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Rainwater Harvesting at Devikulam

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Executive Summary

The Engineering Without Borders (EWB) Challenge 2011 in association with the Pitchandikulam Forest for first-year engineering students throughout Australian universities aimed to develop innovative solutions to assist the sustainable development of the Devikulam village community in Tamil Nadu, India. This report by the ‘Engineering People helping Devikulam (PhD)’ discusses the team's efforts and results in working towards an engineering solution to meet the above need.

The preliminary stage of the discussion revolves around the examination of the background and problems of the Devikulam community in order to identify suitable design areas for the project. Engineering PhD decided to address the design areas of water supply and housing in order to solve the community's current major problems of inadequate clean water supply and weak roofing. A solution based on the implementation of a new roof with an integrated rain water harvesting system was looked at for which user requirements were developed. The user requirements and design criteria took into consideration the limited means, rural lifestyle and cultural considerations of the community to meet their needs effectively.

Based on this, various concepts were generated and finally a suitable cost-effective and long-lasting solution to meet the needs was designed. Validation tests and life cycle assessments were carried out in the latter part of the project to verify that the user requirements developed earlier were met successfully. Based on this, a two-stage implementation process has been recommended to ensure a safe and successful execution of the solution for the development of the Devikulam community.
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1. Introduction

Engineers Without Borders (EWB) is a non-profit organisation that works with developing communities internationally to provide them with knowledge, resources and technologies in-order to improve their livelihood. The EWB challenge is a project run in collaboration with Australian universities that provides students the opportunity to work on sustainable development projects identified by EWB with its community-based partner organisations. This year’s EWB challenge is in partnership with Pitchandikulam Forest and is based in the village of Devikulam, Tamil Nadu, India. The design brief of the project is to:

“Develop innovative and sustainable project solutions that can make a real contribution towards the sustainable development of Devikulam”. (EWB, 2011a)

India is one of the world’s fastest growing economies. However, the fact that it is also the world’s second most populous country contributes to a scene of vivid contrast in the nation. India has a third of the world’s poor with 41.6% of the population below the poverty line of AUD 1.2 a day, approximately 25 – 50 % of the population still lack access to ‘improved’ sanitation and only 74% of the population are literate (UNICEF/WHO, 2010).

The Devikulam community is only a microcosmic representation of the situation in India and is one of the under-developed regions in the state of Tamil Nadu (EWB, 2011a). There are considerable areas in Devikulam where the EWB design brief may be applied. Some of the concerns raised are the limited supply and poor quality of water available to the Devikulam community and the inability of the housing materials to handle the extreme weather conditions. ‘Engineering People helping Devikulam (PhD)’ has chosen to specifically look into these issues and design a residential roof rainwater harvesting system that will provide Devikulam’s occupants with improved shelter and supply of clean water.
2. Background

2.1. Devikulam region and social context

The township of Devikulam is separated into 3 regions; the Colony, Village, and Thoppu. The segregation of these communities is basically due to India’s caste system which is primarily founded from Hinduism - the major religion practiced in India. This system classifies individuals into groups based on socio-economic conditions, and is highly hierarchical in that India’s social boundaries and inequalities are largely attributed to an individual’s caste (Barker, 2005). The two castes identified within Devikulam are the Scheduled (Dalit) Caste and the Most Backward Caste (Buzza, 2010). The Dalit’s are considered ‘untouchables’ and live in the village while the Most Backward Caste’s live primarily in the colony and hold a higher level of hierarchical status. However, it has been indicated from a consultant working in the nearby town of Puducherry that the separate
castes in the community hold good relations, and generally “mingle... and attend each other’s functions” indicating a certain level of equality (Buzza, 2010).

2.2. Lifestyle

Almost all of Devikulam’s occupants, irrespective of caste, live below the poverty line, and their economy is scarce. The population of Devikulam is 322 people and the average annual household income is AUD 570, with an average size of 5 people per house (EWB, 2011b). Household income is most commonly sourced through irregular agricultural work on farms in surrounding areas. Due to the little work available in Devikulam some occupants are forced to travel to nearby settlements where they can find consistent work. Two of Devikulam’s nearest settlements that contain considerable resources, economy and population relative to Devikulam are Tindivanam and Puducherry; Puducherry being the largest with a population of 1.2 million (Government of India, 2011). Both these cities are in a 50km radius of Devikulam (Figure 1).

Devikulam’s water is primarily sourced from three different bores. A major concern for the Devikulam community is that one of these bores has been identified as saline and one of
the other two bores that supply a 30,000L tank for the villagers is not working. In addition, the bore supplying this tank is situated next to the village pond which is also used for bathing and washing. Recent tests have indicated an increase in bacteria in the water from this bore which is still at a safe level but is predicted to be caused from the poor sanitation practices. This will therefore become a significant issue if not addressed (EWB, 2011d).

Furthermore, as there is only one bore functioning, the water is only available to the majority of residents via certain taps. These can only supply water for certain periods throughout the day and are generally in ‘poor condition’ and waste a lot of water due to leaks.

2.3. Climate and housing conditions

Data obtained from the Indian Meteorological Department (IMD) indicates that Devikulam has a tropical climate and experiences a monsoon season from approximately August to December. The average range of temperatures is 21.4°C – 36.8°C and the average annual rainfall is 1331.48 mm with 980 mm falling between August and December (IMD, 2010).

The houses in Devikulam are usually made of mud-brick and 70% of roofs are thatched or made of palm leaf. While these roofs provide good cooling properties for the hot climate in Devikulam, they generally provide poor shelter for heavy storms and rain especially during the monsoon season. In addition to this, thatched roofs are highly flammable which poses a safety issue given most of the homes use open fires to cook, and they decompose readily in moist climates such as Devikulam due to mildew growth. The government tried to overcome these issues by building houses out of concrete but these were unpopular due to their high heat retention. (EWB, 2011c)
3. Design Criteria

The first step towards developing a solution is to define a set of design criteria to work with. The top level of the project will focus on providing sufficient protection from the harsh elements of the Tamil Nadu region. In addition to better shelter, a reliable and clean source of water is required; possibly through the use of rainwater collection and storage.

The average annual rainfall in Villupuram is 1331.48mm (IMD, 2010). The housing must be able to withstand a significant amount of rainfall. Sturdy materials must be selected so that the roof is strong and will not collapse during strong monsoon rains. The gutters must be attached securely and safely, bearing in mind that any blockage may result in a large weight of water being contained in the gutter. In addition to being strong, the roofing must also be light enough to be supported by existing walls. Though some houses in Devikulam are of concrete and cement, there are mud houses as well and these must be able to support the structure. If leakage occurs through the existing walls, rebuilding may be necessary.

The baseline survey (EWB, 2011b) shows that roofing will be required for 50 out of 70 houses and 322 people. Each house requires about 18 litres of water per day; approximately 1300 litres of water is used every day. It is also found from the survey that the average annual income per household in Devikulam is ₹ 27,557 which is AUD 570 (as per 28 May 2011). Hence, it is important to take into consideration that even though external funding may be sourced from aid organisations like AusAID, Global Water and EWB, the villagers would have to shoulder some of the implementation costs and hence, their financial ability should be emphasised while looking for solutions.
Overall, the top level user requirements for the project can be summarised as to provide complete shelter from the rain and severe weather, efficiently collect rainwater to solve water issues and use local materials and labour as much as possible to support their poor economic structure. Now that the top level user requirements have been defined, the specific design criteria for each component of the system have to be identified and performance metrics to evaluate the solutions should be developed as well.

The two main components of the solution are rainwater harvesting and roofing and these must be looked at in detail. The three integral sections of a standard rainwater harvesting system are it’s rainwater capture, filtration and storage. The top level user requirements identified above have to be specialised for these components and cost-effectiveness can be immediately established as a common design criteria for all of these. Further narrowing down, for rainwater capture, the design criteria are defined to address the needs of durability, source-ability, chemical safety and sustainability. The water filtration should also work effectively and safely and hence further design criteria of effective filtration and low maintenance are identified for it. Rainwater storage should provide each household with easy and safe access to the collected rainwater and hence, the design criteria in this case are the accessibility, durability and safety of the solution.

The roofing solution for the project should also integrate itself with the top level user requirements identified and the main design criteria which follow through are it’s cost-effectiveness, durability, sustainability and source-ability. However, the roofing also has a few technical aspects to it and this must be into consideration as well. As the villagers in Devikulam report of problems with the leaking, strength and poor insulation by the current roofs, the new solutions should aim to rectify these issues. Hence further design criteria to
meet these aspects can be defined to attain wind resistance, water resistance, mildew resistance, insulation and the strength-to-weight ratio of the roofing materials.

