REPORT
Madagascar Environmental impact study of the house model, “Case améliorée en bois”

November 2023

croix-rouge luxembourgeoise
Mënschen hëllefen

LUXEMBOURG AID & DEVELOPMENT

Contents

Acknowledgements

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1. Definitions

Carbon neutral means that any greenhouse gases (including but not limited to carbon dioxide) that are released into the atmosphere are balanced by an equivalent amount of greenhouse gases being removed.

Carbon offsetting a way to reduce emissions and to pursue carbon neutrality is to offset emissions made in one sector by reducing them somewhere else.[1]

Carbon positive means that an activity goes beyond achieving zero carbon emissions to create an environmental benefit by removing additional carbon dioxide from the atmosphere[2]

Carbon footprint is a term commonly used which refers to the total greenhouse gas emissions caused by an individual, event, organization, service, place or product, expressed as carbon dioxide equivalent (CO_2 equivalent)[3].

The Climate Risk Index (CRI) indicates a level of exposure and vulnerability to extreme events, which countries should understand as warnings in order to be prepared for more frequent and/or more severe events in the future[4].

Climate change is a long-term shift in global or regional weather patterns. Usually, the term climate change refers specifically to the increase in global temperatures from the mid-20th century to the present[5].

CO_2 equivalent A carbon dioxide equivalent or CO_2 equivalent (a.k.a. CO_2 eq.) is a metric measure used to compare the emissions from various greenhouse gases (GHGs) on the basis of their global-warming potential (GWP), by converting amounts of other gases to the equivalent amount of carbon dioxide with the same GWP[6].

Decompose is the process by which dead organic substances are broken down into simpler organic or inorganic matter such as carbon dioxide, water, simple sugars and mineral salts.[7]

Embodied carbon comes from the embodied energy consumed to extract, refine, process, transport and fabricate a material or product (including buildings). It is often measured from cradle to (factory) gate, cradle to site (of use), or cradle to grave (end of life). The embodied carbon footprint is therefore the amount of carbon (CO_2 or CO_2 emissions) which is generated in order to produce a material[8].

Environment refers to the physical, chemical, and biological surroundings in which communities live and develop their livelihoods. It provides the natural resources that sustain individuals and determines the quality of the surroundings in which they live[9].

Environmental Impact is defined as any change to the environment, whether adverse or beneficial[10], caused by a project, a process, an organism(s) and a product(s), from its conception to its end of life.

Environmental Performance Index (EPI) is a method of quantifying and numerically marking the environmental performance of a state's policies[11].

Environmental sustainability: A state in which the demands placed on the environment can be met without reducing its capacity to allow all people to live well, now and in the future. While environmental sustainability is broader than climate action, limiting climate and environmental impacts can both contribute to mitigating climate change, for instance by reducing emissions and greening practices, and to strengthening people’s resilience to climate change[12].

1 *European Parliament*
2 *Fast Company*
3 *Carbon Trust*
4 *Germanwatch*
5 *National Geographic*
6 *Energy Manager Canada*
7 *Lynch, Michael D. J.; Neufeld, Josh D. (2015). "Ecology and exploration of the rare biosphere"*
8 *Circular Ecology*
9 *NSW Government*
10 *University of Calgary*
11 *Yale Center for Environmental Law & Policy, and Center for International Earth Science Information Network at Columbia University.*
12 *IFRC*

Global warming is the unusually rapid increase in Earth’s average surface temperature over the past century primarily due to the greenhouse gas effect. Global warming is often described as the most recent example of climate change[13].

Greenhouse gas effect a natural phenomenon that causes a rise in the surface temperature of our planet.

IDP (Internally Displaced person) is someone who is forced to leave their home but who remains within their country's borders.[14]

Life cycle refers to the consecutive and interlinked stages of a product or service, from raw material acquisition or generation from natural resource, to design, production, transportation / delivery, use, end-of-life treatment and final disposal[15].

Life cycle assessment (LCA) is a method of evaluating the environmental impact associated with all stages of a product's life, i.e., from the extraction of raw materials, through materials processing, manufacturing, distribution, use, repair and maintenance, to disposal or recycling.

Waste any residue from a production, transformation or use process, any substance, material, product or, more generally, any movable asset disposed of or intended for disposal by its holder[16].

Waste management A set of operations involving the sorting, pre-collection, collection, transport, storage, recycling and disposal of waste, including the monitoring of disposal sites.

13 *NASA*
14 *UNHC*
15 *ISO*
16 *https://assembly.coe.int*

2. General information

Project/mission title: Madagascar Environmental Impact Study of the house model, "Case améliorée en bois"

Countries: Madagascar

Report date: November 2023

Type of operation: Remote consultancy

Requesting Organization: International Aid of the Luxembourg Red Cross

3. Context

The International Aid of the Luxembourg Red Cross (AICRL) has been working for several years in the field of emergency shelters and sustainable housing in sub-Saharan Africa. It relies on its Shelter Research Unit (AICRL-SRU) to develop models of humanitarian architectural solutions tailored to the climatic conditions and cultural contexts of each region. Numerous research missions have led to the development of shelter models that take into account local specificities and the availability of materials. AICRL collaborates closely and in partnership with the different National Society in each country.

Since 2021, the Luxembourg Red Cross has conducted several studies to assess the environmental impact of emergency constructions in the various countries where it collaborates. To date, these studies have been carried out for their shelter model in Niger, Burkina Faso, Chad, and Mali.[17] The same methodology used in the previous studies will be applied to conduct this study. Additionally, the housing models in DRC and Burundi, will also be included in this ongoing research.

AICRL is involved in several emergency reconstruction projects in Madagascar in collaboration with local stakeholders, as well as risk reduction projects in the east and north of the island. These projects include the establishment of improved traditional house models that need to be assessed in terms of their environmental impact and provide guidance, recommendations, and ideas to reduce their negative impact on the environment.

The house model implemented in Mananjary and Antalaha areas, which is the focus of this study, is the "Case améliorée en bois". This model represents a sustainable approach to housing. It is constructed from a variety of local wood and plants, and has an area of 16 square meters. A "case" is a traditional house in Madagascar, constructed using basic materials that are not very durable and with a short to medium lifespan.

Field experience and feedback have allowed AICRL to refine their housing models. However, a detailed analysis of the environmental impact of these models is still pending. This analysis is crucial to identify the model best suited for each local context, aligning with global efforts to enhance the environmental sustainability of humanitarian aid.

The change in weather patterns caused by global warming has happened faster over the past century. Natural disasters, such as floods, droughts, desertification, fires, etc., are increasing due to climate change, and they are contributing to food insecurity, economic losses, population displacements, and are also drivers of conflict. People all over the world are facing the reality of climate change, and in many parts of the world this manifests as increased volatility of extreme weather events. Only between 2000 and 2019, over 475 000 people lost their lives worldwide[18]

17 *Each country report and a compilation report for the Sahel region are available in both English and French on the Global Shelter Cluster website, under. Environment Community of Practice - Documents | Shelter Cluster*
18 *Global Climate Risk Index 2021*

due to these. The 2021 edition of the Climate Risk Index[19] clearly shows that signs of escalating climate change can no longer be ignored, on any continent or in any region. Impacts from extreme-weather events hit the poorest countries hardest as these are particularly vulnerable to the damaging effects of hazards, have a lower coping capacity and may need more time to rebuild and recover[20].

Africa is already one of the continents most affected by climate change, even if is responsible for only 4% of the world's greenhouse gas emissions. However it is disproportionately affected by its consequences, which have profound impacts on lives, livelihoods, and economies. In southern African, Madagascar is one of the countries most vulnerable to the effects of it, ranking 172th out of 182 countries classified on the Notre Dame Global Adaptation Index (ND-GAIN Index in 2021)[21].

Madagascar is a country rich in natural capital and biodiversity, given its 90% endemic biodiversity, but with high levels of poverty, food insecurity, population growth, and exploitation of natural resources. The country faces development and environmental challenges that are expected to be intensified by climate change. Climate risks in Madagascar include increasing temperatures, reduced and more variable precipitation, more frequent droughts, more intense cyclones, rising sea levels and sea temperature.[22] All these effects due to climate change cause negative impacts on its fragile ecosystem and its people.

Governments around Africa are advocating for action to address these impacts. The first Africa Climate Summit held in Nairobi in 2023 concluded with a declaration[23] endorsed by nearly all leaders from across the African continent, urging collective action to combat the adverse effects of climate change on the continent.

Therefore, good environmental practices from humanitarian agencies can also help protect the local environment, contribute to improve the resilience of communities to natural disasters, and reduce their vulnerability, as well as reduce the contribution made to further climate change. However, in the past a lack of consideration for the environment has led to humanitarian responses having a negative impact on the environment. For instance, huge quantities of relief items have been brought into a country, local natural resources have been overused, and large amounts of unmanaged waste generated, without considering the consequences for the environment. Humanitarian agencies should not contribute to the degradation of the natural resources that affected communities rely on, and should take steps to mitigate climate change. The concept of 'do no harm' should also be extended to the environment. This study of the environment impact of Madagascar house model is a contribution to the growing body of work on the environmental impact of humanitarian assistance.

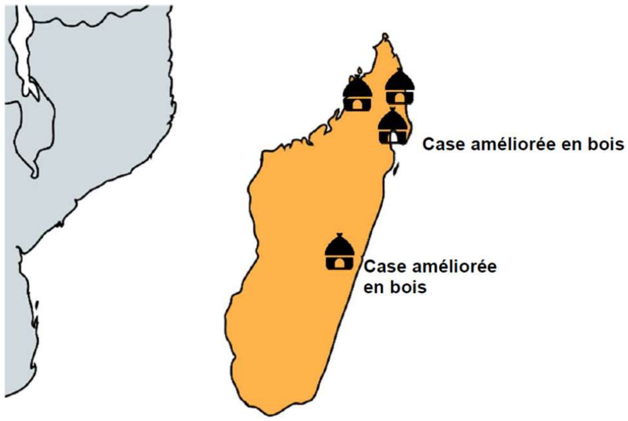
19 *The Climate Risk Index (CRI) is a tool used to assess and rank countries or regions based on their vulnerability to the impacts of climate change. Global Climate Risk Index 2021_1.pdf*

20 *Global Climate Risk Index 2021*

21 *The ND-GAIN, or the Notre Dame Global Adaptation Initiative, is a research project and index developed by the University of Notre Dame's Global Adaptation Initiative. It is designed to assess and rank countries' vulnerability to climate change and their readiness and ability to adapt to its impacts. ND-GAIN provides valuable data and insights to help policymakers, businesses, and organizations understand the climate risks faced by different countries and make informed decisions on adaptation strategies and investments. The index considers various factors, including environmental, social, and economic indicators, to evaluate a country's overall climate readiness and vulnerability. ND-GAIN aims to promote climate resilience and adaptation efforts worldwide by providing a comprehensive assessment of each country's preparedness. Rankings // Notre Dame Global Adaptation Initiative // University of Notre Dame (nd.edu)*

22 *Climate change risks and adaptation options for Madagascar.* Sarah R. Weiskopf, Janet A. Cushing, Toni Lyn Morelli *and* Bonnie J. E. Myers

23 *the_african_leaders_nairobi_declaration_on_climate_change-rev-eng.pdf (afdb.org)*



Map showing the location of the "Case améliorée en bois", built in Madagascar, by AICRL in partnership with the Madagascar Red Cross

4. Outcome and Outputs

Outcome
With the support of SRU, AICRL seeks to improve the quality of the shelter response in Madagascar, and minimise the environmental impact of its operations.

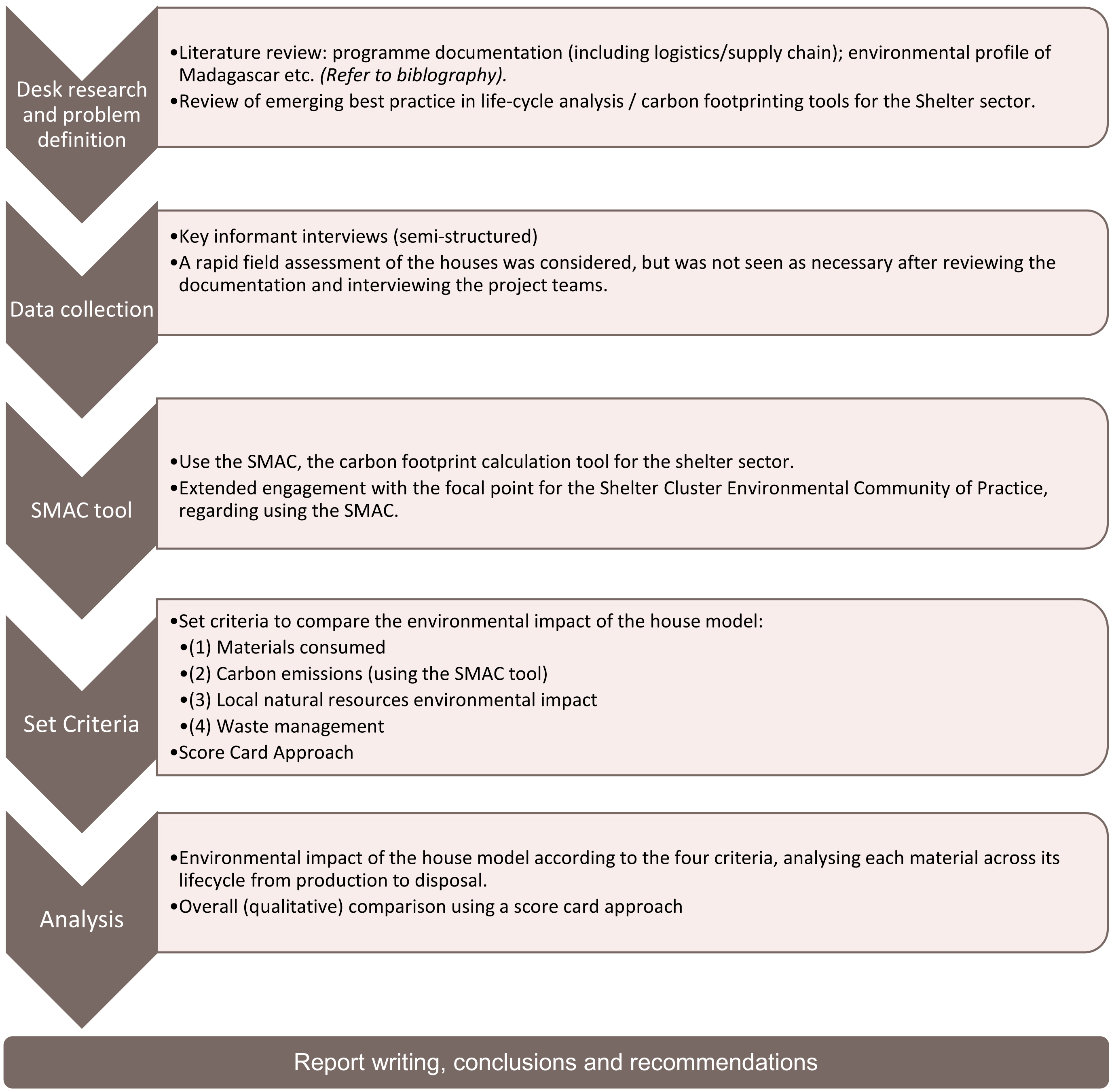
Outputs
- A study of the environmental impact of the house model, "*Case améliorée en bois"* in Madagascar.
- Recommendations to reduce the environmental impact of AICRL shelter interventions

Caveat on scope of this study
The scope of this study is limited to the environmental impact of the house model. It does not include aspects relating to the preparation, construction and maintenance of the sites where the shelters were constructed, nor does it include factors relating to cost, functionality, and satisfaction of targeted populations etc. These have been well covered by previous programme evaluations of the AICRL shelter projects.

5. Methodology

These studies were conducted remotely, with the support of AICRL and Madagascar Red Cross field staff (shelter, logistics, other); the Shelter Cluster in Madagascar; environmental experts from the shelter sector, and different local partners.[24] Organisations that specialise in ecological recycling and waste recovery in the country were contacted for this study, but without success.
The methodology adopted is summarised by the graphic below. This follows the same approach as in the previous studies conducted for the Sahel shelter models in Niger, Burkina Faso, Chad, and Mali. Additionally, this research will extend to include the housing models in the DRC and Burundi, each detailed in a separate country report. [25]

24 *Refer to Annex 1 to see the list of people and organisations contacted.*
25 *Each country report and a compilation report for the Sahel region are available in both English and French on the Global Shelter Cluster website, under. Environment Community of Practice - Documents | Shelter Cluster*


Desk research and problem definition
•Literature review: programme documentation (including logistics/supply chain); environmental profile of Madagascar etc. *(Refer to biblography).*
•Review of emerging best practice in life-cycle analysis / carbon footprinting tools for the Shelter sector.
Data collection
•Key informant interviews (semi-structured)
•A rapid field assessment of the houses was considered, but was not seen as necessary after reviewing the documentation and interviewing the project teams.
SMAC tool
•Use the SMAC, the carbon footprint calculation tool for the shelter sector.
•Extended engagement with the focal point for the Shelter Cluster Environmental Community of Practice, regarding using the SMAC.
Set Criteria
•Set criteria to compare the environmental impact of the house model:
•(1) Materials consumed
•(2) Carbon emissions (using the SMAC tool)
•(3) Local natural resources environmental impact
•(4) Waste management
•Score Card Approach
Analysis
•Environmental impact of the house model according to the four criteria, analysing each material across its lifecycle from production to disposal.
•Overall (qualitative) comparison using a score card approach
Report writing, conclusions and recommendations

6. Background information

6.1. Region profile

MADAGASCAR

Location

Madagascar is an island country located in the Indian Ocean, off the southeastern coast of Africa. Is situated approximately 400 km off the coast of Mozambique. It covers an area of around 587,000 square km[26].

Population

Madagascar has an estimated population of 30 million people[27]. It is currently growing at a rate of 2.68% per year[28]

Economic and social situation

Madagascar's Human Development Index[29] (HDI) score was 0.501 in 2021, which categorizes the country as having a low level of human development. It ranks 173th out of 191 countries.[30] Despite considerable natural resources, has one of the world's highest poverty rates[31].

Crisis overview

Madagascar is frequently impacted by natural hazards. Some 3.86 million people are in need of urgent humanitarian assistance in 2023, following devastating cyclones in the Grand Sud-Est in 2022 and 2023 and the catastrophic drought in the Grand Sud from 2020 to 2022. In 2021, the country experienced its worst drought in 40 years. The food security and nutrition situation have severely deteriorated. This is due to the combined effects of the drought, low agricultural productivity, COVID-19, the lack of essential food staples in the market, and active cyclonic seasons. Madagascar has one of the highest malnutrition rates in the world, more than 50% of children suffer from chronic malnutrition.[32]

Climate

There are two seasons in Madagascar: a very hot rainy season from November to April, and a cooler dry season from May to October. The east coast has a sub-equatorial climate driven by easterly trade winds, along with the heaviest and most consistent rainfall. The west coast of the country is generally drier and is subject to significant coastal erosion. The southwest and the extreme south are semi-desert environments. The average annual temperatures vary between 23°C and 27°C along the coast and between 16°C and 19°C in the central mountains. [33]

Tropical cyclones are an important climatic feature. They form far out over the Indian Ocean, especially from December to March, and approach the eastern coast, bringing torrential rains and destructive floods.[34]

26 *Britannica*
27 *Population, total - Madagascar | Data (worldbank.org)*
28 *Madagascar Population 2023 (Live) (worldpopulationreview.com)*
29 *The Human Development Index (HDI) is a composite measure used to assess a country's overall human development, considering factors such as life expectancy, education, and per capita income. It is calculated and published by the United Nations Development Programme (UNDP)*
30 *Specific country data | Human Development Reports (undp.org)*
31 *Worldbank*
32 *European Commission*
33 *Madagascar - Climatology | Climate Change Knowledge Portal (worldbank.org)*
34 *Madagascar - Tropical, Humid, Rainforest | Britannica*

6.2. Madagascar environmental Challenges

Environmental Challenges

Climate change
Madagascar is highly exposed to climate risks, including more frequent and severe cyclones, changes in precipitation patterns, rising temperatures, costal erosion, etc. These impacts are expected to become more severe over the course of the century due to climate change.

Increasing Temperature
Madagascar has observed an overall increase in average temperatures over the past few decades. Under a high emissions scenario, the mean annual temperature is projected to rise by about 3.4°C on average by the end-of-century. If emissions decrease rapidly, the temperature rise is limited to about 1°C.[35] This warming trend is consistent with global climate change patterns.

Floods and Cyclones
Madagascar has the highest risk of cyclones in Africa; it currently experiences three to four cyclones per year. which cause widespread coastal flooding, loss of life, and damage to infrastructure and livelihoods. Inland heavy rainfall also contributes to gully erosion, flooding in urban areas, and loss of connectivity.[36]

Droughts
Droughts are most common in southern Madagascar but can also occur in the central highlands and eastern region. Deforestation and poor land-use practices have exacerbated damage caused by floods.[37] Droughts contribute to loss of crops and widespread hunger and malnutrition.

