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10 June, 2013

Sam Davies
Engineers Without Borders Australia
PO Box 708, North Melbourne

Dear Mr Davies,

Subject: Effective and Affordable Roofing for Codo, Timor Leste.

Please find enclosed the requested report for the Plan Timor Leste Engineers Without Borders (EWB) challenge through Massey University. The purpose of this report is to present a solution to the Infrastructure and Housing problem in Codo, Lautem district of Timor Leste.

The problem that was outlined in the EWB Brief was that housing was sub-standard, did not protect the occupants from the elements and was unstable in strong winds and earthquakes. Part of the problem with housing mentioned is that the roofing is sub-standard and poorly secured.

The attached solution proposes using readily available waste tyres on a bamboo frame to provide cost effective roofing that is long-lasting, strong and aesthetically pleasing.

Thank you for providing the opportunity to research this project. We hope our suggestions prove helpful to the people of Codo, Timor Leste.

Please feel free to contact us for any further information.

Yours faithfully,
Group F
(David Mountain, Akshaya Kumar, Dylan Mathar and Jordan Vickers)

Affordable Roofing in Codo

Researching affordable alternatives to current roofing methods in Codo Timor Leste

To: Engineers Without Borders
Khalid Arif

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Submitted: 10 June, 2013

EXECUTIVE SUMMARY

This report aims to inform EWB of the findings of innovative construction methods to solve housing shortages in Timor Leste.

The town of Codo in the Lautem District of East Timor suffers from wet weather conditions (strong winds and heavy rainfall) and is susceptible to one cyclone per year. Inadequate housing built by locals comprises primarily of used scrap material found in rubbish dumps and scrap piles. Current roofing materials (corrugated iron) and installation techniques compromise the functionality of houses causing leakage which leads to sickness and ill health. Also, the roofs are often blown off forcing locals to rebuild houses over and over again.

The goal was to provide a long lasting, aesthetically pleasing roofing system that is easy to construct and resistant to high winds, heavy rain and possibly earthquakes. The solution should provide roofs which are stronger and use cheap attainable materials. Research into affordable roofing materials (such as waste tyres and banana thatching) and attachment methods was conducted. The most viable solution recommends the use of recycled tyres as a roofing material installed like tiles on a bamboo trussed frame. Tools needed were a hacksaw and a drill. The bamboo frame was assembled in equilateral triangles (held together via baling twine) to distribute weight and forces evenly in each joint of the truss. The roof was designed to minimise lift during strong wind forces. The weight of the tyre roof was ~331 kg (in comparison to the commonly used ~55.8 kg corrugated iron roof). The weight will make the roof less vulnerable to be blown away by heavy winds. The method is easy to use and follow. An instruction manual was devised (attached in report) to educate the locals on roof construction techniques.

An excellent attribute is the adaptability of the tyre roof design and it's easily explained instalment. The size of houses in Codo is bound to vary. The roof design can be easily adapted to cover different size roof areas with little or no change in the bamboo orientation due the bamboo's excellent tensile strength. Bamboo is an excellent resource because it is abundant in and around Codo; it can be cultivated easily and grows extremely fast. The tyres will deflect all rain pouring at a gentle to moderate angle. If the rain becomes more horizontal during heavy wind then any rain that does seep through the tyres will be caught by a polythene sheet placed just under the tyres to allow the house to remain dry.

The materials used are a valuable feature of the solution. The use of tyres supports recycling waste. Bamboo is a naturally found resource which is quick to replace due to fast growth rate. The materials are obtainable at little or no cost. The implementation method of educating the locals to maintain and build houses will allow the people of Codo, and Timor Leste, to cater towards their housing needs.

The solution is ideal for the people of Codo suffering from wet living conditions and poor house infrastructure as it offers a long lasting and affordable roofing system that not only benefits the people but also the environment.

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1.0 INTRODUCTION

1.1 Problem Description

“Housing has been a serious problem since independence. Nearly 85,000 houses (about 70% of the nation's entire housing stock) were destroyed by the Indonesian military in September 1999” (Housing East Timor, 2013).

According to the Engineers Without Borders (EWB) design brief there is a serious skill shortage in Timor Leste. Low incomes prohibit the importation of quality construction materials and labour therefore it is desirable to have construction design that can be achieved by untrained people with simple-to-follow instructions. The importance of quality housing cannot be overstated. According to the World Health Organisation, “Housing conditions affect people’s health. Inadequate housing causes or contributes to many preventable diseases and injuries, including respiratory, nervous system and cardiovascular diseases and cancer" (World Health Organisation, 2013).

One of the biggest problems with the current houses in Codo is roofs that leak and are not structurally sound. When they have not been correctly secured or let in rain they become a health hazard and a risk of injury in heavy winds. The focus of this report is to address this problem with roofing.

1.2 Subject of Report

This report will cover the research done into affordable roofing materials and methods. It will then identify the most viable solution based on a selection criteria and outline final recommendations.

1.3 Objectives

The goal is to provide a long lasting, aesthetically pleasing roofing system that is easy to construct. The method of construction needs to be described in a manner that can be understood by unskilled labour. It needs to be able to withstand high winds, heavy rain and possibly earthquakes.

1.4 Scope

This report covers the research into and suggested method of construction of roofing only. The design brief is wide, covering many aspects of construction but it was decided to narrow the focus on an innovative construction method of roofing which could be used with any existing house design. While the report focuses specifically on the Codo located in the Lautém district, there is no reason that the recommendations suggested would not be applicable in other parts of Timor Leste, let alone the world.

1.5 Limitations

The recommendations of this report are focused on low income housing and thus it is limited to using materials that are either free or very close to it. It is also presumed that climate conditions will not change significantly, from what is currently known, in the lifespan of the roof. The proposed roof is durable but is designed to current weather conditions within accepted tolerances.

1.6 Issues Raised by Charter

The following issues were recognised during the course of the project:

- Not enough detailed information is available on the amount of waste tyres
- Information on the current size of houses is extremely limited
- Information about availability of materials and tools in Timor Leste is difficult to find

2.0 BACKGROUND

2.1 Current Roofing

The typical house in Codo is 3mx3m, has a bamboo frame and walls, and a corrugated iron sheet as a roof. Currently the iron sheets are attached using crude weighting using rocks or there is no attachment method used. These roofs are problematic as they rust, do not properly protect the houses' inhabitants from the elements and are a potential hazard during high winds. Commonly these iron sheets are picked up from rubbish dumps or are found lying around. The iron sheets are not meant for roofing purposes as they have not being painted or galvanised to prevent rusting in wet conditions.

2.2 Local Weather

Timor Leste, being an equatorial country, has a wet and dry season. There is often one cyclone per year in the wet season. Some areas experience sustained winds of around 100km/h. Figure 1 shows a graph of the Mean Annual Climate in Dili, the capital of Timor Leste. Average monthly rainfall is high as it lies between 110mm-150mm (The Centre for Australian Weather and Climate Research, 2011). However, there is limited meteorological data available specific to Codo.

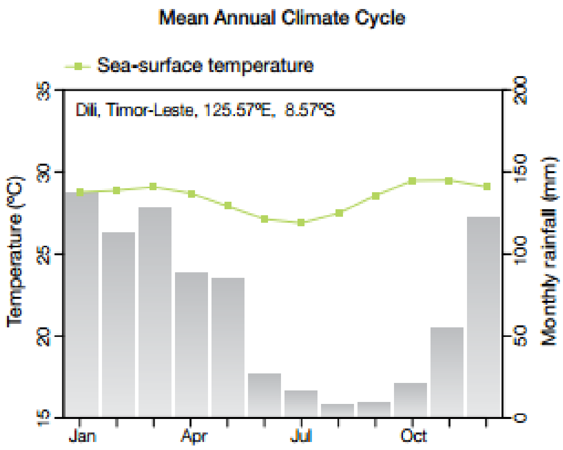


Figure 1: Mean Annual Climate Change in Dili, Timor Leste for 2011.

2.3 Waste tyre problems

Most countries in the world do not have the infrastructure required to dispose of tyres safely so resort to dumping them in either landfills or large mounds, the same is true for Timor Leste. When these large tyre dumps become too full, the tyres are set on fire leading to air pollution.

2.4 Income

As of 2010, (UN Data, 2010) the Gross National Income (GNI) per capita is US$2404. This had shown considerable increase since 2000 when the GNI was just US$389.

3.0 DISCUSSION

3.1 Generating Alternative Solutions for Roof Materials

For the construction of a roof, four materials were investigated and their advantages and disadvantages were compared (Table 1).

3.1.1 Corrugated Iron

Corrugated means folded to produce ridges and grooves. Roofs made out of corrugated iron are lightweight and portable. However, they are prone to rusting and therefore galvanised iron roofs are preferred for longer lasting roofing.

