Multidisciplinary Senior Design
Project Readiness Package

Project Title:	Biochar Concrete Roofing Tile Manufacturing Process and Complete Roof System
Project Number: (assigned by MSD)	P18485
Primary Customer: (provide name, phone number, and email)	4 Walls Project: http://www.4wallsproject.org/; Bonnie Yannie, bonnieyannie@gmail.com; Enlace Project, https://www.enlaceproject.org/ , https://www.facebook.com/enlaceproject/ ; Kellan Morgan, kellanpmorgan@gmail.com, 585-752-0227
Sponsor(s): (provide name, phone number, email, and amount of support)	MSD
Preferred Start Term:	Fall 2017
Faculty Champion: (provide name and email)	Sarah Brownell, sabeie@rit.edu, 585-330-6434
Other Support:	Ithaka Institute: http://www.ithaka-institut.org/en/home; Kathleen Draper, 585 737 7282, kdraper2@rochester.rr.com ; Manitou Concrete, Dr. Todd Dunn, Civil Eng. Tech (for lab use), John Kaemmerlen (previous team's guide), Eagle Roofing Products
Project Guide: (assigned by MSD)	

Sarah Brownell 7/27/17
Prepared By Date

Received By Date

Project Information

The 4 Walls Project (http://www.4wallsproject.org/) helps indigenous families in El Sauce, Nicaragua obtain their own home. The homes are currently 20' x 20', concrete post and beam construction with brick walls, a dirt floor and a zinc roof. 4 Walls tries to support the local economy as much as possible with their purchases, but the roof material is not currently produced locally. It also brings unwanted heat into the house, is very loud in rainstorms, and costs more than $400/house. Each house requires forty 3` x 10` zinc sheets.


Current "housing"


House built by 4 Walls




Current roof design with the exception that 4 Walls has since switched to metal C channel trusses instead of wood beams (which are welded together on-site).

Two years ago, the Ithaka Institute, a non-profit foundation researching and promoting the use of biochar, and the 4 Walls Project teamed up with the MSD program to develop new biochar composite concrete roofing tile designs to replace the galvanized roofing sheets. Biochar is a carbonaceous material created by the thermochemical decomposition of organic materials at elevated temperatures in the absence of oxygen, a process known as pyrolysis. Charcoal is one form of biochar, but biochar can be made from many types of biomass including agricultural wastes. Biochar has interesting characteristics due to its composition and physical structure including low density, high porosity, and elevated pH which can vary based on what it is made from. It can be used as a soil amendment, an animal dietary supplement, a sustainable charcoal replacement, a filter material, and as a component in composite building materials. Because of its stability, it also has potential for sequestering carbon taken from the atmosphere by biomass as a remediation for climate change. Researchers are just beginning to experiment with biochar amended concrete and plastic composites that could result in lighter weight and lower cost building materials with enhanced insulating, filtering, cooling, and humidity control characteristics. Some recent attempts include biochar-concrete panels, biochar-lime bricks, indoor and outside insulating plasters (see http://www.ithaka-institut.org/en/ct/97-Biochar-as-a-Building-Material).

Two years ago, MSD team P16485 took the first steps for developing lightweight concrete roofing tiles that can be manufactured locally in El Sauce from innovated waste materials including biochar and string from plastic bottles. They molded shingles using molds made by vacuum forming and provided a wood and bamboo truss design for the support structure.

Team P16485's roof prototype next to a standard roof design at Imagine RIT.

Last year, Team P17485 improved on the design to eliminate some leaking areas at tile junctures, optimized the concrete mix for strength and weight, and developed a basic manufacturing process. They changed the tile shape to a W shape to mimic existing clay roof tile designs and discovered that the biochar content in the concrete mix could be as high as 20% by volume, along with 35% Portland cement and 45% sand and an additional 0.42lb per cu ft. plastic bottle strings added after mixing. The size of the biochar particles--which act as small air spaces in the concrete to reduce weight--may be a factor in the overall strength of the concrete mix design. The team discovered a company in Nicaragua that was using pumice from local volcanos as an alternative to biochar to make lightweight tiles. The plastic stings help distribute the tensile load in the concrete and also provide a measure of safety—if a tile breaks, it should not completely fall apart. This safety feature helps prevent broken tiles from falling on the inhabitants. Previous teams have tried to mimic the size and length of plastic reinforcements available on the market in the US (these are available in the MSD cubical) and an MSD team last year, P17432, looked at how to create string and rope from bottles which could also be used as reinforcement.

Last year's roofing team also explored various methods for attaching the tiles to the roof, settling on a nub with molded wire design as the best option so far (see their customer handoff page on Edge for various options). The team developed the beginning of a manufacturing system where concrete is poured flat, vibrated to remove air bubbles, placed over corrugated foam molds and stacked for curing. Finally, they began work on a cost analysis, but it needs refining based on feedback from El Sauce residents on real costs. One of the team members was able to visit El Sauces during Winter Break which significantly influenced the team's design decisions, especially related to attachment methods.