Deforestation
Madagascar's forest area has declined from 29% of land-area in 2000 to 21% in 2020. From 2001 to 2022, Madagascar lost 27% of relative tree cover.[38]

Land degradation
Madagascar's landscapes have been subject to degradation for decades. 35 % of the country's land area has been degrading over the last 30 years. Degradation has been particularly severe in the western region and southwestern region.[39]

Sea-level rise and costal erosion
While sea-level rise is primarily driven by the melting of polar ice caps and glaciers, higher temperatures can contribute to the expansion of seawater, leading to a gradual rise in sea levels. Sea-level rise (SLR) in Madagascar has been 1.57 mm/year between 1993 and 2017. Global SLR is projected to be higher by the end of this century under all scenarios.[40] This poses a threat to coastal communities and ecosystems in Madagascar. Coastal erosion is a growing concern in Madagascar. The west is particularly vulnerable to erosion. It can lead to the loss of valuable land and infrastructure.

Solid waste
According to the World Bank, 96.7 % of waste produced in Madagascar ends up in open dumps. When dumps are near the coast or rivers, then much of the waste will likely end up in the ocean, adding

35 *Health and climate change: country profile 2021: Madagascar. World Health Organization, United Nations Framework Convention on Climate Change*
36 *Climate change risks and adaptation options for Madagascar. Sarah R. Weiskopf, Janet A. Cushing, Toni Lyn Morelli and Bonnie J. E. Myers*
37 *Climate change risks and adaptation options for Madagascar. Sarah R. Weiskopf, Janet A. Cushing, Toni Lyn Morelli and Bonnie J. E. Myers*
38 *Madagascar Deforestation Rates & Statistics | GFW (globalforestwatch.org)*
39 *Madagascar Country Environmental Analysis. Promoting Green Resilient and Inclusive Development. 2022. World Bank Document*
40 *Climate change risks and adaptation options for Madagascar.* Sarah R. Weiskopf, Janet A. Cushing, Toni Lyn Morelli *and* Bonnie J. E. Myers

pollutants, including plastics. While when solid waste accumulates in waterways, not only pollutes the water, but can exacerbate the severity of flooding as the waste can block drainage channels.[41]

Water supply

The country was facing one of the world's most severe water crises as of 2021, due to poor water management infrastructure, deforestation, erosion and saltwater intrusion. Decreases in annual rainfall, increased evapotranspiration and sea level rise are projected to further reduce water availability across much of the country.[42] According to UNICEF, in 2018, only 51% of the population have access to basic water supply, with this figure dropping to just 34% in rural areas.[43]

Air Pollution

Air pollution remains the third largest risk factor for deaths and disability in Madagascar, after malnutrition and poor water and sanitation services[44]. In 2022 the annual average concentration of $PM_{2.5}$ was 4.7 times more that the recommended maximum of 10 $\mu g/m^3$ by WHO.[45] However, indoor air pollution, due to the charczoal-burning stoves, drives the health impacts of air pollution.[46]

Fire

In Madagascar, forest and vegetation fires are typically characterized by the spread of bushfires, which are often ignited by farmers clearing new land for subsistence agriculture or by livestock herders seeking fresh vegetation for their animals. These fires can sometimes extend into protected parks and forested areas.[47] According to the Ministry of Environment and Sustainable Development, in 2021, approximately 4,497,000 hectares of land were engulfed in flames, and from January to August 2022, wildfires scorched 90,000 hectares of forested areas across the entire island.

6.3. Madagascar house model

For further technical details for the house model refer to the Annex 2.

CASE AMÉLIORÉE EN BOIS

The "case améliorée en bois" is constructed from a variety of local wood and plants. The main structure, including the polesand rafters, can be built from several types of wood, chosen for their availability. Woods like "Hintsy," "Rahiny," "Nanto," and "Faho," all of which are locally names from the region. These woods are also known as "teza," which denotes the harder part of the wood. The slats are made from "karavoho" (Niaouli tree), while "rapaka," the trunk of the traveler's palm, is used for the bracing.

The walls of the house are made from "falafa," a different part of the traveler's palm, and the floor also employs "rapaka". The house has a dual-sloped roof thatched with "ravinala," the leaves of the traveler's palm. "Hafotra or l'arbre zavy" (Dombeya tree) is used as the binding rope. The doors and windows' panels are made of "raboté," a type of eucalyptus wood.

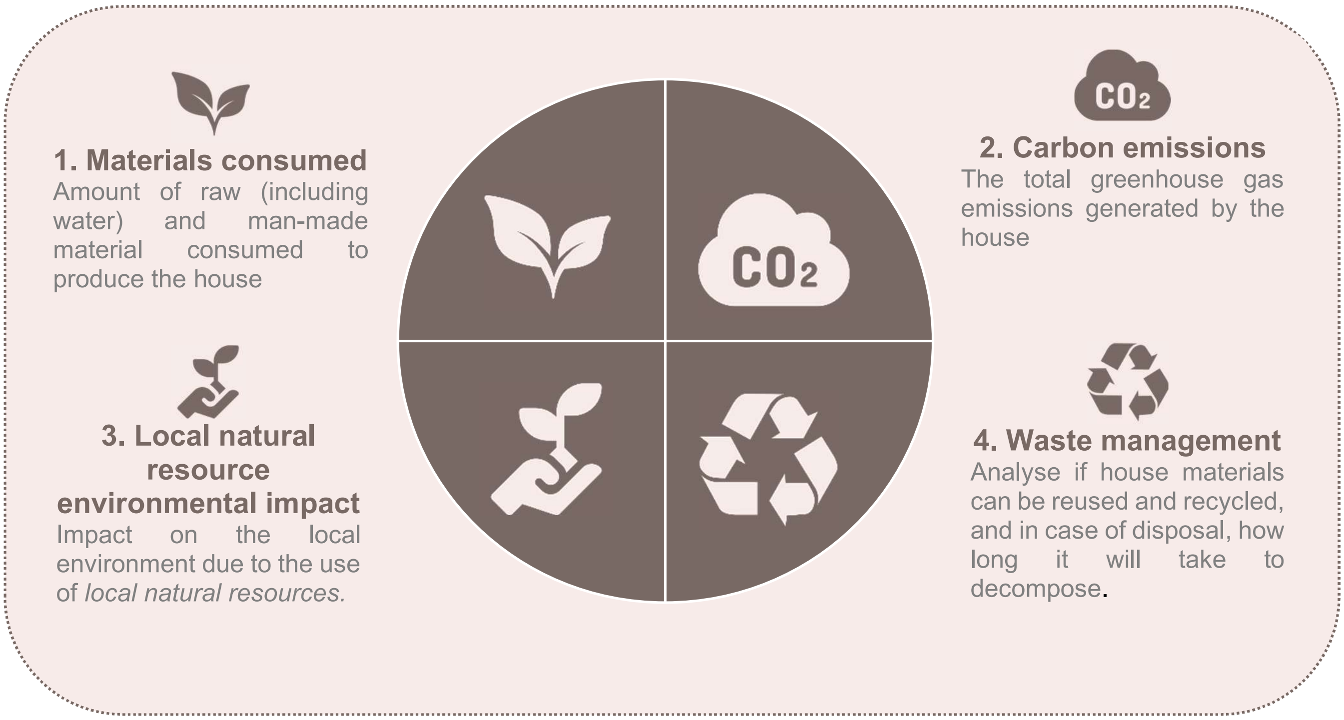
41 *Madagascar Country Environmental Analysis. Promoting Green Resilient and Inclusive Development. 2022. World Bank Document*
42 *Climate change risks and adaptation options for Madagascar. Sarah R. Weiskopf, Janet A. Cushing, Toni Lyn Morelli*
43 *UNICEF. file (unicef.org)*
44 *Madagascar Country Environmental Analysis. Promoting Green Resilient and Inclusive Development. 2022. World Bank Document*
45 *Madagascar Air Quality Index (AQI) and Air Pollution information | IQAir*
46 *Madagascar Country Environmental Analysis. Promoting Green Resilient and Inclusive Development. 2022. World Bank Document*
47 *1.1 Madagascar Humanitarian Background | Digital Logistics Capacity Assessments (logcluster.org)*

7. Criteria used to analyse environmental impact

To do a study of the environmental impact of the house model, each material must be analysed across its lifecycle, from production to end of life and disposal. The following criteria were selected to structure this analysis:

1. *Materials consumed*
2. *Carbon emissions*
3. *Local natural resources environmental impact*
4. *Waste management*

Each of these is explained in detail below.



7.1. Criteria 1: *Materials consumed*

The consumption of materials is calculated by taking into consideration the raw materials and resources needed to build one house. It does not reflect the materials / resources used for the preparation and maintenance of the sites where the houses were constructed. This includes two main groups of materials:

- Natural materials used (in kilograms or litres): any naturally sourced product or physical matter (water, timber, etc.).
- Man-made materials (in kilograms): any product or physical matter that goes through rigorous processing (steel, plastic, etc.).

Water consumption is calculated for all the materials used to build a house. To calculate the embody water in litres, the UNHCR shelter and sustainability tool baseline[48] have been used.

48 *UNHCR-TSS (epfl.ch)*

Any other raw materials which go into the production of the man-made materials are not considered, due to the complexity of this analysis, and since data is not readily available.

Different material quantities were provided during data collection, because the amount is not standard for each house, varying due to location and market availability. The analysis has assumed average quantities of each material. It is important to note that all the information provided comes from the team in Antalaha, so this study only takes this into consideration.

7.2. Criteria 2: *Carbon emissions*

Greenhouse gas emissions (GHS emissions), commonly called carbon emissions (they are measured as CO_2 equivalent) in the atmosphere warm the planet, and are the primary driver of global climate change. Human activities have raised the atmosphere’s carbon dioxide content by 50 percent in less than 200 years.[49] It’s widely recognised that to avoid the worst impacts of climate change, the world needs to urgently reduce emissions.

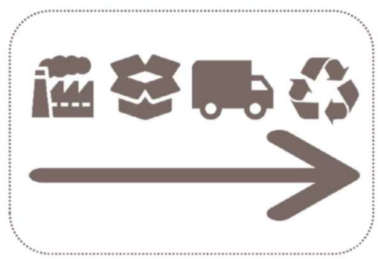
Therefore, it is important to assess the carbon footprint[50] generated by the houses, and identify solutions to reduce these emissions. To do so, it is required to do a life cycle analysis (LCA).[51]

Carbon calculator tool – SMAC tool

The carbon calculator tool used in the study is the new SMAC[52] (Shelter Methodology for the Assessment of Carbon) tool. It calculates the CO_2 equivalent for most shelter designs and allows for the comparison of different humanitarian shelter solutions in terms of their environmental impact over their entire life cycle.

Using CO_2 equivalent doesn’t cover the entirety of the complex issue of environmental impact, as there can be other more local impacts related to humanitarian shelter and settlement practices, but it provides a useful metric that can inform decision making.

The SMAC allows for comparison of up to 4 different shelter/house types, in terms of their embodied CO_2 equivalent emissions from the following factors, or “*life-cycle stages”*:



1. *“Production of the component materials”*
2. *“Packaging”*
3. *“Transport”*
4. *“End of Life”*[53]

Data required to use SMAC

49 *NASA*
50 *A carbon footprint is the total greenhouse gas emissions caused by an individual, event, organization, service, place or product, expressed as carbon dioxide equivalent (CO2 equivalent).*
51 *LCA is a commonly adopted methodology for quantifying carbon emissions and can be used to help compare shelter options. This ‘cradle to grave’ assessment evaluates the carbon emissions, expressed as carbon dioxide equivalent (CO2 equivalent), of the shelter from extraction of raw materials to the end of its life. It is a good starting proxy for a quantitative approach to measuring the environmental footprint of the different shelter options.*
52 *SMAC It is a simplified LCA methodology, developed by BRE Trust, the Global Shelter Cluster Environment Community of Practice, and WWF, based on components of shelter options that use CO_2 equivalent emissions as a metric for assessment. Information on SMAC can be found at https://www.sheltercluster.org/community-of-practice/environment*
This study is one of the second to use the SMAC tool, and feedback has been shared with the developers to improve it.
53 *SMAC uses assumptions about the level of recycling and CO2 eq. released at the ‘end of life’, meaning when the material has reached the end of its useful life, based on standard construction practices for each material. However, the actual portion of each material that is recycled at ‘end of life’ may be overestimated in the CO2 eq. calculation, according to the SMAC developers. This means that the carbon emissions calculated from ‘end of life’ are probably underestimated.*

In order to use the tool and calculate a CO_2 equivalent figure for the house options, the following data has been compiled:

- A list of the house components and materials
- The amount of each material used (in kg) per house [54]
- The type of packaging used for the materials[55] and the amount of each packaging material used (in kg) per house
- The transportation distances and modes from point of source of materials to point of use and disposal (there is further guidance in the SMAC tool on this if accurate distances are not known)[56].

For some of the previous house models in other reports, the data on packaging was not available, therefore this source of emissions has been excluded from the study, in order to ensure consistency and to compare results across all the shelters projects.

Limitations of the SMAC carbon calculator tool

One of the limitations of the SMAC relates to the types of materials included in the database[57] used by the tool. It was not possible to find Environmental Product Declarations (EPD) for all possible shelter / house materials that are used in humanitarian operations. As a result, the user must choose a similar material when the precise material is not listed in SMAC's drop-down lists (for example, thatch was selected instead of Dombeya "hafotra ou l'arbre zavy"). Similarly, assumptions are made in the SMAC relating to *"end of life"* (recycling options and level of CO_2 released from disposal), where the best publicly available data was used. However, the developers of the SMAC consider both of these limitations to be acceptable, and in line with what they term a "good enough approach".

7.3. Criteria 3: *Local natural resource environmental impact*

Going beyond the *carbon emissions* measured by CO_2 equivalent, which is only one measure of environmental impact, this section looks at impacts on the local environment due to the use of *local natural resources*. It is important to analyse whether the production, extraction or harvesting of natural resources could be causing environmental harm.

For instance, while *carbon emissions* analysis may indicate that importing wood generates greater emissions than procurement of locally available wood, this local procurement could result in excessive local tree cutting and environmental degradation. Another example is where using locally-sourced soil to make adobe bricks for a single house might not pose an environmental concern. However, producing 300,000 bricks to construct 150 houses could place significant stress on the local ecosystem and potentially cause major issues in the area.

The following factors are considered: Deforestation and vegetation removal, soil erosion, and degradation of water quality.

An environmental organisation that specialise in the protection of forests and ecosystems in Madagascar was contacted for this study, but without success.[58] Literature review[59] and feedback from the project team and local partners has formed the basis for this analysis.

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54 *Refer to Annex 3 to find the information regarding shelter material and quantity in kilograms.*
55 *Refer to Annex 3 to find the information regarding shelter packaging material and quantity in kilograms. Since for some of the models, this packaging data was not available, it has also been excluded from this study, in order to ensure consistency and to compare of results.*
56 *The average transport distances have been estimated and can be found in Annex 4.*
57 *The data from the tool has been taken from the Inventory of Carbon and Energy (ICE database), as well as from various environmental product declarations (EPD, such as those found in Eco Platform and Greenbooklive). The ICE database is a collation of aggregated and EPDs. Where data did not exist in ICE, and one EPD was available, that data point was used. Where several EPDs were available, an average was used. All data sources have been referenced within the tool. Data for packaging, end of life and recycled content have been sourced from BRE.*
58 *Refer to Annex 1 to see the list of people contacted.*
59 *Refer to biography*

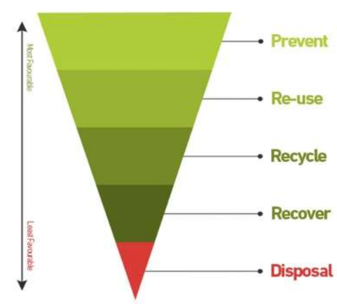
7.4. Criteria 4: *Waste Management*

One of the challenges of humanitarian action is that more end-to-end thinking about waste isn't common in the largely 'truck and chuck' humanitarian reality. All through the project cycle, any organisation that imports, produces, transports, or generates waste in some way, must think of the *waste management* implications. The ultimate goal should be to generate the minimum amount of waste and extract the maximum benefit from products, keeping them in use for as long as possible.

This section studies if the life cycle of the house materials can be prolonged by reusing and recycling, and in case of disposal, how long they will take to decompose.

Waste hierarchy

Reduce, Reuse, Recycle: Commonly referred to as the "3 R's" of the waste hierarchy. Reduce means to minimise the amount of waste created. Reuse refers to using items more than once. Recycle means putting a product to a new use instead of throwing it away. The full waste hierarchy is usually characterised as: Reduce/Prevent; Reuse; Recycle; Recover; Disposal[60]. The different options (in order of preference) are in the illustration.
The levels indicate the progressive order of actions to take to reduce waste. More efforts should be spent on the more significant layers at the top of the chart, like redesigning, reducing, and reusing. And to minimize the activities at the bottom, like residual management or landfill.



Efforts to contact local private companies specialising in ecological recycling and waste recovery within the country,[61] were not successful. Literature review[62], feedback from the project teams and environmental experts from the shelter sector[63] have been considered for this analysis.

7.5. Scorecard approach

A simple 'scorecard' approach is used to compare the house model across the four criteria.

The balanced nature of a scorecard means that no one environmental consideration takes precedence over the other considerations identified as significant. This recognises that *carbon emissions*, while being critical, are not the only environmental factor. While such a Humanitarian Environmental Scorecard is not an environmental impact assessment, it is at least a transparent process which goes beyond focusing on only one environmental consideration to make decisions on how to provide humanitarian assistance.

At its core, a balanced scorecard identifies environmental considerations of proposed actions (e.g., a package of shelter assistance), rates the possible environmental impacts for the proposed action and then combines these ratings into a single score.

A simple scorecard also recognises the challenge to apply any kind of numerical weighting for the four criteria in order to arrive at a calculated score per house. This would require too many assumptions on the relative weight of each criterion. Instead, a qualitative conclusion can be made based on the scorecard.

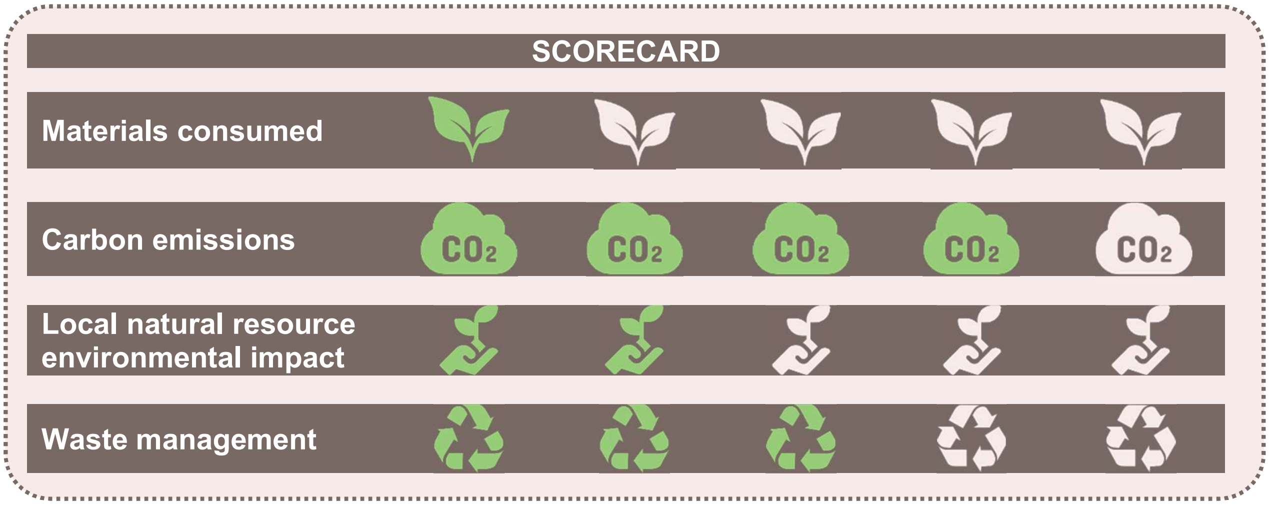
While acknowledging the methodological limitations of this approach, it is the only feasible option in the limited scope and time allotted to this study. A scorecard highlights in a simple way what the main environmental issues are for

60 *EU Commission, 2014*
61 *Refer to Annex 1 to see the list of people contacted.*
62 *Refer to biography*
63 *Refer to Annex 1 to see the list of people contacted.*

each house, thus identifying where mitigating solutions could help to improve the overall environmental impact of the house model.

The house model is scored from 1 to 5 against each of the criteria, to enable comparison.