3.1.2 Concrete Tiles

Concrete tile roofs are made from sand and concrete. These tiles are heavy and durable, lasting to a minimum of 50 years. They can withstand high winds and are thus recommended as roofing material for areas prone to hurricanes. On-going costs of concrete tiles are expensive as the underlayment (material the tiles lie on) must be replaced every 10 – 20 years.

3.1.3 Waste Tyres

Waste tyres are commonly found in landfills and tyre dumps located across Timor Leste. Tyres are made of rubber reinforced with steel belts making them extremely durable. The rubber provides water resistance while the steel gives it strength. Tyre degradation can take 80 – 1000 years (www.car-storage.com, 2013). Using this material would aid in reducing running cost as waste material would be utilised.

3.1.4 Banana Leaf Thatching

Banana leaf thatching is traditionally used in Timor Leste for roofs. Banana leaf is a readily available material in Timor Leste. It is waterproof when applied at large angles, is lightweight and is aesthetically appealing. Thatched roofs are a natural insulator and this makes them an ideal roof for hot and cold climate conditions.

The advantages and disadvantages of these materials have been summarised in Table 1. A weighted scale was used in Table 2 to rank the materials based on certain criteria in order to determine the most useful material option.

Table 1:Advantages and Disadvatages of Roofing Material Options

Material Options	Advantages	Disadvantages
Corrugated Iron	• Strong • Longevity and durable • Aesthetically appealing • Resists rotting • Fire and lightening proof • Reflects heat • Does not require a frame to be supported at an angle	• Easily blown away by wind • Expensive • Noisy during rainy conditions • Requires on-going repair in wet conditions • Expands in hot weather and contracts in cold weather conditions
Concrete Tiles	• Strong • Longevity and durable • Aesthetically appealing • Fire and lightening proof • Resists rotting	• Heavy • Expensive • On-going maintenance costs • Fragile
Waste Tyres	• Strong • Longevity and durable • Cheap • Does not degrade • Readily Available	• Absorbs heat • Fire Risk
Banana Leaf Thatching	• Easy installation • Cheap • Natural Insulator • Aesthetically appealing • Can be supported by light bamboo frame • Readily Available	• Lightweight and easily blown off by wind • Fragile and Weak • Labour intensive • Fire Risk

Table 2: Weighted Scale Analysis of Materials Based on a Comparison from 1-5 (1 = least ideal)

Parameters	**Corrugated Iron**	**Concrete Tiles**	**Waste Tyres**	**Banana Leaf Thatching**
Cost	2	1	4	4
Strength	4	2	4	1
Durability	3	4	4	3
Ease of Installation	4	1	3	4
Weight	2	3	4	1
Aesthetic Appeal	2	4	2	3
Total	**17**	**15**	**21**	**16**

3.1.4 Summary of Roof Material Selection

Following the comparison between materials above, waste tyres have been selected as the choice of material to build roofs. The driver behind selection of waste tyres was its cost effectiveness, high strength and durability characteristics.

Corrugated iron and concrete tiles were not chosen due to high cost. Cost is the most significant parameter when taking into account the fact that the people of Timor Leste have very low incomes and may not be able to afford this type of roofing.

Although being very cost effective, banana leaf thatching was not chosen as the roofing material as it has low strength characteristics and is a light material. This means it will be blown away in the wet season of Timor Leste where winds reach up to 100km/h.

3.2 Alternative Solutions for Roof Frame

The tyre roof which is going to be constructed requires a frame to be supported on so the roof doesn't collapse. This frame will also help to give the roof a natural gradient.

The following materials were investigated and compared for the construction of a frame:

Table 3: Alternative Solutions for Roof Framing

Material Options	Advantages	Disadvantages
Bamboo	• Cheap • Strong • Can be grown locally • Easy to cut • Easy to replace • Environmentally renewable resource	• Rots with exposure to moisture • Can be eaten by insects • Needs to be treated to prevent the above
Other Processed Timber	• Strong • Easy to cut • Easy to replace • Aesthetically appealing • Environmentally renewable resource	• Rots with exposure to moisture • Can be eaten by insects • Needs to be treated to prevent the above • Expensive in comparison to bamboo
Steel	• Very strong	• Expensive • Heavy • Requires specialised tools • Rusts

3.2.1 Summary of Roof Frame Material Selection

Upon investigation, bamboo has been selected for the construction of the roof frames. This is due to bamboo being a strong, cheap and locally sourced material. The primary reason for not selecting timber and steel for roof frames were the associated costs which the people of Timor Leste won't be able to afford.

3.3 Benefits of Suggested Solution

3.3.1 Socio-Cultural

The implementation of the suggested solution is likely to improve the socio-cultural situation in the respective areas. The roof is likely to cost next to nothing to build and maintain as compared to a proper roof used for houses. The design will allow everyone in the area to live under the same quality of roof, so everyone may live in equal comfort, at least in respect to shelter from rain and hot sun. There will be less opportunity to discriminate one other based on housing conditions. As a result there may be a reduction in criminal activity such as stealing and violence which is sparked by jealousy and inequality.

With the increase in functionality and visual appeal of their residences, the individuals and community as a whole are likely to obtain a higher level of self-worth.

3.3.2 Environmental

There are several environmental benefits that come with the solution. The roofing requires plenty of tyres for construction. Without this solution, the vast majority of tyres would be sent to tyre dumps and be burned. Therefore fewer tyres will be burned and this results in a decrease in air pollution. Instead these waste tyres will be used to help build a waterproof roof.

Research (College of Tropical Agriculture and Human Resources, 2007) suggests that there is an abundance of usable bamboo throughout Timor Leste. So the use of bamboo in construction project should not have a significant effect on the environment or wildlife habitat. However if there is objection to the continued use of natural bamboo then bamboo could be grown, this option is plausible due to the high growth rate of bamboo.

The only aspect of the solution that will add to the pollution is the transportation of tyres and bamboo via necessary vehicle.

3.3.3 Economically

The overall cost of housing will be reduced. This will mean that locals be able to spend more money on other essential items.

This may create jobs for some as people will now be able to afford roof construction costs (the less able could afford to pay the more able for house construction). However because the installation of this solution is designed to be as cheap as possible to build and maintain, creating jobs is not one of the objectives.

There is potential for the solution to take jobs as less tyres move to the dump. However it is unlikely as a combination of circumstances is likely to prevent it. Firstly, there are more than enough tyres to continue tyre disposal jobs even when so many are used in construction. Secondly, the disposal jobs are not taken away but rather change to tyre delivery as workers move tyres to construction sites.

3.3.4 Health & Wellbeing

The health and wellbeing implications could be greatly improved. In its current state, roofing is largely inadequate and therefore responsible for leaks that contribute to wet or damp and cold housing. Wet and cold housing conditions create and ideal environment for sickness in humans and uncomfortable living.

Installation of the new and improved roofing will reduce such conditions resulting in a safe, comfortable living space.

Initially there was suspicion that tyres will contaminate rainwater once contact has been made with the roof. However research has indicated the tyres to be sufficiently non-reactive with water or sunshine to produce harmful chemicals.

Tyre and bamboo roofs are heavier and can be secured better than the pre-existing simple corrugated iron sheets held down by rocks. This makes it less probable for people to be injured during storms and heavy winds.

3.3.5 Sustainability

Sustainability of the proposed solution serves as one of its biggest strengths. Longevity of the tyres suggests tyre replacement will not be required for a considerable span of time after the initial build. The high accessibility of tyres is beneficial at time of replacement. Bamboo is also a long-lasting and easily replaced material.

Upon initial completion of the project, EWB supervision is not necessary in the reproduction of roofs and growth of the solution. The solution is simple and ensures that the locals are provided with the skills and connections necessary to share the solution amongst the rest of the communities and future generations.

3.4 Availability of Materials

3.4.1 Waste Tyres

Finding information on the availability of used tyres in Timor Leste has proved to be very difficult and many fruitless hours of searching yielded little information. Research revealed a UN document outlining Timor Leste's national imports and exports. Further searches discovered at least two separate tyre dealers operating in Dili.

The quoted information on the amount of tyre imports was $700,000 per annum. If this was compared to an average tyre cost of say $85 we could say there were 8,235 tyres being imported per year. This would also imply 8,235 tyres being removed from cars and dumped each year.

A possible check on these figures would involve comparison with car ownership. The Timor Leste Ministry of Finance lists the amount of registered passenger cars as 3160. (Timor Leste Ministry of Finance, 2010). Replacing 4 tyres (on average) once every 2 years would give us a figure of 6320 tyres per year, not including truck or motorcycle tyres.