Team P1748's Tile Manufacturing Process

Team P17485's Roof Design being compared to standard galvanized roofing in the rain.

The basic tile design developed by last year's team is considered ready to field test with the possible exceptions of 1) the need for a steeper curve along the mating surface to prevent leaking in windy storms and 2) the need for optimization of the particle size and material of the light weight aggregate (biochar vs. pumice). Other aspects of the larger roof system also need to be refined for construction of a complete roof. This team is tasked with developing:

- A complete roof system including the top plates and gutters.
- A proven method of attaching individual shingles to the roof trusses.
- A method of easily integrating the plastic string reinforcement in the molding process.
- A better understanding of the supply chain.
- A complete manufacturing system for molding at least 20 tiles/day including tools for producing the materials used in the system:
    - Biochar or pumice of the recommended particle size (currently about 1/8"-1/4" diameter particles)
    - Sand of the recommended particle size (coarse sand)
    - Plastic bottle strings of the right size/shape (currently 1/8" wide x 2" long strings, but the previous team also consider making a plastic mesh to insert in the mold)
    - Connector strings for securing the tiles to the roof trusses
- An analysis of economic viability compared to other roofing options.
- A lifecycle assessment comparing the sustainability of the new design to existing roof options.
- In addition, 4 Walls would like the team to explore the viability of using pumice that is locally available in Nicaragua as a replacement for the biochar in the concrete mix.

Other teams may offer some help on this project. Team P18416 Belasenp Arborloo Base Manufacturing is also working with a similar lightweight concrete mix and your team is welcome to collaborate with them on developing processes for producing some of these materials. Team P18432 is working on a process to make rope from recycled bottles, so they are developing devices to make string from bottles. Your team is welcome to explore all options for each task from purchasing equipment to borrowing from or collaborating with other teams, to creating the appropriate tools themselves.

These roofs will need to be produced in quantity in Nicaragua, so manufacturing processes, jigs, and fixtures need to be developed to facilitate easy, low cost production. This project will likely involve the opportunity for student travel to Nicaragua. Fluent Spanish is a plus on this project!

Resources:

Lightweight Concrete Roofing tile teams:

P17485's website: http://edge.rit.edu/edge/P17485/public/Home

P16485's website: http://edge.rit.edu/edge/P16485/public/Home

Previous Concrete Arborloo teams:

http://edge.rit.edu/edge/P14416/public/Home

http://edge.rit.edu/edge/P15416/public/Home

Bottle Rope Team

Ingredient	Range
Cement	7% - 15%
Aggregate	60% - 80%
Water	14% - 18%
Air	2% - 8%

http://edge.rit.edu/edge/P17432/public/Home
Eagle Roofing: http://www.eagleroofing.com/metal-vs-tile-metal-roofing-compare-concrete-roof-tiles/
Standard Concrete Mix Info and ASTM standards:
https://www.concretenetwork.com/aggregate/

*** Preliminary Customer Requirements (CR):**

Roof:

Attaches to the existing post and beam with brick construction used by 4 walls
Prevents rain from entering the house
Reduces noise from rainstorms as compared to galvanized sheets
Reduces solar gain to the house as compared to galvanized sheets
Resists removal by wind
Modular (accommodates different size and shape homes)
Portable by truck for transport to site
Portable by people for installation
Supports a person on the roof for installation and maintenance
Utilizes a local waste product (such as coffee husk biochar, plastic bottles)
Inhibits animals from making homes in the roof
Can be constructed locally in El Sauce
Can be installed using local labor
Cost estimate is less than or equal to current galvanized roof cost
GHG emissions are less than standard galvanized roof

Manufacturing System

Produces component materials for roof construction

- Lightweight aggregate from pumice, sugar cane bagasse, corn cobs, or other ag wastes
- Consistent Biochar/pumice particles (currently about 1/8" – ¼" diameter particles)
- Consistent Sand particles (coarse sand--research concrete standards)
- Consistent Plastic bottle strings of the right size/shape (currently 1/8" wide x 2" long strings)
- Consistently dimensioned roof tiles
- Consistently dimensioned roof cap (top of roof)
- Diversion of water coming off roof for removal away from house or rainwater collection
- Materials for attachment of tile to trusses

Production rate of at least 20 tiles per day
Efficiently utilizes labor hours
The system can be transported to El Sauce or produced there
Made with robust parts or parts that can be replaced in Nicaragua

*** Preliminary Engineering Requirements (ER)**:

Requirement	Ideal	Marginal
Particle size diameter of biochar/pumice (in)	1/16 – 1/8	1/16 – 3/16