An example of the scorecard (noting that a higher score is better, meaning lower environmental impact):



1 poor, 2 average, 3 medium, 4 good, 5 very good

8. Environmental impact of the house model

8.1. Criteria 1: *Materials consumed*

8.1.1. Overview of the materials used and their general impact on the environment

The team used the term “teza” which in Malagasy literally translates to “the hard part of the wood” when referring to the different hardwoods used, in this case for the poles and rafters. The different types of hard wood utilised in the model, depends on market availability, with local names such as “hintsy” (afzelia bi juga) “rahiny” (from the sapotacees family), “nanto”, “faho” (Cyathea similis). For the purposes of this study, only Afzelia Bijuga has been analysed, as this was the only information available. However, in the report, the term “teza” will be used when conducting the analysis, with the understanding that it may represent any type of hardwood used.

The team mentioned that they also used stones for the foundation, and protected the poles with engine oil. However, the amounts of these materials, or any information about them, have not been provided. Therefore, they have been excluded from the study.

RAW MATERIALS

Traveler's Palm “ravinala” (Ravinala madagascariensis) It is native to the island of Madagascar. These tropical plants (it is not a palm) are primarily found in the wild in the tropical and subtropical regions of Madagascar. The most distinctive feature of the Traveler’s Palm is the arrangement of its leaves. The leaves are large, paddle-like, and fan-shaped. They grow in a single plane, creating a symmetrical and striking appearance. On average, a mature Traveler’s Palm can reach heights of around 9 to 12 meters.[64] The sturdy leaf stems and midribs, which resemble small trunks, are used in construction for various purposes. They can be employed as structural components in roofing, fencing, and even building walls in some cases.

General environmental impacts

Water Source: One of the primary uses of the Traveler's Palm in Madagascar is providing a source of water. The large leaves collect rainwater and morning dew, forming natural reservoirs at the base of the leaves.

Habitat and Biodiversity: The flowers serve as a rich source of nectar for other organisms.[65] They provide essential habitat and food for other wildlife species, like lemurs. [66]

Deforestation: When unsustainable harvesting practices and deforestation can lead to negative impacts on the ecosystem, including habitat loss and reduced biodiversity.

Afzelia Bijuga “hintsy” [67] It is an evergreen tree growing to 25 m at a slow rate. It is a species of tree native to several regions including Madagascar, parts of Asia, and the Pacific islands. It's important to note that the scientific name "Afzelia bijuga" might vary, as the genus Afzelia includes several species, and taxonomic classifications can differ. The tree is known for its valuable wood and other significant uses. Afzelia wood is highly prized for its quality, durability, and resistance to termites and water. It's often used in high-end furniture, cabinetry, and flooring. The wood is also known for its attractive appearance, with a rich colour and fine grain.

64 *Traveler's Palm: Identification, Uses, Growing Guide | ForagingGuru*
65 *The Traveler's Palm — In Defense of Plants*
66 *The Traveler's Palm — In Defense of Plants*
67 *Afzelia bijuga Moluccan Ironwood, Ipil PFAF Plant Database*

General environmental impacts

Habitat and Biodiversity: In its native habitats, Afzelia bijuga plays a crucial role in the ecosystem. It is a part of the tropical forest canopy and contributes to the biodiversity and health of these environments.

Niaouli “karavoho”

(Melaleuca quinquenervia) It is a species of tree native to Australia, and New Caledonia, but is now found in many other countries, including, the Solomon Islands, and Vanuatu. It is a small- to medium-sized tree. The grey-green leaves are egg-shaped, and cream or white bottlebrush-like flowers. It is known for its aromatic leaves, which contain essential oils. Niaouli oil, extracted from the leaves of this tree, is used in various applications, including aromatherapy and traditional medicine, for its potential health benefits.

General environmental impacts

Habitat and Biodiversity: The flowers serve as a rich source of nectar for other organisms, including fruit bats, a wide range of insect and bird species.[68]

Exotic invasive plant: It has earned the classification of a noxious weed and invasive species in multiple US states and Madagascar. This species, when invasive, causes a range of severe ecological impacts, including the displacement of native flora, modification of hydrological patterns, alteration of soil composition, reduction in habitat quality for indigenous wildlife, and changes in the frequency and intensity of wildfires.

Eucalyptus “raboté”

It is an ever-green tree native to Australia. It is widely planted in different parts of the world, integrated into various farming systems. It is commonly cultivated as a monocultural crop in short rotations of 3 years for biomass crops and 6 or more for timber use. It is a highly profitable forestry crop.

General environmental impacts[69]

Land degradation: Unsustainable or inappropriate forest timber extraction can cause forest destruction, soil erosion, landslides, land degradation, habitat destruction, and can increase flood risk.

Water consumption; Growing eucalyptus in low rainfall areas may cause adverse environmental impacts due to competition for water with other species.

Soil erosion; Short rotations and intensive management practices, result in soil compaction, soil erosion, and other adverse effects.

Pollution; Due to the use of fertilizers, weedicides and pesticides, and fire hazards. Transport of woods/logs can damage forests and rural roads.

Soil nutrient; When is grown as a short rotation crop for high biomass production and removal, soil nutrients are exhausted rapidly.

68 *Melaleuca quinquenervia - Wikipedia*
69 *Silviculture of eucalyptus plantings – Learning in the region. K.J. WHITE. FAO*

Dombeya "hafotra or l'arbre zavy" is a genus of flowering plants native to Madagascar. There are numerous species of Dombeya, but the specific species used in the model is unknown.

General environmental impacts

Habitat and Biodiversity: The tree attracts bees, butterflies and birds[70]

Water covers 70% of our planet, however, only 3% of the world's water is fresh water. [71] Billions of people worldwide lack access to water. Water is at the core of sustainable development and is critical for socio-economic development, healthy ecosystems and for human survival itself. [72]

Environmental impacts

Water shortage; Water shortages are likely to be the key environmental challenge of this century.[73] More than half the world's wetlands have disappeared. Many of the water systems that keep ecosystems thriving and feed a growing human population have become stressed. Rivers, lakes and aquifers are drying up.

Agriculture; consumes more water than any other source, 70% of the world's accessible freshwater, and wastes 60% of it, much of that through inefficiencies due to leaky irrigation systems, inefficient application methods as well as the cultivation of crops that are too thirsty for the environment in which they are grown. [74]

Water pollution; comes from many sources including pesticides and fertilizers that wash away from farms, untreated human wastewater, and industrial waste.[75]

Climate change; is altering patterns of weather and water around the world, causing shortages and droughts in some areas and floods in others. [76]

MAN-MADE MATERIALS

Steel is an alloy (a metal combined with two or more metallic elements) made up of iron and a percent of carbon, to improve its strength and fracture resistance. Other elements may be present or added. Iron is the world's third most produced commodity by volume - after crude oil and coal. Over 2,000 million tons of iron is mined a year - about 95 percent is used by the steel industry. [77]

General environmental impacts[78]

Energy consuming; Production of steel is the most energy-consuming in the world.

Pollution; Steel production requires large inputs of coke (a type of coal) which is extremely damaging to the environment. Coke ovens emit air pollution highly toxic and can cause cancer. Wastewater from the coking process is also highly toxic and contains a number of carcinogenic organic compounds.

70 *Dombeya wallichii (pink ball) | CABI Compendium (cabidigitallibrary.org)*
71 *WWF*
72 *www.un.org/waterforlifedecade*
73 *www.un.org/waterforlifedecade*
74 *NASA*
75 *University of Dundee*
76 *WWF*
77 *The world counts*
78 *The world counts*

Greenhouse effect; Steel production is responsible for the emission of 3,3 million tons of CO_2 annually[79]

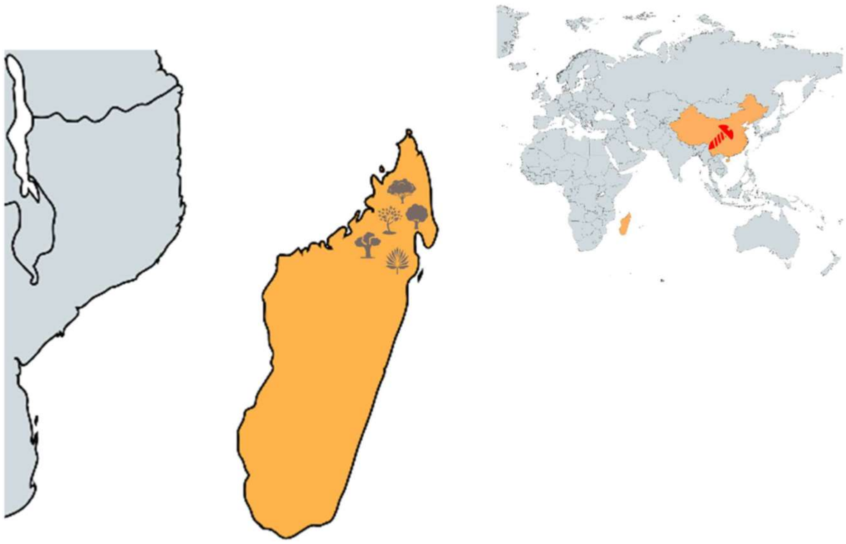
8.1.2. Data and analysis of the materials in the house

Table 1 below shows a simplified representation of the quantities of each material used in the house. It offers a comparative view of the consumption of each material, rated on a scale from 1 to 10. In this assignment, the material used in the maximum quantity (water) is scored at 10 points, while the material used in the least quantity ("hafotra" - Dombeya) receives a score of 1 point. Scores for other materials are assigned relative to these maximum and minimum values, indicating their usage in the construction. For a detailed breakdown of the actual weights of materials used, please refer to Annex 5.

Table 1 - Amount of materials used by the house model

House model	*Materials*	Amount
Case améliorée en bois	Water	
	Teza / hardwood *(hintsy, rahiny, Nanto, Faho)*	
	Traveler's palm *(ravinala, rapaka and falafa)*	
	Niaouli *(karavoho)*	
	Eucalytus *(raboté)*	
	Dombeya *(hafotra ou l'arbre zavy)*	
	Steel	

79 *The world counts*



Map showing where materials were procured from (brown = locally procured; red = imported). This does not reflect where materials were originally produced, if the supply chain is longer, since this information was not available.

8.1.3. Scorecard for *materials consumed*

Scorecard *materials consumed*

CASE AMELIORÉE EN BOIS

1 poor, 2 average, 3 medium, 4 good, 5 very good

The house model scored 5 out of 5, with its positive rating primarily attributed that the house basically use locally available raw materials (trees and plants) and the limited reliance on synthetic materials (only for the hardware). This score is based on the quantity and type of materials used and does not consider whether the extraction of these local raw materials has any adverse environmental effects, which would fall under Criteria 3.

Choosing raw materials for construction offers various benefits, including lower environmental impact, improved energy efficiency, natural insulation properties, enhanced indoor air quality, aesthetic appeal, comfort, economic support for local industries, and overall sustainability through the use of renewable resources.

In terms of the materials used, aside from water, “teza” (a term for hardwoods) is the most abundant, used for poles and rafters. This is followed by “raboté” (eucalyptus) and different parts of the traveller’s palm. The only synthetic material employed is steel, which, despite its high embodied water content per kilogram, is used in minimal quantities compared to the other materials. Nevertheless, it is advisable to explore alternatives, such as recycled steel, where feasible. However, in a place like Madagascar, this suggestion might not be very realistic.

It's important to note that the house's materials result in a relatively high amount of embodied water, especially when comparing the total water against the rest of the materials (Table 1). The majority of this embodied water is attributed to various types of wood and plants. Although steel has a higher embodied water per kilogram, its overall contribution is less significant due to lower quantities. Timber's embodied water comes from various lifecycle stages, including tree growth, post-harvest processing, and potential chemical treatment. However, research indicates that most wood used in the house has not been treated, does not come from irrigated forests, and is transported relatively short distances. This suggests that the embodied water of the wood, and consequently the house, could be lower, reducing the overall water impact.

There is limited scope to improve the score. Exploring the use of recycled steel is an option, although it's recognised that this might be challenging in this context. Additionally, it's crucial to ensure that the quantity of all materials, including natural ones, is minimised, whilst still maintaining the functionality and safety of the house.

Additionally, even under Criteria 3, we will analyse the natural materials used in the house and their impact on the environment. Considering the significant issue of deforestation in Madagascar, and the fact that some of the woods used in construction there are endangered, it is essential to ensure that the wood utilised is not classified as an endangered species. Although finding alternatives might also present challenges in this context, it should be a priority. All these concerns will be further analysed in the report.

How to improve the *materials consumed* score

Making sure the amount of all materials is kept to a minimum without compromising the house.

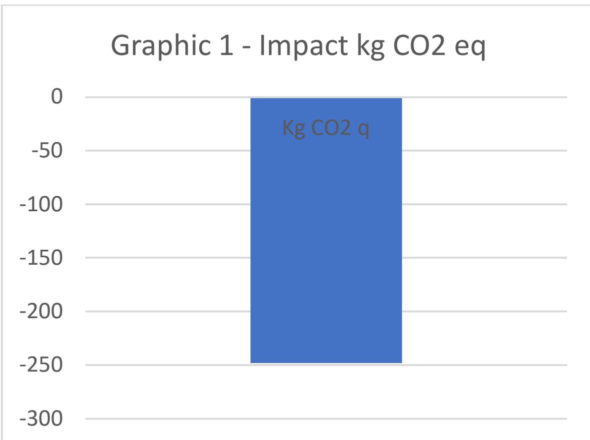
Explore the options of finding alternative recycled steel for the hardware, noting that this could be challenging.

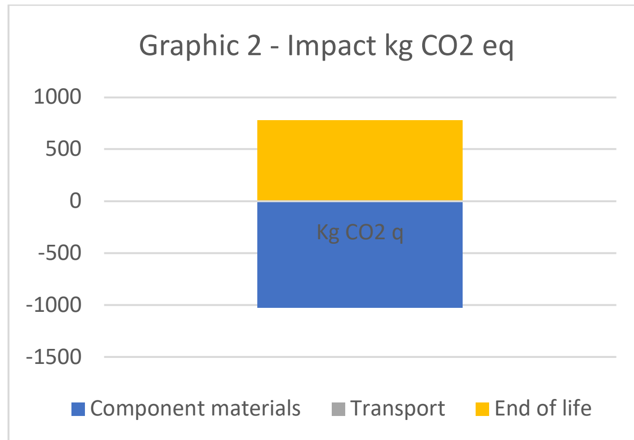
8.2. Criteria 2: *Carbon emissions*

8.2.1. ***Carbon emissions* of the house model**

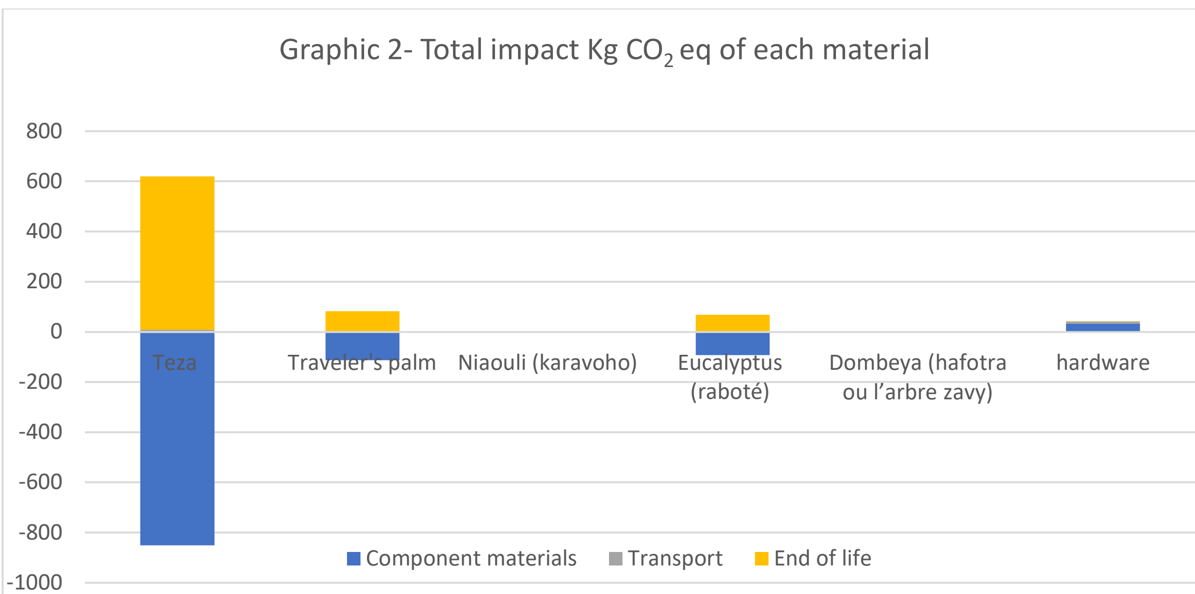
Below are the total *carbon emissions* generated by the house model, in CO_2 equivalent. This is using the SMAC calculator and taking into account all the parameters and assumptions explained above in section 7.2. Please refer to Annex 6 to see the details of the carbon emission calculations for the house.

The following Graphic 1 shows the total impact of *carbon emission* and Graphic 2 shows the breakdown of the total *carbon emissions*.

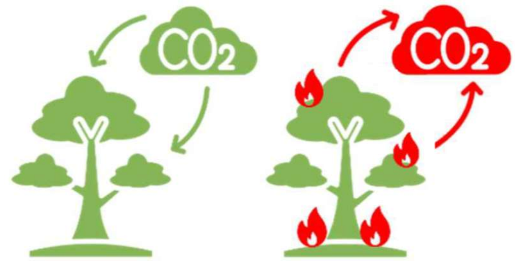




The following Graphic 2 show the breakdown of the *carbon emissions* of each material.



It is important to explain why there are significant carbon emissions generated from the "*end of life*" phase. It is because the house model uses a considerable amount of wood. The reason for these emissions is that the SMAC tool assumes that these materials are burnt at the end of their useful life, which is the case here, releasing the carbon emissions that were sequestered in the materials while growing. However, if these natural materials are left to decompose, or composted, these emissions would be eliminated resulting in even lower total emissions for the house model.



8.2.2. Scorecard for *carbon emissions*

Scorecard *carbon emissions*					
CASE AMELIORÉE EN BOIS	CO_2	CO_2	CO_2	CO_2	CO_2

1 poor, 2 average, 3 medium, 4 good, 5 very good

Please refer to Annex 6 to see the details of the house *carbon emissions* calculations.

The house model scored 5 out of 5 because it produces no net carbon emissions, attributed to the use of natural materials such as wood and plants. Throughout its life cycle, the house manages to achieve negative carbon emissions, thanks to the active absorption of carbon by trees and plants during their growth.

he overall positive picture of carbon emissions is somewhat negated during the "end of life" phase, as natural materials are typically burnt, resulting in a substantial release of the stored carbon emissions. Proper disposal methods, such as decomposition or burial, could amplify the overall positive impact. However, challenges also arise in preventing the use of timber as firewood at the end of its life cycle, given the reliance on firewood for cooking. Distributing stoves that operate on non-organic materials may present a viable solution.

The only contributors to emissions are steel products, both due to their hight carbon embodied and transportation. Despite their low quantity, it is recommended to explore the use of recycled steel, although challenges may exist in the current market. To address carbon emissions from steel transportation, local sourcing is suggested. However, complexities arise in finding locally produced steel meeting quality standards in Madagascar. Further research is recommended to explore potential solutions in this context.

How to improve the *carbon emissions* score

Ensure that the natural materials like wood are not burnt at the end of their useful life, and are composted instead.

Explore the options of finding alternative recycled steel for the hardware, noting that this could be challenging.

To procure hardware steel from local producers if it is feasible and meets quality standards.

8.3. Criteria 3: *Local natural resource environmental impact*

8.3.1. Overview of the *local natural resource environmental impact*

A common assumption is that the more natural a material it is, the better it is for the environment. However, when natural resources are harvested and processed, there are certain impacts on the local ecosystem that need to be considered, such as deforestation and vegetation removal, soil erosion, degradation of water quality, pollution etc. Where possible, options to mitigate these effects should be considered as part of project design.

As per Sphere Handbook Standard 7 on Shelter and Settlements[80], which pertains to environmental sustainability, includes a specific key action on sustainable materials; “select the most sustainable materials and techniques among the viable options. Prefer those that do not deplete local natural resources or contribute to long-term environmental damage."

Additionally, it's important to note that scale plays a role in environmental impact. Perhaps in smaller quantities, the impact may be insignificant and therefore considered acceptable.

While the forestry sector plays a crucial economic role in Madagascar, supporting about 75% of the country's population through subsistence farming and forest-related activities, deforestation, soil degradation, and biodiversity loss pose significant environmental, social, and economic challenges.[81]

The Malagasy government recognises the importance of forests, including tropical forests, for households and local communities. Madagascar is renowned for its rich biodiversity, and forests provide various resources essential for livelihoods, including timber, non-timber forest products (NTFPs), and ecosystem services. However, the government is also working to strike a balance between using forests for household needs and the imperative for conservation and sustainable management.

