FORGE

A Sustainable Approach to Disaster Recovery

Debris Recycling Station

Industrial Design Thesis Report

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Debris Recycling Station

By

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Abstract

With climate change becoming an increasingly prominent issue, there is also an increase in the quantity, and magnitude of natural disasters around the world. After a disaster occurs, vulnerable communities are faced with the dilemma of how to use their existing capacity for recycling, composting, combusting, and disposing natural disaster debris. Collapse of waste management services has led to uncontrolled dumping sites and improper handling of waste. Furthermore, uncollected rubble from damaged buildings has impeded access and prevented rehabilitation and reconstruction. The goal of this thesis project is to provide access to the tools and resources necessary for a smoother recovery process for victims in vulnerable areas. The solution will be heavily based on data collection, user observations, and interviews to get more insights into challenges faced by these people.

Acknowledgments

I am eternally grateful for my parents, Jill and Greg, and their undying love and support. Without them, my journey at Humber would not have been possible.

I would also like to thank my loving partner, Mel. Without her words of encouragement, and endless support, this year would not have been the same.

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Figure 1 - Post Earthquake Cleanup. Retrieved from https://temblor.net/earthquake-insights/how-long-does-it-take-to-recover-from-an-earthquake-1515/

1.1 Problem Definition

Natural disasters or becoming more frequent, and with growing populations, more people are becoming at risk. The biggest demographic of concern during these situations are vulnerable/low-income people. Low-income populations generally live in unstable, dangerous housing that is extremely prone to natural disasters. Additionally, the homes are located in areas that are susceptible to the higher rates of natural disasters as the locations are more affordable. Vulnerable people are an underserved market with a high need for more options to protect themselves from natural disasters. From 1980-2009, the international community spent $86.34 billion on emergency response and reconstruction. Only $3.25 billion was spent on prevention and preparedness.

1.2 Investigative Approach Taken

In order to identify the main challenges of rebuilding, several research tools will be made use of, which include:

- Literature reviews
- Information searches
- Analysis of existing solutions
- User observation
- User interviews
- Ergonomics studies
- Activity breakdown analysis

Information regarding key topics will be collected prior to the idea generation stage:

- Current solution
- Target demographic
- User demographics

This thesis project will be based on the premise of answering some of the below-mentioned questions:

- How can the process of separating debris be improved?
- How can we minimize the challenges involved in lifting and transporting heavy debris.
- How can we minimize the amount of debris going into landfill?

1.3 Background, History, and Social Context

After the occurrence of a natural disaster, cities are often reduced to rubble, leaving streets littered with debris, and toxic material. Before the recovery process can begin, it is crucial to clear out all of this debris. This enormous amount of waste can be difficult to manage as workers are required to go into hazardous environments, navigating materials which can be difficult to separate. In vulnerable areas, NGO's increase productivity by recruiting locals to help clear debris. Unfortunately, locals can face many challenges when having to clear debris with minimal equipment and experience. After a disaster occurs, communities are faced with the dilemma of how to use their existing capacity for recycling, composting, combusting, and disposing natural disaster debris. Communities may need to develop additional staging and storage areas to store, separate, or process the debris before it is sent to a recycling, composting, incineration, or disposal facility. An effective disaster debris management plan addresses issues beyond initial removal, by prioritizing debris management options and including a strategy for recycling and reusing materials (including mulching/composting) to reduce the burden of debris volume on disposal facilities. While recycling and reuse is preferred for most debris types, disposal is often only a consideration. Segregating debris is best performed at the original deposited point (e.g., curbside, field).

Chapter 2: Research

2.1 User Research

The succeeding section outlines the collection of research conducted to answer key questions pertaining to this project. Specific research was undertaken focusing on both users and products, which will aid in identifying core user demographics, current user practice as well as ergonomic research.

2.1.1 User Profile/Persona

Primary User	Local Survivors of Disaster
Secondary User	NGO Relief Teams
Tertiary User	Disaster Debris Specialists

Table 1 – Product Users

IMAGE	DEMOGRAPHIC INFORMATION
 *Figure 2 - Who cleans up after hurricanes, earthquakes and war? Retrieved from https://www.bbc.co.uk/news/resources/idt-d7bc8641-9c98-46e7-9154-9dd6c5fe925e*	Age: 21-36 Gender: Mixed Culture: Mestizo Income: Low Educational background: Secondary school (most likely) Career/ Volunteer: Part time employment
 *Figure 3 - Who cleans up after hurricanes, earthquakes and war? Retrieved from https://www.bbc.co.uk/news/resources/idt-d7bc8641-9c98-46e7-9154-9dd6c5fe925e*	Age: 21-40 Gender: Mixed Culture: Caucasian Income: uncertain Educational background: College/Uni Career/ Volunteer: Mixed

 *Figure 4 - FEMA Debris Specialist at Duval debris staging site. Retrieved from https://commons.wikimedia.org/wiki/File:FEMA_-_38834_-_FEMA_Debris_Specialist_at_Duval_debris_staging_site.jpg*	Age: 30-45 Gender: mixed, predominantly male Culture: Caucasion Income: uncertain Educational background: University Career/ Volunteer: Career

Table 2 - Demographic Information

Literature Search for Demographic Data

A literature search was also performed on the Humber Library website and Google to find statistical data relevant to citizens in El Salvador. A vulnerable nation with a high magnitude of natural disasters. The following search terms were used:

“El Salvador Demographics”

“El Salvador Statistics Data”

Findings.

Findings have been summarized below according to the relevant categories: Gender; Age; Race and Ethnicity; Income and Education.

Gender.

As inferred from the image search, El Salvador has a larger female population at 3,430,199 people. That’s 406,845 more than their male counterparts.

Age.

El Salvador has a population that consists largely of a young demographic. 73.2 percent of the population is under the age of 44 and 25.3 percent of the population is under 15.

Education.

More than four-fifths of Salvadorans aged 10 and over are literate. 71.66 percent of the population has a secondary education, while 29.4 percent has a post-secondary education.

Income.

The average income for El Salvador's population is very low, with 40 percent of people living below the poverty line, and a $4000 (US) income per capita.

Discussion / Conclusions

Based on the above research, we can get a general overview of vulnerable populations living in disaster ridden communities. It can be observed that most of El Salvador's population is under the age of 44, taking up 73.2% of the population. It is also apparent that people living in El Salvador are of mestizo ethnicity, at 86.3%. Income is low with 40 percent of the population living under the poverty line, with a $4000 US income per capita. An education level of at least a high school degree is common with a gross enrollment rate of 71.66 percent. Post-secondary education is less common with a gross enrollment rate of 29.4%. With this statistical data, it's easier to envision common patterns of communities in El Salvador.

Demographic of El Salvador locals	
Age	15 - 29
Gender	Mixed (11.86% more females)
Ethnicity	Mestizo
Income	$4k
Education	Highschool

Primary User	Disaster survivor locals
Secondary User	NGO relief teams
Tertiary User	Disaster debris specialists.

User Behavior

A literature search was conducted to discover traits relating to user behavior. For this search Google and the Humber Library websites were used to extract relevant information. The following search terms were used:

“Disaster debris removal”

“Disaster debris removal process”

Findings.

Findings have been summarized below according to the relevant categories: frequency of use/activity (rate), duration of activity, group or solitary activity/level of focus, motivation and lifestyle, income level & purchasing power, location, personality and cognitive aspects.

Activity Frequency.

Debris removal is part of a multistep plan. Proper handling of materials requires several different steps outside of relocating debris. The image below showcases this process.

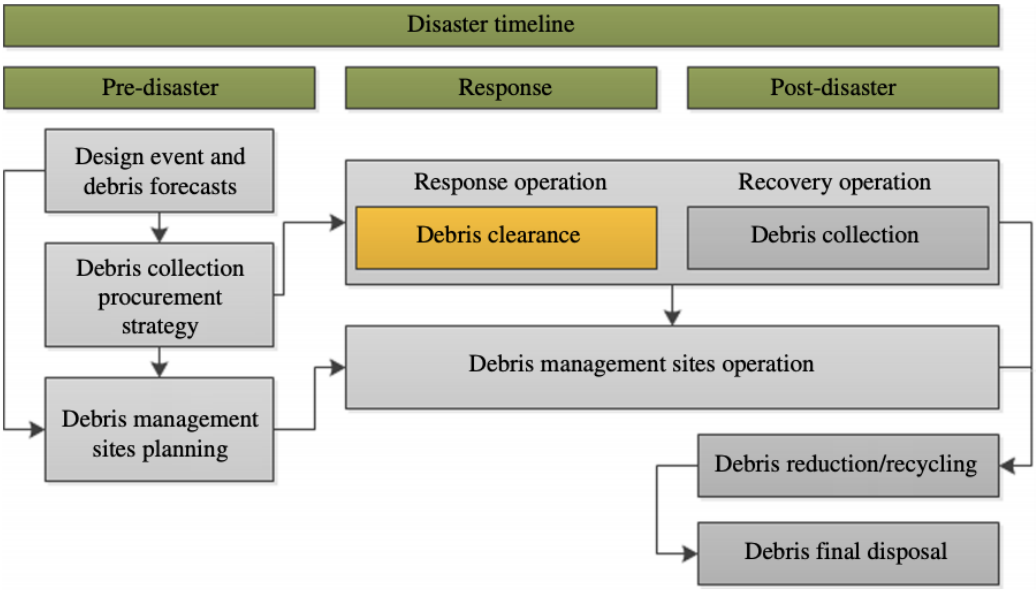


Figure 5 - Elements of a debris management plan during a disaster timeline. [Image] (2017) Retrieved from https://web-b-ebscohost-com.ezproxy.humber.ca/ehost/pdfviewer/pdfviewer?vid=0&sid=97f2d8df-ec4a-4de4-baa4-5cd422e0cc73%40sessionmgr101

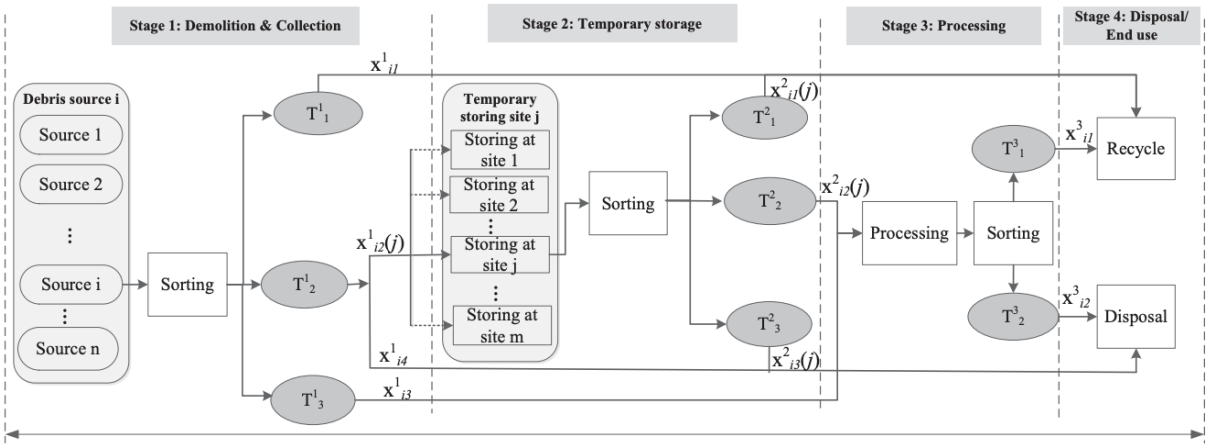


Figure 6 - Reverse logistics framework of recovery phase for debris removal. [image] Retrieved from https://web-b-ebscohost-com.ezproxy.humber.ca/ehost/pdfviewer/pdfviewer?vid=0&sid=05a7e09b-cf1b-47d0-9db9-87f7e90f0ed2%40sessionmgr103

Social.

“authorities work alongside experts and local people to develop a detailed disposal plan.” (Rodgers)

Lifestyle & Personality.

“After the [earthquakes], kinship ties, including the bonds of compadrazgo, [are] mobilized to provide assistance to people [they know]. This is a common-sense procedure, for in a culturally determined context, it is expected that one will first help those one knows, all the more so when calamity strikes. The norms of Salvadoran society foreground biological and ritual kinship ties.” (Sliwinski)

Income Level.

Locals receive income provided by NGO's for their work, however the rate of pay is unclear. "Machinery is fast, but expensive, while cash-for-work is slower, but has the added advantage of engaging the community and providing livelihoods in the early days following an emergency." (Rodgers)

Location.

After a natural disaster occurs, locals witness the "piles of damaged or waterlogged remains of communities line the streets, survivors and anyone else on hand tend to begin the process of moving debris." (Rodgers) El Salvador's population has more urban dwellers, however there is still a very large rural population at 39.8 percent.

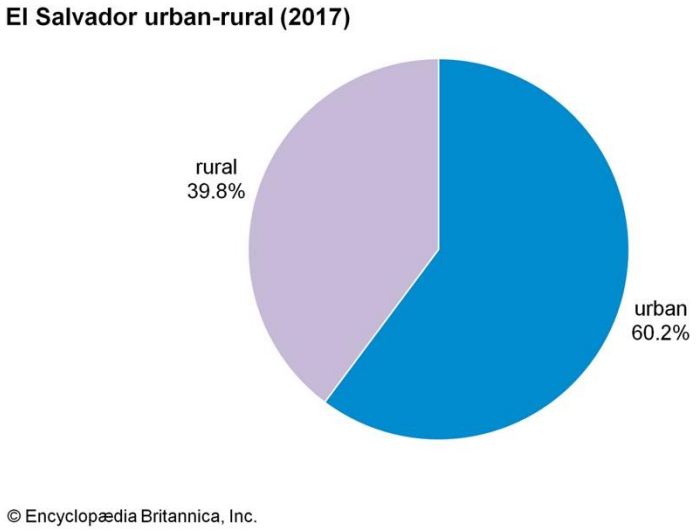


Figure 7 - El Salvador. [Image] Retrieved from https://www.britannica.com/place/El-Salvador/Plant-and-animal-life

User Profile Summary

User	Description
Primary	Disaster survivor locals
Secondary	NGO relief teams
Tertiary	Disaster debris specialists.

Primary User Profile

Demographics		**User Behavior**		**Personality**		**Cognitive Aspects**	
Age	18-35	Frequency of Use	Infrequent	Focus of Control	↑	Technical Skill	↑
Education	High School Diploma	Location	Residential – Rural/ Urban, hazardous				
Ethnicity	Mestizo (86.3%)	Social	High-Social	Changeability	↑		
Gender	Mixed	Duration	1-2 Weeks	Self-Efficacy	↑	Pre-Requisite Knowledge	↓
Income	$4000	Level of Focus	High	Uncertainty Avoidance	↑		

Table 3 - Primary User Profile

Persona

Name: Diego Martinez

Age: 22

Occupation: Coffee farmer

Income: $4000 a year

Education: Highschool diploma

Location: San Miguel, El Salvador

Career/ Volunteer: temporary employment

Social: Works alongside a crew of locals and NGO workers

Frequency of Activity: First time enduring major natural disaster

Profile

Diego Martinez is a 22-year-old male living in San Miguel, El Salvador. He completed his high school diploma to then work on his family coffee form. He earns a yearly salary of $4000. Unfortunately, his community has been destroyed by a massive earthquake leaving everything to rubble. In efforts to help remove debris, Diego has been recruited by red cross to help restore his community.

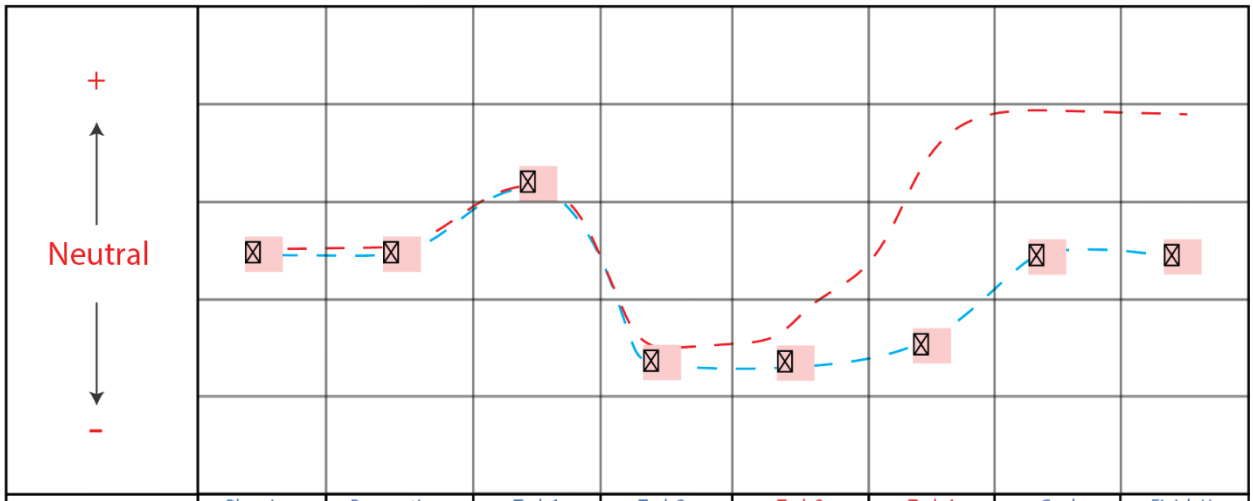
User Behavior:

Diego spends his days helping to restore his broken community, while also trying to make money during an extremely difficult time. Each day he reports to his site where he works alongside a team of locals who've been recruited for similar reasons. They're equipped with standard tools like wheelbarrows, crowbars, and shovels. Following a manual, they sort through debris to try and separate materials, which are then brought to dumping bins/piles back on the site.

2.1.2 Activity Mapping

Figure 8 - Post Earthquake Cleanup. Retrieved from https://temblor.net/earthquake-insights/how-long-does-it-take-to-recover-from-an-earthquake-1515/

To better understand the overall process of debris cleanup after an earthquake, video footage was analyzed. This will help to narrow in on an area of focus and provide a more clear problem definition for improving the process of debris cleanup.



	Planning	Preparations	Task 1	Task 2	Task 3	Task 4	Goal	Finish Up
User Goals	Get approval for demolishing	Marking buildings with red paint/ caution tape	Breaking down buildings	Break down rubble in hard to access areas	Fill wheel barrows with rubble	Deliver rubble to side of road/pickup site	Deliver rubble to dumpsite for disposal	Begin efforts of rebuilding/restoring
Problems/Challenges	Locating the homeowner as fast as possible	Area can be busy with locals trying to move by Watching out for bystanders, having to tell them to keep clear	Avoiding destruction to other properties Safety challenges	Sledge hammer is physically straining on bones and muscle especially after long use	Heavy buckets are awkward and difficult to lift, can cause muscle strain	Difficulty getting over rough terrain	Seperating and organizing rubble. Recycling materials is difficult	Finding materials for new housing Building safe homes that are long lasting
Ideas/Take-aways	Public signup sheet to request appointment	Speakers to tell bystanders to stay clear, better barriers	AI/cameras identify best location to break apart	Grinder machine to break down rubble	Exoskeleton to help with lifting action	Further develop equipment to better assist intense job	Machine to repurpose rubble for reconstruc-tion purposes	Using repurposed rubble for making homes

Table 4 - User Activity Mapping

User Observations 1

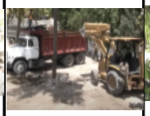
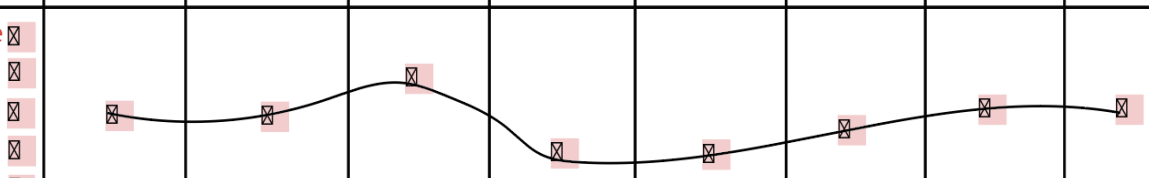
	Planning	Preparations	Task 1	Task 2	Task 3	Task 4	Goal	Finish Up
User Goals	Get approval for demolishing	Marking buildings with red paint/ caution tape	Breaking down buildings	Break down rubble in hard to access areas	Fill wheel barrows with rubble	Deliver rubble to side of road/pickup site	Deliver rubble to dumpsite for disposal	Begin efforts of rebuilding/restoring
User Actions	Approval is signed by property owner in the presence of 3 community witnesses	Government authorities mark building with red allowing workers to know that it is beyond repair and needs to be demolished/removed. The area is secured with yellow tape to stop bystanders from walking on the site.	Excavators and bulldozers destroy what is left of buildings, clear out areas that are accessible by large machines.	Crews are sent in to clear out debris in tight spaces/areas that are not accesible by machines. Debris is broken up with sledge hammers.	Fill rubble into buckets with shovels Empty buckets into wheel barrow.	Deliver rubble to side of road for pickup.	Dumptrucks are loaded with excavators to deliver rubble to dumpsite/landfill.	Locals try to build back shelters in cleared out land with whatever they can get their hands on.
User Thoughts	Quickly trying to locate people required to sign documents	Telling bystanders to avoid interfering with cleanup, or getting injured	Locating contact points to break structure	Maintaining focus during physically straining work Thinking about payout for amount of rubble cleared	Maintaining focus during physically straining work Thinking about payout for amount of rubble cleared	Maintaining focus during physically straining work Thinking about payout for amount of rubble cleared	Keeping things organized Collaborating with other crew to fill dump truck	Focusing on recovering from loss Trying to return to normalcy
Storyboard/Photos								
User Experience + Neutral -								
Problems/Challenges	Locating the homeowner as fast as possible	Area can be busy with locals trying to move by Watching out for bystanders, having to tell them to keep clear	Avoiding destruction to other properties Safety challenges	Sledge hammer is physically straining on bones and muscle especially after long use	Heavy buckets are awkward and difficult to lift, can cause muscle strain	Difficulty getting over rough terrain	Seperating and organizing rubble. Recycling materials is difficult	Finding materials for new housing Building safe homes that are long lasting
Ideas/Take-aways	Public signup sheet to request appointment	Speakers to tell bystanders to stay clear, better barriers	AI/cameras identify best location to break apart	Grinder machine to break down rubble	Exoskeleton to help with lifting action	Further develop equipment to better assist intense job	Machine to repurpose rubble for reconstruc-tion purposes	Using repurposed rubble for making homes

Table 5 - User Observation

Observation Research Insights

The process of cleaning up debris is heavily reliant on a good team dynamic, with communication and cooperation being important factors. Each step of the process involves different roles which bring on their own unique challenges. Additionally, each role may require different types of equipment, or require different types of training.

2.2 Product Research

Objective: The following section aims to review comparable products currently in the marketplace that help in the process of earthquake cleanup. The product being examined is rock crushers, a useful product that aids in breaking down rock and concrete for recycling.

Method: Promotional media of competitor products are researched and evaluated to determine features and benefits, and their relative importance to the design of a new product.

Feature/Function Comparison Table								
								
Weight	29,000 Kg	35,000 kg	26,000 kg	21,000 kg	1380 kg	3,400 kg	1088.6 kg	2,900 kg
Dimensions	40’10”x10’2” x8’5”	47’6”x11’4”x 9’10”	31’2”x10’6”x8’4”	191”x118”x74”		179’1”x58’6”x84’6”		
Power	Diesel/ electric drive	Diesel/electric drive	Diesel/ electric drive		Electric motor 380V	Diesel/electric	Gas 3 phase motor	Excavator attachment
Crush method	Jaw crusher	Cone crusher	Punch plate	Double roll crusher	Jaw crusher	Jaw crusher	Jaw crusher	Roll crusher
Max feed size	20”	7”		24”	3”	4”	7.5”	6”
Capacity	300 tons per h	250 tons per h	250 tons per h	1200 tons per h		30 tons per h	6 tons per h	
Feed Opening	24”x40”		30” x 38”	43” x 25”	23.64” x 11.82"	19”x10”	6”x10”	
Mobile	yes	yes	yes	no	no	yes	no	yes

Table 6 - Feature/Function Comparison

2.2.2 Functionality

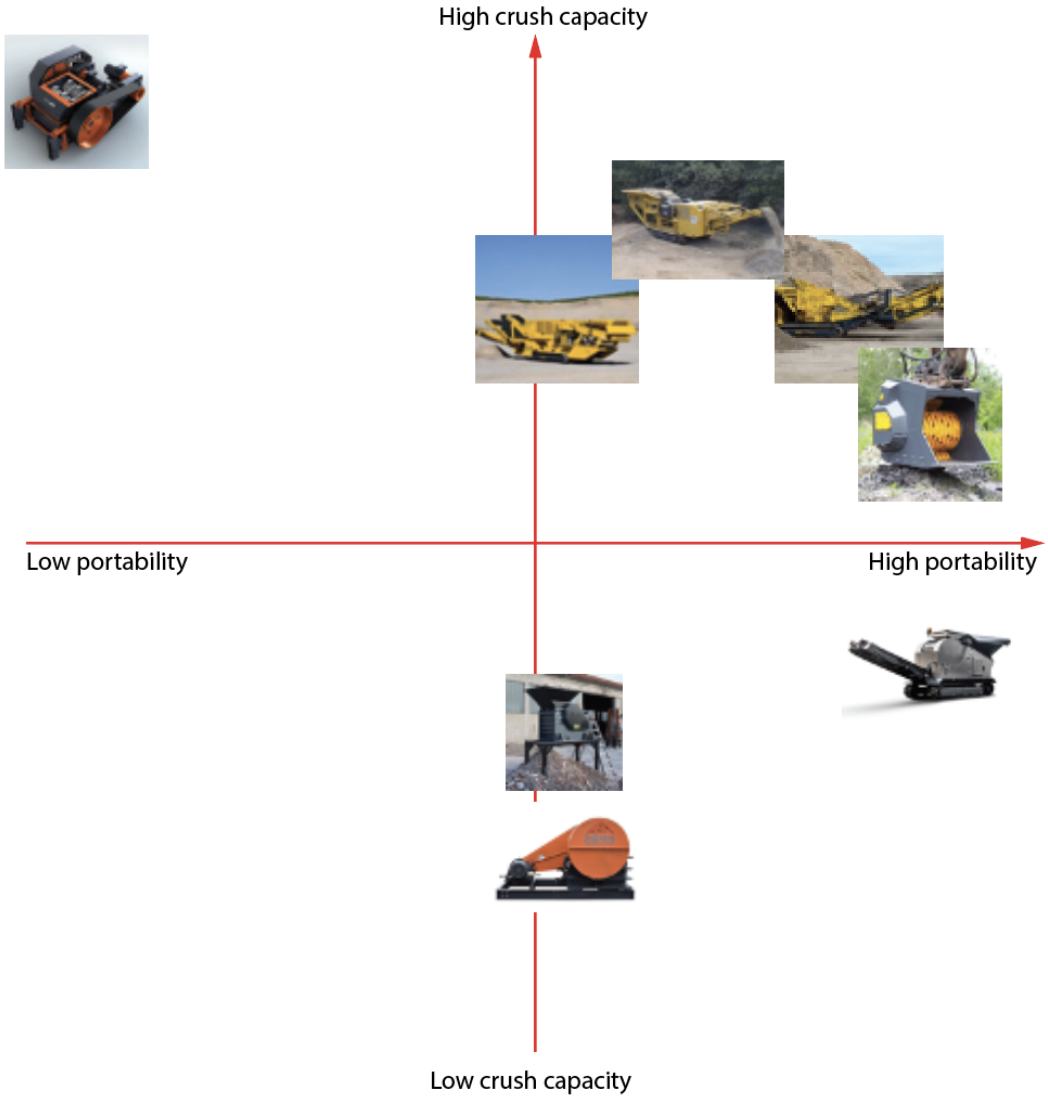


Figure 9 - Functionality Benchmarking

2.2.3 Aesthetics and Semantics Profile

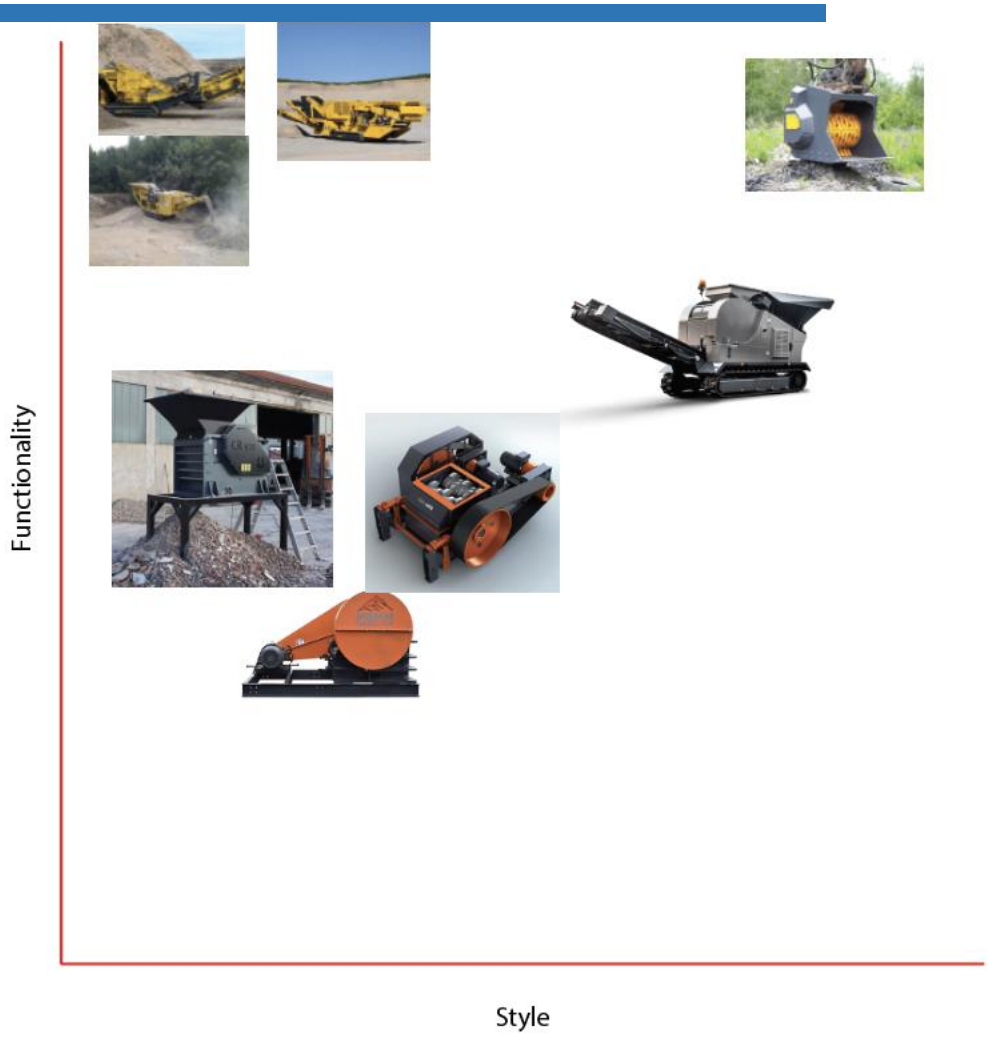


Figure 10 - XY Product Semantics Graph

A range of rock crushers were evaluated using an XY graph to determine their performance in terms of both style and function. Rock crushers are heavy duty machines used to break down rubble into small pieces. They're most commonly used for aggregate production, construction material recycling, and mining operations (Metso Outotec).