This estimate gives a figure that is accurate enough to establish a tyre supply that can support the demand we will place on it. If tyre supply was unable to meet demand, tyres could be sourced from other parts of the world where they are disposed of. It would hardly be a tragedy if every waste tyre was re-used in this manner leaving nothing for landfill.

3.4.2 Bamboo

There are several species of bamboo native to Timor Leste. It was difficult to find information on some of the species, such as *Bambusa Lako* - a beautiful species of black bamboo, but data on one of the dominant species *Dendrocalamus Asper* was readily available (College of Tropical Agriculture and Human Resources, 2007).

All bamboo that has been tested has exceptional properties of compressive and tensile strength. (International Network for Bamboo and Rattan, 1995). Owing to the readily availability of information, *Dendrocalamus Asper* it is the material of choice. This being said, other species are probably safe to use but are outside the scope of this report due to lack of information on their performance.

3.5 Tyre Degradation

Dry rot is the term used for the most significant causes of tyre degradation. Tyres will not biodegrade as they are made of vulcanized rubber.

Vulcanized rubber is susceptible to the environment. Tyres are damaged by UV exposure, oxygen and ozone. The solution requires tyres to act as roofing tiles and to block UV rays. Unless the waste tyres are under shade, they will be exposed to UV rays during daytime. The tyres will also be in contact with oxygen and ozone constantly.
"A severely dry rotted tyre will fade from black to grey and exhibit deep cracks throughout the sidewall" (www.car-storage.com, 2013) - Deep cracks in the tyre could compromise the functionality of our roofing. Deep cracks could render the roof non-waterproof. Throughout the article the part of the tyres the roof is made of, the tread, is not explicitly mentioned. However, because the tread and sidewall are made from the same rubber, it is safe to assume that the tread will also eventually

degrade enough to compromise the design. Even with the steel lining supporting the tread section. It is though, likely to take longer than the sidewall.

Tyre degradation is a slow process; exact periods of time needed to fully degrade seem hard to define, research finds there are varying estimates from 80-1000 years depending on environment. Even with harsh exposure to UV rays in Codo the tyre roof is likely to remain an excellent tile substitute for at least 50 years.

Overall, the pros of the tyre materials will still outweigh the cons in degradation because an individual waste tyre is easily replaced by another one.

3.6 Selected Design and Justification

3.6.1 Frame Design

The suggested design uses a bamboo truss roof frame covered with bamboo purlins. This layer is covered with second layer of bamboo protected by polythene with the recycled tyres laid horizontally.

3.6.1.1 Tying Joints

Every joint mentioned is tied with Donaghys' Top Knot 500 Baler Twine bailing twine, as shown in Figure 2. Care is taken to make sure at least 4 complete wraps of the joint, followed by 3 complete circles between the pieces, tighten the joint (all this uses about 3 meters of twine). The knot is then tied using a simple overhand knot modified by simply turning the free end through the knot 4 times before tightening. This creates extra friction ensuring that the knot will not work its way loose.

Top Knot 500 Baler Twine has minimum knot strength of 226kg and with 3 complete wraps around the joints should provide a minimum breaking strain of 2712kg.

Figure 2: Cross Joint used to tie two bamboo sticks together using polythene.

3.6.1.2 General Method of Joints

All joints requiring end-to-end or end-to-side fixing are drilled, tied and bound to prevent splitting under load (Figure 3 & 4). Cross joints don't need to be drilled as they can simply be bound followed by wrapping between the join and tightening. This tensions the twine creating a much tighter join (Figure 3 & 4).

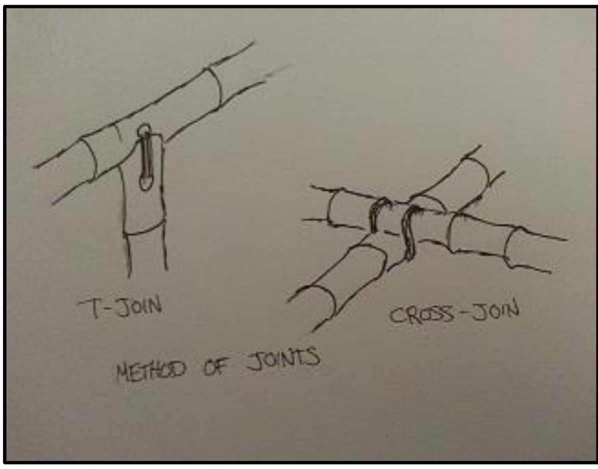


Figure 3: Tying Cross and T Joints

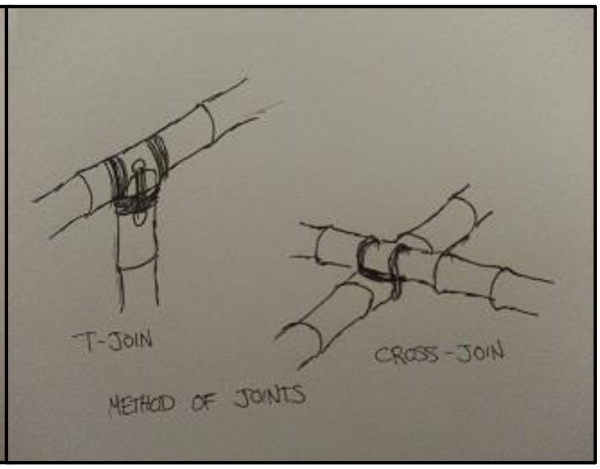


Figure 4: Binding Cross and T Joints

3.6.1.3 Trusses

The roof structure is assembled by creating a truss frame with cross members. The angle of the top rafter is easily calculated because the height and width are the same. This angle helps assure the run-off from the roof is directed out of the house. The roof angle has been tested to as low as 30° however this is not recommended.

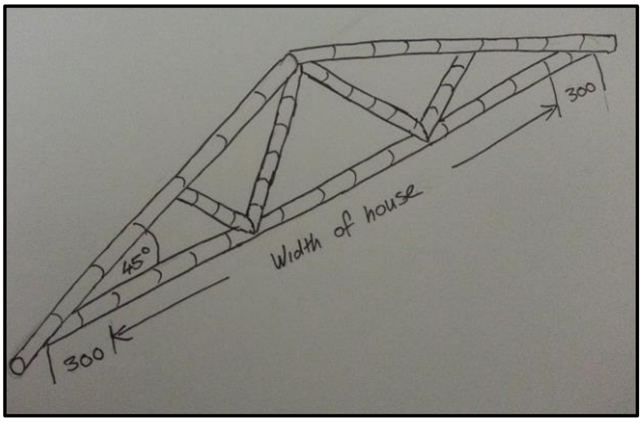


Figure 5: Truss Design for Roof Purlin Support

The length of the bottom chord of the truss is the width of the house it is intended to cover plus at least 300mm overhang on each side. The height of the truss is half the width ensuring the 45° angle. The top chords of the truss are easily measured as the distance between the end of the bottom chords and the uprights. Enough trusses are made to cover the length of the house every 600mm.

Starting with the apex of the truss, both ends are cut on a 45° angle just before a node and then drilled behind the node, tied, and bound (refer Figure 6).

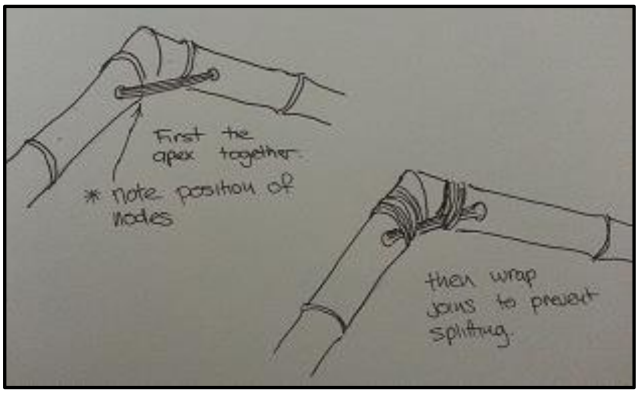
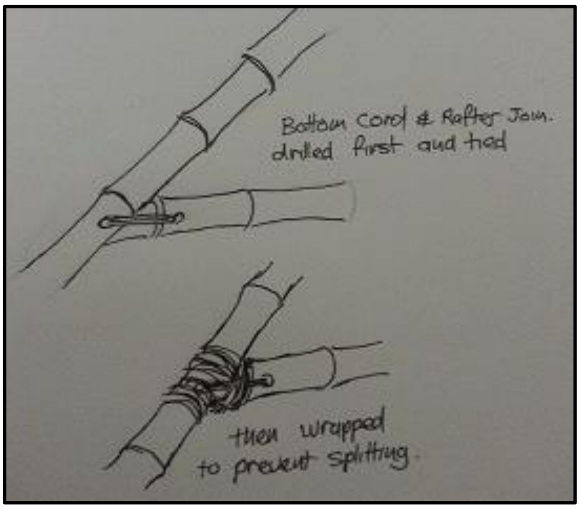


Figure 6: Tying Top Chords at Apex

Following the joining of the apex, the bottom chord is attached at both ends (Figure 7) again cutting the bottom chord on a 45° angle just before a node, and drilling the top of the truss before a node too. These joins are then tied and bound.