Madagascar faces some of the highest deforestation rates globally, with over 80% of its original forest cover already cleared due to factors such as rapid population growth, overgrazing, agricultural expansion, land disputes, and political instability.[82] Additionally, nearly 90% of Madagascar's population relies on biomass for daily household energy needs, and as the population continues to grow, the demand for wood fuel exacerbates deforestation.[83] Only between 2005 and 2015, wood consumption in Madagascar surged from 2.1 million to 2.8 million metric tons, with an average annual growth rate of 15%. The country's management of its wood resources is unsustainable due to this escalating demand for wood.[84]

Sustainable forest management remains a challenging goal to achieve, and there are ongoing disagreements among government departments regarding the regulation of tropical forest wood use, both for local use and export. These disputes continue to be pressing issues. Additionally, as per information from an interviewee, wood suppliers are no longer permitted to cut down trees for commercial purposes, yet they still hold permits to work with and sell wood. This inconsistency creates a loophole that suppliers exploit to continue cutting down trees and selling the wood.

This situation underscores the complexity of addressing sustainable forestry practices and the need for coordinated efforts and clear regulations to ensure the conservation of valuable forest resources.

80 *Sphere Handbook (spherestandards.org)*
81 *Climate change is threatening Madagascar's famous forests – our study shows how serious it is (theconversation.com)*
82 *Climate change is threatening Madagascar's famous forests – our study shows how serious it is (theconversation.com)*
83 *Combining global tree cover loss data with historical national forest cover maps to look at six decades of deforestation and forest fragmentation in Madagascar.*
84 *A4-snaphot-bois-02p-FINALE.pdf (wavespartnership.org)*

Currently, local communities can harvest timber from natural forests for personal needs like fuel and home construction, as long as they adhere to regulations prohibiting commercialisation. However, illicit logging remains a major concern, and enforcing forest-related laws is a significant challenge due to widespread corruption, jeopardizing Madagascar's unique biodiversity.[85] In Madagascar's coastal regions, over 80% of houses are self-built, non-engineered traditional wooden structures using materials sourced from nearby forests, reflecting heritage practices.[86]

Climate change further exacerbates the issue, as it ranks as the second most significant driver of global biodiversity loss after habitat destruction. As global temperatures rise, the situation is expected to worsen.[87] The consequences of land degradation are extremely serious, particularly for communities heavily dependent on agriculture and livestock. Land productivity decreases, leading to poorer harvests, food insecurity, and malnutrition.

Sustainable forest management is imperative to address these multi-faceted challenges in Madagascar. Therefore the use of local forest resources in house construction necessitates careful consideration and analysis.

In the context of climate change and pressure on *local natural resources*, it is important to analyse whether the house model contribute to this degradation of the environment. To do a proper study of potential harm done to the environment, it should really go beyond the *local natural resources* used, and look into the overall sheltering strategy and implementation (site selection, access, infrastructure and services, environmental protection, etc.). However, this is beyond the scope of this study and so analysis is restricted to the local materials used.

A quick overview about forests, why they are important to fight against climate change, and environmental issues

Forests play a key role in mitigating climate change[88] and increase the resilience of rural communities. They regulate ecosystems, protect biodiversity, play an integral part in the carbon cycle, support livelihoods, protect homes from major weather events, improve health and can help drive sustainable growth.[89]

Environmental issues[90]

- 30 % of global tree species are threatened with extinction. And over the past 300 years, the global forest area has decreased by about 40%.
- The main threats to tree species are unsustainable forest management practices; forest clearance and other forms of habitat loss, direct exploitation for timber and other products. Climate change, like fire, extreme weather and sea level rise, is also having a clearly measurable impact.
- Around 25% of global emissions come from the land sector. About half of these come from deforestation and forest degradation.
- Madagascar has 5% of the world's tree species, high endemicity, but also one of the highest deforestation rates.[91] Around 90% of its plant life in Madagascar are endemic[92] are found nowhere else on Earth.
- The country's forests have been greatly diminished. Accounting for an estimated 29% of land area in 2000, Madagascar's forests now cover only 21%.[93]

85 *Madagascar moves to reopen domestic trade in non-precious timber (mongabay.com)*
86 *Fragility assessment of traditional wooden houses in Madagascar subjected to extreme wind loads - ScienceDirect*
87 *Effects of future climate change on the forests of Madagascar. 2021. Daniel Hending. Marc Holderied. Grainne McCabe. .Sam Cotton*
88 *Forests and climate change. IUCN*
89 *Forests and climate change. IUCN*
90 *State of the World's Trees. Sept 2021. Botanic Gardens Conservation International*
91 *Madagascar's vanishing trees (mongabay.com)*
92 *WWF*
93 *Madagascar Country Environmental Analysis. Promoting Green Resilient and Inclusive Development. 2022. World Bank Document*

- Between 2001 and 2019, Madagascar lost 3.89 million hectares of tree cover, the equivalent of 23% of the tree cover present in 2000[94]
- A high population growth rate puts pressure of the few remaining forest lands.

8.3.2. Overview of the local natural resources used in the house model

While most of the entries below highlight the potential negative environmental impacts associated with using local natural resources, it is crucial to note that these impacts largely depend on the scale or quantity used. When used in small quantities, the environmental repercussions might be minimal and more manageable to mitigate. However, as the quantity or scale increases, the negative impacts can intensify, becoming less easy to mitigate or absorb by local ecosystems.

TRAVELER'S PALM "Ravinala" is used in the house model for the roofing, wall and the floor.

In Madagascar, the Traveler's Palm (is often referred to as a palm due to its palm-like appearance, but it is plant) is culturally significant and holds symbolic value. It is sometimes referred to as the "Ravinala," and its image is often associated with the island's identity. The plant's striking appearance and the legend of its ability to provide water to thirsty travellers have contributed to its status as a symbol of Madagascar.

This plant is used for various aspects of construction in Madagascar, each component has unique local names. The upper leaf is referred to as "ravinala" the lower part of the leaf is known as "falafa", and the trunk is called ""rapaka".

The "ravinala" is used for the roofing, "falafa" for the walls, and "rapaka" for the floor.

It is an endemic tree to Madagascar. Today, traveller's palm in Madagascar, is listed as "Less Concerned" from extinction. According to the "Tree species list in Madagascar" from the Botanic Gardens Conservation International.[95]

AFZELIA BIJUGA "Hintsy" [96] is used in the house model for the poles and rafters.

"Hintsy" it is used as a hardwood in construction in Madagascar. According to the IUCN Red List of Threatened Plants Status is Vulnerable, world wise [97]. However, it can poses several environmental risks when exploited unsustainably. Logging this valuable timber species can lead to deforestation, causing habitat loss and disrupting local ecosystems. Biodiversity may suffer, and soil degradation can occur, impacting overall ecosystem health.

NIAOULI "Karavoho" is used in the house model for the roof slats.

94 *Madagascar moves to reopen domestic trade in non-precious timber (mongabay.com)*
95 *Country Search | Botanic Gardens Conservation International (bgci.org)*
96 *Afzelia bijuga Moluccan Ironwood, Ipil PFAF Plant Database*
97 *Afzelia bijuga Moluccan Ironwood, Ipil PFAF Plant Database*

This tree is also known by the paperbark tree, is an invasive species in Madagascar. It is not clear when was introduced to the country. This tree is recognised by its shaggy, light-coloured bark and is commonly found in humid lowlands, especially in riparian and wetland areas, which are prevalent in Madagascar's coastal regions. Once established, it can become the dominant tree species, displacing native flora and negatively impacting local biodiversity. It reproduces abundantly through seeds, which can remain viable for several years and disperse after disturbances like fires. The spread of this invasive species poses a significant threat to Madagascar's native ecosystems and disrupt the natural balance of the environment. Efforts to manage and control this invasive species are essential to protect Madagascar's unique biodiversity.[98]

It is not rated on the “Tree species list in Madagascar” from the Botanic Gardens Conservation International.[99]. However, it is listed as “Least Concern” on the IUCN Red List of Threatened Species worldwide.[100]

EUCALYPTUS “raboté” is used in the house model for the windows and doors panels

Eucalyptus is not native to Madagascar. It is an introduced species in the country. Eucalyptus plantations are easily established and fast growing, and can be highly profitable, even in areas that are traditionally poor in timber production.[101] However, there are also negative environmental impacts in planting eucalyptus.[102] The use of eucalyptus wood in Madagascar can lead to environmental concerns including deforestation habitat loss, and biodiversity reduction. Eucalyptus trees consume large amounts of water, affecting local water availability and soil nutrients. If not native, they might displace local plant species, impacting biodiversity negatively. The demand for eucalyptus wood can also affect the livelihoods of local communities and may lead to unsustainable exploitation if not properly managed.

They are several species of Eucalyptus tree in Madagascar. It is unclear which species is used at the “case” model.

The eucalyptus is not listed in Madagascar tree species list, in the Botanic Gardens Conservation International, So the conservation status is unclear. At global level depending on which species is listed as “Threatened” or “Not Threated”.[103]

DOMBEYA “hafotra or l’arbre zavy” is used in the house model as a rope. The Dombeya is native to Madagascar and there are numerous species of Dombeya, but the specific species used in the model is unknown. However, According to the botanic gardens conservation international, most of the Dombeya plants in Madagascar are either clinically endangered or endangered[104]

8.3.3. Quantity of the *local natural resources* in the house model

The following Table 2 provides a simplified representation of the amount of local natural resources used by the house model. For the actual quantities of these resources in kilograms, please refer to Annex 7. It's important to note that

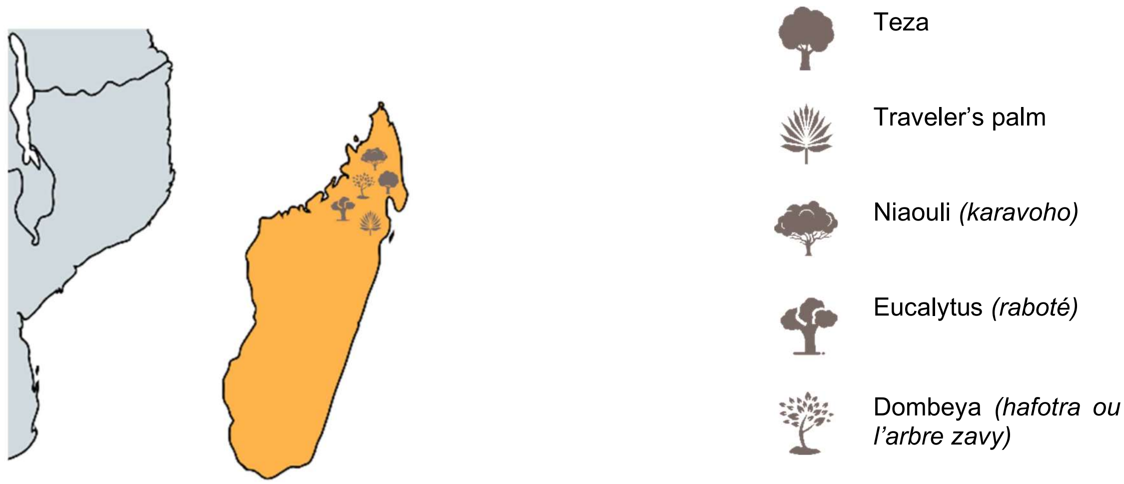
98 *Surveying the Distributions of Melaleuca quinquenervia, Psidium cattle" by Hanusia Higgins (sit.edu)*
99 *Country Search | Botanic Gardens Conservation International (bgci.org)*
100 *https://www.iucnredlist.org/species/49278407/49278461*
101 *Eucalypts in Madagascar – Why? | EnviroReach*
102 *Chaojun Chu, P.E. Mortimer, P.E. Mortimer, Hecong Wang, Yongfan Wang, Xubing Liu, Shixiao Yu. 2014*
103 *Botanic Gardens Conservation International*
104 *Madagascar Trees (bgci.org)*

the data used in this study was provided by the AICRL logistics teams in Antalaha. Therefore, the study focuses exclusively on this area, and information from other locations where they operate was not available for consideration.

This assignment gives the maximum amount (“teza”) a score of 10 points and the minimum amount (“hafrota”) a score of 1 point, with scores for the other materials falling in between based on their amounts relative to the maximum and minimum.

Table 2 - Amount of *local natural resources* used by the house model

House model	*Materials*	Amount
Case améliorée en bois	Teza / hardwood *(hintsy, rahiny, Nanto, Faho)*	
	Traveler’s palm *(ravinala, rapaka and falafa)*	
	Niaouli *(karavoho)*	
	Eucalytus *(raboté)*	
	Dombeya *(hafotra ou l’arbre zavy)*	



Map of the source of the natural resources used

8.3.4. Scorecard for *impact on local natural resources*

1 poor, 2 average, 3 medium, 4 good, 5 very good

The house achieved a score of 3 out of 5, primarily due to significant concerns surrounding the use of wood in Madagascar. The country faces challenges related to its fragile forests and endangered local plant species. However, finding suitable alternatives has proven to be a difficult task.

While Criteria 1 and 2 underscore the advantages of using natural materials such as wood in construction, it's essential to acknowledge the accompanying challenges, which we will examine here. For example, the natural resources are used traditionally by the communities for many years, and the harvesting and preparation provides a source of income. So in principle, the use of construction materials that are being sourced locally from the natural environment is desirable. However, in practice, if the demand significantly outweighs the available resources, it poses a high risk of environmental degradation and accelerated deforestation.

The government's stance on wood usage for construction is unclear and inconsistent, with challenges in enforcement and control mechanisms. Also, obtaining clear information about the wood used in the model, its sustainability methods, and environmental risks has been challenging. However, what is evident from all the interviewers, is that the use of wood in Madagascar is a cause for concern, there are not control over it, and requires action.

The most commonly natural material used in the model, in terms of quantity, consists of various types of "teza" wood, depending on their availability. Traditional woods like rosewood and ebony, which were previously used for construction as "teza," are now banned due to their endangered status. In their place, other types of wood, such as “hintsy”, “rahiny”, “nanto”, and “faho”, have been used in the model, raising questions about their impact on the forest ecosystem and their endangered status. Further investigation is required to assess the environmental implications of using these replacement woods.

The second most commonly used material in the model, in terms of quantity, is the traveller's palm. This versatile plant is referred to by different names depending on the part of the plant used, such as "ravinala," "falafa," and "Rapaka".

The use of traveller’s palm in the model offers several advantages. Beyond its cultural significance as a symbol of Madagascar's heritage, it serves as a renewable and versatile resource. Traveler's palm can regrow new leaves after harvesting, making it a sustainable choice for construction. Its various parts, including the top leaf “ravinala”, the bottom part of the leaf “falafa”, and the trunk “rapaka”, have diverse applications. This use reduces the demand for endangered or overexploited wood species, contributing to biodiversity conservation. However, it is imperative to conduct comprehensive studies to assess its sustainability, regrowth rates, and potential ecological impacts, ensuring responsible and eco-friendly usage.

The house model uses eucalyptus for doors and windows panels, which has both advantages and environmental concerns. On one hand, eucalyptus helps deter the use of tropical woods associated with deforestation. However, it also poses environmental challenges, including high water consumption, potential soil degradation, biodiversity loss, monoculture creation, invasiveness, and negative impacts on local land use. To address these concerns, the local team should ensure that eucalyptus is sourced from private plantations with sustainable practices in place. These practices should involve harvesting methods that allow trees to regrow significantly over time, mitigating the aforementioned environmental issues. Exploring more eco-friendly alternatives is also advisable.

Furthermore, the use of other wood types such as Niaouli “karavoho” for the slats is a cause for concern. Niaouli is considered an invasive species and poses a significant threat to Madagascar's native ecosystems, disrupting the natural balance of the environment. [105] Efforts to manage and control this invasive species are essential to protect Madagascar's unique biodiversity, as highlighted in a survey. Therefore, exploring alternative options for construction materials is encouraged, alongside measures to eradicate this plant.

The Dombeya plant, known as "hafotra ou l'arbre zavy," is used in small quantities as a rope in the model. However, the exact species of Dombeya used has not been specified. It is advisable to conduct further environmental assessments to ensure responsible plant usage practices.

To address wood and plants usage challenges in Madagascar's construction projects, a multifaceted approach is recommended. This includes collaborating with wood suppliers for sustainability, raising awareness about responsible wood / plants usage, and exploring alternative materials like bamboo (prototype testing in progress) or adapting adobe construction “fotaka” (considering local conditions). Extending house and materials lifespans through good practices, training, and reforestation projects can reduce wood demand, promoting sustainability.

What is clear is that these resources provide multiple benefits for communities, and over-harvesting is a potential problem. However a question remains unanswered, whether the supply of each species could keep up with the demand of the houses in the region. Overexploitation and climate change could have a negative impact on production of the plants and tree.

105 *Surveying the Distributions of Melaleuca quinquenervia, Psidium cattleianum, and Litsea glutinosa at Analalava Special Reserve (sit.edu)*

How to improve the *impact on local natural resources* score

Including a reforestation/replanting or forest protection project, or advocating for such a project or partnering with a suitable local organisation who can make this happen in the relevant area. Note that this would also offset the overall *carbon emissions* generated, as well as ensuring protection of the local eco-system.

To ensure that the wood used is sourced legally and sustainably, if necessary, working with wood suppliers to promote sustainability by monitoring and ensuring responsible practices is a viable approach. However, it comes with complex monitoring challenges. However, this may be very challenging due to the lack of regulation and monitoring systems.

Keep exploring other alternative materials such as bamboo.

Identifying alternatives to Niaouli, also known as "karavoho," is crucial due to its classification as an invasive plant. There are concerns about its usage, and efforts should be made to promote measures for eradicating this plant. It's important to note that this is a long-term plan and may present challenges in terms of implementation.

Raising awareness among the local population about the importance of responsible and sustainable wood usage. Given the heavy reliance on wood for construction and limited alternatives, this can be a challenging task. Education and advocacy efforts may help in the long run, but they might face initial resistance.

Extending the useful life of houses, so it can reduce the demand for more wood over time, by protecting wood against weathering. Currently, only the poles are treated with engine oil for preservation. It's worth exploring additional techniques and best practices for preserving the entire house.

Implementing good practices and providing training to the local population and construction workers can help prolong the lifespan of houses, reducing the need for additional wood.

Bamboo as an alternative material

As pointed out in this study, while wood is a crucial construction resource in Madagascar and is well-utilised by communities for housing, addressing the associated environmental and socio-economic challenges became imperative. Implementing sustainable practices and exploring alternative materials can help strike a balance between meeting construction needs and preserving Madagascar's unique biodiversity and ecosystems.

The Luxembourg Red Cross is currently piloting a project in Antalaha, where bamboo is used as a primary construction material for housing ("Case"), serving as an alternative to traditional wood-based houses ("Case améliorée en bois"). Most of the traditional wood houses are constructed using local wood, which has raised sustainability concerns.

Bamboo, it is often touted as one of the most sustainable construction materials available[106], bamboo offers an array of benefits:[107] [108] [109] [110]

- **Rapid Growth**: Some bamboo species can grow up to a meter per day, reaching maturity in 3 to 5 years, in stark contrast to hardwood trees, which may take decades.
- **Quickly Renewability:** Bamboo can regrow from its roots post-harvest without the need for replantation, offering a continuous, renewable source of material.
- **Low Environmental Impact:** The cultivation of bamboo requires neither pesticides nor fertilisers. It actively utilises carbon dioxide during growth, aiding in climate change mitigation.
- **Erosion Prevention:** The roots of bamboo plants help stabilize the soil, acting as a natural barrier against erosion.
- **Forst Conservation:** Bamboo cultivation can co-exist with natural forests unless these forests are cleared specifically for bamboo planting.
- **Biodegradability:** As a natural material, bamboo is biodegradable and environmentally benign at the end of its life cycle.
- **Strength and Durability:** Bamboo's tensile strength surpasses steel, making it a durable construction material. Its flexibility also enhances earthquake resistance.
- **Light & Energy-Efficient**: Its lightweight nature ensures reduced energy in transportation. Moreover, bamboo's insulating properties promise energy-efficient constructions.
- **Versatility**: Suitable for various applications, bamboo can effectively replace conventional construction materials used in flooring, roofing, scaffolding, and structural supports.
- **Affordable:** Often more affordable than conventional building materials, bamboo is a cost-effective construction option, particularly where it can be locally sourced.
- **Socio-Economic Benefits:** Bamboo cultivation can offer livelihood opportunities for communities in developing regions, fostering social and economic sustainability.
- **Cost-Effectiveness**: Due to its abundance and ease of cultivation, bamboo offers a cost-effective solution for various construction needs.
- **Supporting Indigenous Communities:** Bamboo cultivation supports the livelihoods and traditional knowledge of indigenous peoples.