When considering the function of these products and they're environment of use, it is understandable that they all share a rugged appearance. Majority of these designs appear to have a strong focus on function and safety, with aesthetics and semantics coming secondary. Most of these products have a monochromatic colour scheme, using typical yellow, red, and orange colours which are a staple for construction vehicles. These bright colours are not cosmetic, but rather functional as they allow for the vehicles to be more visible on job sites (Engineer Supply). When considering form, most of these products consist of flat planes built with relatively simple sheet metal parts. Some products have incorporated some aesthetic details such as large chamfers. These chamfers do a good job of providing visual interest and personality to the product, while still maintaining a rugged and durable design language. This will be used as inspiration for the final thesis design, as the chamfered theme provides a good middle ground for having the appearance of ruggedness and reliability, while still emphasizing consideration of aesthetics and a visible design language.

2.3 Summary

Currently, rock crushers are one of the best solutions for breaking down debris. These crushers come in a variety of sizes with different capabilities including portability, crushing speed, crushing mechanisms, and rock size capacity. The ideal solution for debris removal is something that is portable, can access uneven terrain, with a moderate to high crushing capacity.

Chapter 3: Analysis

The following chapter will analyze the experiences of the primary user to identify unmet needs and how these needs can be met with an improved design solution. Additionally, current products used in earthquake cleanup will be assessed in terms of functionality, usability, aesthetics and sustainability to explore areas of improvement.

3.1 Needs Analysis

After the occurrence of an earthquake, the recovery process can be challenging and take a long amount of time. This is especially the case in developing countries, often lacking the resources and institutional capacity to implement an effective plan for post disaster recovery. Still, government must act quick to remove rubble as quickly and efficiently as possible. It is during this stage, that recycling is a critical component of the process, however disposal facilities are overwhelmed with an unprecedented amount of waste, so the majority of rubble will go to landfill. Quick fix solutions like this can have serious implications on the environment and are highly unsustainable. An increased focus on recycling is crucial as it will lessen the burden on disposal facilities and natural resources for reconstruction, while still providing work opportunities for local people and businesses.

3.1.1 Needs/Benefits Not Fulfilled by Current Products

Needs	Benefits
Comfort	• Ergonomic workflow, eliminating crouching/other uncomfortable positions
Safety	• Eliminating injury from heavy manual labour • Alternative housing from tents, with more structural support
Ease of use	• Machine can be operated with little instruction • Loading materials is easy, intuitive, can be done manually • Convenient access to tools and hardware
Efficiency	• Reducing time and cost of importing materials for Reconstruction • Reducing time and cost of delivering waste for disposal • Providing more work for locals to aid in cleanup/reconstruction process
Sustainability	• Giving function to rubble and debris • Keeping debris from going into landfill

Table 7 - Needs/Benefits

3.1.2 Latent Needs

Fundamental needs of humans were evaluated alongside the benefits of improved debris cleanup, referencing Maslow's Hierarchy of Needs chart.

Benefit	Fundamental Human Need(s)	Relationship with Benefit
Comfort/Ergonomics	Physiological, safety, esteem	Moderate
Health/Safety	Physiological, safety, esteem	Strong
Efficiency	Safety, esteem, belongingness, physiological	Strong
Sustainability	Physiological, safety, esteem	Strong

Table 8 - Maslow's Hierarchy of Needs Chart

Comfort/Ergonomics:

Locals working with cash for work programs perform manual labour such as shoveling and transporting debris via wheelbarrow and buckets. Disaster sites can be difficult to navigate, often having uneven terrain, and little infrastructure. This can make for an uncomfortable work environment, making manual labour even more strenuous.

Health/Safety:

After losing their homes to an earthquake, survivors usually will live in tents as an alternative and temporary solution for shelter. Sometimes it can be months or even years until a new, proper shelter is built. Meanwhile, survivors must live among hazardous debris until it is removed.

Efficiency:

Although vulnerable communities may require outside help, it is important that locals still have a large role in their own recovery process. Locals are better supported when receiving new job opportunities rather than having them taken away by outside workers. A solution that can increase productivity, without taking away jobs is an important consideration.

Sustainability:

It is crucial to remove debris before the reconstruction process can begin, but it must be done in a sustainable manner. A solution that can recycle material and utilize it for reconstruction will not only aid in the process of rebuilding communities but will prevent large amounts of waste going into landfill.

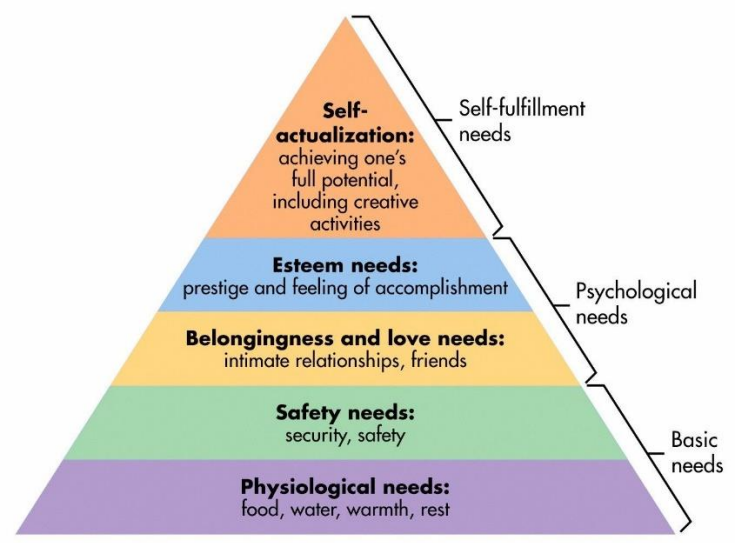


Figure 11 - Maslow's Hierarchy of Needs. Retrieved from https://www.simplypsychology.org/maslow.html

3.1.3 Categorization of Needs

Wishes/Wants

- Easy to maintain
- Easy to operate
- Easy to ship/deploy

Immediate Needs

- Breaks down/recycles material
- Reduces waste that goes into landfill
- Improves debris cleanup workflow
- Provides new building materials for reconstruction
- Can maneuver rough terrain

Latent Needs

- Stylish design

3.1.4 Needs Analysis Diagram

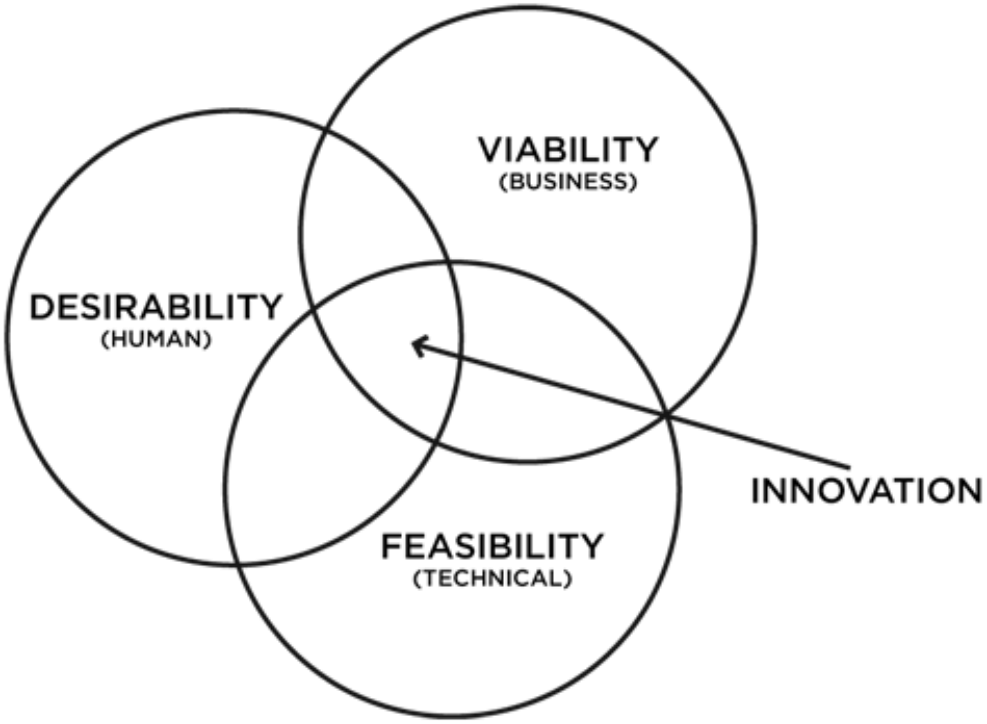


Figure 12 - IDEO Venn Diagram. Retrieved from https://spin.atomicobject.com/2015/01/06/human-centered-software-creating-value-balancing-feasibility-viability-desirability/

Desirability

Waste management facilities often do not have the capacity to handle the amount of debris produced after earthquakes. Since most of the debris is deposited into landfill sites, there is a strong need for an improved method of recycling debris. Additionally, vulnerable communities lack the means to build safe housing that can withstand future disasters, often having to resort to living in tents.

Viability

Debris management is a critical issue faced by all countries that experience natural disasters. Natural disasters will continue to be a prevailing issue, along with the waste produced from them. For economic, and sustainable reasons there is great opportunity in exploring how to reuse disaster waste towards something useful.

Feasibility

Outside the context of natural disasters, solutions have been developed to break down waste material from concrete, allowing it to be reused for new construction projects. This technology can be evolved to incorporate mobility, along with other features that would be useful in the context of natural disaster recovery.

3.2 Usability

3.2.1 Usability

After narrowing in on a specific problem area for the topic of disaster recovery, a different user process was observed from the one seen from section 2.1.2.

Process	Observation
Breaking concrete	User kneels down, breaking concrete with hammer placing material on rock
Adding materials	User adds aggregate and cement based on approximation of correct ratio. User mixes solution with a spade. (Working on floor)
Mixing concrete	User adds water and continues to mix with spade
Pouring concrete into mold	User shovels concrete mixture into mold with shovel. Flattens top with shovel.

Table 9 - Process and Observation

3.3 Human Factors

3.3.1 Introduction:

In the last 30 years, the number of natural disasters has doubled, economic losses from natural disasters have more than tripled, and low-middle income countries alone have lost $1.2 trillion dollars in damages. After a disaster occurs, communities are faced with the dilemma of how to use their existing capacity for recycling, composting, combusting, and disposing natural disaster debris. Collapse of waste management services has led to uncontrolled dumping sites and improper handling of waste. Furthermore, uncollected rubble from damaged buildings has impeded access and prevented rehabilitation and reconstruction.

An effective solution for disaster debris management can help address issues beyond initial removal, by prioritizing debris management options and including a strategy for recycling and reusing materials to reduce the burden of debris volume on disposal facilities.

Literature Review:

Anthropometric measurements were made with reference to Henry Dreyfus', The Measurement of Man and Women: Human Factors in Design (Tilley & Dreyfuss, 2002). For this ergonomic study, reference was made to the 5th percentile female and the 95th percentile male. This establishes a range of human dimensions that accommodates 90% of the population. (Hedge, 2013)

METHODOLOGY

Objectives:

The goal of this evaluation is to gain a clear understanding of how each full-bodied human interaction design feature will be properly incorporated in the final design of a debris recycling station. In the context of a debris recycling station, full-bodied interaction will signify four major body parts that the design interacts with (Chong, Zaccolo, Kappen, Thomson, Burke & White, 2020). These 4 interaction points will be analyzed to gain an understanding of how the ergonomic experience can be improved for the end user.

Decisions to be made

Major areas to be considered for ergonomic assessment of a portable debris recycling station include:

1. Height and depth of work bench (Arms and hands)
2. Height and depth of stairs leading to roof (Legs)
3. Height and thickness of stair railing (Arms and hands)
4. Height and angle of rock crusher (Full body)

Description of Users Targeted by Product

Although the product is intended to be used by a wide range of vulnerable communities recovering from natural disasters, El Salvador will be used for this case.

Age: 18-50
Gender: Male or Female
Culture: Mestizo
Income: Low
Educational background: Secondary school
Career/ Volunteer: Part time employment

Evaluation process

A full scale 1:1 ergonomic model was created using the 95th percentile male, and the 5th percentile female as reference. The model was created in Virtual Reality using a modelmaking platform called Gravity Sketch. This program was an excellent tool for providing an immersive, full scale reference, allowing for the observation of how the user will perform the following tasks:

1. Observation of how the user goes up and down compact (steep) stairs.
2. Observation of how the user utilizes the work bench to make concrete.
3. Observation of how the user loads concrete debris into the rock crusher.

Description of User Observation Environment Used in this Study

A video was used as reference to showcase the environment that vulnerable communities work within while undergoing debris cleanup. The video also provides information on methods used to recycle concrete debris, demonstrating specific constraints in the process.

Location and Timeframe

Date of Observation: 03/01/2021

Location of video: India

RESULTS

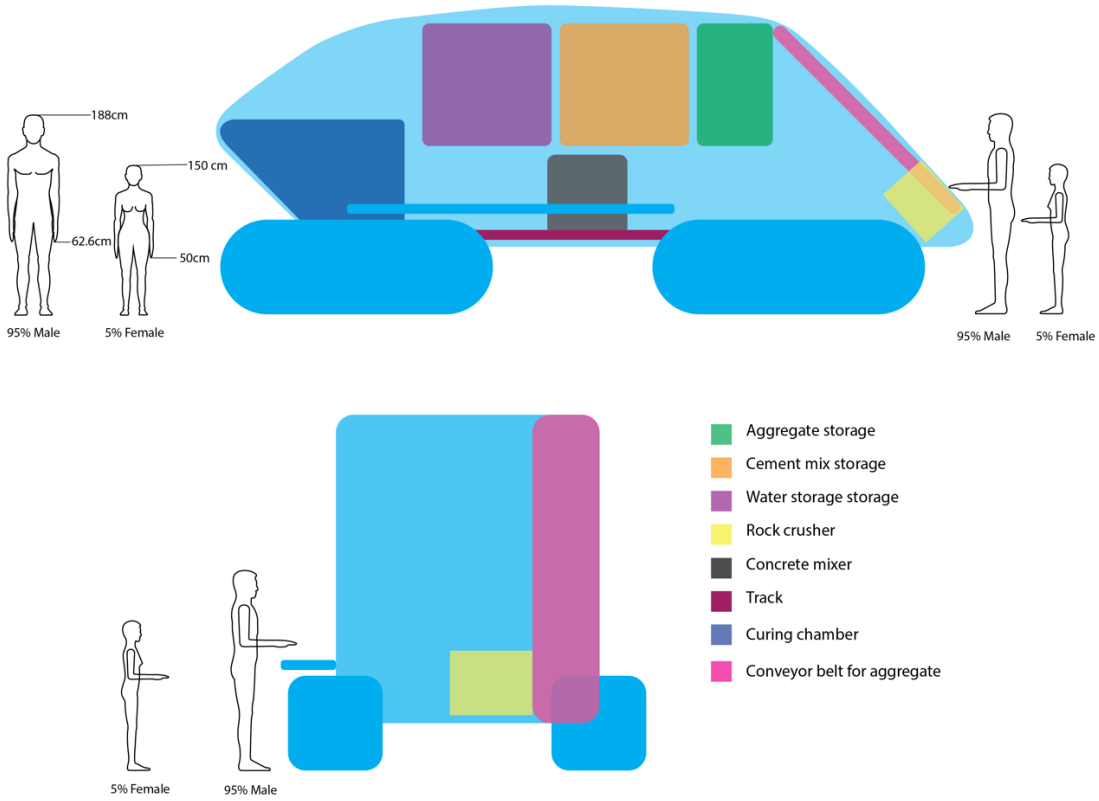


Figure 13 - Concept #1 Schematic Dimensions

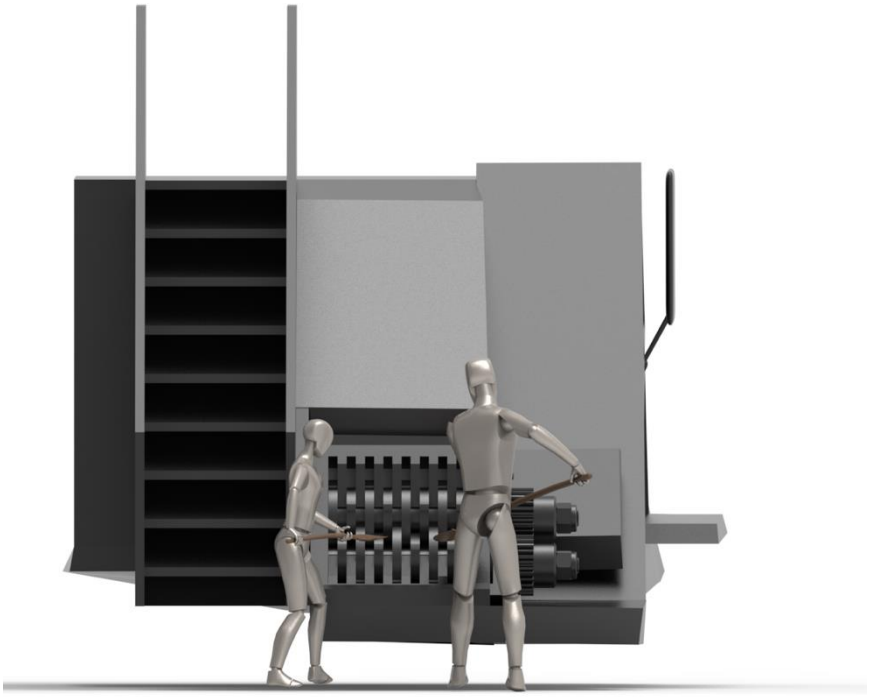


Figure 14 - Rock Crusher Rear View

Figure 15 - Rock Crusher Side View

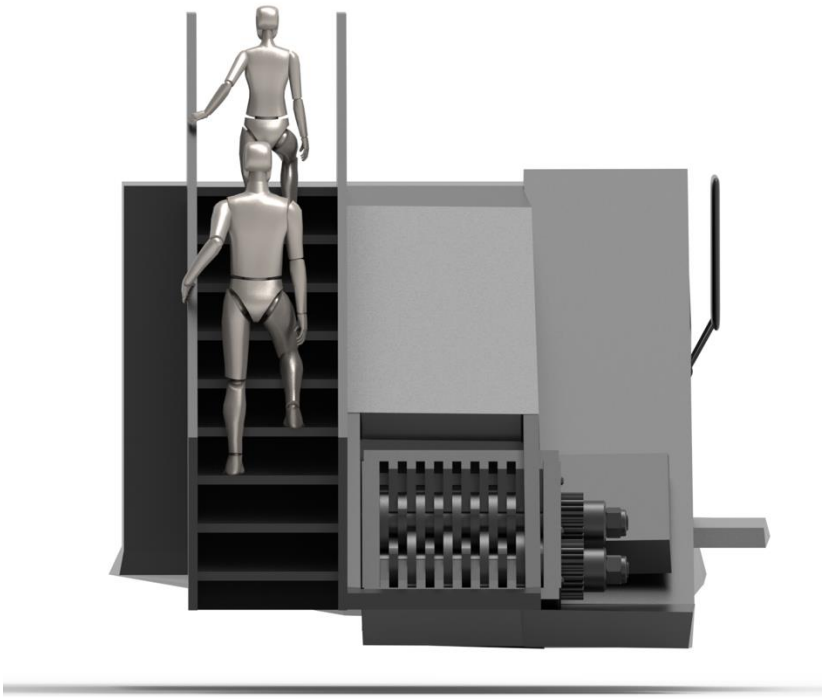


Figure 16 - Stairs Rear View

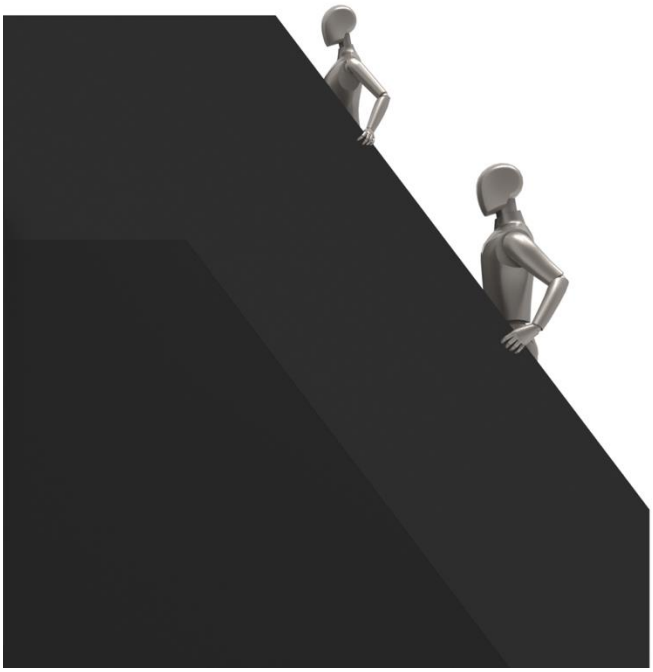


Figure 17 - Stairs Side View

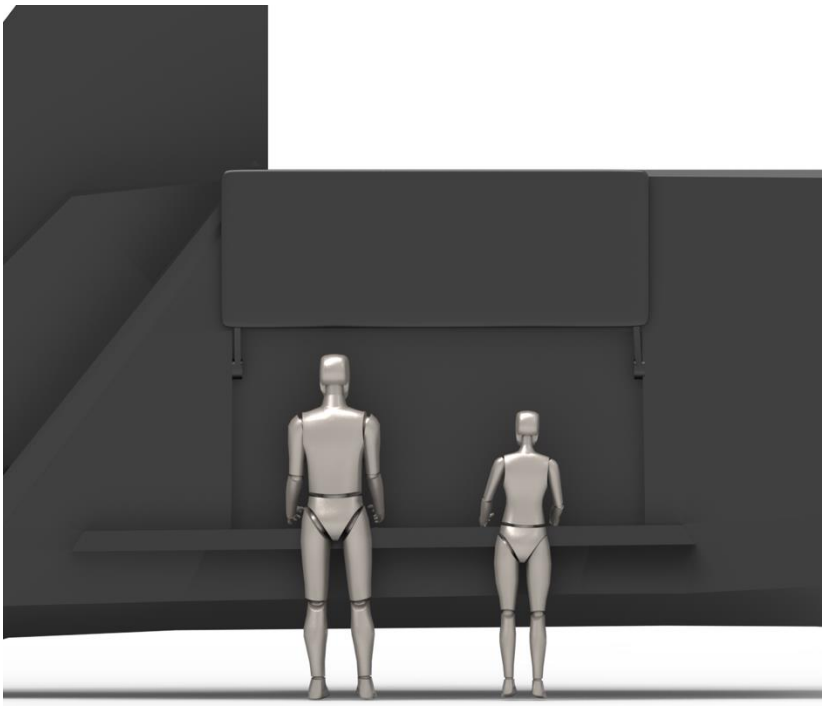


Figure 18 - Work Bench Front View

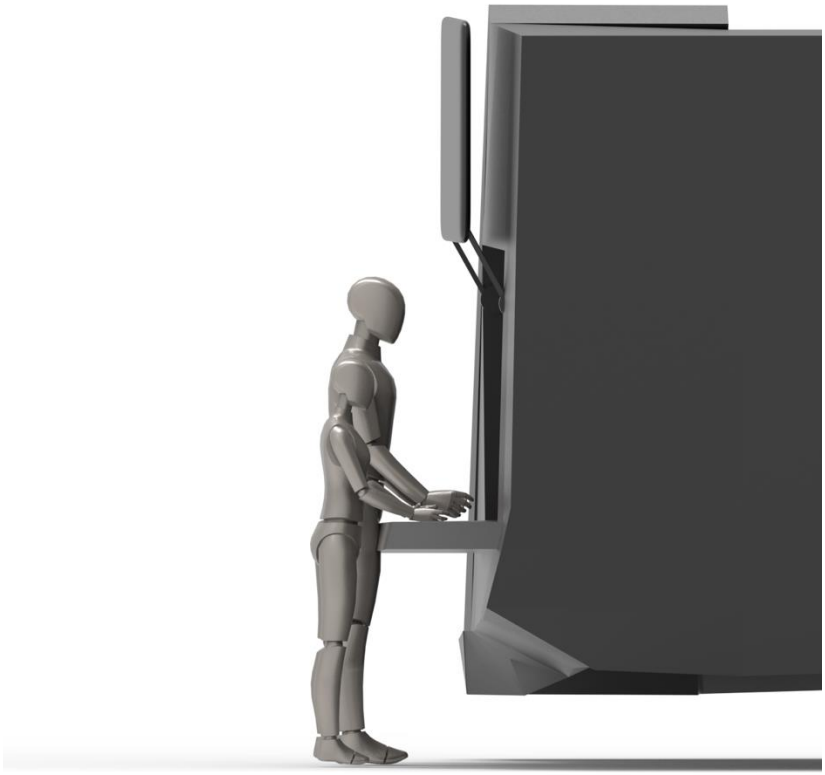


Figure 19 - Workbench Side View

ANALYSIS

Stairs:

The cement and water chambers are to be filled at a loading station prior to arriving at the disaster cleanup site. In the case that the user needs to access the chamber for manual refills, or to inspect them, the user must be able to get to the roof where the hatch openings are. Stairs will be the best solution for the user to gain access to the top of the vehicle, as they must be able to use their hands if they are carrying a bucket, bin, or hose. The stairs must be compact and steep enough (60 °) so that they don't add unnecessary length to the vehicle, while still being accessible for the 95th percentile male and 5th percentile female. A handrail will also be necessary for comfortable use. After observations, it was determined that 37.6" in height and 2" in thickness are appropriate dimensions for this.

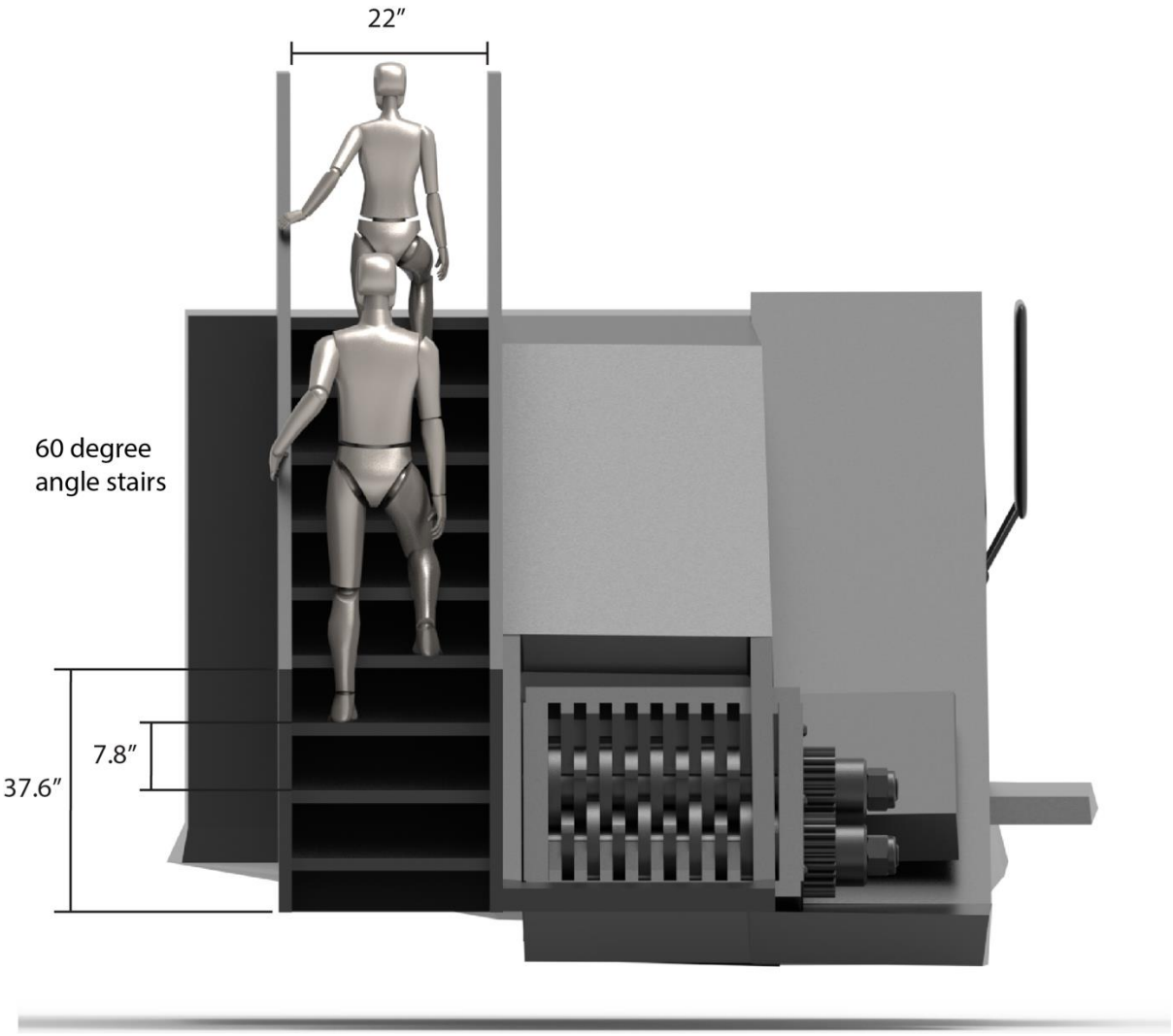


Figure 20 - Stairs Dimensions

Workbench:

The workbench is a feature used as a workspace to fill brick moulds with concrete. It Is retractable so that the vehicle is more compact when the workbench is not in use. The workbench must be at a height that is accessible for the 5th percentile female, but not too low for the 95th percentile male. This can be achieved with a worktable set at 36 inches in height. There also must be enough depth that the table provides enough room for the user to work on. 25.5 inches is an appropriate amount for this.