The webs are measured from the apex of the truss to 1/3 of the way in from both sides. These are cut as close as possible to a node, drilled and tied to both the apex and the bottom chord (refer Figures 8 and 9).

Figure 7: Tying Bottom Chord

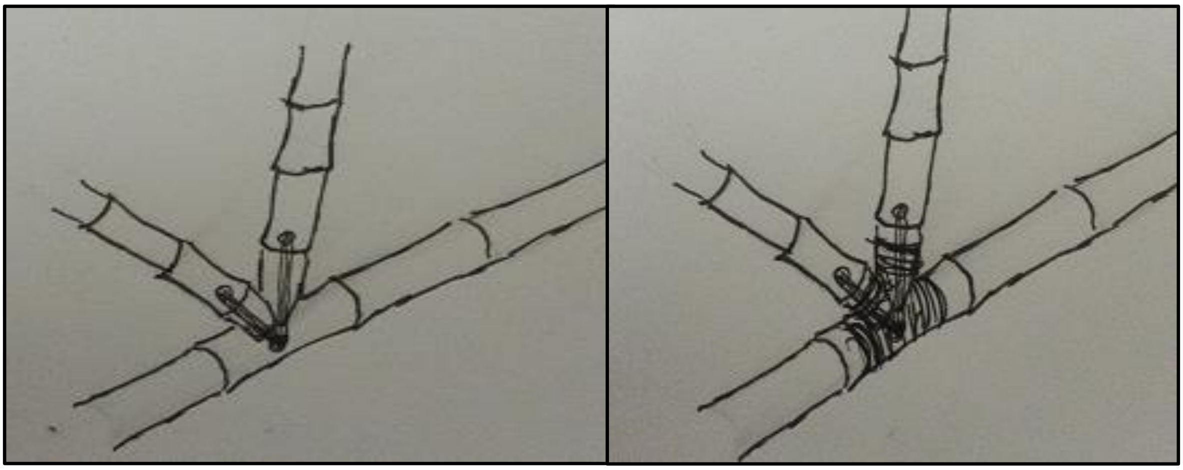


Figure 8: Tying and Binding Webs to Bottom Chord

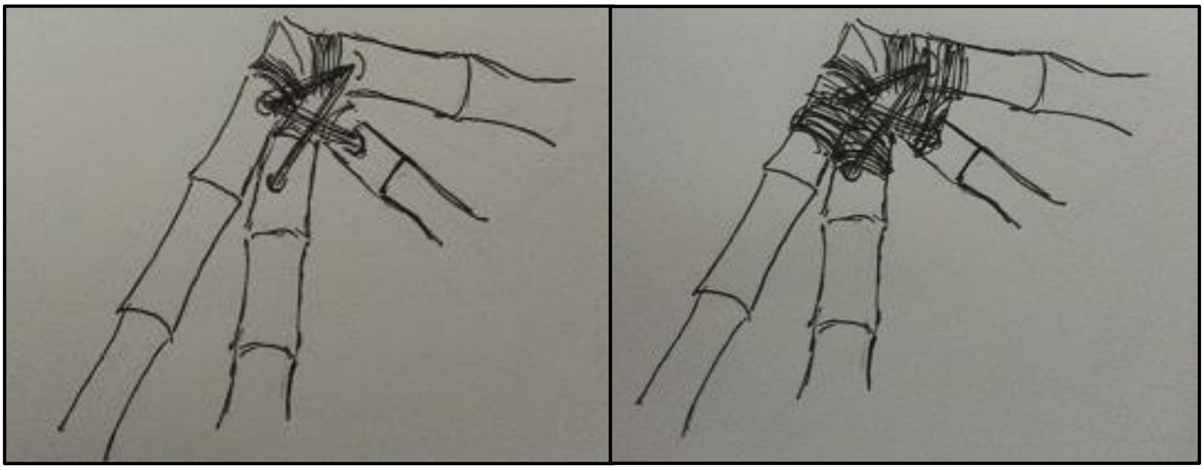


Figure 9: Tying Apex

Finally the outside webs are measured and tied into place from the junction of the inside web and the bottom chord to the middle of the outside web (Figure 10).

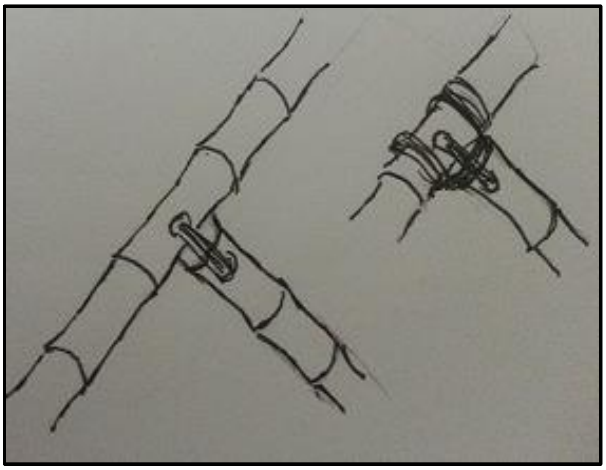


Figure 10: Tying and Binding Web to Top Chord

3.6.1.4 Purlins

The trusses are stood on the wall frames and braced in place ready for the purlins to be placed on top. Purlins are then placed across the trusses at least every 600mm but evenly spaced between the bottom of the roof and the ridge. The ends over run the trusses by at least 600mm on each end of the roof. This over run shelters the walls underneath.

This pattern is repeated on both sides of the roof being tied at each join as mentioned.

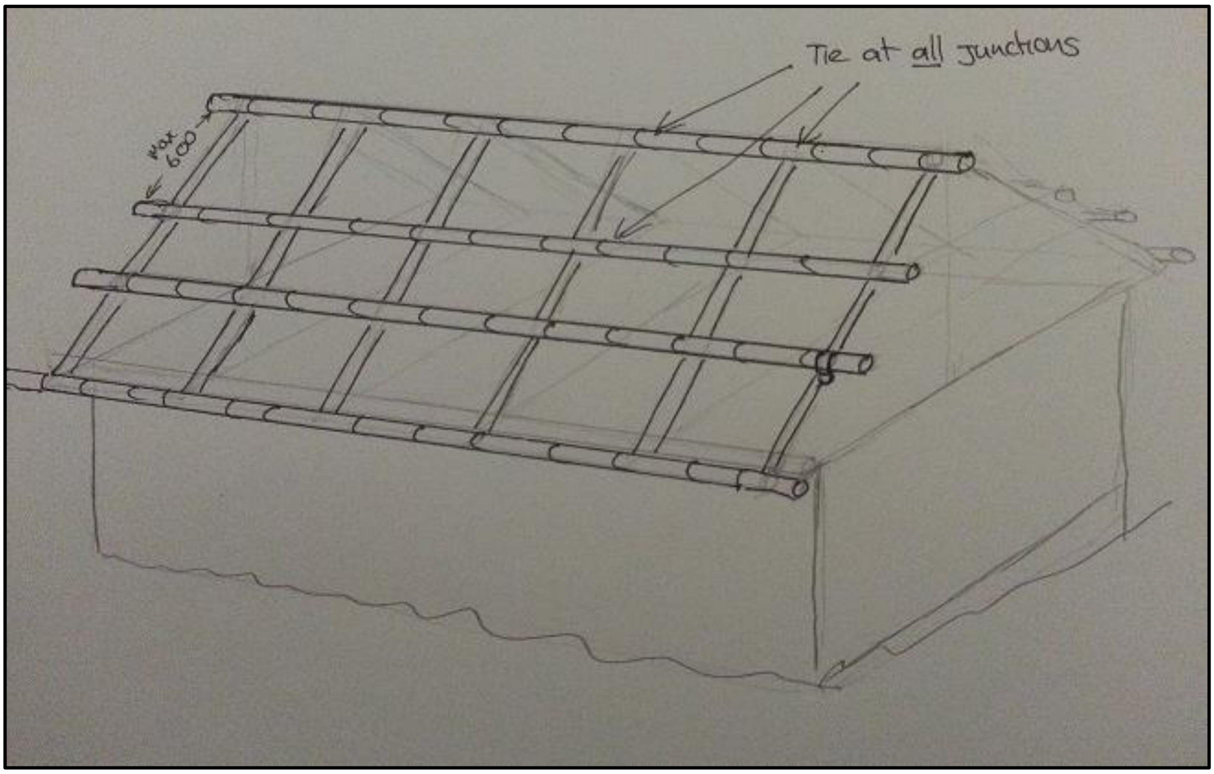


Figure 11: Purlin Layout over Trusses

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3.6.1.5 Over-Purlins

Over the top of these purlins the final layer of bamboo is laid. This can be significantly smaller in diameter than the trusses and purlins as it is there only to fix the tyres to and hold the polythene in a pattern that allows clear draining.