However, like all materials, bamboo isn't without its challenges[111]. These include susceptibility to insects, potential shrinkage, and the need for treatment before use, conventional bamboo treatment methods as Borax or boric acid can cause pollution and health risks due to the use of harmful chemicals, although non-toxic alternatives are

106 *https://buildingrenewable.com/most-sustainable-building-materials/*
107 *Bamboo vs. Regular Lumber: Which Is Better to Build With? - Building Renewable,*
108 *Shelter and sustainability overview-UNHCR.pdf*
109 *The Most Sustainable Building Materials: We Pick 5 Winners - Building Renewable*
110 *Shelter and sustainability overview-UNHCR.pdf*
111 *Shelter and sustainability overview-UNHCR.pdf*

available. Also, in areas where bamboo isn't indigenous, import costs can be a deterrent, Uncontrolled harvesting can also lead to environmental issues like habitat loss and riverbank erosion.[112]

To ensure bamboo serves as a truly sustainable alternative, it's imperative to adopt best environmental practices. This includes confirming sustainable harvesting, having a well-defined harvesting plan, encouraging material reuse, and ensuring treatments are both effective and safe for workers and end-users.
In summary, while wood remains a central construction material in Madagascar, bamboo offers a promising, sustainable alternative that could redefine housing in the region and beyond, provided its use is approached with an informed, eco-conscious perspective.

Household Energy and fuel efficient cookstoves

The question of household energy and the use of wood biomass for cooking fuel is not an aspect of the shelter project being specifically considered in this study. However, it is closely linked to the household needs and it is too important an environmental issue to ignore. On one hand, burning of the house wood products releases *carbon emissions* (meaning worse environmental impact from the house), but on the other, it also provides a source of fuel for households, avoiding more deforestation. If we want to advocate to not burn the wood from the house, to avoid emissions, and also to avoid further deforestation, then the household energy question (especially for cooking) needs to be considered.

Around 3 billion people globally still cook over an open fire, usually using some form of biomass (wood, charcoal etc.). In 2019 the Moving Energy Initiative (MEI) estimates that forcibly displaced families living in camps are burning 64,700 acres of forest (equivalent to 49,000 football pitches) each year.[113] As was mentioned above, in Madagascar is a high demand for fuelwood and charcoal. The predominant use of firewood directly accelerates the rate of deforestation and desertification already occurring in other parts of the world.

The question of household energy is a cross-cutting issue, often ignored by humanitarian agencies because it does not easily fit into one sector. There are the issues of health (indoor smoke pollution, harmful particulates in the air); environment (deforestation); protection (women and girls spending a lot of time collecting wood in insecure contexts); and also, the extensive time spent collecting wood and cooking on an open fire. However it is also closely linked to the shelter and settlements sector.

Where more sustainable fuels are not an option, fuel efficient cookstoves are a well-recognised solution to improve the sustainability of household energy. Affected populations generally have limited access to modern cooking solutions. Most either depend on insufficient humanitarian agency handouts of ‘in-kind’ firewood or have to travel long distances to collect firewood (in the latter case, exposing themselves to the risk of attack and/or sparking conflict with host communities). In many cases, host governments are recognising the environmental damage and are now pushing for change, banning in-kind firewood distribution or requesting humanitarian agency support to transition refugees to alternative more sustainable fuels.[114]

As well as considering the impact of use of wood and other plants for the construction of houses, future projects should also consider the use of wood for cooking fuel by the families living in the houses, the impact on local forests, and how it can be reduced. Even if initiatives to provide alternative fuels or fuel-efficient stoves are not integrated, partnerships with organisations who can do this could be promoted.

112 *Shelter and sustainability overview-UNHCR.pdf*
113 *Cooking in displacement Setting. Engaging the Private Sector in Non-wood-based Fuel Supply. Laura Patel and Katie Gross. January 2019*
114 *Cooking in displacement Setting. Engaging the Private Sector in Non-wood-based Fuel Supply. Laura Patel and Katie Gross. January 2019*

8.4. Criteria 4: *Waste Management*

8.4.1. Overview of *waste management*

When designing a shelter solution and choosing the construction materials, what happens to each material at the end of its useful life should be considered. Prolonging the life of each material by looking at the options in each country, for reusing or recycling contributes to reducing waste. However, the survey carried out in 2022 by the "Joint Initiative for Sustainable Humanitarian Assistance Packaging Waste Management" (JI), revealed that in numerous humanitarian context, the responsibility for handling waste resulting from humanitarian assistants, falls on local authorities and communities.[115] Unfortunately, due to the absence of proper waste management systems, once these materials are no longer used, most of them will end up discarded in open fields or unsafely burnt, contributing to pollution, and environmental degradation, the spread of disease, and damage to wildlife. [116] In countries with very weak waste collection, storage and treatment systems, this is a major concern. This is especially relevant for those materials which take many years to decompose, potentially harming the environment for years to come. Thinking in advance of all the different waste management options in place should be a must for all programs.

This should also extend to the packaging of materials and other items which are purchased. According to JI[117] 32% of packaging materials used to deliver food and non-food items are made of plastic.[118] This is an obvious source of waste but also a relatively simple one to reduce, by reducing packaging, switching to biodegradable packaging, and eliminating all single-use plastics. JI highlights the importance of minimising packaging materials and giving priority to refusal and reduction, rather than relying on recycling, primarily because of the challenges associated with waste collection and recycling in humanitarian operational areas.

According to the *Madagascar environmental profile of the country for the shelter/housing response*, done by the Global Shelter Cluster,[119] waste management in Madagascar faces significant challenges. Particularly in rural and peri-urban areas where formal waste collection services are limited or non-existent. This results in the accumulation of waste in the streets, posing environmental and health risks. Additionally, Madagascar lacks adequate waste treatment infrastructure, such as controlled landfills and recycling facilities, leading to improper waste disposal and environmental contamination.

The analysis suggests that there is no effective *waste management* system covering the areas of implementation. Even if some of the durable items are reused and recycled, much of the solid household waste is typically burnt, buried, or left scattered.

Addressing these challenges, improving waste management practices and find value in the waste are essential to mitigate the adverse impacts on the environment and public health in the country.

8.4.2. Analysis of the waste generated by the house model

The following Table 3 shows a simplified representation of how many *long-lasting* and *quickly degrading materials* the house used, and the house *life expectancy*.

Please refer to Annex 8 to see for each of the house materials their life expectancy, how long it takes for them to decompose and if they can be reused and recycled, based on potential in Madagascar[120] according to ideas shared by some of the interviewees.

115 *https://eecentre.org/2019/07/15/https-www-eecentre-org-2019-07-15-sustainable-humanitarian-packaging-waste-management/*
116 *Guidelines-for-Packaging-Waste-Management-in-Humanitarian-Operations-compressed.pdf*
117 *https://tinyurl.com/jalnew-PoA*
118 *https://eecentre.org/2019/07/15/https-www-eecentre-org-2019-07-15-sustainable-humanitarian-packaging-waste-management/*
119 *A14_GESTION DES DEBRIS ET DES DECHETS _RECYCLAGE _REUTILISATION ET RECONVERSION - Google Docs*
120 *Refer to Annex 1 to see the list of people contacted.*

Table 3 – Amount of long lasting & quickly degrading materials and house life expectancy

House model	Long lasting materials	Quickly degrading materials	House life expectancy
Case ameliorée en bois			

The Global Shelter Cluster at the *Madagascar environmental profile of the country for the shelter/housing response*, covered the context of waste management situation in Madagascar.[121] Providing other tips and resources, which should be adapted based on the specific needs of each program.

The JI[122] was contacted for this study. One of the activities they are working on in partnership with the *Global Logistics Cluster* is to map out recycling and waste management infrastructures in countries with humanitarian contexts. Madagascar in one of the countries.[123]

JI has also created a guide of best practices and innovations in packaging waste management in humanitarian operations. However, at the moment, none of these innovations have been implemented in Madagascar. Nonetheless, it serves as a basis for examples of what can be done.[124]

8.4.3. Scorecard for *waste management*

Scorecard *waste management*

CASE AMELIORÉE EN BOIS

1 poor, 2 average, 3 medium, 4 good, 5 very good

The house received a score of 4 out of 5, primarily due to its use of biodegradable materials, such as wood, which offers significant waste management benefits. Wood is environmentally friendly, biodegradable, and can be composted, reducing landfill waste and minimising its environmental impact. However, the presence of non-biodegradable materials, specifically steel hardware products, was a contributing factor to the slightly lower score.

Another important consideration is what happens to the wood at the end of its useful life. According to the local team, once the wood has reached the end of its useful life, it is burnt by the families, contributing to environmental pollution. Therefore, promoting responsible wood disposal practices, such as composting, should be considered.

121 *A14_GESTION DES DEBRIS ET DES DECHETS _RECYCLAGE _REUTILISATION ET RECONVERSION - Google Docs*
122 *Information can be found at https://eecentre.org/2019/07/15/https-www-eecentre-org-2019-07-15-sustainable-humanitarian-packaging-waste-management/*
123 *The information is then uploaded onto the Global Logistic Cluster LCA; Madagascar Waste management and recycling assessment | Logistics Cluster Website (logcluster.org)*
124 *OPTIONS FOR HUMANITARIAN PACKAGING REUSE, REPURPOSING, AND RECYCLING (eecentre.org)*

Even though the quantity of steel products is relatively small, it is crucial to minimise their consumption because they can contribute to long-lasting waste in landfills. Implementing a waste management strategy for potential reuse or recycling of these steel products at the end of their lifespan is essential. Unfortunately, the existing programme lacks such strategies, placing the responsibility for waste management on local communities and governments, resulting in some of these materials being improperly discarded in open fields, which harms the environment.

Regarding packaging, the only materials with packaging are the steel warehouse products, which are wrapped in cardboard. Cardboard is a recyclable material and 100% biodegradable.

To further reduce waste, extending the house's lifespan and, consequently, the turnover period of materials is crucial. This can be achieved by using high-quality materials and construction practices. Poor construction not only poses safety risks but also increases the turnover period of materials, worsening the environmental impact of house construction. Although the current life expectancy of the house is around 7 to 10 years, measures to enhance its durability should be actively promoted. Therefore, advocating for superior construction standards is essential in every program.

Based on the information provided, it appears that the program lacks protective measures to safeguard wood, except for the foundation poles. It is strongly recommended that all wood is protected, and the program actively promotes this practice to ensure the longevity of the materials.

How to improve the *waste management* score

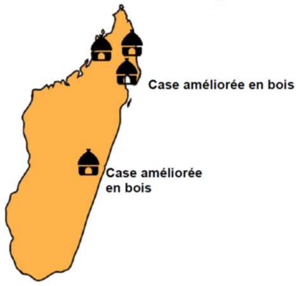
Promote composting of the natural materials, consider to use the compost in urban gardens or household kitchen gardens, instead of burning them at their end of life. This could be difficult to implement, since families often rely on burning organic matter for cooking fuel. This can be partially addressed by integrating clean household energy into the shelter project

Continue encouraging best construction methods, emphasising the "build back safer" approach, and advocating for extending the lifespan of materials through proper care and maintenance. This will reduce the need for frequent material replacements.

Raising awareness of environmental sanitation and the pollution generated by the disposal of the materials, though the programme or through advocacy in partnership with other organisations.

Attempt to locate the steel recycling facility in Madagascar.

8.5. Summary of the results

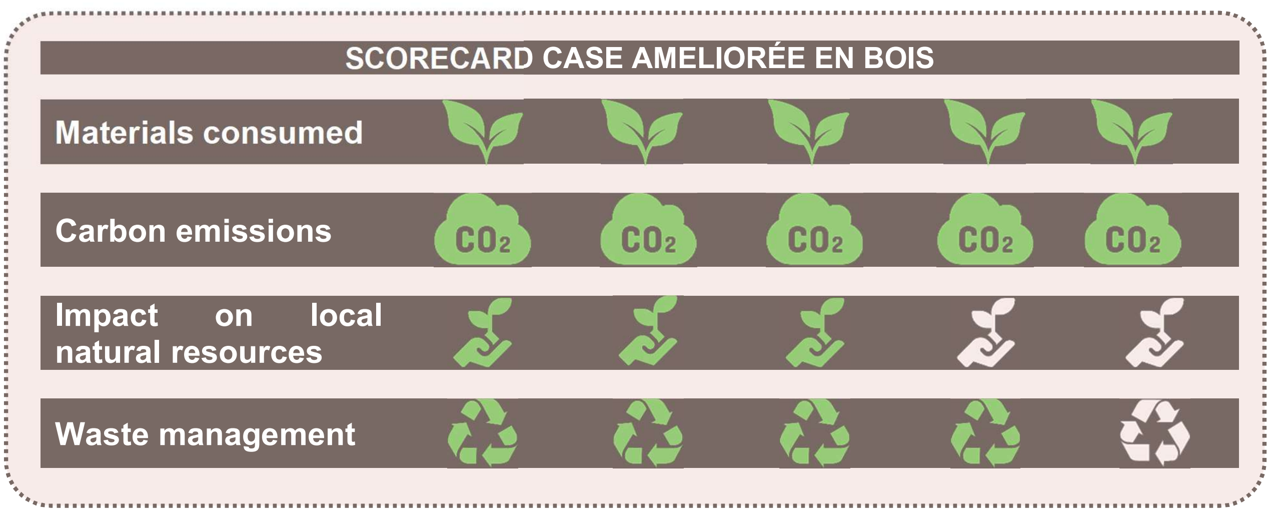


The house model uses mostly locally available raw materials (trees and plants) and has very limited reliance on man-made materials (only for the steel hardware). Using local materials offers an environmental advantage due to their lower impact. These materials are more sustainable, locally sourced, and renewable compared to synthetic options.

The house model maintains a positive carbon balance throughout its life cycle, meaning house captures more carbon emissions than it releases, mainly due to the use of natural materials like wood and plants that actively absorb carbon during their growth. However, a significant portion of carbon emissions occurs during the "end of life" phase, primarily from the combustion of wood and plants, even though the overall balance remains no net carbon emissions. Steel products also contribute to carbon emissions, although their quantity is relatively low, resulting in a comparatively modest impact on the overall carbon balance, which remains in favour of carbon sequestration.

The house model predominantly relies on local natural resources, such as wood and plants, for its construction. However, this reliance on wood in Madagascar raises significant concerns due to the country's fragile forests and endangered local plant species. Specifically, the use of Niaouli wood, considered an invasive species, poses a significant threat to Madagascar's native ecosystems. Similarly, the use of eucalyptus wood requires careful examination due to potential environmental impacts.

The house primarily utilises biodegradable materials, such as wood and plants, offering significant waste management benefits. Wood is environmentally friendly, biodegradable, and can be composted, effectively reducing landfill waste and minimising its environmental impact. However, it's essential to note that the inclusion of non-biodegradable materials, specifically steel hardware products, even in small quantities, requires careful consideration.



1 poor, 2 average, 3 medium, 4 good, 5 very good

9. Conclusion

This research emphasises the importance of examining the entire lifecycle of a house and its materials, from their production to their disposal. The evaluation not only considers carbon emissions but also factors such as the utilisation of local natural resources and waste management. While reducing carbon emissions is crucial and widely recognised, it is equally important to consider the impact of using natural resources on the local environment. Furthermore, management of waste represents a hidden challenge in the humanitarian sector, often overlooked during project planning and rarely discussed at more strategic levels.

To assess the environmental impact of the house model requires us to balance relative sources of environmental harm across the different criteria. The scope of this remote study does not allow for a quantitative weighting for each criteria, leading to a numerical score. An overall qualitative comparison is all that is feasible, which is done through the scorecard.

One of the advantages of using a scorecard approach is that it helps identify environmental concerns linked to each criteria and allows for the identification of mitigation solutions. However, it's important to recognise that there are cross-cutting issues that affect multiple criteria, and a single solution can address more than one criteria. For instance, products made from steel not only raise concerns due to their embodied carbon emissions but also because they are long-lasting materials. Therefore, exploring alternatives such as recycled steel products can simultaneously address carbon emissions and waste management.

It is recommended that a simple environmental impact assessment or at least environmental screening using a tool such as the NEAT+[125], and following that identification of mitigation strategies, should accompany the design of all shelter and site planning activities.

The "case améliorée en bois" model has been designed with consideration for local architecture in Madagascar. It emphasises environmental sustainability primarily through the use of locally available natural resources, such as wood and plants. These materials have a deep historical connection to Madagascar's vernacular architecture and remain vital for local construction. However, the heavy reliance on wood and plants has sometimes led to unsustainable harvesting practices, driven by significant demand for construction materials in rapidly growing regions.

While using natural materials like wood offers cultural and economic advantages, it also presents challenges related to deforestation and environmental degradation. The demand for these materials frequently exceeds the available resources, contributing to accelerated deforestation in a country already grappling with this issue. Therefore, it's imperative to approach the use of natural materials with a strong focus on sustainability and environmental conservation.

It is evident from the research that Madagascar lacks clear guidelines for wood usage, and the existing regulations are often contradictory and challenging to enforce. Therefore, the programme should take ultimate responsibility for promoting good practices and finding solutions to the deforestation problem in Madagascar.

The house model primarily employs various natural materials, with the most abundant being "teza" (hardwood), which includes different type of wood such as "hintsy," "rahiny," "Nanto," and "Faho," chosen based on their availability in the market. However, the use of these hardwoods raises concerns regarding their potential impact on the forest ecosystem and the endangered status of certain tree species. Therefore, it is crucial to conduct further environmental assessments to evaluate the implications of using these hardwoods. According to the "Guide pour l’amélioration de la résistance des cases d’habitation traditionnelle face aux cyclones," “hintsy” is one of the hardwood species recommended for reforestation efforts.

The second most used material is the versatile traveller’s palm, known by different names based on the plant part used. This practice highlights the versatile use of natural resources in different cultures, where various parts of a

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125 *https://neatplus.org/*

single plant can have multiple applications and distinct names based on their specific use. The traveller’s palm symbolises Madagascar's heritage and offers a renewable resource as its parts can regrow after harvesting. This reduces the demand for endangered wood species, promoting biodiversity conservation. However, comprehensive studies are needed to assess its sustainability and ecological impacts of using the plant.

Eucalyptus “raboté” is employed for doors and windows panels, deterring the use of tropical woods but presenting concerns like high water consumption and biodiversity loss. Sourcing from sustainable private plantations and exploring eco-friendlier alternatives are recommended.

Niaouli "karavoho," poses a threat as an invasive tree in Madagascar, disturbing native ecosystems. A long-term efforts should be made to eradicate it. In the short term, promoting the use of alternative species is an important step in mitigating its impact.

The dombeya plant, known as "hafotra" or "l'arbre zavy," is used as a rope. However there is limited information available about this plant, primarily because the exact species of dombeya used has not been specified,

It's worth mentioning that the program is already exploring alternative construction materials, such as bamboo. Bamboo is known for its sustainability and fast growth, making it an environmentally friendly choice. This demonstrates the program's commitment to considering environmental factors and seeking practical solutions for sustainable construction.

An additional concern is the use of timber and plants as firewood at the end of their life cycle, which results in the release of previously sequestered carbon, offsetting their environmental benefits. This issue is complex due to the dependence of affected families on firewood for cooking. Therefore, using timber for heating and cooking can help reduce the consumption of other forest resources, as approximately 90% of Madagascar's population relies on biomass for their daily energy needs. To address this dilemma, it may be beneficial to consider stoves that operate on non-organic materials as part of the program.

The focus should also be on the steel hardware materials, due to their high carbon emissions per kilogram and extremely long decomposition time, even though their quantities are relatively small compared to the other natural materials used. This concern is amplified in countries like Madagascar, where waste management systems are inadequate. However, there is potential for recycling these materials. The study has not identified recycling enterprises in the country or program areas, but it is highly recommended to explore and facilitate connections between such enterprises and the affected families if possible. Another alternative is to find value in waste by promoting recycling projects within the families. This could be a source of income.

Additionally, these steel materials are sourced from China, as there are no factories in Madagascar producing them according to the local team. This reliance on materials from distant sources pose transportation-related environmental challenges. It is advisable to investigate if there are alternative hardware materials available from closer regions, such as East Africa, to reduce transportation-related environmental impacts.

Furthermore, the correct treatment and construction techniques during the building, maintenance, and repair phases play a crucial role in determining a house's integrity and longevity. Ensuring that a house remains durable over the long term, thereby extending the turnover period for its materials, is not only cost-effective but also environmentally efficient. This is particularly relevant when using natural materials, as their lifespans can vary depending on the quality of construction and maintenance practices.

The current estimated lifespan of houses ranges from approximately 7 to 10 years, according to the local team. However, certain parts like the roof last only 3 years. To prolong the lifespan of these houses, it is recommended to implement protective measures, especially for wooden and plant components. Currently, only the poles are treated with engine oil. It is advisable to expand this protective treatment to other wooden parts of the house when feasible. Additionally, exploring alternative, environmentally friendly methods of wood protection should be considered to minimise any adverse environmental impacts.