**Table 1: Hierarchical structure of consolidated user requirements and design criteria**

<table>
<thead>
<tr>
<th>User Requirements</th>
<th>Shelter from extreme weather</th>
<th>Clean and efficient rainwater capture</th>
<th>Use of local materials and labour to minimise cost</th>
</tr>
</thead>
</table>

**Rainwater Storage**

<table>
<thead>
<tr>
<th>Design Criteria</th>
<th>Performance Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installation Cost</td>
<td>&lt;50 AUD</td>
</tr>
<tr>
<td>Accessibility</td>
<td>Pass</td>
</tr>
<tr>
<td>Durability</td>
<td>&gt;20 years</td>
</tr>
</tbody>
</table>

**Rainwater filtration**

<table>
<thead>
<tr>
<th>Design Criteria</th>
<th>Performance Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective filtering</td>
<td>Pass</td>
</tr>
<tr>
<td>Low maintenance</td>
<td>Pass</td>
</tr>
<tr>
<td>Cost-effective</td>
<td>&lt;50 AUD</td>
</tr>
</tbody>
</table>

**Rainwater Capture**

<table>
<thead>
<tr>
<th>Design Criteria</th>
<th>Performance Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source-ability</td>
<td>Pass</td>
</tr>
<tr>
<td>Durability</td>
<td>&gt;20 years</td>
</tr>
<tr>
<td>Chemical Safety</td>
<td>Pass</td>
</tr>
<tr>
<td>Sustainability</td>
<td>Pass</td>
</tr>
<tr>
<td>Cost-effectiveness</td>
<td>&lt;150 AUD</td>
</tr>
</tbody>
</table>

**Roofing solution**

<table>
<thead>
<tr>
<th>Design Criteria</th>
<th>Performance Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit Cost</td>
<td>&lt;50 AUD</td>
</tr>
<tr>
<td>Water Resistance</td>
<td>Pass</td>
</tr>
<tr>
<td>Anti-mildew</td>
<td>Pass</td>
</tr>
<tr>
<td>Insulation</td>
<td>Pass</td>
</tr>
<tr>
<td>Local Availability</td>
<td>Pass</td>
</tr>
<tr>
<td>Durability</td>
<td>&gt;20 years</td>
</tr>
<tr>
<td>Ongoing Costs</td>
<td>&lt;10% annual income</td>
</tr>
<tr>
<td>Installation</td>
<td>Pass</td>
</tr>
<tr>
<td>WSR</td>
<td>&gt;100 Nm/kg</td>
</tr>
<tr>
<td>Sustainability</td>
<td>Pass</td>
</tr>
<tr>
<td>Wind Resistance</td>
<td>Pass</td>
</tr>
</tbody>
</table>

The above table summarises the essence of all the user requirements and design criteria developed. Observing these criteria in the design process will ensure a safe and successful solution which will be easy to implement and maintain for this project scope.
4. Concept Generation

4.1. Concept Generation of Roofing

New roofing materials are needed to provide better protection from rain as well as collection of rainwater. High durability, impermeability of water and low costs are the three main criteria considered in the wide range selection of new materials.

- Sisal-CNSL Composite:

One of the sisal fibre reinforced composites is made from sisal woven mats and Cashew Nut Shell Liquid (CNSL) called Sisal-CNSL composite. Mercerised woven mats of sisal fibre are superior in mechanical properties than untreated sisal fibre. Thermosetting resins will be obtained from polymerised CNSL with formaldehyde. Plain and corrugated laminated composite can be produced from impregnation with mercerised woven mats and CNSL thermosetting resins (Bisanda & Ansell, 1992). Both sisal trees and cashew trees are very easily obtained around the Devikulam region. In addition to this, a simple technique with a low-skill requirement has been suggested to produce the Sisal-CNSL composite. Easy access of the raw materials and simple manufacturing technique assures a low cost of the product.

The Sisal-CNSL composite has a mean tensile strength of 94.5 MPa and 8.8 GPa of Young’s Modulus (Li, Mai, & Ye, 2000). Compared to the thatched and palm-leaf roofs, this material would be assumed to have a higher strength subject to detailed testing. Although the mechanical properties of the Sisal-CNSL composite are not as robust as some other conventional roofing materials, it can be deployed for low-cost housing, especially for the Devikulam region. The sheets of the Sisal-CNSL composites for roofing have met the British Standards (BS) requirements. (Bisanda, 1993)
• **EPDM:**

Ethylene-Propylene-Diene Monomer (EPDM) has been used as a commercial roofing product for over 40 years. The characteristics of high wind resistance, high UV resistance, and being lightweight are its strengths. However, there are some certain limitations of EPDM roofing. Firstly, the EPDM only works well for flat roofs. However, most palm-leaf and thatched roofs at Devikulam are gable roofs and sloped. Secondly, a rigid insulation needs to be implemented in order to have sufficient support for EPDM materials (RoofHELPER, 2011). Moreover, EPDM roofs are weak relative to other materials (Doityourself, 2010). These three disadvantages seem to indicate that EPDM is not a very suitable roofing material for use in Devikulam.

• **PVC-Membrane:**

PVC is a mature product that has been used in the commercial roofing market for more than 40 years. PVC membrane mainly consists of one layer of polyvinyl chloride. It has a high resistance to water. This feature makes the material well suited for collecting rainwater. Sustainability is one of its outstanding advantages due to its high solar reflectance and recyclability. PVC is a thermoplastic material, so it is fully recyclable. In addition to this, PVC membrane roofs are also inherently fire resistant. The main issue with the technology is that high rainfall areas are not desirable for the implementation of PVC materials. Devikulam has a monsoon season, so further research is needed. (RoofHELPER, 2011)

• **Coated Metal:**

Most metal roofs have a coating in order to have a longer durability and higher performance. Coated Metallic roof is made from a steel substrate with coatings on both
sides. Coated metal roofs have been widely implemented due to their high weight-strength ratio, high durability, and high design flexibility. However, one of the major unavoidable disadvantages is the cost. Although metal roofs have higher performance than other alternative roofing materials, it has a much higher cost per unit than other alternative roofing materials. Highly-skilled labourers are required for installation (CMRC, 2011). This could contribute to additional costs of implementation as well.

4.2. Rainwater Harvesting System

4.2.1. Guttering Solutions

Guttering is required to collect the rainwater run-off from the roof of the house and let it flow to the water storage sub-system. Hence, to collect water from all around the roof, guttering will have to be used around the perimeter of the house. Assuming an average roof of dimensions 6mx7m (42m²) for a house (Government of India, 2004), the total guttering material required will be 26m. The various materials available are as follows.

- **Aluminium:**

  This is the most popular guttering material in the market. It is lightweight and rust-proof giving it a long life-expectancy of up to 30 years. However, it tends to be structurally weak; easily incurring damage from falling branches. Seamless guttering is available which reduces chances of leaks with lesser occurrence of joints. Aluminium guttering can cost between AUD 3 to 5 in India per metre. (Gutter Supply, 2011a)

- **Bamboo:**

  Bamboo was a material used for guttering in times before the Industrial Revolution in developing countries. However, after the departure of the British Empire from Asian colonies, this material has been replaced by others due to a cultural perception of being
“poor man’s timber”. However, the advantage in this case is that it is a locally available material in Devikulam and can be processed by the villagers themselves giving them a source of income. However this requires special tools and skills. Disadvantages with bamboo are that it rots in constant exposure to water and is prone to catching fire. This may be an issue considering Devikulam residents cook with open fires. (Roach, 1996)

- **Copper:**

  Copper used to be a popular material as well due to it's natural appealing finish. It is also rust-proof which reduces maintenance worries and has a long life-expectancy due to it's strength as well. However, copper guttering costs from around $15 - $20 per metre and is economically non-viable for common purposes. (Gutter Supply, 2011a)

- **Galvanized Steel:**

  Galvanized steel is one of the most economical materials available for guttering as it costs around $4 - $8 per metre. While it is extremely strong, it has a tendency to rust unless a protective coating is applied at additional cost. It also has a tendency to sag over time due to it’s heavy weight. It can however last long with proper maintenance.

- **Stainless steel:**

  Stainless steel is extremely strong and rust-proof rendering it one of the most long-lasting materials available on market. It does not require any painting or maintenance. However, it’s cost is relatively much higher than other materials and is very scarcely used. It is also quite heavy and this poses a problem as the houses in Devikulam with mud-brick walls may not be strong enough to support them. Hence, stainless steel gutters may also sag over time. (Gutter Supply, 2011a)
• Vinyl:

Vinyl is also a relatively cost-effective and common material used in guttering. It is lightweight and easy-to-install while also being rust-proof. However, it tends to be brittle and may crack under extreme weather or with age. This gives it a short life-span though it costs only around $3 - $5 per metre. They are also not regarded eco-friendly and may pose dangers of contaminating the run-off water. (Service Central, 2011)

• Wood:

Wood is a very rarely used material for guttering. Wood is likely to cost very less and easily sourced. However, wood can rot over time in standing water and it may also tend to absorb the water into it's cells. Hence, it has maintenance problems and a very short life-span. (Gutter-Protection, 2011)

4.2.2. Filtration Solutions

Primary filtration is required to clean the water from any leaves, bird-droppings and debris on the roof that may be collected from the rainwater run-off. Primary filtration renders the water safe for all non-potable purposes. However if pure drinking water is required, expensive secondary filtration may be required. Considering that Devikulam is a village with no current industries and urbanisation, it is assumed that the rainwater may not be polluted. However, this will have to be tested to see if it conforms to WHO regulations and quality standards. Thus, under this project scope, the captured rainwater is recommended for all non-potable purposes and drinking the rainwater without boiling is not recommended. This project scope focuses on only means of primary filtration for which solutions are considered and discussed as follows.
• **Gutter Mesh:**

This method is suggested individually by Engineering PhD as it is cost-effective and does not require much maintenance due to its simplistic nature. The top of the gutters and the downpipe entry can both be fitted with a removable mesh which keeps any debris from even entering the storage stage of the system. This works like a typical filter mesh used in kitchens and can be removed and cleaned periodically.