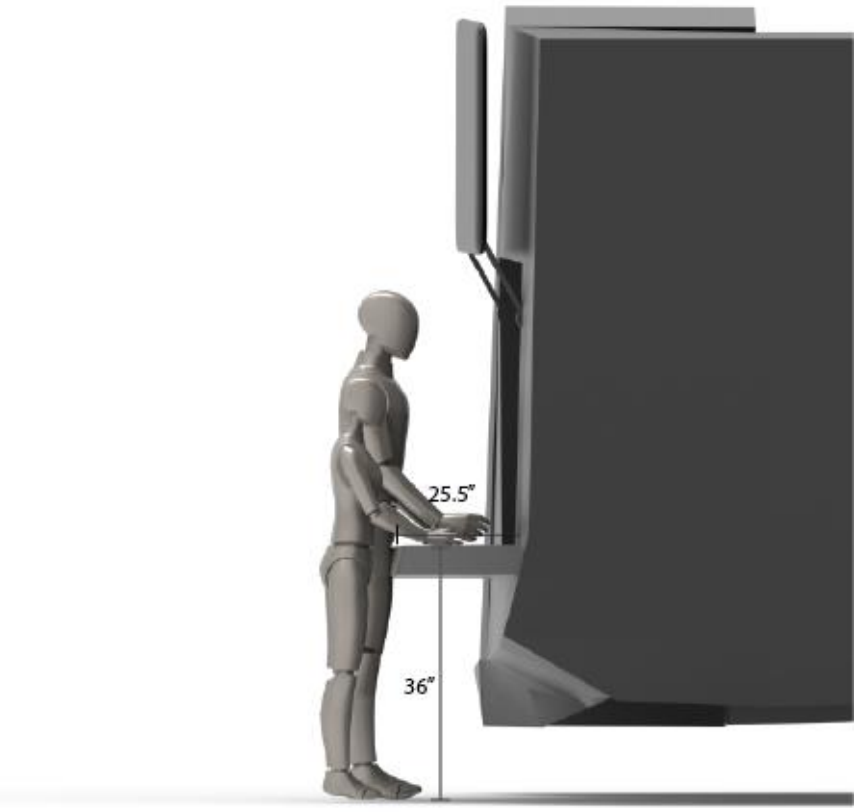


Figure 21 - Workbench Dimensions

Rock crusher:

The rock crusher must be at a height that is accessible for the 5th percentile female, but not too low for the 95th percentile male. This can be achieved with a height of 21.5 inches. The Rock crusher should be wide enough that at least two people at a time can use it. 35.8 inches is an appropriate width to achieve this.

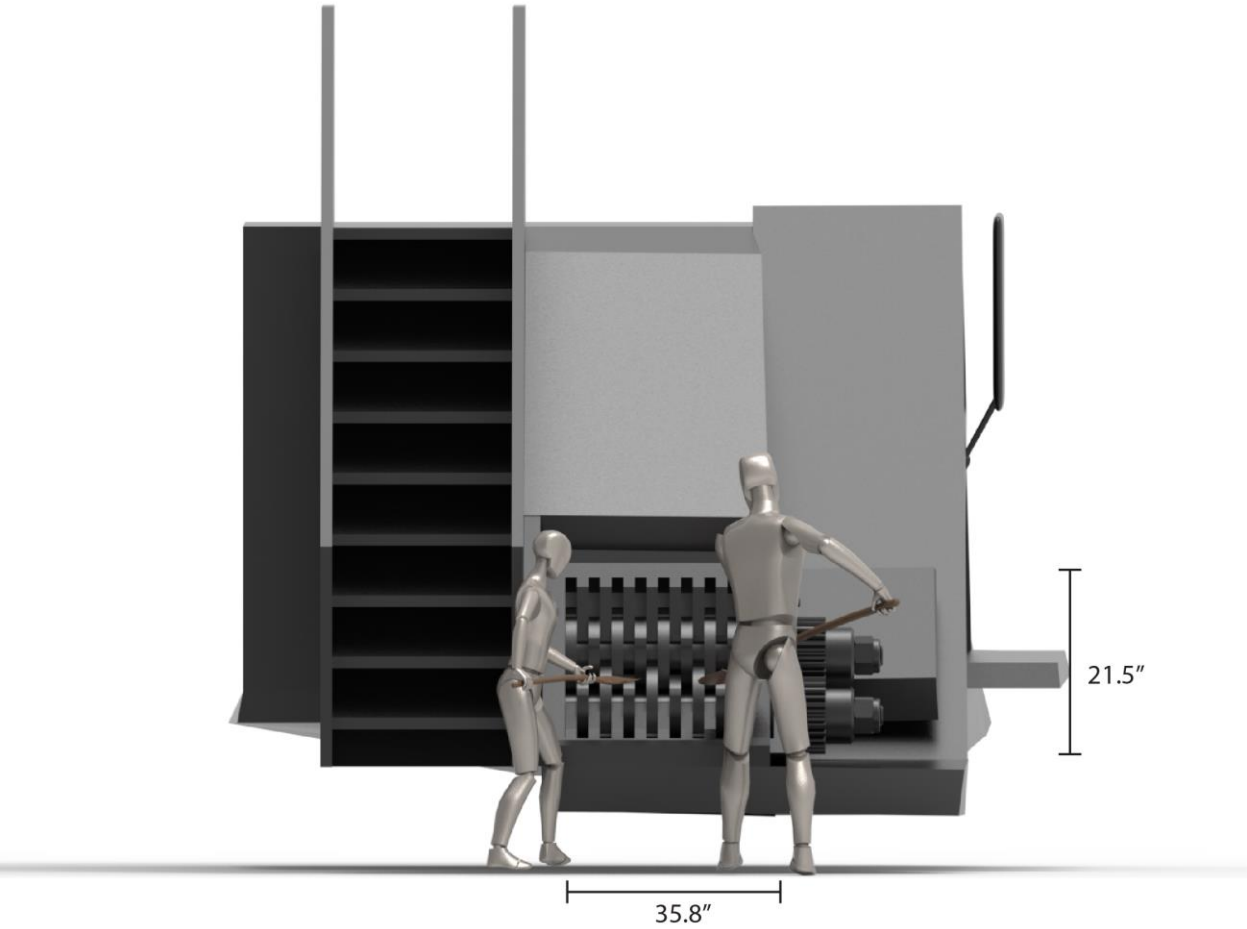


Figure 22 - Rock Crusher Dimensions

LIMITATIONS AND CONCLUSION

Critical human dimensions were determined for the following:

1. Acceptable height for compact (steep) stairs that can still be easily navigated by 95th percentile male and 5th percentile female.
2. Acceptable height and depth for workbench that is accessible for 5th percentile female, while not too low for 97th percentile male, that it causes back/neck pain.
3. Acceptable height for rock crusher that provides comfortable access for 95th percentile male and 5th percentile female as well as width that allows for more than one person to use machine at a time.

Some Ergonomic Issues That Are Still Not Yet Resolved

Some features that still need to be considered are the remote controls for the recycling station (used to transport the vehicle), size of concrete dispenser as well as method of access, and how the storage rack for bricks will be integrated.

Alternate Possibilities for the Future

Based on the current study, alternate options that could be explored in the future are as follows:

1. Use of physical and tangible mock-ups to provide further sense of scale for features.
2. Further detailing in model to provide more clear understanding of components and features to be used.

This ergonomic study was highly beneficial in providing critical dimensions for features to be considered for a debris recycling station. Working with the model in virtual reality was helpful in providing a sense of scale for the larger objects which would otherwise be difficult to visualise on a computer. This research will contribute to the understanding of necessary dimensions needed for the user will interact with the product comfortably, ultimately helping to create a more informed design solution.

3.4 Aesthetics and Semantics

Figure 23 - Aesthetics and Semantics Mood Board

While formulating the design direction for the aesthetic and semantic profile of this thesis project, lots of consideration went into its environment of use, referring to similar existing products for inspiration. A mood board was created which includes a range a vehicles which all have a rugged appearance. Although these vehicles are similar in the sense that they are rugged, they still have very different design languages, with each one evoking a different emotion. Some of these vehicles have an appearance that comes off as threatening and aggressive with many sharp details and hard lines densely packed into an angular form. Other vehicles achieve the rugged look through a more minimal box-like form, which still looks robust and functional, but less threating. For the context of this thesis project, it's important to consider the fact that vehicle will be working within communities that have been devastated by the effects of a natural

disaster. During the phase of recovery when these communities are in a time of need, locals would likely feel intimidated or threatened by the prospect of an aggressive looking vehicle entering their area. Although the design should not be aggressive looking in appearance, it should not be whimsical either. This is where it became evident that the design should fall somewhere in between the line of these two characteristics. The intention for this thesis project is to design a vehicle which looks robust, and like it is there to do a job, while having a more reserved design language. A reserved design language is crucial as a flashy vehicle with lots of stylistic lines and an aerodynamic form might give off the wrong impression of being gaudy and pretentious. A monochromatic colour scheme will be incorporated to help bring simplicity to the vehicle's appearance. Bright colours such as the commonly used yellow in construction will be used as accents on key components where safety is essential. To help further form exploration, reference will be made from animals to help inspire biomimicry in the final design. A selection of animals including buffalos, wombats, and armadillos will used as reference. These animals are good candidates as their appearance communicates something that is sturdy and robust but not overtly threatening. Reference will be made to features such as the rounded, armadillo shell, as well as the wide and heavy profile of the buffalo and wombat.

3.5 Sustainability

Intro

For this report, research will be conducted to evaluate the materials, manufacturing, sustainability, and user health and safety in the context of a disaster debris recycling station. This thesis project works towards 4 of the UN's 17 sustainable development goals with a focus on climate action, responsible production of materials, providing work/economic growth and

resilient infrastructure. When making decisions for which materials and manufacturing processes will be used, both function and environmental responsibility will be prioritized. Where this thesis project excels the most, is the business model in which it is designed for. Rather than sending massive amounts of concrete to landfill sites after a disaster occurs, this station will provide new use for the debris to help rebuild damaged communities. Not only will this system help to rebuild communities and reduce landfill sites, but it will minimize large amounts of C02 emissions required source and deliver aggregate for concrete production. Lastly the business model considers the economy of struggling communities by providing new work opportunities for Cash for Work programs to aid in the production of new concrete.

Literature Review

Research was collected on the Humber library website to ensure that information was being sourced from peer reviewed articles.

1.1 and 1.2 - Materials and Manufacturing

Material	Benefits + Manufacturing Process	Reference
Alloy Steel	Alloy steel is a mixture of metals including nickel, copper, and aluminum. The material is durable, strong, resistant to corrosion, and it comes at a relatively affordable cost. This makes it a great application for heavy duty vehicles such as ship hulls. Steel is also highly sustainable, holding an annual recycling rate of nearly 100 percent in the automotive industry.	https://www.weerg.com/en/blog/what-are-the-four-types-of-steel https://www.steel.org/steel-markets/automotive/steel-vehicles-offer-environmental-advantage/
Tandem Perovskite Solar Cell	A new development of solar cell technology which uses compound materials with a special crystal structure. The new solar cell technology is 23 percent efficient whereas traditional silicon solar cells are 18 percent efficient. In addition to being more efficient, the material and fabrication costs are low.	https://www.sciencedaily.com/releases/2019/05/190514081554.htm
Recycled Automotive Plastics	New development of sustainable composite panels which incorporate raw material from waste automotive plastics, and waste from printed circuit boards. The material has excellent mechanical properties with a wide range of applications. Moreover, it provides function to otherwise low value waste going into landfill.	https://www-sciencedirect-com.ezproxy.humber.ca/science/article/pii/S0959652616322028?via%3Dihub
Mild Steel	One of the top choices for automotive manufacturers due to its ability to weld and form easily using methods like cold stamping. Used for general purposes and	https://ehdtech.wixsite.com/ehd-tech/single-post/2018/06/11/futu

	light structural elements. This material does not serve well for major structural components.	re-automotive-manufacturing-materials-and-processes
Recycled Aggregate	Recycled Aggregate (RA) is a sustainable alternative for making concrete, currently being practiced with material from demolished buildings. By incorporating RA in the production of concrete, the process of mining and delivering materials are eliminated, greatly reducing C02 emissions.	https://www-sciencedirect-com.ezproxy.humber.ca/science/article/pii/S0921344920302482?via%3Dihub
Cement	Manufactured by mixing fine limestone, clay and sand. The material is then heated to 1450° C in a kiln. The material makes up about 7 percent of concrete.	rediscoverconcrete.com/en/sustainability/how-cement-concrete-are-made.html#:~:text=Cement%20is%20manufactured%20by%20heating,in%20the%20manufacture%20of%20cement.http://
Fly Ash	An alternative and less harmful solution for cement. The material is a by-product of coal combustion, and U.S federal law now requires power plants to capture this ash to avoid pollution to earth's atmosphere. The material is not only cheaper than cement, but it has excellent cement like properties, and can produce even higher quality concrete than traditional methods. The fly ash still must be mixed with a small portion of cement, however much less is needed.	https://search-proquest-com.ezproxy.humber.ca/docview/190524088?accountid=11530&pq-origsite=summon

Table 10 - Materials and Manufacturing

Sustainability

Concrete plays a crucial role in the development of modern-day civilization, providing shelter for billions, fortifying defences against natural disaster and “providing a structure for healthcare, education, transport, energy and industry.” (Watts, 2019)

Concrete being the most widely used material on the planet, comes with a giant carbon footprint that’s associated with it (Rodgers, 2018). The production of concrete creates environmental challenges not only in how it’s manufactured, but also how its disposed of. The greatest environmental threat associated with the production of concrete comes from cement, an ingredient that makes up about 7-10 percent of the material (Federal Information & News Dispatch, 2009). In order to process cement, a mixture of limestone, clay, and iron are heated in a kiln at temperatures of 1,500 ° c. This heat usually comes from burning oil or coal which creates high levels of carbon dioxide. For each metric ton of cement produced, another metric ton of C02 gas is created. As a result, this process now accounts for 7 percent of the world's industrial carbon dioxide emissions at 2.8 billion tonnes. (Federal Information & News Dispatch, 2009) (Rodgers, 2018)

Fortunately, an alternative and less harmful solution for cement has been discovered called fly ash. The material happens to be created from other industrial processes and is a by-product of coal combustion. The U.S federal law now requires power plants to capture this ash to reduce pollution to earth’s atmosphere. The material is not only cheaper than cement, but it has excellent cement like properties, and can produce even higher quality concrete than traditional methods. The fly ash still must be mixed with a small portion of cement, however much less is needed (Federal Information & News Dispatch, 2009).

Another component used to make concrete which can be made more sustainable is aggregate. “Until recently, most of the world's used concrete went into landfills, at enormous environmental cost. But today, some manufacturers, especially in Europe, are crushing used concrete and recycling it for use as an ingredient in new concrete” (Rodgers, 2018). In fact, Switzerland and Austria use RA on a regular basis. Aggregate is traditionally made from crushed rocks and boulders, usually extracted from a quarry. The use of recycled aggregate from debris or demolition waste can provide a sustainable advantage by eliminating the need to mine new materials from quarries, greatly reducing CO2 emissions. Another benefit of using recycled aggregates in concrete production is the advantage it provides in the transport chain. Heavy traffic is greatly reduced, which not only relieves the climate footprint, but other environmental and health risks associated with heavy traffic (noise, dust, etc.)(Rodgers, 2018).

Health and Safety

Health considerations for this design will relate to the experience and workflow of workers using the machine to make concrete. Through the incorporation of a rock crusher and a cement mixer, the process of breaking aggregate with a hammer, and mixing the concrete solution with a stick/hoe strain is removed. This addresses the risks that come from potential injuries and strain from heavy and repetitive work. Additionally, the extending workbench provides a comfortable worksurface for the user lay concrete into the brick moulds.

Sustainability Statement for Final Design

This machine will prevent large amounts of concrete from going into landfill, which would otherwise cause harmful effects to the environment. Additionally, carbon emissions will be greatly reduced by removing the need to source and deliver fresh aggregate. With these portable workstations, more work opportunities will be provided for cash for work programs to help rebuild struggling economies. The new concrete will go towards helping communities to build back faster and stronger, avoiding the need for unsafe temporary shelters.

Conclusion

The research conducted for this report has informed elements involving the materials, manufacturing, sustainability, and user health and safety in the context of a disaster debris recycling station.

3.6 Design Brief

The eventual design solution should be able to:

1. Provide a solution that breaks down rubble easily and safely
2. Provides tools to combine old recycled materials with new material
3. Easily maintained
4. Easily operated
5. Easy to ship/deploy
6. Reduce waste going into landfill
7. Provide smooth workflow amongst workers
8. Maneuver rough terrain
9. Provide new material for reconstruction
10. Provides building materials that can be easily installed/assembled

Chapter 4: Design Development

4.1 Idea Generation

4.1.1 Aesthetics Approach

Figure 24 - Aesthetics and Semantics Mood Board

While formulating the design direction for the aesthetic and semantic profile of this thesis project, lots of consideration went into its environment of use, referring to similar existing products for inspiration. A mood board was created which includes a range a vehicles which all have a rugged appearance.

4.1.2 Mind Mapping

Before beginning the design process, a mind map was developed to layout as much relevant information as possible. By considering factors such as the user, ergonomics, experience, challenges, and existing technology, it was easier to make informed design decisions when formulating ideas for concepts. This also would help in exploring as many different design solutions as possible.

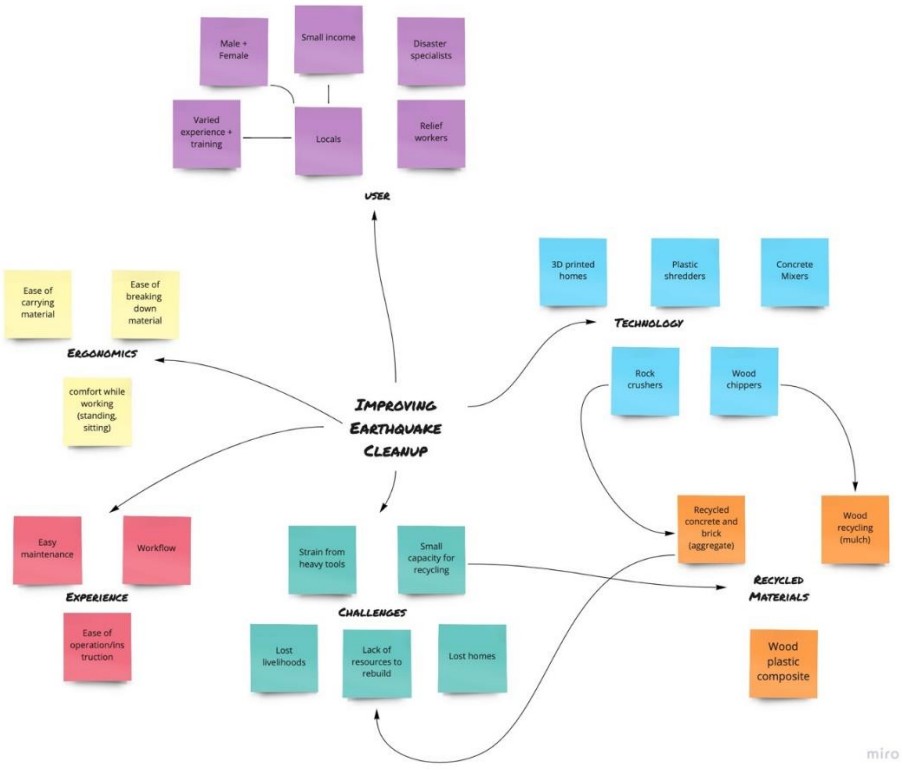


Figure 25 - Mind Mapping

4.1.3 Ideation Sketches

At this stage of the design process, there was an emphasis of quantity over quality when it came to how through each concept was. This would help in formulating as many ideas as possible. These concepts explore how to solve relevant problems to disaster cleanup using different and unique approaches.

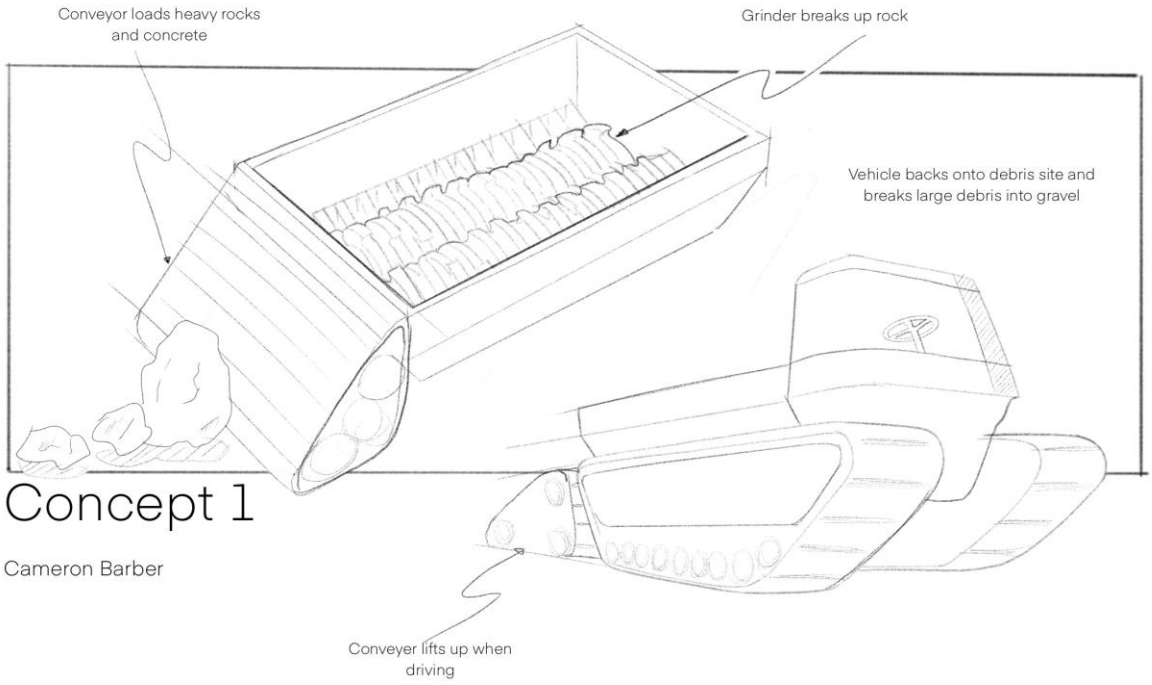


Figure 26 - Ideation Sketch 1

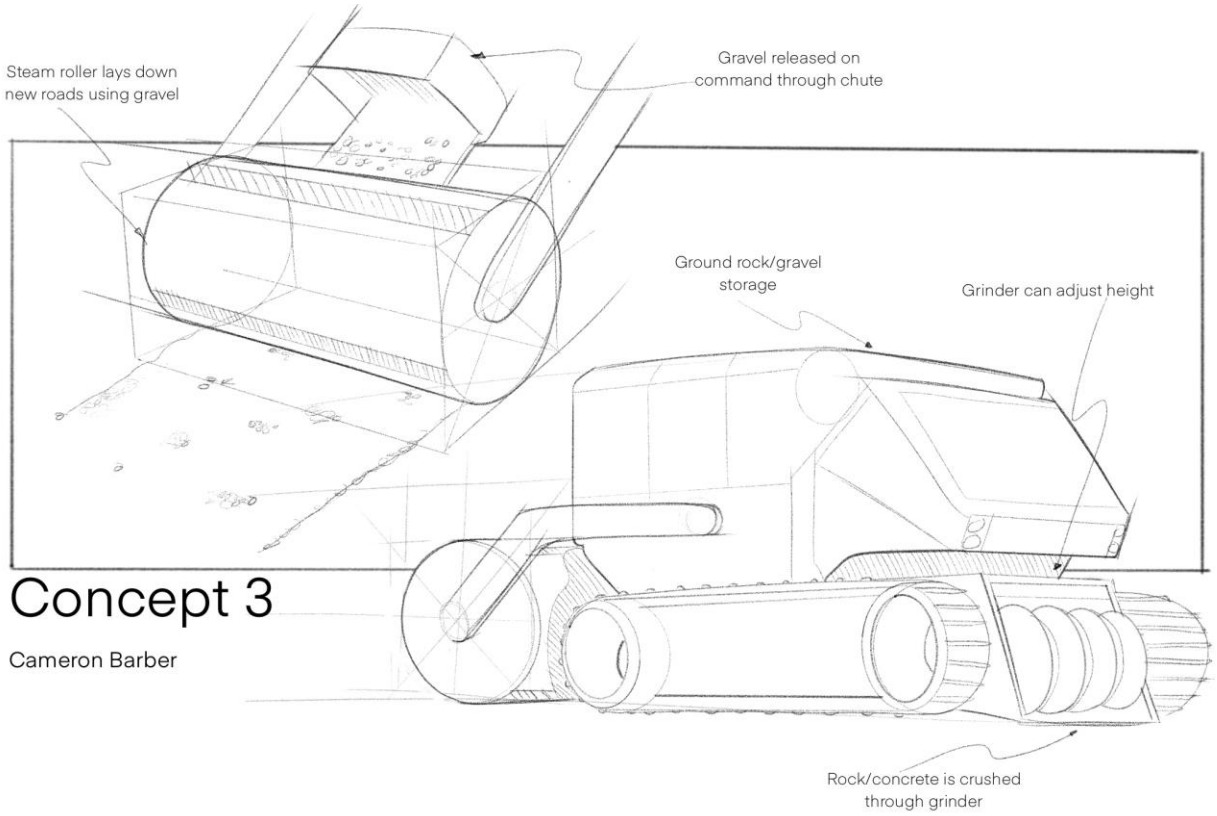


Figure 27 - Ideation Sketch 2

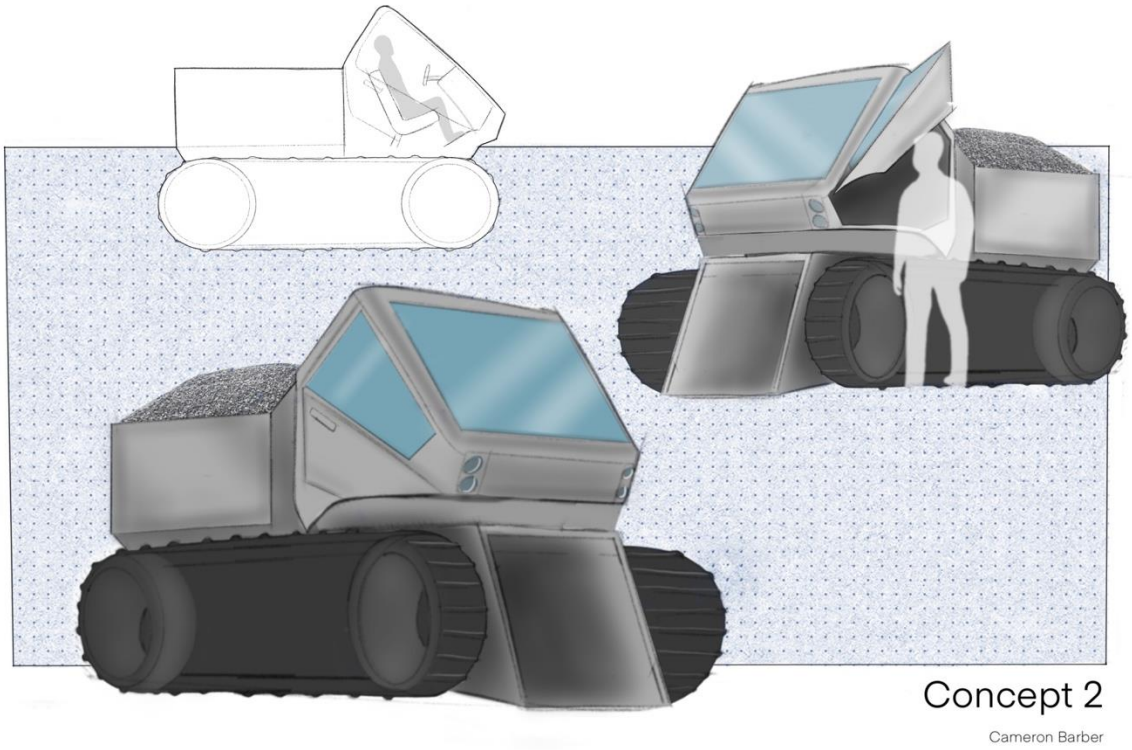


Figure 28 - Ideation Sketch 3

4.2 Preliminary Concept Exploration

During this stage of the design process, the general idea for the final solution had been determined. These sketches were done to further explore form variations with different characteristics and personality.