By incorporating these protective measures and emphasising regular maintenance alongside the use of high-quality construction techniques and materials, the longevity of the house can be significantly improved. To support these efforts, it is crucial to continue and enhance existing training programs focused on house maintenance and construction improvement. This comprehensive approach ensures not only the sustainability of the houses but also their environmental and economic efficiency.

In summary, the "case améliorée en bois" model considers local architecture in Madagascar, using natural resources like wood and plants, offering environmental sustainability benefits. However, heavy reliance on these materials raises concerns in a country facing deforestation and environmental degradation. Clear government guidelines for wood usage are lacking, necessitating responsible practices. The primary materials include various types of "teza" (hardwood) like "hindy," followed by traveler's palm, and eucalyptus "raboté." Sustainable sourcing is recommended. Invasive Niaouli "karavoho" requires long-term eradication and short-term promotion of alternative species is recommended. Dombeya plant, used for rope, needs environmental assessments despite low quantities. Avoiding wood and plant burning at the end of their life cycle reduces the overall environmental impact of the house; however, also using this wood as firewood would help to avoid tree cutting used for such purposes. To achieve this, it can be helpful to provide families with more fuel-efficient cook stoves cook stoves. Continuously exploring alternative materials like bamboo is an integral part of the sustainability efforts within the program. Steel hardware materials sourced from China raise concerns related to transportation and recycling opportunity in the country. It recommends exploring recycling options and sourcing materials locally or from nearby regions, such as East Africa. Proper treatment and construction techniques are essential for the longevity of houses, reducing the need for material replacement. To extend their estimated 7 to 10 years' lifespan, implementing protective measures, such as treating wood and exploring eco-friendly methods, is recommended for enhanced sustainability and economic efficiency. Training programs play a crucial role in complementing these efforts.

It is important to clarify that this study does not make a definitive recommendation. The final verdict rests on the available options to mitigate some of the worst concerns, which if adopted in future could reduce the overall environmental impact of the house. This study essentially captures a “snapshot” of the current situation, as a baseline. If the study is repeated in the future for the same house model, it can indeed create a timeline that illustrates how the environmental impact has evolved over time. This can help track the effectiveness of mitigation measures, identify trends, and assess whether the environmental situation is improving or deteriorating.

It's worth noting that implementing some of the recommendations might be challenging, and their feasibility should be verified, as the scope of this work didn't allow for in-depth verification. Many suggestions involve behavioural changes, which can be time-consuming. However, initiating discussions on these topics is already a step in the right direction.

In closing, the notion of an ideal housing solution that meets every requirement is not realistic. As well as the environment, there are multiple other considerations, such as technical efficiency, longevity, habitability, cost-effectiveness, and cultural relevance, to name a few. While these elements haven't been the focus of this study, they play a crucial role in comprehending the entirety of the house context. No shelter solution is perfect; it's about finding the one which is most suitable, feasible, and least harmful to the environment.

10. Recommendations

House-specific recommendations

Collaborating with wood suppliers to ensure sustainable plantation practices and responsible wood sourcing, to ensure over-extraction or other environmental damage is not happening. Understanding the environmental measures they are implementing and monitoring their compliance can contribute to more responsible wood procurement. However, the complexity of monitoring and enforcing sustainable practices poses challenges in this regard.

Identifying alternatives to Niaouli, also known as "karavoho," is crucial due to its classification as an invasive plant. There are concerns about its usage, and efforts should be made to promote measures for eradicating this plant. It's important to note that this is a long-term plan and it will be challenging in terms of implementation for the team. So working with environmental association is encourage.

Keep exploring other alternative materials such as bamboo. Further research and testing are needed to evaluate its viability for widespread use.

Exploring adobe construction: Adobe construction, successfully used in other parts of the country, it could be considered as an alternative building method. However, it may be less suitable for the program's target areas due to high humidity and poor soil quality. Further investigation and adaptation of this construction method may be required to make it suitable for the specific conditions in the target areas.

Promote composting the natural materials, consider to use the compost in urban gardens or household kitchen gardens, instead of burning them at their end of life. This could be difficult to implement, since families often rely on burning organic matter for cooking fuel. This can be partially addressed by integrating clean household energy into the shelter project. See point below.

Procure more locally produced steel, when possible, to reduce the carbon emissions from *“transport”.*

General programme recommendations

Include reforestation or replanting projects within the programme. Either directly with communities, or if on a bigger scale through partnerships with other specialist organisations. Planting trees to replace those harvested for construction can help restore local ecosystems and maintain a sustainable source of wood.

Continue encouraging best construction methods, emphasising the "build back safer" approach, and advocating for extending the lifespan of materials through proper care and maintenance. This will reduce the need for frequent material replacements. Currently, only the poles are treated with engine oil for preservation. Exploring additional techniques and best practices for house preservation should be considered.

Raising awareness among the local population about the importance of responsible and sustainable wood usage. Given the heavy reliance on wood for construction and limited alternatives, this can be a challenging task. Education and advocacy efforts may help in the long run, but they might face initial resistance.

Raising awareness of environmental sanitation and the pollution generated by the disposal of the materials, though the programme or through advocacy in partnership with other organisations.

Promoting good practices and offering training: Implementing good practices and providing training to the local population and construction workers can help prolong the lifespan of houses, reducing the need for additional wood.

Encourage people to brainstorm what can be done with the steel materials at the end of the useful life, through community engagement. Defining how to turn waste into value. Materials can be collected and reused as raw materials in other products, especially those materials that take a long time to decompose, like steel. This can easily be linked with livelihoods or education programmes.[126]

Link communities to private waste companies, if possible, to collect materials which are not reused, for recycling. There is also the possibility to generate income for communities from this.

Consider to provide families with access to cooking stoves that do not rely on organic materials, and rely more on solar power or alternative fuels; or at least are more fuel-efficient if they have to burn wood fuel or other biomass. It will reduce the dependency on firewood and take pressure off of forest resources.

Advocate and work with the Shelter Cluster working group and other partners in each country and the region, to pass key environmental messages.

Consider to do an environmental impact assessment or at least environmental screening using a tool such as the NEAT+[127], during the design of all shelter / house and site planning activities.

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126 *recycling_reuse_and_disposal_of_plastic_sheeting.pdf (sheltercluster.org). Also there are a few initiative at OPTIONS FOR HUMANITARIAN PACKAGING REUSE, REPURPOSING, AND RECYCLING (eecentre.org)*
127 *https://neatplus.org/*

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12. Annexed documents

- Annex 1 - Informants
- Annex 2 – House model technical information
- Annex 3 – House components material, packaging, quantity and country of origin
- Annex 4 - Transport distance
- Annex 5 - Materials used in the house model
- Annex 6 - Carbon emissions calculation
- Annex 7 - Local natural resources used for the house
- Annex 8 - Protentional reuse option and recycling options
- Annex 9 - Advantages, impacts and best practice of each material

ANNEX 1 - Informants

International Aid of Luxemburg Red Cross & Croix Rouge Malagasy

- JAOMILA Pascal. CP TSARAHONENANA. Croix Rouge Malagasy
- LAMPERTZ, Eric Desk Madagascar
- LEDESMA Daniel, Research officer
- MARTIN, Sylvain Martin, Chef de mission Madagascar
- RAKOTOZANDRY, Niaina CV Shelter CRM et point focal de l’évaluation environnementale au Madagascar

Shelter Cluster Madagascar

- Andrianina FANOMEZANTSOA, *Shelter Officer, Indian Ocean Islands Cluster*

Global Shelter Cluster

- KELLY, Charles, Co-Chair, Environment Community of Practice, Global Shelter Cluster.
- MARARA, Madelaine, Global Shelter Cluster Environnemental Focal Point.
- GEORGE, Mandy, Senior Environmental Advisor

Other organisation contacted in Madagascar

- NAHAVITATSARA, Angelo - Medair Project Support Manager – PNK DR Congo

Other person contacted:

- GENOT, Xavier t ; Architect and independent consultant, deployed in rapid response shelter on Operation Batsirai.
- BRAGEON, Samantha. Consultant- JI Sustainable Humanitarian Packaging Waste Management
- Directeur Régional of DREDD Vatovavy Fitovinany

ANNEX 2 – House Model Technical Information

Different material quantities were provided during data collection, because the amount is not standard for each house, varying due to location and market availability. The analysis has assumed average quantities of each material. It is important to note that all the information provided comes from the team in Antalaha, so this study only takes this into consideration.

CASE AMÉLIORÉE EN BOIS

The "Case améliorée en bois" is designed as a sustainable housing solution, with the assistance of the Madagascar Red Cross in Antalaha, Maroantsetra, Ambanja and Manajanry. 42 houses have been built and 1028 are plant to be built

Total area
16 m^2

Occupancy
5 persons

Construction time
4 to 5 days

Cost
830 euros

Durability
7 to 10 years

Total # Built
42

To Build
1028

Dimensions
3 m x 4 m

Foundation
The foundation is designed with a depth of 70 - 100 cm, which can be adjusted depending on the soil resistance at the specific site. The poles are directly embedded into the ground and compacted with rocks for stability. To protect them from bacteria and insects, the poles are treated with engine oil.

Structure
The poles and rafter are made of several types of wood, depending on their availability. Woods like “Hintsy,” “Rahiny,” “Nanto,” and “Faho,” all of which are locally names from the region. These woods are also known as “teza,” which denotes the harder part of the wood.

The slats are made from “karavoho” (Niaouli tree), and the bracing are made of “rapaka” the trunk of the traveler's palm.

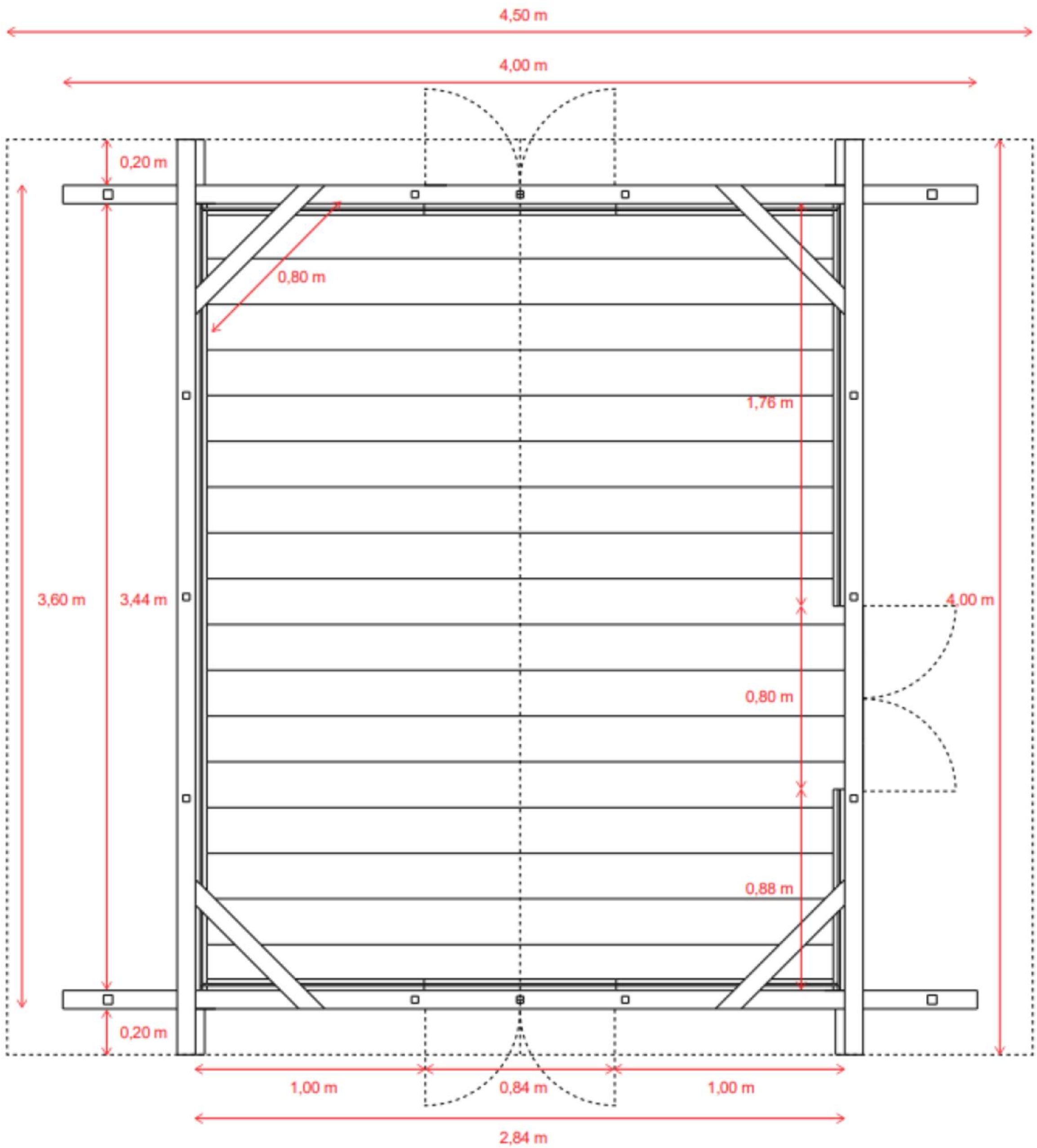
Walls
The walls of the house are made from “falafa” from the traveler’s plant.

Flooring
The floor is made of “Rapaka” from the traveler’s plant.

Roof covering
The house has a dual-sloped roof thatched with “ravinala,” the leaves of the traveler's palm. “Hafotra or l'arbre zavy” (Dombeya tree) is used as the binding rope

Openings
The doors and windows are made from panels of “raboté,” a type of eucalyptus wood.