• **3P Filter Collector:**

This is a product manufactured by 3P Technik and is installed in the middle of the downpipe connecting it to the storage system. This product is experimentally claimed to be highly efficient in filtering debris (85 – 95%). However, a disadvantage of this filter is that debris is still allowed to enter the downpipe and though it can be removed and cleaned, it involves more joints in the pipework. Moreover, it has to be imported from the EU and is expensive. (3P Technik, 2011)

• **First Flush Water Diverter:**

This is a product from Rain Harvesting Pty Ltd and is an innovative low-maintenance system to flush out the first few litres of water entering the system before the storage tank. This is a relatively cost-effective unit which ensures that the first run-off containing debris is not used. However, it does not effectively do the job of a primary filter as large debris like leaves have potential to jam the unit. It also has to be imported from Australia which imposes additional costs. (Rain Harvesting Inc., 2011)

• **RainTube:**

This is a product from RainTech and is a round porous material inserted into gutters to
ensure only water is let through past it into the gutter while other debris stays on top. This is a low-maintenance product as the tube is designed to aerodynamically “blow” away the debris from its top. However, this is an expensive product and once again, has to be imported from the USA. (RainTech, 2011)

- **GutterFilter:**
  This is a foam-based porous product which can be made to required shape and is resistant to physical stress. It only needs to be inserted into the gutter and it ensures only water is let through it and other debris is filtered out at the top. However, it has to be imported from the USA and is not economically viable. (GutterFilter, 2011)

### 4.2.3. Water Storage Solutions

Water tanks are required to store the rainwater run-off from the roof of the house. They need to provide easy and safe access to the captured rainwater to be used anytime. Also keeping the conditions in mind, it is important the tanks also be durable, stable and chemically inert. Keeping these criteria in mind, available options for the storage tanks can be generated.

- **PVC Water Tank:**
  Polyvinyl chloride (PVC) is a durable thermoplastic polymer. The rainwater tanks made from PVC are light and easily installed. They have great impact strength and resistance to corrosion due to their seamless construction. Their lifespan is approximately 25 years. PVC tanks are about USD$0.085 per litre, and one of the cheapest tanks on the market. (Rainwater Tanks Direct, 2011)

- **Steel:**
  Most steel tanks are made from low carbon galvanised steel. They have higher
resistance to harsh environment. However, they are relatively heavy and more expensive. Steel tanks can cost about USD$0.15 per litre which is 77% more expensive than a PVC tank. The lifespan of steel tanks are around 20 years. In this particular case, steel tanks cannot be easily obtained around Devikulam as well. (BlueScope, 2011)

- **Fibre Glass:**
  Fiberglass tanks are extensively used in industrial applications. They provide an environmentally safe and durable alternative and their prime advantage is that they never rust or corrode and hence can be used in extreme conditions with acid contact and such. These tanks are generally tough to source in smaller sizes especially in India. They also cost up to 3 times the cost of steel making them a premium product.

- **Concrete:**
  Concrete tanks are made from steel reinforcement, gravel, sand, cement and water. Concrete tanks are extremely strong compared to steel and PVC tanks. Therefore, they have a longer lifespan of about 30 years. However, highly skilled workers are needed to build and install concrete tanks. In addition, concrete tanks are about 26 times heavier than a same-size PVC tank. Concrete tanks also cost much more than normal tanks because of the extensive materials used. (Rainwater Tanks Direct, 2011)

Considering the accessibility issues of using large shared tanks for a group of households, it is seen that using an individual tank for each household may be more beneficial as each family will be able to fulfil their needs independently without reliance on external factors. Also, if a large tank needs to be repaired for damage, it will affect more households than just one. It is also recommended that a normal above-ground tank be used since underground tanks have large installation requirements and are expensive to repair if cracked as they have to be excavated for any purpose.
5. Concept Selection

For the selection of the final concept, concepts were chosen according to their relative performance against each other in respect to the design criteria, and in general, their suitability to Devikulam and the project at hand. Where possible, concepts were quantitatively analysed using a matrix based on the respective design criteria. Performance metrics in the design criteria that were based on an exact target or relative rating were just assigned a rating out of 5 for this matrix, where a score of 5 indicated the component held the most desirable characteristics in regard to the metric.

In most cases the criteria for the maximum & minimum score will be indicated, however, in general these scores were primarily based on how good its performance was relative to the other examined options, and for exact target metrics, a score equal to or greater than 2 in the matrix indicated the exact target was met. Performance metrics in the design criteria that were founded on a pass or not pass basis will be indicated, and were given a score out of two numbers, generally a 1 for a pass, and a 0 for a not pass.

5.1. Roofing Solution

The examined concepts for the roofing material were coated metal (steel), corrugated sisal/CNSL composite, EPDM, and PVC membrane. The generation of these concepts was fairly unspecific as in it needed to include a large scope of options, which will be narrowed down upon concept selection and final design. Thus, due to the generality of these concepts, a quantitative analysis did not seem appropriate as it would require specifying certain subsets or grades of each roofing material, which would not provide full insight into the opportunities available from each concept as a whole. Hence, a more qualitative analysis was used to decide a final concept that took into account a holistic view of the top...
level user requirements. Where necessary, however, specific user requirements were also considered.

For roofing material the Sisal-CNSL composite material was chosen as the final concept for further development. This choice was primarily supported by the fact that this material sufficiently met the first two of the previously mentioned top level user requirements, and is theoretically the lowest costing material from the concepts. (Ansell, 2011) It is also the only concept where key materials in its composition are locally available to Devikulam and its manufacturing process can potentially generate income for the Devikulam community - which was a highly desirable potential that was not available from any of the other concepts. In addition it had a low specific heat capacity that was suitable to Devikulam’s climate and a high strength to weight ratio relative to the other concept materials.

### 5.2. Guttering Solutions

Table 2: Selection Matrix used for guttering solutions (with weighted criteria as shown)

<table>
<thead>
<tr>
<th>Solution/ Criteria</th>
<th>Aluminium</th>
<th>Bamboo</th>
<th>Copper</th>
<th>Galvanized Steel</th>
<th>Stainless steel</th>
<th>Vinyl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Durable (2)</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Source-ability (1)</td>
<td>3</td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Safety (2)</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Sustainable (2)</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Cost-effective (3)</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>33</strong></td>
<td><strong>30</strong></td>
<td><strong>28</strong></td>
<td><strong>27</strong></td>
<td><strong>27</strong></td>
<td><strong>26</strong></td>
</tr>
</tbody>
</table>

Based on the selection matrix, aluminium is the best material to be used for the gutter system. It is lightweight and rust-proof giving it a long life-expectancy of up to 30 years. These properties are a main reason why it is one of the most popularly used materials in
the market. Seamless guttering is available for aluminium gutters. This reduces the chances of leaks as the number of joints is reduced. The only con is that it has to be sourced from the nearby town of Puducherry indicating transport costs.

Bamboo sounds like a trendy choice as well considering it’s “green” implications and potential local source-ability. However, it is important to keep in mind that they have an extremely short life-span of an estimated 4 years. They tend to rot on constant exposure to water while they pose a fire-risk in the dry season. Bamboo is also culturally considered “poor man’s timber” in Asian countries and people generally like to dissociate with such materials in order to distance themselves from their colonial memories of suppression. (Roach, 1996) However, as the EWB design brief also intends to look at innovative solutions, bamboo will be considered as a second recommendation for further evaluation before implementation even though it is impractical in long-term analysis.

This gutter system should use semi-circular gutters as they allow the water to flow through the more quickly and smoothly. Half round gutters also accumulate less fine dust than gutters with sharp corners. The downpipes of the gutter system should be constructed using PVC pipes, as they are cheap and reliable.

5.3. Water Filtration Solutions

Table 3: Selection Matrix used for the water filtration solutions

<table>
<thead>
<tr>
<th>Solution / Criteria</th>
<th>Gutter Mesh</th>
<th>3P Filter Collector</th>
<th>First Flush Diverter</th>
<th>RainTube</th>
<th>GutterFilter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective filtering</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Low Maintenance</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Cost-effective</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>TOTAL</td>
<td><strong>12</strong></td>
<td><strong>9</strong></td>
<td><strong>10</strong></td>
<td><strong>9</strong></td>
<td><strong>9</strong></td>
</tr>
</tbody>
</table>
This project scope focuses on primary filtration for which two solutions have been selected from the above selection matrix. A gutter mesh should completely cover the top of the gutters. This prevents the majority of debris from entering the gutters and downpipes. Debris may cause the gutters or pipes to become blocked preventing water from passing through the gutter system into the water tank or cause the gutters to overflow.

