tskutchi, Chengo, Zakiel and all others: Thank you for making me feel so comfortable at EcoWorld. The vibe was lovely and I had so much fun. Thanks for making me part of the team.

When I got back in the Netherlands my partner, friends and family were so warm and welcoming. I want to thank them greatly for supporting me throughout this project. It can be hard being on your own, so thank you for motivating me, being my listening ear and being sparring partners when needed.

Finally, thanks to my supervisory team. JC your knowledge on BoP design and sharp questions brought this project much further. You challenged me to think deeper about consequences and impact, teaching me to have a more holistic approach towards the design process. Caroline, we had a great connection already from the beginning. Thank you for giving me guidance and structure throughout the project. I could loose the overview sometimes, but you knew how to give it back to me.

To the reader, I hope you have as much fun reading this project as I had writing it. Thank you for your interest!

Figure . Willy, Luci and Balusi at EcoWorld

Figure . Different experimental brick samples

Glossary

BoP	=	Base of the pyramid
Fundi	=	Someone that is very good at something, but does not have the required paper or education to be a professional
HDPE	=	High Density Polyethylene
Ksh	=	Kenyan shillings
MPa	=	Mega pascal
MRF	=	Material recovery facility
PET	=	Polyethylene terephthalate
PP	=	Polypropylene
SME	=	Small medium enterprises
TBL	=	Tripple bottom line

Executive Summery

Plastic waste pollution is a well known global problem, also in Watamu, a little village on the coast of Kenya. The living conditions in Watamu are harsh, with a lot of unemployment and poverty. People depending on tourism which is negatively related to the plastic pollution on the beach and in the village. The housing situation for locals suffers from poverty as well, many locals lack proper shelter.

The project described in this report helps to solve these issues in many ways:

1. Remanufacturing of plastic waste creates economic opportunities and reduces the waste in the environment
2. Making building blocks out of the plastic waste provides low cost building material
3. Low cost building material enables better housing opportunities for the locals

The research was made possible by Steve Trott, owner of EcoWorld, a local plastic waste processing company. The company's ambition is to grow and ignite the plastic waste circular economy in coast province Kenya. The next step in this ambition is remanufacturing plastic waste material into useful products.

The deliverables of this project are:

1. A minimal viable production process of (re-)manufacturing building material from plastic waste
2. Identification of the impact on social-wellbeing, environment and economic opportunities (using the triple bottom line framework).
3. Implementation roadmap for EcoWorld

Research process and outcome

The following research activities are performed, described with the outcome:

1. An analysis to get a good and qualitative understanding of the local context and the (potential) impact of the design.
2. Data analysis to create a list of insights that are used as inspiration and requirements for the design process.
3. An inclusive decision making process concluded to focus on designing building bricks for school in Watamu.
4. Material selection based on availability of waste and producibility at EcoWorld, resulting in recycled PP waste as feedstock.
5. Literature study on plastic waste bricks to learn from existing research, resulting in melting and moulding the plastic waste into an interlocking brick shape.
6. Design cycles on production process and material composition of the bricks. The outcome was a series of 23 different bricks containing either HDPE, PET or PP in combination with sand or other additives.
7. Destructive testing on the 23 bricks to find the influence of the different plastic sorts, with a chosen best option as outcome; PP plastic.
8. Final test on compressive strength at the TUDelft to find the best recycled PP mixture composition considering strength and cost and to prove the feasibility of the selected brick (the minimal viable product).

Description of the final design

The minimal viable production process was co-designed locally, with local skill and materials. This process was used as an experimental set-up to test the shape, weight and size of the brick, the local opinions, the mixture composition and insights for the next phase of the brick production line development.

The tests with different material compositions lead to the final choice of 50% recycled PP and 50% fine sand. This composition is stronger (compressive strength) than the currently used coral block. It was also found that the locals want the brick to be big and heavy to be trustworthy as building material, therefor the weight of the brick is 6kg's with similar dimensions as currently used coral blocks. The final cost of one brick is around 128 Ksh, which is less than the current coral block.

The final design of the minimal viable production process is explained in requirements that fit the local context. The process includes an extruder, enabling a controlled heating process and minimal hazardous fumes exhaustion. The process also includes a mould and a compacting hand press with 14.9 kN compressive force that are both operated manually.

Reflection

The brick production is proven to be feasible and viable, but is it also desirable? The Tripple Bottom Line framework is used to measure the impact of this project. The designed plastic waste brick with its minimal viable production process was co-evaluated together with employees from EcoWorld. The conclusion was that the project does make a positive social, environmental and economic impact. The designed bricks are more affordable and accessible than the current situation. The brick is made from recycled PP giving value to this low-valued plastic waste stream, adding also environmental benefits. The implementation of the brick creates new SME opportunities and empowering collaborations with Women and youth groups. Lastly, challenges were identified during the project, which are translated into recommendations.

Table of content

1. Introduction

The introduction gives an outline of what the goal of this project is and why. The focus of the project is also explained by giving a scope. The design approach will give an overview of elements that form the foundation and approach of this design report.

Chapters:

1.1 Project introduction

This project is a design request from a plastic recycling company, EcoWorld, in Watamu Kenya. They collect plenty of plastic waste in their facility, however their revenue stream is depending on external demand of waste material and there is not yet a market for all plastics. Remanufacturing the plastic waste is an opportunity to add value to the plastic waste and potentially enhancing local self-sufficient community and unleash livelihoods.

Plastic waste pollution
Plastic waste pollution is a major environmental problem that affects oceans, rivers, and ecosystems around the world. Plastic is a versatile and inexpensive material that has transformed many industries, but it has also created a significant waste problem. Plastic waste can take hundreds of years to degrade, and it harms wildlife, pollutes oceans, and can have negative effects on human health. In chapter 2.1 more information is given about the waste problems. Despite the magnitude of this problem, there are many ways in which individuals, organizations, and governments can and are taking action to reduce plastic waste pollution and protect the environment.

Plastic waste pollution particularly affects coastal areas. Plastic debris washes up on beaches, harms marine animals and can also damage local economies, reduce tourism and negatively impact the aesthetic of the place (Chakraborty et al., 2022). Efforts to reduce plastic waste in coastal areas include beach cleanups and community education to reduce plastic use.

The coastal area researched in this project is Watamu, Kenya, East-Africa. Chapter 2.3 tells more about the village. It is the location of the first recycling sight of EcoWorld recycling. The company was founded in 2016 by Steve Trott, an Englishmen who came to Watamu 22 years ago. As a marine biologist he was researching marine preservation, when he was confronted with the plastic waste problem. No local waste management systems were in place and he had to do something about it. Thus EcoWorld was born.

EcoWorld
The mission of EcoWorld is "Leading Change and Igniting the Plastics Waste Circular Economy in Coast Province Kenya", with their pillars being:

- Economic - Creating market demands for quality remanufactured products.
- Social - Unleashing livelihoods of community locals by creating local economic opportunities.
- Environmental - Decreasing plastic pollution and its negative impact.

Chapter 2.4 further explains the vision and mission of EcoWorld.

It is crucial to strive for a circular economy as a linear economy operates under the assumption that resources are limitless and the primary objective for businesses is economic prosperity. However, this approach neglects societal and environmental values. Innovative business models are being developed to incorporate these values while maintaining economic viability. The concept of a circular economy is modeled after natural ecosystems, in which the waste of one system serves as a resource for another (Ellen MacArthur Foundation, 2016). Circular businesses aim to prolong the retention of a product's added value. In the context of the Value Hill in figure 1, value is added as the product progresses "uphill" and circular strategies aim to maintain the product at its highest value for as long as possible (Achterberg et al., 2016).

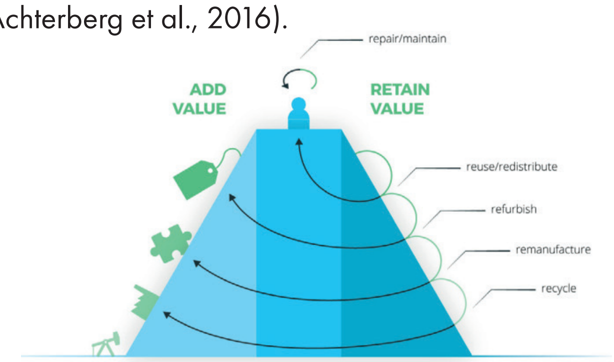


Figure 1. The value hill (Circular economy 2016)

EcoWorld is now operating at the bottom of the hill, selling the recyclates to recycling companies. That means being depended on the demand of those recycling companies, and for some plastics there is no demand at all. To grow towards their ambition of becoming a plastic waste circular company, the focus is on getting higher on the Value Hill: remanufacture, described as "Providing products from recaptured materials and components".

Housing challenge
In Watamu life is hard for locals. Many live in poverty and are depending on tourism for income. Also the housing situation is critical. The poorest locals live in badly maintained wood and mud houses, which can lead to diseases and homelessness due to degradation of the houses. That is quite critical considering shelter is, next to food and clothing, an immediate basic need (Basic Needs Definition, n.d.). The people that can afford building a house use coral building blocks and cement. The problem is, resourcing the raw materials for those building elements are bad for the factory workers' and planetary health. A more in depth analysis on building material is given in chapter 2.6.

Conclusion
The challenges of the plastic waste pollution are quite obvious. Something needs to be done to mitigate the negative impact on human and planetary health. EcoWorld is doing exactly that. Their vision is to strive for a plastic waste circular economy. The value hill explains a circular economy is based upon the natural ecosystem of one system's waste is another's resource. The objective is to add value to the waste. One step higher than recycling is remanufacturing: providing products from recaptured materials and components.

By introducing remanufactured products at EcoWorld, they become less depended on the market demand of recyclates. It can contribute to enhancing local self-sufficient community. The definition of self-sufficiency is: "needing no outside help in satisfying one's basic needs" (Webster n.d.). Basic needs are said to be: food, clothes and shelter. What can possibly be made from remanufactured plastic waste? Shelter. As said the housing situation in Watamu is critical, but everyone needs and deserves proper housing. Therefor this project focuses on remanufacturing plastic waste into building material.

Figure . EcoWorld beach clean-up at Watamu

Chapter 1.2 Scope

The plastic waste pollution is growing, having negative impact on the people of Watamu. Human and planetary health issues are rising. Economically it also imposes challenges since it threatens the tourism industry, which Watamu people heavily depend on. The living conditions in Watamu are hard, with a lot of poverty and bad housing conditions. The focus of this report is to contribute to a solution for these challenges.

Challenges

- The living conditions in Watamu are hard due to poverty.
- The housing situation in Watamu is poor and has a negative human and planetary health impact.
- There is a need for local and independent economic opportunities.
- Plastic waste pollution imposes threats to the local economy and human and planetary health.

Project assignment:

These challenges combined form a great opportunity to solve multiple problems at once, with remanufacturing plastic waste as its core. Therefor the assignment is: *Design remanufactured plastic waste building material with an accompanying implementation plan that enhances local self-sufficiency and unleash livelihoods while cleaning the environment from plastic waste.*

Scope

To further define the project assignment it is decided together with Ecoworld to scope down what the building material is used for. When building a multistory flat different parameters and elements matter compared to for instance a one bedroom house. The building type this project will focus on is school buildings. Steve expressed it is not their intention to compete with the existing commercial construction industry. Schools are built in collaboration with governmental or humanitarian organizations, so it won't interfere too much with the commercial industry. In the future using the designed building material for other kinds of buildings can be researched, but for this project using the building material for schools is the scope.

Tripple bottom line

The solution to the assignment can be a complex system. To keep focus in this research, the Triple Bottom Line framework in figure 2 is used. The Triple Bottom Line (TBL) framework, first introduced by John Elkington in 1994, aims to broaden the traditional focus on financial performance in business by including considerations for social and environmental impact. The TBL framework encourages companies to consider the connection between financial success, environmental health and social well-being for more comprehensive and sustainable performance measurement (Miller, 2020). The real sustainable solution is a balance between Social, Environmental and Economical benefits.

To keep focus and measure the success of the project the TBL impact questions are:

- *Social*: Does the final design provide social gain for the local people of Watamu compared to the current situation and in what ways?
- *Environmental:* Does the final design provide environmental gain compared to the current situation and in what ways?
- *Economical:* Does the implementation of the final design provide economical gain compared to the current situation and in what ways?

The answers to these questions come back in the final chapter 6 "evaluation", in which the impact of the final design is reflected upon. A trip to Watamu is made for research, co-design and testing. The field study, literature research, interviews and a locally co-designed experimental test set-up together are the foundation of finding the right solution for EcoWorld.

Figure 2. The triple bottom line framework

One man's trash is an other man's treasure.
-Thomas Brown

Chapter 1.3 Design approach

The design framework used in this report is the double diamond model, a framework used in managing product innovation, see figure 3 (British Design Council, 2005). This model is chosen since this project is not just about a design, but also the implementation and impact. The project consists of four parts: Discover, Define, Create, Deliver. In the first two parts the research is done to identify the solution space. The third and fourth parts are the creative design process. All four steps are the foundation of the creative process leading to the final design deliverable.

1. Discover
This chapter focuses on a wide analysis of the context. Interviews, field research, observations and literature research lead to understanding of the local context, challenges and its opportunities.

2. Define
In this chapter all insights from the discover phase are used to chose a design direction and form requirements, which will function as a starting point for the design phase.

3. Create
The create phase starts with a literature research on the chosen direction. The insights are used as ground and inspiration for the design phase. An experimental brick production test set-up is co-designed locally. A very practical approach has been taken to get more insights on shape and weight, user interaction, acceptability and material selection.

4. Deliver
Here the final design and its implementation steps are explained. It will give an overview of the experimental test-setup design, as well as production requirements. A cost analysis and the implementation plan are also described.

5. Evaluation
After "delivery" the final designed solution will be evaluated and reflected upon. The TBL framework will be used again to analyze the impact of the implementation.

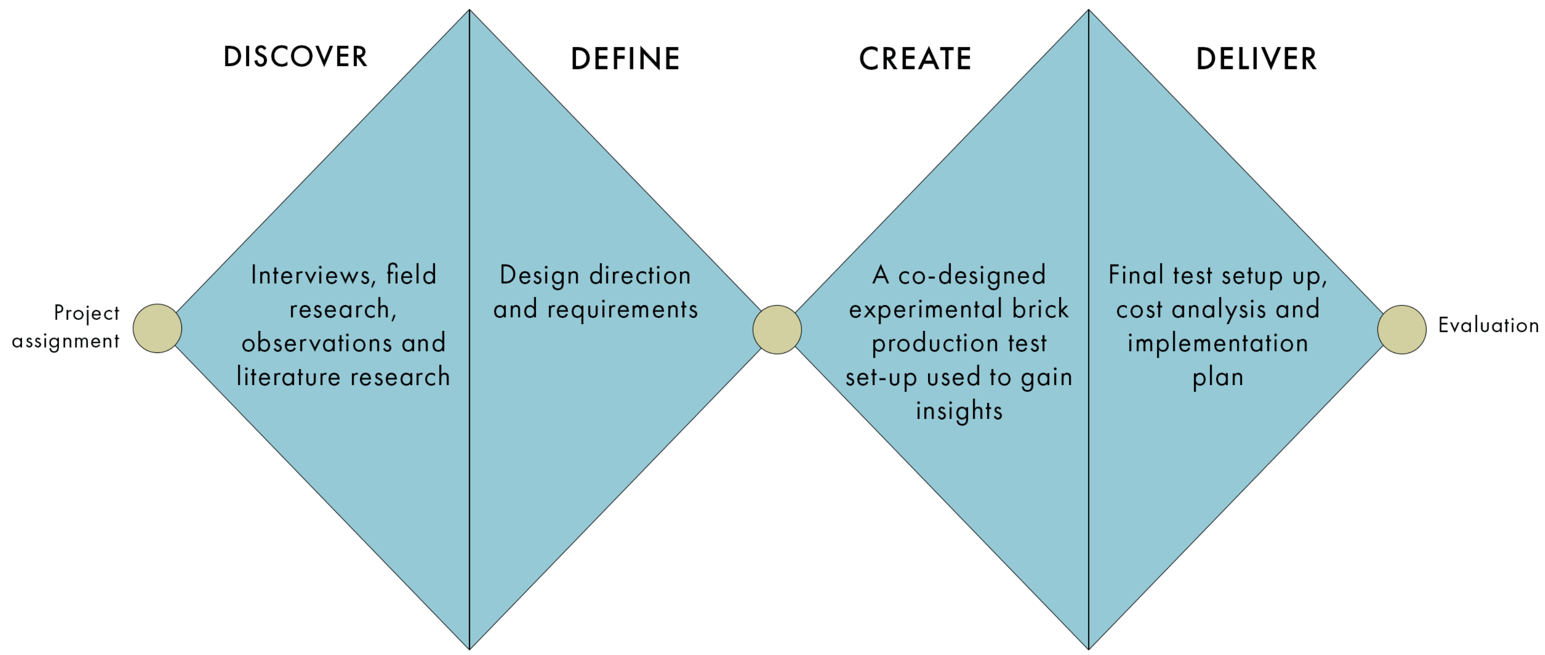


Figure 3. The double diamond design approach

2. Discover

The goal of the first phase is to get a deep understanding of the context and the opportunities to make positive impact of the final design, as well as gaining insights from existing literature. The findings are based on desk research, interviews, literature research and a field study. Every chapter is concluded and useful insights are summarized.

First it is important to understand the main material component of this project; plastic waste. Why is it so bad, and what can be done with it? The local setting of the project is analyzed to understand the possible interaction with the designed solution. Then there will be zoomed in on the EcoWorld company to understand the resources for the feasibility and viability of the designed product. Insights and opportunities are derived from the research and used to make a design direction decision in chapter "Define".

Chapters:

2.1 Plastic waste in general

Since plastic waste is the core of this research it is a good starting point to get familiar with. What is plastic, and why is it bad? Can anything good come from it as well?

A little history
The history of plastic can be traced back to the 19th century, when scientists first began experimenting with new materials that could be moulded into various shapes. In 1907, Leo Hendrik Baekeland invented the first synthetic plastic, called Bakelite. It was made from a mixture of waste materials from processing crude oil and natural gas, produced under high pressure and heat (Science museum, 2019).

In the 1940s and 1950s, plastic production increased dramatically as it was widely used for packaging for foods and medicine, consumer goods and military equipment during World War II. The rise of plastic continued in post-war era as it became popular in automobiles, appliances, and a wide range of other products (Freinkel, 2011).

Since then, the use of plastic has grown exponentially, with many new types of plastic being developed and used in a wide range of applications. However, the environmental impacts of plastic have also become increasingly clear, leading to growing concerns about plastic pollution and calls for greater regulation and reduction of plastic use (Pinto Da Costa, 2020).

There is an important distinction between two kinds of plastics: thermoplastics and thermosets. Thermoplastics can melt and change shape when heated. Thermoset plastics on the other hand, keep their shape even when heated. Because thermoplastics melt at a lower temperature, they are good for recycling. (Twi-global, n.d.) From now on in this report when writing about plastic, always thermoplastics are meant. Plastics can melt, but they can also burn. Since plastic is made from crude oil it is flammable. Every different sort of plastic has different fire resistances (Zeus, 2005).

Why is it waste?
Plastic is not biodegradable, meaning from the moment it is produced it keeps existing for hundreds of years. Annually 390.7 million tonnes of plastic is produced, an amount which is expected to grow in the future (Janssens, 2022). Less than 10% is recycled meaning all of the rest of the plastic has piled up or has been incinerated over the last 70 years. The plastic production and incineration is contributing largely to the climate change. In 2050 we should not emit more than 570 billion tons of CO2, plastic production and processing is currently emitting 56 billion tons of CO2. That is about 10% of the total limit in 2050! (Hamilton et al., 2019) Throughout its lifetime plastic harms human health and animals as well. Animals choke on plastic parts mistaken for food. Clogged rivers and drainage causing diseases to spread, see figure 4 (Karcher, 2020).

Figure 4. Clogged sewage in Kenya (CEJAD-Kenya, 2019)

When plastic degrades it generates microplastics (small parts of 100nm-5mm). If exposed to environmental factors such as UV or rain, microplastics are formed quicker. When plastic is left in the environment these microplastics enter the groundwater, called leaching, contaminating the water causing environmental and health hazards. Microplastics entering the body by drinking water or ingestion causing harm to the organs (Mortula, 202).

An other effect of plastic in the environment is the negative impact on tourism. Polluted beaches and towns reduce revenue greatly due to their appearance which is not attractive and aesthetically appearing to tourists. This loss is quantified in a study done on the Asia Pacific Economic Communities, showing a loss of US$622 million per year due to plastic pollution (Watkins, 2017).

What can be done with plastic waste?
At the end of life mostly three things happen, plastic waste ends up on landfill, it is incinerated or recycled. See figure 5 for percentages (Plastic soup, n.d.):

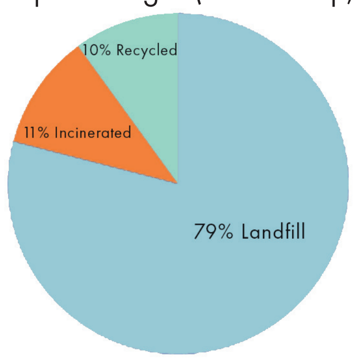


Figure 5. Global plastic waste processing

Still a lot of plastic waste ends-up in landfill where it pollutes the environment. Capturing the plastic waste in remanufactured products is a way of keeping it out of the environment. As explained in the introduction chapter, the value hill shows the impact of the waste processing. From recycling to reusing. Remanufacturing is better than recycling, that is what this reports focuses on. With remanufacturing is meant: "Providing products from recaptured materials and components". When plastic waste is remanufactured it can be divided into two groups: Aesthetic purpose or functional purpose. This project focuses on the latter, and what is more functional than building material considering shelter is a basic need.

Which building material can be made from plastic?
With the global challenges of plastic waste and critical housing situations it is no shock that many have experimented with remanufacturing plastic waste into building material. The mood board on figure 6 is created to show the wide range of existing possibilities; plastic posts from EcoPost, tiles from EcoUnified, roof tiles from EcoBlocks, pavers from the Gjenge makers and an interlocking brick from ByFusion.

Conclusion
Plastic is an incredible material which made a lot of great things possible like distributing food and medicine. However it is now overused in people's daily live and it is everywhere. The challenge is that the material is not biodegradable and instead degrades into smaller particles. This causes a lot of harm worldwide, which has to stop. Plastic pollution is bad for tourism as well. In an attempt of giving value again to the waste, it can be remanufactured into aesthetic or functional products. In this project functional products will be the focus, building materials in particular.

Insights
- Plastics are flammable, the fire resistance is depending on the type of plastic
- The plastic waste pile continues to grow
- Plastics are not bio-degradable, they degrade overtime into smaller particles called micro-plastics
- Polluted beaches and nature is bad for tourism
- Existing plastic waste building material are an inspiration of the feasibility of the project

Figure 6. Mood board of existing remanufactured plastic waste building material (EcoPost, EcoUnified, EcoBlocks, Gjenge makers, ByFusion)

Figure 7. Map of Kenya

2.2 The context research

A trip to Watamu was made, the coastal village seen on figure 7. The goal was to gain insights on the local context by observing and interviewing inhabitants, examining the village's waste management practices, observing the operations of EcoWorld, and identifying ways to implement plastic waste building material.

The research methods that were used are desk research, interviews, working at Ecoworld, observational research and keeping a diary. The trip took a total of 3.5 weeks in November/December 2022.

EcoWorld currently only sells their shredded plastic to recycling companies. However they want to take the next step and go up the Value Hill, starting remanufacturing waste into building material. Therefore during the context research in Watamu the current building material demand is analyzed. Different construction sights were visited and construction workers were interviewed.

Each context section ends with a conclusion and a list of insights, used as foundation for the design direction choice in the next chapter "Define". The topics that will be discussed are Watamu, EcoWorld, plastic waste composition and the buildings in Watamu.

Figure . Karen, Helen, Luci and Zakiel

2.3 Watamu

Watamu is a village located on the coast of Kenya in Kilifi county, 105 km north of Mombasa. The village has 30,000 inhabitants. The town has been inhabited since the 13th century by the Bajuni people, who trace back their origin from intermarriage between the local Giriama people and Arab traders. Around 600 years ago Watamu was abandoned and only in 1937 people started living in Watamu again. In 1952 the first bar was opened which turned into a hotel. This was the beginning of tourism in Watamu (Watamu Marine Association, 2009).

Economy

The poverty rate in Kilifi country is more, 48.4%, than the Kenyan number, 36.1% in 2016 (Knoema, 2016). The unemployment rate in Kenya is measured 10.7% in 2020 (Nyasha et al., 2022). In Kenya the biggest problem lies with the youth, age 15-24, with an unemployment rate of almost 40% in 2020 (Karcher, 2020). There is also gender inequality. The labour force participation of women is 64%, whereas for men it's 69%. However, women earn on average 35% less (Hunt et al. 2019). Nowadays 50% of the income of the Watamu citizens comes from tourism (Carter, 2014). Due to COVID-19 no tourists were coming leading to big losses in the Kenyan economy, especially in places like Watamu depending heavily on tourism (Ministry of tourism and wildlife, 2020). During the field study it was found that many locals in Watamu struggle to pay their basic needs such as food and gas. Housing is also part of that, for most people it's financially impossible to finish a house at once. They just start and when the money runs out they stop, until they have enough funds to resume again. The public primary and secondary schools are free in Watamu, however the classes are often overcrowded and there is a lack of resources influencing the quality of education. This is a result of governmental budget cuts and corruption (Ominde, 2022)

Climate

The climate of Watamu is hot tropical. All year round temperatures vary from 27°C to 32°C during the day and 19°C to 25°C during the night. It is mostly sunny. It has two rain seasons, one big one in April, May and June. And a small one in October, November. However the rainfall was low in the last years, leaving Watamu in a drought for 2 years already. The NE monsoon current in Nov-March, and the SE monsoon current in may-sept bring a lot of plastic waste on the beaches of Watamu. In those months the plastic pollution on the beach is biggest (Trott, 2021).

Infrastructure

There are three types of infrastructures described, electricity, digital and roads.

The electricity in Watamu is quite unreliable. During the field study it was noticed there are frequent powercuts, which can take from 30 minutes up to a full day. Hospitals, resorts and wealthy residents have a generator that can be switched on in minutes. The Kenyan Power and Lighting Company (KPLC) is the only grid power supplier in Watamu, so there is no back-up company. Local Watamu citizens are experiencing more and more black-outs over the last years, and accuse the KPLC for negligence and poor back-up options (SKanyara, 2022). Solar power is still too expensive, some people use very small ones to power their light, see figure 8.

Figure 8. Solar panel on mud house

The digital infrastructure is rising quickly in Kenya. 42% of Kenyan citizens use the Internet (Kemp, 2022). During the field study it became clear that almost everyone in Watamu has a phone, either a simple phone or smart phone with internet excess. They also use their phone number to pay, this is called M'Pesa (mobile money in KiSwahili). When asking around it was found they really rely on their phones and it gives them a sense of freedom.

The roads in Watamu are observed during the field study. The main road is made of concrete, and has many speed bumps. All the side roads are made of roadsand, and are poorly maintained with many holes. People travel around per motorcycle, tuktuk or car seen in figure 9.

Figure 9. Transportation in Watamu

People

The people of Watamu are very practical. It was found that they learn quickly by doing. They don't really tend to question why something is done a certain way, as long as it works it's good. They also follow by example, when someone else is doing something that works, it is being reproduced. They really have a go-getter mind set trying to find any way to make money and provide for their family. The new president William Ruto has told the Kenya citizens, especially the youth, to start "hustling". Try to find all possible ways to make money. The criminal activity in Watamu is low, because the citizens know when the village gets a bad reputation tourists will stop coming.

Conclusion

There is a lot of room for improvement considering the living conditions. The poverty numbers are higher compared to the rest of Kenya and there is gender inequality and more youth unemployment. Their local economy is very dependent on tourism making it an unstable economy. When there is no more tourism due to externalities like the COVID crisis, the local economy collapses resulting into horrible living conditions.

This poverty is seen back withing all other researched areas. Struggling to pay basic needs and proper housing, unstable electricity supply, bad roads and the hustling-mentality.

Insights

- Many citizens are very poor and struggle to get by day to day, the poverty rate in Kilifi county is 48.4%
- 50% of the income in Watamu is generated by tourism, depending on it creates an unstable economy
- The climate is hot-tropical. A lot of sun with average temperatures of 30°C during the day, and 23°C during the night
- They experience very regular power cuts and solar energy is still too expensive
- Almost everyone has a phone, which they use for paying as well. The younger generation has smartphones
- The roads are not asphalted and very bumpy
- The means of transportation are cars, tuktuk and motorbikes
- The people have a learning-by-doing, following by example and hustling mentality

2.4 EcoWorld

Now there is a clear understanding of the location of the project, it is important to get to know more about the company. Ecoworld already exists for 7 years and is growing. But what kind of company is it, and what are their resources?

Company
EcoWorld was founded by Steve Trott, an English man who moved to Watamu 22 years ago on a marine biology project. About 50 people work at Ecoworld. The management team exists of Steve and Karen as operational manager. At the moment they have 2 interns, Morris and Helen, helping out with management tasks. The management team and machine operators are on a monthly pay-roll. The other staff is working on daily income. EcoWorld is a social enterprise, all the generated profit goes back into the company.

Their vision, pillars and mission are seen on figure 10, now they will be further elaborated (Trott, 2021).

Vision
The vision of EcoWorld is : "Leading change and igniting the plastic waste circular economy in coast province Kenya". As said before the poverty rate on the coast is high. Next to Watamu, recycling and remanufacturing can also spark economic opportunities and self-sufficiency in the other coastal areas. The plastic waste pollution isn't restricted to Watamu, and plastic waste management is lacking along the entire coast (UN Habitat, 2022). Therefor the vision of EcoWorld is to expand its operations.

Pillars
EcoWorld has 4 pillars in their mission:

Pillar 1. Supply Chains
Expanding collection networks. Up-skilling processes to scale up feedstock volume and quality to meet supply demands and drive the circular economy.

Pillar 2. Market
Strengthen & extend key partnerships to generate market demand for quality remanufactured products, fortifying the system transition to a circular economy-based Net-Zero Plastics Waste Management model.

Pillar 3. Socio-economic
Women-championed 'waste to value' livelihood opportunities plus value-adding artisanal SMEs nurtured to ignite the micro- and macro-circular economy for plastic waste. Facilitate towards a local self-sufficient and independent community.

Pillar 4. Environment
Targeted tracking measures & monitors specifically for ocean-bound plastics leakage at key coastal hotspots, marine plastics pollution and landfill usage levels. Eradicating plastic waste pollution from the environment.