These over-purlins are laid again, perpendicular to the purlins and at 300mm centres. This gives regular fixings for the tyres.

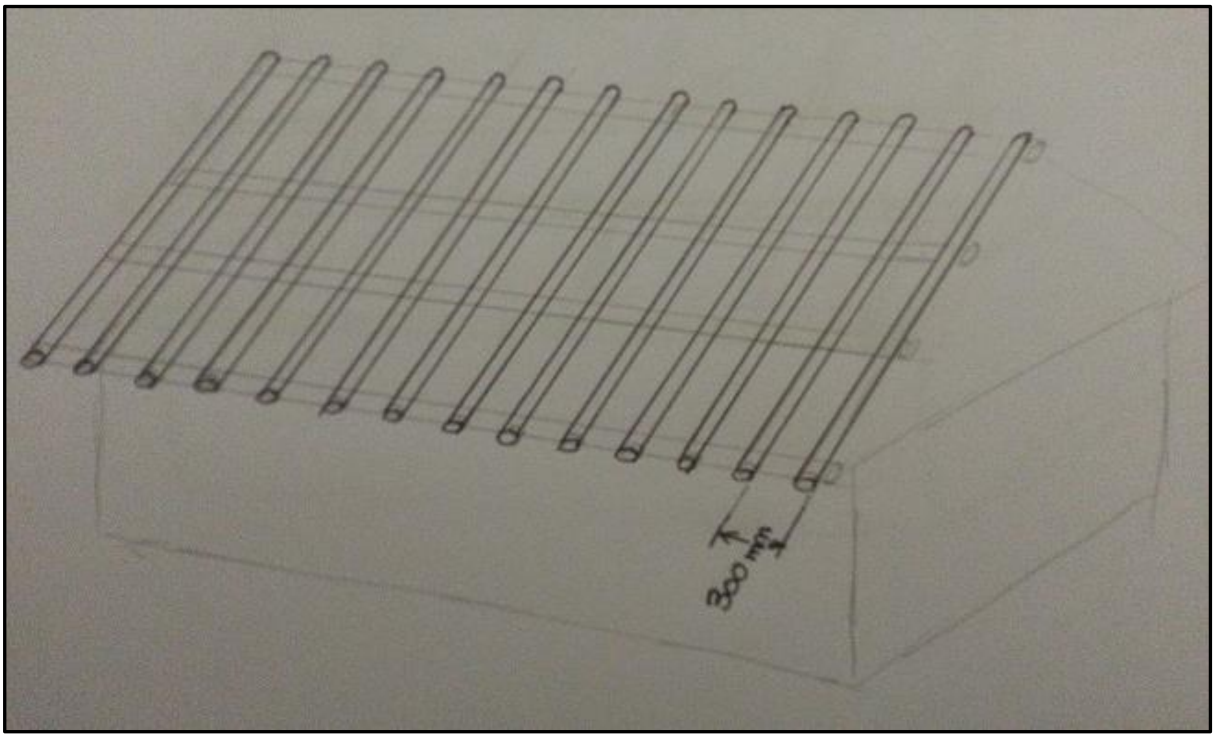


Figure 12: Over-Purlins laid over Purlins

3.6.1.6 Polythene

The entire roof is now covered in a layer of polythene. This functions as a final barrier to prevent water ingress. Polythene on its own would quickly degrade in UV light and strong wind would tear it, but protected from the mentioned elements should make it last many years. It can be stapled in place until the tyres are attached. This forms the final fixing layer.

3.6.2 Tyre Disassembly and Attachment

3.6.2.1 Disassembly

In order to disassemble the tyre into a usable form it is easiest to catch them at their source. Tyre retailers and fitters usually have to pay to dispose of their used tyres therefore it's often easy to convince them to do some of the work for you.

As much as possible try and source similar sized tyres. It is possible to work with multiple size tyres but for uniformity and consistency similar tyres work best. As the tyres are on the machine anyway it is easy to simply cut the walls out of the tyre with a Stanley knife while the tyre rotates on the machine.

Figure 13: Tyre Disassembly: Cutting walls of a tyre (left), Cutting tread of tyre (right)

In the event that tyres can only be sourced whole it is still very easy to simply cut around the edge with a Stanley knife as close as possible to the tread while taking care to get an even cut (Figure 13, left). Most used car tyres are steel belted radials which have a wire mesh running through the tread area. This area is difficult to cut through but can be achieved with a little effort with a hacksaw or with ease with a hand held grinder with a steel cutting blade (Figure 13, right).

What remains can quite easily be laid flat on the ground. There will be some kinks in the tyre owing to its previous curvature but these can be aligned with the over-purlins.

3.6.2.2 Attachment of waste tyres to roof

Once the tyres are disassembled the treads are attached to the roof. It is important that they be attached with galvanised pan-head 35mm – 45mm 10G screws (depending on tread thickness to screw through). It is imperative that holes be pre-drilled with a 3.5 mm drill bit as bamboo splits easily which almost completely negates the holding power of the screws.

Figure 14: Attaching Tyres to Over-Purlins

Starting at the bottom, a complete row of tyres is attached overlapping the treads 100mm at joins. It is ensured that the joins end up in a trough between over-purlins; this prevents the next layer having a big gap every time it encounters a join from the layer beneath (Figure 14, polythene left out to assess possible leakage).

Once the first layer has been laid, the second layer is placed on top in a similar fashion overlapping approximately 40mm onto the layer underneath. A line can be made using a chalk-line to ensure the layers don't start rising unevenly at one end or the other.

Once the top is reached and all sides have been covered, the ridge can be covered in a similar fashion.

Figure: 15 Completed roof constructed from bamboo frame and tyres. Top view (top). View from under roof (bottom).

3.7 Alternative Methods of Construction/Concepts

Prior to the construction of the final tyre roof solution, many other methods were tested.

Figure 16: Curved Roof Testing

For the layout of the tyres on the roof, tyres were cut in half and the natural curve of the tyres was used to try and create a dome shaped roof. The tyres had a natural curve due to the steel wires bending the rubber to a circular shape. The tyres were attached together using steel wire, demonstrated in Figure 16. The tyres successfully held together but water leaked through due to many gaps being present where the tyres overlapped. This was a result of irregularity in cutting the tyres. This method was not improved on due to the difficulty associated in cutting each tyre perfectly using a Stanley knife.

As a result, weatherboard layout of tyres was investigated along with alternative options of holding the tyres together.

Figure 17: Tyres stitched together lengthwise

Firstly, steel wire was used to "stitch" the tyres together. Holes were made using a nail and the steel wire was tightly weaved in and out, as show in Figure 17. This method held the tyres together but water leaked in between the tyres due to the seal not being tight enough.

Figure 18: Testing for water ingress

Secondly, nails were used instead of steel wire to hold the tyres together. This method held the tyres together however, the seal was not strong enough to prevent leakage. Figure 18 demonstrates the tyres joined via nails.

3.8 Ethical Considerations

This project gives primary importance to every resident of Timor Leste being entitled to a safe, waterproof roof regardless of their socio-economic standing. Care has been taken to minimize risk and avoid any negative impact to the people involved in the project to promote their safety and wellbeing. An emergency protocol procedure shall be in place in case of injuries during the construction of the solution. Appropriate materials will be selected for the project solution to protect the environment and prevent abuse of natural resources. The final engineered solution will only be implemented in Timor Leste following permission and consent of the locals.

3.9 Cost and Affordability

The cost of a tyre roof can be split up into 3 categories which are materials, tools, and labour:

3.9.1 Materials

Material costs include purchasing of twine, waste tyres, bamboo, screws and polythene. Waste tyres are assumed to be free as they would otherwise cost to be taken to a dump from a tyre shop. Bamboo is locally grown therefore also assumed to have minimal cost. Any cost involved consists of twine, screws and polythene.

3.9.2 Tools

A re-chargeable hand drill and hacksaw are the only tools required to make the roofs and involve a cost of approximately NZ$150.00. This is a start-up cost; the drill and hacksaw can be re used to construct more than one roof. On-going running costs include electricity to re-charge the tools and are estimated at NZ$1.00 per roof. This category includes accidental breakages.