The gutter downpipes must be connected to a first flush water diverter, in order to prevent the first flow of polluted water running off the roof to be stored in the tank. The first flush diverter’s chamber should be able to divert 25L to 100L of rainwater, depending on the size of the roof and its exposure to pollution. (Rain Harvesting Inc. 2011)

5.4. Water Storage Solutions

The first consideration for the concept selection of the rainwater storage system was the location (above or below ground). Given the high installation cost of an underground tank and its required components (e.g. water pump) it was accordingly decided that an above-ground tank would be more suitable for the Devikulam community’s means. An underground tank also poses maintenance difficulties if cracks or leaks occur. Given the common standards for materials used in these tanks, these were analysed using a matrix.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>PVC tank</th>
<th>Steel tank</th>
<th>Fibre glass tank</th>
<th>Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source-ability</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Durability</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Chemical safety (0,1)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Sustainability</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Cost</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>TOTAL / 21</td>
<td>16</td>
<td>12</td>
<td>11</td>
<td>13</td>
</tr>
</tbody>
</table>

Based on the ratings derived from the above selection matrix, a PVC tank supplied by Sintex is recommended for progress to the final design of the concept.
6. Detailed Design

6.1. Prototype Pictures

Figure 3: Graphical model of whole design solution depicting the new roofing panels

Figure 4: Graphical model of rainwater harvesting system in detail

Figure 5: Picture of rudimentary prototype developed
6.2. Concept Equations and Models

This section covers all the mathematical equations worked out behind the use of the concepts. They provide a model for the implementation basis of the project and there are a few assumptions involved as well. The first part is to develop a model for the dimensions of an average household expected in the village of Devikulam.

- Average floor area in rural Indian households = 38m$^2$ (Government of India, 2004)
- Estimate for average roof dimensions = 40m$^2$ (based on floor area)
- Estimated average roof dimensions ≈ 6m x 7m
- Perimeter of roof = 2 x (6m + 7m) = 26m ≈ 25m

The next section is related to the estimated collection of rainwater from the harvesting system. This is based on the average rainfall in the district as per data obtained from the Indian Meteorological Department (IMD, 2010).

- Annual rainfall in Villupuram district = 1331.48mm = 1.33m
- Total rainfall per year on roof = 40m$^2$ x 1.33m = 53.2m$^3$ = 53,200L
  Estimated rainwater run-off loss = 20%
  Estimated wastage loss = 5%
- Estimated rainwater captured = 0.75 x 53,200L = 39,900L ≈ 40,000L
- Average rainfall captured per day = 40,000L / 365.25 days ≈ 110L
- Average water consumption per household per day = 18L
- Water storage recommended (considering dry periods) = 500L
- Estimated gutter volume = (0.5 x π x radius$^2$) x length of gutter
  Estimated gutter volume = (0.5 x π x 0.1$^2$) x 25m = 0.3926m$^3$ = 392.6L
6.3 Bill of Materials

Table 5: Bill of Materials for Rainwater Harvesting

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Item</th>
<th>Purpose</th>
<th>Supplier</th>
<th>Quantity</th>
<th>Cost (AUD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Aluminium Guttering</td>
<td>Gutter</td>
<td>Puducherry contractor</td>
<td>25m</td>
<td>125</td>
</tr>
<tr>
<td>2</td>
<td>PVC downpipe</td>
<td>Gutter</td>
<td>Puducherry supplier</td>
<td>5m</td>
<td>15</td>
</tr>
<tr>
<td>3</td>
<td>Plumbing materials</td>
<td>Gutter</td>
<td>Puducherry supplier</td>
<td>as reqd.</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>Plumbing labour</td>
<td>Gutter</td>
<td>Locally sourced</td>
<td>10 hours</td>
<td>30</td>
</tr>
<tr>
<td>5</td>
<td>Gutter Mesh</td>
<td>Filtration</td>
<td>Puducherry Supplier</td>
<td>25m</td>
<td>15</td>
</tr>
<tr>
<td>6</td>
<td>First Flush Diverter</td>
<td>Filtration</td>
<td>Locally produced</td>
<td>1 unit</td>
<td>10</td>
</tr>
<tr>
<td>7</td>
<td>Tank (500L)</td>
<td>Storage</td>
<td>Sintex</td>
<td>1 unit</td>
<td>50</td>
</tr>
</tbody>
</table>

**Total Cost per Household** 260

Table 6: Bill of Materials for Roofing and Material Production

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Item</th>
<th>Purpose</th>
<th>Supplier</th>
<th>Quantity</th>
<th>Cost (AUD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sisal Fibre</td>
<td>Roof</td>
<td>Locally sourced</td>
<td>As reqd.</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>CNSL Liquid</td>
<td>Roof</td>
<td>Pratipa Cashews</td>
<td>1500 kg</td>
<td>900</td>
</tr>
<tr>
<td>3</td>
<td>NaOH</td>
<td>Processing</td>
<td>Puducherry chemist</td>
<td>1215 kg</td>
<td>485</td>
</tr>
<tr>
<td>4</td>
<td>Formalin</td>
<td>Processing</td>
<td>Puducherry chemist</td>
<td>7.5 kg</td>
<td>3.5</td>
</tr>
<tr>
<td>5</td>
<td>Hydraulic Press (15T)</td>
<td>Production</td>
<td>Khalsa Engineering Works</td>
<td>1 unit</td>
<td>2500</td>
</tr>
<tr>
<td>6</td>
<td>Mixer Machine (100L)</td>
<td>Production</td>
<td>Trover (Mumbai)</td>
<td>1 unit</td>
<td>1500</td>
</tr>
<tr>
<td>7</td>
<td>Industrial Oven (10L)</td>
<td>Production</td>
<td>Asian Test Equipments</td>
<td>1 unit</td>
<td>500</td>
</tr>
<tr>
<td>8</td>
<td>Safety Gloves</td>
<td>Work</td>
<td>Ansar Corp. (Mumbai)</td>
<td>20 nos.</td>
<td>18</td>
</tr>
<tr>
<td>9</td>
<td>Safety Goggles</td>
<td>Work</td>
<td>Maniar Injectoplast</td>
<td>20 nos.</td>
<td>12</td>
</tr>
<tr>
<td>10</td>
<td>Safety Masks</td>
<td>Work</td>
<td>Venus Safety</td>
<td>20 nos.</td>
<td>13</td>
</tr>
<tr>
<td>11</td>
<td>Production Labour</td>
<td>Production</td>
<td>Locally sourced</td>
<td>20 people</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>Material Transport</td>
<td>Materials</td>
<td>Variable</td>
<td>as reqd.</td>
<td>200</td>
</tr>
</tbody>
</table>

**Total Cost for Village** 6131.50

**Total cost per Household** 122.63

The above tables summarise the Bill of Materials for the proposed solution. Based on these lists, the total implementation cost for each household is AUD 383 (₹ 18,380) incorporating aluminium guttering and AUD 258 (₹ 12,381) incorporating bamboo guttering – roughly 45 to 67% of an average Devikulam household’s annual income.
6.4. Construction Techniques

Rainwater Harvesting System

In order to attach the gutters to the walls of the houses, circle hangers and shanks will be needed for every 1.2m of guttering. A metal spring clip is required to connect the gutter to the hanger; a nut and bolt will be required to connect each hanger to a shank and four nylon tap-ins will be required to connect each shank to the walls. (Gutter Supply, 2011b)

![Diagram of gutter installation method](Gutter Supply)

One end of the gutter mesh is screwed to the rafters under the second last row of the roofing panels. The other end of the gutter mesh is connected to the top-outer edge of the gutter. The PVC pipes require a PVC bracket every 1 metre to be securely mounted to the wall of the house. Each bracket requires two nylon tap-ins to be attached to the wall. The first flush diverter requires two thick metal brackets, one at the top of the chamber and one at the bottom, to be attached to the wall of the house. These brackets are attached to the walls with Nylon Tap Ins. (Fence It Yourself, 2011)

Manufacturing corrugated sisal/CNSL roofing panels

Preparation of the matrix (CNSL resin)

The preparation of CNSL resin requires the reaction between formalin (100 parts by weight) and CNSL (87 parts by weight) with a sodium hydroxide catalyst (0.5 parts by weight). Liquid CNSL must first be placed in a vat while slowly adding the formalin and continuously
stirring the mixture. Once mixed a 0.5M sodium hydroxide solution must be added and stirring continued which catalyses the exothermic reaction between the formalin and CNSL. Once the reaction and temperature has stabilised the temperature is maintained at 85-88°C. This reaction takes approximately one hour to complete. (Bisanda, 1993)

**Manufacturing the composite**

The sisal fibre mats need to be treated in a 0.5M solution of sodium hydroxide for 48 hours, rinsed and dried. This process improves the fibre surface's adhesive characteristics by removing natural and artificial impurities from the surface. The mats are then soaked in the CNSL resin, placed in the hydraulic press, and subsequently pressed with a 15-ton force at 150°C for 20 minutes. The composite panel is then heat treated at 100°C for 24 hours.