Mission
Their mission is also displayed in figure 10. EcoWorld strives to demonstrate a systemic, viable and replicable model so it can more easily be implemented along the entire coast of Kenya, or even other coastal areas in the world since the challenges are global,increasing its impact potential. Working towards an inclusive and women-centered model is to ignite and empower the minority groups in Kenya. The social, economic and environmental pillars ensure a holistic approach to sustainability.

For the next step in growing their business they want to develop valuable remanufactured plastic waste products. The goal of doing so is not only to generate business, but also to unleash livelihoods in Watamu and cleaning the environment. Generating market demand for quality remanufactured products will create opportunities towards a local self-sufficient community.

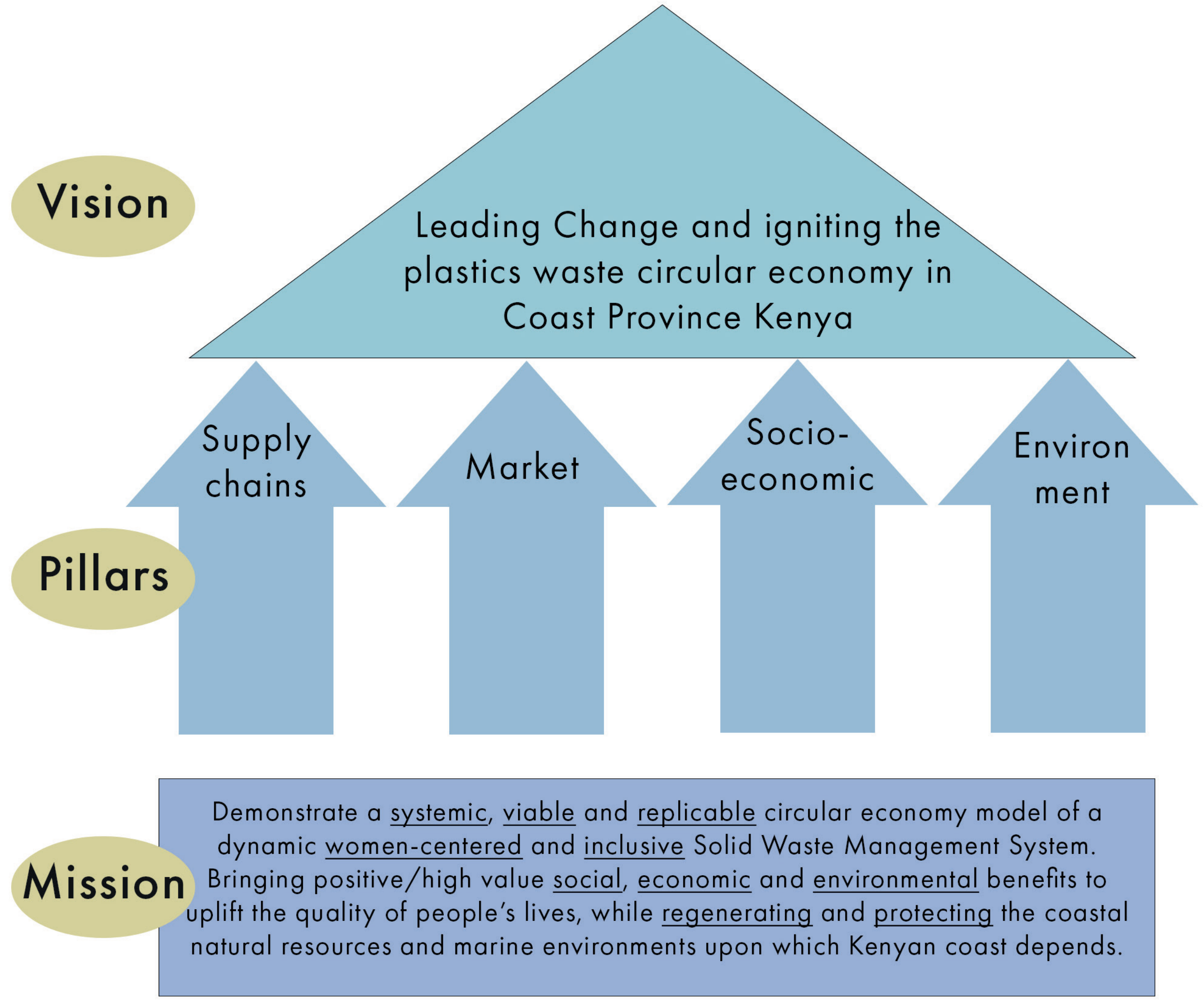


Figure 10. Vision, pillars and mission of Ecoorld

Value stream

In this paragraph the current value stream of EcoWorld is described. The plastic waste comes in through a "weight-and-pay" scheme, from beach clean-ups, local residents and hotels. It is processed at the Eco-World sight in Watamu and stored or sold as recyclates. The figure 11 shows an overview of the value stream. The red numbers are the costs and the green is revenue. The stakeholders are drawn, with the description underneath. The yellow circles is the EcoWorld's added value for that stakeholder.

Two stakeholders that are not mentioned in the visual, because they are more on the background, are; the government and grand givers. They are needed for approving certain project plans and to generate funds for investment. EcoWorld's value to them is:

The government

- Agility for testing disposal and collection systems
- Advocacy of evidence-based circular approaches

Grant givers

- CSR / EPR responsibilities promoting and publicity

Legend:

Value proposition EcoWorld

Incoming money

Outgoing money

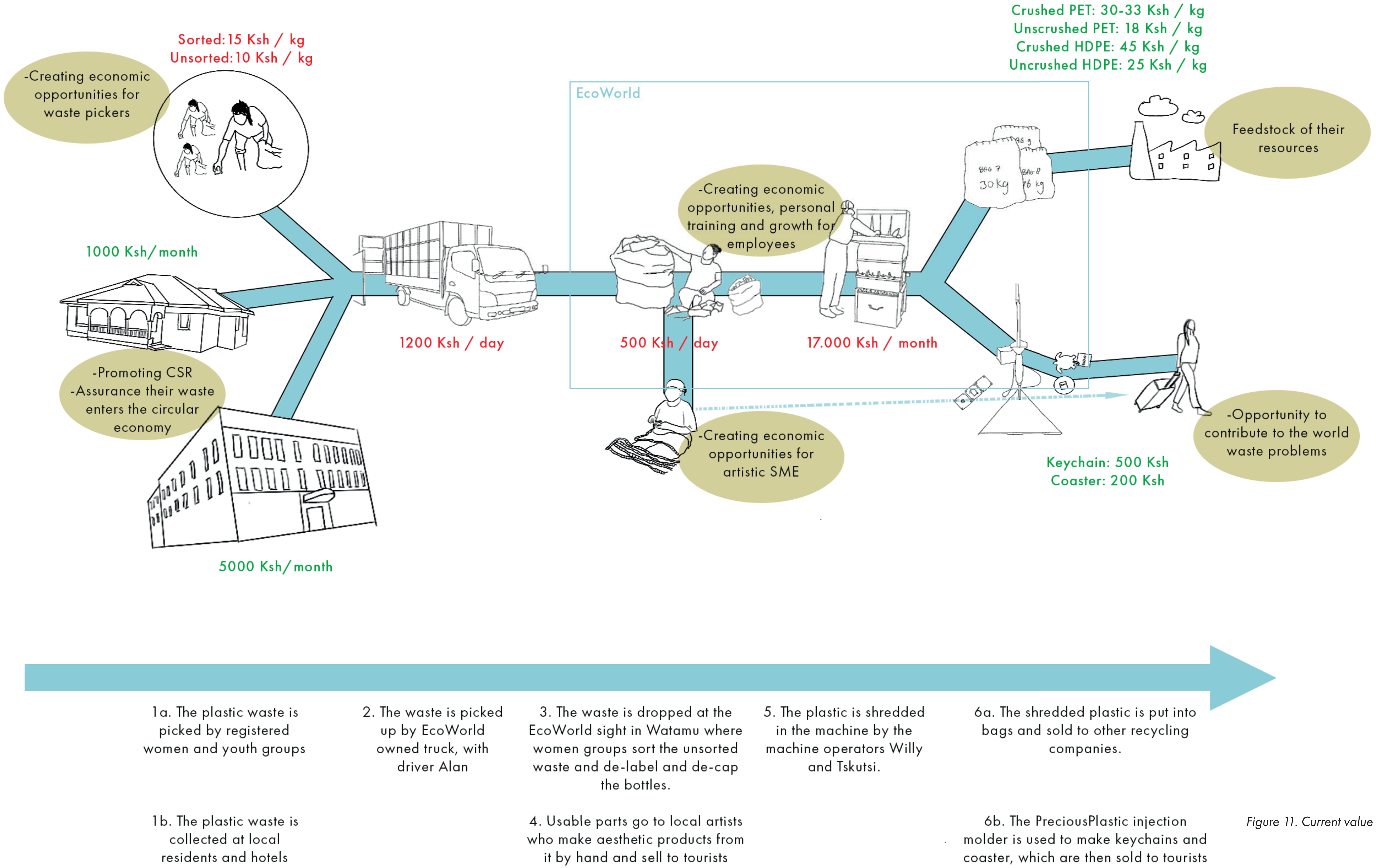


Figure 11. Current value chain of EcoWorld

Machinery
The machines available at EcoWorld is shown in figure 12.

- The HDPE shredder processes 3000kg per day
- The PET shredder processes 3000 kg per day
- A PET bailing machine that processes 1000 KG per day
- The precious plastics injection moulder
- Standard tools like pliers, cutting machine, cutting knifes, saw, drill

The machines run on three phase power, 240V and are operated by specifically trained machine operators. The Precious Plastic moulder is only used from time to time, by higher skilled and trained employees in the management team.

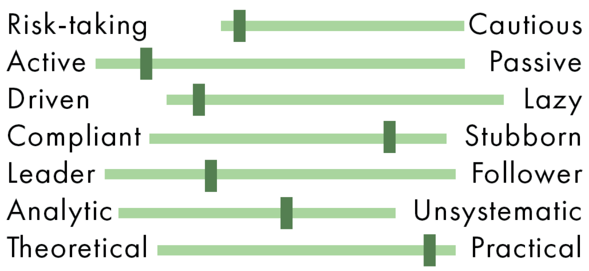
Figure 12. Machinery at EcoWorld

Fundi Willy
Since the machine operators are specifically trained employees, it is needed to get a good understanding of what kind of person they are. The machine operators will be the ones to interact with the final design. Willy is one of them, he is used to create the persona in figure 13 to understand his drivers and possible interaction with the designed solution.

Willy
Age: 64
Lives in: a one room house in Watamu village
Family: 5 children from age 12 to 28
Occupation: Machine operator at EcoWorld
Pay: 17.000 Ksh / month
Side hustle: Making drink-glasses from glass bottles

Bio
He started working as a beach operator, then he became part of the beach cleanup team. He worked his way up to machine operator and works at EcoWorld already since the beginning.

Personality



Motivation
He likes to learn new things and become a fundi at something.
He always tries to find new opportunities of making money.

A fundi is an expert in something without the official papers

Dream
Willy wants to work abroad for 5-7 years so he can save around 700.000 Ksh. With the savings he wants to start his own petrol station.

Frustrations
People that do not do their work properly.
The struggle of paying his basic needs everyday due to inflation.
Corruption and the government, they don't take good care of Kenyans.

Figure 13. Persona of machine operator

Conclusion

Conclusion

EcoWorld is a social enterprise and all of its profits go back into the company. Their mission is to create a plastic circular economy in coastal Kenya, focusing on economical, environmental and social aspects. In order to grow they invest in machinery, like shredders en bailing machines. The machine operators are specifically trained to use them. Willy, one of the machine operators is used to create a persona to understand his possible interaction with the final design. He is hard working, very practical and want to do things his way. He doesn't question reasons, instead he just tries everything to get the desired outcome.

The plastic waste comes in through local waste pickers and contracts with residents and hotels. At the Eco-World sight in Watamu women groups sort the waste. Only HDPE and PET are sold to bigger recycling companies, and HDPE keychains and coasters are sold to tourists to generate a bit of revenue. Part of EcoWorld's mission is to develop valuable remanufacturedv products to create an independent local economy with stable business opportunities.

Insights

- The waste comes in through a weight-and-pay scheme and contracts with local residents and hotels.
- HDPE and PET recyclates are sold to bigger recycling companies.
- The PET shredder and HDPE shredders process 3 tonnes per day. Their PET bailing machine processes 1 tonne per day.
- They want to develop remanufactured products to create a self-sufficient local community and create SME opportunities.
- The machine operator is very practical and works through trial and error

2.5 Plastic waste composition

The main component for this project is plastic waste. In order to work with this resource, the composition and availability needs to be researched. This paragraph looks into the waste in coastal Kenya as well as zooming in into EcoWorld's specific situation.

Coastal Kenya waste

In Mombasa, the second biggest city of Kenya with 1.3 million inhabitants, 81 tonnes of plastic waste is generated daily (WWF, 2022) There is no specific data available on the generated plastic waste in Watamu, however considering they are both coastal areas a rough estimation is made based on the waste per capita of Mombasa. 81 tonnes plastic waste per 1.3 million inhabitants, makes 1.9 tonnes per 30 thousand inhabitant of Watamu, generated per day.

In Kenya the waste management is usually the responsibility of the municipal authorities, however these entities fail to meet the required standards as managing the waste is often beyond their capacity. The waste collection trucks are unable to reach collection points due to poor roads, there are financial challenges to pay the workers and often trucks are out of service leaving the waste piling up (Henry et al., 2006). In Watamu there is no plastic waste management initiated by the municipal authorities. During the field trip it was observed everywhere you look you see plastic waste in the environment. Locals just don't know what to do with it, ending up just throwing it anywhere or burning it. The chart in figure 14 shows what is done with the waste in Watamu.

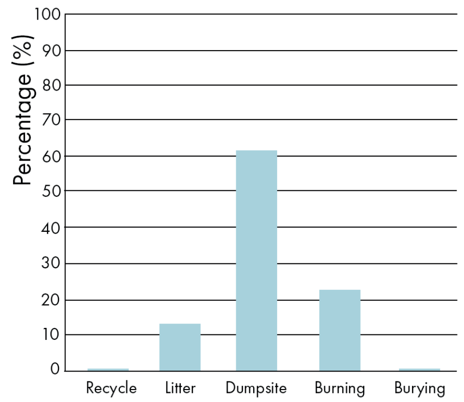


Figure 14. Plastic waste processing in Watamu (Gwada et al., 2019, p91)

Most of the plastic waste ends up on dumpsites. These dumpsites are often not well-managed and overflowing. To manage the amount locals burn the plastic causing toxic fumes to enter the atmosphere (Woima, n.d.). The dumpsites used in coastal Kenya are Kibarani and Mwakirunge, both around Mombasa city, see figure 15.

Figure 15. Mwakirunge dumpsite (Nassir, 2021)

By observation it was seen that most of the plastic waste in the environment in Watamu is low-value plastic. That is LDPE, PP or multilayer plastics (MLP) seen in figure 16. These plastics have low value due to limited acceptance at recycling facilities lacking the necessary technology and innovations to put these plastics back in the loop (Thanal, 2020).

When asking around a couple of reasons were given:
"We can't reuse it to put water or something in"
"I don't know where else to put it"
"Why not, what does it matter, who cares"
"No-one wants to buy it"

Apparently it is not only a matter of lacking a waste management system and value, but also lack of awareness and knowledge. In Watamu EcoWorld is not the only one that buys plastic through the weight-and-pay scheme. There are self-employed waste brokers who are willing to work with anyone that picks waste, however they pay unfair wages of 10 Ksh/kg.

The waste is not always just discarded or burned, sometimes the people in Watamu make something new and useful out of their waste. Mostly for storage of water, oil or other foods (Gwada et al., 2019).

Other innovative ideas are making a plant pot, or art pieces that are sold on the beach to tourists seen in figures 17 and 18.

Figure 16. Low-value plastics in Watamu nature

Figure 17. Plant pot from old jerry can in Watamu

Figure 18. Shark from flipflops and drift wood at Watamu beach

EcoWorld waste

EcoWorld processes 5-10 tons plastic waste per month. As stated in chapter "value chain" the waste comes in through residents and hotel collection or the 'weight-and-pay' scheme. For the latter they collaborate exclusively with Women and youth groups. This has two reasons, first these are the disadvantaged population groups in Watamu. Secondly because it was advised by the locals, they said when working with anyone the plastic waste picking will get out of control with incidents like fighting over the waste or even steeling it from each other or residents. By working exclusively with acknowledged Women and youth groups the situation is mitigated and controlled. The waste is either sorted or unsorted, the amount the pickers get paid depends on whether it is sorted or not. (15Ksh/kg vs 10Ksh/kg) The remaining sorting is done at EcoWorld by Women groups, see figure 20 on the next page. Since the sorting is done manually, the women are trained to identify the plastic sort. However this still leaves room for human error, so the waste piles can't be assumed to be 100% monoplastic. The women are casual workers meaning they get paid per day and are not on a payroll.

When the waste comes in it is carefully monitored and the quantity per waste type is written down in a ledger. Also tin and glass enters Watamu, the tin is sold to scrap dealers for 10 ksh/kg and glass is currently not sold but stockpiled. In figure 20 the waste composition of the year 2022 is displayed.

The total waste coming in that year was 92 tonnes of waste. As seen on the graph the plastic waste coming in most is PET. From interviews and observation it became clear that plastic bottles are also extracted most from the environment, since it is easiest to pick and sort. Also it is promoted mostly amongst the waste pickers since it has high market value. As mentioned before the PET and HDPE are sold to recycling factories. The unsorted incoming waste contains mostly PP plastic, however PP is piled and stored because there is not yet a market for. It is stored on the other side of the road.

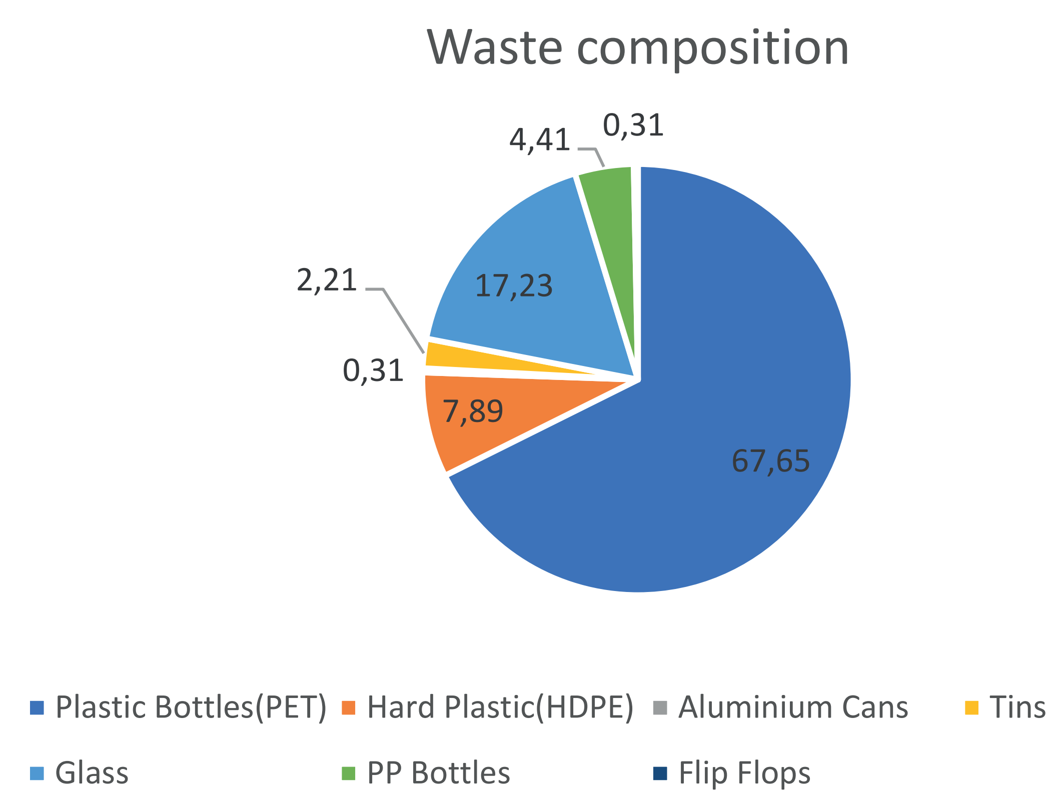


Figure 19. Plastic waste composition EcoWorld (EcoWorld, 2022)

Figure 20. Women groups sorting the waste

Conclusion

The waste that is still found in the environment in Watamu are mostly low-value plastics like LDPE, PP and MLP. That is because PET and HDPE have higher market value and are easier to grab, like low hanging fruit. Also the waste pollution is not only due to the lack of waste management systems but also the lack of awareness and knowledge. EcoWorld however does except other waste like PP as well, in fact most of the unsorted waste coming in is PP. It is piled up since there currently is no market for. In total 5-10 tons of plastic enter EcoWorld per month, with PET by far the highest quantity.

Insights

- In Watamu the most seen plastics in nature are low-value plastics like LDPE, PP and MLP.
- The plastic waste in nature is not just because the lack of waste management systems, also due to lack of knowledge.
- At EcoWorld the plastic that comes in most is PET.
- PP is piled up without any use yet.
- 5-10 tons of plastic enter at EcoWorld monthly.

2.6 Buildings in Watamu

The goal of this project is to find remanufactured plastic waste building material. To find a fitting solution the current building desires and methods in the context have to be analyzed. This chapter describes the current building situation in Watamu, as inspiration for solution opportunities.

Current buildings

There are two main ways of construction in Watamu. The poorest live in houses made of wood and mud see figure 21a, and others in houses made of coral blocks see figure 21b. The roof is either dried palm leaves or corrugated iron sheet. It was found that the type of house has a cultural meaning, people want to upgrade their house from mud to stone as soon as they can, since it has a cultural meaning of higher economic status.

Figure 21a. Wood and mud house in Watamu

Figure 21b. Coral blocks house in Watamu

Schools
As defined in the project scope the focus of this project is using the designed building material for community buildings and schools. The currently used construction materials for building those buildings are used as benchmark for the final design. In the end the final designed material should be able to replace one of currently used materials in school or community buildings. In figure 22 all elements and it's material is shown. The schools and community buildings are all one-story buildings, and the average size is 15x5 m with a wall height of 3 m.

Figure 22. School building In Watamu with building elements

Origin of material
Iron roofs, coral stone and cement are all produced starting with raw material quarrying in Kenya. The negative impacts of quarrying are the degradation of land and vegetation and health issues for the workers (Ming'ate & Mohamed, 2016). Other environmental impacts are fugitive emissions of dust and fumes from quarrying equipment, negative impact on surrounding flora and founding, noise and vibration (Serrat, 1994). The raw material has to be processed, which costs a lot of energy and heavy machinery. With the production of cement a lot of CO_2 is emitted due to chemical processes (Rodgers, 2018).

For the coral stone quarry there are often strikes, the workers feel badly treated and payed, receiving only 1 Ksh per block. Often strikes happen due to low wages and unhappiness of the workers (Mwema, 2016). Using the machines is also dangerous, causing workers to hurt their fingers and nails (Hilson, 2003). Opposed to iron and cement, coral stone is a biomaterial. It originates from fossilized coral found in the ground in coastal areas. Coral stone was formed along the coast in the Pleistocene period, starting from the corals, fossils, and other marine animals, the majority of the coral limestone has originated in the reefs. It is a fossil material meaning it will run out eventually (Diez & Herrera, 2011). Already huge "scars" on the quarry land in Kilifi are visible. The blocks can either be hand cut, or machine cut, see figures 23 and 24. The machine cut blocks are used most often since they are bigger and easier to work with. The compressive strength of one block is 12.9 MPa (Ochieng, 2012) and the production for one block consumes 5.55Kwh energy (Experimental Plant, 2020).

The wooden beams are a natural resource, but the production of the beams still have negative impacts on the environment. Harvesting the raw material leads to loss of diverse and natural ecosystems and deforestation. The processing also costs a lot of energy (Ramage et al., 2017).

Figure 23. Hand cut coral blocks quarry Lamu (Lorgnier, n.d.)

Figure 24. Machine cut coral blocks quarry in Kilifi (Prima, 2021)

Building costs

The figure 25 gives an overview of the costs of a coral block building like a school. The building costs can be divided into two parts: materials and labour. The total cost of building with coral block calculated per block is named the "coral block equivalent". The block, cement and labour together is 138 Ksh/block.

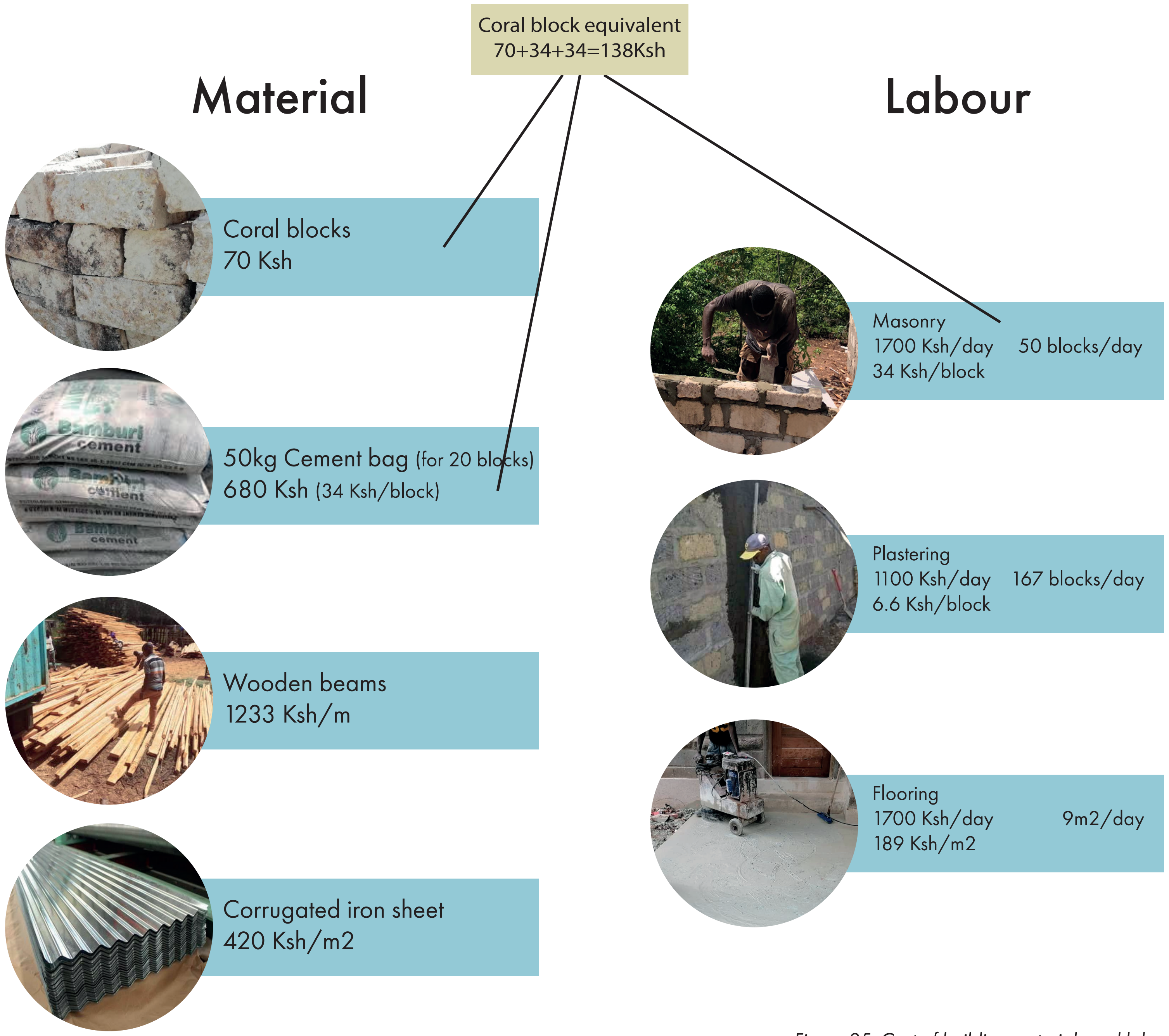


Figure 25. Cost of building materials and labour (Chengo, 2022)

The challenges

The current building methods in Watamu come with some challenges.

Required skill

To build a house prior knowledge and skill is needed on making and using cement, building straight and solid walls and other building basics. The building-owner can't build the house by themselves, making it more expensive because it requires a Fundi. A Fundi is a person that is very experienced in a certain skill, but does not have the official schooling and papers for it.

Degradation

The environmental elements create wear and tear of the blocks when it is not maintained or plastered accordingly. The coral blocks degrade because of the wind, see figure 26. Holes appear and sand and grassroots enter the holes. That causes the brick to crack and eventually fail. This process takes about 10-20 years.

Time consuming

When building the wall, only 3-5 layers per day can be built, see figure 27. To prevent the wall from bending, the cement has to dry until it is strong enough to put new layers on. So it is a time consuming process. Also the blocks are quite heavy, 12-17 kg, making it a physically hard job for the Fundi.

Corrosion

The roofs are made of corrugated iron sheet. Iron is prone to rusting resulting into corrosion over time, see figure 28. It is not just rain and wind that damage the iron sheets, it is also caused by corrosive air pollutants which is become worse in the future (Omanga, 2014)

Cracks in mud walls

Mud walls show cracks over time, see figure 29. They appear quickly due to the interaction with the environment. Especially the rain and damp which introduces soluble salts into the mud causing it to expand and split. The mud walls also degrade due to other environmental factors such as wind and biological factors like penetration of plant roots, burrowing of rodents and insects (Friesem, 2011). This all can be mitigated slightly by intensive maintenance like mending the cracks as soon as they appear. However this is a very labour intensive process and not carried out accordingly due to lack of skill and knowledge (Eze, 2018).

A study shows that people living in a house made of mud are more prone to getting mosquito born diseases like malaria, due to openings and cracks in the walls and roof (Ondiba et al., 2018).

Figure 26. Coral block degradation

Figure 27. Masonry fundi laying coral blocks

Figure 28. Corroded iron sheet

Figure 29. Mud wall with crack

Also climate change causes more extreme weather patterns, resulting into increasing danger of floods in Kenya (Opere, 2013). A mud building is very vulnerable to floods, the building will be destroyed completely (Shah, 2013).