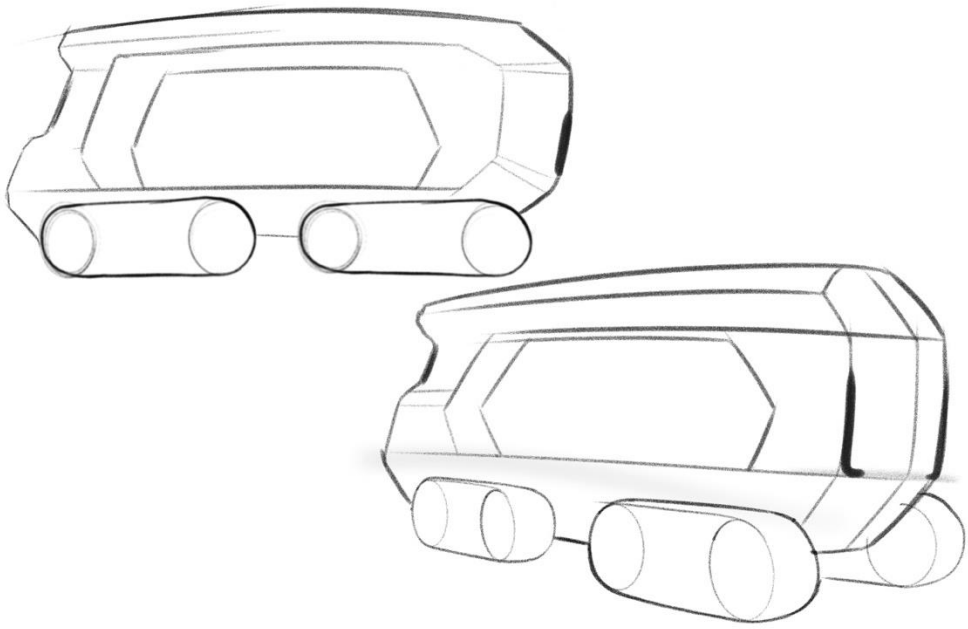


Figure 29 - Concept Exploration 1

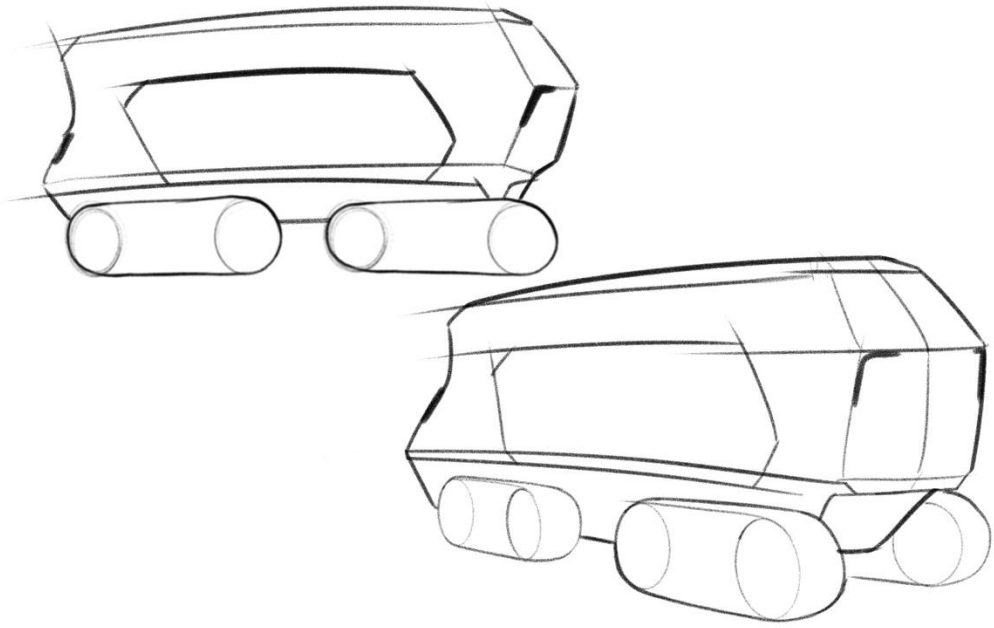


Figure 30 - Concept Exploration 2

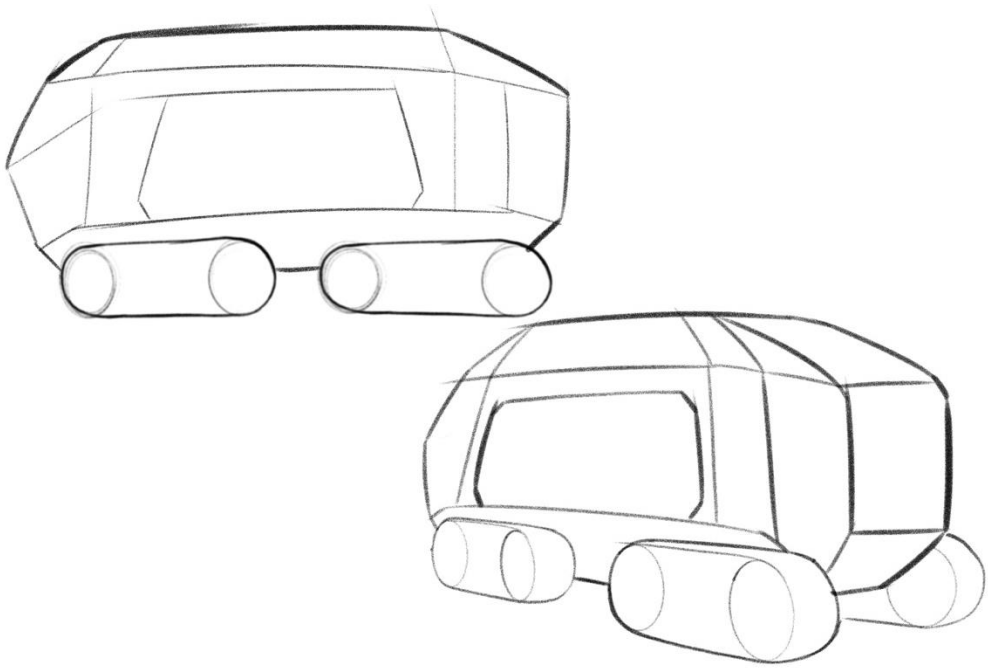


Figure 31 - Concept Exploration 3

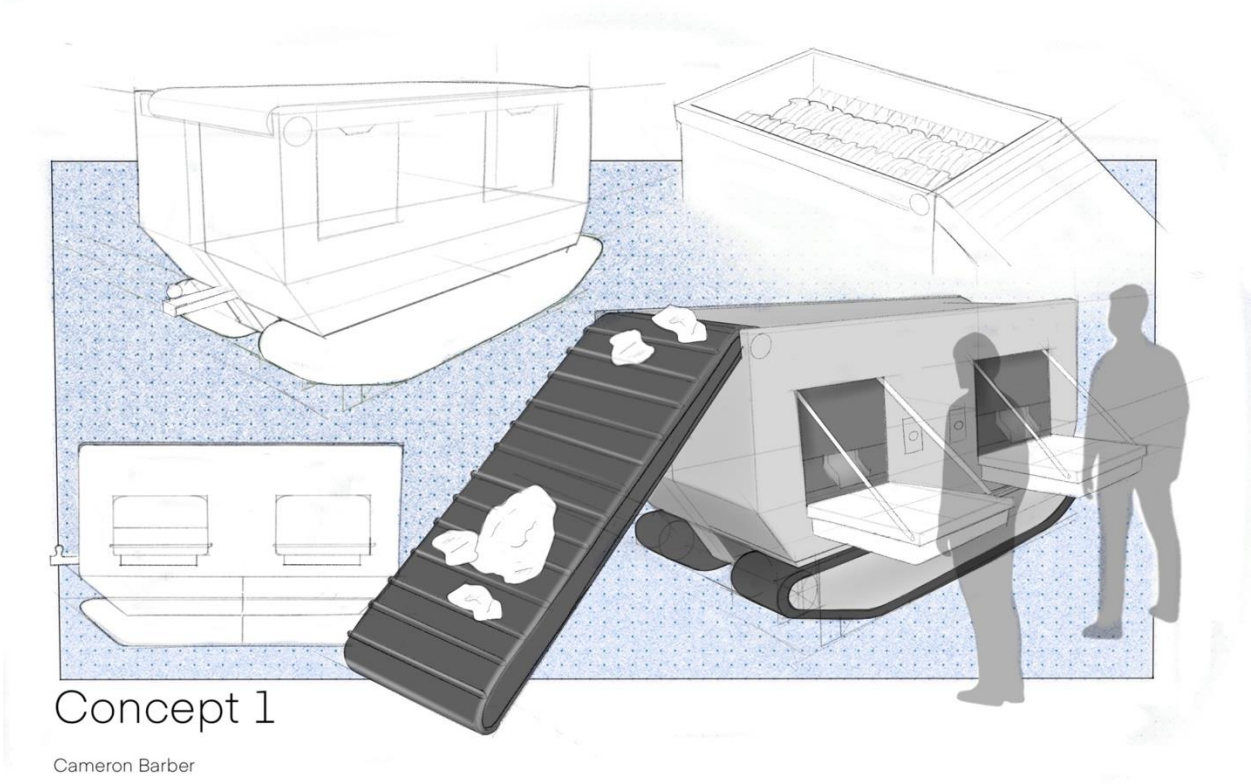


Figure 32 - Concept Exploration 4

4.3 Concept Strategy

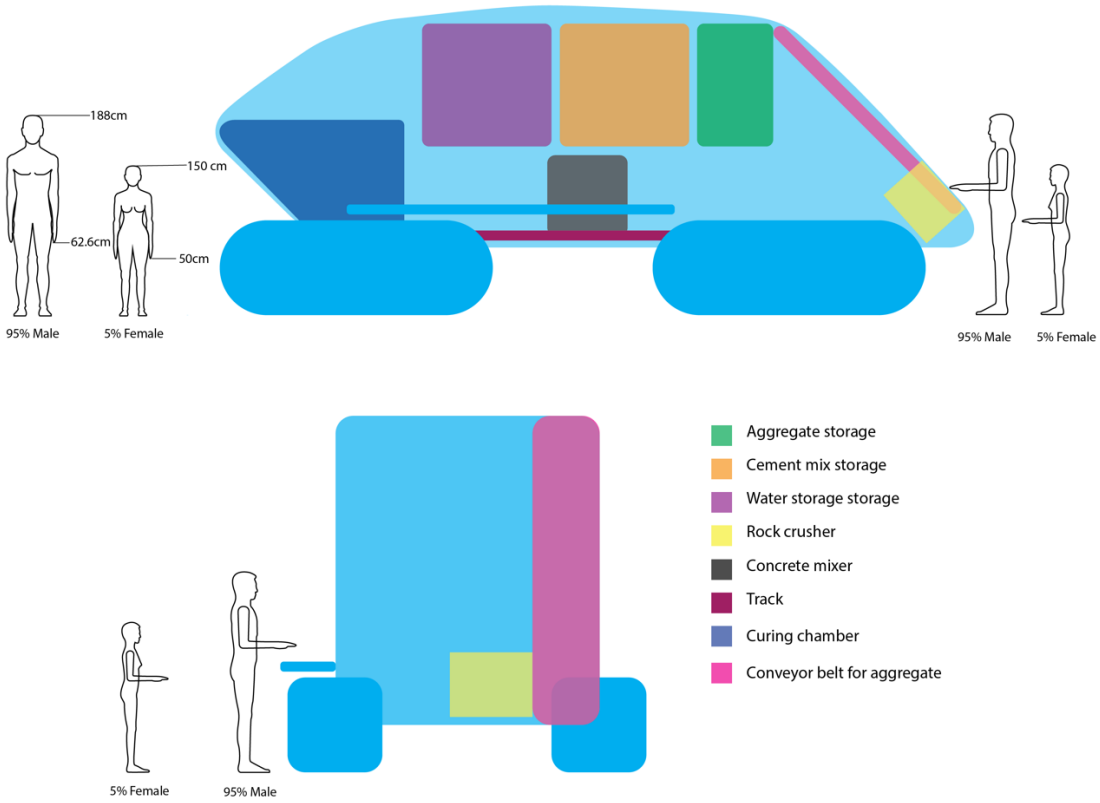


Figure 33 - Concept Strategy Schematic

4.4 Concept Refinement

At this stage of development, more of the inner workings and functionality of the design were determined. Although most of the design functionality was determined in this phase, the physical appearance and form changed a lot during the final stage of development.

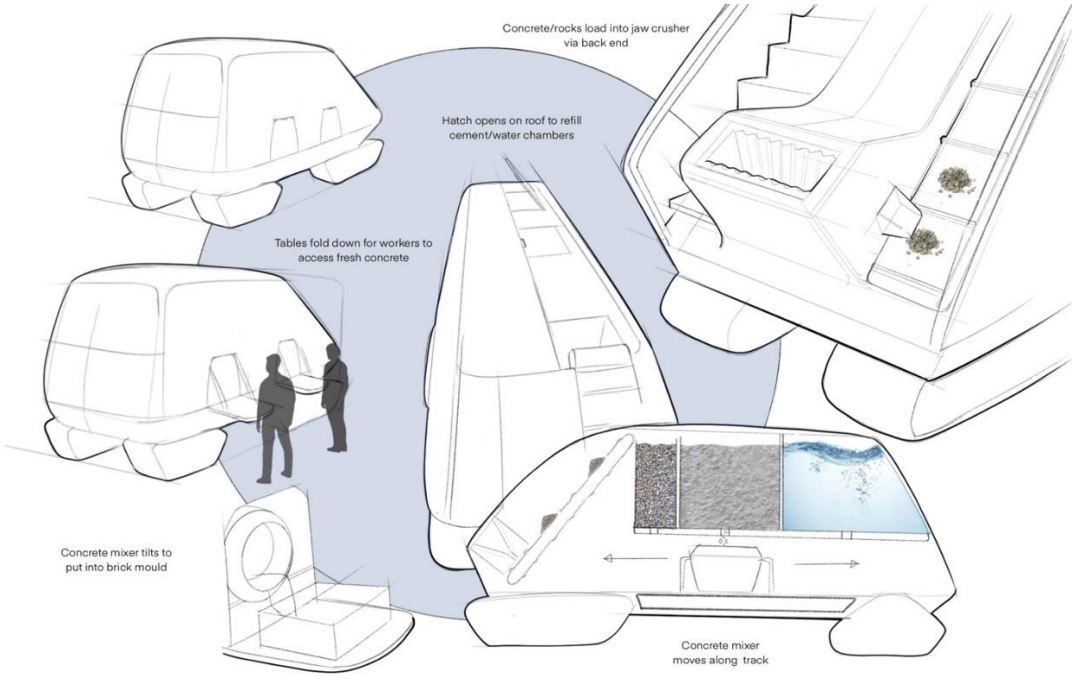


Figure 34 - Detail Refinement

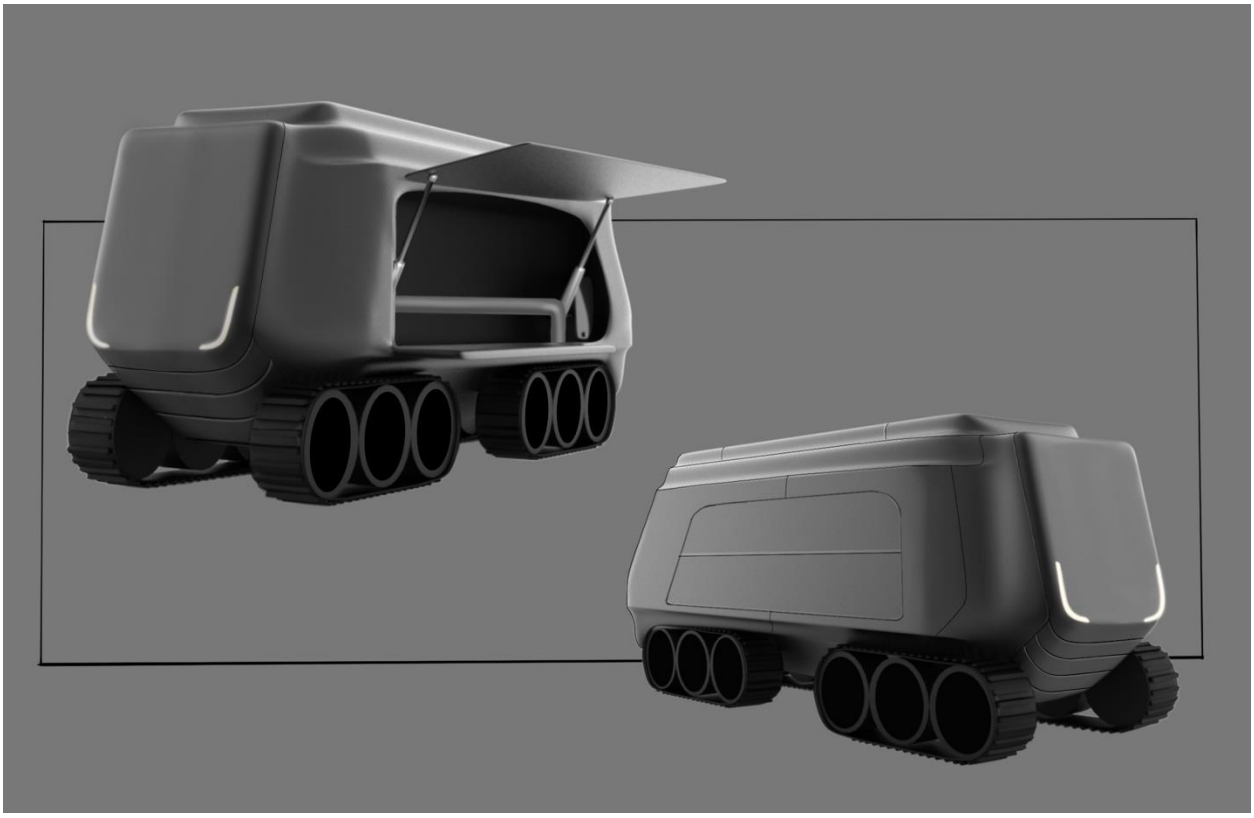


Figure 35 - Form Development

4.5 Design Realization

4.5.1 Physical Study Model

A sketch model was constructed using reference to the proposed design layout at the given time. Analyzing the design in a 3D space allowed for better understanding of ergonomics and how each component would relate to each other in scale.

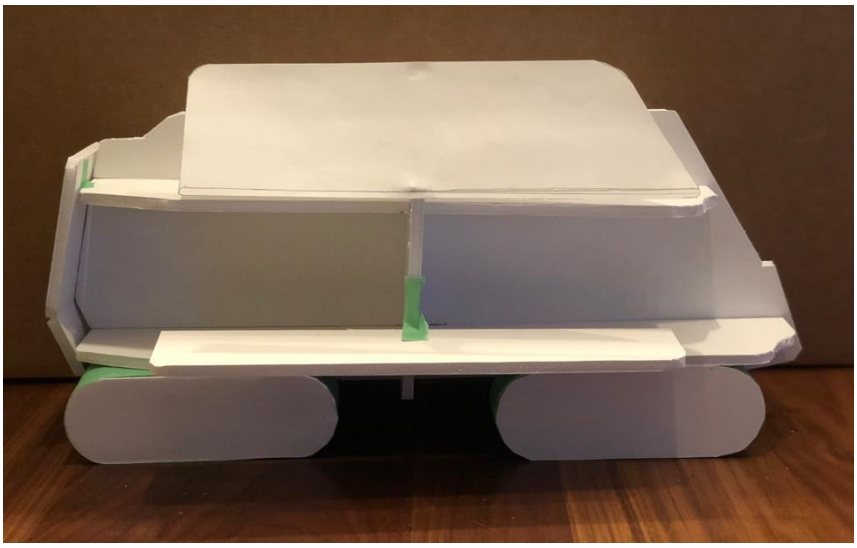


Figure 36 - Sketch Model View 1

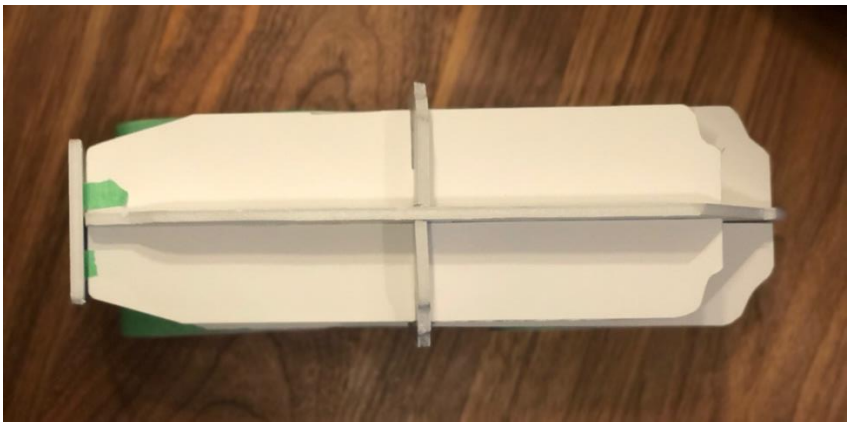


Figure 37 - Sketch Model View 2

Figure 38 - Sketch Model View 3

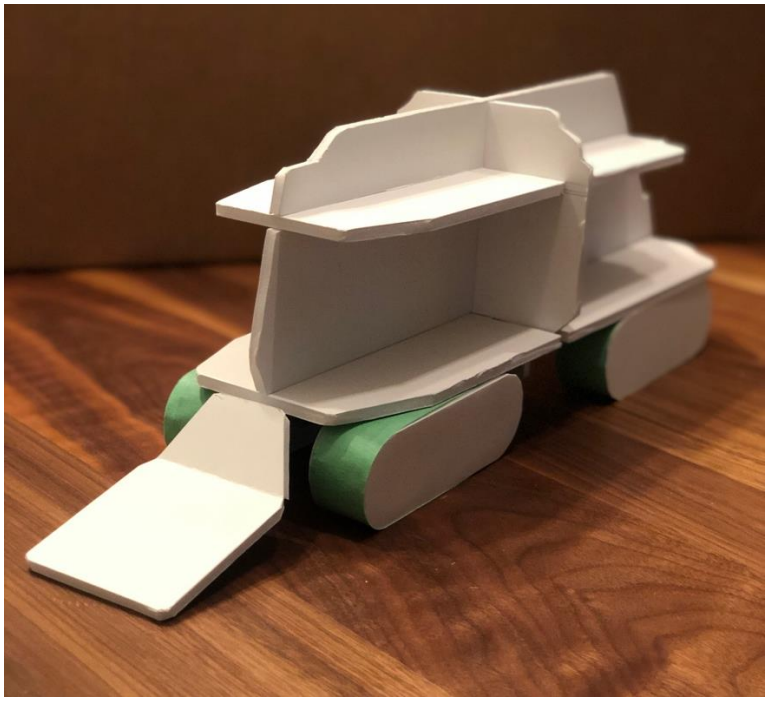


Figure 39 - Sketch Model View 4

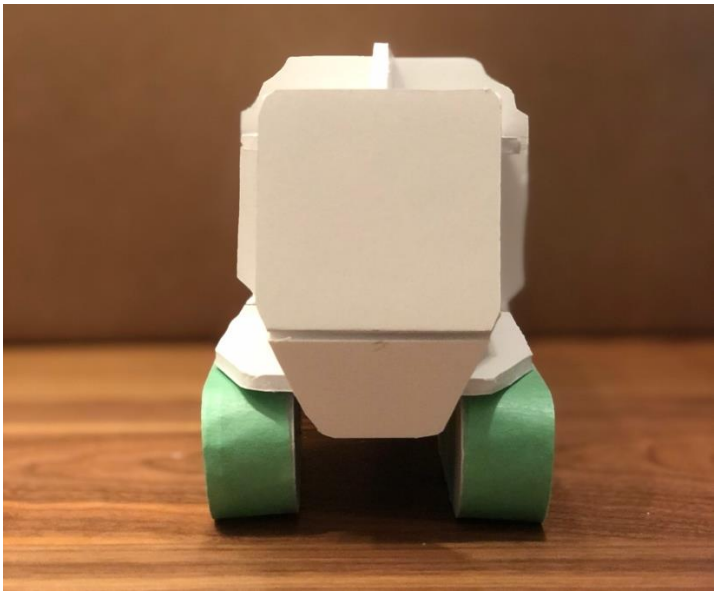


Figure 40 - Sketch Model View 5

4.5.2 Product Schematic

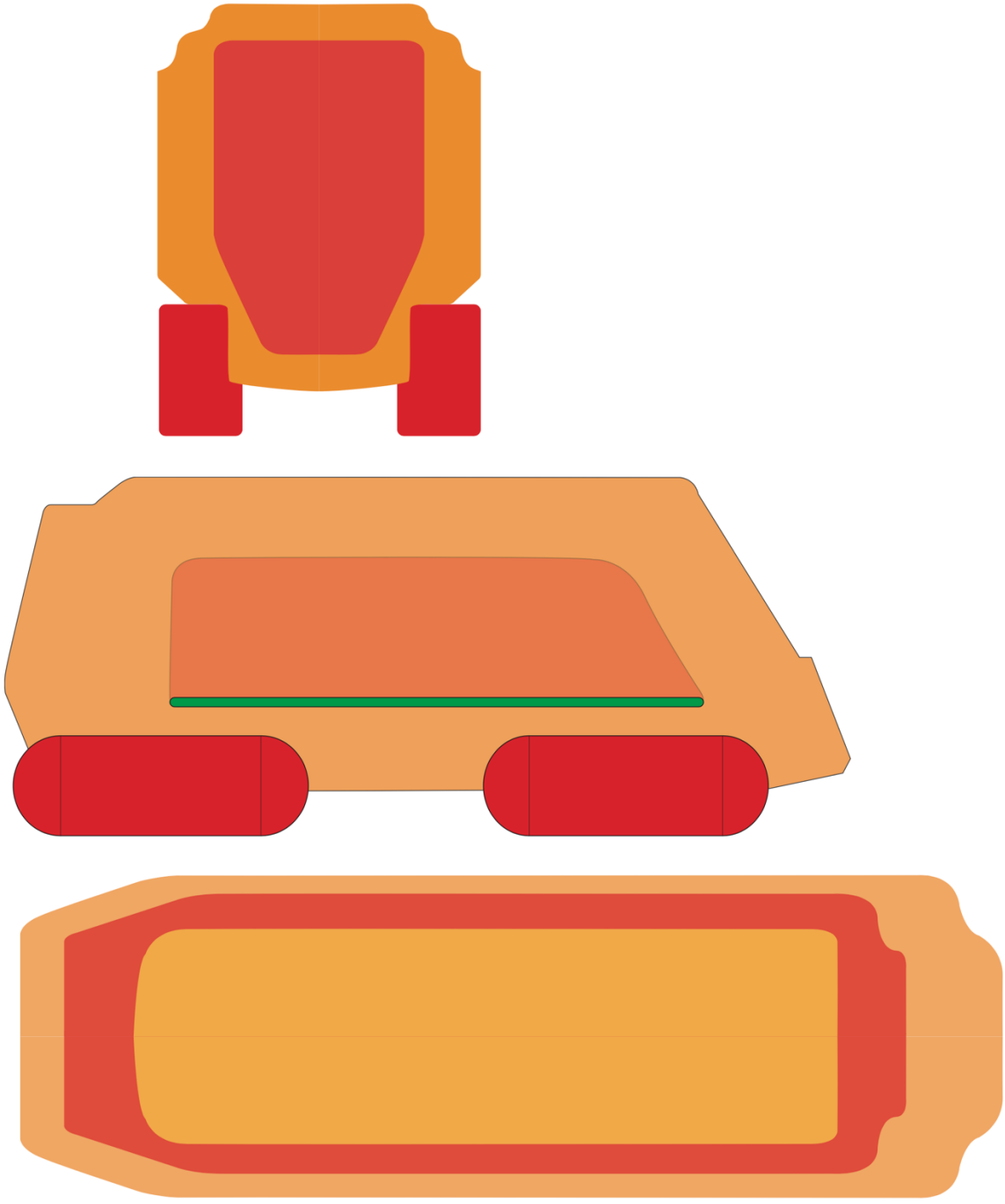


Figure 41 - Product Schematic

4.6 Design Resolution

During this final stage of the design process, most internal details had been determined. The decision was made relatively late in the process to completely change the form of the vehicle so that it had more personality, while keeping the same robust appearance.