3.9.3 Labour

Start-up labour cost is estimated at NZ$20.00. This involves teaching volunteer workers roof construction methods. Running costs are also expected to be minimal (if not nil) an instruction manual (Refer Appendix A) will provide step by step methods for all processes involved in roof production.

3.9.4 Summary of Costs

Table 4: Summary of Costs

Area	Start Up Cost(NZ$)	Running Cost (NZ$) (per house)
Materials	0.00	50.00
Tools	150.00	1.00
Labour	20.00	0.00
Total	**$170.0**	**$51.00**

The cost per house, excluding start-up costs, is estimated at NZ$51.00.

3.9.5 Affordability

The tyre roof is affordable as it costs 1.7% of the average person's annual income in Timor Leste (approximately NZ$3000). If the start-up cost is split by the Codo community (20 families) the total cost (start-up and running cost) per tyre roof will be 2% of the average person's annual income. Thus the tyre roof solution is low and affordable.

3.9.6 Weight Calculation

The weight of a tyre roof will vary from roof to roof. This is due to some materials varying in weight. Different sizes and amount of tyres will be used depending on availability in Timor Leste and thus no fixed weight of a tyre can be provided.

Table 5: Roof Weight Calculations

Material	Weight of 1 item (kg)	Amount needed	Weight (kg)
Waste Tyres (20 inches)	2.96	56	166
Bamboo	400kg/m^3	139 metres	157
Screws	0.0097	236	2.3
Twine	-	325 metres	2
Polythene	.28	13metres^(2)	3.6
Total			331

Thus for calculations, weight of a 20 inch tyre has been used. Bamboo does not have a fixed diameter and grows in varying size and thus weight of bamboo also varies. For calculations, weight of bamboo has been approximated. In Timor Leste, bamboo might weigh more or less and thus weight of bamboo again will vary from roof to roof.

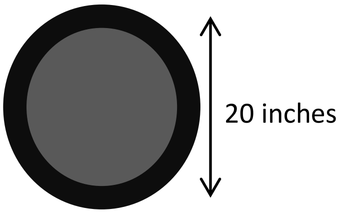
The approximated weight of a 3m by 3m tyre roof is calculated to be 331 kg.

The weight of the tyre roof is greater than the weight of a 3mx3m corrugated iron roof at 55.8 kg. This will result in the roof being more stable and sturdy in high wind conditions of Timor Leste as it will be harder to blow away by the wind. The tyre roof despite being heavy will still be able to be supported on current houses in Codo as the walls of the houses are made of stone, bamboo or mud and the roof constructed is designed to sit on top and so the weight is distributed evenly.

3.9.7 Cost - Supporting Calculations

A. Amount of tyres needed per house

Using 20 inch tyres as a standard size for calculations for a 3mx3m house:



20 inches = 0.508metres. Radius (r) = .254metres
Tyre shape is assumed to be same a Circle.

Circumference = $2\pi(0.254)$
= 1.6m

Overlapping of tyres onto each other during assembly (length and width) = 0.04m

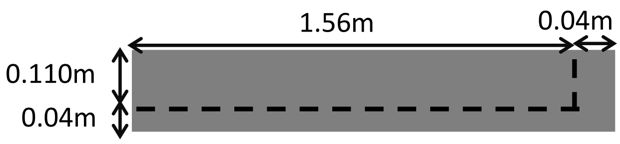
Circumference/Length of a tyre = 1.6m
Useable length = 1.6m-0.04m
= 1.56m

Amount of tyres required lengthwise = 3.0m/1.56m
= 1.92
= 2

Width of a tyre = 0.150m
Useable Width = 0.150 – 0.04m
= 0.110m

Amount of tyres required width wise = 3.0m/0.110m
= 27.27
= 28

Total tyres required = 2x 28
= 56



In total, 56, 20inch tyres are required for a 3mx3m house.

B. Cost of Materials

Table 6: Calculations for Costs

Lenght (Meters)	3		
	Number	**Meters of Bamboo**	**Number of Joins**
Trusses	5	55	8
Purlins	8	24	40
OverPurlins	14	60	114
Totals		139	162
		Cost	**Total Cost**
Twine (Meters)	325		39
Tyres (Average Tyre)	41		Zero (Waste)
Screws (For Tyres)	236		7
Polythene (M^2)	13		4
		Total	50

4.0 CONCLUSIONS

- The bamboo framed tyre roof is the best solution to the stated problem because it makes use of local materials, waste products, is easily assembled and strong.

- The method outlined in this report can provide quality, long-lasting roofing to the people of Codo once final testing is complete.

5.0 RECOMMENDATIONS

Resource constraints meant that our prototype was not completed to the specifications of our final solution. Further prototyping of the design is thus required. We suggest the following changes:

1. Build another prototype to specification.
2. Conduct weather testing to assess water ingress to investigate further modifications.
3. Modify the design if necessary.
4. Display prototype in Codo to get locals interested in the concept and relevant feedback
5. Offer training to locals for roof construction.
6. Upon completion of training, the solution can be implemented by the people of Codo to build their own houses. The roof building concept can also serve as a possible business idea to build roofs for others.

5.1 Implementation

To implement this solution EWB must educate the villagers by means of tutorial sessions and the distribution of an instruction manual (Appendix A). The educating process will include required materials, construction techniques and any necessary tools. The following steps should be taken as part of this procedure:

- Gather locals willing to participate, especially those skilled in construction or labour.
- Brief the participants on the method of construction.
- Run a demonstration and workshop on skills such as tying joins and securing the tyres to the frame.
- Run tutorials on maintenance and repair of roofing.

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8.0 APPENDIX

A. Instruction Manual

Assembly of a Tyre Roof

Instruction Manual

1.0 Equipment Required

A. Materials required:

- 56, 20 inch Waste Tyres
- 139 Metres of Bamboo
- 236 galvanised pan-head 35mm – 45mm 10G screws
- 325 metres of Donaghys' Top Knot 500 Baler Twine baling twine
- 13metres squared Polythene

B. Tools Required:

- 1 x Electric Drill
- 1 x Hacksaw
- 1 x Stanley Knife

Note:

1. Try and source similar sized tyres. It is possible to work with multiple size tyres but for uniformity and consistency similar tyres work best. This manual approximates building the tyre roof with 56, 20inch tyres for a 3x3 metre house.

2. Use a Stanley knife to cut the walls of the tyre out and use the hacksaw to cut the tread of the tyre before starting construction. This ensures all waste tyre materials are ready for construction.

3. Cut bamboo to required lengths using the hacksaw before starting construction.

2.0 Disassembly of Waste Tyres

1) In the event that tyres can only be sourced whole, it is still very easy to simply cut around the edge with a Stanley knife as close as possible to the tread while taking care to get an even cut (Figure 1).

Figure 1: Cutting walls of a tyre

Figure 2: Cutting tread of tyre

2) Most used car tyres are steel belted radials which have a wire mesh running through the tread area. This area is difficult to cut through but can be achieved with a little effort with a hacksaw or with ease with a hand held grinder with a steel cutting blade as shown in Figure 2.

3.0 Tying Joints and General Method of Joints

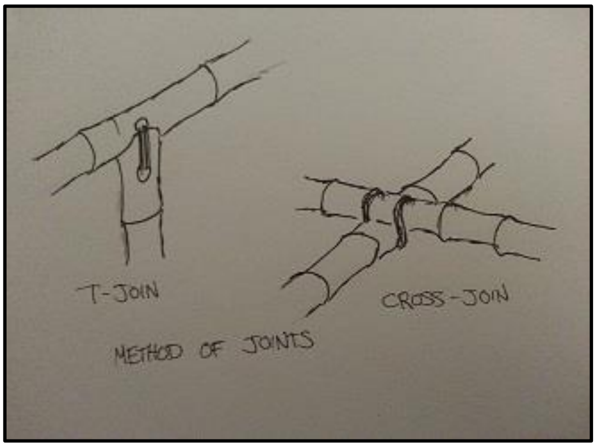
- Every joint mentioned should be tied with Donaghys' Top Knot 500 Baler Twine bailing twine as in Figure 3.

- Care should be taken to make sure there are at least 4 complete wraps of the joint followed by 3 complete circles between the pieces to tighten the joint (all this uses about 3 meters of twine).

- The knot is then tied using a simple overhand knot modified by simply turning the free end through the knot 4 times before tightening. This creates extra friction ensuring that the knot will not work its way loose.

Figure 3: Cross Joint

- All joints requiring end-to-end or end-to-side fixing should be drilled and tied and then bound to prevent splitting under load (Figure 3 & 4). Cross joints don't need to be drilled they can simply be bound followed by wrapping between the join and tightening.