Conclusion
The buildings in Watamu are either made of wood and mud, or coral building blocks and cement. The roof is dried palm leaves or corrugated iron sheets. Having a house of coral blocks also has a cultural meaning: showing you have money to build it. However in reality this way of building is to expensive and many buildings are left unfinished or take up to 5 years to finish. The main components of a house roof, bricks, beams and flooring. For all materials the production has a negative environmental impact. There are some challenges concerning the current construction methods like required skill, time consuming, cracking, degrading or corrosion.

Insights
- The two ways of building is wood and mud, and coral block with cement
- It takes a long time for someone to finish their house due to lack of budget and skill
- Schools and community buildings are 1 story high and made of machine cut coral blocks
- Main building components of a school building are roof, bricks, beams and flooring.
- A machine cut coral block has a compressive strength of 12.9 MPa
- Mud and wood houses degrade over time leading to diseases and loss of house.
- The most used coral block equivalent is 138 Ksh

2.7 Insights overview

The project assignment was:
"Enhance local self-sufficiency and unleash livelihoods by introducing a plastic waste pollution solution: re-manufacturing plastic waste into building materials."
In the discover phase a lot of context is analyzed forming an in-depth understanding of the foundation of the assignment. All of that information is summarized into insights concluding the discover phase. All the diverged information now will be converged into a specific design direction in the next chapter "define."

Total list of insights
Plastic waste:
- Plastics are flammable, the fire resistance is depending on the type of plastic
- The plastic waste pile continues to grow
- Plastics are not bio-degradable, they degrade overtime into smaller particles called micro-plastics
- Polluted beaches and environment is bad for tourism
- Existing plastic waste building material are an inspiration of the feasibility of the project

Watamu:
- Many citizens are very poor and struggle to get by day to day, the poverty rate in Kilifi county is 70,8%
- 50% of the income in Watamu is generated by tourism, depending on it creates an unstable economy
- The climate is hot-tropical. A lot of sun with average temperatures of 30 degrees during the day, and 23 during the night
- They experience very regular power cuts and solar panels is still too expensive
- Almost everyone has a phone, which they use for paying as well. The younger generation has smartphones
- The roads are not asphalted and very bumpy
- The means of transportation are cars, tuktuk and motorbikes
- The people have a learning-by-doing, following by example and hustling mentality

EcoWorld:
- The waste comes in through a weight-and-pay scheme and contracts with local residents and hotels.
- HDPE and PET recyclates are sold to bigger recycling companies.
- The PET shredder and HDPE shredders proces 3 tonnes per day. Their PET bailing machine processes 1 tonne per day.
- They want to develop remanufactured products to create a self-sufficient local community and create SME opportunities.
- The machine operator is very practical and works through trial and error

Waste composition
- In Watamu the most seen plastics in nature are low-value plastics like LDPE, PP and MLP.
- The plastic waste in nature is not just because the lack of waste management systems, also due to lack of knowledge.
- At EcoWorld the plastic that comes in most is PET.
- PP is piled up without any use yet.
- 5-10 tons of plastic enter at EcoWorld monthly.

Buildings in Watamu
- The two ways of building is wood and mud, and coral block with cement
- It takes a long time for someone to finish their house due to lack of budget and skill
- Schools and community buildings are 1 story high and made of machine cut coral blocks
- Main building components of a school building are roof, bricks, beams and flooring.
- A machine cut coral block has a compressive strength of 12.9 MPa
- Mud and wood houses degrade over time leading to diseases and loss of house.
- The most used coral block equivalent is 138 Ksh

Opportunities
The research has identified different opportunities for the solution space of the assignment. The school buildings in Watamu contain basic building components: Roof, walls, beams and floor. The research shows all four component can be created from plastic waste material. Additionally the resources for all four elements currently have a negative social and environmental impact. In the next chapter "define" a design direction will be chosen from these opportunities.

3. Define

The insights from the discover phase have identified the opportunities for designing remanufactured plastic waste building material. In the Define chapter all the information is converted into a design direction decision which will be the start of the design phase.

Chapters:

3.1 Design direction

During the discover phase multiple opportunities where identified for remanufacturing plastic waste into building materials. The TBL framework (Social, Environmental and Economic) is said to be used to create focus throughout this project, so in this chapter it is used to measure the value each possible direction. The design opportunities are evaluated on advantages and disadvantages compared to each other within the TBL framework.

The TBL questions were:

- *Social:* Does the final design positively impact the local people of Watamu, and in what ways?
- *Environmental:* Does the final design provide environmental gain compared to the current situation and in what ways?
- *Economical:* Does the implementation of the final design provide economical gain compared to the current situation and in what ways?

From the research it became clear that the basic components of a school building in Watamu are: Roof, floor, wall and beams. Mining of iron, cement quarry, coral stone quarry and cutting wood all have a negative impact on human and planetary health. Ideally all of them are replaced with something with a less negative social and environmental impact. The ambition of EcoWorld is to build an entire building out of plastic waste, but reaching that goal has to be done step by step. Therefore one building element is chosen to focus on.

The four elements are evaluated within the TBL framework during a co-creation with EcoWorld.

Social

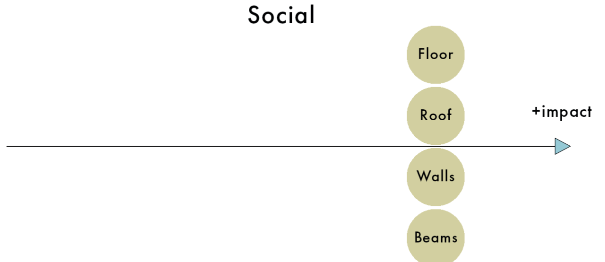


Figure 30. Social impact of the building elements

First the social aspect. All four elements are expected to have an equal impact on the social well-being of the Watamu citizens. The four elements are all crucial for building a school.

Environmental

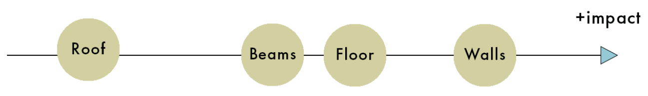


Figure 31. Environmental impact of the building elements

Secondly the environmental aspect. Here some difference is expected. The roof is constantly in immediate contact with environmental factors such as UV, wind and rain, making it more prone to degrading into microplastics compared to the other elements. You can argue that bricks are more in contact with these factors than the beams and floor. However considering the fact that the quantity of bricks needed compared to the other elements is significantly more, it is expected that a lot more plastic waste can be captured in walls than in the other elements. Therefore the wall in comparison is expected to have the most positive impact on the environment.

Economical

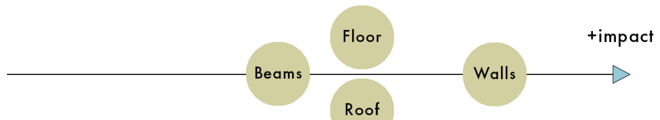


Figure 32. Economial impact of the building elements

Lastly the economical impact. In this category the measurement is based on the quantity again. The plastic waste material that goes into the different elements is assumed to have the same cost/kg. Since the quantity of bricks in a wall is higher than the other elements it is expected to generate more economical opportunities for local entrepreneurs and EcoWorld.

One other interesting insight derived from the "discover" phase is the fact there currently is no market for PP plastic yet, however it is collected by Ecoworld. They currently have a huge stockpile on the other side of the road and there is still a lot of PP plastic in the environment. That is a big opportunity for this design project, giving value to a low-value plastic that does not have a purpose yet.

To conclude, considering the quantity of bricks in a bricks is much higher than the other elements, the wall is expected to have the most positive impact environmentally and economically. Additionally using PP creates new value too. Therefore it is decided together with EcoWorld to continue focusing on developing a building brick from PP plastic.

3.2 Program of requirements

From the list of insights and the chosen design direction a program of requirements is derived, for elaborations see appendix 7.1. This list is the first version made and is used as a starting point of the create phase.

Category	Number	Wish/ req	Description
General	1.1	Req	The implementation of the brick should provide benefits to the social well-being of Watamu citizen
	1.2	Req	The Implementation of the bricks should provide environmental gain in Watamu
	1.3	Req	The implementation of the brick should provide economical gain to EcoWorld and the people of Watamu
	1.4	Req	The brick should have a compressive strength of at least 12.9 MPa
Material	2.1	Req	The brick should be made from plastic waste
	2.2	Wish	The brick should be made from PP plastic
Cost	3.1	Req	The brick should be cheaper than 138Ksh
	3.2	Wish	The brick should be as cheap as possible
Use	4.1	Wish	The brick should be able to be used by 1 low-skilled person without prior information
	4.2	Req	With the brick it should be able to build an one story building
	4.3	Req	The bricks should be accepted by locals to use as building material
	4.4	Req	The bricks must not fail in outside temperatures between 20-40 ° C non-stop
	4.5	Req	The bricks must not fail after 12 hour sun (UV) exposure
	4.6	Req	The bricks must not fail due to heavy rainfall with a duration of 1 hour
	4.7	Req	The bricks should be fire resistant
Production	5.1	Req	The resources for the production must be available locally in Watamu and surrounding areas
	5.2	Req	The bricks must be produced locally in Watamu
	5.3	Wish	Using the production tools must be straight-forward for the machine operator at EcoWorld
	5.4	Wish	The production tools and machines should only be able to be used the desired way
Repairability	6	Req	The production tools should be repairable by local people
Recyclability	7	Req	At the end-of-life the brick should be reusable again
Energy	8.1	Req	The production process should be able to deal with power-cuts with a duration of 24 hours
	8.2	Req	The production process should be able to resume after a power-cut
	8.3	Req	The production tools should be able to run on three-phase power, 240 V
	8.4	Wish	The production of the brick should consume less than 5.55 Kwh
Transportability	9	Req	The brick should be able to withstand vibrations from transportation on poor maintained roads

Table 1. Program of requirements

3.3 Design goal

Now the design direction and matching requirements are formed the project goal is discussed. The general goal was already decided on in the introduction of this project. Here the goal will be further clarified and expectations are set.

Design brief
The design brief is derived from the project assignment on page , updated with the decision to focus on walls:

Design a remanufactured plastic waste building brick with an accompanying implementation plan that enhances local self-sufficiency and unleash livelihoods while cleaning the environment from plastic waste.

Research questions
The following research questions are based on the feasibility, viability and desirability of this project respectively:

- Can a plastic waste building brick be made at Ecoworld, and if yes, how?
- It is economically possible to produce plastic waste building bricks in Watamu?
- What are the steps EcoWorld has to take to implement the production of plastic waste building bricks?
- What is the social, environmental and economical impact of producing plastic waste bricks?

Approach
In the create phase interviews, observations and literature research is done, as well as co-designing an experimental brick production set-up. This test set-up will be used to experiment with the brick shape and weight, mixtures, costs and to test local opinions and reactions. With that the research questions can be answered, see figure 33. The findings are the foundation of the final implementation plan and roadmap presented in chapter "deliver".

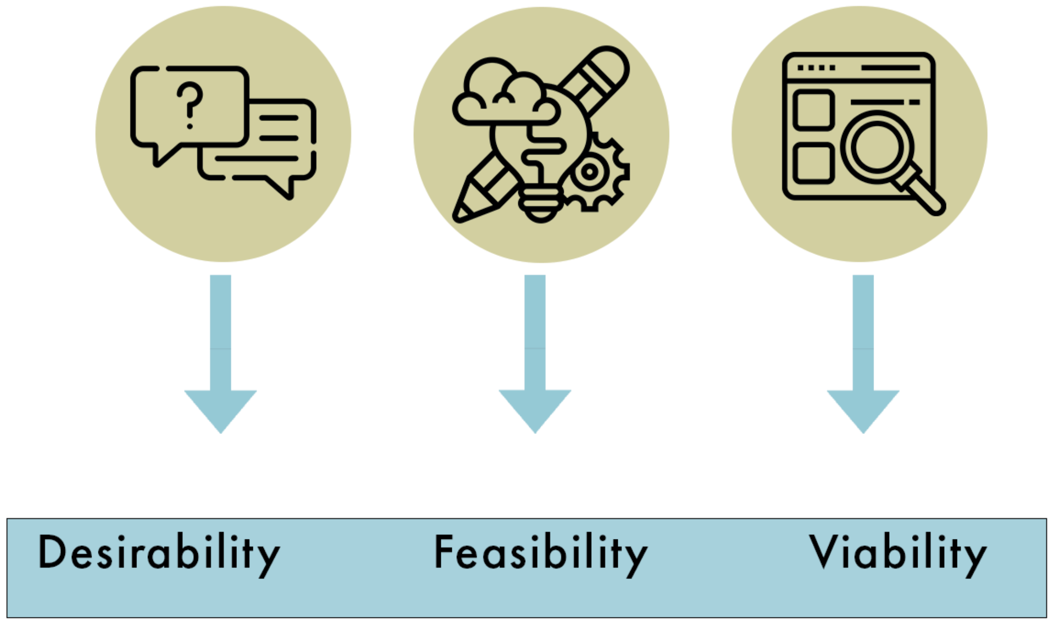


Figure 33. Research questions approach

3.4 Design drivers

In this paragraph the insights found in the "discover" chapter leading to the desirability are converted into design drivers. These drivers seen in figure 34 are the factors that motivate the design process. It inspires to constantly have the TBL impact reflection in mind when making decisions.

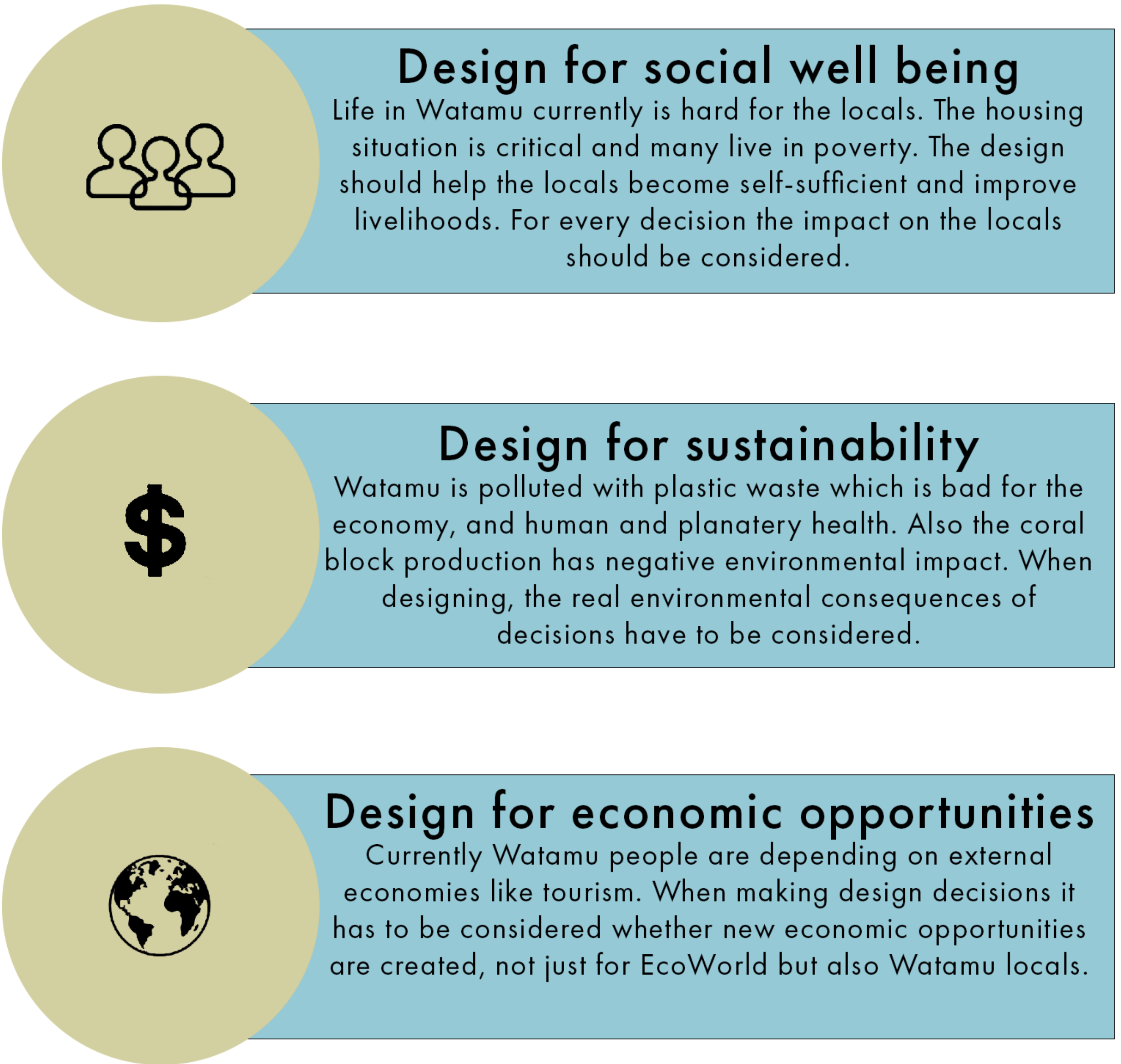


Figure 34. Design drivers

4. Create

From the first research chapters it is now clear the final design will be a building brick from plastic waste. It has been done before, so the design chapter start with a literature review on existing building bricks. Insights are derived from this research that inspire and motive the co-design sessions.

Then an experimental set-up is designed though local co-design to test the final brick shape and weight and mixture composition. Production insights and requirements are derived from the experiments done in Watamu.

Chapters:

4.1 Existing plastic bricks analysis

The housing crisis and the plastic pollution are both global challenges, which makes it quite logical many others have looked into this topic. Great take-aways can be subtracted from this global interest. Therefore a literature study has been executed to get a clear understanding of opportunities and threats when developing a plastic waste brick.

The goal of this literature research is to learn from existing research on plastic waste building bricks. The insights are used as starting point for designing the experimental brick production set-up. The paragraphs are divided in different parts of the plastic waste brick production process, the production, shape, material and acceptance. The aim is to find out what their influence is on the total process.

1. What is the influence of different production technologies?

There are a few different ways the bricks are being made:

1. Injection moulding

The PreciousPlastics plastic waste brick is made with an extruder inserting the molten plastic straight into a mould, see figure 34. It takes 4 minutes to fill the mould, that buildup pressure is not enough causing the plastic inside the mould to cool before it is filled completely leading to cracks. When the mould is taken off the machine, plastic spills out of the gate releasing the pressure needed for density and strength (Talsma, 2021). Also non-uniform plastics mixtures create a problem since they have different melting temperatures which leads to phase separation. This can harm the machine and leads to non-uniform cooling causing cracks (Hubo, 2014). Operating the extruder also requires a higher skill set of machining (Precious Plastics, 2022).

Figure 34. Precious plastics injection moulder (Precious Plastics, 2021)

An other company called Conceptos Plasticos also uses injection moulding, however a much more robust version where gas fire is used as heating source, see figure 35. Between the screw and barrel is enough space for the sand to move, making it possible to use sand mixes. Still the same problems of fast cooling occur (Great big story, 2018).

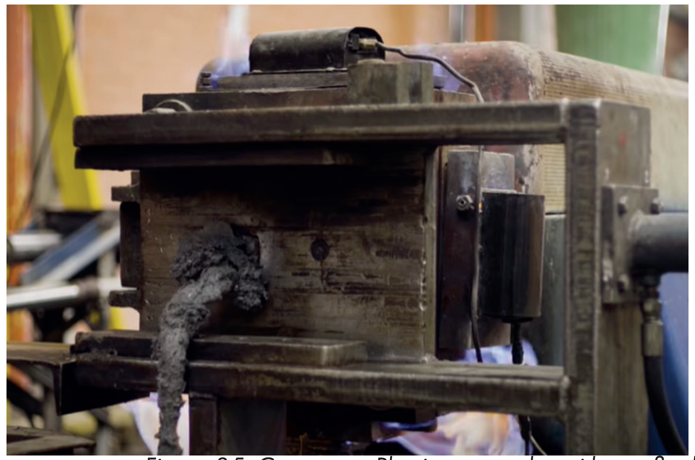


Figure 35. Conceptos Plasticos extruder with gas fire heating (Great big story, 2018)

2. Compression moulding

Nelplast is a Ghanaian company that uses a big extruder machine, they take the molten mix out of the extruder by hand and put it onto a hydraulic press mould, see figure 36. This technique is robust and can operate under less controlled circumstances. Mixed materials can be used (Nelplast, 2020). Research has show that increasing the compression pressure results into higher strength and density (Wei, 2020).

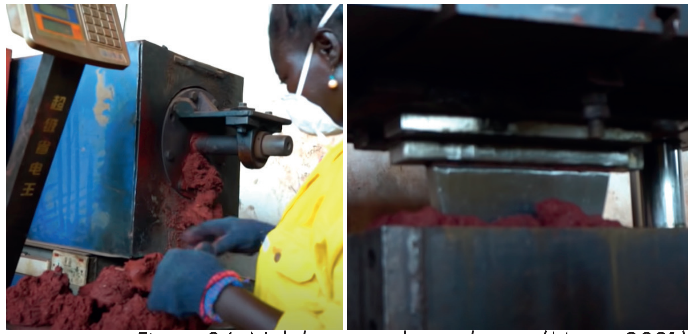


Figure 36. Nelplast extruder and press (Maya, 2021)

3. High steam and compression

The company ByFusion has developed a patented production method using high temperature steam and pressure, see figure 37. They claim the waste doesn't need to be sorted or cleaned. The downside it that little parts of plastic can fall off over time (Brandon, 2022). Since this is a patented technology they don't disclose any information on the specifics.

Figure 37. ByFusion high temperature steam press (CNN, 2022)

4. Mixing mill and mechanical mould

In the previous studies all mixtures are based on the principle of applying heat to melt the plastic parts together, functioning as a binder. The mixing mill however is used for cold applications, where cement is the binder and plastic the filler. The mixture goes into a regular mechanical soil brick press and will have to be cured for about 28 days, see figure 38. This process can be done manually without requiring any energy (Metzker et al., 2021).

Figure 38. Cold brick press (Makiga, 2018)

Conclusion

The influence of the production technology is on vulnerability to external factors such as skill needed, lack of controlled mixture composition and brick strength. Secondly using heat elements or not has a big influence on the final material composition, without heat the plastic is not molten.

2.What is the influence of the shape of the brick?

Currently there are two main groups of brick shapes: interlocking, see figure 39, and non-interlocking bricks. Literature shows using the interlocking bricks results into reduction of building costs due to reduced requirement for skilled labour, saving construction time and reduced requirement of costly material like cement. Research shows the interlocking technique is 24% cheaper per m2 than using conventional bricks (Tyas, 2018). The interlocking bricks structure strength depends on self-weight to resist external loads, meaning the weight plays an important role (Bansal, 2010). At the end-of-use of the brick, the wall structure can be taken apart en rebuild somewhere else.

The disadvantage however is that the joints are not entirely rain and wind resistant, small insects may nest in the open space as well. To mitigate that it is advised to put plastering on the wall (Khan, 2015). Also a small tolerance is needed for the bricks to be stacked, however more layers introduces a potential for tolerances accumulation leading to decrease in strength resistance to external forces (Lacey et al., 2019). Research shows that interlocking plastic waste bricks can not be used for heavy load-baring purposed (Heiniger, 2022).

Conclusion

There are two directions: interlocking and non-interlocking. The interlocking bricks are 24% more cost effective, much easier to use and don't rely on cement. However there is one major challenge; the tolerance needed creates small spaces making the structure more susceptible to wind, rain and insects. Literature has shown that can be mitigated with plastering.

Figure 39. Interlocking plastic waste bricks of Conceptos Plasticos (UNICEF, 2019)

3. What is the influence of the material of the bricks?

There are different directions within material use: Molten plastic mixtures and not molten plastic cement mixture.

Molten

Seven reports about molten plastic compositions are analyzed to find the influence of adding different materials on the compressive strength, see figure 40. It is noticeable that in general sand makes the mixture stronger, however at some point the more sand added the weaker the mixture becomes. There is an ideal ratio curve for each different mixture composition.

Other research states the amount of energy needed to melt the plastic mixture is depending on the amount of plastic inside the brick. This automatically means that a brick made of 100% plastics needs more energy, thus is more costly to produce (Qian et al., 2003).

Not molten

Research shows that it is possible to mix cement with sand. When the plastic is 50% of the mix, the compressive strength is 19MPa compared to 70 MPa without plastic. The more plastic the less strong the bricks is (Siddique et al., 2008). However recycling such brick is currently not possible since the plastic-cement brick production can't be reversed to make a new mix (Gu & Yaseen, 2016).

Conclusion

A lot of literature is available on plastic mixture compositions, showing multiple ways are possible. A few takeaways are:

- The more plastic in the mix, the more energy is needed to melt the plastic
- Sand makes the mixture stronger, but too much sand makes it weaker again, the ideal ratio needs to be found
- Not molten mixtures are not recyclable

When making the decision of which material to use important factors are the local availability of the waste and the local economic opportunities of the material. Different ratios have to be tested to find the ideal composition ratio.

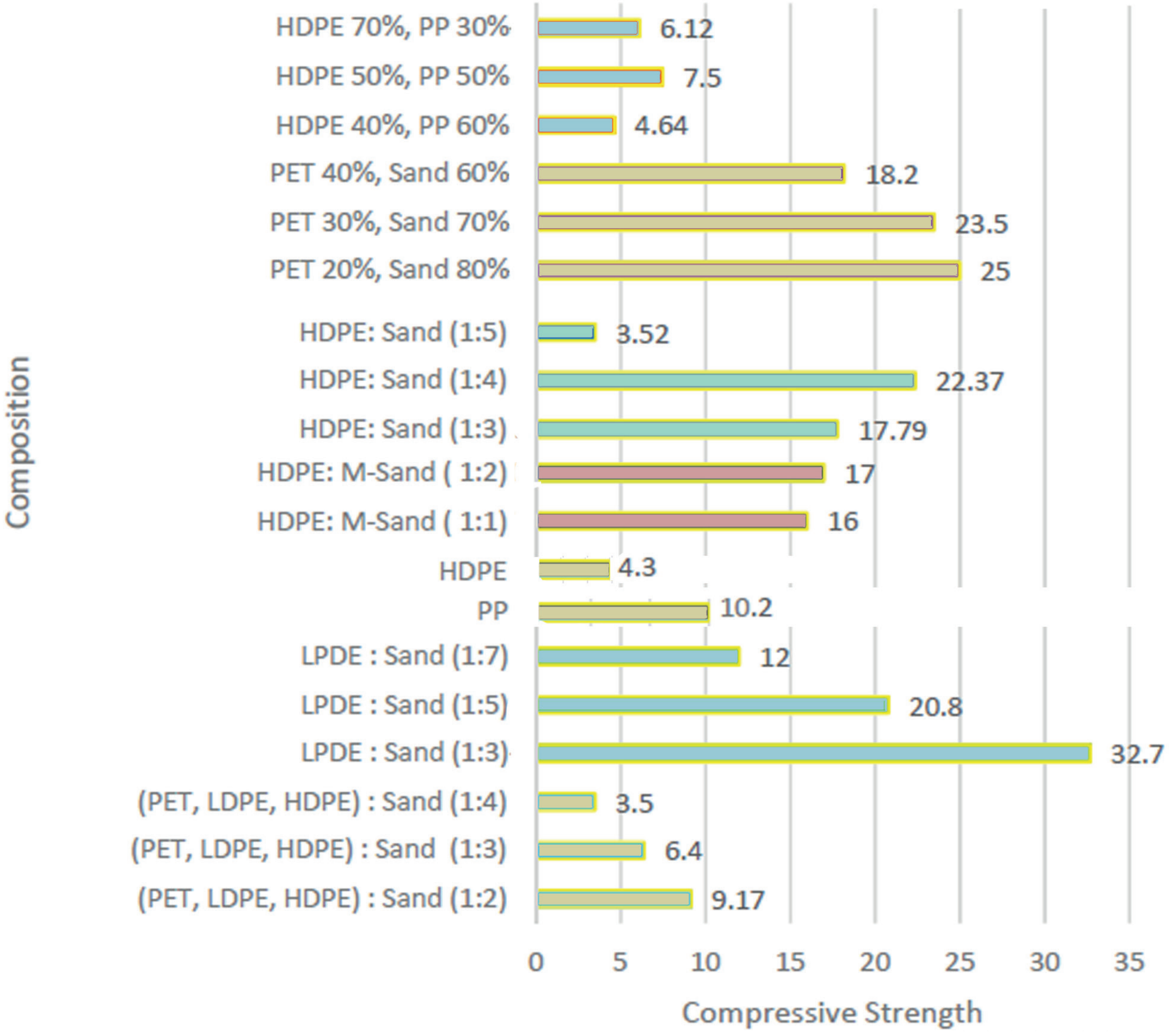


Figure 40. Analysis mixture compositions (Al-Sinan 2022)

4. What is the influence of the local acceptance of the brick?

A study in Nigeria shows the acceptance of living in a house made of plastic bottles. Even though the benefits, some locals found it not acceptable to live in. The bottles were already re-used for other purposes such as storage for second hand oil. Due to this association plastic bottles may be discarded as poor quality. The concern of the locals is the strength and life-time of the house, as it uses novel building material (Oyinlola et al., 2018)

Conclusion

There is not yet a lot of literature on the local acceptance of plastic waste bricks, so it should be well taken into account for the final design in the local context. The study in Nigeria shows acceptance can be a challenge.

Figure 41. Plastic bottle structure in Nigeria (Oyinlola et al., 2018)

The main question

What is the best way to make bricks out of plastic waste in the local setting of EcoWorld and Watamu?

The literature research has shown there are many different ways of making good bricks, with all advantages and disadvantages. The goal of the create phase is to design an experimental brick production set-up to gain insights the brick shape and weight, mixtures, costs and to test local opinions and reactions. From the literature research a few useful insights for the desired goal are derived:

- No energy is required when not melting the mixture
- The machinery used is depending on the local control over the parameters
- Making the bricks interlocking has proven to be more cost efficient and accessible.
- Interlocking bricks can also be used again after it's end of use
- Interlocking bricks have some challenges such as open spacing leading to cracks
- Interlocking plastic waste brick can not be used for heavy load-baring purposes
- Molten compositions are recyclable compared to not molten compositions
- Sand makes the brick stronger in a molten composition, but too much makes it weaker. The ideal ration is found through testing.
- The more plastic inside the molten composition, the more energy required to melt the mixture, also meaning more costly.

Together with EcoWorld it is decided to continue with a molten mixture and an interlocking structure. The environmental advantages outweighs the disadvantages.

4.2 Let's get practical

The context research has let to useful insights, a design direction and requirements. In the first chapters of the"create" phase further research is done to learn from existing literature. Now it is time to get practical.