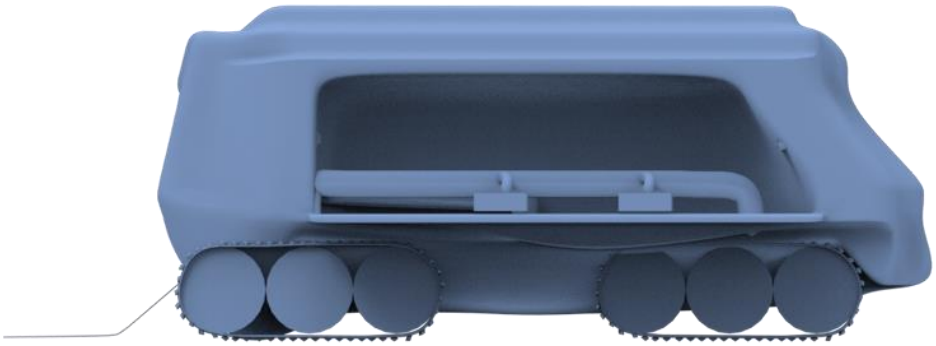


Figure 42 - Detail Resolution 1

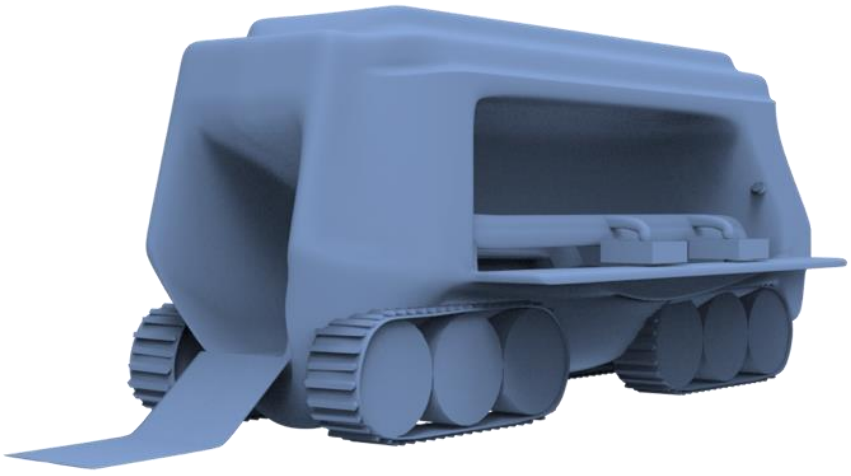


Figure 43 - Detail Resolution 2

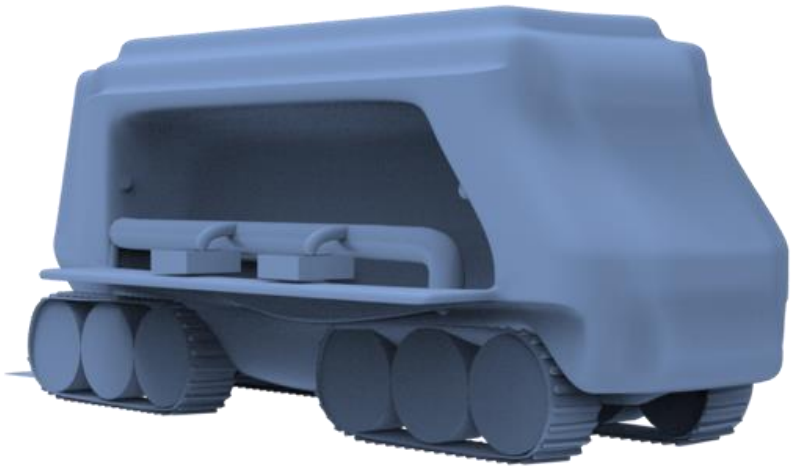


Figure 44 - Detail Resolution 3

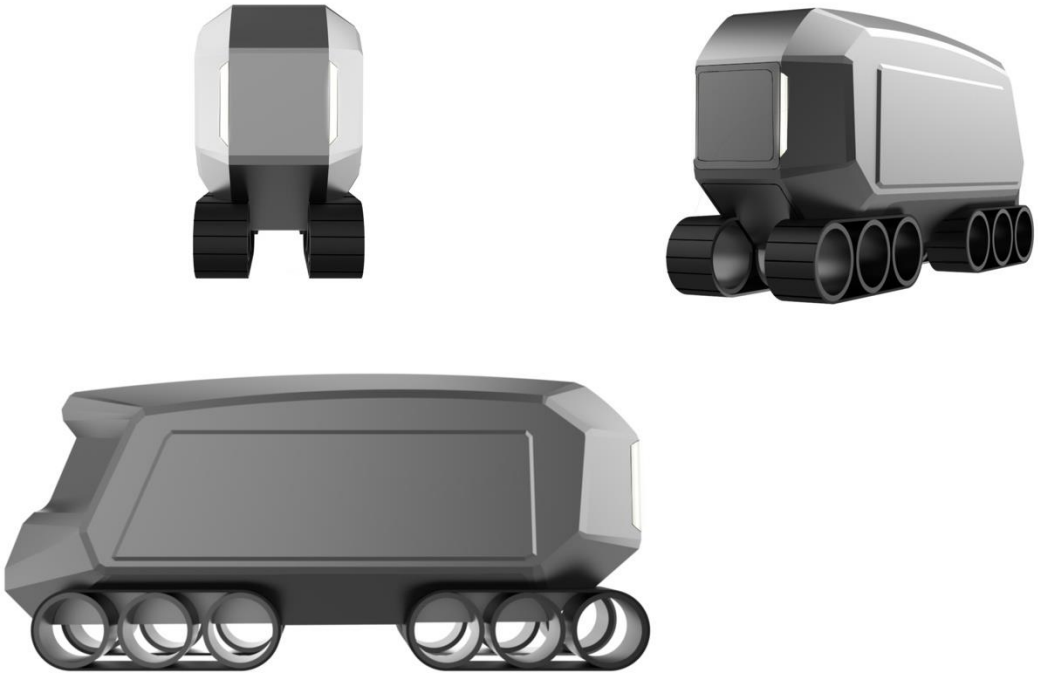


Figure 45 - Detail Resolution 4

4.7 CAD Development

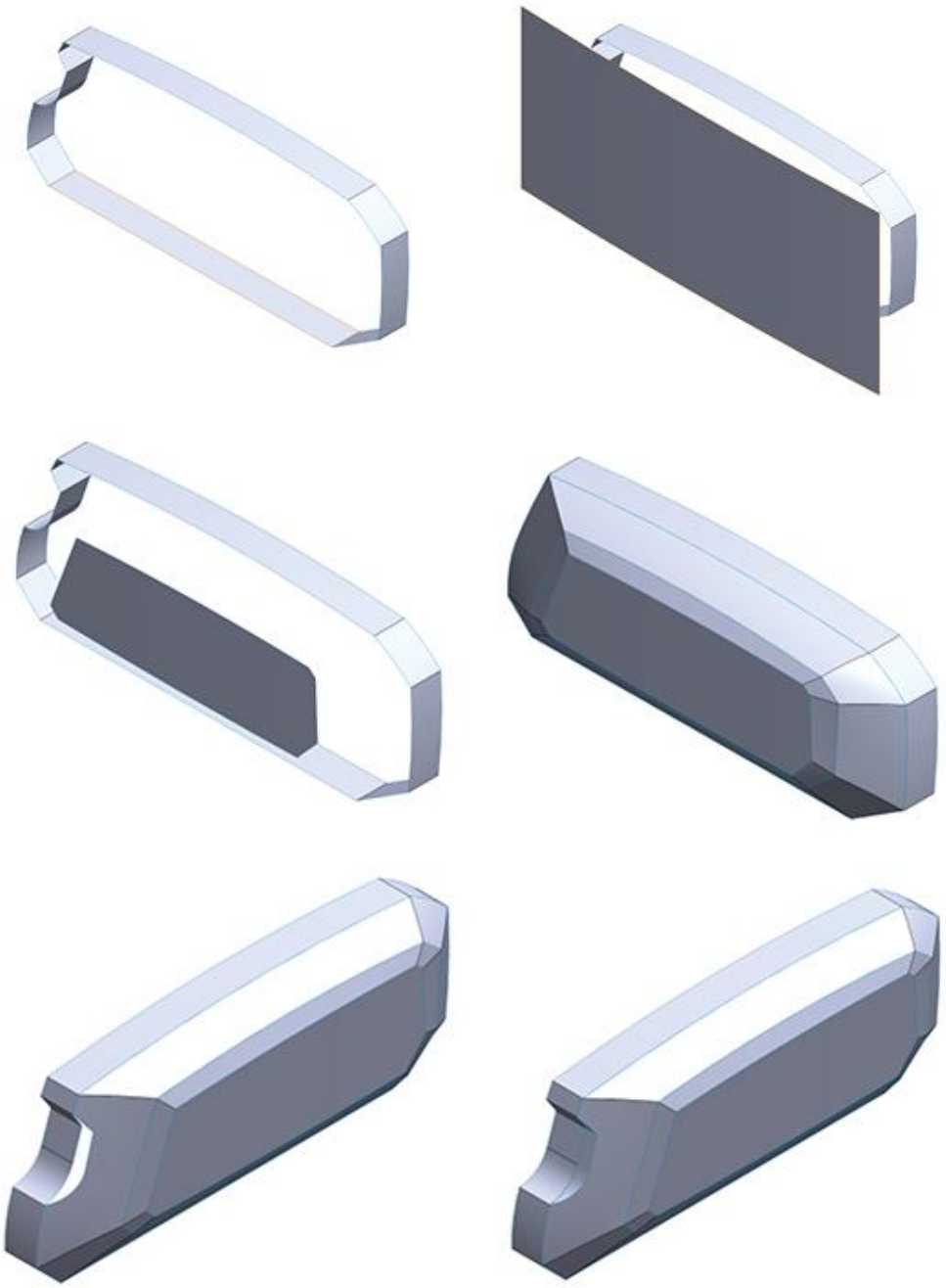


Figure 46 - CAD pt. 1

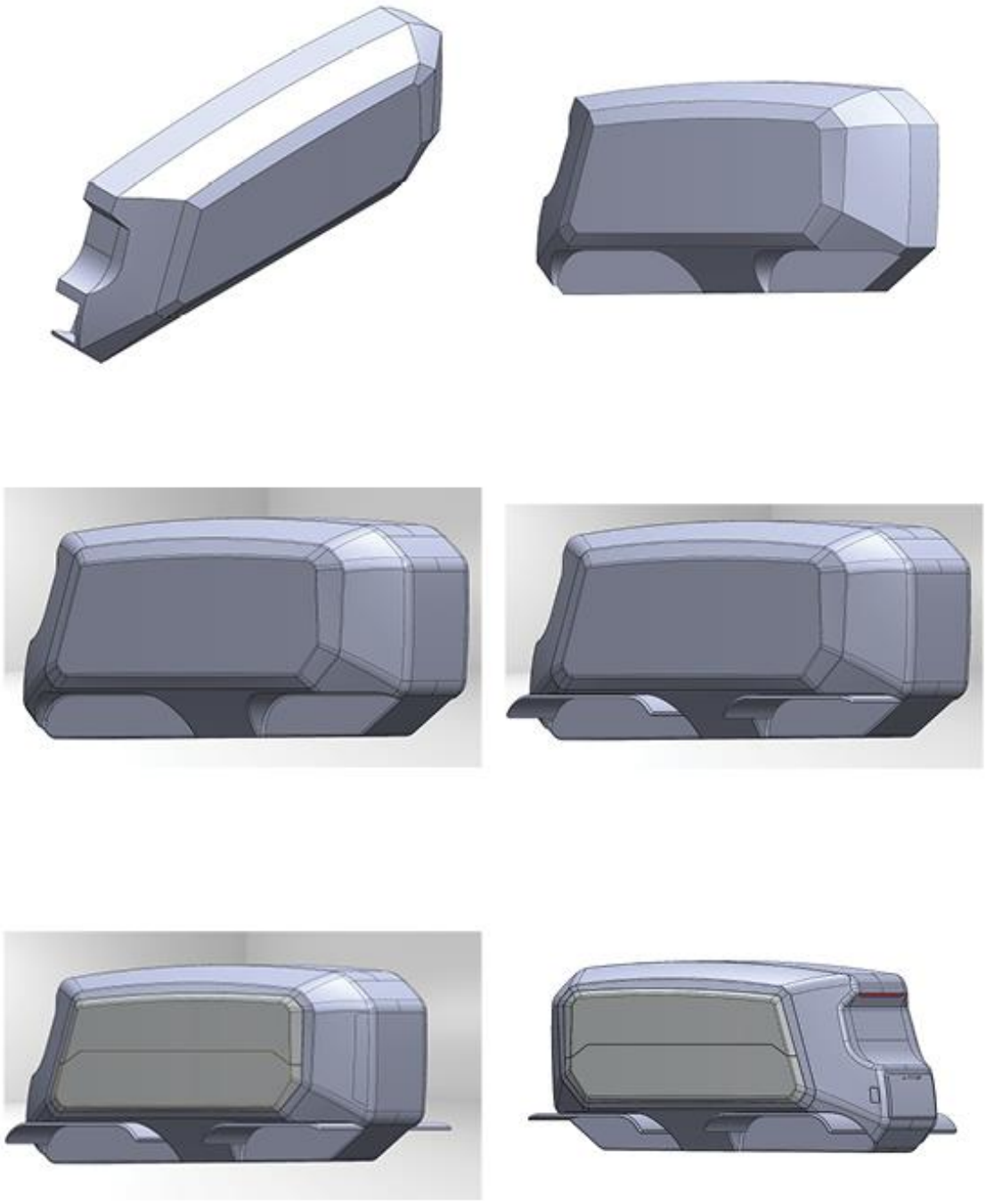


Figure 47 - CAD pt. 2

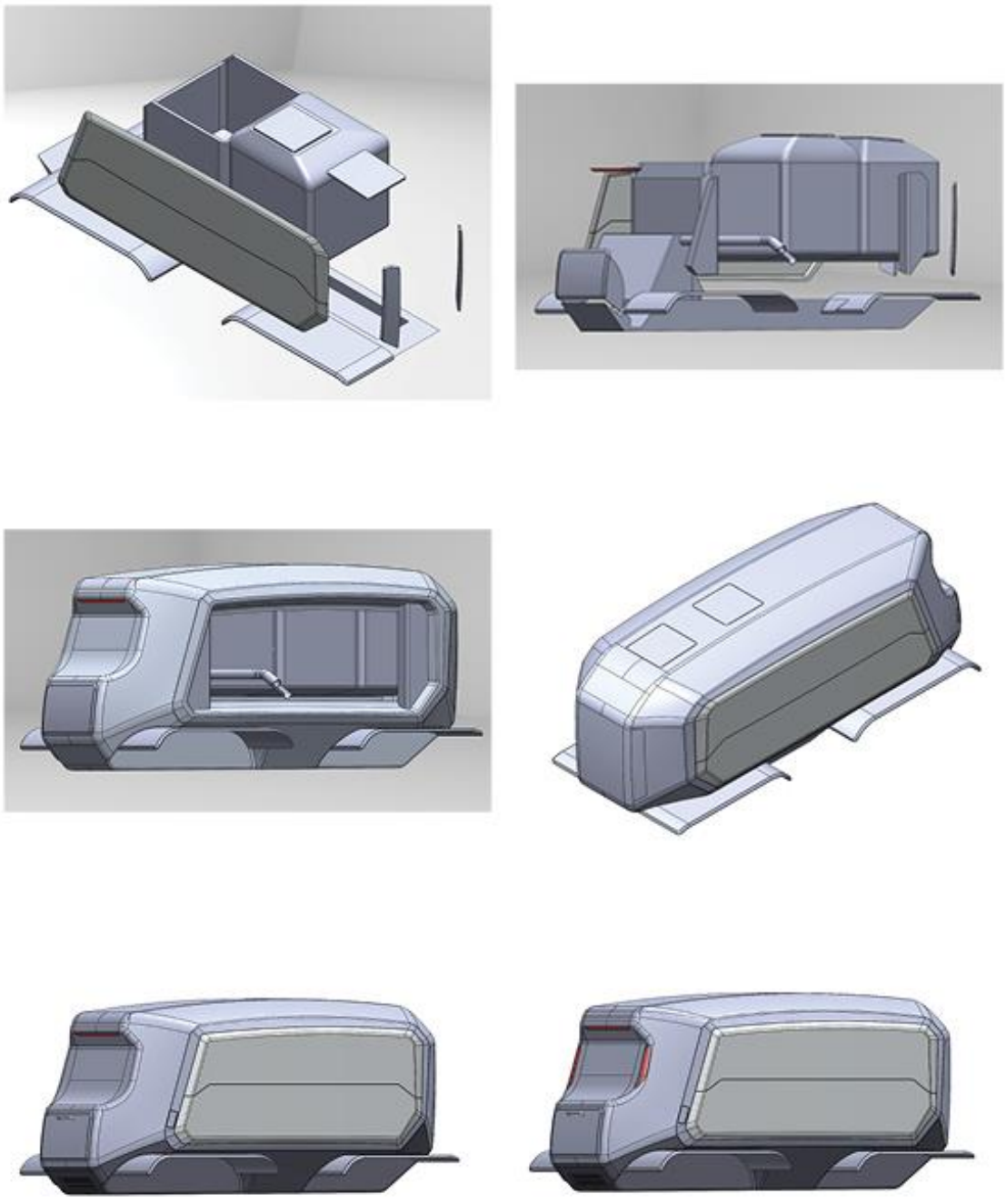


Figure 48 - CAD pt. 3

Figure 49 - CAD pt. 4

Figure 50 - CAD pt. 5

The CAD modeling process took place over a period of 7 weeks, using the 2020-2021 version of Solidworks. The process involved a big learning curve, picking up new skills such as how to do surface modeling for relatively complex forms. The model was completed in different part files to avoid clutter with the large number of parts. The tracks, conveyor belt, concrete mixer, and pneumatic hinge were each downloaded from grabcad, and redesigned to be integrated in the CAD model.

4.8 Physical Model Fabrication

While completing this model during the COVID-19 pandemic, some challenges were faced during the fabrication process. The model was 3D printed at home on the Flashforge Adventurer. The main body was printed as one single part, with each track printed separately. The tracks were then glued on the main body. The model was not able to be sanded or painted due to lack of space and resources working in a small apartment.

Figure 51 - Model Photos

Chapter 5: Final Design

This chapter will be a culmination of the previous chapters, showcasing the final design. Key features of this design proposal will be highlighted including design features, ergonomics, and sustainability.

5.1 Summary

After disaster occurs, vulnerable communities struggle with existing capacity to dispose of disaster debris. Rubble in particular, is the worlds largest polluter in volume. FORGE is a solution to help find new use for this rubble.

5.2 Design Criteria Met

The following section will highlight the different elements of FORGE, and how it satisfies each of the design criteria.

5.2.1 Full Bodied Interaction Design

A full scale 1:1 ergonomic model was created using the 95th percentile male, and the 5th percentile female as reference. The model was created in Virtual Reality using a modelmaking platform called Gravity Sketch. This program was an excellent tool for providing an immersive, full scale reference, allowing for the observation of how the user will perform different tasks highlighted below.

Workbench:

The workbench is a feature used as a workspace to fill brick moulds with concrete. It Is retractable so that the vehicle is more compact when the workbench is not in use. The workbench must be at a height that is accessible for the 5th percentile female, but not too low for the 95th percentile male. This can be achieved with a worktable set at 36 inches in height. There also must be enough depth that the table provides enough room for the user to work on. 25.5 inches is an appropriate amount for this.

Rock crusher:

The rock crusher must be at a height that is accessible for the 5th percentile female, but not too low for the 95th percentile male. This can be achieved with a height of 21.5 inches. The Rock crusher should be wide enough that at least two people at a time can use it. 35.8 inches is an appropriate width to achieve this.

5.2.2 Materials, Processes, and Technology

Concrete plays a crucial role in the development of modern-day civilization, providing shelter for billions, fortifying defences against natural disaster and “providing a structure for healthcare, education, transport, energy and industry.” (Watts, 2019)

Concrete being the most widely used material on the planet, comes with a giant carbon footprint that’s associated with it (Rodgers, 2018). The production of concrete creates environmental challenges not only in how it’s manufactured, but also how its disposed of. The greatest environmental threat associated with the production of concrete comes from cement,

an ingredient that makes up about 7-10 percent of the material (Federal Information & News Dispatch, 2009). In order to process cement, a mixture of limestone, clay, and iron are heated in a kiln at temperatures of 1,500 ° c. This heat usually comes from burning oil or coal which creates high levels of carbon dioxide. For each metric ton of cement produced, another metric ton of C02 gas is created. As a result, this process now accounts for 7 percent of the world's industrial carbon dioxide emissions at 2.8 billion tonnes. (Federal Information & News Dispatch, 2009) (Rodgers, 2018)

Fortunately, an alternative and less harmful solution for cement has been discovered called fly ash. The material happens to be created from other industrial processes and is a by-product of coal combustion. The U.S federal law now requires power plants to capture this ash to reduce pollution to earth's atmosphere. The material is not only cheaper than cement, but it has excellent cement like properties, and can produce even higher quality concrete than traditional methods. The fly ash still must be mixed with a small portion of cement, however much less is needed (Federal Information & News Dispatch, 2009).

Another component used to make concrete which can be made more sustainable is aggregate. "Until recently, most of the world's used concrete went into landfills, at enormous environmental cost. But today, some manufacturers, especially in Europe, are crushing used concrete and recycling it for use as an ingredient in new concrete" (Rodgers, 2018). In fact, Switzerland and Austria use RA on a regular basis. Aggregate is traditionally made from crushed rocks and boulders, usually extracted from a quarry. The use of recycled aggregate from debris or demolition waste can provide a sustainable advantage by eliminating the need to mine new materials from quarries, greatly reducing CO2 emissions. Another benefit of using recycled

aggregates in concrete production is the advantage it provides in the transport chain. Heavy traffic is greatly reduced, which not only relieves the climate footprint, but other environmental and health risks associated with heavy traffic (noise, dust, etc.)(Rodgers, 2018).

5.2.3 Implementation – Feasibility & Viability

Material	Benefits + Manufacturing Process	Reference
Alloy Steel	Alloy steel is a mixture of metals including nickel, copper, and aluminum. The material is durable, strong, resistant to corrosion, and it comes at a relatively affordable cost. This makes it a great application for heavy duty vehicles such as ship hulls. Steel is also highly sustainable, holding an annual recycling rate of nearly 100 percent in the automotive industry.	https://www.weerg.com/en/blog/what-are-the-four-types-of-steel https://www.steel.org/steel-markets/automotive/steel-vehicles-offer-environmental-advantage/
Tandem Perovskite Solar Cell	A new development of solar cell technology which uses compound materials with a special crystal structure. The new solar cell technology is 23 percent efficient whereas traditional silicon solar cells are 18 percent efficient. In addition to being more efficient, the material and fabrication costs are low.	https://www.sciencedaily.com/releases/2019/05/190514081554.htm
Recycled Automotive Plastics	New development of sustainable composite panels which incorporate raw material from waste automotive plastics, and waste from printed circuit boards. The material has excellent mechanical properties with a wide range of applications. Moreover, it provides function to otherwise low value waste going into landfill.	https://www-sciencedirect-com.ezproxy.humber.ca/science/article/pii/S0959652616322028?via%3Dihub

Mild Steel	One of the top choices for automotive manufacturers due to its ability to weld and form easily using methods like cold stamping. Used for general purposes and light structural elements. This material does not serve well for major structural components.	https://ehdtech.wixsite.com/ehd-tech/single-post/2018/06/11/future-automotive-manufacturing-materials-and-processes
Recycled Aggregate	Recycled Aggregate (RA) is a sustainable alternative for making concrete, currently being practiced with material from demolished buildings. By incorporating RA in the production of concrete, the process of mining and delivering materials are eliminated, greatly reducing C02 emissions.	https://www-sciencedirect-com.ezproxy.humber.ca/science/article/pii/S0921344920302482?via%3Dihub
Cement	Manufactured by mixing fine limestone, clay and sand. The material is then heated to 1450° C in a kiln. The material makes up about 7 percent of concrete.	rediscoverconcrete.com/en/sustainability/how-cement-concrete-are-made.html#:~:text=Cement%20is%20manufactured%20by%20heating,in%20the%20manufacture%20of%20cement.http://
Fly Ash	An alternative and less harmful solution for cement. The material is a by-product of coal combustion, and U.S federal law now requires power plants to capture this ash to avoid pollution to earth's atmosphere. The material is not only cheaper than cement, but it has excellent cement like properties, and can produce even higher quality concrete than traditional methods. The fly ash still must be mixed with a small portion of cement, however, much less is needed.	https://search-proquest-com.ezproxy.humber.ca/docview/190524088?accountid=11530&pq-origsite=summon