**Installation**

Thatched roofs cover 70% of the homes in Devikulam. In order to replace these roofs, it is proposed that the thatch is removed from the roof and the sisal fibre composite is laid on the underlying roof structure as this would pose minimum labour and material costs. It has been found that the minimum and common underlying structure of thatch roofs in rural regions is bare rafters where thatch is stacked and tied on top (Morton, 1997).

![Figure 7: Common underlying structure of thatch in rural regions (Morton, 1997)](image)

It is considered that the sisal/CNSL composite panels are lighter per m² than common thatch, can be manufactured to any size depending on the size of the hot press plates and only need to be fastened using screws to a flat supportive structure for installation. Hence,
this proposal is feasible making the assumption that it is the previously mentioned
minimum structure of thatch roofs that underlie all houses in Devikulam (Kemlite, 2011).
However so, if this project is further developed further, first-hand investigation will be
required into the underlying roofing structure of the houses in Devikulam.

For installation, the first step would require the removal of the thatch. This could be done
with unskilled labour and the required time would vary depending on the type of thatch.
After removal of the thatch, it would be recommended that cross braces be installed
between rafters to provide further surface area for the panels to be bolted down to. This
would simply require bamboo or wood to be nailed, glued, or screwed (depending on what
is appropriate) between the rafters. The panels would then have to be fastened from the
bottom of the roof upward, overlapping each panel as demonstrated by figure 8.

For the bolting, the panels are required to be bolted down from the crest of the corrugated
pattern onto the supportive frame. Finally, at the crest of the roof a ridge covering would
be required to cover the tops of the panels on either side of the roof. This ridge is simply
bolted onto the panels and the underlying structure. The total installation of these roofing
panels can be achieved with semi-skilled labour. (Kemlite, 2011 & INBAR, 2011)

**Figure 8: Installation of the corrugated roofing panels (INBAR, 2011)**
6.5. Running and Maintenance Costs

The solutions identified in this project were chosen to be requiring minimal maintenance as per the design criteria. However, there are still some maintenance procedures the users will have to adhere to in order to ensure the longevity and successful operation of the product. The rainwater harvesting and roofing system have no running costs as such since the only input they need is from the natural rainfall. However, a few maintenance procedures have been recommended as below.

- Clean the gutter mesh every month
- Empty the First Flush Diverter after every major storm
- Check downpipes for clogging every 3 months
- Clean the water storage tank annually

These activities are fairly simple and do not demand extensive expertise or equipment. The only need is that the user be able to reach the gutter and considering visual evidence of house structures in the village, it is seen that low roofs are used and this wouldn’t be a hindrance. At maximum, only a stool or ladder might be required for this purpose. In the case where the residents are not able to clean their water tanks, it may be fairly easy to obtain the service of a Dalit resident in the village whose list of professions include cleaning as well. (National Geographic, 2003) Hence, the running and maintenance costs for the solution can be deemed to be negligible in terms of cost and not demanding on extensive labour or equipment.

6.6. Potential Revenue and Income streams

The use of Sisal fibre in the solution gives rise to an excellent revenue stream for the community of Devikulam as the villagers can manufacture and sell roofing panels.
Sisal took the 6th place in the market for fibre plants in 2007. There are several advantages for the community to grow Sisal fibre at Devikulam. First, the annual internal demand of Sisal fibre in India is about 25,000 tonnes. However, the current production is less than 5,000 tonnes. Therefore, there is a huge potential internal market for Sisal plants. At the same time, the market price of Sisal fibre increased by 30% in 2007. These plants have high resistance to dry climate and high tolerance to a diversity of soils. Sisal plants grow best with 40-300cm annual rainfall with temperatures up to 42°C – 48°C. They also have high immunity to diseases and weeds. (Saxena and Ashokan, 2011)

**Plantation and processing**

Sisal plants can be planted and harvested perennially. 20 – 30 days before monsoon season is the right time for planting sisal trees. Sisal trees can be planted in either single or double rows with 2mx1m space. This implies that 5000 plants can be grown in one hectare. After harvesting sisal leaves, extraction will be done by retting. This is a biodegrading process that will normally take 15-20 days to finish. (Saxena and Ashokan, 2011)

**Applications**

Sisal leaves can be used for a wide range of applications. Products such as ropes, carpets, handicrafts and twines can be produced. After extraction, sisal pulp will be left. They can be used for making paper, hecogenin, wax, and biogas. With CNSL, Sisal-CNSL can be made for corrugated roofing panels. These products can be sold in both domestic and international markets. People at Devikulam can share their profits as their extra incomes.

**6.7. Broader benefits from use**

Apart from just solving the problems mentioned in the design brief, the solutions implemented have potential to help the community of Devikulam in other aspects of life as
well. The greatest benefit the people are likely to gain is self-sufficiency in terms of solving their needs. They will no longer need to rely on the government pipes and their unpredictability. Since each household has its own system, they won’t need to go to other sources for help.

The implementation plan has also been designed in order to involve the villagers in the production as well. This will provide them with a sense of pride in ownership as they would feel it is their product as well. This approach has been shown to work successfully under a similar project by the UN in Cambodia (UN Water, 2006). The chance to manufacture their own Sisal-CNSL panels also provides them with an opportunity for extra income for their livelihood. This is likely to promote the sense of entrepreneurship in the community and show that they also have a chance to grow to higher levels in their society which currently has been identified to be of Backward Castes.

The overall solution is also a sustainable one in terms of low environmental impact and this will be a new stepping stone for them. They will be able to join the world in the movement for eco-friendliness and sustainability putting them ahead in the society. This will also help protect and nurture the rich environmental resources Devikulam possesses.

6.8. End of Life consideration

With the increasing onus on sustainability and eco-friendliness in modern engineering, it is important to design solutions which meet this criterion. This means that even at the end of a product’s use, its life cycle should not end but instead continue to contribute to benefit the society. Considering the limited means of the Devikulam community, it is even more
important to ensure that solutions give back as much value to them for the input they put in. Hence, a few ways to extend the solution’s life cycle have been explored as well.

The materials used for roofing, Sisal fibre and CNSL, are derived naturally which means that any wastage incurred can possibly be processed in some way. Sisal fibre wastage from the production process is useful in this manner such that it serves as a good biomass fuel. Hence, it can be used by the villagers to supply their green fuel needs and bio-digester input as well. If the fibre excess is in passable condition, they can also be used to produce handicrafts and other similar goods as well. Sisal fibre mats, rugs and dolls are very commonly produced in rural Indian villages and this provides an opportunity for women to be involved in a potential entrepreneurship as well. Once the Sisal-CNSL roofing panels have surpassed their lifetime, if they are not good enough to continue serving the roofing purpose, they can be removed and used for other less demanding purposes like fencing and livestock shelter in the community.

With the rainwater harvesting system, most of the materials are prefabricated and their combined estimated life-span is around 25 years. In this case, the condition of the materials will have to be monitored and when they are no longer suitable for serving their purpose, it is likely that they will have to be sent to a recycling plant. Considering the time period of 25 years and the fact that India is the 2\textsuperscript{nd} fastest developing country, it might be a safe assumption that a recycling plant may be available near the town of Puducherry which the villagers may be able to access. In the case that aluminium guttering is used, it can be recycled successfully. However, if bamboo guttering is used, this will not be possible as it will rot and won’t be useful for any other purpose anymore. Overall, re-use and recycling of the materials used in the solution seems to be a potentially possible prospect.
# 7. Validation