The design research questions are:

- What is the best suitable mixture composition for a interlocking plastic waste brick for Watamu?
- What is the most suitable shape and weight of the interlocking plastic waste brick?
- How can the interlocking plastic waste brick be produced?
- Can the required tools be sourced locally?
- Can an interlocking plastic waste brick be made by the local employees at EcoWorld?

During the trip to Watamu an experimental brick production test set-up is designed together with the EcoWorld employees. The co-design approach is used to learn from their way of doing things and to make sure the final design and principle is well understood by the local people in Watamu.

All parts are created and produced in Watamu, with locally available materials, skills and tools. The experimental brick production set-up is low-investment and low-skill, so it can be replicated elsewhere. A manual is made to reproduce this experimental set-up.

To get started the production is subdivided into subprocesses, and the morphological chart in figure 42 is made during a brainstorm session with EcoWorld, with the literature research insights as inspiration.

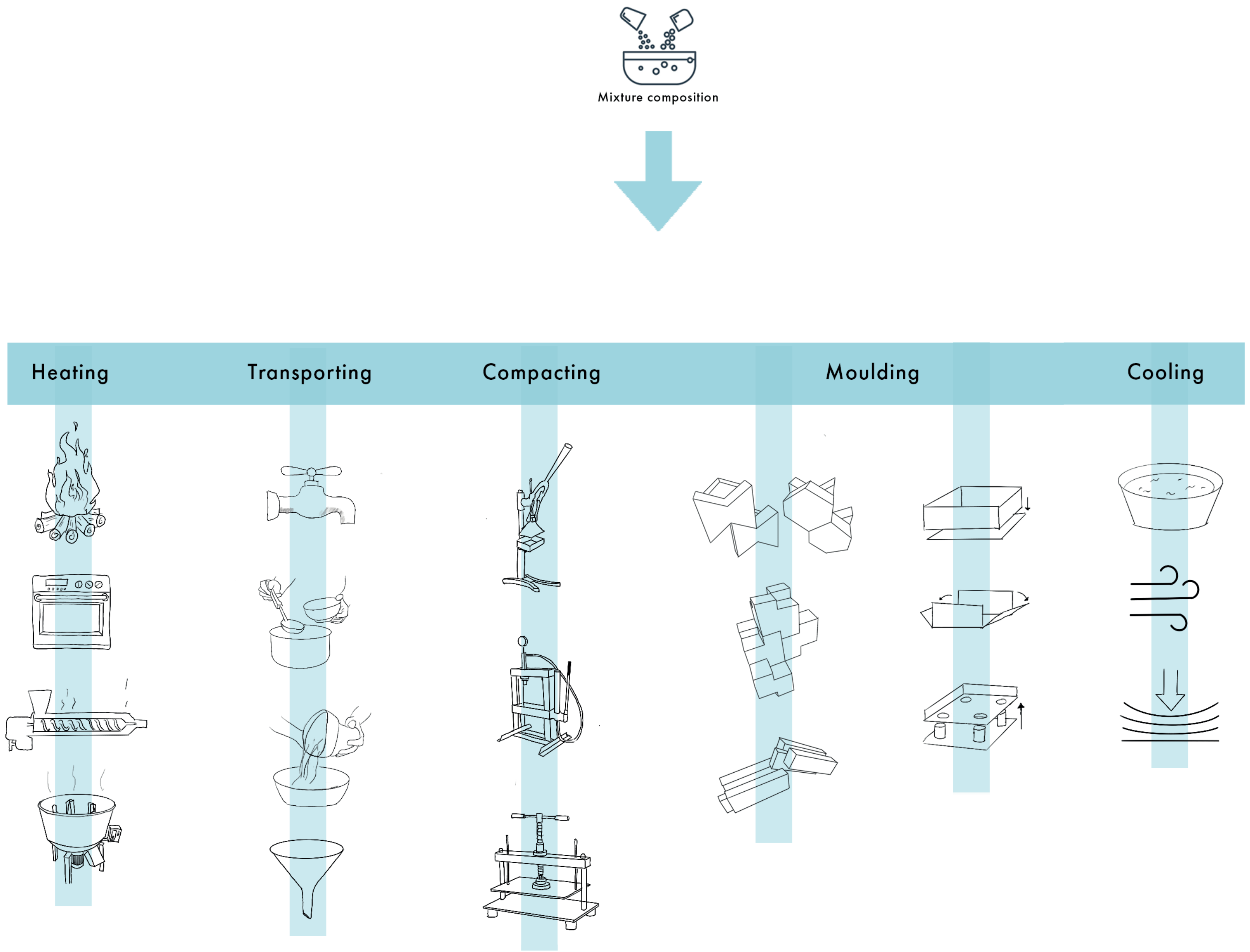


Figure 42. Morphological chart through co-design

4.3 The mixture

The starting point is to test the mix composition. In the program of requirements on page it was a wish to use PP plastic in the mixture. PP plastic does not have any market demand and is stockpiled at EcoWorld. By using PP in the brick it adds value to the plastic, creating more income opportunities for the waste pickers and Ecoworld. There is an environmental benefit as well since PP is still laying around in nature a lot in Watamu. However other plastic mixes are experimented with as well, to find out what their influence is on the mixture and brick performance and if PP is also a suitable option from a performance perspective. At last the compressive strength is tested in the Netherlands to decide on the final mixture.

4.3.1 Different plastics

To find out whether PP is suitable for this application compared to other plastics, experiments have been done with PET, HDPE, and PP mixes. In total 23 mixes were created and experimented. The focus of the experiment was on three different aspects:

- The thickness and workability of the mixture
- The melting and cooling behaviour
- The impact strength and workability of the brick
- The cost of the material

In Watamu rough tests are performed using available tools such as a drill, screwdriver, hammer and a saw. The rough tests gave a good feeling of the material influence on the workability and impact strength of the brick. Testing it locally together with EcoWorld employees facilitated having discussions about the observations. The learnings were used to substantiate next mixture compositions trials on and compare it with literature. In figure 43 all the bricks are seen after the rough tests.

Figure 43. Rough testing of locally produced bricks

Conclusion
All 23 mixes have been tested and the elaborated observations and results can be found in appendix 7.2.

As expected from the literature there are multiple mixture compositions that can work, it depends on local conditions and resources. From an economical perspective using PP is most promising. It was still the question if PP had good brick and mixture performances in the setting of EcoWorld, and the answer is yes. Now further research is done into the PP mixture composition ratios to find the right balance between cost and strength.

4.3.2 Overview of the PP mixes

Six different PP mixtures of total 6kg are prepared to find the right mixture composition considering cost and strength. Other additives like cement and multi layer plastics (MLP) are experimented with as well since these materials were also available at EcoWorld. In table 2 the mixture compositions can be seen, as well as the material price of the specific mixture.

The cost is based on:

Plastic waste: 15 Ksh/kg sorted
10 Ksh/kg unsorted (chapter 2.4)

Finesand: 0.7 Ksh/kg
Cement: 13.6 Ksh/kg (chapter 2.6)

	PP	Fine sand	Other	Material cost
Mix 1	6kg			90Ksh
Mix 2	4kg	2kg		61.4Ksh
Mix 3	3kg	3kg		47.1Ksh
Mix 4	2kg	4kg		32.8Ksh
Mix 5	3kg	3kg	0.1kg Cement	48.5Ksh
Mix 6	2kg	3kg	1kg MLP	42.1Ksh

Table 2. Mixture compositions recycled PP

Result of the PP mixes
The PP brick samples are cut into three smaller cubes of 4x4x4 cm per mixture seen in figure 44, suggested by concrete expert Maiko van Leeuwen. The brick cubes were taken to the Netherlands to perform the test at the faculty of Civil Engineering, TUDelft, under supervision of Maiko. The cubes were put into a compressive strength machine with a maximum compressive force of 250kN, see figure 45. The test took place 30 days after the bricks were produced. The results can be seen in appendix 7.3.

The results of the compressive strength test are plotted in a graph whit the cost and the strength per brick shown, see figure 46 on the next page . The cost and strength are used as axes since the final composition decision is based on the consideration of both factors. The red line indicates the requirement that the brick should be stronger than the current coral block with 12.9 MPa compressive strength. The mix numbers 3, 1, 5, and 2 are strong enough:

- Mix 3: 16.6 MPa
- Mix1: 18.4 MPa
- Mix 5: 23.7 MPa
- Mix 2: 24.2 MPa

Figure 44. Test specimens of 4x4x4

Figure 45. Compressive strength machine at TUDelft

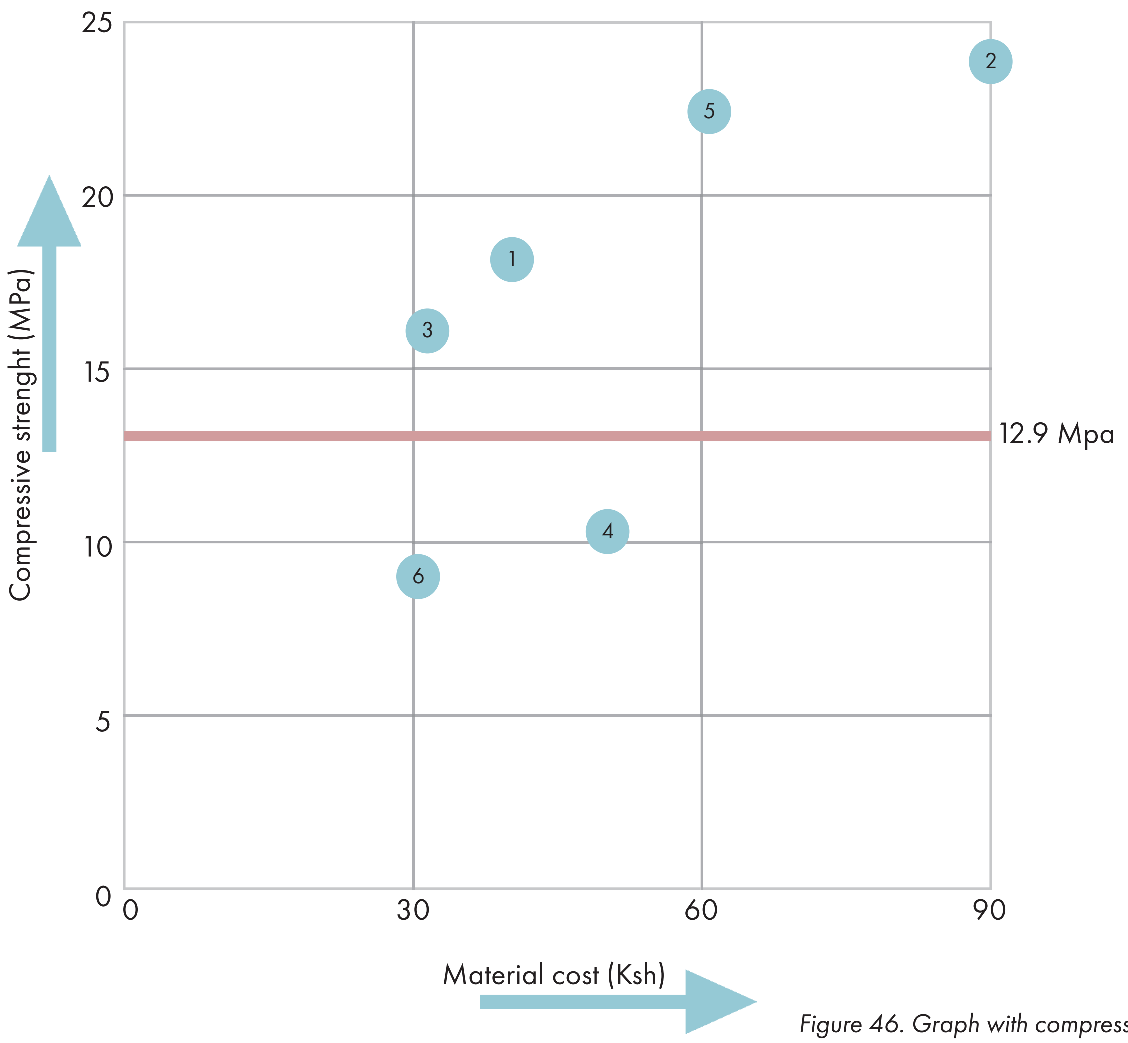


Figure 46. Graph with compressive strength vs cost

Conclusion

The first experiments have been done to find the ideal mixture for the local context at Ecoworld. First PET, HDPE, and PP were tried. It was found that PET is to brittle, HDPE has big sink marks and PP was workable and strong. When looking at the cost, HDPE and PET are almost impossible to use considering there is already a selling market for it. The goal is to produce a brick with economic gain, but being less than the current equivalent of 138Ksh. The combination of the performance and cost led to the decision of continuing with PP mixes.

The compressive strength of the PP mixes was tested in the Netherlands. The program of requirements also stated the compressive strength should be at least 12.9 MPa, which is the compressive strength of the current coral block.

Four mixes meet the cost and strength requirements: 3, 1, 5 and 2.

The wish was for the building brick to be as cheap as possible. Currently as stated in the discover phase many people can't even afford to built with coral blocks. Meaning they can't afford paying 138ksh per brick. The cheaper the brick, the more accessible for people with less money making more positive social impact. From this social perspective sample number 3, 3kg PP and 3kg sand, is chosen as the ideal mixture for making plastic waste bricks in Watamu. In figure 47 the amount of plastic waste and sand that go into the brick is shown.

Figure 47. 3 kg of PP, 3 kg of sand and the final brick

4.4 Melting

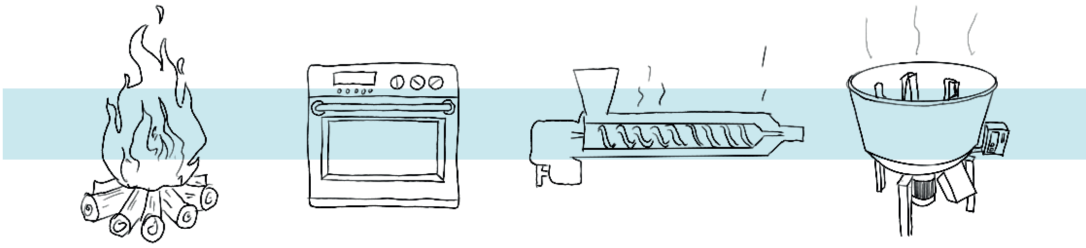


Figure 48. Morphological chart: melting

During the morphological chart brainstorm session with EcoWorld four possible ways of melting the mixture were identified, see figure 48. Using wood fire, an oven, an extruder or a heat mixing bowl. Since the experimental brick production test set-up is designed only for testing purposes it is important to keep the investment as low as possible. Secondly, when EcoWorld wants to expand to other locations the tests have to be done again locally. So designing the test set-up to be easily replicable, understandable and requiring only locally available tools is crucial. Therefor melting on a wood-fire is chosen.

The materials used in all experimental mixes are locally available at EcoWorld. Different plastics have been tried, PET, HDPE and PP. As well as other additives such as cement, fine sand, glass and wrappers. A weighting scale is used to create marked containers improving efficiency of the process. It was noticed that since the mixing process is done manually it allows for human error. Sometimes there were some unintended types of plastics in the mix, due to a sorting mistake. Very good training and quality control is needed to guarantee constant quality bricks.

The sand that is used is road sand. To get rid of big chunks or particles the sand was sieved using an old mosquito net with a mesh size of 1 mm, see figure 49.

Figure 49. Sieving the sand

Two different ways of mixing have been tried; first melting the plastic, then adding the sand into the molten plastic. Secondly the sand plastic mix was mixed first and then put into the melting pot. The latter worked best, because when adding the cold sand later it solidifies the mixture instantly forming chunks. The mixture has to be put into the drum bit by bit, otherwise the plastic works as insulation and it will take a lot longer. See figure 50 for the mixing flow chart.

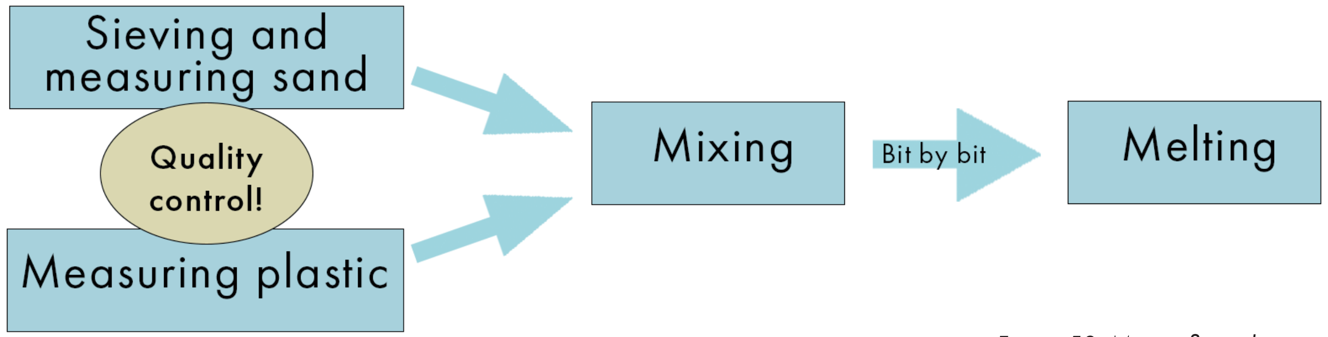


Figure 50. Mixing flow chart

For melting the plastic mixture a big melting drum was made with parts from the local scrapyard, see figure 51. The material and labour cost 1000Ksh in total. The drum used to be a hot water tank, so it is a good heat conductor. By using a good heat conducting material the heating process can be more efficient. The size of the drum is ø 50cm by 40cm high, big enough for the plastics mixtures to fit.

The drum is put on the fire and the mixture goes bit by bit into the drum. One thing that became clear was the necessity to steer the mixture. Otherwise the mixture in the bottom gets too hot causing it to burn, while the mixture in the top is not even molten. While melting the mixture the fire has to be closely monitored. To control the heat wood can be extracted or added. When steering a lot of irritating fumes arise, so wearing a mask is important. See figure 52 for the setup. These melting fumes are not toxic, see appendix 7.4 for safety data sheet of PP plastic.

Calculations
The amount of energy needed to melt the mixture depends on the mixture composition. The ideal mix was 3kg PP and 3kg sand. To calculate the required energy the heat capacity formula is used:

$E_{melt} = \Delta T \times CP \times m$
$\Delta T = T_{pp melt} - T_{outside} = 165 - 30 = 135\,°C$
CP (specific heat)= $CP_{sand} = 830 J/kg/°C$
$CP_{pp} = 1920 J/kg/°C$
$m_{sand} = 3kg$, $m_{pp} = 3kg$
$E_{melt} = 336150 + 777600 = 1.1 mJ = 0.31 Kwh$

Insights for upscaling
The goal was to design a low-investment experimental test-set up, for that wood fire works. However for upscaling the production line a few critical points surfaced:

- Sometimes there were some unintended types of plastics in the mix, due to a sorting mistake.
- The wood fire is badly-controllable.
- The wood fire is an inefficient heat source since a lot of heats get lost in the open air.
- It took 30-40 minutes to melt the mixture for one brick
- The fuel used for a wood fire is wood, which breaks down in small particulate while burning that are bad for human and planetary health.
- The smoke and fumes coming from the fire and melting plastic can cause damage after longer exposure

These point lead to requirements for the next phase of production line development.

Figure 51. Preparing the melting drum

Figure 52. Melting plastic on a fire

Requirements for the next phase production line:

- *The quality of the mixture composition should be controlled*
- *The sand-plastic mixture should be premixed before melting*
- *The mixture should be heated dosed*
- *The mixture has to be mixed constantly when heated*
- *The heat source should be controllable per 10 degree.*
- *The heat source should be electrical*
- *The plastic fumes should be captured / contained*

4.5 Transporting

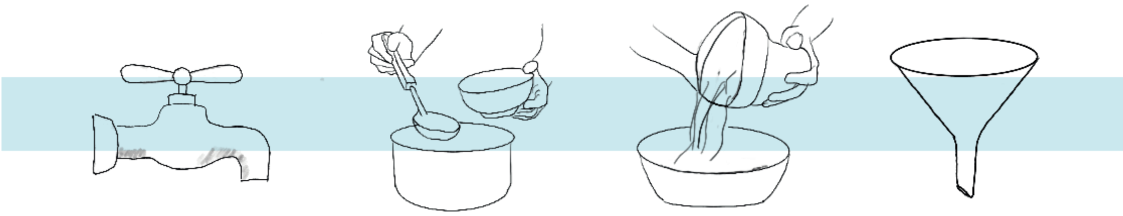


Figure 53. Morphological chart: Transporting

The molten mixture s are obviously very hot, varying from 160-320 °C depending on the used plastics. Therefor getting the molten substance in the mould should be done very carefully, heat resistant gloves and a mask have to be worn. During the co-design it was decided to simply scoop or pour the mixture into the mould since that leaves more experimental freedom. Some mixtures can be quite thick and it must not get stuck, which can be the case when choosing a faucet or funnel.

Figure 54. Fumes exhaustion while pouring

When pouring the mixture into the mould, it was noticed that the PP sand mixture solidified after 4 minutes due to cooling down. Compressing the mixture has to be done before it solidifies, otherwise air pockets are formed and solidified bonds break due to the pressure leading to weaker bricks.

When practicing the chosen technique it was noticed that a lot of fumes come from the molten mixture, which was experienced as very unpleasant to Willy. See figure 54. This evolved into a requirement for the next phase production line:

- *When transporting the molten mixture into the mould the user should not get in contact with the fumes.*
- *One brick should be produced under 4 minutes.*

4.6 Compacting

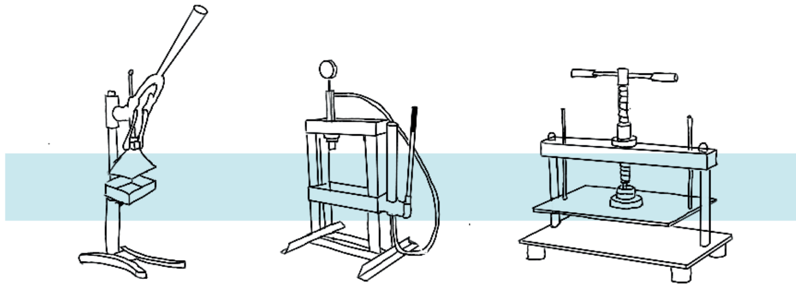


Figure 55. Morphological chart: Compacting

As mentioned in the research the molting mixture has to be compacted in the mould. There are two ways of adding pressure: by hand and body mass or using a tool/machine. It was quickly noticed that compacting by hand led to weaker and more brittle bonds. The tools in the morphological chart were found during a brainstorm with fellow design students.

The compression machine mostly used in the literature research is the hydraulic press. A hydraulic press uses fluid to apply a compressive force on an object by using the principle of Pascal's law, through a cylinder and piston system (Hemel, 2021).

A garage hydraulic press, with 12 tonnes compression force max, has been tried for the experimental test-set-up, see figure 56. The machine however was found to have too high pressure capacity, too heavy (75kg), and too complex in use for the experimental test set-up. An other press was tried: a book press with 14.7kN compression force, seen in figure 57.

The book press was taken to Kenya. During testing the workers at EcoWorld understood the machine and its use immediately. To apply the same amount of pressure for every brick, the crank is rotates until not further possible.

A critical point came across leading to a requirement, there was no tool for measuring the exact amount of pressure making it difficult to apply the same pressure for every brick

Requirement for the next phase production line:

- *The amount of pressure should be precisely manageable*

An other critical point is the fact that the book press is not locally available in Watamu. Further research should be done into designing a pressure tool for the experimental brick production test set-up that can be produced locally, or is locally available.

Figure 56. Garage hydraulic press

Figure 57. Book press

4.7.1 Brick shape

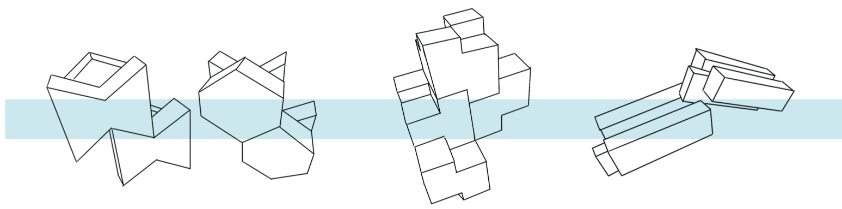


Figure 58. Morphological chart: Interlocking shapes

To get the molten mixture into the desired shape a mould is needed. Interviews with local inhabitants and building experts have been done to find the shape and size of the mould. From the literature research it was derived the blocks should be interlocking. When looking at many different interlocking structures two main directions were found: symmetrical and asymmetrical. When designing the shape perpendicular forces on the wall structure should be taken into account, as well as the interlocking connection strength in the horizontal and vertical direction to ensure good joints. Different shapes are designed, see appendix 7.5.

The designed interlocking shapes are tested in an interview with a masonry fundi named Chengo. Different blocks made of Styrofoam were tested, see figure 59.

Chengo made it very clear the third shape on figure 58 was the preferred one. He said: "Everyone should be able to use the brick, without prior knowledge or explanation. It should be intuitive and only one possible way they can be put together". A visit to a building side was done and the other masonry fundi's at work agreed. They also thought the shape looks familiar which made it easier for them to adapt and to see themselves working with this designed shape.

Figure 59. Local builder Chengo trying shapes

The second thing to find out is the size, and with that the weight. The first sample, see figure 60 was taken on the streets of Watamu to ask around what people though of the size and shape. The size was 10x10x20, and the weight was between 1-1,5kg.

Figure 60. First sample of plastic waste bricks

It became clear they directly connect the size and weight to the strength of the brick. They didn't feel like the material plays a role in that. One man who was building a wall said: "Oh very nice, we can use that for inside walls because it's light and small. Not for outside because then we use bigger and stronger blocks". Other inhabitants reacted in a similar way. Some of them also stated that the brick was way too light so they didn't believe it was strong enough.

These reactions were discussed with Chengo and a co-creation led to the new design in figure 61. He mentioned the length of the brick should be 300mm, since that is the equivalent of 1 foot, and the coral block is 300mm to so it will be easier for a masonry fundi to adjust when using the same measurements.

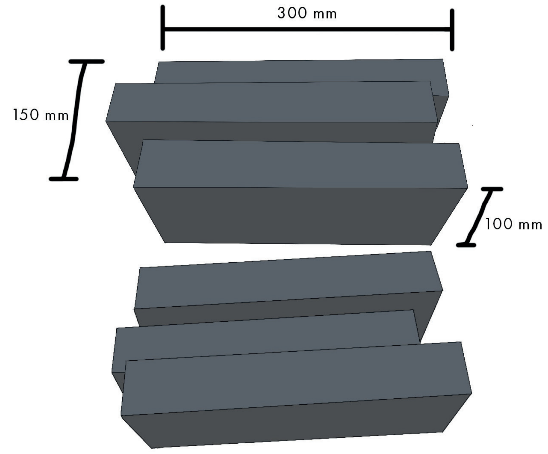


Figure 61. Final shape of the brick

The new shape was tested again with 8 different weight samples varying from 3-7 kg, which concluded into the following statements:

- Positive reaction to the size, similar to the coral block they are familiar with
- The blocks that were between 6.9 and 4.7 kg where said to be good considering the weight

The derived requirements are:

- *The interlocking brick should weight 6kg*
- *The brick should be 300x150x100mm*

Figure 62. Discussing different brick samples

4.7.2 Making the mould

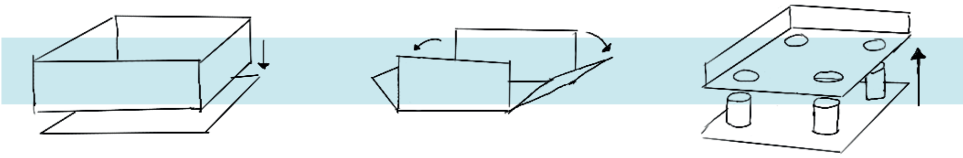


Figure 63. Morphological chart: The mould

The process of making the mould was iterative, through experimenting different design insight were identified leading to the next iteration. The first 4 design cycles can be seen in appendix 7.6. The 5th mould design is the final one that is tested.

The mould is created from local material from the scrabyard for 3140 Ksh, see figure 64, and the labour to assemble the mould was 1500 Ksh. The tools that were needed for the assembly are: a welding machine and a circular saw. It took 2 days to create the mould and the final mould was 14kg. This mould was made by one person, sometimes two or three just to assist in holding something.

Figure 64. Mould making process

The final mould

The final mould was oiled and tested, getting the brick out was very easy. The oil was put on the mould to make sure no plastic was sticking to the sides. However when testing the final mould one more challenge arose. When the mould is filled to the brim and the lid is put on top of the filled mould with pressure, leaking appears, see figure 65. Leaking causes air pockets insided the brick making it less strong. To mitigate two last adjustment should be done. An user guide on assembling the final mould design can be found in appendix 7.7.

Making the mould higher

It was found when the mould was not filled to the brim, less leakage occured. So 10 cm is added to the hight of the mould, however the mould should only be filled until 15cm to obtain the right size brick. The15 cm line is marked with a knife.

Making the cover thicker

The spilling occurs along the edge of the thin cover. In the final mould the edges are made 10 cm thick. In figure 66 the final mould parts and measurements can be seen.