Table 11 - Materials + Manufactiring

5.3 Final CAD Rendering

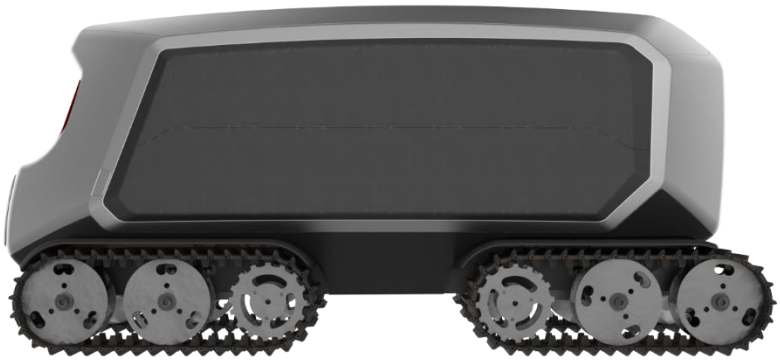


Figure 52 - Side Profile Closed

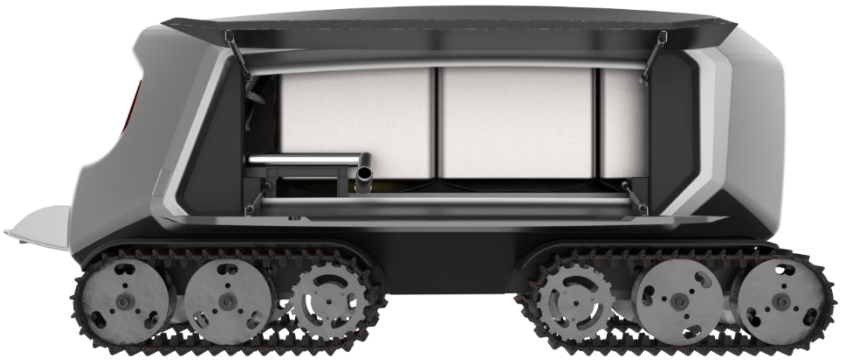


Figure 53 - Side Profile Open

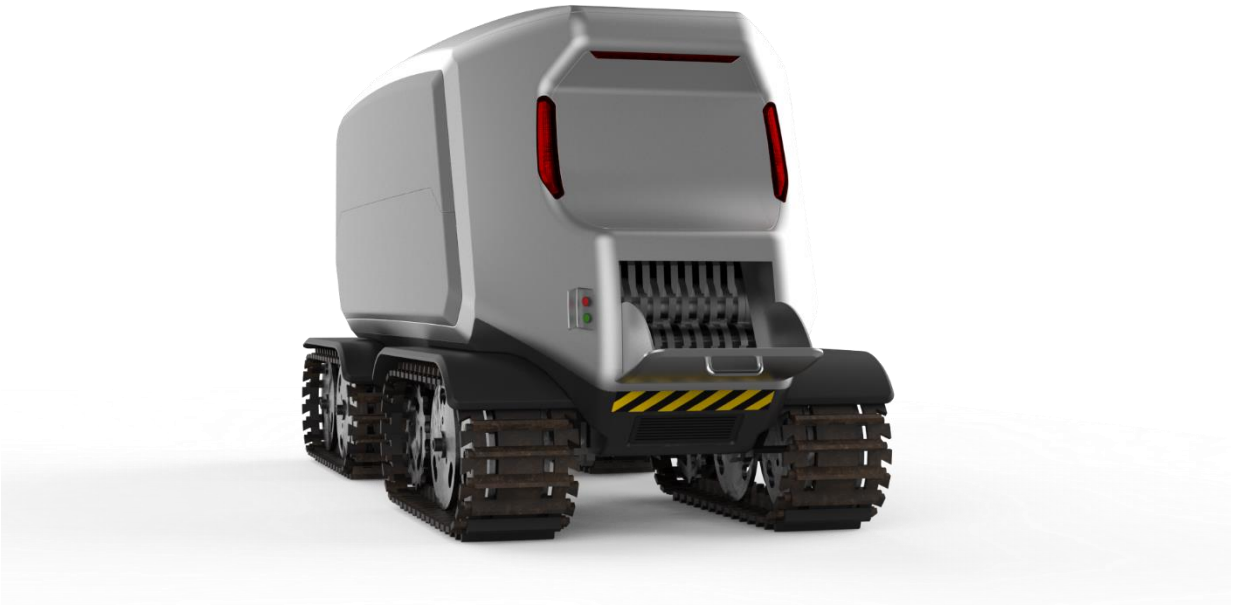


Figure 54 - Rock Crusher Closed

Figure 55 - Rock Crusher Open

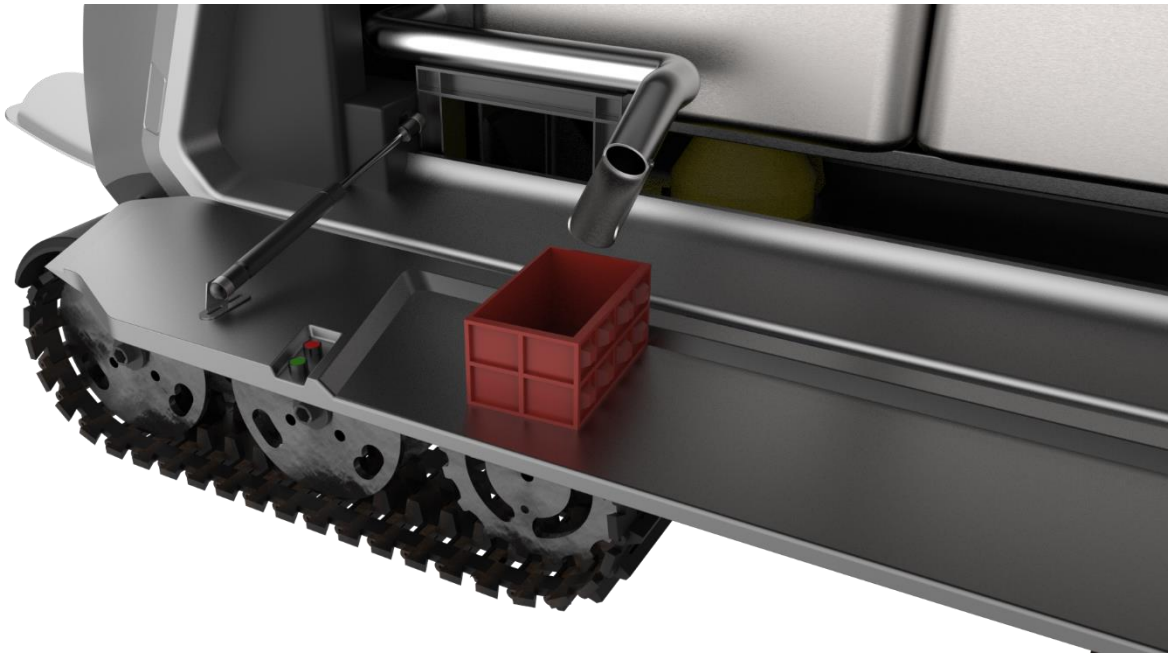


Figure 56 - Concrete Dispenser Off

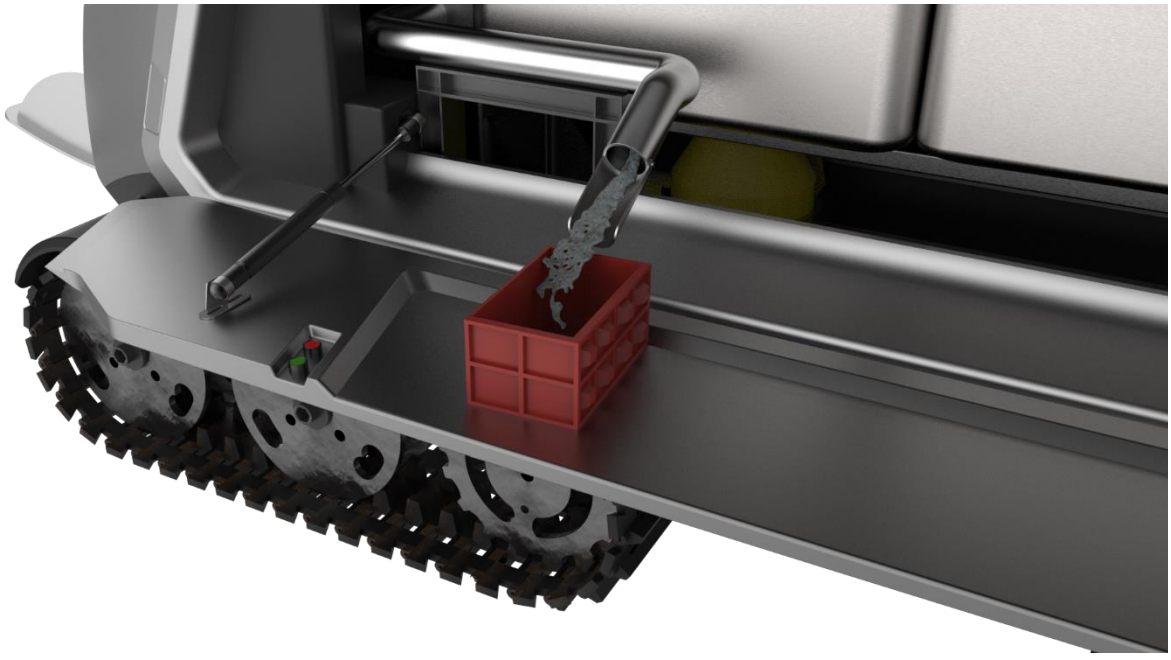


Figure 57 - Concrete Dispenser On

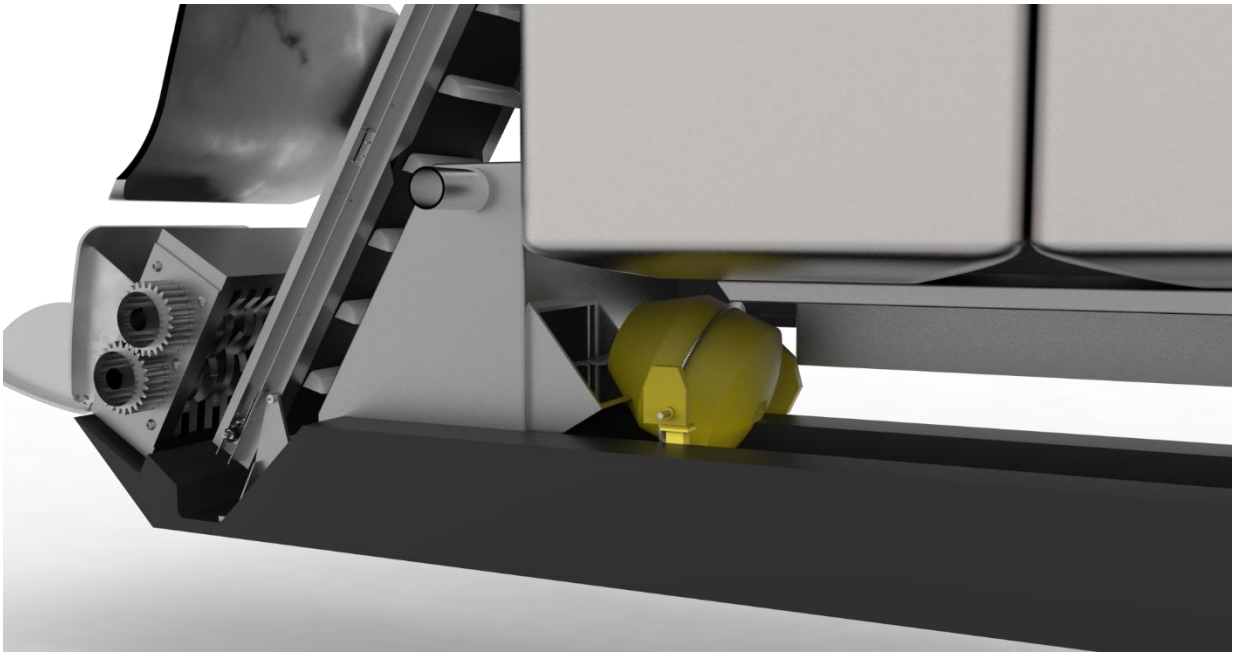


Figure 58 - Concrete Mixer Pouring

Figure 59 - FORGE Inner Workings

5.4 Physical Model

Figure 60 - Final Model

5.5 Technical Drawings

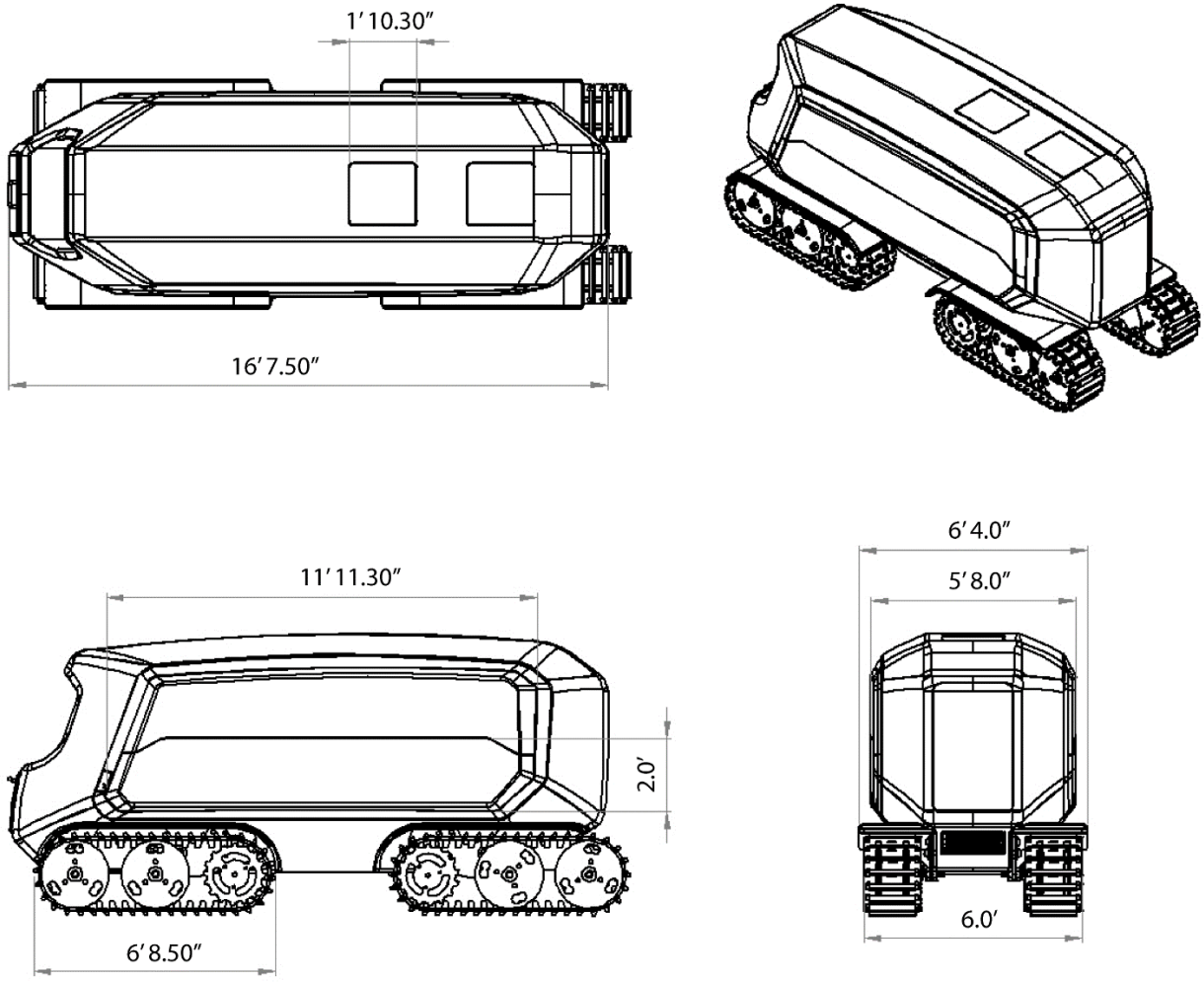


Figure 61 - Technical Drawings

5.6 Sustainability

This machine prevents large amounts of concrete from going into landfill, which would otherwise cause harmful effects to the environment. Additionally, carbon emissions are greatly reduced by removing the need to source and deliver fresh aggregate. With these vehicles, more work opportunities will be provided for cash for work programs to help rebuild struggling economies. The new concrete will go towards helping communities to build back faster and stronger, avoiding the need for unsafe temporary shelters.

Chapter 6: Conclusion

Figure 62 - FORGE In Situ

In the last 30 years, the number of natural disasters has doubled, economic losses from natural disasters have more than tripled, and low-middle income countries alone have lost $1.2 trillion dollars in damages. Vulnerable communities are faced with the dilemma of how to use their existing capacity for recycling, composting, combusting, and disposing natural disaster debris. Collapse of waste management services has also led to uncontrolled dumping sites and improper handling of waste. Furthermore, uncollected rubble from damaged buildings has impeded access and prevented rehabilitation and reconstruction.

FORGE provides a solution to find new use for this rubble by turning it into recycled aggregate to be used towards new building materials. By combining existing technologies, such as a rock crusher, concrete mixer, a conveyor belt, and a pumpcrete dispenser FORGE acts as a

portable factory for making concrete. Benefits include reduced amounts of concrete from going into landfill, which would otherwise cause harmful effects to the environment. Additionally, carbon emissions are greatly reduced by removing the need to source and deliver fresh aggregate. With these vehicles, more work opportunities will be provided for cash for work programs to help rebuild struggling economies. The new concrete will go towards helping communities to build back faster and stronger, avoiding the need for unsafe temporary shelters.

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Chapter 8: Appendix

Appendix A - Discovery

Scope: Natural disasters or becoming more frequent, and with growing populations, more people are becoming at risk. The biggest demographic of concern during these situations are vulnerable/low income people.
Background: Low income people generally live in unstable, dangerous housing that is extremely prone to natural disasters. Additionally, the homes are located in areas that are susceptible to the higher rates of natural disasters as the locations are more affordable.
Needs Statement: Vulnerable people are an underserved market with a high need for more options to protect themselves from natural disasters.
How is this need being addressed currently?
From 1980-2009, the international community spent $86.34 billion on emergency response and reconstruction. Only $3.25 billion was spent on prevention and preparedness.

Key Article 1

Method

A key article for this topic was sourced and selected. Required article content (Abstract, Introduction, and Conclusion sections) was copied and highlighted.

- Search Engine: Humber Library Discover
- Key Words: Disaster response el Salvador
- **Citation**:

Korteweg, H. A., van Bokhoven, I., Yzermans, C. J., & Grievink, L. (2010). Rapid health and needs assessments after disasters: A systematic review. BMC Public Health, 10(1), 295-295. doi:10.1186/1471-2458-10-295
Key Content: Reproduced below:

Abstract: Results reported in Part I of the Earthquakes in El Salvador series (see Disaster Management & Response 2003;1:105-9) indicated clinically relevant findings. The findings indicated a need for greater public health action within all five categories reviewed: healthcare, access to healthcare, housing, food, water and sanitation. Significant results between urban and rural communities indicated a need for broader community aid, public health and sanitation services to rural areas. Faster and more efficient disaster management and care services throughout the San Sebastian community were also necessary modifications.

Introduction:

As Part II of the Earthquakes in El Salvador Descriptive Study Series, the health concerns of people living in a Salvadoran rural community after major earthquakes were evaluated. Part I reviewed the background, methods, and results of post earthquake

conditions and this article will address the implications of these results and recommendations for improvements within the community.

Conclusion:

conclusion, this review shows that questionnaires were primarily used to assess health needs and registries to assess health status. Questionnaires were also frequently used to assess health status, but registries were rarely used to assess health needs. In practice, questionnaires are sufficient to assess health status and needs. However, to minimize the possible burden of survivors we prefer the use of registries to assess health status and needs if possible. The use of existing registries also makes it possible to routinely collect information. Another advantage of the use of existing registries is the possibility to compare the health status in a disaster situation with a non-disaster situation. Comparison of data from registries provides longitudinally information about possible increase of illnesses, injuries or hospital visits due to the disaster. In general, the use of reference data provides insight into the actual need for health care and whether this need is different or more extensive than the needs regular health system normally deals with. This may provide direction for public health interventions. We also found that with the use of registries a large number of participants can be included in a survey, showing that registries can easily deal with a large amount of information. Nevertheless it is important to realise that it is not possible to internationally develop a standardized registration system, because the possibilities in each country are different. For example European countries have different types of health registries and different privacy rules to use the data for health research purposes. Furthermore, this review showed that the most commonly used registries are hospital registration systems. When deriving the health status from hospital registration systems only the most severe conditions will be found. In the Netherlands, we have experience with an ongoing surveillance program of health problems registered by general practitioners after a disaster [9, 10]. If the disaster did not disrupt the normal health structure, usually people will visit their general practitioner in stead of a hospital. To prevent lack of information we recommend assessing also information from registries of general practitioners apart from hospital registrations. To use these medical registries rapidly, preparation is essential.

Health needs can be derived from health status, for example which medications are needed. But not all needs can be established with registries, for example access to food and water and personal health needs other than medical necessities are important to consider. To assess this kind of information a supplementary questionnaire is necessary. A questionnaire is also necessary in case access to existing registrations is not rapidly possible.

Summarizing we recommend the use of registries in combination with a brief questionnaire for rapid assessment of health status and health needs. Development of this questionnaire needs to be carefully prepared in a non-disaster situation. First the content needs to be established and should be combined with (personal) exposure assessment as much as possible [53]. Second, decisions should be made about translations of the questionnaire to prepare for possible population groups. Third, it is important that the researcher collects data directly; telephone or face to face interviews are for this reason recommended for rapid assessment. Furthermore, the method, use of questionnaire or existing registration, should be operational within two weeks post-disaster. Finally we must be aware that if a large scale disaster with tens or hundreds of thousand evacuees strikes, several assessments in the first weeks post-disaster might be necessary.

Overall, it is important that the rapid assessment tool can be applied after all types of disaster when the regular health system is disrupted or overloaded. In general special attention should be directed to vulnerable groups like people with pre-existing health conditions, pregnant women and vulnerable elderly. This is important because these sensitive subpopulations concern people with unique health needs. For example, it can be more difficult for them to evacuate after a disaster or to obtain access to the medical services they need [54, 55]. Beyond the issues of measurement we recommend the development of a standardized questionnaire which can be used internationally. This makes it possible to compare the data that is unambiguous. Preferably one questionnaire will be developed with different modules. This modules are sets of questions that can be modified to the specificity of the disaster situation such as type of disaster and country. A basic set of questions can be developed for each disaster situation, such as disaster involvement (e.g. passenger or citizen) and the experiences and losses due to the disaster. This standardized questionnaire makes it possible to internationally compare the data that is unambiguous. This review summarizes the existing questionnaires which can serve as a starting point to develop a standardized questionnaire.

Summary Statements

1. Findings from studying earthquakes in El Salvador show a need for greater public health action within all five categories reviewed: healthcare, access to healthcare, housing, food, water and sanitation.
2. There is a need for broader community aid, public health and sanitation services to rural areas.
3. The most commonly used registries are hospital registration systems. However, hospital registration systems only receive people with the most severe conditions.
4. To prevent lack of information, it is recommended that people assess information from registries of general practitioners apart from hospital registrations. To ensure these medical registries are used rapidly and effectively, preparation is essential.
5. If a large scale disaster with tens or hundreds of thousand evacuees strikes, several assessments in the first weeks post-disaster might be necessary.

Key Article 2

Method

A key article for this topic was sourced using Google and selected. Required article content was copied and highlighted.

- **Search Engine**: Google Search

- **Key Words**: Disaster response el Salvador

Findings

- **Citation:** Woersching, J. C., & Snyder, A. E. (2004). Earthquakes in el salvador: A descriptive study of health concerns in a rural community and the clinical implications--part II. Disaster Management & Response, 2(1), 10-13. doi:10.1016/S1540-2487(03)00150-0

- **Key Content**: Reproduced below:

- **Abstract:** When disaster strikes it is important to realize that apart from acute health problems that will be addressed by the emergency departments many other problems are likely to occur [1]. Homes may be damaged, sometimes resulting in displacement of the population. Survivors might develop diseases or have other health problems as a consequence of the disaster. These problems may result in health related needs like medical treatment and medication use. Since a disaster might have direct consequences for public health care a clear overview of these health needs is important. Therefore rapid assessment methods are needed to collect reliable, objective information that is immediately required for decision making in the recovery phase of the event. Health care agencies, stakeholders and policy makers will request a rapid insight into health status to take care of the needs of the affected population [2]. With this collected information about health status and needs, public health interventions can be prioritized. Rapid assessment tools are also important to guide the emergency efforts in the affected area [3]. For example, public health interventions and emergency efforts may include improvements of access to medical care, financial support and restoration of damaged houses.
- **Introduction:** Since health needs can rapidly change [2] after the acute phase and a quick insight into common health problems is important to preserve adequate health care, this article focuses on assessment methods which can be applied in the first two weeks after a disaster. This is also important because collection of possible exposure data, such as the extent of involvement or the use of protection measures, is the most reliable in the first two weeks after an event (to prevent recall bias). Furthermore, we assume that a rapid assessment can provide information that can be necessary in case the need for the regular local health and medical systems is unknown or if these systems are overloaded or disrupted due to the disaster. After all, if the regular local health care is operative no information is needed for collective health care.
- Objectives and primary goal
- Which type of rapid assessment tools are developed and used internationally is the main question that forms the basis of this article, in which is examined which aspects of assessments may influence the rapidness such as preparation and procedure of assessment. The primary goal of this article is to describe and analyze these existing aspects which will contribute to the development of a useful rapid assessment tool. With this review we will show what is internationally known in the literature and to show any possible gaps of information in the literature. Ideally a tool is needed which does not add to the burden of disaster victims. This is an important consideration when collecting health information about disaster victims. We will discuss some aspects that might add to or relieve this burden and view and compare the most commonly used rapid assessments in this light. This article focuses on assessment of health status and needs; however, when disaster strikes other consequences such as exposure that can influence the health of affected people needs to be considered and/or incorporated to minimize the burden of survivors and to restore their collective control [1].
- **Conclusion:**

Recommendations

Strengthening local rural health care response

These study results show there is a need for change in general health care conditions and disaster preparedness by local rural organizations. International support extended to El Salvador proved to be minimal for rural areas. There were barriers in transportation, access, and communication with the rest of El Salvador and the world. These factors place more responsibility on the local community groups and health organizations after a disaster. The local providers must be able to do immediate assessments, conduct a short-term survey, and provide initial primary care needs. Providing disaster aid can be less of a burden if providers are given continuing health education and assistance with practices that improve overall health conditions and access to care. Community leaders must take on this initiative, and community members must be made aware of health concerns within their community and their ability to change those conditions. For example, the local Red Cross and the *Unidad de Salud* can sponsor continuing education programs, such as health fairs, on market days. The fairs would provide sustainable learning opportunities that would keep health concerns on the minds of community members.

The role of nursing students without borders (NSWB)

The members of the NSWB El Salvador initiative have several challenges. They will develop their role as health educators and promoters in the community. They also must build a partnership between local health groups and act as a resource for health and community action education. Health promotion is an essential element of public health work, which needs long-term investment within a community. NSWB must define its involvement after the disasters and make sure that a common plan for responsibility and action is established between the group and community leaders.

Summary Statements

1. Rapid assessment methods are needed to collect reliable, objective information that is immediately required for decision making in the recovery phase of the event.
2. Local rural organizations seek the biggest need for change in terms of general health care conditions and disaster preparedness. This is because international support extended to El Salvador has proven to be minimal for rural areas. Additionally, rural areas face barriers in transportation, access, and communication with the rest of El Salvador and the world.
3. Local communities and health organizations end up having the most responsibility in care providing, since they can provide it the fastest.
4. The local providers must be able to do immediate assessments, conduct a short-term survey, and provide initial primary care needs.
5. Community leaders must take on this initiative, and community members must be made aware of health concerns within their community and what they can do to help. These providers must be given proper health education and assistance with practices that improve access to care.

Unknown 0:00

Number of bigger hurricanes where there's a lot of debris. In the smaller size ones people just do their own thing, but I think you know you, if, if there's, you know, something related to bigger debris I think that, you know, bigger quantity of debris that's probably something that could be interesting in the only thing to figure out is something that would actually help you know the kind of smaller scale as well but obviously you know if it's more peaceful people just kind of do their own thing, but I think it's really good I mean in Haiti, for example, it was you know there was having an urban disaster like that I mean everyone just concentrated in clusters and just chokes off chokes off people's lives are already their livelihoods their shelter everything right so. So I think it's a really interesting idea. I can't pretend I dealt with that like at a specific level like I've led work overall where that's happening and not so much he was the engineer, of course. But, but it's obviously a huge problem, right, and sometimes it's dealt with inefficiently, I think it was years before they really got that cleared but I mean, if you can find ways to do it efficiently and low cost and it can be pretty useful for a lot of people.

Unknown 1:19

Yeah, so I was um yeah just kind of like what I've done for research like looking at, you know how it's done in the process and it looks like in these areas though they'll bring in large machinery and bobcats and bulldozers and stuff like that but then they'll also employ locals to help out doing labor, like on the ground. And just from the videos that I saw I saw that they you know they have buckets and wheel barrels where they'll load it up in hard to access areas and they'll bring it to the side of the road where it'll get cleared out later. Did you experience like that work process at all?

Unknown 2:01

Yeah, I mean, I think I think you again not knowing exactly how to organize I would say that's probably pretty accurate observations, you know in being here and driving by and seeing people deal with it you know exactly how you described it, you know, you kind of, you're kind of cleaning up what you can, putting it off by the side of the road somebody picks it up, picks it up to the dump. And then back end there's also rather interesting too, in Haiti after the earthquake we were quite involved actually with actually some of the work of the, the waste disposal area too which is, you know, can also have its own challenges right just to, you know, see all the stuff we can do with it. It would be a different project.

Unknown 2:42

You know that that is that is part of the chain of things you have to deal with this kind of thing but I think the way you describe it. It's pretty accurate from from my experience. Yeah.

Unknown 2:54

So I guess I guess kind of

Unknown 2:57

the main the main question I'm not sure how easy it is to answer but is there anything that any process that stood out in your own work or watching other people work where you saw a task that that seemed like very challenging or uncomfortable, where there might be an area where this could be done better, or, you know, there could be a tool that might help here. That's a great question.

Unknown 3:26

interesting topic. Yeah, it's a big one. It's a big one and it's also you know obviously you

Unknown 3:32

don't want to take jobs away from people because often that's the only way to recover is to get some job moving debris because everything else has gone right in there. So, you know, could you equip people to be more effective with their labor is a good question. You know, it like I don't want to displace people with a machine per se, because often these people need the job, basically right so unless it's putting there someone risk. A good idea, or it's so slow that it can't be done. Obviously I think as you said, we're sometimes just bringing in the big machine and bringing stuff up right and it's not that elegant, but it's that's all that's left right, is that clear what's there and get rid of it.

Unknown 4:13

And I'm not sure how you got more efficient, you know the

Unknown 4:17

words, tighter returning to get out of its people with wheelbarrows

Unknown 4:22

just carrying stuff around altogether

Unknown 4:23

and of course they also often in big sites they might be doing it on their own home on the side. It's easy both right and the bigger industrial sort of level cleanup and also just individuals cleaning their property and trying to recycle some of it. Amazingly enough so, yeah. Nothing really jumps out at me but I don't just make a rocking imagination.

Unknown 4:47

Yeah. and obviously you can't have a solution immediately it's, and I guess it's not about the solution yet but more just you know pinpointing where, where things are more difficult than they have to be,

Unknown 5:01

you know, I suppose.

Unknown 5:05

I mean, it's probably hard to envision not using the wheelbarrow but then is it needs that kind of, you know, obviously just thinking aloud here Is it is it, you know, being able to create a good bath and there seems to be very specialized tools to clear on good path for wheelbarrows but if it isn't that kind of getting your get, if people have to kind of work through the debris. You know it is a bit dangerous it is a bit you know either stepping on things or things falling on you or whatever I think it's. You see some of that work that has to happen because some places you just can't get heavy equipment in right if it doesn't happen right in the street from some of these, like, cities like Puerto prince or others where you where you often have the worst mess is in the most densely packed areas and you can't get heavy equipment in easily right so you end up with a conundrum you're, you're in, and you do need people to do things and then, you know, how do you, how do you help them do it safely whether it is get the stuff, or get it into a wheelbarrow or something else and get it out, you know whether there's ways around that I'm not sure I mean the wheelbarrow is flexible. Right. Firstly the wheelbarrow has that ultimate flexibility, it's hard to design around. It's got all the right parts there it's just, how do you how do you do that safely. But I think that's probably the area where I would be the most focused on but I don't know that there's an easy solution there I mean, whether it's a more, you know, durable type of wheelbarrow and low cost, or whether it's something else that helps them to be more safe and more efficient. Those are probably just what I'm thinking now. I'm not sure if there's other areas that would be better but again I think that listen to some of the bulk stuff really just has to grow with with heavy equipment and

Unknown 6:55

I think that's where you might focus if you're going to do something.

Unknown 6:58

Yeah, I haven't heard, I haven't. Again, I haven't been around enough to sit have someone's like, oh yeah. If only we had, you know this or that, right i mean there's I so i don't i'm looking at from a distance, what I think are the points of pain you know but I think if you've watched enough or in some researches that you may actually have as much a sense of inside you, I just, I just haven't really got in depth in that so i that would be where I would think issues are. As I said there, potentially is something on the back end about how do you process all this stuff for recycling right I mean that in there there there perhaps is room for efficiency and in a perfect right would be, we do with all this stuff, you know, and, you know, how do you how do you reuse the stuff you can or, you know, or safely, you know, kind of process the stuff in cans because that's also, I would think a big problem and so it was an haiti in Puerto Princesa, not a very well functioning city but they really hadn't done a lot of work at the at the dump base and make it safe right and and so there's there's just to get that into there might be some work or there may not be but I don't, that's not an area I know enough about either in terms of actual you know how you manage waste facilities. But that could be another thing, you know, because again, I think most places where you have a disaster in this scale the waste facilities aren't that good either. Generally speaking, So that's it, that would be that would be the other area. Think about what we are doing with the waste processing. You know, is there a more efficient way to process and so you can recycle the good stuff or, or, you know, process the smaller stuff to the point where it is easier to handle, because I think that would probably be some of the problem was just how do you get rid of all this stuff right and in the lab, but there's probably methodology on there too. Yeah. Not sure what that is, to be honest.

Unknown 8:55

Yep.

Unknown 8:57

Yeah, so, do you know if there is like any sort of process that that people are getting to try and sort through the debris or is it kind of just like get out there and load up your wheel barrels and and bring it back, sort of deal.

Unknown 9:11

I think it probably, I don't think there's a standard process I would say you know there who do that I just don't know anybody who everything right so I'm trying to think if there's some worry points here because I'm just I'm just not sure. You know that I can give you a whole lot more than you're gonna watch on the video and actually no. I mean, it just check your I don't know. There's something called the logistics cluster and the global logistics cluster which is kind of like the coordinating mechanism. Around logistics for humanitarian operations right. Okay. And as literally just a Google global logistics cluster you'll find it.

Unknown 9:57

That would be the one place I would start

Unknown 10:02

is they might have something around you know guidance around this kind of stuff,

Unknown 10:07

which may help you

Unknown 10:13

to grow coverage, faster as well which

Unknown 10:17

is a couple of either kind of established by the UN but there

Unknown 10:21

they are.

Unknown 10:23

They are kind of

Unknown 10:27

meant to coordinate all of us, basically interesting. Yeah, so just thinking they're not going to be everything but you might actually be able to find something

Unknown 10:38

on website.

Unknown 10:40

So, I think

Unknown 10:47

it was entirely possible there there might be something early recovery because that is kind of starting to pick up over the weekend, and although this is usually more once you get over in the crisis which really is not always where, where this kicks in sometimes. This is what you're talking about, sort of kicking in and sort of, you know, for me it's survival but then also you know with it, you can go long,

Unknown 11:08

depending on how much it is but it's amazing when people move.

Unknown 11:13

I was in

Unknown 11:16

the Philippines after a major hurricane and it was amazing. Seeing the pictures from right afterwards in the streets were up to me on the second story from the brain and by that I was there you could you could sit down for a beer a little cafe. Wow. Yeah, and that was three months in right so I was like I'm gonna get all the things right so. But as I said Haiti was trickier behavior and a lot of concrete buildings collapsing, you know more debris than from from 911 so they, you know, there's different things can happen right. Yeah, so, so the other one is called the early recovery cluster.

Unknown 11:57

Anyways, early early recovery

Unknown 12:03

and see if I can get

Unknown 12:04

kind of, I won't check too much here but if so then down dam down website. Yeah. But anyway, that's that's another option. Those are two places that. Let's take a global level there might be some guidance that might help you. Okay,

Unknown 12:18

but I could tell you more than that.

Unknown 12:22

Yeah, that's, yeah, the UN Development Programme or UNDP like they are, they are pretty tied to the state might that actually chair this cluster. I don't know what's going on here it's like either website isn't working, or. Anyway, it's the logistics cluster works for sharing on that website this one. For some reason, so it may it may be the offline right or something I keep getting bigger anyway so. So the UN Development Programme UNDP you can Google that.

Unknown 12:58

So there, you know, they are what they sound like

Unknown 13:02

they would get involved in some of this, I would think, as well beat me. Since the early recovery cluster thing isn't working, might be worth checking UNDP as well to see if they have any guidance on that kind of thing that way they get it might just help you get a sense of where the choke points are worrying what the areas of improvement. But

Unknown 13:25

yeah, that's

Unknown 13:26

kind of tricky. I couldn't even point you to someone who was involved in this and I can say away and talk to this guy.

Unknown 13:33

Yesterday, very often at

Unknown 13:36

a local government thing right so it wasn't like I worked for World Vision that you may or may not have heard but it's not like we, you know, like we you know we might have done a little local bit with the community but it's not like we, you know, the bigger work around this is typically done by governments, as it were, right. So, so I just, I just couldn't point you to someone, you should talk to this guy but I just don't deal with them directly as much so yeah so that's some of what I can get my head around I mean like you know we get we get bits and pieces. Right. So it's pretty manual right it's, you know, a bunch of guys do their work, clean up the mess and hopefully, you know, in most cases, it's not too bad but it in some ways it's really significant.

Unknown 14:25

Yeah.

Unknown 14:26

I'm not sure if there's also any any challenges that stood out to you, outside of the topic of cleanup. Just just generally in disaster response, perhaps,

Unknown 14:37

because I'm still not, I'm still not.

Unknown 14:41

I know there's probably a million that could maybe come to mind. But, anything that just anything in general, in your in your work in disaster response where you just thought you know this process can be better, even outside of disaster cleanup.

Unknown 15:01

Some areas you'd be most excited because it is a pretty broad topic right so i think you get your problem.

Unknown 15:08

Yeah, I mean more so from, from a physical standpoint, rather than a political or economic problem, but uh, yeah.

Unknown 15:19

Soft probes now. For example, you know, and I'll tell you, probably a place you don't want to go down is the shelter side of things right there's about 100 million people who think they've got the world's best shelter designed

Unknown 15:29

to help people with

Unknown 15:31

HIV. It's pretty similar pretty cool. Yeah, the challenge has been cost but, so you know that that would be attending a low hanging fruit for a lot of people who, you know, have some engineering skills and want to do something that's there your shelter seems like the obvious one, how can I, I would say don't go down that path just because there's a lot out there already.

Unknown 15:49

Water is similar,

Unknown 15:52

there's a lot of interesting effectives I'm not so effective, you know, kind of emergency water supply stuff. Typically, you know, it's how to get into the household level you know there's always a Labrador filter system. Sorry, other bigger ones over, you know, some of the big ones you see a lot of work in our shelter household water supply and then suddenly cookstoves and stuff like that have been one of the kind of

Unknown 16:15

the Holy Grail. Yeah, stuff like that.

Unknown 16:19

Yeah, exactly right so some of the real basics right food, water and shelter. So yeah, what would be interesting ground to cover. Sorry I got that.