Table 7: Validation of final solution against design criteria and metrics

<table>
<thead>
<tr>
<th>Criteria #</th>
<th>Design Criteria</th>
<th>Performance Metric</th>
<th>Solution’s Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Roofing Solution</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Unit Cost</td>
<td>&lt;50 AUD</td>
<td>28 AUD</td>
</tr>
<tr>
<td>2</td>
<td>Water Resistance</td>
<td>Pass</td>
<td>✓</td>
</tr>
<tr>
<td>3</td>
<td>Anti-mildew</td>
<td>Pass</td>
<td>✓</td>
</tr>
<tr>
<td>4</td>
<td>Insulation</td>
<td>Pass</td>
<td>✓</td>
</tr>
<tr>
<td>5</td>
<td>Local Availability</td>
<td>Pass</td>
<td>✓</td>
</tr>
<tr>
<td>6</td>
<td>Durability</td>
<td>&gt;20 years</td>
<td>25 years</td>
</tr>
<tr>
<td>7</td>
<td>Ongoing Costs</td>
<td>&lt;10% annual income</td>
<td>7.56%</td>
</tr>
<tr>
<td>8</td>
<td>Installation</td>
<td>Pass</td>
<td>✓</td>
</tr>
<tr>
<td>9</td>
<td>WSR</td>
<td>&gt;100 Nm/kg</td>
<td>231.67 Nm/kg</td>
</tr>
<tr>
<td>10</td>
<td>Sustainability</td>
<td>Pass</td>
<td>✓</td>
</tr>
<tr>
<td>11</td>
<td>Wind Resistance</td>
<td>Pass</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Rainwater Capture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Source-ability</td>
<td>Pass</td>
<td>✓</td>
</tr>
<tr>
<td>2</td>
<td>Durability</td>
<td>&gt;20 years</td>
<td>25 – 30 years</td>
</tr>
<tr>
<td>3</td>
<td>Chemical Safety</td>
<td>Pass</td>
<td>✓</td>
</tr>
<tr>
<td>4</td>
<td>Sustainability</td>
<td>Pass</td>
<td>✓</td>
</tr>
<tr>
<td>5</td>
<td>Cost-effectiveness</td>
<td>&lt;150 AUD</td>
<td>125 AUD</td>
</tr>
<tr>
<td></td>
<td>Rainwater Filtration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Effective filtering</td>
<td>Pass</td>
<td>✓</td>
</tr>
<tr>
<td>2</td>
<td>Low maintenance</td>
<td>Pass</td>
<td>✓</td>
</tr>
<tr>
<td>3</td>
<td>Cost-effective</td>
<td>&lt;50 AUD</td>
<td>25 AUD</td>
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<td>Rainwater Storage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Installation Cost</td>
<td>&lt;50 AUD</td>
<td>50 AUD</td>
</tr>
<tr>
<td>2</td>
<td>Accessibility</td>
<td>Pass</td>
<td>✓</td>
</tr>
<tr>
<td>3</td>
<td>Durability</td>
<td>&gt;20 years</td>
<td>20 years</td>
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<td></td>
<td>Final Solution</td>
<td></td>
<td></td>
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<tr>
<td>1</td>
<td>Shelter from extreme weather</td>
<td>Yes / No</td>
<td>Yes</td>
</tr>
<tr>
<td>2</td>
<td>Clean and efficient rainwater capture</td>
<td>Yes / No</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>Use of local materials and labour</td>
<td>Yes / No</td>
<td>Yes</td>
</tr>
</tbody>
</table>
The validation table above takes into account the earlier developed design criteria and performance metrics at the start of the project to evaluate the final recommended solution against them. This helps to check if the solution that came out of the design process adheres to the main user requirements and needs of the project scope. As seen from the performance of the final solution in the table above, it is confirmed that even though the solution was on the boundary limit of a couple of performance metrics, all the design criteria identified have been successfully met.

This obviously follows logically as the same set of design criteria were used in the selection matrices while selecting the final concepts after the concept generation stage of the project. The various generated concepts had hence already been indirectly evaluated in the concept selection section. This ensured that the final recommendations for the solution were corresponding to the above factors.

At the start of the project, the problems identified in the village were the lack of regular access to clean and safe water, lack of adequate strong shelter and the weak economy. The user requirements formulated to address these problems were to develop a system to provide clean and efficient water capture and shelter from the extreme weather with an attempt to emphasise on the use of local materials and labour. The rainwater harvesting system and the Sisal-CNSL roof have been chosen to meet the technical demands of this purpose with the help of practical and cost-effective materials as well as the innovative composite roof. The local manufacturing possibility of the roofing panels has also opened a new employment and revenue generation prospect in the economy. These considerations have potential to fully address the above user requirements. Hence, it is validated that the chosen engineering solution is appropriate for the community of Devikulam.
8. Life Cycle Assessment (LCA)

Table 8: Visual summary of Life Cycle Assessment for chosen solution

The above chart summarises the inputs and outputs of the recommended solution with respect to it’s general life cycle.
The first and most resource-intensive phase of the solution’s life cycle is in obtaining the raw materials since there are a lot of components in the system. The primary inputs required are labour for production and energy to run the machinery. Apart from these, the other basic inputs required are all the materials required for the production of the solution.

For the roofing components, Sisal fibre and CNSL are required while the rainwater harvesting system requires aluminium and bamboo for guttering. PVC piping, a First Flush Diverter System (FFDS) and other plumbing materials like taps, joints and brackets will be required as well. However, as some of these materials involve transportation needs, there are waste outputs from this process. These include emissions as well as effluent and organic waste. The organic waste from this process is recommended to be recycled to provide manure in the village and it can also be used in potential biomass energy systems.

The next step in the life cycle of the solution is the actual manufacturing and implementation process. This involves working with the raw materials from the previous stage to produce the final solution. The manufacturing is likely to be done in a separate low-scale workshop in the village or in a part of the community centre. This process will involve input mainly from machinery for the roofing panel production as well as other tools and equipment like safety goggles and gloves to observe Occupational Health & Safety procedures. Labour is also a key integral input as it provides the villagers with a new means of job and income. There will be effluent and organic waste form this process too while there is likely to be a lot of offcut remains of the sisal fibre. Both of these waste outputs have also been included in the recycling plan in order to make sure they don’t actually contribute to waste. The organic waste can be used as bio-fuel or in bio-digesters while the sisal fibre offcuts can be used to produce sisal-based handicrafts and rugs.
Sisal-based goods have an existent rural market and provide an extra means of job and income for women in the Devikulam community. Sisal mats and rugs are also commonly produced and sold in rural India. This way the offcut wastage can be minimized and kept in the life cycle in a productive way.

The usage part of the product life cycle is a smooth stage with minimal inputs required. This stage is estimated to last an estimated 20 to 25 years. The only inputs coming into this process are the natural rainwater from the environment and marginal labour efforts in maintaining and keeping the system clean. There may however be some minor waste outputs from this stage in the form of organic waste as leaves and debris from the guttering as well as graywater filtered form the First Flush Diverter. Both of these wastes have however been included in the recycling process wherein the organic waste will be used for compost purposes in the village. The residents in Devikulam own two-wheelers and animals so the graywater can be used to clean them and also to water plants.

The final stage in the product life cycle is termed it’s End of Life. This stage in general cases has potential to create large waste outputs. However, considering the limited means of the Devikulam people, this has to be minimised in this project scope. In fact, the selection of the concepts in the design criteria was done using the sustainability factor of the materials in mind. Hence, even at the end of the roof’s and guttering’s lives, they can be re-used. The roofing panels have been recommended to be used for fencing or animal shelter while aluminium material can be sent for recycling. However in the case of a few materials like bamboo and PVC, scrap waste may become inevitable. Overall, the careful selection of the solution has ensured that the usage inputs of the system are minimal and that most of the waste is either recycled or re-used successfully.
9. Proposed implementation steps

The people of Devikulam living under palm and thatched leaf roofs have already expressed their wish for roofs that don’t leak. Therefore they would be comfortable with their roofs being replaced with the better quality Sisal-CNSL composite material. Everyone in Devikulam may need to be educated on the importance of clean drinking water, and the potential health risks of drinking dirty water. This would help to encourage the community to adopt this design so that they can access clean drinking water throughout the year. Hence, interactive awareness camps with the villagers will be conducted first.

After the transportation and installation of materials required, the solution implementation will be carried out in a two-stage process. The first stage in this scheme is a pilot evaluation stage where the two variants of the solutions will be initially implemented on two houses. One of these will incorporate a solution based on aluminium guttering and the construction of the new roof after removing the existing thatched roofs. A second household will be chosen to incorporate a bamboo-based guttering system with the new Sisal-CNSL roof being laid on top of the existing thatched roof as an extra layer.

EMS labs, which tested the quality of the water from the bore wells for the EWB organisation will be hired to test the water quality in the tanks of both houses after the 1 week trial period. (EWB, 2011d) If both tanks have water suitable for drinking then the most cost effective design will be implemented for the whole community in the second stage of the process. Although the design with the aluminium gutters is more expensive in the initial implementation, it will require less maintenance and has a greater life-span. This means it will be significantly cost-effective in the long run compared to bamboo which would have to be replaced quite often. But it will be up to the people of Devikulam and the...
funders of the project to decide which design to implement based on the cost. If it is determined that only one of the designs has water of a high enough quality to be used, then that design will be implemented. If neither design has collected water suitable for drinking then the design re-examined, possibly incorporating a better filtration system or different materials based on evaluation. The recommended implementation process in relation to time-span has been summarized in the Gantt chart below.