Figure 65. Plastic leakage in mould

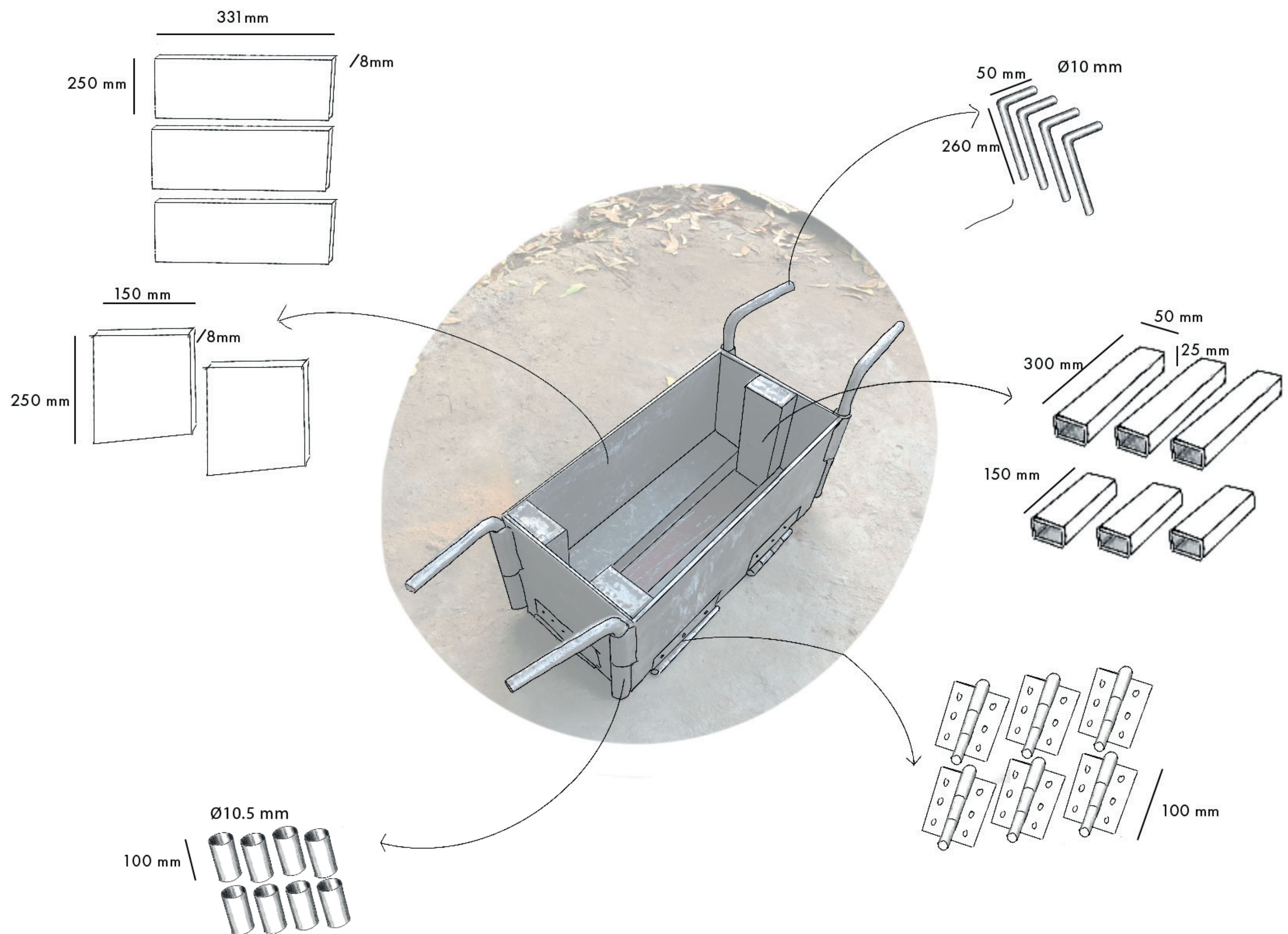


Figure 66. Final mould parts

4.8 Cooling

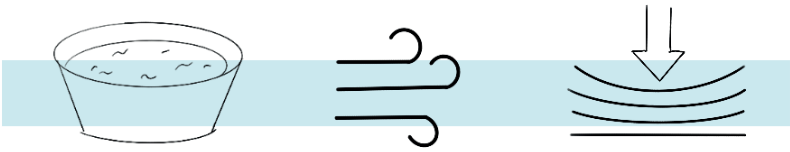


Figure 67. Morphological chart: Compacting

After the plastic mixture is moulded, it needs to be cooled. The influence of different elements have been tried for the experimental test set-up:

Water
Air
Under pressure.

The challenge of the cooling process is the occurring deformation. At the molecular level, shrinkage occurs as plastics melt and cool. This shrinkage, called volumetric shrinkage, is caused by thermal contraction and affects all types of polymers. As the material changes from a liquid to a solid, it can shrink by as much as 20-25% during the moulding process (Skar, 2019).

Literature shows cooling in water mitigates deformation by "freezing" the outside edges of the brick. (Hansen plastic, 2021). However during testing it became clear running water is needed, since the water gets hot within seconds. EcoWorld currently does not have that option, see figure 67.

Figure 67. Cooling brick in water

Cooling in air under pressure made sure the brick didn't deform, see figure 68. There was no obvious difference between cooling under pressure for 30 minutes or over night. One critical note: when the brick has to cool under pressure, it means the production tools are occupied for the amount of cooling time limiting the production capacity.

Figure 68. Cooling brick under pressure

For the experimental brick production test set-up cooling under pressure for 30 minutes was experience to be good. But when upscaling it can mean downtime of the mould, which makes the process more costly.

Requirements for the next phase production line:

- *The cooling process should not limit the production capacity*

4.9 Conclusion

Different processing tools and procedures have been tried to find the best suitable solution for a low-investment experimental test set-up in the local context.
The mixture experiments showed using PP and sand, 3KG's each, is the most suitable mixture for Ecoworld. From the "discover" phase it already became clear that using PP has the most economical and environmental impact, now in the "create" phase it showed PP is also the most suitable plastic to use judging on feasibility and brick performance.

The final brick is interlocking to safe money and make the brick more accessible and weights 6kg. The weight was found though interviewing locals, they didn't trust lighter bricks because they thought that those bricks are not strong enough.

Many critical insights were identified and converted into requirements for the next phase of the plastic waste production line development. An overview of the additional requirements of the next phase production line are listed below.

Category	Wish/req	Description
Mixing	Req	The quality of the mixture composition should be controlled
	Req	The sand-plastic mixture should be premixed before melting
Heating	Req	The mixture should be heated dosed
	Req	The mixture has to be mixed constantly when heated
	Req	The heat source should be controllable per10 degrees
Transporting	Req	The heat source should be electrical
	Req	The brick should be produced under 4 minutes
	Wish	The plastic fumes should be captured / contained
Compacting	Req	The compression force should be at least 1.5 tonnes
Moulding	Req	The interlocking brick should weight 6kg
	Req	The brick should be 300x150x100mm
	Req	The mould should be completely tight to prevent leaking when pressing
Cooling	Req	The cooling process should not limit the production capacity

Table 3. Additional requirements for next phase production line

5. Deliver

During the design phase an experimental set-up is co-designed locally to test the feasibility, viability and desirability of the implementation of remanufactured plastic waste interlocking brick. Through co-design the most suitable process, brick shape and weight and mix composition was found. This chapter summarizes the final design and describes the cost analysis and implementation roadmap.

Chapters:

5.1 Research questions

In the delivery-phase the research questions will be answered based on the findings in the discover- and create-phase.

In chapter 3.3 "The design goal" the assignment was stated: *Design a remanufactured plastic waste building brick with an accompanying implementation plan that enhances local self-sufficiency and unleash livelihoods while cleaning the environment from plastic waste.*

The research questions also formed in chapter 3.3 "the design goal" are seen in figure 69, with the corresponding chapter.

Research question		Chapter
Can a plastic waste building brick be made at Ecoworld, and if yes, how?	→	Chapter 5.2 Chapter 5.3 Chapter 5.4
It is economically possible to produce plastic waste building bricks in Watamu?	→	Chapter 5.5
What are the steps EcoWorld has to take to implement the production of plastic waste building bricks?	→	Chapter 5.6 Chapter 5.7 Chapter 5.8
What is the social, environmental and economical impact of producing plastic waste bricks?	→	Chapter 6.1

Figure 69. Research questions

5.2 Final design minimal viable product

The pictures give a visual overview of the designed test set-up for interlocking building bricks.

Figure 70. General production steps

-Locally made-
-Low-investment-
-Experimenting production steps separately-
-Low-skilled-
-2 bricks/hour-
-16.6 MPa compressive strength-

Explained test-set up process

1.Creating the mixture

2. Melting and mixing until completely molten state

3. Oiling the mold

4. Scooping or pouring molten mixture into the mold

5. Pressing the mixture with a 14.7kN book press

6. Aircooling in press for 20-30 minutes

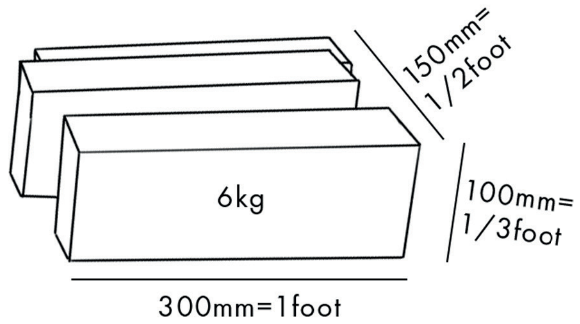
7. Taking the brick out of the mold

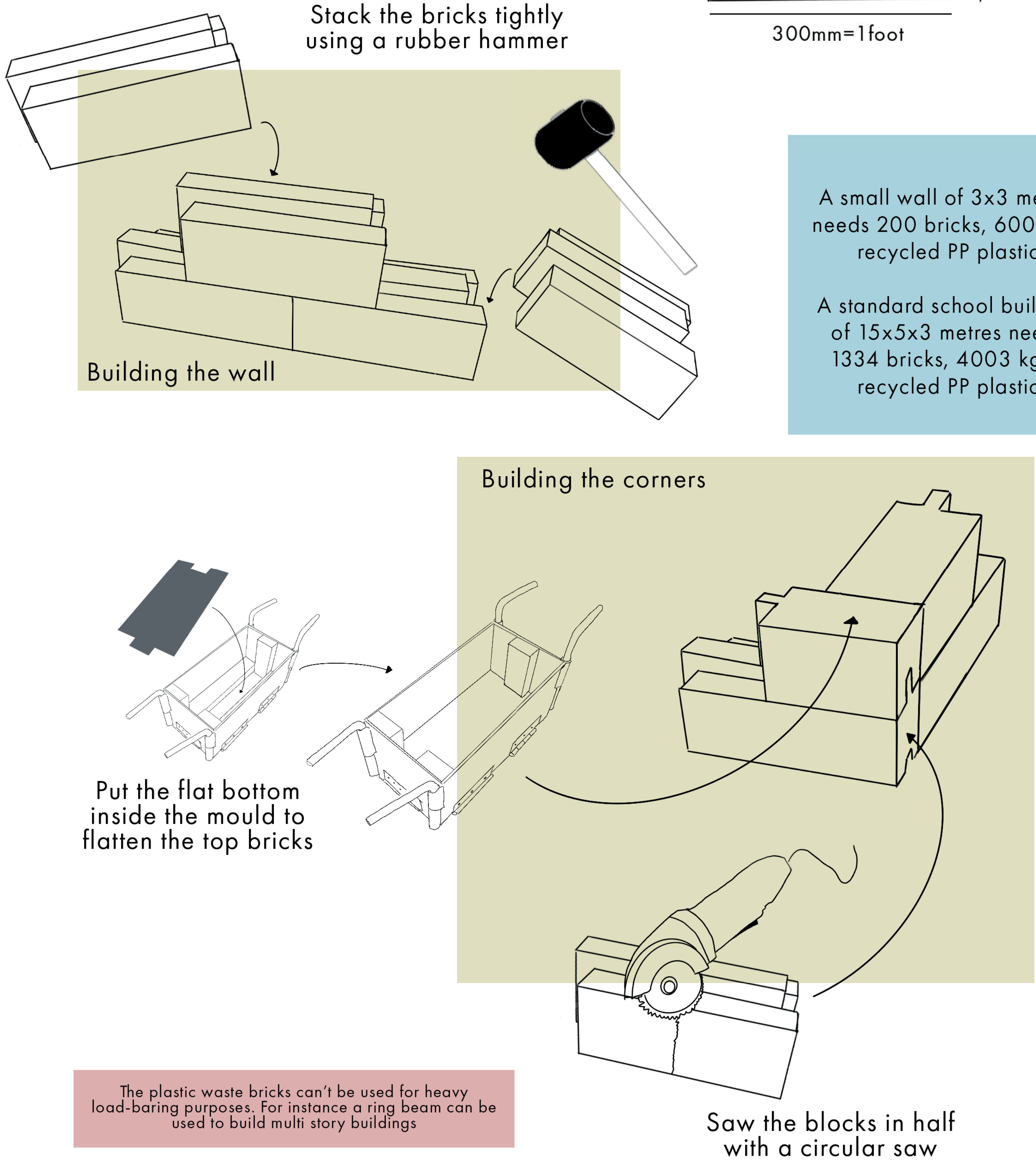
8. Leave the final brick until completely cool

Figure 71. Detailed production steps

5.3 Using the brick

The visual shows how the bricks can be used to build, and the measurement are given to calculate how many bricks are required.





A small wall of 3x3 metres needs 200 bricks, 600kg of recycled PP plastic

A standard school building of 15x5x3 metres needs 1334 bricks, 4003 kg of recycled PP plastic

The plastic waste bricks can't be used for heavy load-baring purposes. For instance a ring beam can be used to build multi story buildings

Figure 72. Final designed brick use

5.4 Minimal viable product improvement

In the create-phase an experimental brick production test set-up is designed through co-creation. The final brick has an interlocking shape, weights 6 kg's and consists of 3kg sand and 3kg PP. During the design of the heating process it became clear that while using a fire is low-investment, easy to understand and replicatable, it has downsides as well. The temperature is uncontrollable and an open fire is inefficient and unhealthy. Therefor based on the insights in the create phase an improvement for the heat source is given.

The heating requirements were:
The mixture should be heated dosed
The mixture has to be mixed constantly when heated
The heat source should be controllable per10 degree.
The heat source should be electrical
The plastic fumes should be captured / contained

Considering an oven, extruder and a heat mixing bow the extruder is the only machine that meets all requirements. An exemplary extruder is discussed.

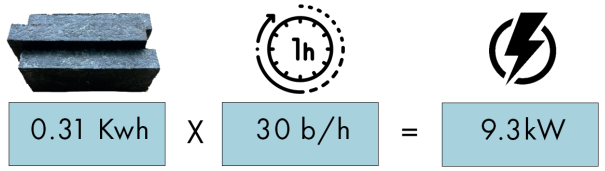
Extruder
In chapter 4.4 it was calculated that the required energy to melt the mixture for one brick is 0.31Kwh. In the requirements it says the brick should be produced under 4 minutes to prevent premature solidification. For the sake of the calculation the time to melt and the time to mould are equal, both 2 minutes, which is 30/hour. The heating power of the extruder should at least be 9.3kW.

The speed of the extruder should be 2 minutes per brick and is defined by three variables; the motor power, the length of barrel and the screw threats. The machines for extruding plastic sand compositions exist in different price range and level of complexity. From the requirements and insight for the suitable solution for EcoWorld an exemplar extruder is derived, seen in figure 72.

The machine cost is 8,500 USD. The specifications can be seen in table 4.

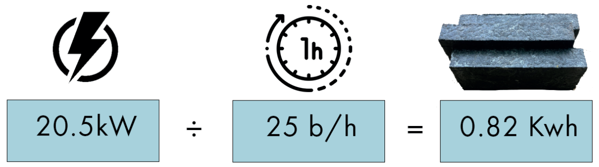
The production capacity is 150 kg/h, and one brick is 6 kg. That means 25 bricks per hour, 2.4 min/brick, so1.6 min is left for the moulding process. With this machine specifications the required energy to melt and extrude the material for one brick is 0.82 Kwh.

Figure 72. Exemplar plastic-sand extruder



Parameter description	Nominal value
Production capacity, kg/h	150
Nominal drive capacity, kW	**5,5**
Nominal electric heaters capacity, kW	**15**
Number of adjustable zones, items	3
Number of controllable zones, items	3
Mix temperature at the exit, ºC	150-200
Maximum temperature in heating zones, ºC	350
Overall dimensions, mm:	
length	3000
width	**700**
height	1400
Weight, kg	750

Table 4. Specifications of exemplar extruder



5.5 Cost analysis

To check the viability of the final design implementation a holistic cost analyses is done. There are two parts of the coast analysis, first the investment cost which is an one time expense. Secondly the production costs of the brick, which is continuous. The costs are an estimation.

Investment costs
For the next step in setting up a production line an extruder has to be bought. The costs for the given exemplar in chapter 5.4 is 8,500 USD.

Production costs per brick
The production cost per brick is calculated for the minimal viable set-up + extruder, as explained in chapter 5.2 and 5.4. The mixture of the brick is 3kg PP and 3kg sand.

What	Calculation explanation	Calculation	Cost (ksh)
Material	Sorted plastic :15Ksh/kg Sand: 0.7 Ksh/kg	(15x3)+(0.7x3)=46.8	47.1
Shredding labour	Shredder capacity: 3000kg/day Machine operator: 773Ksh/day	(3000/773)x3= 3.9x3=11.7	11.7
Brick production labour	Production capacity: 2 bricks/hour Production operator: 110Ksh/hour	110/2=55	55
Production energy (extruder)	Melting energy: 0.82Kwh/brick Energy cost: 17.9 Ksh/Kwh (Global petrol prices, 2022)	0.82x17.9=14.7	14.7
Total			**128.5**

Table 5. Total cost calculation of the brick

Viability
The research question was: is it economically possible to produce plastic waste building bricks in Watamu? Considering the total price per brick in this minimal viable production set-up is 128.2 Ksh, which is below the required 138 Ksh, the short answer is yes. The reselling Women and youth groups can make 9.8 Ksh per brick.

However, the brick should be as cheap as possible to be more accessible to the locals in Watamu. In the table can be seen that the production labour is costing the most. It is known that the exemplar extruder can extrude the material of 25 bricks per hour, that would make the production labour decrease to 4.4 Ksh per block.

In the minimal viable production set-up one mould and one pressing machine is used, with 20-30 minutes cooling time under pressure. This accounts for the production of just 2 bricks per hour. Therefor to upscale the amount of bricks to 25 bricks per hour, more research has to be done in upscaling the moulding and compression process.

5.6 Process map

The process map seen in figure 73 is made to identify stakeholders and potential external threats for each part of the process. This map can be used as first step of the implementation journey.

An elaboration on the external stakeholders and threats:

Grant givers
Grant money is needed to make machinery investments and for building showrooms or to donate buildings to the local community. If there are no grants, there is no budget for investments and starting up the brik production operations.

Government
The government in Kenya is said to be quite corrupt, they may introduce new legislation or try to make money out of the plastic waste brick implementation.

Watamu Marine Association, hotels, residencies and waste pickers
These three groups are responsible for the feedstock of plastic for the brick production. The threat is that not enough PP enters Watamu for the brick production.

Humanitarian organizations
Organizations such as UN Habitat have already shown interest in building with plastic waste bricks. They are buying customers for local and social building projects. When there are no organizations that want to buy the bricks, it might jeopardize the operation.

Women and youth groups
For the local distribution of the bricks in different villages Women and youth groups will be resellers thus creating SME opportunity for the local people. They should be trained as resellers and ambassadors to create the feeling of empowerment and involvement. When these groups can't find buyers, it might jeopardize the operation. An action plan has to be made together with the Women and youth groups.

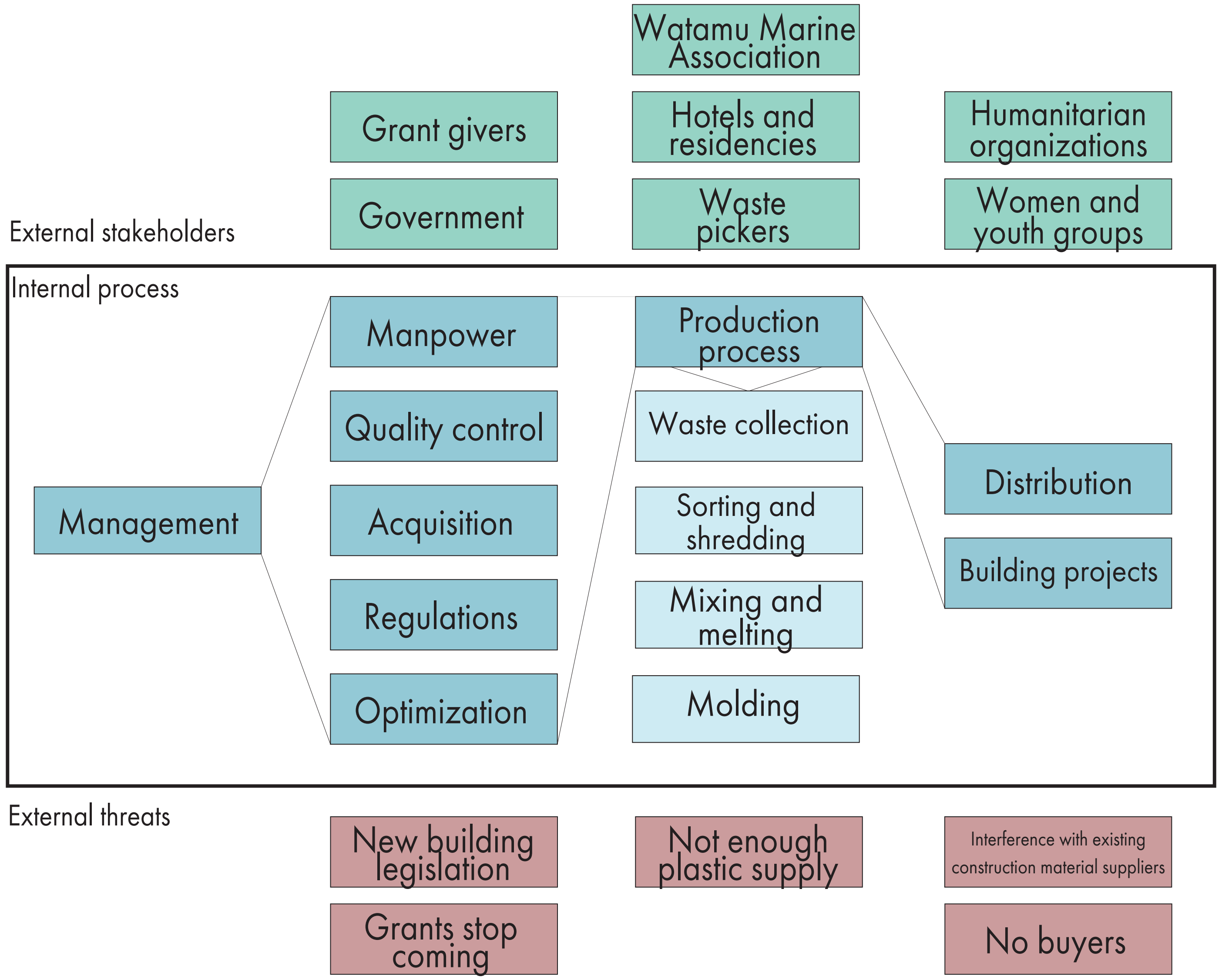


Figure 73. Process map with stakeholders and threats

5.7 First steps of implementation

All insights from previous chapters have been converted into action points. The recommended steps to take for setting up a plastic waste brick production line are described in this chapter. The list is divided into the management steps and the operational steps.

Operational
1. Start with an interactive session with the EcoWorld workers, talk about the future vision and control management
2. A task system has to be put into place. Who is going to be responsible for what. Important: Involve the team, what are their personal preferences and ambitions. Everyone involved should be part of the vision.
3. Together make a planning with achievable goals.
4. Do an extended research on the existing machinery, ask other companies for their advice.
5. Scale up the PP plastic supply at EcoWorld.
6. Design a machine en production testing trajectory. Estimate how long the testing will take until the production can start.
7. Create a quality control protocol in order to preserve quality bricks and become a well-trusted supplier.

Management
1.Invest in qualified manpower on management level and machine operator level. The brick production operation should not be interfering with the existing operations and management tasks.
2 Set up an infrastructure and make space for the production line. Set quality control protocols in place.
3. Map out and divide tasks, and map out potential risks with its mitigation.
4. Start acquisition and find valuable partnerships such as UN Habitat.
5. Together with Women and youth groups develop a sales strategy and training plan. Arrange communication and collaborative agreements. It is important to train these groups to be ambassadors creating involvement and a feeling of empowerment.

5.8 Implementation roadmap

The first steps have been discussed in the previous chapter. In the implementation roadmap in figure 74 a longer plan is made that was created together with EcoWorld owner Steve.

Building a small 1 story high building from plastic waste bricks is a big milestone planned in mid 2024. It will function as a showroom where customers, whether organizations or citizens, can see the end result and try out building with the blocks themselves. It is a marketing tool based on the Watamu saying: "first seeing then believing".

Also from the "discover" phase it became clear that the plastic pollution is not only caused by the lack of waste management systems, but also lack of knowledge. The showroom should be used for educational purposes and creating awareness as well. An educational program and campaigns focusing on "waste is value" should be designed and promoted.

The final produced brick in the pilot production phase should be tested on the standard brick performance tests like strength, durability and fire resistance. It is only a GO moment when these tests are done and the results are positive. Then the next phase of setting up the real production line starts.

The goal of EcoWorld is to create a plastic waste circular economy, implementing the plastic waste brick production is part of that journey. To really make it circular, the end-of-life has to be considered as well. In the literature research it showed the interlocking plastic waste bricks can be used again and again. In the future (beyond the implementation roadmap) a system or service has to be developed to facilitate reusing or recycling the bricks.

Time	**2023**		**2024**		**2025**
Focus	Research	Investing	Pilot production line	Start operations	Expanding operations
Go/No-go	Go/No-go Acquired 100.000 USD funding for entire research and development phase		Go/No-go Acquired standardized building material test results on the final bricks	Go/No-go Successful systematic implementation of bricks in Watamu	
Internal	Create an EcoWorld task force Research on required machinery Research on leaching of micro-plastics and mitigation through surface sealants available on the market	Procure the required machinery Hire a remanufacturing operator	Install the machinery and organize production space Machinery operation trainings Perform certified tests on final bricks	Test different construction methods and specifications like load bearing properties Evaluate on the implementation, is the plan working or does it need changing? Is the brick locally accepted? Use the "Tripple bottom line" framework	Hire more operators and expand production
Develop	Expand PP plastic supply chain working with Women and youth groups Expand the material recovery facility to make space for the production line and storage	Create a quality control protocol Create an ambassadors program with Women and Youth gourps	Set-up the logistics of a selling network Create marketing, sales and business plan	Built a showroom and demo sights in Watamu where people can see and use the bricks Set-up educational awareness project as part of a training center at EcoWorld Watamu	Testing other products that can be made with the set-up production line
External	Find 100.000 USD funding for research, procurement and implementation trough CSR investors, plastic manufacturing companies and other organizations like USAID Research legislation on building material development	Find organizations that want to buy the bricks like UNHabitat	Work together with Women and youth groups and SME's for the selling network Find a partnership with a research facility like university for testing the final bricks Set-up partnerships with building developers and builders as clients	Set up partnerships with universities to further investigate upcycling opportunities Make buying agreements with clients such as UN Habitat Involve Women and youth groups in a trainings center to set-up the educational project and train to use and sell the brick	Expand operations to other material recovery facilities in coastal cities and towns Information sharing with other not commercial/for profit organizations such as NGO and non-profit creating a community of plastic waste brick producers Create media exposure about the implementation of the brick in Watamu

Figure 74. Implementation roadmap

6. Evaluation

Now that the project resulted in an actual design of the bricks, including the design of an experimental production set-up, recommendations for machinery, cost analysis and implementation roadmap it is time to reflect on the whole project. The feasibility and viability are explained in chapter "delivery", in this chapter the desirability is explained. The impact of this design project is anaylzed using the TBL framework. Critical observations are pointed out, leading to recommendations for future research. Finally a personal reflection is done reflecting on the lessons and experience.

Chapters:

6.1 Impact evaluation

In the "deliver" chapter the feasibility and viability of the designed product is explained. Now it's know that producing plastic waste bricks in Watamu is feasible and viable. However is it also desirable, what is the impact of implementing the brick?

In the beginning of this project the TBL framework, Social, Environmental and Economical perspective, was used to set impact measurement guide lines throughout the project. In this chapter the impact of the final designed brick and implementation is analyzed in collaboration with EcoWorld, using the life-cycle-analysis framework subdivided into social, environmental and economical perspective.

A qualitative life-cycle-analysis (LCA) is done to compare the current situation to the designed situation. The LCA is a method for evaluating all environmental impacts throughout multiple stages of a product's life cycle, including materials sourcing, manufacturing, use, and disposal, see figure 75. It promotes sustainable design and reduces negative impacts on the environment and human health by identifying key areas for improvement in a product's life cycle. It also helps decision-makers choose the most effective solutions by identifying the costs and benefits of different options (Ilgin & Gupta, 2010). Usually the LCA is used quantitatively, focusing on the carbon emissions per stage and relying on available data. However in this design project many other impact factors are important and not all quantitative data is available. Therefor the six stages of the LCA are used to analyze the impact in the social, environmental and economical area, in a qualitative way.

The impact questions set in the project brief were:

- *Social:* Does the final design provide social gain for the local people of Watamu compared to the current situation and in what ways?
- *Environmental:* Does the final design provide environmental gain compared to the current situation and in what ways?
- *Economical:* Does the implementation of the final design provide economical gain compared to the current situation and in what ways?

The answers are discussed on the next pages.

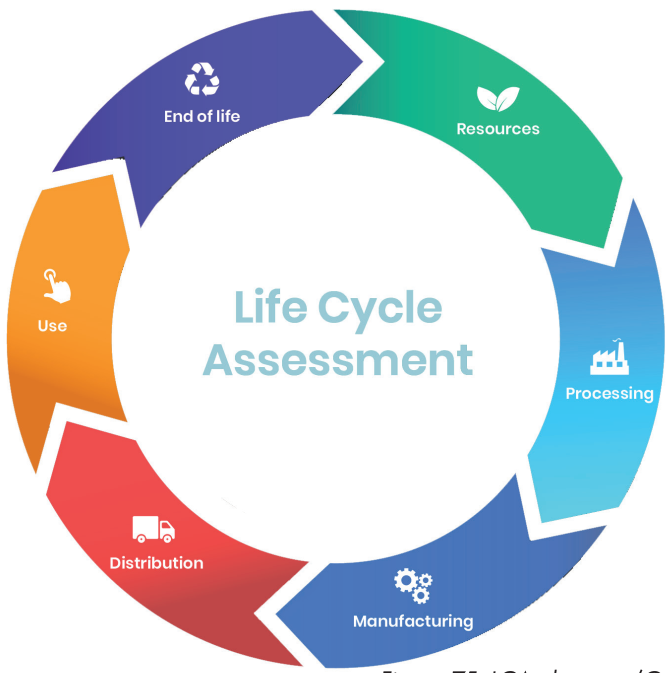


Figure 75. LCA elements (One Click, n.d.)

Social impact

Does the final design provide social gain for the local people of Watamu compared to the current situation and in what ways?