Unknown 16:32

I know it's a big question sorry yeah,

Unknown 16:35

it's a good one. Because what you picked up on. I like I like, I like where your head went here on this one cause it's actually a good question. It's like, you know, it's not needed everywhere because not everywhere has a big debris problem, but when it happens. It's a real choker for a while you just can't go anywhere and the streets are clogged with debris right and people can rebuild their homes if all so. And I do think, just as a first notion, your topic is a very interesting idea that I don't think has been ripe with innovation so that's good here. Yeah, see one of the things is we're moving increasingly just giving people cash and letting tap into the local markets right so there's been less I mean you still have to give people water sometimes because even if you give them money to go buy water from some supplier doesn't need cleaning or whatever right so it's not like you can just say magically give people cash and everything's fine because of course, depending on the gun the contents and maybe a mask and a lot of cases, the disaster had a you know sort of a selected impact and hasn't destroyed everything so actually helping the markets provide as important as anything right so just just to give you a sense of what what happens a lot of what we do is there. But we do still give out, you know, physical assistance right whether it be material or that kind of thing or we do help you know things like again like the debris clearance talked about is when we do a small

Unknown 18:14

more physical problem to address

Unknown 18:22

mean food we tend to get packaged already like if we're giving out food.

Unknown 18:27

Very often coming from organizations like the World Food Program

Unknown 18:30

you've probably heard each other, they give it the package straight so you don't really need to do anything they're

Unknown 18:38

trying to also do

Unknown 18:44

a lot of our problems now like try to sort of technologies right like we're trying to figure out how to use 3d printers better make drones better. Yeah, and that kind of stuff, which is obviously quite, you know, physical on the fence but also. It's also the technology there's more abstergo adaptive more than it is than it is the technology itself or the tool itself. Yeah.

Unknown 19:12

Even on the logistics side, we're behind the commercial logistics sector so you know it's more about adapting their technologies than it is building new ones if you're going to grow, we're kind of. It's because it has to be simple and has to be able to work well in a difficult environment. So it can't be too expensive can be too complicated, etc etc. Generally speaking,

Unknown 19:38

so yeah cost simplicity. Probably portable. Yeah, I

Unknown 19:46

think it's an interesting sector like everyone's well I get a call from somebody who's come up with a great new invention for this or that guy who figured out how to you know make bags of water so you could give them the bottles we had, it was like a plastic bag and get you to give out and drink it is pretty good but a lot of waste and things like that. And all these kind of ideas that are out there, people and generally speaking, they haven't you know

Unknown 20:11

exploded. Yeah.

Unknown 20:17

Now, you came to me from Ruben Ruben referred you to me sir

Unknown 20:22

so my Yeah, my aunt actually did work with Rubin, and I actually know. I also know cam Szczepanski. I'm not sure if you're familiar with him. Okay. So yeah, Rubin yeah my aunt does work has done humanitarian work alongside Rubin. Yeah,

Unknown 20:42

or somebody else. I'm not

Unknown 20:44

sure if it was, if with rural vision. I think she went to Ethiopia. But, yeah, that's how she knows what's your name. What's your name, I'm Robin Cobb flesh. See.

Unknown 21:01

Interesting thing maybe she began in a group and sub genre, you probably don't. Yeah, I'm

Unknown 21:07

not, I actually haven't met Ruben just had been referred through

Unknown 21:12

some interesting

Unknown 21:15

automotive design but he's right now running what's called the response Innovation Lab in Somalia, not mistaken, so we have a bit of a collaborative kind of effort with a bunch of organizations to

Unknown 21:28

kind of create these

Unknown 21:31

little kind of catalysts for innovation in the humanitarian sector. And I would actually be shocked I mean he's smart guy and he might actually be able to do it here's, among other things, what they're doing, they

Unknown 21:48

you know they they kind of almost match my

Unknown 21:49

intelligence, someone says, Hey, I got a problem with this stuff right and then, and then someone else may say we have this solution that worked well in

Unknown 21:58

Sudan, that maybe will work in Somalia we came

Unknown 22:03

up with the, it may help you. To be frank, he may have some ideas where some of the gaps like maybe I'm able to answer that question and use that to me more specifically. Yeah. What were some of the, what's in the gaps or choke points where some sort of design thinking might actually help. I mean he literally was on both design, more common knowledge so I actually looked for what like what should the response Innovation Lab is sort of some kind of there from World Vision so I could, I could get get his contact information and he might actually be helping more

Unknown 22:40

yeah that sounds great.

Unknown 22:40

I think that would actually be a far more profitable way to kind of explore as a method and if you know, he may have something or he might say hey you stuck to the lab in Puerto Rico on sand or wherever like we got a few of them around the world so that's I think that would be, I think he might go further with them, to be frank. Yeah, yeah. They've been great talking to me so let me, let me do that. can I make sure I send that to get his contact information. I will just pay him first just to make sure he's good to talk, I'm sure he will be, but just, just to confirm that I can pass on his contact info to you. And then go from there. by group in the first place. Yeah. Yeah. So what, why don't you do that, and I mean I'm happy to talk more if I can be of help, but I really my most useful contribution is a little more on the coalface in this kind of thing right because it really is exactly what you did, they're looking for ways to solve practical problems.

Unknown 23:45

Yeah well so far you've been the most useful contact I've had so it's still been super useful, and yeah, I appreciate the, the potential contact. And yeah, the, the insights you've given skill. So, yeah.

Unknown 24:04

You got lots of time.

Unknown 24:08

Yeah, so the, the final submission of this will be at the midway through April so still got still got many, many months to go still in preliminary exploration here, but we're getting kind of ramped up on our research so the sooner the better probably but,

Unknown 24:30

yeah, I'll just I'll just message him today.

Unknown 24:36

So I will pick him just to confirm he's good to go. And I think he I think he's gone back he was in Canada for a while, obviously with the pandemic but he got back so he might be in Nairobi or something right now, like that would be cool.

Unknown 24:51

Yeah, I'm not sure I know you're a busy guy. If I would you be willing to potentially review any concepts that I send you

Unknown 25:03

in upcoming weeks.

Unknown 25:06

Yeah, I mean I do my best to give you some some thought.

Unknown 25:10

Yeah, any insights are valuable I like any thoughts from from someone who has some experience doing humanitarian work is is super valuable so yeah that's great.

Unknown 25:22

All right, sounds good. Well then I will

Unknown 25:27

get back to you as soon as possible. Some stuff just just let me know and I'll give that a quick look great.

Unknown 25:34

Oh, thank you so much for your time and for doing this phone call with me It's been great talking to you.

Unknown 25:45

Even if this doesn't turn out to be the right topic you're thinking along the right lines. Yeah, actually, you know, it's good to see someone kind of putting their brain to this this this area because it's definitely something that we can we can use new thinking in a few different areas I would think. I will get back in on. Yeah, I'll just go back to my email for starters and go from there. Okay,

Unknown 26:07

awesome. Thank you. Have a good, have a good day.

Unknown 26:11

take care of that.

Unknown 26:12

Good luck. Thanks.

Transcribed by https://otter.ai

Appendix B – User Research

Literature Search for Demographic Data

A literature search was also performed on the Humber Library website and Google to find statistical data relevant to citizens in El Salvador. A vulnerable nation with a high magnitude of natural disasters. The following search terms were used:

“El Salvador Demographics”

“El Salvador Statistics Data”

Findings.

Findings have been summarized below according to the relevant categories: Gender; Age; Race and Ethnicity; Income and Education.

Gender.

As inferred from the image search, El Salvador has a larger female population at 3,430,199 people. That’s 406,845 more than their male counterparts.

Age.

El Salvador has a population that consists largely of a young demographic. 73.2 percent of the population is under the age of 44 and 25.3 percent of the population is under 15.

Education.

More than four-fifths of Salvadorans aged 10 and over are literate. 71.66 percent of the population has a secondary education, while 29.4 percent has a post-secondary education.

Income.

The average income for El Salvador's population is very low, with 40 percent of people living below the poverty line, and a $4000 (US) income per capita.

Discussion / Conclusions

Based on the above research, we can get a general overview of vulnerable populations living in disaster ridden communities. It can be observed that most of El Salvador's population is under the age of 44, taking up 73.2% of the population. It is also apparent that people living in El Salvador are of mestizo ethnicity, at 86.3%. Income is low with 40 percent of the population living under the poverty line, with a $4000 US income per capita. An education level of at least a high school degree is common with a gross enrollment rate of 71.66 percent. Post-secondary education is less common with a gross enrollment rate of 29.4%. With this statistical data, it's easier to envision common patterns of communities in El Salvador.

Demographic of El Salvador locals	
Age	15 - 29
Gender	Mixed (11.86% more females)
Ethnicity	Mestizo
Income	$4k
Education	Highschool

Primary User	Disaster survivor locals
Secondary User	NGO relief teams
Tertiary User	Disaster debris specialists.

User Behavior

A literature search was conducted to discover traits relating to user behavior. For this search Google and the Humber Library websites were used to extract relevant information. The following search terms were used:

“Disaster debris removal”

“Disaster debris removal process”

Findings.

Findings have been summarized below according to the relevant categories: frequency of use/activity (rate), duration of activity, group or solitary activity/level of focus, motivation and lifestyle, income level & purchasing power, location, personality and cognitive aspects.

Activity Frequency.

Debris removal is part of a multistep plan. Proper handling of materials requires several different steps outside of relocating debris. The image below showcases this process.

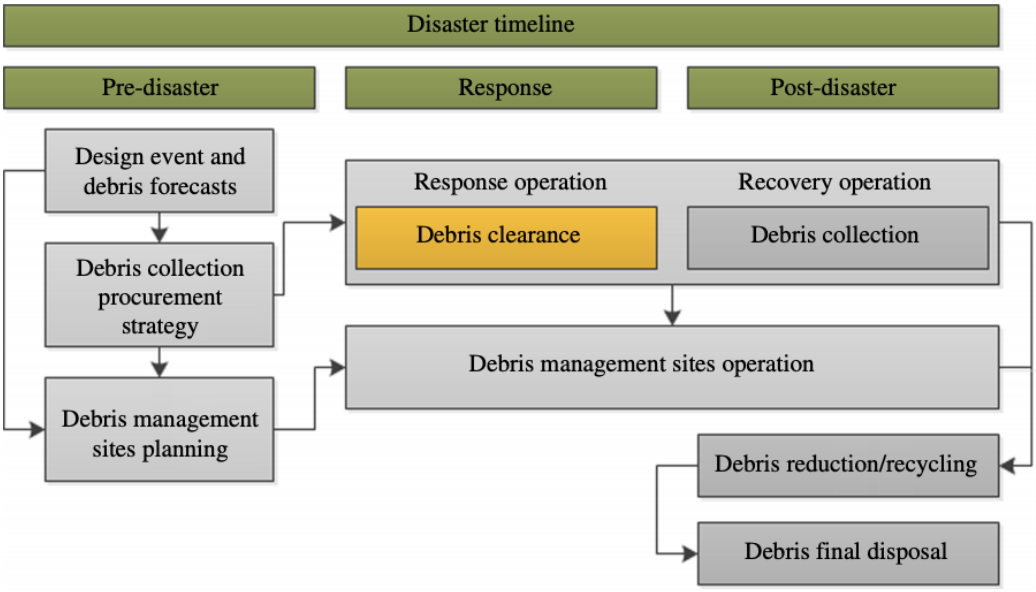


Figure 12 - Elements of a debris management plan during a disaster timeline. [Image] (2017) Retrieved from https://web-b-ebscohost-com.ezproxy.humber.ca/ehost/pdfviewer/pdfviewer?vid=0&sid=97f2d8df-ec4a-4de4-baa4-5cd422e0cc73%40sessionmgr101

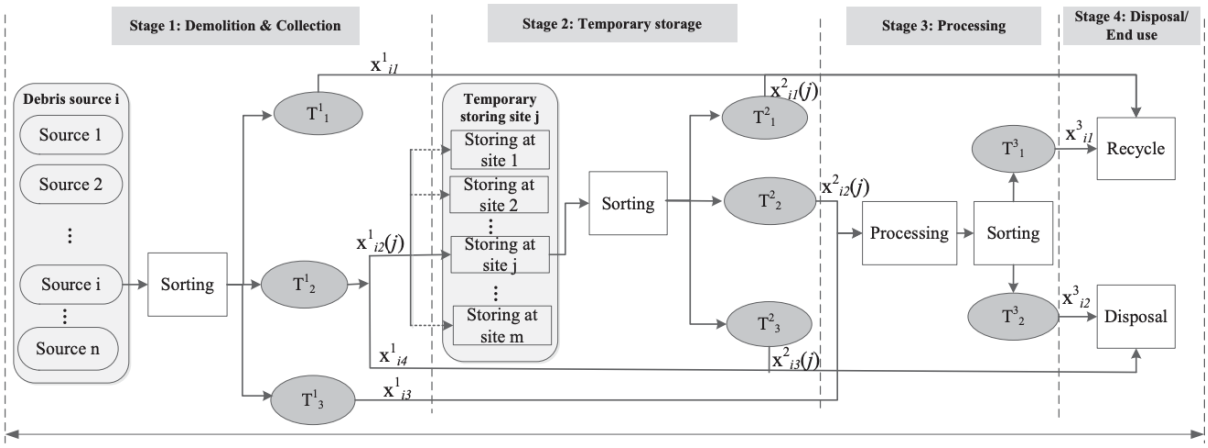


Figure 13 - Reverse logistics framework of recovery phase for debris removal. [image] Retrieved from https://web-b-ebscohost-com.ezproxy.humber.ca/ehost/pdfviewer/pdfviewer?vid=0&sid=05a7e09b-cf1b-47d0-9db9-87f7e90f0ed2%40sessionmgr103

Social.

“authorities work alongside experts and local people to develop a detailed disposal plan.” (Rodgers)

Lifestyle & Personality.

“After the [earthquakes], kinship ties, including the bonds of compadrazgo, [are] mobilized to provide assistance to people [they know]. This is a common-sense procedure, for in a culturally determined context, it is expected that one will first help those one knows, all the more so when calamity strikes. The norms of Salvadoran society foreground biological and ritual kinship ties.” (Sliwinski)

Income Level.

Locals receive income provided by NGO's for their work, however the rate of pay is unclear. "Machinery is fast, but expensive, while cash-for-work is slower, but has the added advantage of engaging the community and providing livelihoods in the early days following an emergency." (Rodgers)

Location.

After a natural disaster occurs, locals witness the "piles of damaged or waterlogged remains of communities line the streets, survivors and anyone else on hand tend to begin the process of moving debris." (Rodgers) El Salvador's population has more urban dwellers, however there is still a very large rural population at 39.8 percent.

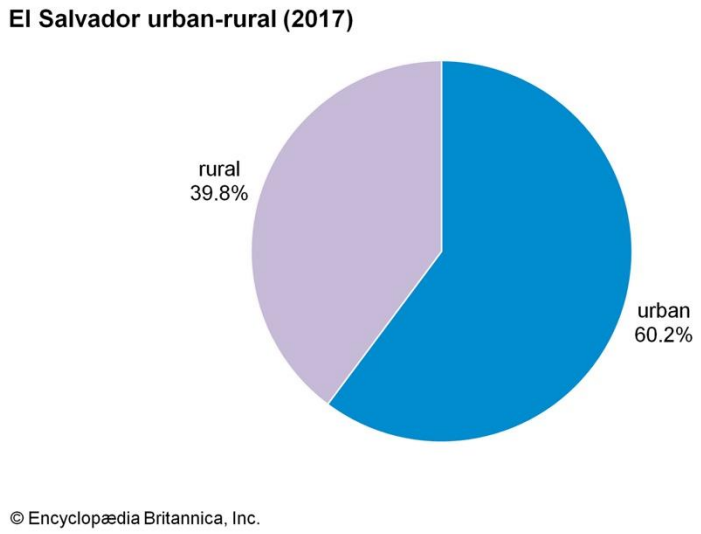


Figure 14 – El Salvador. [Image] Retrieved from https://www.britannica.com/place/El-Salvador/Plant-and-animal-life

User Profile Summary

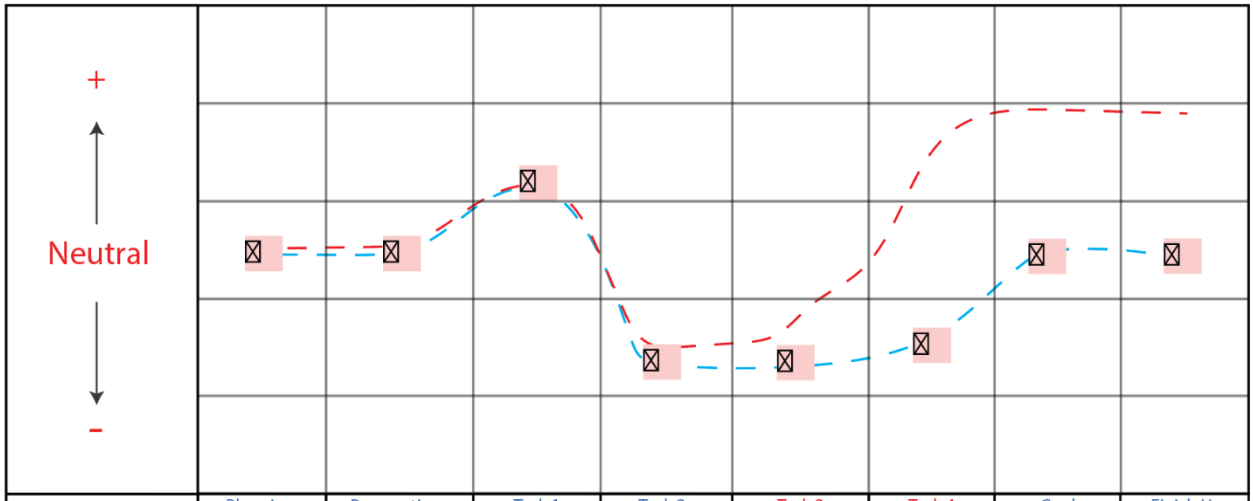
User	Description
Primary	Disaster survivor locals
Secondary	NGO relief teams
Tertiary	Disaster debris specialists.

Primary User Profile

Demographics		**User Behavior**		**Personality**		**Cognitive Aspects**	
Age	18-35	Frequency of Use	Infrequent	Focus of Control	↑	Technical Skill	↑
Education	High School Diploma	Location	Residential – Rural/ Urban, hazardous				
Ethnicity	Mestizo (86.3%)	Social	High-Social	Changeability	↑		
Gender	Mixed	Duration	1-2 Weeks	Self-Efficacy	↑	Pre-Requisite Knowledge	↓
Income	$4000	Level of Focus	High	Uncertainty Avoidance	↑		

User Observation

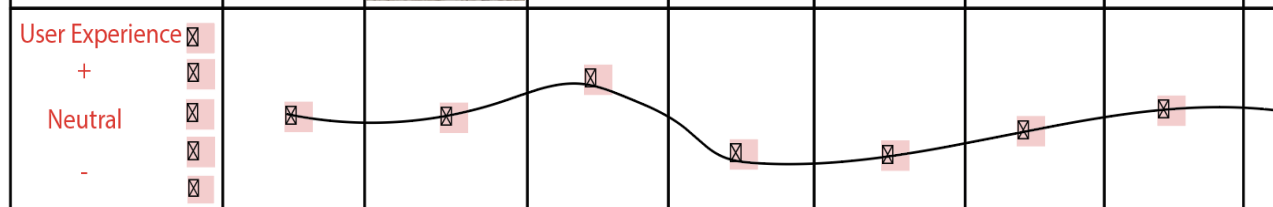
To better understand the overall process of debris cleanup after an earthquake, video footage was analyzed. This will help to narrow in on an area of focus and provide a more clear problem definition for improving the process of debris cleanup.



	Planning	Preparations	Task 1	Task 2	Task 3	Task 4	Goal	Finish Up
User Goals	Get approval for demolishing	Marking buildings with red paint/ caution tape	Breaking down buildings	Break down rubble in hard to access areas	Fill wheel barrows with rubble	Deliver rubble to side of road/pickup site	Deliver rubble to dumpsite for disposal	Begin efforts of rebuilding/restoring
Problems/Challenges	Locating the homeowner as fast as possible	Area can be busy with locals trying to move by Watching out for bystanders, having to tell them to keep clear	Avoiding destruction to other properties Safety challenges	Sledge hammer is physically straining on bones and muscle especially after long use	Heavy buckets are awkward and difficult to lift, can cause muscle strain	Difficulty getting over rough terrain	Seperating and organizing rubble. Recycling materials is difficult	Finding materials for new housing Building safe homes that are long lasting
Ideas/Take-aways	Public signup sheet to request appointment	Speakers to tell bystanders to stay clear, better barriers	AI/cameras identify best location to break apart	Grinder machine to break down rubble	Exoskeleton to help with lifting action	Further develop equipment to better assist intense job	Machine to repurpose rubble for reconstruc-tion purposes	Using repurposed rubble for making homes

Image 2.2 User Activity Mapping

User Observations 1

	Planning	Preparations	Task 1	Task 2	Task 3	Task 4	Goal	Finish Up
User Goals	Get approval for demolishing	Marking buildings with red paint/ caution tape	Breaking down buildings	Break down rubble in hard to access areas	Fill wheel barrows with rubble	Deliver rubble to side of road/pickup site	Deliver rubble to dumpsite for disposal	Begin efforts of rebuilding/restoring
User Actions	Approval is signed by property owner in the presence of 3 community witnesses	Government authorities mark building with red allowing workers to know that it is beyond repair and needs to be demolished/removed. The area is secured with yellow tape to stop bystanders from walking on the site.	Excavators and bulldozers destroy what is left of buildings, clear out areas that are accessible by large machines.	Crews are sent in to clear out debris in tight spaces/areas that are not accesible by machines. Debris is broken up with sledge hammers.	Fill rubble into buckets with shovels Empty buckets into wheel barrow.	Deliver rubble to side of road for pickup.	Dumptrucks are loaded with excavators to deliver rubble to dumpsite/landfill.	Locals try to build back shelters in cleared out land with whatever they can get their hands on.
User Thoughts	Quickly trying to locate people required to sign documents	Telling bystanders to avoid interfering with cleanup, or getting injured	Locating contact points to break structure	Maintaining focus during physically straining work Thinking about payout for amount of rubble cleared	Maintaining focus during physically straining work Thinking about payout for amount of rubble cleared	Maintaining focus during physically straining work Thinking about payout for amount of rubble cleared	Keeping things organized Collaborating with other crew to fill dump truck	Focusing on recovering from loss Trying to return to normalcy
Storyboard/Photos								
User Experience + Neutral -								
Problems/Challenges	Locating the homeowner as fast as possible	Area can be busy with locals trying to move by Watching out for bystanders, having to tell them to keep clear	Avoiding destruction to other properties Safety challenges	Sledge hammer is physically straining on bones and muscle especially after long use	Heavy buckets are awkward and difficult to lift, can cause muscle strain	Difficulty getting over rough terrain	Seperating and organizing rubble. Recycling materials is difficult	Finding materials for new housing Building safe homes that are long lasting
Ideas/Take-aways	Public signup sheet to request appointment	Speakers to tell bystanders to stay clear, better barriers	AI/cameras identify best location to break apart	Grinder machine to break down rubble	Exoskeleton to help with lifting action	Further develop equipment to better assist intense job	Machine to repurpose rubble for reconstruc-tion purposes	Using repurposed rubble for making homes

Observation Research Insights

The process of cleaning up debris is heavily reliant on a good team dynamic, with communication and cooperation being important factors. Each step of the process involves different roles which bring on their own unique challenges. Additionally, each role may require different types of equipment, or require different types of training.

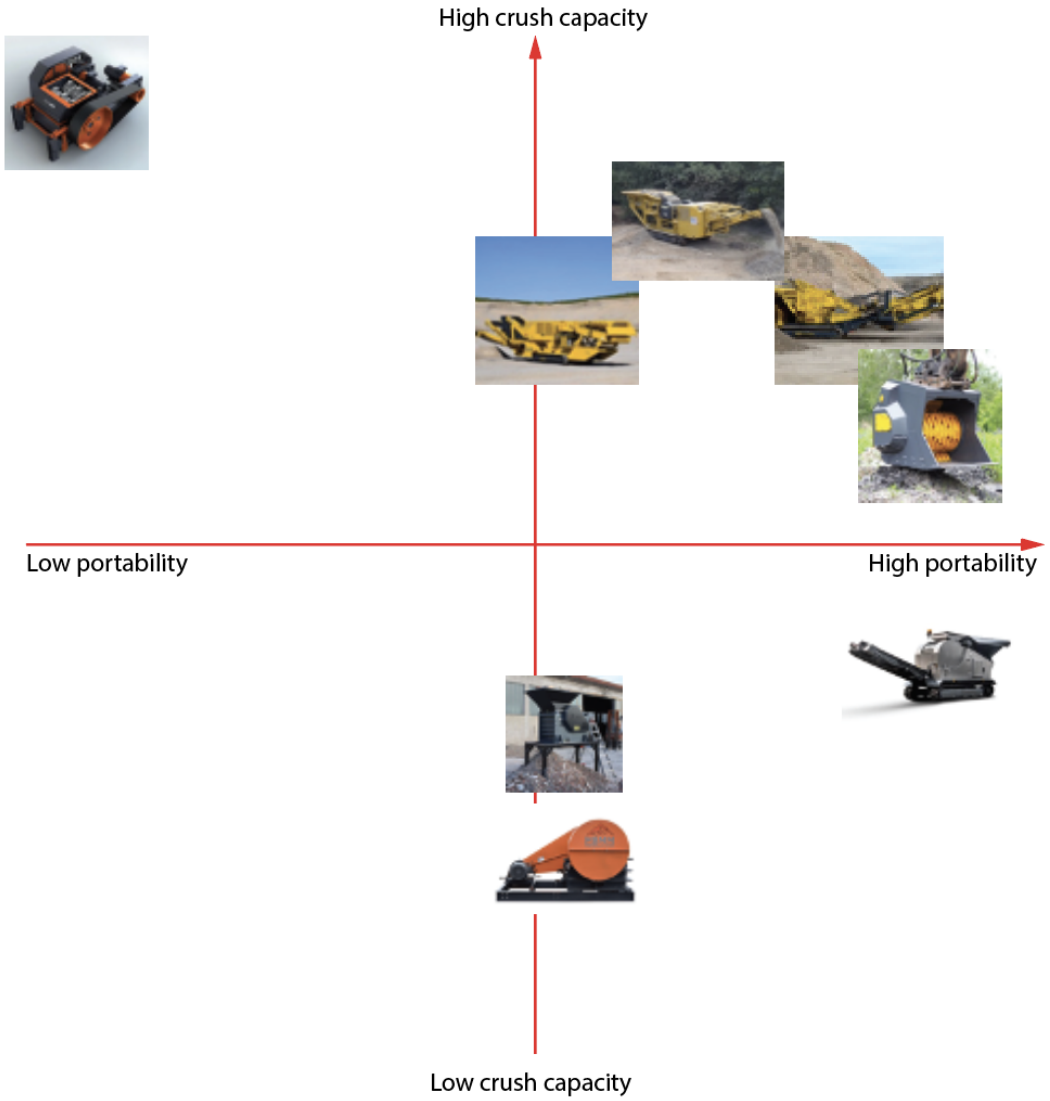
Appendix C – Product Research

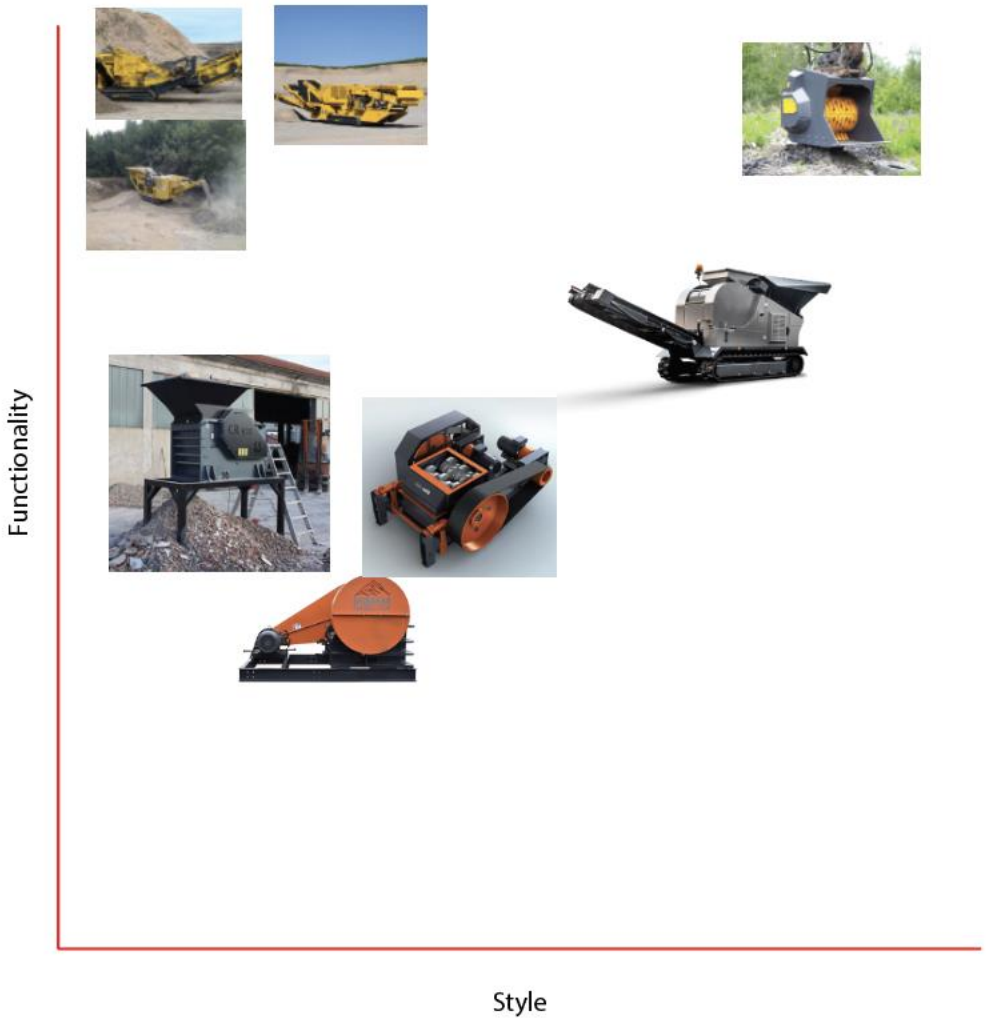
Objective: The following section aims to review comparable products currently in the marketplace that help in the process of earthquake cleanup. The product being examined is rock crushers, a useful product that aids in breaking down rock and concrete for recycling.