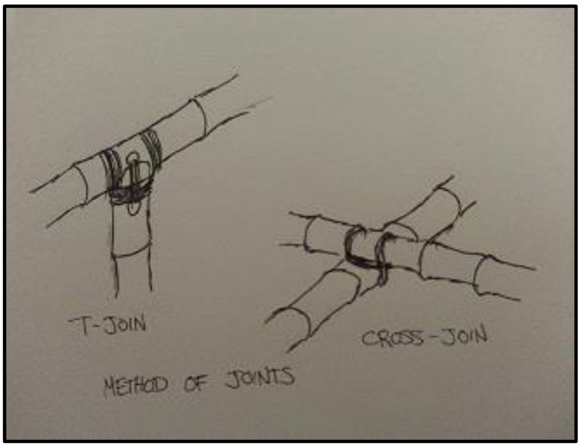


Figure 4: Tying Cross and T Joints

Figure 5: Binding Cross and T Joints

4.0 Assembly of Roof Structure

The Roof structure should be assembled by creating truss frame with cross members. This angle of the top rafter is easily calculated because it is the same height as its width.

1. The bottom chord of the truss should be the width of the house it is intended to cover plus at least 300mm overhang on each side.

2. The height of the truss should be half the width ensuring the 45 degree angle. The top chords of the truss are then easily measured as the distance between the end of the bottom chords and the uprights.

3. Enough trusses should be made to cover the length of the house every 600mm

4. Starting with the apex of the truss, both ends should be cut on a 45 degree angle just before a node and then drilled behind the node, tied, and bound – See Figure 6.

5. Following the joining of the apex, the bottom chord should be attached at both ends as in figure 7 again cutting the bottom chord on a 45 degree angle just before a node, and drilling the top of the truss before a node too. These joins are then tied and bound.

6. The webs should be measured from the apex of the truss to 1/3 of the way in from both sides. These are cut as close as possible to a node, drilled and tied to both the apex and the bottom chord. Note Figures 8,9,10, and 11.

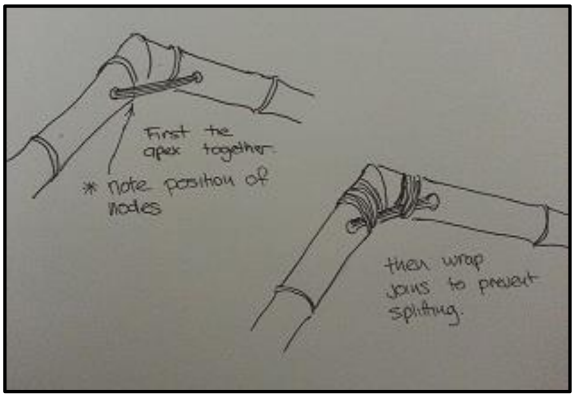


Figure 6: Truss Design for Roof Purlin Support

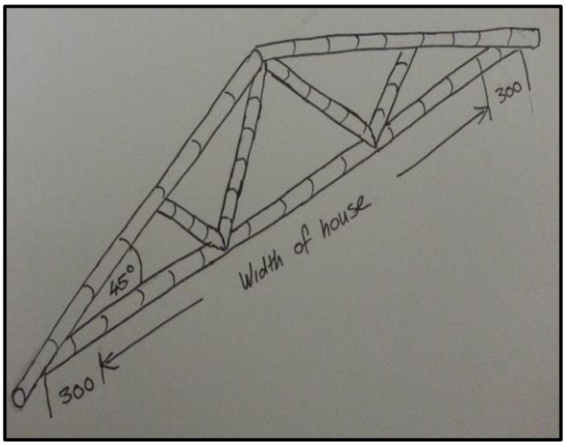


Figure 7: Tying Top Chords at Apex

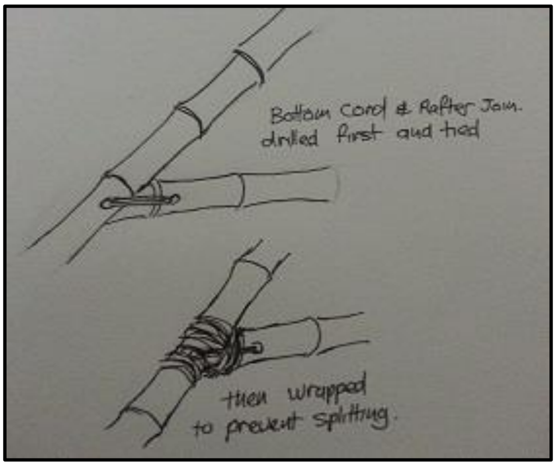


Figure 8: Tying Bottom Chord to Top Chord

7. Finally measure and tie the outside webs into place from the junction of the inside web and the bottom chord to the middle of the outside web (Figure 12).

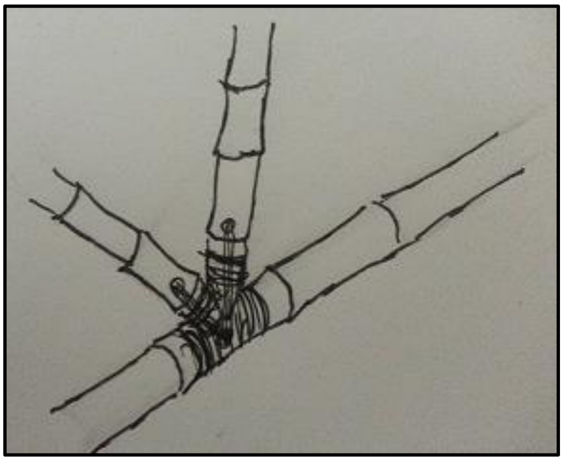


Figure 9: Tying Webs to Bottom Chord

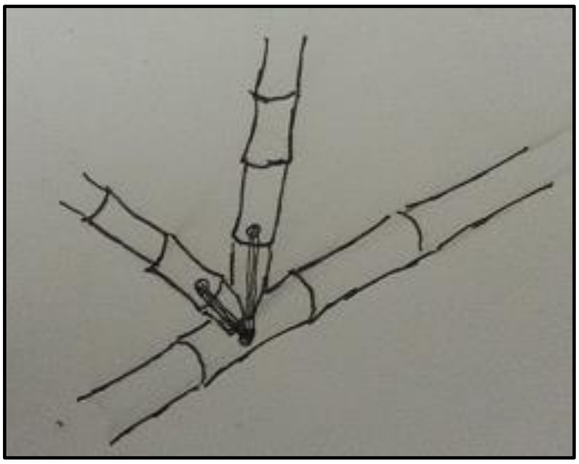


Figure 10: Tying Webs to Bottom Chord

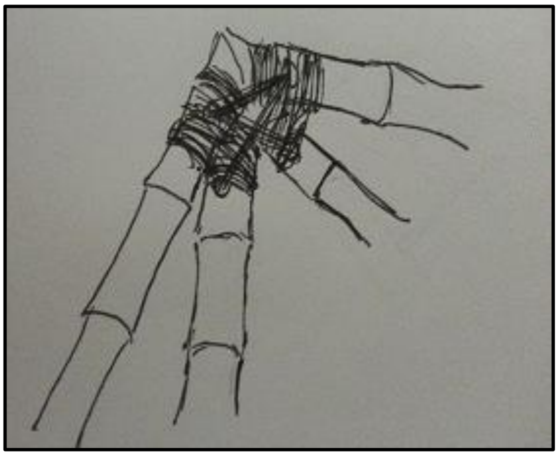


Figure 11: Binding Webs to Apex

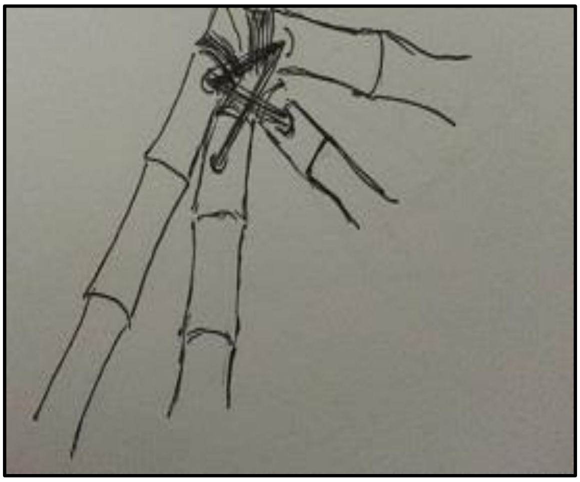


Figure 12: Tying Webs to Apex

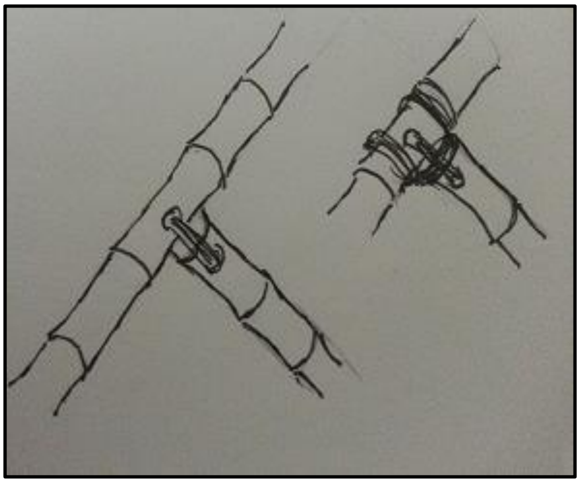


Figure 13: Tying and Binding Web to Top Chord

5.0 Assembly of Purlins and Polythene

1. The trusses should stand on the wall frames and should be braced in place ready for the purlins to be placed on top.

2. Place the purlins across the trusses at least every 600mm but evenly spaced between the bottom of the roof and the ridge. Over run the ends of the trusses by at least 600mm on each end of the roof (this over run shelters the walls underneath).