Percent of biochar/pumice particles in the range (%)	90	70
Particle size of sand	Coarse sand	
Bottle String width (in)	1/8	1/8-3/16
Bottle string length (in)	1.75-2.15	1.5-2.5
Full line Production rate (tiles per day)	>20	>10
Time to install a roof on 4 Walls House (h)	Faster than current	<1.5 x current
Resists lifting force (N)	Estimated class II hurricane	Estimated class 1 Hurricane
Meets waterproof standards (oz/hr or check for better metric)	0	1
Loudness in rainstorm (db)	>25% less than galvanized sheet	Less than galvanized sheet
Supports a person (lb)	250	150
Reduces solar heat gain transmitted (%)	>20	>10
Weight of each piece (lb)	<30	<50
Estimated weight of full 4 Walls roof (lb)	Same or less than current	Supported by house with FOS >2
Largest hole/space in roof connections (mm)	<5	Resists snake nesting
Total roof cost for 4 Walls ($)	<300	<400
Power tools required for installation	0	<2
Hand tools required for installation	<2	<4
Skilled operators required for fabrication	<1	<2
Total operators required for fabrication	<2	<4
Max dimensions of each subassembly/piece	< size of local truck bed	Size of local truck bed
Roof materials imported (% of total roof cost)	<25	<50
Level of modularity (dimensions accommodated in length and width)	<2 foot increments	<4 foot increments

Some roof testing reference worth looking into:

- ASTM C406: Tests for roofing slate may be a useful reference.
- Metal roof testing method: http://www2.iccsafe.org/states/Florida2001/FL_TestProtocols/PDFs/Testing%20Application%20Standard%20125-95.pdf

*** Constraints:**

- Roof attaches to post and beam construction
- Roof is adjustable for different size houses

- Roof is modular and transportable
- Consider earthquake and hurricane resistance in the design (may not be possible to fully test)
- Utilize local materials readily available in Nicaragua for all roof components
- Construct and install roof locally
- Manufacturing tools made from robust parts or parts that can be replaced in Nicaragua
- Manufacturing tools must be able to be transported to Nicaragua (by checked luggage preferably or by boat)
- Keep cost of roof materials to <$400 per roof
- Keep labor costs + roof costs to <125% of current

* **Project Deliverables:**
Minimum requirements:
- All design documents (e.g., concepts, analysis, detailed drawings/schematics, BOM, test results)
- Molds or custom fabrication tools
- working prototype
- technical paper
- poster
- All teams finishing during the spring term are expected to participate in ImagineRIT

Additional required deliverables:
- Construction manual
- Installation manual
- User manual
- LCA and economic analysis
- 3 minute video for 4 Walls

† **Budget Information:**

Item	**Cost**
Concrete materials (may be able to get donated)	$100
Molds (limiting factor…depends on size of each piece)	$250
Test fixtures (solar gain, water proof-ness)	$100
Misc.	$50
Total	**$500**

Some materials can likely be scavenged from previous MSD teams or Manitou Concrete might donate some…Some parts of the system may not be able to be purchased due to budget constraints. The team should recommend the best system. Solutions can possibly be shared by the various concrete teams. For example, a grinder might be out of budget. Or one team can purchase sieves to be shared while the other purchases a grinder, etc.

* Intellectual Property:

NA

Project Resources

† Required Resources (besides student staffing):
Describe the resources necessary for successful project completion. When the resource is secured, the responsible person should initial and date to acknowledge that they have agreed to provide this support. We assume that all teams with ME/ISE students will have access to the ME Machine Shop and all teams with EE students will have access to the EE Senior Design Lab, so it is not necessary to list these. Limit this list to specialized expertise, space, equipment, and materials.

Faculty list individuals and their area of expertise (people who can provide specialized knowledge unique to your project, e.g., faculty you will need to consult for more than a basic technical question during office hours)	**Initial/ date**
Environment (e.g., a specific lab with specialized equipment/facilities, space for very large or oily/greasy projects, space for projects that generate airborne debris or hazardous gases, specific electrical requirements such as 3-phase power)	**Initial/ date**
Civil Tech concrete lab (Todd Dunn)	
Equipment (specific computing, test, measurement, or construction equipment that the team will need to borrow, e.g., CMM, SEM,)	**Initial/ date**
Tension test machine	
Materials (materials that will be consumed during the course of the project, e.g., test samples from customer, specialized raw material for construction, chemicals that must be purchased and stored)	**Initial/ date**
Biochar (ask Kathleen Draper at Ithaka Institute), Pumice—purchase or bring from Nicaragua	
Other	**Initial/ date**
Manitou Concrete (consultation, possible material support)	

† Anticipated Staffing By Discipline:
Indicate the requested staffing for each discipline, along with a brief explanation of the associated activities. "Other" includes students from any department on campus besides those explicitly listed. For example, we have done projects with students from Industrial Design, Business, Software Engineering, Civil Engineering Technology, and Information Technology. **If you have recruited students to work on this project (including student-initiated projects), include their names here.**

Dept.	# Req.	Expected Activities
BME		
CE		

EE		
ISE	2	Ergonomics, manufacturing engineering, DFx, materials science, materials processing, mold design, Engineering Economics, Shop Floor IE, project management (prioritizing), DOE on biochar/pumice
ME	3	3D CAD, machining, mold design, materials selection, GD&T, Composites, Machine elements
Other		