LCA	Current situation	Designed situation	Gain
	The quarry workers in Kilifi have to work in harsh conditions; heat, dust and hard physical labor.	The plastic is hand-picked from the environment. Picking for long hours can be quite labour intensive. It is enhancing a self-sufficient community because the resourcing, processing and producing is all done locally in Watamu. When the waste is collected at the source it destresses resident owners about their waste management.	
	The tools and machines to process and cut the blocks are dangerous to use, often hurting their fingers and nails.		
		During the processing and manufacturing of the plastic waste brick irritating fumes are emitted.	
	The distribution the coral block is tough physical labour. The blocks weight 13-17kg and they are manually loaded on and off the truck.	The plastic blocks are a lot lighter, 6kg, thus easier and more human friendly to distribute. Also by working together with local Women and youth groups and training them as ambassadors and resellers creates a feeling of empowerment, self-growth and self-sufficiency.	
	The use of the blocks requires educated skill, so the user is always depending on a fundi. That makes the process more expensive and time consuming, thus less accessible for the locals. It also has a cultural meaning that when a person has a house of coral blocks it shows they are not at the bottom class economically.	The brick can be applied by low-skilled people saving time an money. Being able to build your own house can give the locals a sense of independence and empowerment. The acceptation should be researched when the	
	When a person is done living in their building either it is left as it is, bringing down the aesthetic value of an environment and occupying space without a purpose. Or it is demolished by hand which is labour intensive again.	When a person is done living in a house or wants to move elsewhere, they simply deconstruct the bricks and rebuild elsewhere or sell it back to EcoWorld for recycling.	

Conclusion

Yes, implementing the plastic brick production provides social gain. The brick is easy to use thus more accessible. The distributions of the bricks is done through a collaboration with Women and youth groups creating a feeling of empowerment.

Environmental impact

Does the final design provide environmental gain compared to the current situation and in what ways?

LCA	Current situation	Designed situation	Gain
	The quarry has a negative impact on local ecosystems, as well as emitting of green house gases by the machinery used during brick production. Along the coastal area of Kilifi county a big "scar" is visible from the quarry.	The PP plastic is taken out of the environment by waste-pickers, or even prevented from coming entering the environment by collecting it at it's source, hotels and residents. By extracting the plastic out of the environment is has a positive impact, preventing the plastic to pollute human and planetary health.	
	To produce one machine cut brick 5.55Kwh is needed.	To produce one plastic waste brick 0.82Kwh is needed.	
	The coral blocks are produced in Kilifi county, but distributed along all coastal provinces. In combination with the weight of the block the transportation done by truck emits quite some CO2.	Since the ambition of EcoWorld is to create a replicable model, the plastic waste brick production can be potentially done anywhere with enough PP waste supply. The distribution distances will be much shorter and the brick weight is less than half of the coral block, emitting less CO2 during transportation.	
	When the bricks are ready to be used, it needs 2.5KG of cement per brick to build a wall. Therefor the bad environmental impact of the cement industry needs to be taken into account as well. When the wall is built the degradation of coral block and cement is minimal.	To build a wall of the designed brick, no cement is needed due to their interlocking feature. When the wall is built degradation into micro-plastics occur due to external elements such as wind and UV-light.	
	When someone is done with their house, the blocks are demolished and end up in landfill.	When the wall is not in use anymore, the blocks can be taken apart and rebuild somewhere else. The blocks that are not usable anymore can be crushed, remelted and remoulted into a new brick. This process will require energy consumption.	

Conclusion

Yes, implementing the plastic brick production provides environmental gain. The PP plastic is extracted from the environment and the production of a plastic waste brick requires less energy than a coral block. To use the brick no cement is needed and the brick can be reused.

Economical impact

Does the implementation of the final design provide economical gain compared to the current situation and in what ways?

L: For the locals
E: For EcoWorld

LCA	Current situation	Designed situation	Gain
	The coral quarry industry is a fundamental source of livelihoods for some communities.	L: The brick is design from PP plastic, a plastic sort which currently is low-value. By creating the brick out of PP the raw material's value increases too. Local waste pickers gain economical opportunities since there is more valued waste to pick from the environment.	
	The wages are really low, 1Ksh per block. Often strikes happen due to the low wages and unhappiness of the workers.	L: The production of the brick creates local job opportunities at the production facility. The bigger the facility, the more job opportunities creates.	
	Distributing the coral blocks create economical opportunity for the truck drivers and their helpers.	L: Setting up collaborations with local Women and youth groups creates economic opportunities for them. The groups will be the ambassadors and resellers of the bricks, making sure it reaches every local community and finding new selling opportunities. E: Selling the bricks generates a new income stream for EcoWorld since PP is not sold currently.	
	The use of the coral blocks requires educated skill and time, which costs money. The brick equivalent is 138 Ksh/brick. For the poorest people of Watamu it is to expensive to build with coral blocks.	L: The interlocking feature makes the brick cheaper than the coral block equivalent, 128.2Ksh. Thus the brick is economically more accessible than current materials creating new housing opportunities for the poor.	
	The economic value of the coral block disappears since the blocks are just left or demolished and end up in landfill.	The brick user only has to invest in bricks once, since they can deconstruct the wall and rebuild it elsewhere.	

Conclusion

Yes, implementing the plastic brick production provides economical gain. For Ecoworld a new income stream is created. For the locals of Watamu SME opportunities are created and the bricks more affordable.

6.2 Critical observations

When evaluating the impact of the design and the implementation also some critical points were observed. It is important to know the weaknesses of a design in order to mitigate it, or to make considered decisions. They are discussed in this chapter, including possible mitigations. These mitigations are derived from brainstorming with EcoWorld, not from in depth research. They form new research areas which are suggested in the recommendations on page .

Leaching of microplastics
As explained in the "discover" chapter plastic waste in nature degrades over time into smaller particles called micro-plastics. Those particles contaminate ground water over time called leaching. The plastic brick are also exposed to environmental factors, meaning in theory they would degrade and pollute the ground water too. It is expected to degrade, however it is unsure how much. Only the outside part of the brick is exposed to the environment, so it is expected to degrade much slower then random plastic in nature.

To mitigate that the brick should be protected from external factors. Plastering is one option, or using the bricks only for inside walls.

Flammability of the plastic brick
Plastics is a flammable material, since it is made from petroleum. In Watamu people have open fires in and around their houses, making the brick very vulnerable to melting or burning down. It also releases toxic fumes when burning. A local even said: " but will my house not just melt down?"

To mitigate that plastering could be used, since plaster (cement) is fire resistant. Also the bricks should probably not be used in the kitchen area. Adding sand lowers the flammability too.

One production process to the other
Just like the production of coral blocks the production of plastic waste bricks requires energy consumption. The ultimate solutions is to stop using plastic for so many single-used products. The brick solution should not be an excuse for the polluting companies to stop efforts of using less plastic in general.

To mitigate that, EcoWorld has to put emphasis on the fact that producing plastic waste bricks is applicable only to the plastic waste that is already in the environment. The longterm solution is eradicating the use of single used plastic in general.

6.3 Recommendations

This project was just the beginning of starting up a plastic waste brick production in Watamu. The design ground has been set and the foundation for further developing is created. A list of recommendations has been created based on the evaluation with EcoWorld, see appendix and personal observations throughout this project.

Technical:

Research machinery
In the "create" chapter an experimental test-set up is designed leading to requirements for the next phase production line development. Based on a brief machine research an extruder exemplar is given. However future in depth research has to be done to find the suitable machinery based on the provided requirements. It is recommended to begin with contacting other remanufacturing companies such as FlipFlopi or EcoPost, both in Kenya. Talk about their experience with the machinery, tests they have done and if they have any advice for choosing the machinery. If they don't want to let go such information, it might help to offer information in exchange like this report or future tests.

Power supply
As mentioned in the "discover" chapter Watamu experiences frequent power cuts. First of all research has to be done what the impact of power outages is on the acquired machinery. Secondly, it would be interesting to analyze alternative ways of powering the machine. On short term that might be a generator, however for the obvious environmental reasons it is recommended to look into solar energy as a long term solution. There is more than enough sun, so EcoWorld would not have to be dependent on a grid or generator fuel to operate, and power their machinery momre sustainable.

More tests on final material mix
Different material mixes are tested and judged on cost, performance and workability. The final mix has been tested on compressive strength and workability. It is advice to conduct those tests again on a brick from the acquired machinery, and additionally perform certified tests on the brick considering fire resistance, thermal performance, weathering of the brick, emissions, odour and tensile strength. This data is most likely mandatory when working with governmental organizations like UN Habitat.

Test the structure
With the bricks from the acquired machinery construction tests have to be performed. Research questions like: What is the best way to build with the bricks? What are the critical parameters when using the brick? What happens with the structure over time? How strong are the joints?

Plastering of the brick
In the literature research of existing bricks it became clear that plastering a plastic brick can be very challenging, since the surface is too smooth. However plastering can be a solution to micro-plastics degrading from the brick and the flammability of the brick. It is recommended to further research the possibility and influence of plastering.

Quality control
It is important all bricks that are produced are above a certain standard. In this project the coral block performance is used as benchmark. It is advised to set-up a quality control protocol, to ensure all bricks deliver the same quality. Think about controlling the mixture proportions, the melting temperature, the amount of plastic in one mould and the curing/cooling process.

Leaching of microplastics
Plastic degrades into smaller microplastics, especially when exposed to environmental factors. The designed brick is expected to degrade too. However it is not know how much. Many people and critics ask questions about leaching. To answer them it is recommended to do scientific research on the degradation of microplastics.

Recycling the bricks
As explained in this project recycling the designed bricks is possible and should be done when striving for a circular plastic waste economy. Crushing, remelting, remoudling and reselling. It is recommended to research the technical possibilities and processes, but also the systematic processes. The bricks will need to come back to EcoWorld somehow. Will that be a provided service, or paid service?

Systematical:

Resource material
In this research PP plastic was found to be the ideal resource. However in chapter the critical note was mentioned that the ultimate solution is stop using single used plastic in general. When that goal is reached, an other material should be found to make the interlocking bricks with. It is recommended start thinking about alternative materials as back up.

Setting up selling network

Distributing the bricks will be done in collaboration with Women and youth groups. In pursuance of creating personal involvement and drive it is advice to set up a training and ambassador program. Focusing on selling techniques and basics, but also on self-empowerment and development. Working on soft skills like pitching, networking and listening contribute to a better performance, feeling of involvement and personal growth.

Unleashing livelihoods

In this project is talked about the potential of unleashing livelihoods and enhancing self-sufficient communities. It can have that impact, but that doesn't mean it will. Periodical research has to be done into the social impact of the implementation of the brick production. Always unintended consequences can emerge. To mitigate that it is advice to set up a discussion group with all involved stakeholders, think of pickers, government, users, but also people in the brick industry. Have periodical meetings with the entire group to monitor the social impact of the implementation over time and foresee issues timely.

Quantitative LCA

A qualitative LCA has been done in this report to understand the gains ans losses between the current and the designed situation. A quantitative LCA can help explain the goal and inspire others to join the mission. The quantitative information is hard to obtain since it is not available currently. It is advice to research the required data and perform a quantitative LCA to substantiate the current qualitative LCA.

Showroom

It is recommended to work towards the goal of creating a showroom. A place where people can try out the bricks, see a wall or even a building. The place will be a marketing measurement to get interested people motivated to buy bricks and spread the word. Invite locals, humanitarian and governmental organizations. But also hotel and resort owners, for them using the bricks contributes to their CSR which they can promote.

Awareness and education

During the research is became clear that plastic pollution in Watamu is not only due to the lacking waste management systems, but also the lack of knowledge and awareness. Ecoworld can play an active roll in spreading awareness. It is recommended to create an educational programm and campaign, using the plastic waste bricks to show waste can have value.

New R&D

As said in the introduction the final goal is to build an entire house of plastic waste material. The bricks are just the beginning. Already many other building materials are being made all over the world. It is suggested to establish R&D partnerships with universities either in Kenya or elsewhere and research new plastic waste product opportunities.

Information sharing

The plastic pollution and lack of shelter are global problems. It is advice to share the findings of starting up a brick production with like-minded organisations that are not commercial or for profit. Not only to spread the EcoWorld vision, but also to create a community where new ideas, findings, innovations and knowledge can be shared. Benificial for everyone, including EcoWorld.

6.5 Self reflection

"Reflection is one of the most underused yet powerful tools for success" - Richard Carlson. A quote that I really love. Reflecting on the lessons learned and emotions that were experienced brings you closer to getting to know yourself. From there you can grow and develop.

As long as I can remember I wanted to study Industrial Design Engineering and become an inventor. Now the moment of acquiring the official papers is almost there. To be able to finish this journey with a project at which I could combine my passion for plastic waste solutions and my love for African countries is beyond imagination. Someone that graduated from IDE years ago told me once: "Don't put to much pressure on yourself, instead make sure you really enjoy your thesis journey". Well I can certainly say that I enjoyed my journey a lot.

The project all started in September '22 with a project brief. In that document I had identified some learning objectives which I will now reflect back on.

The first learning objective was:

Getting insight in the plastic waste issues and gaining more in depth knowledge about plastic remanufacturing and it's opportunities.

This objective is a quite practical one. Prior to this project I had never worked with remanufacturing plastic waste. First I had to learn a lot about plastics in general, especially their melting behavior. Since I am a very practical person I just started melting plastics and see what happened, then connecting the observations to the written theory. Learning by doing really gives me the feeling of understanding the theory, and being able to apply it easier. Through all the testing I was able to experience how different plastics respond to heat and cold, which I then could apply in Kenya to find the best materials and mixes.

The second learning objective was:

Learning to design with people from the BoP, that have completely different cultures and social-economic backgrounds.

This objective was more of a soft skill. I am a firm believer of designing with the user instead of for the user. Especially when the user's background is so different than mine. I could never put myself in their shoes and try to think like them, designing together is crucial. I was very lucky to be able to go to Kenya and actually do that. Some assumptions I had made turned out to be different, shifting the focus. For example first I thought that the brick had to be made from PET since that was the biggest quantity at EcoWorld, but when I was in Kenya I found out that shredded PET is already sold and PP is not. And it turned out considering the brick performance PP was also best suitable.

I was very exited to go to Watamu on my own, but also a bit nervous. I didn't know what to expect, are people willing to work with me, can we understand each other, to what extend can we build stuff together. The very first day my nerves vanished. The EcoWorld team was so nice, warm and welcoming from the beginning. Their interest in the project was so genuine. Willy especially was there every day of my stay, working together on the mould and the mixtures. I learned from him to approach challenges from a practical point of view instead of theoretical. Go back to the basics of the challenge: what is it supposed to do? As said before I love practical approaches so me and Willy got along really well.

While it was my favorite lesson, it was also my biggest challenge. I prefer to connect what we experience with the written theory to understand why things happen. However Willy was not too interested in that and wanted to go go go. In the beginning I stepped back a bit frustrated and just observed what he was doing, but towards the end I found a way to reflect together on what we experienced. We would walk away from the experiment area and together take pen and paper, discuss and formulate the next steps.

Coming back to Holland it was time for testing and evaluating. I realized that my project until that moment had been quite practical, focusing on the feasibility. Now it was time to zoom out again, put the design into context and focus more on the "why". At first I was struggling to do that and especially to document that in a report. There are so many things to take into consideration that it was a bit chaotic at first because I didn't have a systematical approach. However then I started to find methods and frameworks that I felt suited this project. Using those tools gave me more grip on the process. For each different part or research I started asking myself first: why do you do this? I tried finding a tool or framework to fit with that "why". Then drawing conclusions for every part, checking if it answers the "why". In the future I will definitely apply that lesson from the beginning of a project.

When looking back at the design approach I had chosen, the double diamond, I realized that the diamonds never stop. The end of my double diamond, a minimal viable plastic waste brick production, I could go all the way back to the beginning again to design the next phase of developing a plastic waste production line. These are all continuous design cycles which probably never really stop. The art is in defining the boundaries of your own double diamond. Towards the end I found it difficult to do that. There is still so much to discover and develop within this project. I was so enthusiastic so I wanted to do more and more. But that causes the project to become too big and too out of focus. Stepping away from the project and zooming out to the original design brief helped me to define the beginning and end better and come back into focus.

Now looking back at this project I think it sets a foundation for further development of producing plastic waste bricks into more specific areas and directions. I hope this design project inspires EcoWorld and all other interested readers to use this as first steps towards doing many great things!

I had one overarching goal for my thesis journey: having fun, and learning a lot while I'm at it! I can 100% say that goal has been accomplished.

Asante Sana, kwaheri

Figure 75. Steve and Luci holding the designed brick at EcoWorld

6.6 References

Achterberg, E., Hinfelaar, J. & Bocken, N. (2016). Master circular business with the value hill. Retrieved from https://www.circonl.nl/resources/uploads/2019/11/value-hill-white-paper.pdf

Bansal, D. (July 2010). Interlocking Dry Stacked Masonry. International Masonry Society.

Basic needs Definition | Law Insider. (n.d.). Law Insider. Retrieved from https://www.lawinsider.com/dictionary/basic-needs

Brandon, E. M. (January 2022). This startup is turning nonrecyclable plastic into building blocks fit for construction. Retrieved from https://www.byfusion.com/this-startup-is-turning-nonrecyclable-plastic-into-building-blocks-fit-for-construction/#:~:text=ByFusion%20uses%20a%20combination%20of,machines%20used%20to%20make%20them.

British Design Council, (2005). Framework for Innovation: Design Council's evolved Double Diamond. Retrieved from https://www.designcouncil.org.uk/our-work/skills-learning/tools-frameworks/framework-for-innovation-design-councils-evolved-double-diamond/

Carter, C., & Garaway, C. (2014). Shifting Tides, Complex Lives: The Dynamics of Fishing and Tourism Livelihoods on the Kenyan Coast. Society and Natural Resources: An International Journal, 27(6), 573–587. https://doi.org/10.1080/08941920.2013.842277

Chakraborty, J., Palit, K., & Das, S. (2022). Metagenomic approaches to study the culture-independent bacterial diversity of a polluted environment—a case study on north-eastern coast of Bay of Bengal, India. Elsevier EBooks, 81–107. https://doi.org/10.1016/b978-0-323-85455-9.00014-x

Definition of self-sufficient. (n.d.). In Merriam-Webster Dictionary. Retrieved from https://www.merriam-webster.com/dictionary/selfsufficient#:~:text=%3A%20able%20to%20maintain%20oneself%20or,ability%20or%20worth%20%3A%20haughty%2C%20overbearing

Diez, T.G. & Herrera, C. (December 2011). Coral Stone. LITOS 111. Understanding stone. Retrieved from https://www.litosonline.com/en/article/coral-stone

EcoWorld. (2022). EcoWorld recycling pitch deck. Powerpoint document.

Ellen MacArthur Foundation. (2016). Towards a circular economy: Business rationale for an accelerated transition. (n.d.). Retrieved from https://ellenmacarthurfoundation.org/towards-a-circular-economy-business-rationale-for-an-accelerated-transition

Experimental Plant. (2020). Low-benching machine "Prima". Retrieved from https://e-z3.com/quarry-machines/prima

Eze, C. J. (2018). Evaluation of Traditional Methods in the Maintenance of Mud Houses for Environmental Sustainability in Northern Nigeria. http://repository.futminna.edu.ng:8080/jspui/handle/123456789/9612

Freinkel, S. (2011). Plastics: A Toxic Love Story. New York: Henry Holt, p. 4.

Friesem, D. E., Boaretto, E., Eliyahu-Behar, A., & Shahack-Gross, R. (2011). Degradation of mud brick houses in an arid environment: a geoarchaeological model. Journal of Archaeological Science, 38(5), 1135–1147. https://doi.org/10.1016/j.jas.2010.12.011

Global petrol prices. (June 2022). Kenya electricity prices. Retrieved from https://www.globalpetrolprices.com/Kenya/electricity_prices/

Great big story. (October 2018). How Recycled Plastic Bottles Are Building Homes. Retrieved from https://www.youtube.com/watch?v=5BMOL4VwlII

Gu, L., & Yaseen, Z. M. (2016). Use of recycled plastics in concrete: A critical review. Waste Management, 51, 19–42. https://doi.org/10.1016/j.wasman.2016.03.005

Gwada, B., Ogendi, G., Makindi, S.M. & Trott, S. (2019). Composition of plastic waste discarded by households and its management approaches. Global Journal of Environmental Science and Management 5(1): 83-94.

Hamilton, L. A. & Feit, S. (May 2019). Plastic & Climate: The Hidden Costs of a Plastic Planet.

Hansen Plastic. (June 2021). How to Control Shrinkage During Injection Molding. Retrieved from https://www.hansenplastics.com/how-to-control-shrinkage-during-injection-molding/

Heiniger, S. (2022). Development of Interlocking Composite Bricks Made From Recycled Plastic and Construction Waste. EPFL.

Hemel. (April 2021). Hydraulic press. Retrieved from https://www.hemel.com.tr/what-is-a-hydraulic-press-and-how-does-it-work#:~:text=A%20hydraulic%20press%20is%20a,is%20bigger%20than%20the%20other.

Henry, R. K., Yongsheng, Z., & Jun, D. (2006). Municipal solid waste management challenges in developing countries – Kenyan case study. Waste Management, 26(1), 92–100. https://doi.org/10.1016/j.wasman.2005.03.007

Hilson, G. (2003). Defining "cleaner production" and "pollution prevention" in the mining context. Minerals Engineering, 16(4), 305–321. https://doi.org/10.1016/s0892-6875(03)00012-8

Huba, S., Ragaert, K., Leite, L. & Martins, C. (September 2014). Evaluation of post-industrial and post-consumer polyolefin-based polymer waste streams for injection moulding.

Hunt, A., Samman, E., Tapfuma, S., Mwaura, G. & Omenya, R. (November 2019). Women in the gig economy. Paid work, care and flexibility in Kenya and South Africa.

Ilgin, M. A., & Gupta, S. M. (2010). Environmentally conscious manufacturing and product recovery (ECMPRO): A review of the state of the art. Journal of Environmental Management, 91(3), 563–591. https://doi.org/10.1016/j.jenvman.2009.09.037

Janssens, V. (October 2022). Plastics – the Facts 2022. Plastics Europe.

Karcher, S., Wekesa, Z., Waweru, J., et al., (2020). Circular economy in the Africa-EU cooperation : country report for Kenya, Publications Office, https://data.europa.eu/doi/10.2779/751082

Karcher, S.Y.; Wekesa, Z.W.; Waweru, J.K.; Käsner, S.; Desmond, P., K.; Smit, T.A.B; Hemkhaus, M.; Ahlers, J.; Van Hummelen, S.; Chewpreecha, U.; Smith, A. & McGovern, M. (2020) Circular economy in the Africa-EU cooperation - Country report for Kenya.

Kemp, S. (February 2022). Digital 2022: Kenya. Datareportal. Retrieved from https://datareportal.com/reports/digital-2022-kenya

Khan, S. S. & Deshmukh, A. S. (December 2015). Mortarless Masonry with Interlocking Blocks. International journal of research in engineering, science and technologies.

Knoema. (2016). World data atlas – Kenya – Kilifi. Retrieved from https://knoema.com/atlas/Kenya/Kilifi

Lacey, A., Chen, W., Hao, H., & Bi, K. (2019). New interlocking inter-module connection for modular steel buildings: Experimental and numerical studies. Engineering Structures, 198, 109465. https://doi.org/10.1016/j.engstruct.2019.109465

Metzker, S. L. O., Sabino, T. P. F., Mendes, J. V., Ribeiro, A. L. R., & Mendes, R. F. (2021). Soil-Cement Bricks Development Using Polymeric Waste. Environmental Science and Pollution Research, 29(14), 21034–21048. https://doi.org/10.1007/s11356-021-16769-z

Miller, K. (December 2020). The triple bottom line: what it is & why it's important. Harvard Business School. Retrieved from https://online.hbs.edu/blog/post/what-is-the-triple-bottom-line

Ming'ate, F. L. M., & Mohamed, M. A. (2016). Impact of Stone Quarrying on the Environment and the Livelihood of Communities in Mandera County, Kenya. Journal of Scientific Research and Reports, 10(5), 1–9. https://doi.org/10.9734/jsrr/2016/24945

Ministry of tourism and wildlife. (June 2020). Impact of covid-19 on tourism in Kenya, the measures taken and the recovery pathways.

Mortula, M., Atabay, S., Fattah, K. P., & Madbuly, A. (2021). Leachability of microplastic from different plastic materials. Journal of Environmental Management, 294, 112995. https://doi.org/10.1016/j.jenvman.2021.112995

Mwema, F. (November 2016). Coral Quarries Closed In Kilifi. KUtv. Retrieved from http://kutv.co.ke/coral-quarries-closed-kilifi/.

Nelplast. (June, 2020). Nelson Boateng: From Ashaiman To Building Ghana's First Plastic House. Retrieved from http://www.nelplastgh.com/nelson-boateng-from-ashaiman-to-building-ghanas-first-plastic-house/

Nyasha, S., Odhiambo, N. M., & Magombeyi, M. T. (2022). Bank Development and Unemployment in Kenya: An Empirical Investigation. Managing Global Transitions, 20(2). https://doi.org/10.26493/1854-6935.20.85-107

Ochieng, O. P. (June 2012). An investigation into the durability, weathering and strength properties of coral stone. University of Nairobi. Department of civil and construction engineering.

Omanga, E., Ulmer, L., Berhane, Z & Gichuru, M. J. G. (2014). Industrial air pollution in rural Kenya: Community awareness, risk perception and associations between risk variables. BMC public health. 14. 377. 10.1186/1471-2458-14-377.

Ominde, S. H., Ingham, K. & Ntarangwi, M. (2022) Kenya – Economy. Retrieved from https://www.britannica.com/place/Kenya

Ondiba, I. M., Oyieke, F., Ong'amo, G., Olumula, M. M., Nyamongo, I. K., & Estambale, B. B. (2018). Malaria vector abundance is associated with house structures in Baringo County, Kenya. PLOS ONE, 13(6), e0198970. https://doi.org/10.1371/journal.pone.0198970

Opere, A. (2013). Floods in Kenya. Developments in Earth Surface Processes, 315–330. https://doi.org/10.1016/b978-0-444-59559-1.00021-9

Oyinlola, M. A., Whitehead, T. A., Abuzeinab, A., Adefila, A., Akinola, Y. M., Anafi, F. O., Farukh, F., Jegede, O., Kandan, K., Kim, B., & Mosugu, E. (2018). Bottle house: A case study of transdisciplinary research for tackling global challenges. Habitat International, 79, 18–29. https://doi.org/10.1016/j.habitatint.2018.07.007

Pinto Da Costa, J., Rocha-Santos, T. & C. Duarte, A. (2020). The environmental impacts of plastics and micro-plastics use, waste and pollution: EU and national measures

Plastic Soup. (n.d.). Plastic production and decomposition. Retrieved from https://www.plasticsoupfoundation.org/en/plastic-problem/plastic-environment/plastic-production-decomposition/#:~:text=Only%209%25%20of%20that%20waste,as%20plastic%20does%20not%20decompose.

Precious Plastics. (October 2022). Extrusion Pro information. Retrieved from https://community.preciousplastic.com/academy/build/extrusionpro.

Qian, B., Todd, D., & Gogos, C. G. (2003). Plastic energy dissipation and its role on heating/melting of single-component polymers and multi-component polymer blends. Advances in Polymer Technology, 22(2), 85–95. https://doi.org/10.1002/adv.10039

Ramage, M. H., Burridge, H. C., Busse-Wicher, M., Fereday, G., Reynolds, T. M., Shah, D. U., Wu, G., Yu, L., Fleming, P., Densley-Tingley, D., Allwood, J. M., Dupree, P., Linden, P., & Scherman, O. A. (2017). The wood from the trees: The use of timber in construction. Renewable & Sustainable Energy Reviews, 68, 333–359. https://doi.org/10.1016/j.rser.2016.09.107

Rodgers, L. (December 2018). Climate change: The massive CO2 emitter you may not know about. BBC. Retrieved from https://www.bbc.com/news/science-environment-46455844

Science museum. (2019) The Age of Plastic: From Parkesine to pollution. Retrieved from https://www.sciencemuseum.org.uk/objects-and-stories/chemistry/age-plastic-parkesine-pollution#:~:text=Belgian%20chemist%20and%20clever%20marketeer,phenol%2C%20under%20heat%20and%20pressure.

Serrat, O. (1994). The Environmental Impacts of Mining and Quarrying.

Shah, A., Khan, H & Qazi, E. (March 2013). Damage Assessment of Flood Affected Mud Houses in Pakistan. Journal of Himalayan Earth Sciences 46 (1), 2013

Siddique, R., Khatib, J., & Kaur, I. (2008). Use of recycled plastic in concrete: A review. Waste Management, 28(10), 1835–1852. https://doi.org/10.1016/j.wasman.2007.09.011

SKanyara. (May 2022). Watamu frequent power blackouts affecting image of renown tourism destination. Star. Retrieved from https://www.the-star.co.ke/news/2022-05-13-watamu-frequent-power-blackouts-affecting-image-of-renown-tourism-destination/

Skar. (November 2019). Injection moulding – how to avoid plastic shrinkage. Retrieved from https://skar.co.uk/plastic-shrinkage-2/#:~:text=Plastic%20shrinkage%20is%20an%20unfortunate,in%20a%20slightly%20different%20way
.

Talsma, G. (May 2021). Recycled Plastic Brick 2.0. Recycle Rebuild. p.21.

Thanal. (July 2020). Study of inflow of low value plastics. Zero Waste Team.

Trott. S. (2021). Watamu Marine Association Pitch Deck. EcoWorld. p. 3.

Twi-global. (n.d.). Thermoset vs thermoplastic (what is the difference?). Retrieved from https://www.twi-global.com/technical-knowledge/faqs/thermoset-vs-thermoplastic

Tyas, I. W. (2018). Lock-brick System for Sustainable and Environment Infrastructure Building Materials. IOP Conference Series, 371, 012016. https://doi.org/10.1088/1757-899x/371/1/012016

UN Habitat. (June 2022). UN-Habitat project to improve municipal solid Waste management in Kenya's coastal area. Retrieved from https://unhabitat.org/news/14-jun-2022/un-habitat-project-to-improve-municipal-solid-waste-management-in-kenyas-coastal

Watkins, E. & Brink, p. (2017). Marine Litter Socio Economic Study, United Nations Environment Programme, Nairobi. Kenya.

Wei, R.; Sakai, Y. Influence of Pressure and Temperature on Compacted Plastic–Concrete Bending Strength. Preprints 2020, 2020030006 (doi: 10.20944/preprints202003.0006.v1).

Woima. (n.d.). DROWNING IN WASTE – CASE MOMBASA, KENYA. Retrieved from https://woimacorporation.com/drowning-in-waste-case-mombasa-kenya/

WWF. (August 2022). Mombasa: First city in Africa to join WWF's Plastic Smart Cities Initiative. Retrieved from https://www.wwfkenya.org/?233970/Mombasa-first-city-in-Africa-to-join-WWFs-Plastic-Smart-Cities-Initiative#:~:text=In%20Mombasa%2C%20900%20tons%20of,81%20tons%20are%20plastic%20waste.