PLAN CASE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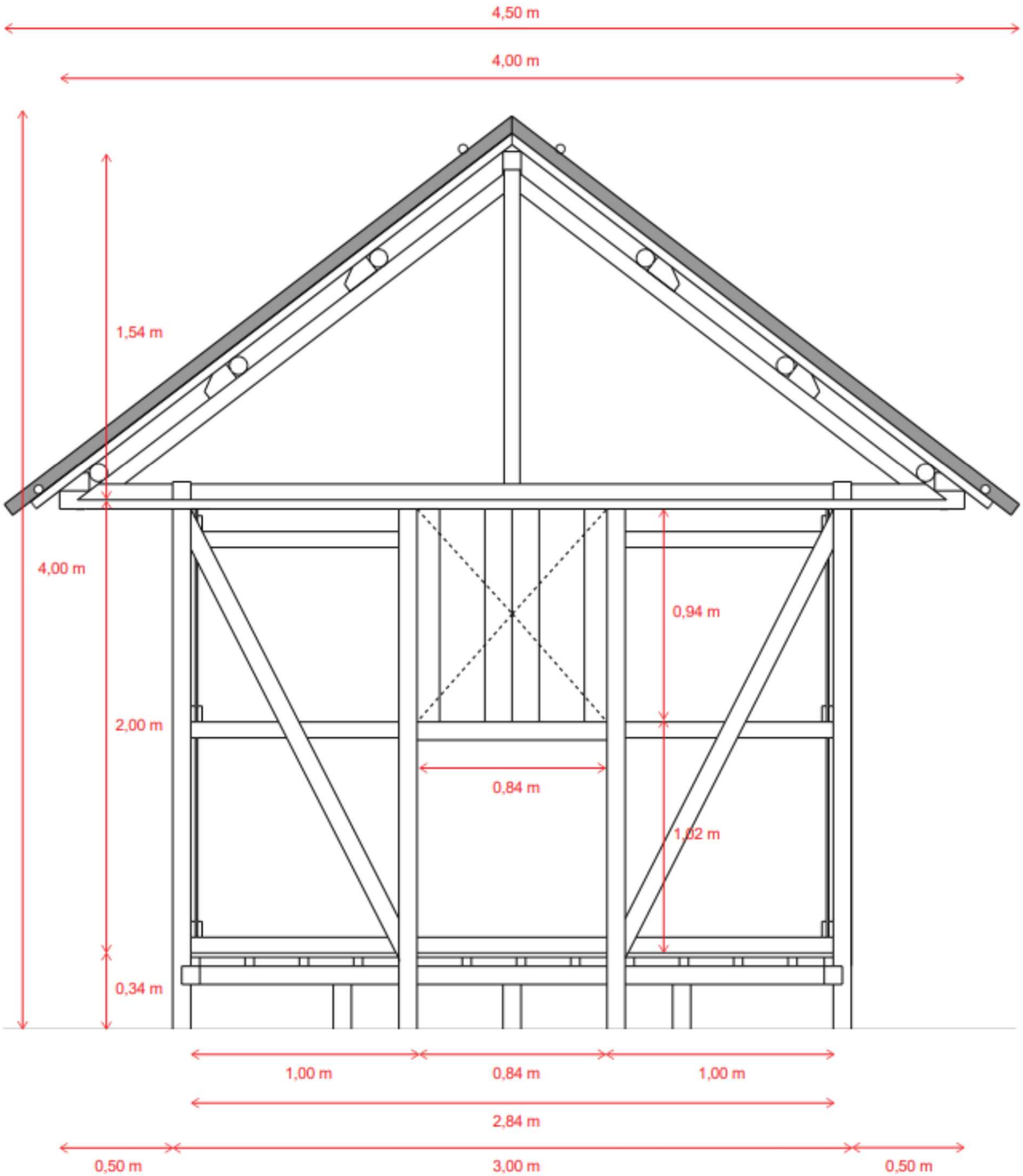
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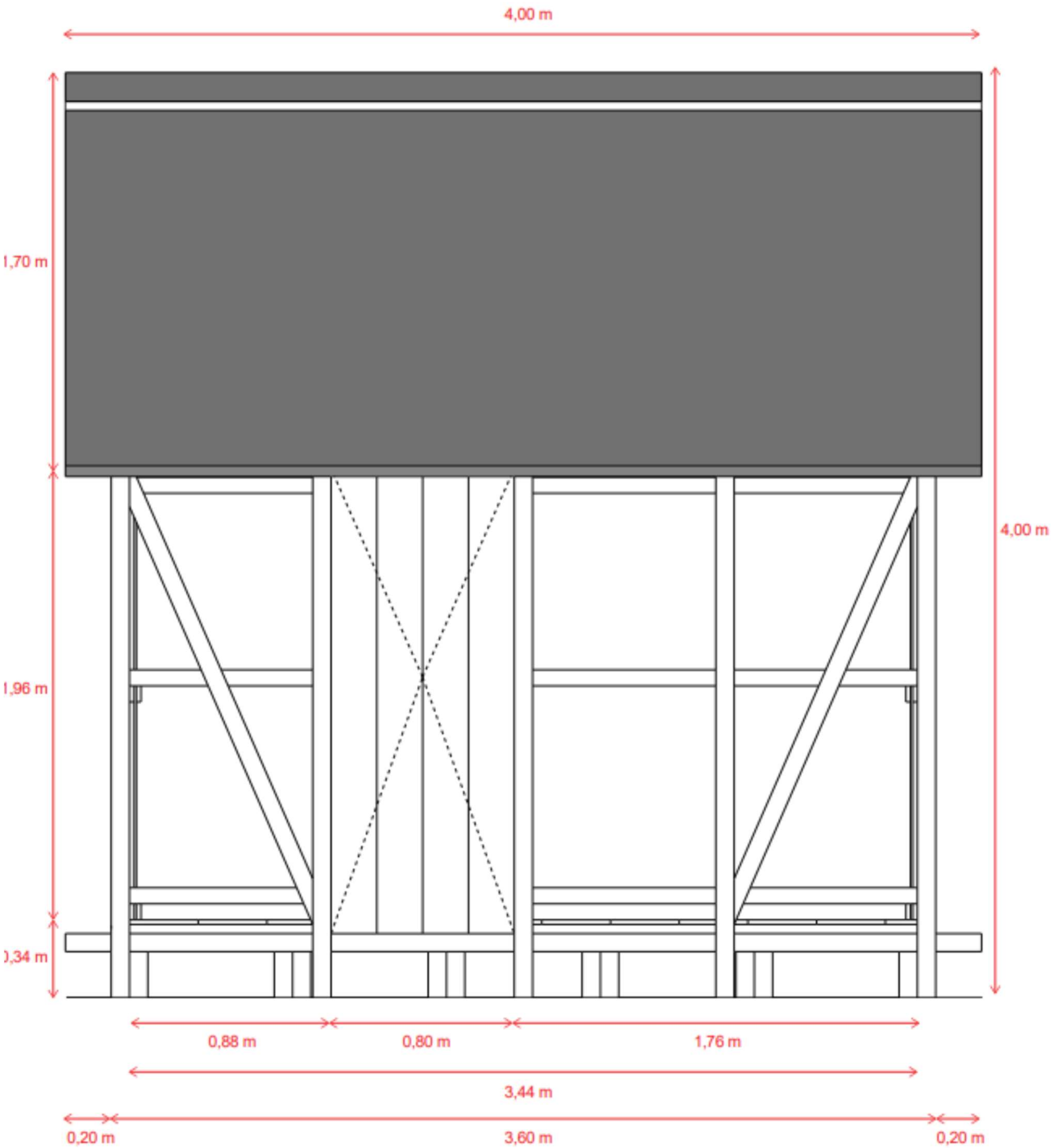
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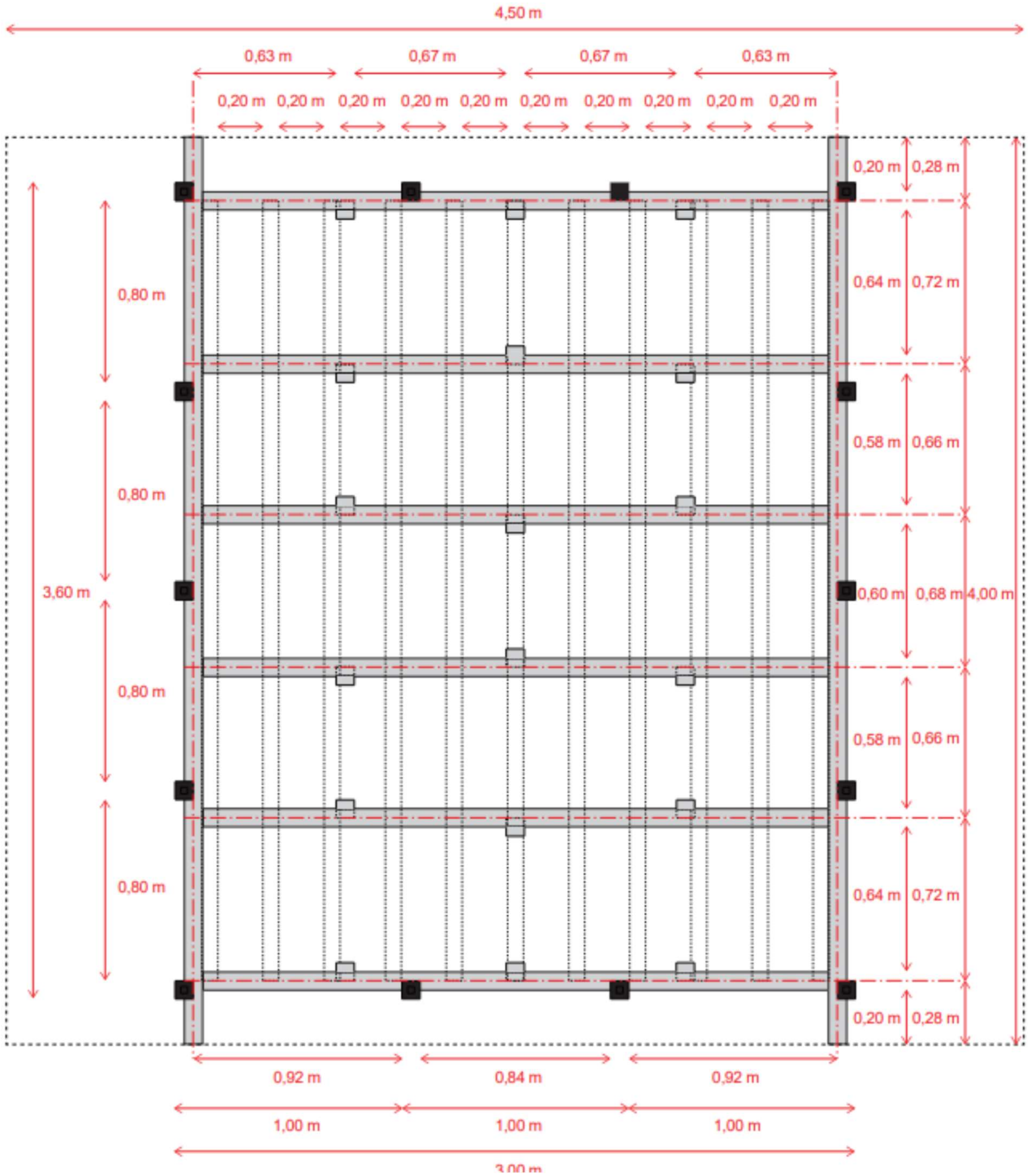
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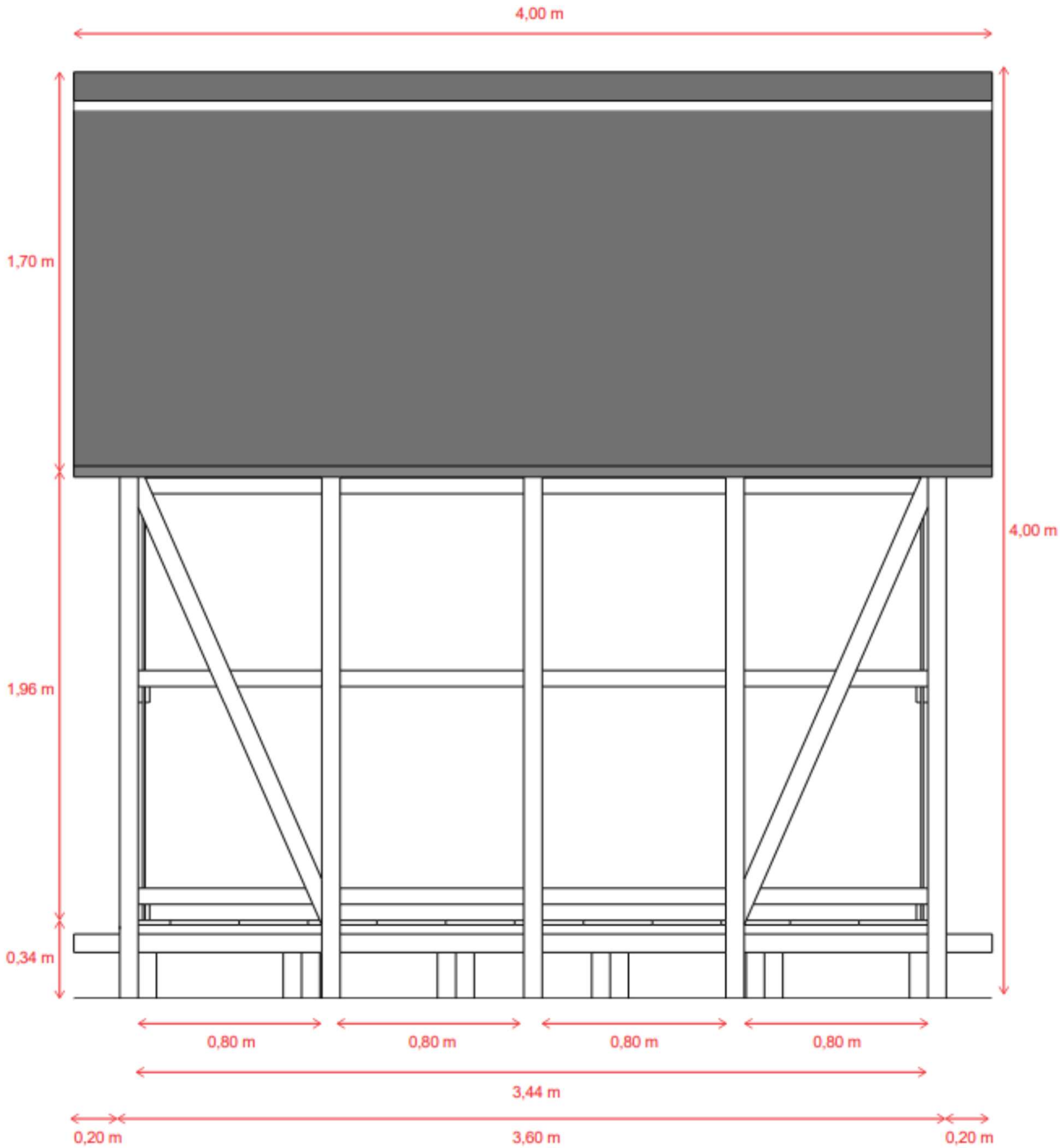
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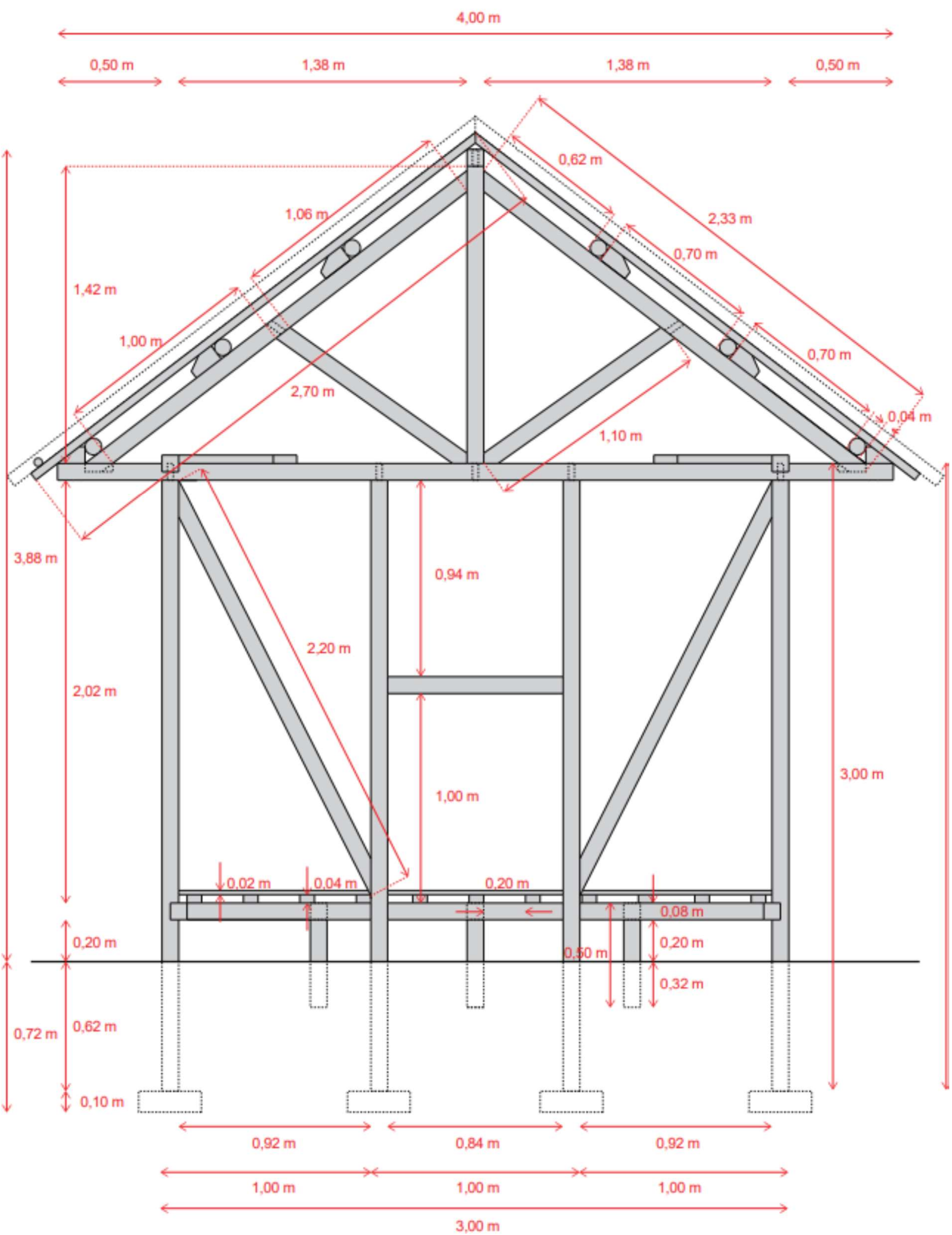
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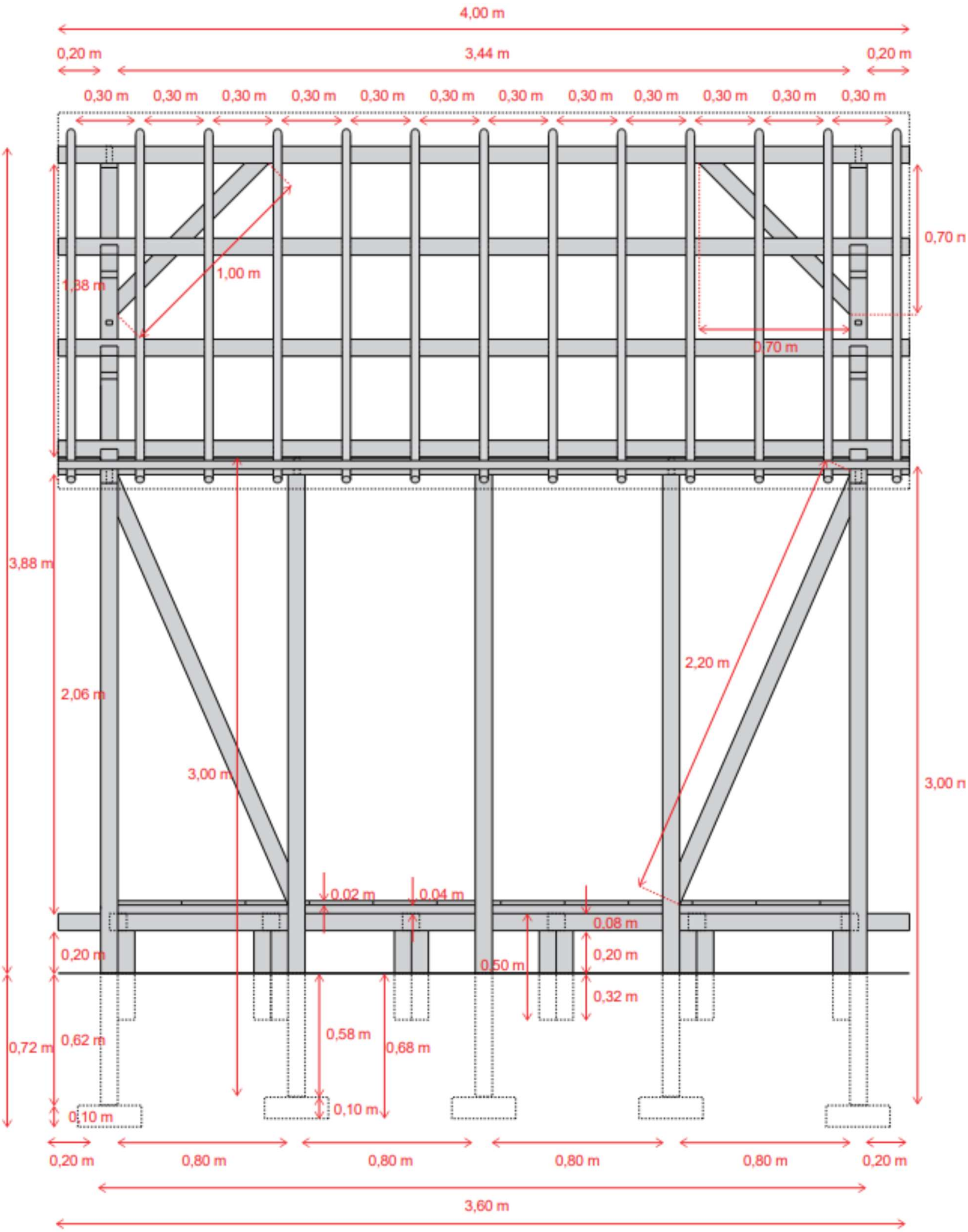
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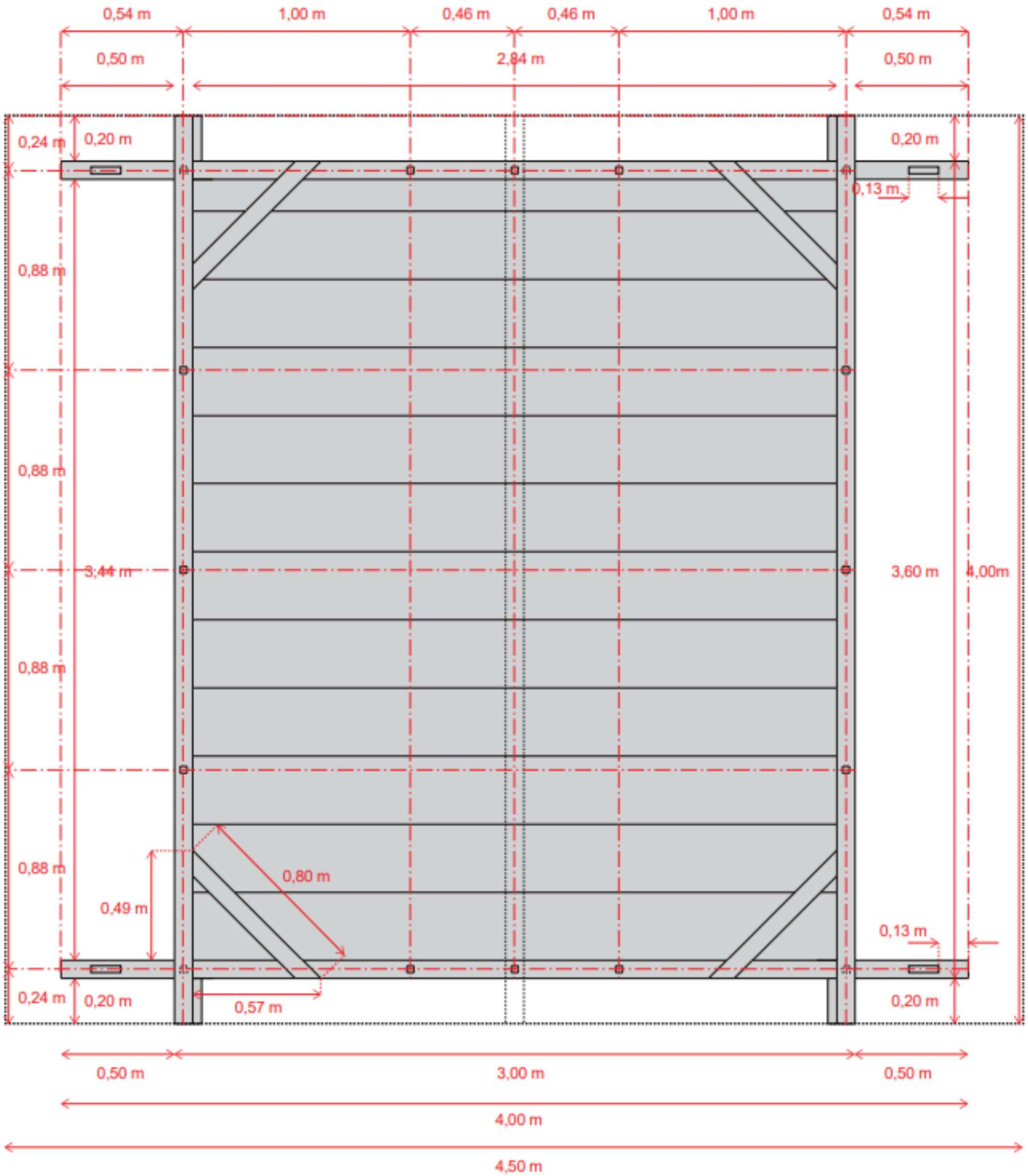
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ANNEX 3 - House components material, packaging, quantity and country of origin

All the information below was provided by the AICRL team in-country.

Table 1 - Case améliorée en bois

Name	Raw material	Quantity/ Kg	Country of origin	Packeting	Quantity/ Kg
Poles	Teza - "Hintsy", "Rahiny", "Nanto", "Faho"	360kg	Madagascar	None	
Rafter	Teza - "Hintsy", "Rahiny", "Nanto", "Faho"	200 kg	Madagascar	None	
Slats	"Karavoho" (Niaouli tree)	0.4 kg	Madagascar	None	
Bracing	"Rapaka" (Traveler's Palm tronc)	0.5 kg	Madagascar	None	
Walls	"Falafa" (Traveler's Palm tronc)	40 kg	Madagascar	None	
Floor	"Rapaka" (Traveler's Palm tronc)	7 kg	Madagascar	None	
Roof	"Ravinala," traveler's palm leaves	40 kh	Madagascar	None	
Rope	"Hafotra" or "l'arbre zavy" (Dombeya tree)	0.30 kg	Madagascar	None	
Doors and Windows panels	"Raboté," Eucalyptus	72 kg	Madagascar	None	
Lock for doors and windos	Steel	0.20 kg	Chine	cardboard	0.150 kg
Simple bolt	Steel	0.20 kg	Chine	cardboard	0.05 kg
Bolt with lock	Steel	0.20 kg	Chine	cardboard	0.05 kg
Handle	Steel	0.20 kg	Chine	cardboard	0.05 kg
Mounting nails	Steel	0.20 kg	Chine	cardboard	0.05 kg
Ordinary nails	Steel	11 kg	Chine	cardboard	0.150 kg
Rubble	Rubble	*It has not been specified*	*It has not been specified*	*None*	*It has not been specified*
Engine oil	Engine oil	*It has not been specified*	*It has not been specified*	*It has not been specified*	*It has not been specified*

ANNEX 4 - Transport distances

When calculating the CO_2 equivalent, one of the key factors is the origin of the materials, since transportation can make a big contribution to *carbon emissions*. Whether a material has been purchased locally or imported, transported from a neighbouring country by road, or produced in a distant country and transported by sea or air, will have a material impact on total *carbon emissions*.