3. Repeat this pattern on both sides of the roof and tie at each joint as shown below in Figure 14.

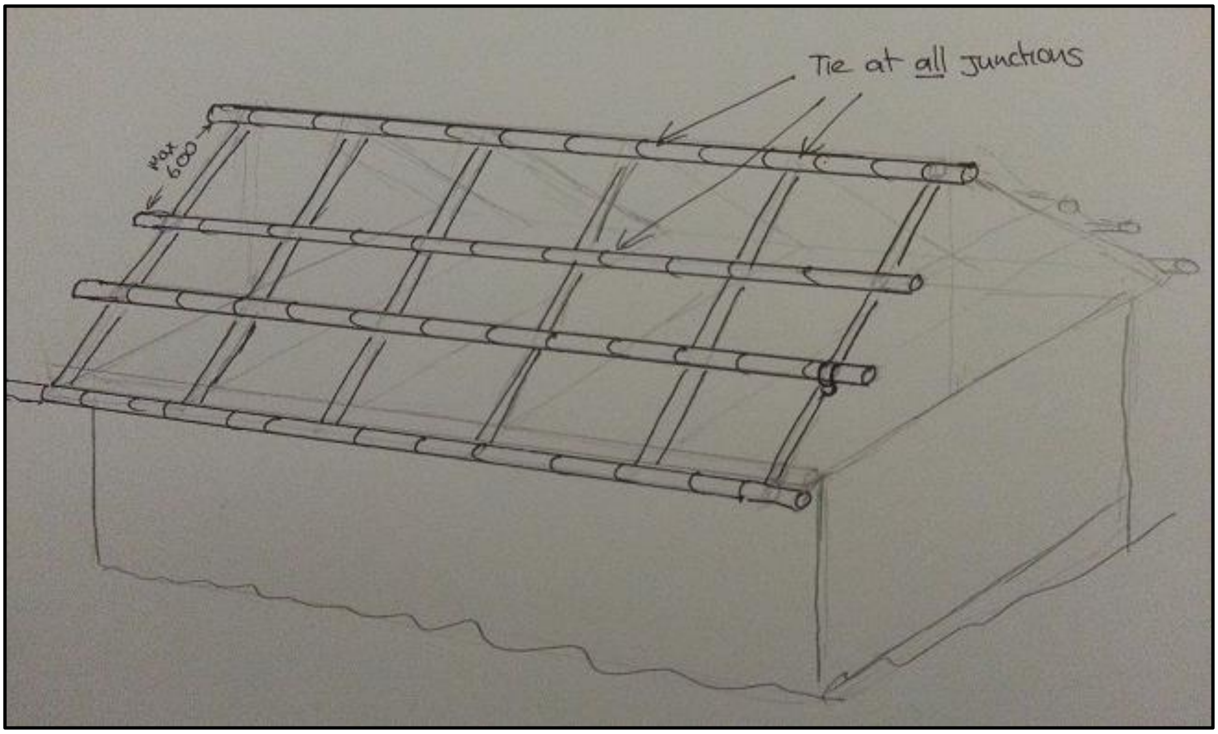


Figure 14: Purlin Layout over Trusses

The final layer of bamboo is laid over the top of these purlins. This can be significantly smaller in diameter than the trusses and purlins as it is there only to fix the tyres to and hold the polythene in a pattern that allows clear draining.

4. Lay the over-purlins perpendicular to the purlins placed before at 300mm centres. This gives regular fixings for the tyres.

5. The entire roof is now covered in a layer of polythene. It can be stapled in place until the tyres are attached which will be its final fixing layer.

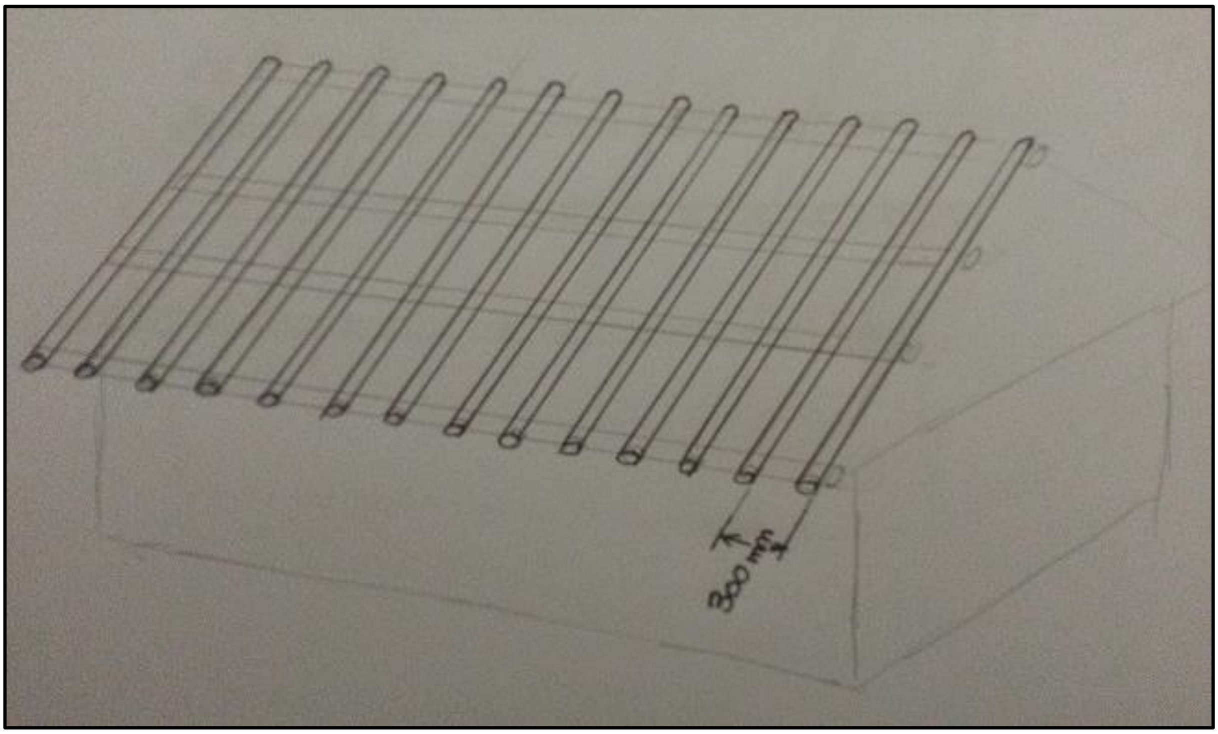


Figure 15: Over-Purlins laid over Purlins

6.0 Attachment of Waste Tyres to Roof

Once the tyres have been disassembled the treads can be attached to the roof.

1. Pre-drill all holes on the bamboo where tyre will be fixed with a 3.5 mm drill bit. This is to prevent the bamboo from splitting.

2. Starting at the bottom, attach a complete row of tyres overlapping the treads 40mm at joints. Ensure that the joints end up in a trough between over-purlins; this prevents the next layer having a big gap every time it encounters a join from the layer beneath. See figure 15 (Polythene left out to assess possible leakage).

Figure 16: Attaching Tyres to Over-Purlins

3. Once the first layer has been laid, lay the next layer on top in a similar fashion overlapping approximately 40mm onto the layer underneath. A line can be made using a chalk-line to ensure the layers don't start rising unevenly at one end or the other.

4. Finished roof should resemble Figure 17.

Figure 17: View from under Roof

Figure 18: Finished Product