Zeus. (2005). Flammability of Polymers. Retrieved from https://www.appstate.edu/~clementsjs/journalarticles/zeus_flammability.pdf

6.7 Figure references

Figure 1. The Value Hill
Circular economy. (2016). Master circular business with the Vallue Hill. [Figure]. Circo. https://www.circonl.nl/kennis/circular-business-with-the-value-hill/

Figure 4. Clogged sewage in Kenya
CEJAD-Kenya. (2019). Plastic Waste New Investment for America's Dow in Kenya. [Photograph]. Business today. https://businesstoday.co.ke/plastic-waste-american-company-dow-kenya-circular-economy/

Figure 6. Mood board of existing remanufactured plastic waste building material
1. EcoPost. (2012). Plastic lumber. [Photograph]. https://www.ecopost.co.ke/index.php?page=products
2. EcoUnified. (2017). EcoUnifying Tiles. [Photograph]. https://www.shaynaecounified.com/products/
3. Reuters, T. (2019) Hope Mwanake, cofounder of Eco Blocks and Tiles, poses for a photo at her factory in Gilgil, Kenya. [Photograph]. Aljazeera. https://www.aljazeera.com/economy/2019/12/13/kenyan-scientist-uses-throw-away-plastics-to-build-homes
4. Gjenge Makers. (2021). Recycled plastic bricks stronger than concrete. [Photograph]. Atlas of the future. https://atlasofthefuture.org/project/gjenge-makers/
5. ByFusion. (2022) This startup is turning nonrecyclable plastic into building blocks fit for construction. [Photograph]. Fast company. https://www.fastcompany.com/90714272/this-startup-is-turning-non-recyclable-plastic-into-building-blocks-fit-for-construction

Figure 14. Plastic waste processing in Watamu
Gwada, B., Ogendi, G., Makindi, S.M. & Trott, S. (2019). Plastic waste disposal methods among households in Watamu ward. [Graph]. Composition of plastic waste discarded by households and its management approaches. p91.
Figure 15. Mwakirunge dumpsite
Nassir, Y. (2021). Minors offload garbage at Mwakirunge dumpsite. [Photograph]. The Star. https://www.the-star.co.ke/counties/coast/2021-07-11-mombasa-put-on-spot-for-poor-waste-management/

Figure 19. Plastic waste composition EcoWorld
EcoWorld. (2022). Products into & out of Ecoworld upto date 2022. [Graph]. Excel file.

Figure 23. Hand cut coral blocks quarry Lamu
Lorgnier, A. (n.d.). Tailor coral blocks in a career - Lamu Kenya. [Photograph]. Alamy. https://www.alamy.com/stock-photo-tailor-coral-blocks-in-a-career-lamu-kenya-125960764.html

Figure 24. Machine cut coral blocks quarry in Kilifi
Prima. (2021). PRIMA - Stone Cutting Machine in Kenya. [Screenshot]. Youtube. https://www.youtube.com/watch?v=rmajs-RXEMg

Figure 34. Precious plastics injection moulder
Precious Plastics. (2021). The ultimate guide to the Precious Plastic Extrusion machine. [Photograph]. One Army. https://www.onearmy.earth/news/extrusion-machine

Figure 35. Conceptos Plasticos extruder with gas fire heating
Great big story. (2018). How Recycled Plastic Bottles Are Building Homes. [Screenshot]. Youtube. https://www.youtube.com/watch?v=5BMOL4VwlII

Figure 36. Nelplast extruder and press
Maya, W. (2021). How A Ghanaian Man Is Building Affordable Homes With Waste Plastics!. [Screenshot]. Youtube. https://www.youtube.com/watch?v=EP-mZmUBFryY

Figure 37. ByFusion high temperature steam press
CNN business. (2022). Are these building blocks a solution to the plastic problem?. [Screenshot]. CNN Business. https://edition.cnn.com/2022/08/03/business/byfusion-waste-plastic-blocks/index.html

Figure 38. Cold brick press
Makiga Engineering Services Ltd. (2018). Makiga Stabilized Soil Block Press. [Photograph]. Engineering For Change. https://www.engineeringforchange.org/solutions/product/makiga-stabilized-soil-block-press/

Figure 39. Interlocking plastic waste bricks of Conceptos Plasticos
UNICEF. (2019). Plastic bricks created by the Colombian company Conceptos Plásticos. [Photograph]. AA. https://www.aa.com.tr/eng/mundo/empresa-colombiana-y-unicef-construyen-escuelas-en-%C3%A1frica-con-pl%C3%A1stico-reciclado/1617521

Figure 40. Analysis mixture compositions
Al-Sinan, M.A. & Bubshait, A. A. (2022). Compressive strength of various compositions. [Graph]. Using Plastic Sand as a Construction Material toward a Circular Economy: A Review. p13.

Figure 41. Plastic bottle structure in Nigeria
Oyinlola, M. A., Whitehead, T. A., Abuzeinab, A., Adefila, A., Akinola, Y. M., Anafi, F. O., Farukh, F., Jegede, O., Kandan, K., Kim, B., & Mosugu, E. (2018). Plastic bottle Wall construction. [Photograph].). Bottle house: A case study of transdisciplinary research for tackling global challenges. p24.

Figure 75. LCA elements
One Click. (n.d.) Life-cycle assessment stages. [Diagram]. One Click LCA. https://www.oneclicklca.com/fr/life-cycle-assessment-explained/

All other figures are created or photographed by the author, Luci Santema.

7. Appendix

7.1 Program of requirements explained

Category	Number	Wish/ req	Description	Explanation
General	1.1	Req	The implementation of the brick should provide benefits to the social well-being of Watamu citizen	Currently the livelihoods of Watamu citizens is hard
	1.2	Req	The Implementation of the bricks should provide environmental gain in Watamu	The production of machine coral blocks consumes energy and the plastic waste is found in the environment
	1.3	Req	The implementation of the brick should provide economical gain to EcoWorld and the people of Watamu	The economical opportunities in Watamu are limited and live gets more and more expensive, also about 50% of the income is dependent on tourism
	1.4	Req	The brick should have a compressive strength of at least 12.9 MPa	The designed brick has to be at least as strong as the current coral block
Material	2.1	Req	The brick should be made from plastic waste	This projects is about plastic waste remanufacturing
	2.2	Wish	The brick should be made from PP plastic	PP plastic does not have a purpose yet at EcoWorld, it is currently piled up in huge quantities.
Cost	3.1	Req	The brick should be cheaper than 138Ksh	The brick should be at least cheaper than the current coral block equivalent of 138 Ksh to be accepted locally
	3.2	Wish	The brick should be as cheap as possible	The cheaper, the more likely people are to buy it since life is already so expensive. Also many citizens don't have enough money for the coral block, so to make the designed brick as accessible as possible it should be affordable.
Use	4.1	Wish	The brick should be able to be used by 1 low-skilled person without prior information	It makes the brick more accessible and saving cost in labour.
	4.2	Req	With the brick it should be able to build an one story building	Schools are the scope of this project, they all are one story buildings
	4.3	Req	The bricks should be accepted by locals to use as building material	If the bricks are not accepted, they will not be used
	4.4	Req	The bricks must not fail in outside temperatures between 20-40 ° C non-stop	These are the climate conditions in Watamu
	4.5	Req	The bricks must not fail after 12 hour sun (UV) exposure	These are the climate conditions in Watamu
	4.6	Req	The bricks must not fail due to heavy rainfall with a duration of 1 hour	These are the climate conditions in Watamu
	4.7	Req	The bricks should be fire resistant	The local people cook on open fires near the buildings
Production	5.1	Req	The resources for the production must be available locally in Watamu and surrounding areas	The plastic waste should come from local resources to empower the local economy
	5.2	Req	The bricks must be produced locally in Watamu	To empower the local economy
	5.3	Wish	Using the production tools must be straight-forward for the machine operator at EcoWorld	The use should be easy and intuitive to prevent human errors
	5.4	Wish	The production tools and machines should only be able to be used the desired way	The persona shows the machine operator can be quite stubborn and wanting to do it their own way, but that compromises the continues quality of the brick
Repairability	6	Req	The production tools should be repairable by local people	To maintain the continuity of the brick production as much as possible
Recyclability	7	Req	At the end-of-life the brick should be reusable again	To increase environmental gain
Energy	8.1	Req	The production process should be able to deal with power-cuts with a duration of 24 hours	Watamu experiences regular power-cuts of 20 min-24 hours
	8.2	Req	The production process should be able to resume after a power-cut	Otherwise the machine can't be used again after the power-cut
	8.3	Req	The production tools should be able to run on three-phase power, 240 V	This is the grid power supply in Watamu
	8.4	Wish	The production of the brick should consume less than 5.55 Kwh	The production of a machine cut coral block is 5.55 Kwh, the designed bricks should propose environmental gain compared to the current situation
Transportability	9	Req	The brick should be able to withstand vibrations from transportation on poor maintained roads	The roads in Watamu are not asphalted and contain many holes and speed bumps

All the mixture compositions that are tried are shown in this table, including the material price. As said in the discover phase there is already a market for selling PET and HDPE recyclates to recycling factories. For that the prices are:

HDPE: 45 Ksh/kg

PET: 33 Ksh/kg

One of the goals of this project is to create economical gain. So if HDPE or PET are used, it should create more economical value than it currently has. Therefore the recyclate prices named above is added to the material cost per composition. The price per brick should be lower than the current coral block equivalent of 138 Ksh. It can be seen most compositions containing PET and HDPE are not viable enough.

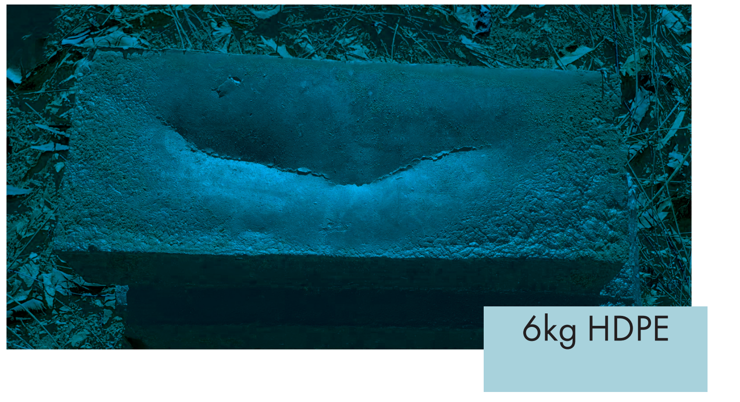
Sample number	Material	KG	Material cost	Current profit	Minimal block cost
13	PP:Finesand	2:4	30,00	-	30,00
14	PP:Finesand:cement	2.5:4.5:0.1	38,87	-	38,87
11	PP:Finesand	3:3	45,00	-	45,00
16	PP:Finesand	3:4	45,00	-	45,00
17	PP:Wrappers:Finesand	2:1:4	45,00	-	45,00
22	PP:Finesand	4:2	60,00	-	60,00
15	PP:Finesand:cement	4:4:0.1	61,37	-	61,37
21	PP	6	90,00	-	90,00
20	PET:PP:Wrappers:finesand	1:4:1:1	90,00	32,00	122,00
10	HDPE:PP:Finesand	1.5:2.5:2	60,00	67,50	127,50
1	PET:Finesand	3:3	45,00	96,00	141,00
6	HDPE:PP	2:2	60,00	90,00	150,00
18	PET:PP:Finesand	3:2:3	75,00	96,00	171,00
9	PET:PP:Finesand	3:2.5:3	82,50	96,00	178,50
4	HDPE:Finesand	3:3	45,00	135,00	180,00
12	HDPE:PP:Glass	2.5:2:2	67,50	112,50	180,00
7	HDPE:riversand:cement	3:2:0.5	54,70	135,00	189,70
8	PET:riversand:cement	4:2:0.5	69,70	128,00	197,70
19	PET:HDPE:Finesand	1:3:1	60,00	167,00	227,00
2	HDPE	4	60,00	180,00	240,00
3	HDPE:Riversand	4:2	62,90	180,00	242,90
5	PET:HDPE	3:3	90,00	231,00	321,00

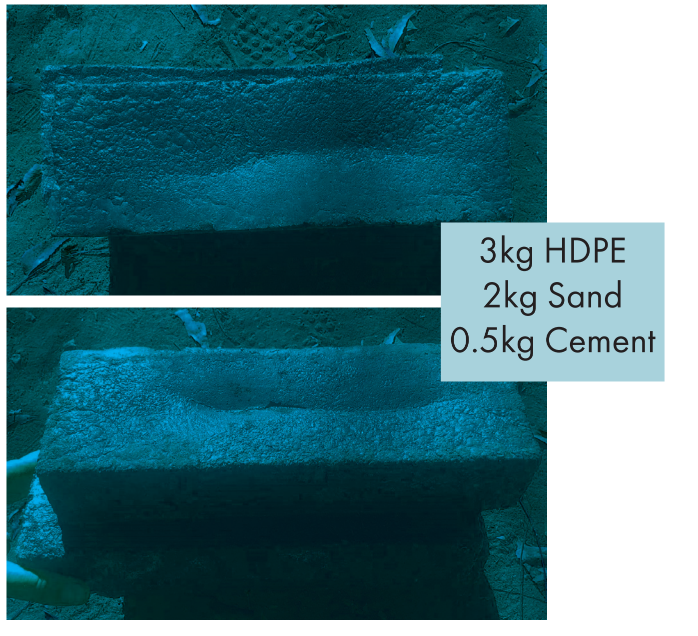
7.2 Extensive material composition research

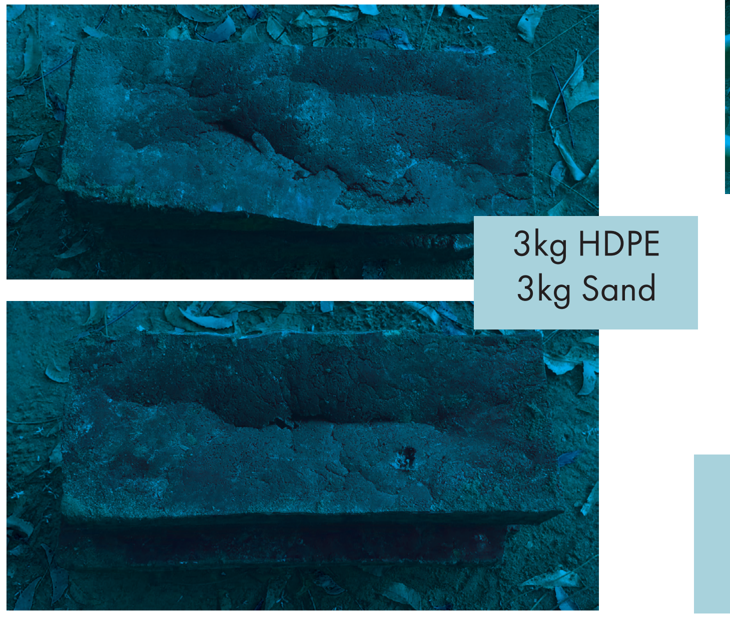
All the blocks are observed and experimented through rough tests using a hammer, screwdriver, power drill. The results are shown in this paragraph.

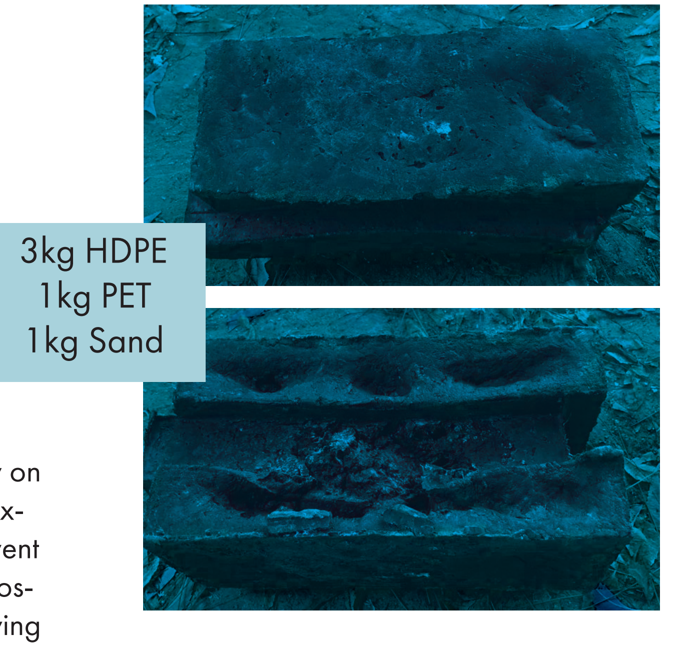
HDPE

Many compositions containing HDPE showed sinkmarks









Insights

Many HDPE containing bricks show sinkmarks, especially on the long side. It happens because the plastic molecules expand when heated, and when cooled they shrink. To prevent it from happening, the temperature should be as low as possible, since more heat means more expansion. Also applying more pressure, and cooling under that same pressure allows less space for the molecules to expand (Bryce, 2003)

HDPE

HDPE containing bricks are good workable

3kg HDPE
3kg PP

4kg HDPE
2kg Sand

1.5kg PET
2.5kg PP
2kg Sand

3kg HDPE
3kg PP

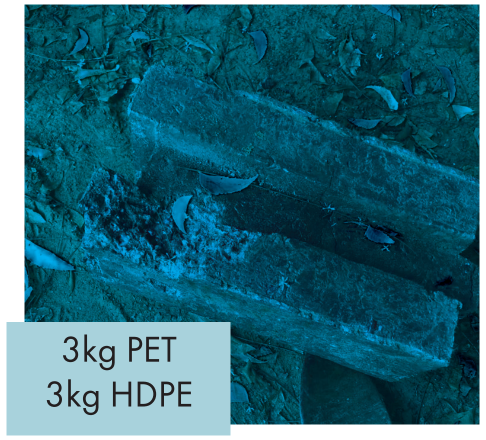
Insights
Bricks containing HDPE are very good workable. When combined to much with other plastic or sand it crumbles a bit when hitting with the hammer.

PET

Very non-uniform cooling leading to brittle bricks

3kg PET
3kg Sand

Low impact strength



3kg PET
3kg HDPE

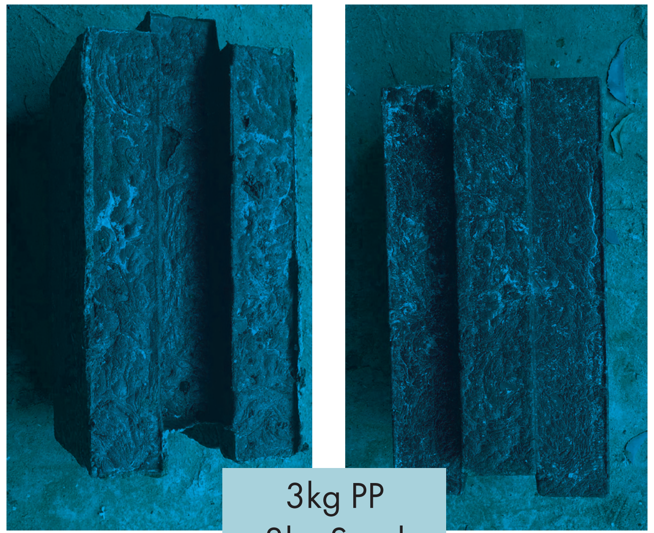
3kg PET
2.5kg PP
3kg Sand

1kg PET
3kg HDPE
1kg Sand

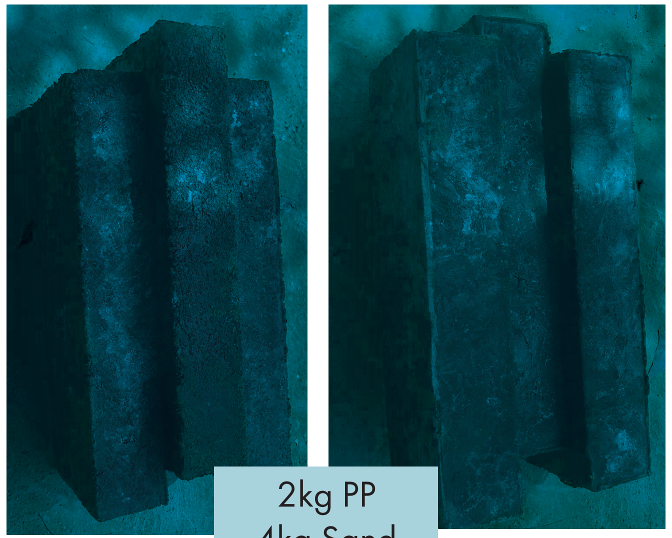
Insights
PET makes the brick brittle because of the not uniform cooling of the molecules leading to small air pockets. The regular coral block also has a low impact strength, so it is not necessarily a big problem. However the process of using PET has to be carefully managed to deliver continuous quality, and that is hard to do in the local context of EcoWorld.

PP

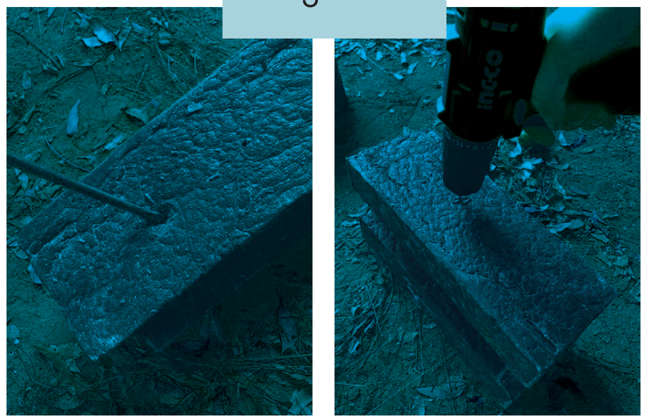
Using PP in the composition shows good results

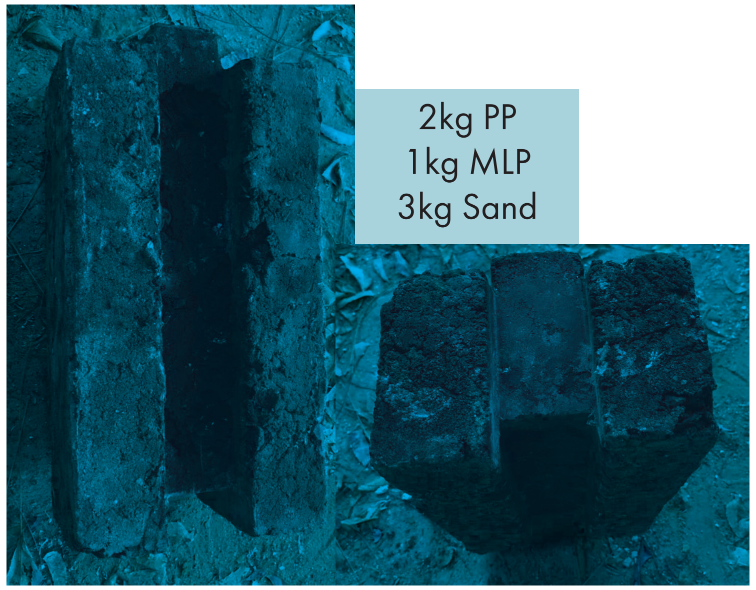


3kg PP
3kg Sand

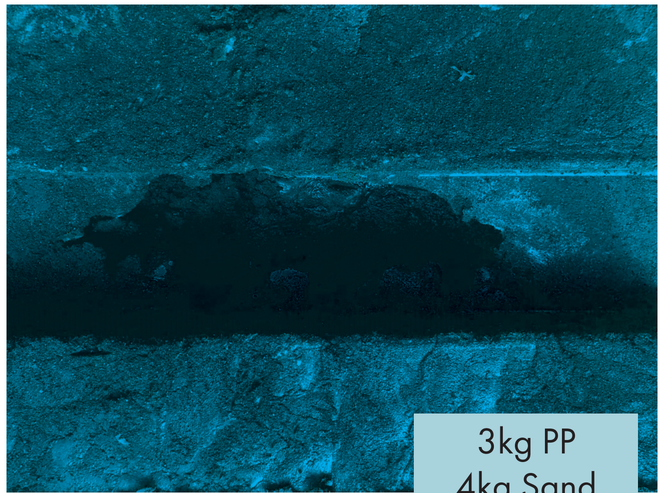


2kg PP
4kg Sand

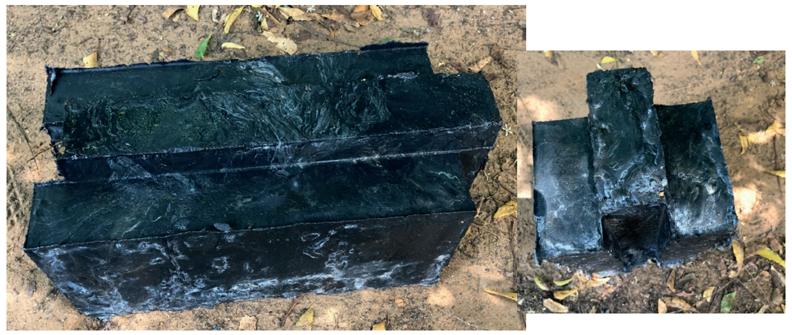




2kg PP
1kg MLP
3kg Sand



3kg PP
4kg Sand



4kg PP
2kg Sand

Insights
PP does not have any deformations and fills the mould uniformly. The brick is very workable. In some cases holes occurred due to leaking, it is quite a liquidly substance. More sand makes the molten mixture less thin.

It became clear that all mixes with PET had very non-uniform cooling and where too brittle. Almost all mixes with HDPE showed big sink marks along the sides. When different plastics were mixed, it was noticed that PP and HDPE bond well, and PET does not. It is explainable by the fact that the melting temperature of HDPE and PP are a lot closer, 125°C and 165°C respectively, compared to PET, 260°C. As found in the literature research these different melting temperatures causes the mixture not to become uniform. In one mixture some plastics might burn compared to an other type that has not melted yet.

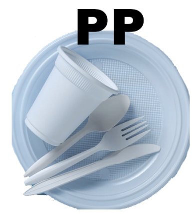
It was also found that since there is already a market for PET and HDPE it is not possible to create a good brick that has economic gain compared to selling the recyclates, while still fitting to the requirement of costing less than the coral block equivalent of 138 Ksh. PP was experienced to be the most promising, considering the combination of cost, workability and strength. The summery of the findings:

- Makes the mixture very liquid
- Makes the bricks brittle causing breakage
- Solidifies too quick during cooling so no uniform mould filling and cooling
- Doesn't bond well with sand
- The existing recyclate market makes using PET economically impossible

- Huge quantities at EcoWorld

- 8/9 bricks containing HDPE show sink marks
- Has a very smooth finishing making it impossible to plaster
- The existing recyclate market makes using HDPE economically impossible

- Makes the mixture thick and uniform
- Doesn't cool quickly making it easy to fill the mould uniformly
- The bricks with HDPE are very strong, durable and workable
- HDPE bonds well with sand in the mixture
- The thick mixture prevents leaking in the mould



- Makes the mixture sticky
- PP is currently not widely collected at EcoWorld

- There is no market yet for selling the PP
- The mixture is uniform and bonds well with sand
- The brick is very strong, durable and workable

7.3 Compression test results

MIX 1

Mixture composition	kg/sample	ratio (%)	kg/brick	Material-Ksh/brick
PP	85,33636752	100%	6	90
Finesand				
Cement				
Multi layered plastic				
Total	**85,34**	**100%**	**6**	**90**
Samples sizes	4x4x4 cm			
Test results				
Specimen number	**1**	**2**	**3**	
Failure load (KN)	17,492	44,095	25,727	
Compressive strenght (Mpa)	11,558	27,560	16,079	
Avarage compressive strenght (Mpa)		**18,399**		
Photo after failure		 		
Remarks	There is a unmolten piece of PP where the crack is	This specimen has a much higher failure load, because the mixture is more uniform and compact, hardly any holes or irregularities are visible	Small airpockets are visible	

MIX 2

Mixture composition	g/specimen	ratio (%)	kg/brick	Material-Ksh/brick
PP	56,89	67%	4	60
Finesand	28,45	33%	2	1,4
Cement				
Multi layered plastic				
Total	**85,34**	**100%**	**6**	**61,4**
Samples sizes	4x4x4 cm			
Test results				
Specimen number	**1**	**2**	**3**	
Failure load (KN)	38,650	41,927	35,352	
Compressive strenght (Mpa)	24,156	26,205	22,095	
Avarage compressive strenght (Mpa)		**24,152**		
Photo after failure				
Remarks	Small airpockets are visible	Not all pp is totally molten, still it has a high failure load	Small airpockets are visible	

MIX 3

Mixture composition	g/specimen	ratio (%)	kg/brick	Material-Ksh/brick
PP	42,67	50%	3	45
Finesand	42,67	50%	3	2,1
Cement				
Multi layered plastic				
Total	**85,34**	**100%**	**6**	**47,1**
Samples sizes	4x4x4 cm			
Test results				
Specimen number	**1**	**2**	**3**	
Failure load (KN)	27,769	23,432	28,677	
Compressive strenght (Mpa)	17,356	14,645	17,923	
Avarage compressive strenght (Mpa)		**16,641**		
Photo after failure				
Remarks	A big piece of not molten PP causes cracking	A big piece of not molten PP causes cracking		

MIX 4

Mixture composition	g/specimen	ratio (%)	kg/brick	Material-Ksh/brick
PP	28,45	33%	2	30
Finesand	56,89	67%	4	2,8
Cement				
Multi layered plastic				
Total	**85,34**	**100%**	**6**	**32,8**
Samples sizes	4x4x4 cm			
Test results				
Specimen number	**1**	**2**	**3**	
Failure load (KN)	17,798	18,957	13,880	
Compressive strenght (Mpa)	11,124	11,848	8,675	
Avarage compressive strenght (Mpa)		**10,549**		
Photo after failure				
Remarks	Breaks into many pieces	Breaks into many pieces	Breaks into many pieces	

MIX 5

Mixture composition	g/specimen	ratio (%)	kg/brick	Material-Ksh/brick
PP	42,67	50%	3	45
Finesand	42,67	50%	3	2,1
Cement	1,42	-	0,1	1,36
Multi layered plastic				
Total	**86,76**	**100%**	**6,1**	**48,46**
Samples sizes	4x4x4 cm			
Test results				
Specimen number	**1**	**2**	**3**	
Failure load (KN)	38,221	43,030	32,503	
Compressive strenght (Mpa)	23,888	26,894	20,315	
Avarage compressive strenght (Mpa)		**23,699**		
Photo after failure				
Remarks	The mixture looks very compact	The mixture looks very compact and breaks into multiple pieces	The mixture looks very compact	

MIX 6

Mixture composition	g/specimen	ratio (%)	kg/brick	Material-Ksh/brick
PP	28,45	33%	2	30
Finesand	42,67	50%	3	2,1
Cement				
Multi layered plastic	14,22	17%	1	10
Total	**85,34**	**100%**	**6**	**42,1**
Samples sizes	4x4x4 cm			
Test results				
Specimen number	**1**	**2**	**3**	
Failure load (KN)	14,730	14,550	14,395	
Compressive strenght (Mpa)	9,206	9,094	8,997	
Avarage compressive strenght (Mpa)		**9,099**		
Photo after failure				
Remarks	The failure point doesn't crack all the way through	The failure point doesn't crack all the way through	The failure point doesn't crack all the way through	

SAFETY DATA SHEET
Polypropylene (PP)

- Minimize source of ignition, such as static build-up, heat, spark or flame.
- Ventilation; Good general ventilation should be sufficient for most conditions.
- Local exhaust ventilation may be necessary for some operations.
- Check the recommended threshold exposure limit.