Normally, to calculate the transportation distance, the following distances in kilometres for each product are required.

- Country of origin to point of arrival in country
- Point of arrival to warehouse / store
- Warehouse to construction site
- Construction site to disposal site
- Type of transport used for each phase (truck/road, train, sea or air)

For the purpose of this study, since the exact travel distance and the exact location of each factory and timber yard are not known, average transport distances have been estimated. The following assumptions have been made:

- The distances have been provided by the local team, considering only the house model built in Antalaha and not in other locations. Therefore, for this study, only the Antalaha model is consideredThe distances in kilometres have been provided by the field team.
- A few materials have been manufactured in China and transported by boat[128].
- Since the exact location of the Chinese factory wasn’t available, the suggested approximate distance baseline provided by the SMAC guidelines from Asia to East Africa has been used: 9,000 kilometres.
- Since it is not known exactly what happens with disposal, transportation from the site of construction of the house for disposal is not included.

Distance by boat

Departing point	Arrival point	Distance
Chine	Tamatave	9000 km

Distance by boat

Departing point	Arrival point	Distance
Tamatave	Antananarivo	360 km

Departing point	Arrival point	Average Distance
Antananarivo	Antalaha	1500 km

128 *Refer to Annex 4 for further information*

ANNEX 5 - Materials used in the house model

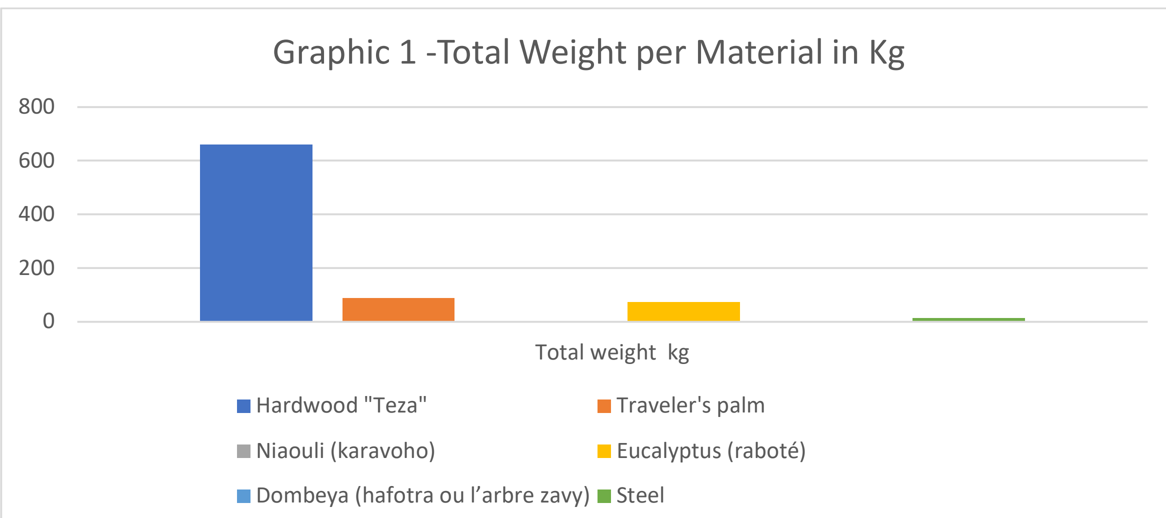
Below are the tables showing the materials used in the house model of Antalha, by weight (kilograms). The data was provided by the AICRL logistics teams in the country.

Water consumption is calculated for all the materials used to build the houses. To calculate the embody water in litres, the UNHC shelter and sustainability tool baseline[129] have been used.

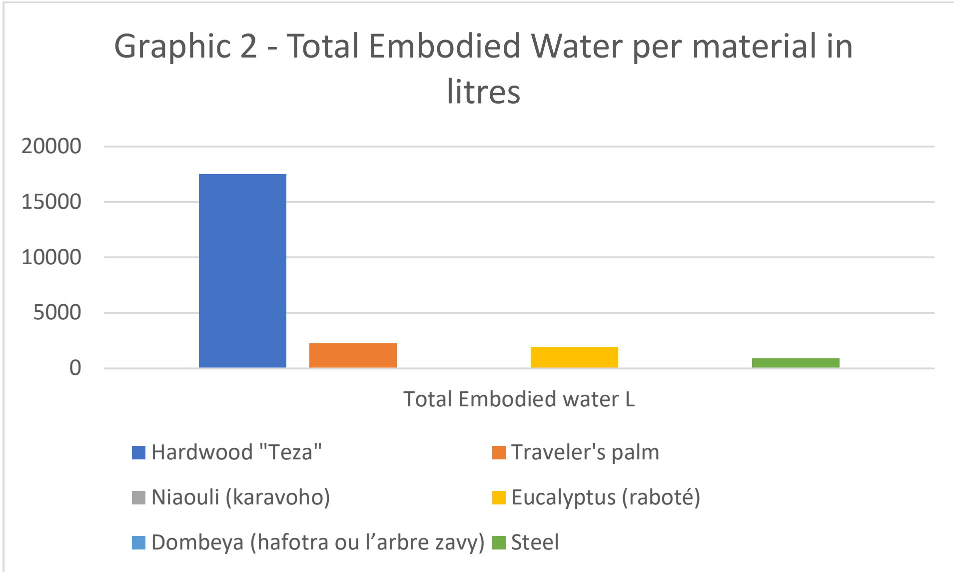
Table 1 –CASE AMELIOREE EN BOIS

Raw made material	Quantity / Kg	Embodied water (L)
Hardwood (Teza)	660 kg	17,516 L
Traveler’s’ palm	87.50 kg	2,245 L
Niaouli (karavoho)	0.40 kg	11 L
Eucalyptus (raboté)	72 kg	1,911 L
Dombeya (hafotra ou l’arbre zavy)	0.30 kg	8 L
Water consumption	22607 L	-
Man-made material	**Quantity / Kg**	**Embodied water (L)**
Steel	11.8 Kg	916 L

The follow Graphic 1 shows the total weight in kilograms of each material, and Graphic 2 shows the total embodied water in litres produced by each material



129 *UNHCR-TSS (epfl.ch)*


Graphic 2 - Total Embodied Water per material in litres
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Total Embodied water L
Hardwood "Teza"
Traveler's palm
Niaouli (karavoho)
Eucalyptus (raboté)
Dombeya (hafotra ou l’arbre zavy)
Steel

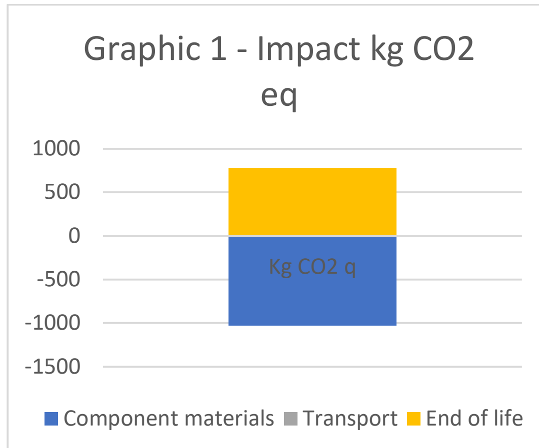
ANNEX 6 - *Carbon emissions* calculations

For some of the previous house models in other reports, the data on packaging was not available, therefore this source of emissions has been excluded from the study, in order to ensure consistency and to compare results across all the shelters projects, as previously mentioned in section 7.2.1.

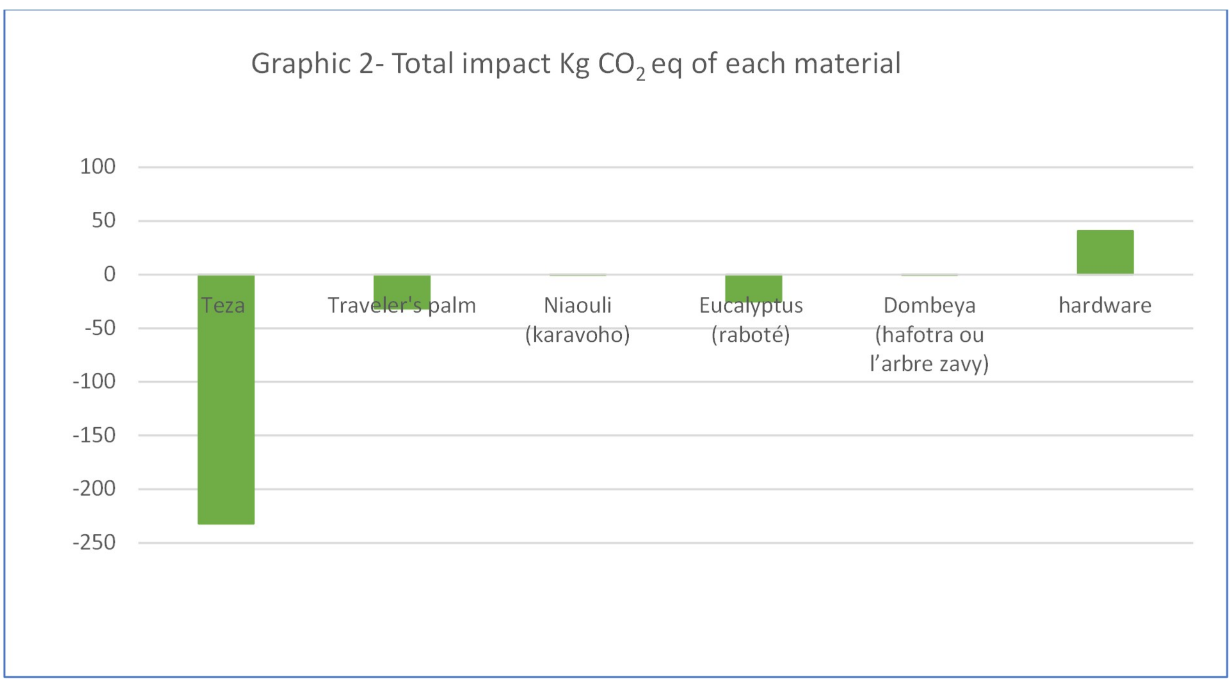
Below are the total *carbon emissions* generated by the house model, in CO_2 equivalent. This is using the SMAC calculator and taking into account all the parameters and assumptions explained in section 7.2. The follow Table 1 & and Graphic 1 show the breakdown of the *carbon emissions*, in terms of Kg CO_2 eq. of the house unit per "*life-cycle stages*": *"production of the component materials"*, *"transport"* and *"end of life"*.

Table 1

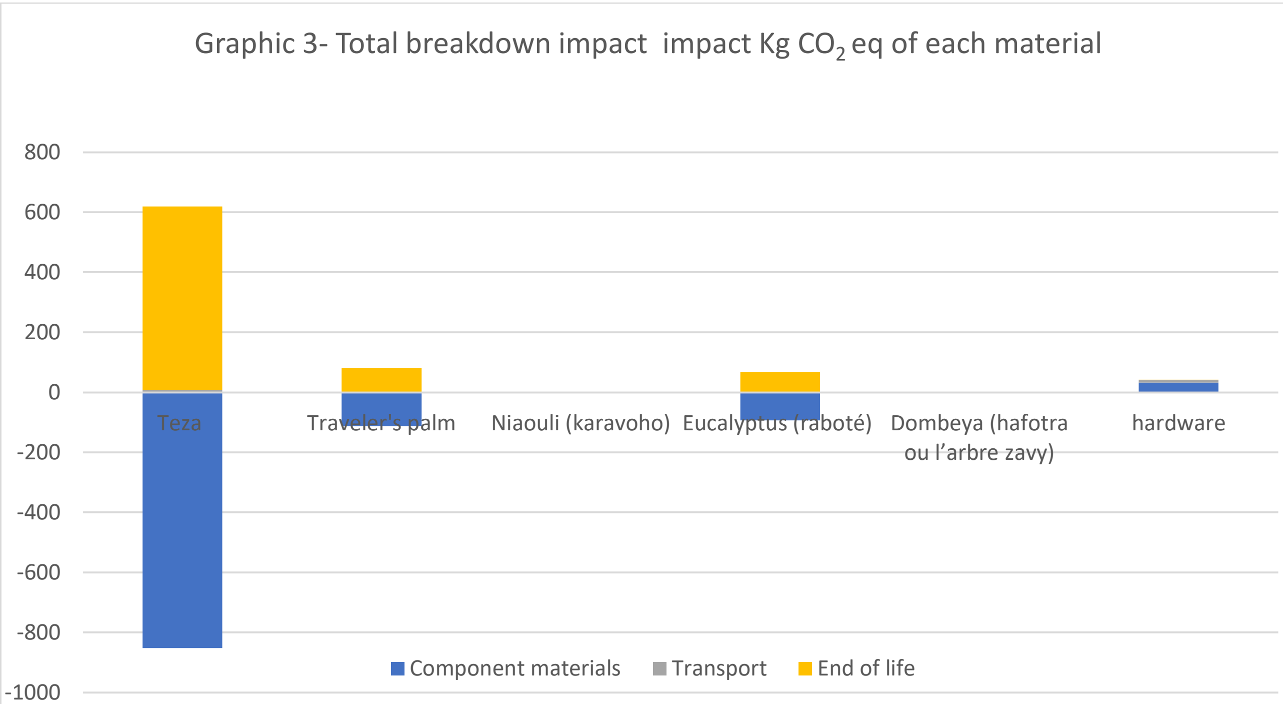
Impact	**Carbon emissions Kg CO_2 eq.**
Production of the component materials	-1025
Packaging	*Data not considered*
Transport	18
End of life	759
Total	**-248**



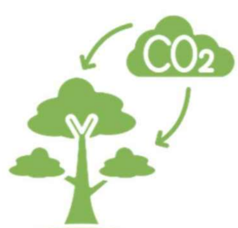
The follow Graphic 2 shows the total Kg CO_2 eq. impact of each material.



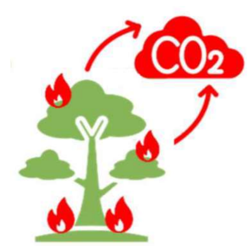
The follow Graphic 3 shows the total Kg CO_2 eq. emissions of each material, broken down into the emissions generated by "*production of the component materials*", "*transport*" and "*end of life".*



It is important to explain why there are significant carbon emissions generated from the *"end of life*" phase. This is because the SMAC tool assumes that these materials are burnt at the end of their useful life, thus releasing the carbon emissions which were sequestered in the materials. If in fact these natural materials are left to decompose, or composted, these emissions would be eliminated and therefore the overall emissions of the house model would be even lower.



Natural material "captures carbon" when they are growing



When burnt, the carbon is relisted

ANNEX 7 - *Local natural resources* used

Total amount of hardwood (teza) used in the house model

- Approximately 660 kilos in total. 360 kilos for the poles, and 300 kilos for the rafters.

Total amount of traveller’s palm used in the house model

- Approximately 87.50 kilos in total
  - 0.5 kilos as “rapaka” (traveller’s palm tronc) for the bracing
  - 7 kilos as “rapaka” (traveller’s palm tronc) for floor
  - 40 kilos as “falafa” (traveller’s palm branches) for the wall
  - 40 kilos as “ravinala” (different part of the traveller’s palm branches) for roof

Total amount of Niaouli (karavoho) in the house model

- Approximately 0.40 kilos for the slats

Total amount of Eucalyptus (raboté) used in the house model

- Approximately 72 kilos for the doors and windows panels

Total amount of Dombeya (hafotra ou l’arbre zavy) used in the house model

- Approximately 0.30 kilos to used as rope

ANNEX 8 - Protentional reuse option and recycling options

The Table 1 below examine for each of the house materials their life expectancy, how long it takes for them to decompose and if they can be reused and recycled, based on potential in other countries. It is important to note that the rate of decomposition can depend upon disposal or landfill conditions.

Table 1 – Case améliorée en bois

Material	Life expectancy[130]	Time to decompose	Reuse	Recycling
wood[131]	Between 3 to 10 years[132]	10–15 years[133]	Yes	Yes
Steel	Around 40 years	200 to 500 years	Yes	Yes

According to the field team, the steel materials are discarded once they are no longer used or reach an advanced state of deterioration.

The timber and plants, when they reach the end of their useful life, are often used as firewood, which can contribute to air pollution.

The Table 2 below examines the potential reuse and recycling options for each material. This is based on insights from interviewees, and findings from a desk review.

Table 2 - Potential options in Madagascar

Materials	Potential reuse options	Potential recycling options
Timber	• To reuse for auxiliary construction (like stable) • Combustible wood • Art objects	• Art objects
Steel	• To reuse for auxiliary construction	• Made into various functions if welding is available. Like school tables and benches
Screw	• They are not reused	• Production of carts; wheelbarrows, keys, shovels; pickaxes; hoes; machetes, chair, etc

130 *Information provided by the field team through direct observation on the field.*
131 *The time it takes for wood to decompose depends on various factors, including the type of wood, environmental conditions, and whether it is exposed to microorganisms that facilitate decomposition. In natural environments, such as forests, it can take several years to decades for wood to decompose fully. In more controlled conditions, such as composting or decomposition in landfills, the process can be accelerated, typically taking months to a few years for wood to break down. Hardwoods like oak may decompose more slowly than softwoods like pine due to differences in wood density and composition.*
132 *Depending on the weather conditions and drying before use*
133 *How Long It Takes 50 Common Items to Decompose | Stacker*

ANNEX 9 - Advantages, impacts and best practice of each material

Table 1 below shows the advantages, impacts and best practices of each material analysed in this study from an environmental point of view.

Table 1 – Advantage, mpacts and best practice of the materials

MATERIALS	ADVANTAGES	IMPACTS	BEST PRACTICES
Timber & plants	• It "captures carbon" (and other greenhouses gases) during their growth. • Doesn't take long time to decompose. • It is a renewable resource when managed well.	• "Life expectancy" is short, if not well treated. • If the material is burnt at the end of its useful life, it released a hight amount of CO_2 eq. into the atmosphere. • Growing eucalyptus in low rainfall areas may cause adverse environmental impacts due to competition for water with other species. • Extraction can lead to deforestation, landslides, soil degradation, habitat destruction, as well as risks of flooding, flash floods, droughts, and a growing cycle of difficulties. • Transporting wood can further damage forests and rural roads. • Where processing is carried out, poorly managed factories cause pollution from solid waste, noise, and air. • The use of toxic chemicals for treatment purposes poses risks to the environment and health.	• Whenever possible, avoid oversizing or specifying too many requirements. Carry out appropriate structural design and calculate wood requirements accordingly. • Minimise wood cuts. • Treat wood properly to ensure its long-term durability. There are certainly several wood treatment recipes that can vary locally depending on product availability. • Minimise the use of wood for formwork (if applicable), prefer reusable modular formwork. • Encourage wood reuse (e.g., door and window frames, structural elements). • Cuts of chemically treated wood must be considered hazardous and should never be used as firewood.
Rubble	• Local stone requires no transportation and doesn't create pollution or waste. • It is a recyclable material. • "Life expectancy" can be very long	• Unplanned rock extraction can lead to landslides and hydrogeological impacts. Without planning or protection, blasting poses occupational risks. • Transporting rocks can affect rural roads. • Extraction can leave large pits that may pose health risks. • Stone construction in earthquake-prone areas must be carried out with seismic design.	• Design and construct properly to ensure long-term durability. • Use stone only in areas where it can be extracted without causing danger or environmental impact. • Employ good storage and loading practices during transportation. • Implement measures to mitigate the negative impacts of extraction, such as erosion control, sedimentation ponds, and proper disposal of waste materials.

Steel	• Production of steel is the most energy-consuming in the world. • The production of the steel, generated a high amount of *carbon emissions*. • Long-lasting material, which take long time to decompose.	• Can be reused and recycled • “life expectancy” is relative hight.	• Procure steel from reputable suppliers who adhere to sustainable and ethical sourcing practices. Ensure that steel is not linked to illegal mining or deforestation. • Implement stringent quality control measures to verify the quality and strength of the steel used in construction, • Optimise the design to minimise the amount of steel required. • Consider alternative materials or designs that use less steel while maintaining structural integrity. • Encourage recycling and proper disposal practices.