Table 9: Gantt Chart of Implementation process

<table>
<thead>
<tr>
<th>No.</th>
<th>Task</th>
<th>Duration</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
<th>Week 7</th>
<th>Week 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>User Awareness Camp</td>
<td>1 Week</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Transportation</td>
<td>1Week</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Machinery Installation</td>
<td>1Week</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Training</td>
<td>1Week</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Manufacturing</td>
<td>3Weeks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Roofing Installation</td>
<td>1 Week</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Water System Installation</td>
<td>1Week</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Testing &amp; Improvements</td>
<td>1Week</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>User Evaluation</td>
<td>1Week</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The people of Devikulam will play a big part in the implementation and maintenance of this design. Any semi-skilled labourers of Devikulam will be able to install the rainwater capture system on the houses of Devikulam, if they are provided with the necessary tools and materials and given adequate guidance. Training sessions for this purpose are also recommended in the implementation plan to ensure good quality work. All Devikulam residents will be able to maintain their rainwater capture system by themselves, although some residents may need the help of their neighbours. As the system doesn’t require much time or resources to maintain, and it is easy to do. Ideally the residents of Devikulam would help each other, especially the less able residents.
As the implementation of this solution also involves a new career-opportunity window for the residents of Devikulam in the manufacturing of Sisal-CNSL corrugated roofing panels, training sessions for the required production skills will also have to be conducted. This may need the involvement of professional people from outside Devikulam. Based on the scale at which the funders want to implement the solution, they may even be able to support this need through their professional contact network. The Occupational Health & Safety requirements for this stage have also been accounted for in the Bill of Materials for the project with the machinery and equipment. An estimated 20 workers may be able to be employed in this process and safety goggles, gloves and masks for them have been included. While the NGOs supporting the community may be initially able to help in the business start-up and market activities in the short run, the long-term responsibility for the business lies in the hands of the members of the community adopting the project as with any other entrepreneurship.

The primary role of the external supporting organisations like the EWB and the Pitchandikulam Forest will mainly revolve around providing grass-root level support in the project. Initial funding may be required from these organisations as well as international aid agencies like AusAID and Global Water. Considering the deep-rooted involvement of the EWB in the community, it would be very fruitful for them to be involved in the awareness stages of the implementation and also supporting the villagers to gain the rudimentary skills for maintaining the system. If the residents of Devikulam are given the right level of awareness and training in this project, the long-term success of the solution is more likely. Hence, co-operation with the villagers in communication is very important and the EWB organisation is a critical link in this relationship.
10. Conclusion

The aim of this engineering project in conjunction with the EWB Design Brief was to develop a sustainable solution to promote the development of the Devikulam community in the selected areas of rainwater harvesting and roofing. Various factors like the limited means, shallow technical skills and cultural considerations of the people were kept in the crux of the design criteria and user requirements in developing the solution.

The main problems addressed by the solution were the lack of sufficient access to clean and safe drinking water in the community as well as the inability of the roofs in the village households to sustain the harsh weather or aid rainwater collection. The final solution recommended by Engineering PhD was a cost-effective, long-lasting rainwater harvesting system with the implementation of new composite roofs for the households in Devikulam. The solution meets the primary user requirements of providing strong shelter and protection to the residents while ensuring efficient rainwater harvesting to promote the independence of the villagers to meet their needs.

This engineering solution has been recommended to be implemented in the Devikulam community in a two-stage process involving a pilot evaluation before final implementation. There will also be interactive awareness sessions with the villagers about the product. The solution will be implemented in 2 households initially to test specific variables and performance based on which data and feedback from users will be collected. This data will be evaluated and the final implementation process will be carried out based on information from this evaluation. This will ensure the delivery of a safe and successful solution to meet the needs and requirements of the Devikulam community.
11. Reflection

11.1. Ethics (Samuel Richardson)

The group made decisions on the direction of the design impartially and objectively. An example of this behaviour was the decision to move away from a new and innovative form of power generation. This technology may not have been able to solve Devikulam’s energy problem and it may have cost too much to be implemented and for the community to maintain. Despite this, it may have been rewarding for our group in the project as the design was innovative and potentially very beneficial if it could be afforded. Our group decided to do what was best for the community, a design to overcome poor shelter and the shortage of clean water, over what may have been more beneficial for our group. This decision to solve the health and safety problems of Devikulam demonstrated our integrity as engineers.

Our group practiced competently, as we operated in a way where we met frequently to review each other’s work and collaborate on it. In addition, the group sent emails to each other with their work attached, and then each group member sent a reply email with feedback on the work. These procedures practiced by our group demonstrates how the group frequently used peer review and furthered the development of each team member by giving constructive feedback on their work.

Leadership was demonstrated when our group organised a meeting with our lecturer, and a stakeholder in our project, Mr Jeremy Smith, to discuss the potential risks of our design due to the lack of research into the material to be used for roofing, the sisal-CNSL composite material.

Sustainability was promoted by our group in our design, as we decided to use the sisal-CNSL composite material in our design. This material uses the locally sourced sisal plant, which is not only an abundant resource in the area, but will also provide jobs for locals in harvesting the plant. Our group’s design also promotes sustainability in that it seeks the involvement of the community in deciding if they want to implement the design after the trial period, and if so, whether they want to implement the design with half round aluminium gutters or bamboo gutters.
11.2. Australian Context (Benjamin Courtney-Barrer)

Many concepts and approaches utilised in this project are equally appropriate for an Australian context. From the project, it is immediately evident that the design area of an efficient rain water catchment and storage system fits this criteria as that, like Devikulam, Australia is facing some serious issues with water supply due to its temperamental climate conditions and the rapid rate at which the population is increasing, which is expected to double by 2050 (CSIRO, 2011). Furthermore, due to climate change and the arising political movements towards a carbon tax; the emphasis put on the natural materials, local production and community engagement for the manufacturing and implementation of components in this project is an essential aspect of any new system being designed for Australia’s community.

This emphasis strongly correlates to the environmental ethics surrounding this project in regard to its life cycle assessment, which, in a similar and perhaps more profound way in an Australian context, presents the responsibility for environmental sustainability in the design. In-addition to this, the ethics surrounding the absolute safety in the design is the same in any context, irrespective of location and culture.

If this project were reassigned to a region in Australia, the only component of the project that would require reorientation is emphasis on the production and installation of roofing materials, as that majority of Australian homes have tiled or metal roofs that are suitable for rain water catchment, and that provide adequate shelter for their residents. Besides this, the emphasis on low cost, local materials and production, and efficient water catchment would remain the same.
11.3. Sustainable Development (Shuai Li)

Sustainable development is one of the compulsory elements that we have considered in our project design. When we started shaping the design, we tried to solve the problems for Devikulam with the least environmental impacts. At the same time, we also considered the sustainability from social and cultural perspectives. Most people living in Devikulam have thatched roofs and mud-brick houses. Therefore, residents of Devikulam have become used to using natural materials in their life. In addition to that, the average annual income of each household is about 27,557 rupees (EWB, 2011b) which is relatively low compared to developed countries. All the information implied that most of the materials that we were going to would be natural and local. With this guidance, we came up with the idea of sisal fibre for part of the roofing panel materials and bamboo for the gutters. Both materials can be obtained locally and their wastes won’t cause any negative impacts on the environment.

Several conventional materials have been used in the final design. This is due to the low durability of natural materials. Most natural materials start decomposing after a short period of use. In the long term, it will have a negative impact on the environment with regard to regular maintenance and replacement. Based on this consideration, we chose aluminium as the alternative solutions for guttering and PVC as the material for the water tank and pipes. Generally, both aluminium and PVC can last more than 20 years and can be fully recycled after their application. This can reduce the negative environmental impacts in the long term. However, the resin in the sisal-CNSL composite is not recyclable due to the thermosetting structure. Therefore, disposal of the sisal-CNSL composite is the only process that might have a negative impact the environment. A solution to this problem is to find alternative applications for the roofing panels, such as fencing.

Comparing to other options which include no actions, our final design has high suitability with Devikulam people’s context and needs. The final design is recommended based on the comprehension of social, cultural, and environmental responsibilities with consideration of principles of sustainable development.
11.4. Technology Adoption (Tristan Anderson)

Justification of use

The people of Devikulam have some very serious issues with their water supply. As only one of their three bores is still available for drinking water, they are in a very dangerous situation because if the bacteria level in that bore was to exceed the level of safe drinking then they would have little or no water supply.

Our design is a vital investment for the people of Devikulam as it will provide a reliable source of clean drinking water. By capturing rainwater from the roofs of houses and storing it in water tanks, it is possible to ensure a safe water supply throughout the year. This will eliminate the people’s reliance on bore water and give them a feeling of independence.

In addition to providing water, our design will also give them proper shelter from the elements. Approximately 70% of houses have thatched roofs (EWB, 2011), and these provide poor shelter from the harsh rains of monsoon season. Replacing the roofs with Sisal CNSL will increase the quality of living inside their houses during the monsoon season.

Possible problems that may be encountered

One possible problem that may be encountered is the social gap between the colony and the village. Implementing the same system for everyone in Devikulam is fair; however the villagers may not see things with an open mind. Promoting equality between two classes that consider themselves apart could cause unrest in the community. Another possibility is that the people may not completely understand the implications of their new technologies, such as the vital maintenance that is required to ensure clean water. Even worse, the people could one day begin to take their water supply for granted, and the system may fail through a period of abnormally dry weather or even poor maintenance.

Challenges upon implementation and use for the community

One of the main challenges for implementing the system for the community will be the installation of their new roofs. It may or may not be possible to have people living in a house when it is given a new roof. Another factor that his may depend on is whether a roof can be installed in one day, and then the house be available for occupation during the night. If this is not a possibility then it will be necessary for the community to pull together and provide shelter for families when their houses are being rebuilt.