Individual protection measures such as personal protective equipment (PPE)

Eye/face protection:
Wear Safety glasses with side shields. Safety eyewear complying with an approved standard should be used when a risk assessment indicates this is necessary to avoid exposure to molten polymer, mists, gases or dusts.

Skin protection:
Protective gloves are required when handling hot polymer. Also, long sleeve cotton shirt and long pants if handling molten polymer.

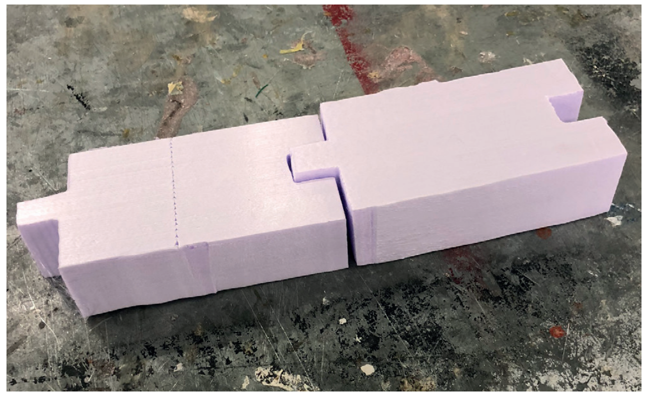
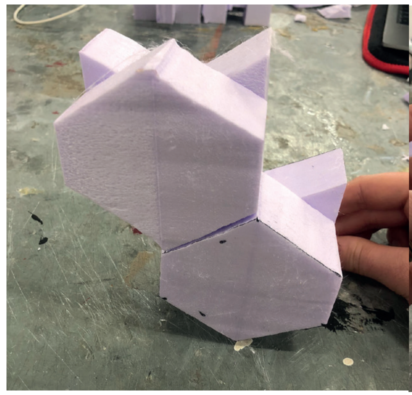
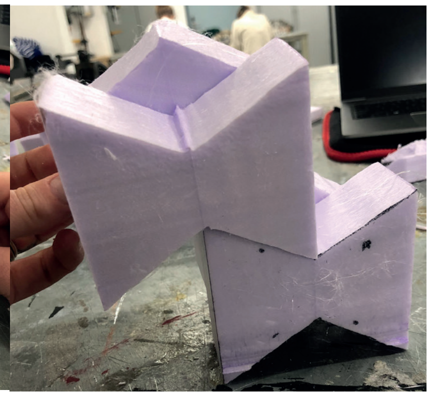
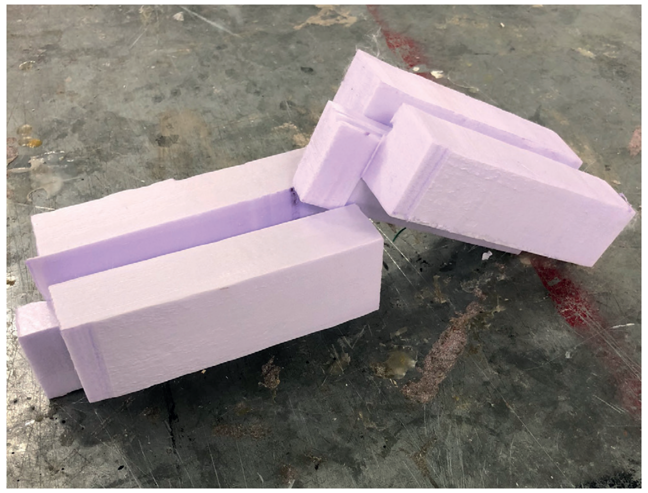
Respiratory protection:
NIOSH approved respirator for dust and vapors. Ventilation is normally required when handling this product at high temperatures.

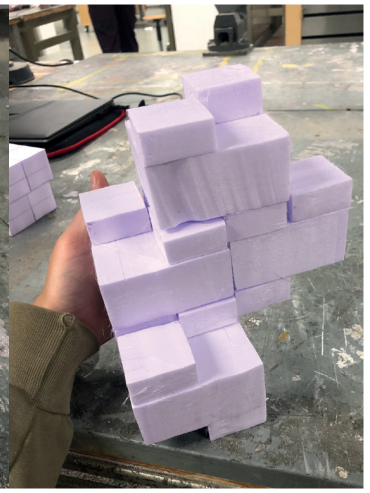
Thermal hazards:
Hot molten polymer can stick to skin. Use proper PPE before handling the hot molten polymer. Hot fumes can come out from hot molten polymer. Use appropriate mask. Provide appropriate exhaust ventilation at machinery.

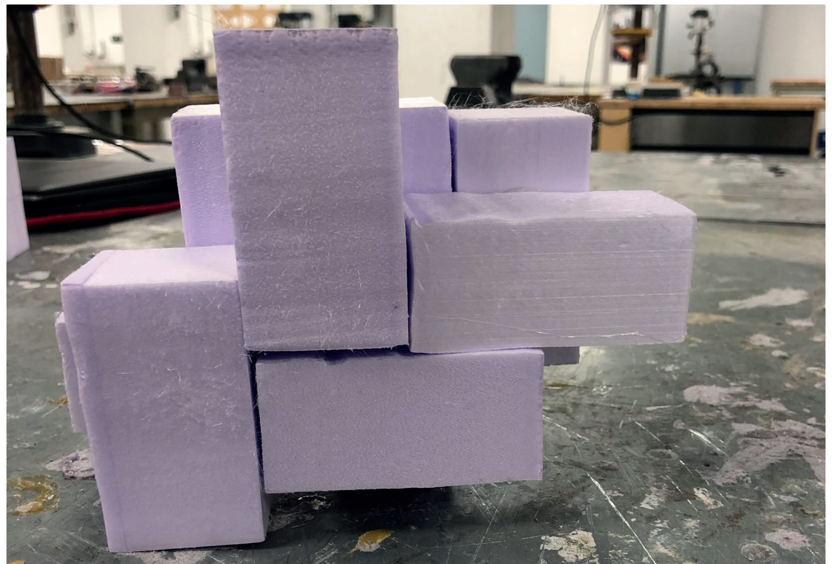
SECTION 9- PHYSICAL AND CHEMICAL PROPERTIES

Appearance and odor	Granular, Translucent to white solid pellets/ Odorless	Threshold odor concentration	Not available.
Melting Point	150-170 °C (DSC)	Boiling point	Not applicable
Relative Density (H_2O = 1): At 23 °C	0.880 - 0.913	Vapor pressure	Not applicable
PH	Not applicable	Vapor density	Not applicable
Flash point	>300°C (>572°F), Closed cup	Flammable limits in air	Not available
Evaporation rate	Not applicable	Partition coefficient: n-octanol/water	The product is insoluble in water and octanol
Decomposition temperature	>300°C (>572°F)	Percent volatile by volume	<0.1 %
Soluble in:	Hot Xylene	Viscosity	Not applicable
Auto-ignition temperature	>410°C (>770°F)	Molecular weight	approx. >200000 Dalton

7.5 Interlocking shapes






7.6 Mould design cycles

The process of making the mould was iterative, through experimenting different design insight were identified leading to the next iteration.

Iteration	Picture	Insights
1 - wooden mould in rectangular shape		The heated plastic was so hot that it scorched the wood surface, leaving pieces of wood stuck to the brick.
2 - Small steel mould		Steel is the right material for the mould, the surfaces of the brick were smooth. However, it was hard to get the brick out of the mould since the angles didn't allow for releasing.
3 - Steel interlocking mould with releasing hole from the bottom		Even though the mould had releasing angles and a hole in the bottom to push the mould out, it still took a lot of force and time to get the brick out.
4 - Steel interlocking mould with hinges		The parts can get lost, better to have as little parts as possible. Also, when adding the pressure to this mould the molten mixture will leak through the bottom openings because the sides are not attached to the bottom

Mould making manual

Tools

Circular saw

Welding machine

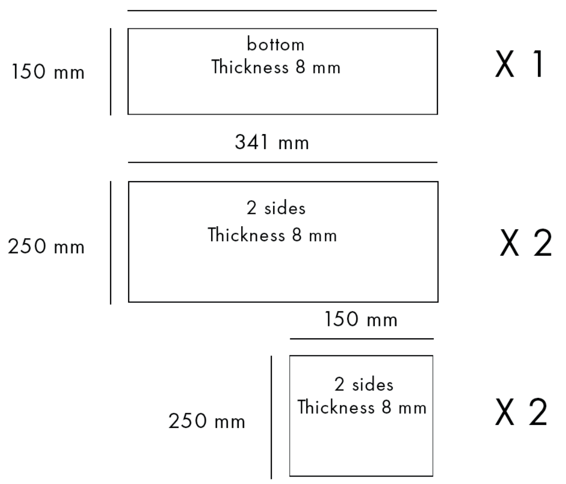
Materials

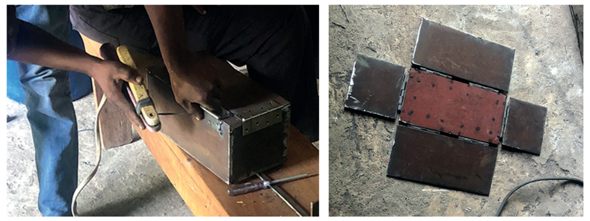
Black sheet
Rectangular tube 25x50mm
6 hinges of 100mm each
Iron rod Ø 10mm
Tube Ø 15mm

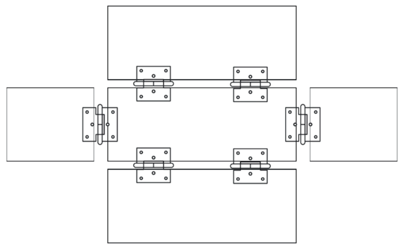
Step 1. The main part

1. Cut the iron sheet in 6 pieces as shown above

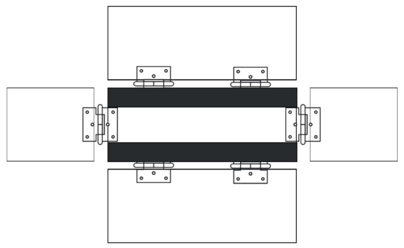
Be very precise cutting the iron sheet in the exact rights sizes with straight edges, otherwise you get in trouble later!



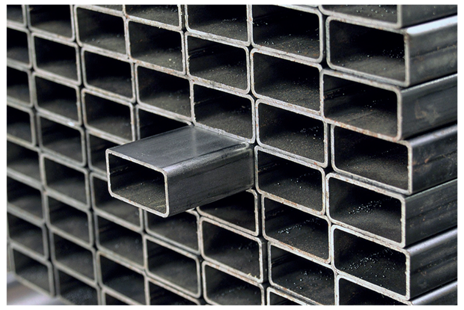




2. Weld the hinges to the sides and bottom to connect the parts

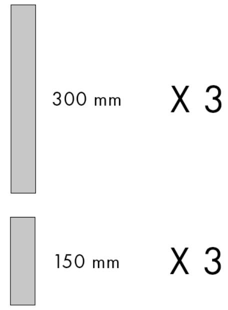


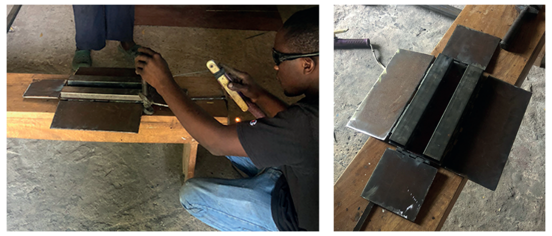
3. Weld pieces of metal to the bottom outside to make sure the hinges don't touch the ground



4. Cut the rectangular tube in the right sizes

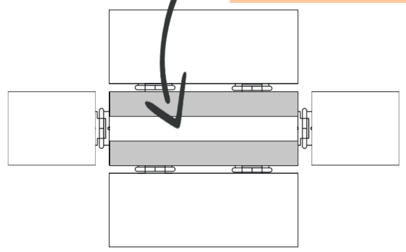
Make sure you cut straight!





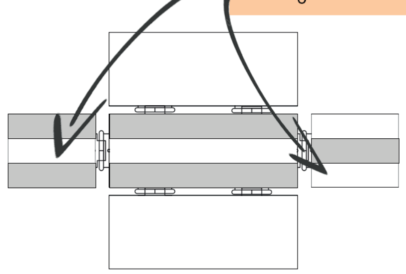
5. Weld the 2 rectangle tubes to the bottom

Make sure these white spaces are EXACTLY the size of the rectangle tube. You can lay a tube in the white space before welding to make sure the space has the right size



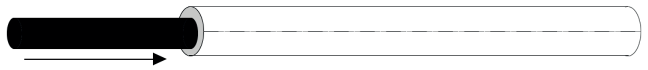
6. Weld the 3 rectangle tubes to the sides

Make sure these white spaces are EXACTLY the size of the rectangle tube. You can lay a tube in the white space before welding to make sure the space has the right size

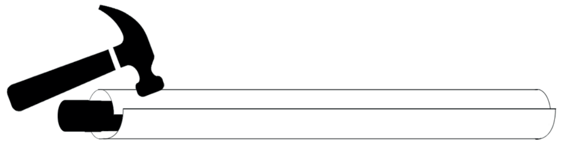


Step 2. The edges

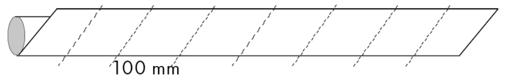
1. Make a cut on the long side of the tube, to open up the tube



2. Insert the rod



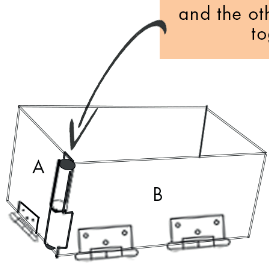
3. With a hammer hit the tube so it becomes the right size to fit around the rod



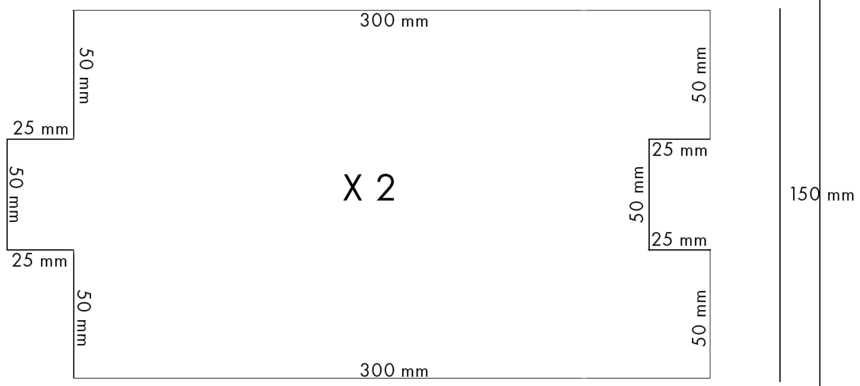
4. Take the rod out and saw the adjusted tube in 8 parts of 100 mm each

5. Weld the 8 small tubes to the 4 edges. 2 small tubes per edge

Make sure one small tube is attached to side A, and the other small tube to side B so they come together when the sides go up



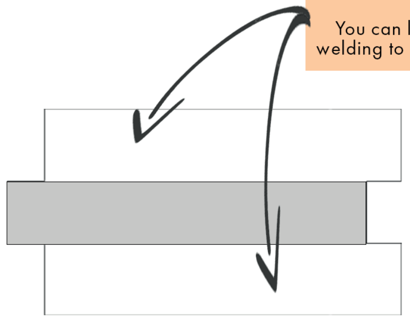
Step 3. The cover



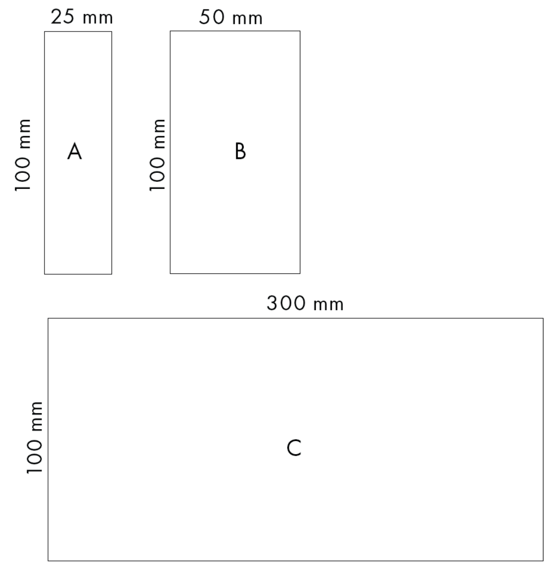
Try to fit the cover inside the mould, if it does not fit adjust the edges a bit with the saw

1. Cut the shape above two times from the iron sheet. One time for the cover, one time as insert for the flat top layer bricks

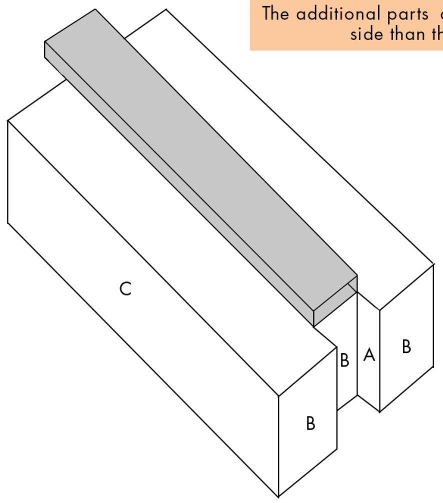
Make sure these white spaces are EXACTLY the size of the rectangle tube.
You can lay a tube in the white space before welding to make sure the space has the right size



2. Weld the final rectangle tube to the cover



The additional parts are welded on the opposite side than the rectangle tube

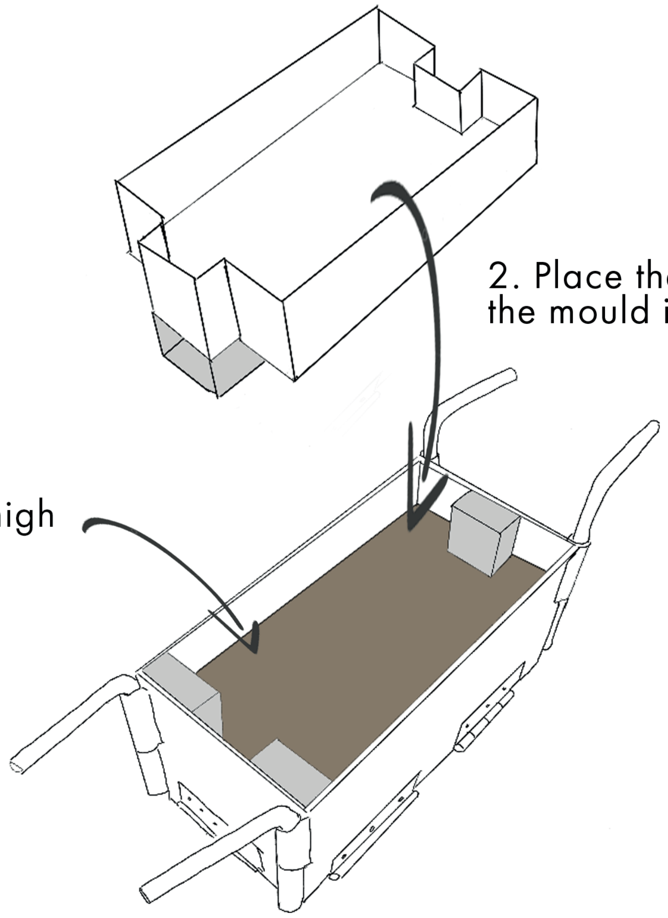


3. Cut the above shapes from the iron sheet and weld it to the cover.
(This is done to make the cover thicker and prevent leakage)

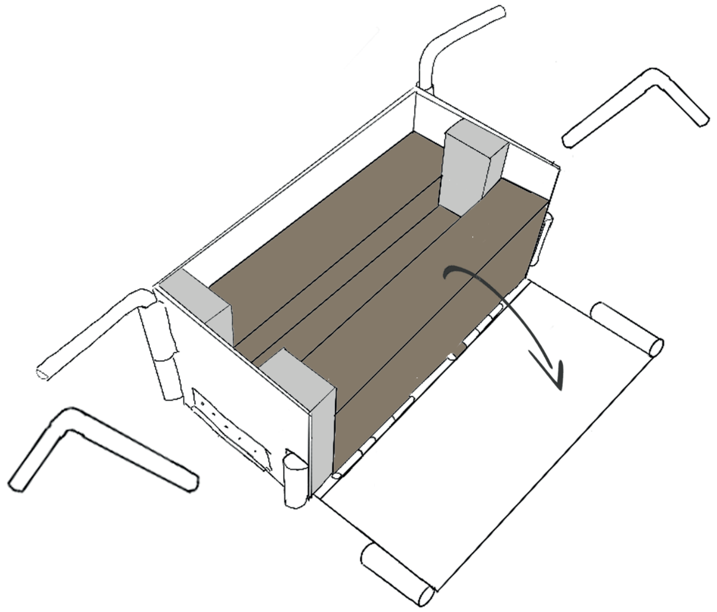
Step 4. Use of the mould

2. Place the cover on top and put the mould in the press

1. Fill to 150mm high



3. Take the rods out and open the mould



APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair ________ date 31 - 10 - 2022 signature ________

CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair.
The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: ______ EC

Of which, taking the conditional requirements into account, can be part of the exam programme ______ EC

List of electives obtained before the third semester without approval of the BoE

YES all 1st year master courses passed

NO missing 1st year master courses are:

name ________ date - - signature ________

FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **.
Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: APPROVED NOT APPROVED

Procedure: APPROVED NOT APPROVED

comments

name ________ date - - signature ________

Design construction material from recycled plastic in Watamu, Kenya

project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 22 - 09 - 2022 | 23 - 02 - 2023 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

There are many social and environmental challenges in the world. For my thesis I will deep dive into two of all those challenges, specifically in Watamu, Kenya. Watamu is a small town on the coastal area of Kenya. It is located 100 km north of Kenya's second largest city Mombasa, and has about 30,000 inhabitants. One of their challenge is the large number of plastic waste laying around in their nature and ending up in the ocean. This is a health-disaster for people, animals and plants on land and in the sea. Since Watamu is far away from Nairobi, where most of the recycling plants are, it has to deal with its own plastic waste problem (and other plastic from the ocean). They can handle 20 tons per month, and scaling up to 50 tons per month. 90 % Of that waste is PET plastic. Other challenges are the unemployment in Watamu and the lack of proper housing and building materials for the low-income households. In Watamu they use fossilized coral to make blocks, which has a really negative impact on the environment. In my graduation I will combine these challenges into one solution: developing building material from plastic waste. With three goals, listed on priority:

1. Getting rid of the plastic waste in the nature by giving it value
2. Creating jobs, collecting and upcycling the plastic waste
3. Upcycling the plastic into building material creating (improved) buildings for low-income households

In Watamu I found an organization that is active within these challenges, and willing to help with my thesis. It is called: EcoWorld, as part of the Watamu Marine Association. They turn the plastic waste, collected by waste pickers, into new products and raise awareness regarding the plastic waste challenges. The sell the recycled products to consumers as well as the plastic flakes to large recycling companies to generate revenue. It is a non-profit social enterprise meaning they reinvest all revenue back into their organization. They provide an income for plastic waste collectors and create jobs to empower locals. EcoWorld is looking for new products from the plastic that they can sell to become less dependent on external funding. The population is growing and more and more housing is needed, so turning waste into building material is a win-win. That building material can be sold to organizations to generate revenue for EcoWorld and its employees. It should be kept in mind that there is a local system in place regarding building houses.

The main stakeholders are:
- EcoWorld organization: They need to invest in the production
- The machine operators at Ecoworld: They will produce the designed material
- The builders: They use the material
- The citizens of low-income and rural areas in Kenya: they will live in buildings made from the material

The biggest limitation during my graduation is that I am in the Netherlands. It can be hard to find the right people during the analysis phase. To minimize this limitation I will be closely working with the EcoWorld organization. They are located in Watamu, and they agreed to helping me connect with local people as much as they can. For the testing and product interaction phase I'm happy to have the opportunity to go to Watamu and do that part of my graduation on the ground, with the actual end-users. A second limitation can be time. Designing and testing construction parts can take a long time. To make sure I can finish with a working product it is important to scope my framework early on in my graduation. Keeping in mind the saying: "Design the painting, for on the wall, in the room, as part of a house", instead of designing the house.

space available for images / figures on next page

introduction (continued): space for images

image / figure 1: Plastic collection in Watamu

image / figure 2: Plastic shredder owned by EcoWorld

Initials & Name Student number

Title of Project

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

The problem is: There is too much plastic waste without a purpose in Watamu, Kenya.

The scope of my project will be to design a solution for the machine operators at EcoWorld, since they have to be able to produce the final designed material. And the builders, since they have to use the material to build the houses. The benchmark for the design of the building block is the currently used building materials and methods in rural Kenya. Which is mud and wood huts, and fossilized coral block houses. There is already a system in place regarding building houses, and the new designed material should not compete with that system. Therefore the goal is to make a community house out of the plastic waste, to show the citizens that plastic can be of value.

When looking at building material made from plastic there are many challenges. It is important for my graduation to scope the solution space. First, the kind of plastic that will be used. As said before, PET is by 90% the most plastic that comes in and does not have a purpose yet. Therefore using PET waste has the preference, however I will look briefly into other plastic waste as well. Next, I will focus mostly on the design of the building material, as well as the specific tools that need to be developed, for example a mold. The usebility and implementation will also be included. The in-depth focus wil not be on the existing machinery like shredders, ovens or mixers. Neither on all the different buildings that can be made with the material.

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

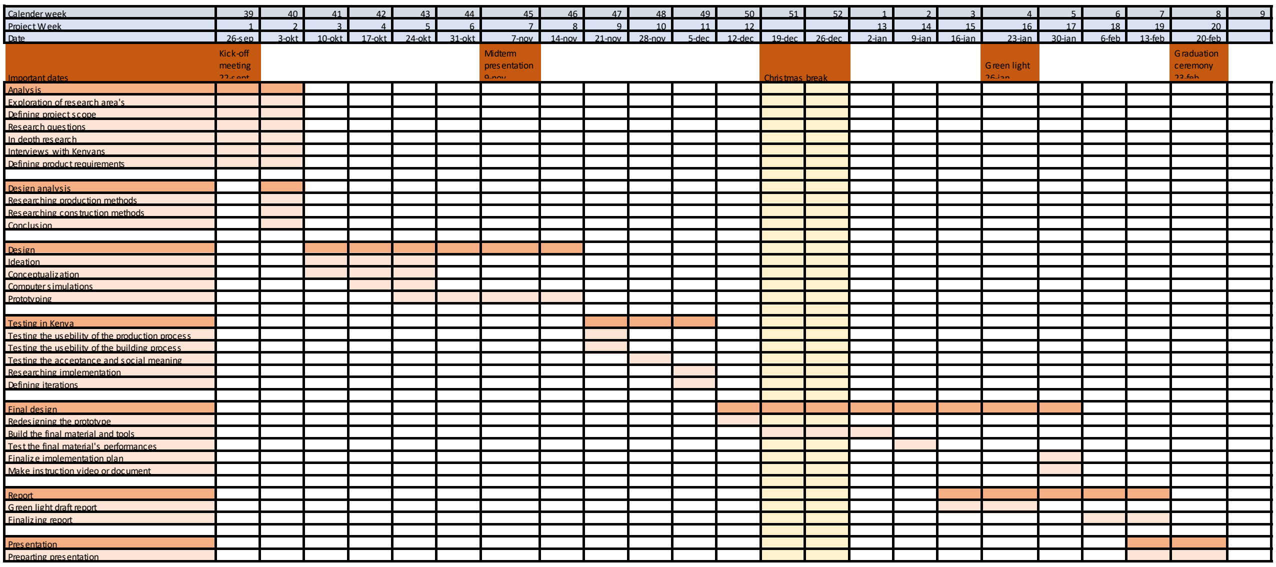
Design a construction element that consists plastic waste, that can be produced in a low-resource plastic recycling facility in Watamu. The building material will be used in the construction of buildings in low-income and rural areas in Kenya.

The final delivery will be a product: the designed construction element and it's specific production tools. For the implementation a stand-alone user guide will be designed. The way I will be getting there is through interventions and co-creation with the end users and other stakeholders as well as by materials and product performance testing.

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 22 - 9 - 2022 23 - 2 - 2023 end date



Making the planning I used the backwards design approach.
What is the desired result? Design construction material + tool.
How are you going to show/prove that result? By producing a prototype.
What do you need to do to produce a prototype? Design.
What do you need to know to make a design? Research and interviews.

Initials & Name ______________________ Student number ______________________

Title of Project ______________________

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

This project is something I wanted to do already for a long time. I have a big ambition contributing to getting rid of the plastic waste problem. With my education I believe I can really make an impact in this area.

To understand the problem a bit better I have done an internship at Unilever's R&D sustainable packaging team. What can be done to limit the use of plastic in general? Now it's time for me to learn about the other end of the spectrum, what can we do with the plastic that is already in nature? I absolutely love nature, love the ocean, love surfing. So it is horrible to see all the unnecessary plastic waste everywhere.

The last years I developed my entrepreneurial skills since I launched my own company in product design. This will be of great help during my graduation project, managing the project and stakeholders independently. The biggest learning objective is getting insight in the plastic waste issues and gaining more in depth knowledge about plastic upcycling and it's opportunities. As well as designing for the Base of the Pyramid and co-working with people and clients from completely other cultures and social-economic background.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.