Another challenge of using the system is keeping up with the maintenance requirements. Roofs that have been polluted with sodden leaves are not very pleasant – but completely necessary – to clean. The peoples of Devikulam may notice that having leaves on the roof does not have significant implications on the purity of their water; however the damage of dirty water may be incurred even if they cannot detect it.
11.5. Cross-Cultural Work (Sriraj Gowthaman Srilakshmi)

With the whole design project being based in an overseas location such that no direct access to the community of Devikulam was possible, the cross-cultural context during the project was highly stressed upon. In this respect, it was probably useful for the team that I am a Hindu person of Indian origin – specifically born in the same state of Tamil Nadu.

I personally realised the deep implications and difficulties embedded in this theme while discussing certain aspects with Australians involved in the project such as tutors. Though it can be considered that they have not been exposed to Indian cultures, there were a few confusions. One of the tutors I interacted with seemed to be skeptical of access to “Western” materials in India and also a bit too cautious about the people in Devikulam having their current roofs removed and replaced.

However, it can be guaranteed that cultural considerations had indeed been taken into account in several instances. During the initial brainstorming, we took into consideration that the village’s lake might probably not be allowed to be used for invasive filtration as it holds religious significance to the people as implied by the name meaning “The Lake of the Goddess”. The main confusion in the project arose with the selection of the guttering material where-in the team seemed to concur with using aluminium while a tutor seemed to suggest bamboo; citing “Western” materials may not be available. However, in reality, the converse is true as it may be surprising for ‘First-World’ people to know that it is cheaper and easier to source such materials in India. The suggestion that “Western” technology is rare in India is unfounded considering India is one of the fastest developing countries in the world.

In fact, while recommending aluminium over bamboo, the long-term benefits were looked at keeping in mind that Indians are well-known for long-term thinking. The cultural consideration of India being a former colonised country was also taken into account as the people may want to move away from using traditional materials towards new advanced materials in order to distance themselves from colonial memories. Using bamboo might have given them the notion that they may still be stuck in the past era of economic difficulties and political suppression before gaining independence.

Such minute cultural considerations were kept at the heart of all decisions during the project. We have also included an interactive awareness campaign in our implementation plan to communicate effectively with the people. Hence, I firmly believe that these cultural aspects have influenced our final design solution deeply and may be mutually accepted by the community of Devikulam.
12. References


13. Appendices

Appendix A

Chart 1: Contour map for average annual rainfall in India

(Survey of India, 2008)

<http://www.surveyofindia.gov.in/soi_maps/atlas/p_28_200.jpg>
Appendix B

Chart 2: Average rainfall (mm) per month in Villupuram

(Gowthaman Srilakshmi, Sriraj. Processed from IMD, 2010)

Chart 3: Average rainfall collectable (Litres) per month per household

(Gowthaman Srilakshmi, Sriraj. ENGN1211 Assignment B. Report. 2011)
Appendix C

Table 1: Annual Rainfall in Villupuram District, India. (IMD, 2008)

<table>
<thead>
<tr>
<th>State</th>
<th>District</th>
<th>Year</th>
<th>Annual Rainfall (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAMILNADU</td>
<td>VILLUPURAM</td>
<td>2004</td>
<td>1567.9</td>
</tr>
<tr>
<td>TAMILNADU</td>
<td>VILLUPURAM</td>
<td>2005</td>
<td>1384.4</td>
</tr>
<tr>
<td>TAMILNADU</td>
<td>VILLUPURAM</td>
<td>2006</td>
<td>1072.0</td>
</tr>
<tr>
<td>TAMILNADU</td>
<td>VILLUPURAM</td>
<td>2007</td>
<td>1200.1</td>
</tr>
<tr>
<td>TAMILNADU</td>
<td>VILLUPURAM</td>
<td>2008</td>
<td>1433.0</td>
</tr>
</tbody>
</table>

Average Annual Rainfall (mm) 1331.48

Figure 1: Mind mapping the user requirements

(Anderson, Tristan. ENGN1211 Assignment B. Report. 2011)
Appendix D

Shuai (Jack) Li had e-mail correspondence with Dr. Martin Ansell (author of sisal-CNSL journal articles) about the properties of sisal-CNSL. The transcript of the communication is shown below. The order of the e-mails are such that the newest message is shown first.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Thank You!</th>
</tr>
</thead>
<tbody>
<tr>
<td>From</td>
<td><a href="mailto:u4748327@anu.edu.au">u4748327@anu.edu.au</a></td>
</tr>
<tr>
<td>Date</td>
<td>Monday, March 28, 2011 9:19 am</td>
</tr>
<tr>
<td>To</td>
<td>Martin Ansell <a href="mailto:M.P.Ansell@bath.ac.uk">M.P.Ansell@bath.ac.uk</a></td>
</tr>
</tbody>
</table>

Hi Dr. Martin,

Thanks for taking your valuable time to answer my question. I will do the suggested tests if my team can. Appreciate your positive consideration.

Regards,
Jack

----- Original Message ----- 
From: Martin Ansell <M.P.Ansell@bath.ac.uk>
Date: Monday, March 28, 2011 8:43 am
Subject: RE: RE: Academic Question on Sisal-CNSL Composites for Roofing
To: 'Shuai Li' <u4748327@anu.edu.au>

Hi Jack,

No, only if an insect tries to eat the CNSL will there be a problem (for the insect!). If the CNSL is fully cross-linked it should be stable and should not leach out. You would have to carry out purity tests to prove that the water is potable.

Best wishes,

Martin

From: Shuai Li [mailto:u4748327@anu.edu.au]
Sent: 26 March 2011 23:14
To: Martin Ansell
Subject: Re: RE: Academic Question on Sisal-CNSL Composites for Roofing

Hi Dr. Martin,

What do you think about collection of rain water by using the Sisal-CNSL composite
roofing? Do you think the poison of CNSL will affect water quality? Thanks again.

Regards,

Jack

----- Original Message -----  
From: Martin Ansell <M.P.Ansell@bath.ac.uk>  
Date: Sunday, March 27, 2011 7:31 am  
Subject: RE: Academic Question on Sisal-CNSL Composites for Roofing  
To: 'Shuai Li' <u4748327@anu.edu.au>

> Hi Jack,
> The cashew tree is pretty poisonous except for the edible kernel of the nut, hence its ability to survive in tropical conditions.
> We didn't have time for environmental tests during Elifas's PhD programme but my expectation is that the CNSL would be very stable although any exposed natural fibre would not be. CNSL is a constituent of paints, coatings and brake linings.
> See:  
> http://www.cardanol.net/  
> http://www.cardolite.com/  
> Best wishes,
> Martin

> Dr Martin P. Ansell  
> Reader in Materials  
> Department of Mechanical Engineering  
> University of Bath  
> Bath  
> BA2 7AY  
> http://people.bath.ac.uk/mssmpa/  

> From: Shuai Li [mailto:u4748327@anu.edu.au]  
> Sent: 26 March 2011 09:52  
> To: M.P.Ansell@bath.ac.uk  
> Subject: Academic Question on Sisal-CNSL Composites for Roofing  

> Dr Martin Philip Ansell,
> I am an mechanical engineering student from the Australian National University. One of
my projects is working on improvement of roofing conditions for a small village in India.

> I have been very interested in one your past student’s PhD thesis, "Sisal fibre reinforced composites" by Bisanda, E.T.N.. I know it was long time ago, but I still hope you could give some advice or reference to my question about the Sisal-CNSL composite since you are an expert in this field.

> One of the issues about natural-plant roofing, such as palm-leaf roof or thatched roof is about mildew or mold due to long-term high temperature and humidity. Does the Sisal-CNSL have a high resistance to mildew or mold? And, how’s its durability performance?

> Thanks for taking your time to read my email. I appreciate any positive consideration from you.

> Regards,

> Shuai “Jack” Li
Appendix E

Pictures of brainstormed roofing material solutions

Fig 2: Model of house with sisal thatch roof
(Vectis.co.uk, 2011)

Fig 3: A completed EPDM flat-roof
(Flat Roofing, 2011)

Fig 4: Typical PVC corrugated roofing sheets
(Oursbiz, 2011)
Appendix F

Pictures of rainwater-capture solutions

Figure 5: Typical roof-top rainwater harvesting system (Allthingsrainwater, 2009)

Figure 6: RainTube working (RainTech, 2011)
Figure 7: GutterFilter installed in gutter (GutterFilter, 2011)

Figure 8: Schematics of 3P Filter Collector (3P Technik, 2011)

Figure 9: Typical Sintex water tank produced in a single seamless piece (Sintex, 2011)
Appendix G

Primary filtration techniques

Figure 10: Example of fine gutter mesh used to protect gutter from debris
(Gutter Mesh Queensland, 2011)

Figure 11: Schematic representation of how the First Flush Diverter System
(FFDS) works using a hollow floating ball
(BRAE Water, 2011)
Appendix H

Thumbnails of Engineering PhD building prototype model
(Courtney-Barrer, Benjamin. Photo. 2011)