Method: Promotional media of competitor products are researched and evaluated to determine features and benefits, and their relative importance to the design of a new product.

Feature/Function Comparison Table

								
Weight	29,000 Kg	35,000 kg	26,000 kg	21,000 kg	1380 kg	3,400 kg	1088.6 kg	2,900 kg
Dimensions	40’10”x10’2” x8’5”	47’6”x11’4”x 9’10”	31’2”x10’6”x8’4”	191”x118”x74”		179’1”x58’6”x84’6”		
Power	Diesel/ electric drive	Diesel/electric drive	Diesel/ electric drive		Electric motor 380V	Diesel/electric	Gas 3 phase motor	Excavator attachment
Crush method	Jaw crusher	Cone crusher	Punch plate	Double roll crusher	Jaw crusher	Jaw crusher	Jaw crusher	Roll crusher
Max feed size	20”	7”		24”	3”	4”	7.5”	6”
Capacity	300 tons per h	250 tons per h	250 tons per h	1200 tons per h		30 tons per h	6 tons per h	
Feed Opening	24”x40”		30” x 38”	43” x 25”	23.64” x 11.82"	19”x10”	6”x10”	
Mobile	yes	yes	yes	no	no	yes	no	yes


High crush capacity
Low portability
High portability
Low crush capacity


Functionality
Style

Appendix D – Analysis

After the occurrence of an earthquake, the recovery process can be challenging and take a long amount of time. This is especially the case in developing countries, often lacking the resources and institutional capacity to implement an effective plan for post disaster recovery. Still, government must act quick to remove rubble as quickly and efficiently as possible. It is during this stage, that recycling is a critical component of the process, however disposal facilities are overwhelmed with an unprecedented amount of waste, so the majority of rubble will go to landfill. Quick fix solutions like this can have serious implications on the environment and are highly unsustainable. An increased focus on recycling is crucial as it will lessen the burden on disposal facilities and natural resources for reconstruction, while still providing work opportunities for local people and businesses.

Needs	Benefits
Comfort	• Ergonomic workflow, eliminating crouching/other uncomfortable positions
Safety	• Eliminating injury from heavy manual labour • Alternative housing from tents, with more structural support
Ease of use	• Machine can be operated with little instruction • Loading materials is easy, intuitive, can be done manually • Convenient access to tools and hardware
Efficiency	• Reducing time and cost of importing materials for Reconstruction • Reducing time and cost of delivering waste for disposal • Providing more work for locals to aid in cleanup/reconstruction process
Sustainability	• Giving function to rubble and debris • Keeping debris from going into landfill

Fundamental needs of humans were evaluated alongside the benefits of improved debris cleanup, referencing Maslow's Hierarchy of Needs chart.

Benefit	Fundamental Human Need(s)	Relationship with Benefit
Comfort/Ergonomics	Physiological, safety, esteem	Moderate
Health/Safety	Physiological, safety, esteem	Strong
Efficiency	Safety, esteem, belongingness, physiological	Strong
Sustainability	Physiological, safety, esteem	Strong

Comfort/Ergonomics:

Locals working with cash for work programs perform manual labour such as shoveling and transporting debris via wheelbarrow and buckets. Disaster sites can be difficult to navigate, often having uneven terrain, and little infrastructure. This can make for an uncomfortable work environment, making manual labour even more strenuous.

Health/Safety:

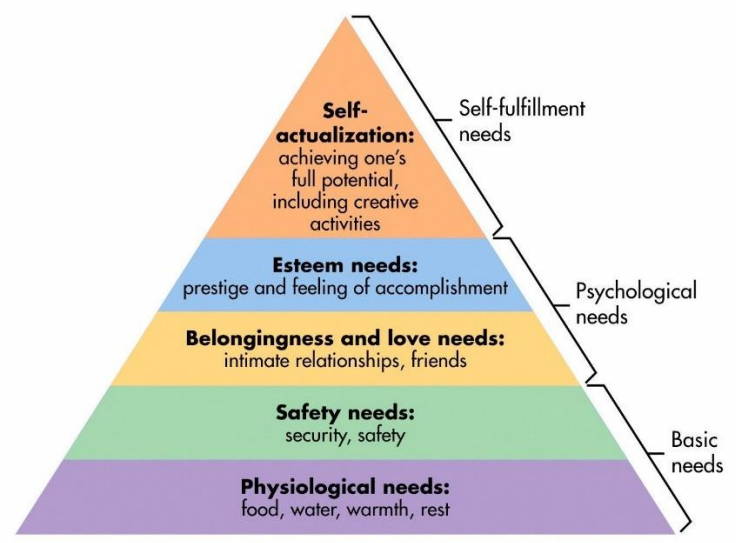
After losing their homes to an earthquake, survivors usually will live in tents as an alternative and temporary solution for shelter. Sometimes it can be months or even years until a new, proper shelter is built. Meanwhile, survivors must live among hazardous debris until it is removed.

Efficiency:

Although vulnerable communities may require outside help, it is important that locals still have a large role in their own recovery process. Locals are better supported when receiving new job opportunities rather than having them taken away by outside workers. A solution that can increase productivity, without taking away jobs is an important consideration.

Sustainability:

It is crucial to remove debris before the reconstruction process can begin, but it must be done in a sustainable manner. A solution that can recycle material and utilize it for reconstruction will not only aid in the process of rebuilding communities but will prevent large amounts of waste going into landfill.


Self-actualization: achieving one's full potential, including creative activities
Esteem needs: prestige and feeling of accomplishment
Belongingness and love needs: intimate relationships, friends
Safety needs: security, safety
Physiological needs: food, water, warmth, rest
Self-fulfillment needs
Psychological needs
Basic needs

Wishes/Wants

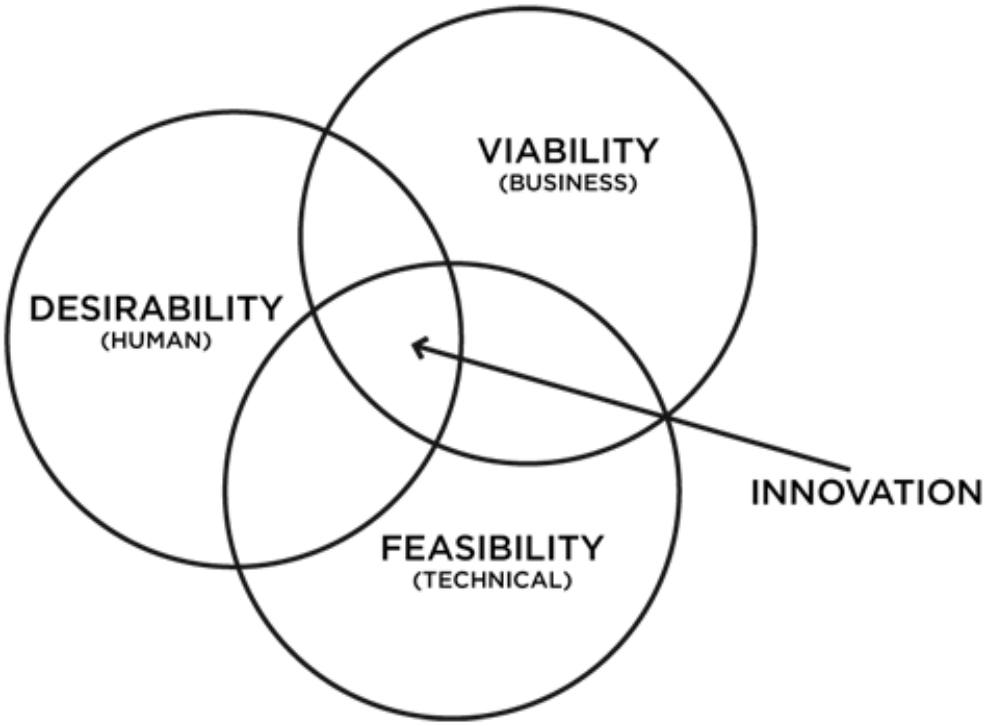
- Easy to maintain
- Easy to operate
- Easy to ship/deploy

Immediate Needs

- Breaks down/recycles material
- Reduces waste that goes into landfill
- Improves debris cleanup workflow
- Provides new building materials for reconstruction
- Can maneuver rough terrain

Latent Needs

- Stylish design



Desirability

Waste management facilities often do not have the capacity to handle the amount of debris produced after earthquakes. Since most of the debris is deposited into landfill sites, there is a strong need for an improved method of recycling debris. Additionally, vulnerable communities lack the means to build safe housing that can withstand future disasters, often having to resort to living in tents.

Viability

Debris management is a critical issue faced by all countries that experience natural disasters. Natural disasters will continue to be a prevailing issue, along with the waste produced from them. For economic, and sustainable reasons there is great opportunity in exploring how to reuse disaster waste towards something useful.

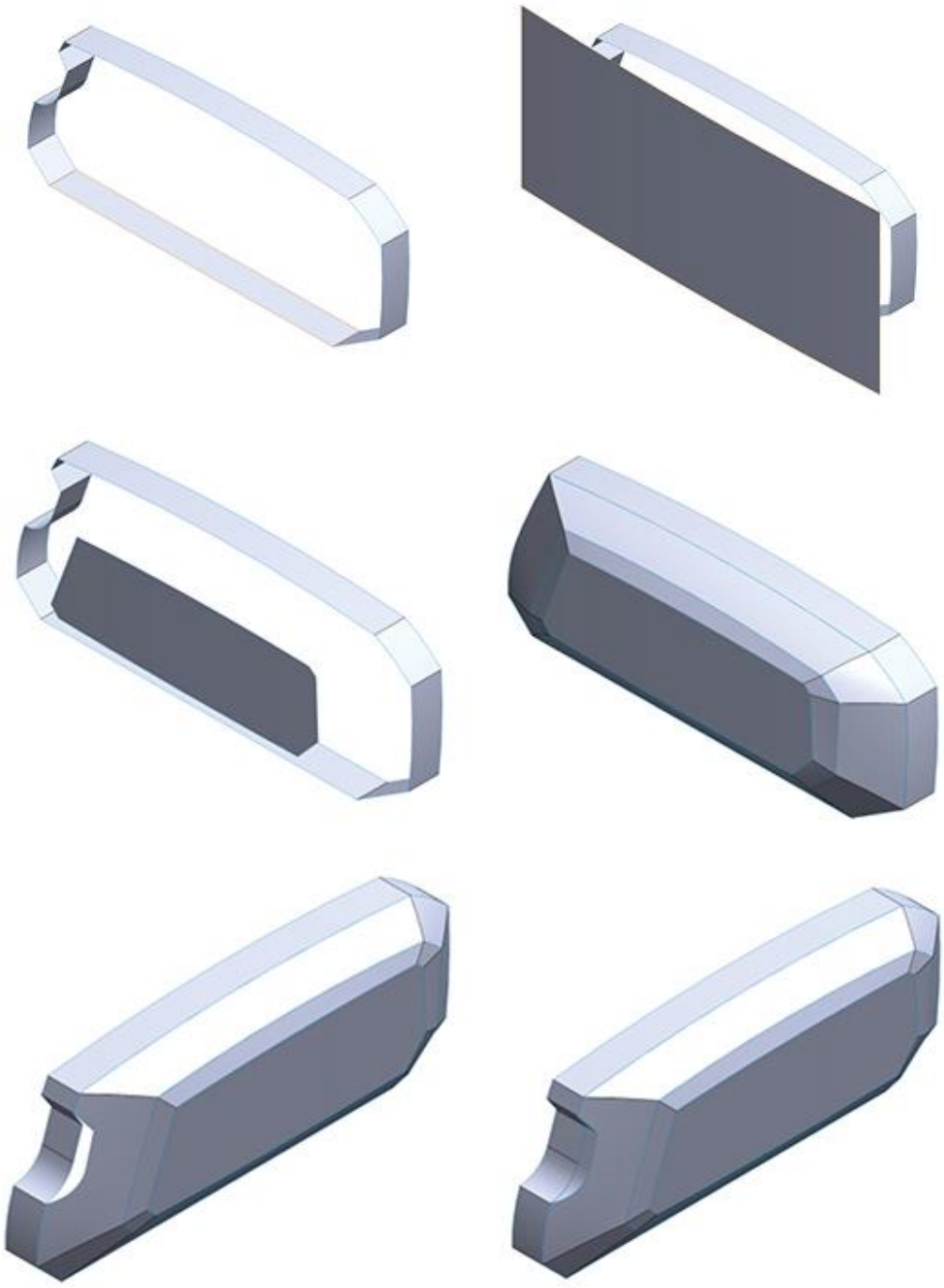
Feasibility

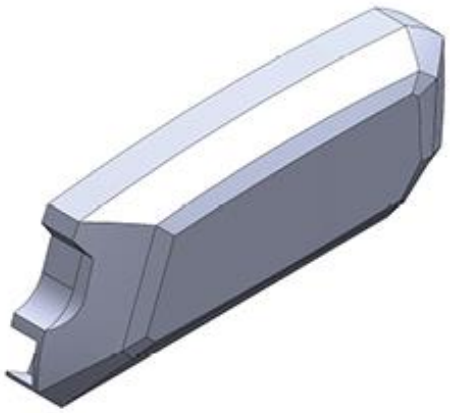
Outside the context of natural disasters, solutions have been developed to break down waste material from concrete, allowing it to be reused for new construction projects. This technology can be evolved to incorporate mobility, along with other features that would be useful in the context of natural disaster recovery.

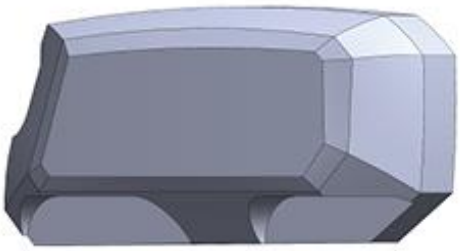
After narrowing in on a specific problem area for the topic of disaster recovery, a different user process was observed from the one seen from section 2.1.2.

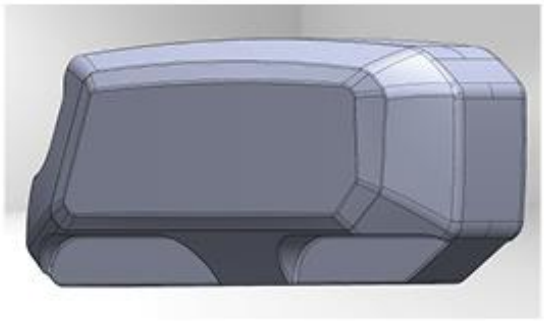
Process	Observation
Breaking concrete	User kneels down, breaking concrete with hammer placing material on rock
Adding materials	User adds aggregate and cement based on approximation of correct ratio. User mixes solution with a spade. (Working on floor)
Mixing concrete	User adds water and continues to mix with spade
Pouring concrete into mold	User shovels concrete mixture into mold with shovel. Flattens top with shovel.

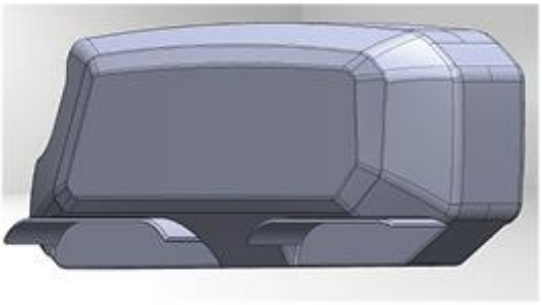
Appendix E – CAD Development

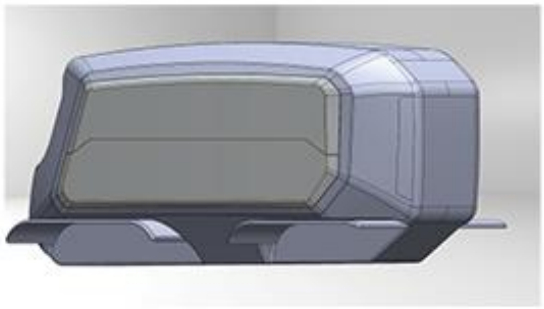


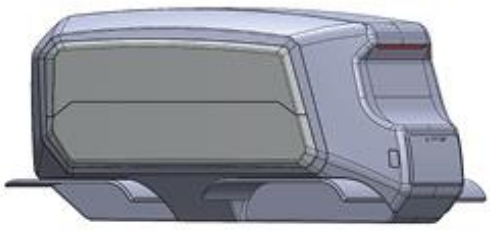


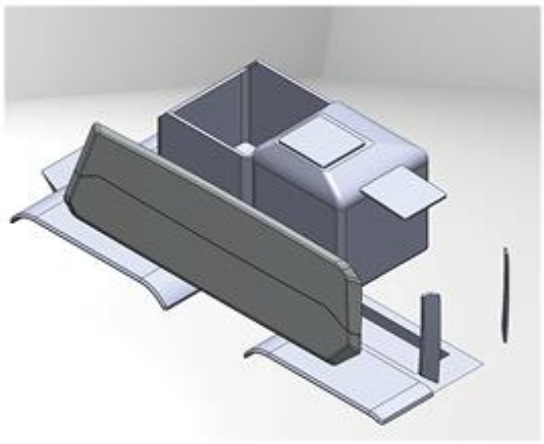


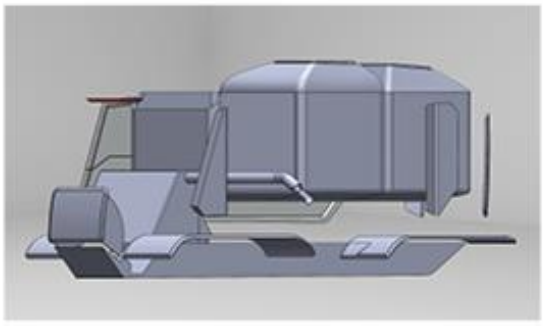


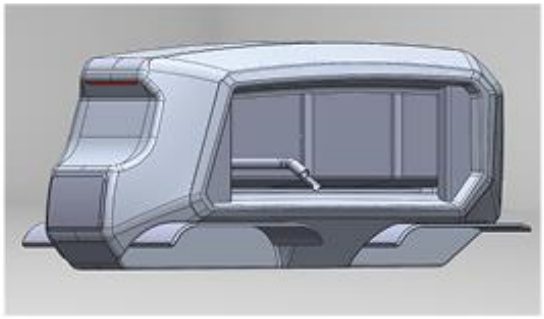


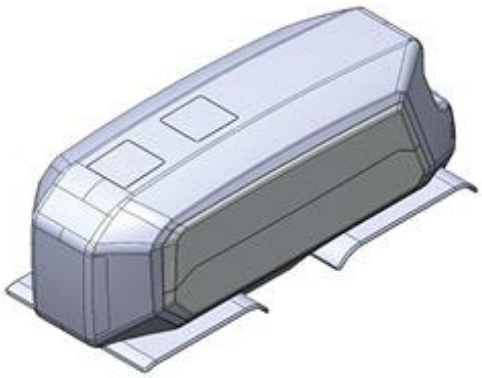


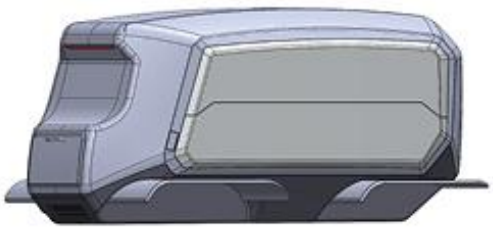


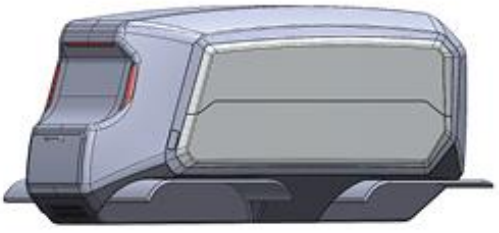


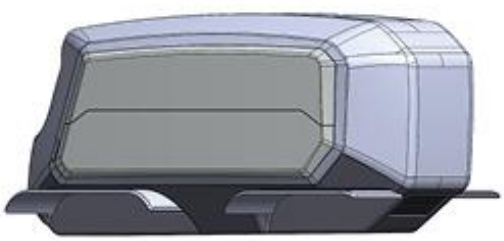


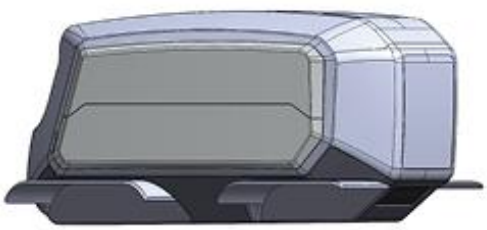


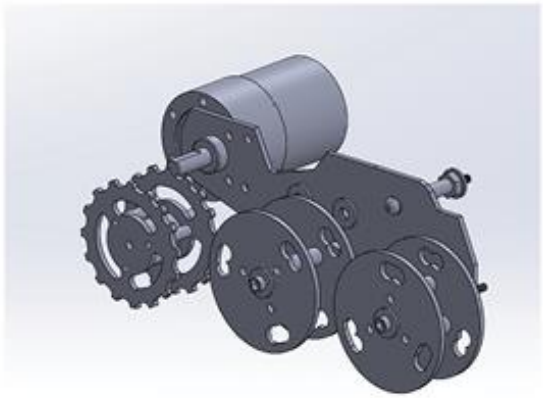


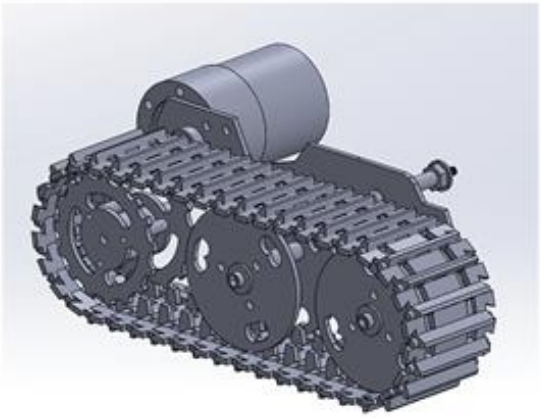


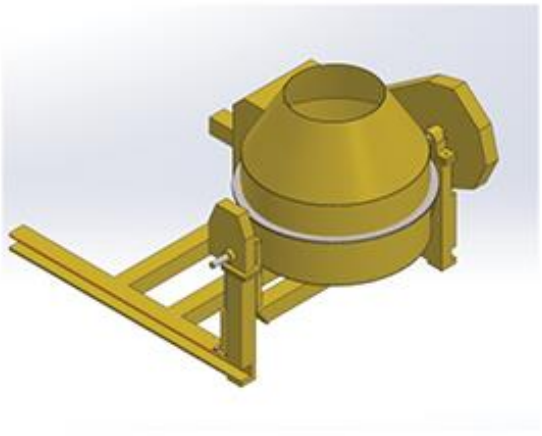


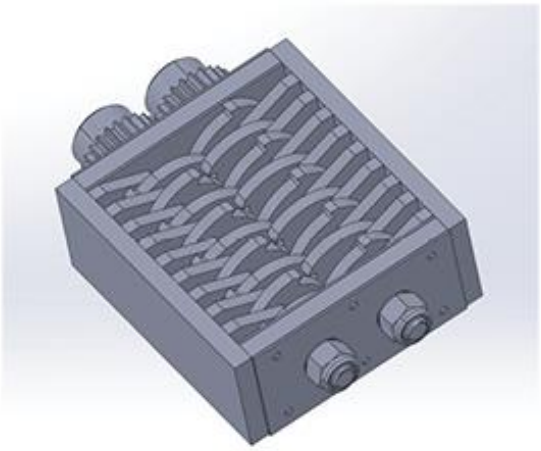






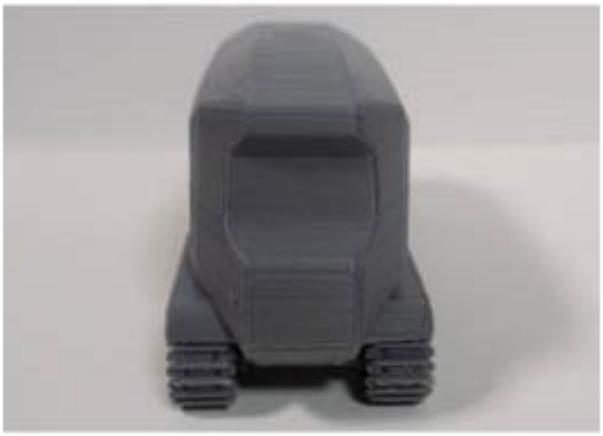




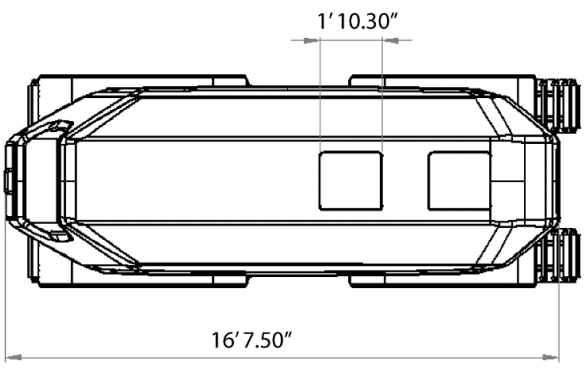


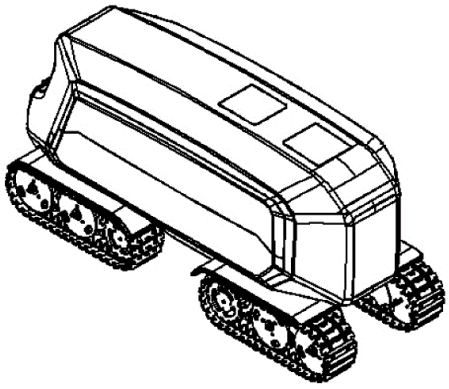
Appendix F – Physical Model Photographs

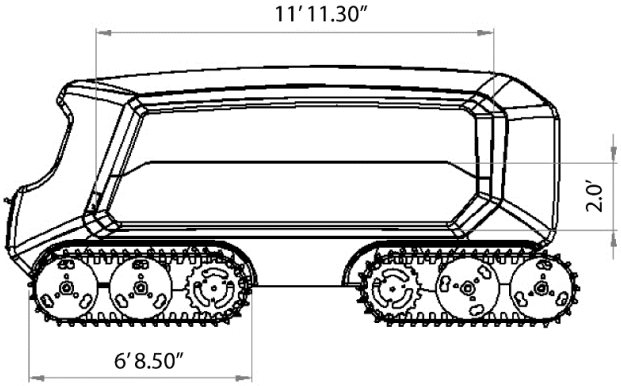


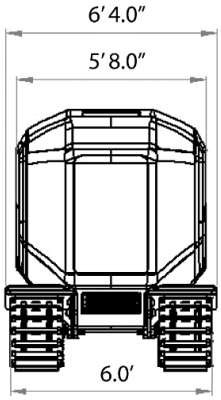



Appendix G – Technical Drawings









Appendix H – Manufacturing Info

Material	Benefits + Manufacturing Process	Reference
Alloy Steel	Alloy steel is a mixture of metals including nickel, copper, and aluminum. The material is durable, strong, resistant to corrosion, and it comes at a relatively affordable cost. This makes it a great application for heavy duty vehicles such as ship hulls. Steel is also highly sustainable, holding an annual recycling rate of nearly 100 percent in the automotive industry.	https://www.weerg.com/en/blog/what-are-the-four-types-of-steel https://www.steel.org/steel-markets/automotive/steel-vehicles-offer-environmental-advantage/
Tandem Perovskite Solar Cell	A new development of solar cell technology which uses compound materials with a special crystal structure. The new solar cell technology is 23 percent efficient whereas traditional silicon solar cells are 18 percent efficient. In addition to being more efficient, the material and fabrication costs are low.	https://www.sciencedaily.com/releases/2019/05/190514081554.htm
Recycled Automotive Plastics	New development of sustainable composite panels which incorporate raw material from waste automotive plastics, and waste from printed circuit boards. The material has excellent mechanical properties with a wide range of applications. Moreover, it provides function to otherwise low value waste going into landfill.	https://www-sciencedirect-com.ezproxy.humber.ca/science/article/pii/S0959652616322028?via%3Dihub
Mild Steel	One of the top choices for automotive manufacturers due to its ability to weld and form easily using methods like cold stamping. Used for general purposes and light structural elements. This material does not serve well for major structural components.	https://ehdtech.wixsite.com/ehd-tech/single-post/2018/06/11/future-automotive-manufacturing-materials-and-processes

Recycled Aggregate	Recycled Aggregate (RA) is a sustainable alternative for making concrete, currently being practiced with material from demolished buildings. By incorporating RA in the production of concrete, the process of mining and delivering materials are eliminated, greatly reducing C02 emissions.	https://www-sciencedirect-com.ezproxy.humber.ca/science/article/pii/S0921344920302482?via%3Dihub
Cement	Manufactured by mixing fine limestone, clay and sand. The material is then heated to 1450° C in a kiln. The material makes up about 7 percent of concrete.	rediscoverconcrete.com/en/sustainability/how-cement-concrete-are-made.html#:~:text=Cement%20is%20manufactured%20by%20heating,in%20the%20manufacture%20of%20cement.http://
Fly Ash	An alternative and less harmful solution for cement. The material is a by-product of coal combustion, and U.S federal law now requires power plants to capture this ash to avoid pollution to earth's atmosphere. The material is not only cheaper than cement, but it has excellent cement like properties, and can produce even higher quality concrete than traditional methods. The fly ash still must be mixed with a small portion of cement, however, much less is needed.	https://search-proquest-com.ezproxy.humber.ca/docview/190524088?accountid=11530&pq-origsite=summon

Appendix I – Sustainability Info

Concrete plays a crucial role in the development of modern-day civilization, providing shelter for billions, fortifying defences against natural disaster and “providing a structure for healthcare, education, transport, energy and industry.” (Watts, 2019)

Concrete being the most widely used material on the planet, comes with a giant carbon footprint that’s associated with it (Rodgers, 2018). The production of concrete creates environmental challenges not only in how it’s manufactured, but also how its disposed of. The greatest environmental threat associated with the production of concrete comes from cement, an ingredient that makes up about 7-10 percent of the material (Federal Information & News Dispatch, 2009). In order to process cement, a mixture of limestone, clay, and iron are heated in a kiln at temperatures of 1,500 ° c. This heat usually comes from burning oil or coal which creates high levels of carbon dioxide. For each metric ton of cement produced, another metric ton of C02 gas is created. As a result, this process now accounts for 7 percent of the world's industrial carbon dioxide emissions at 2.8 billion tonnes. (Federal Information & News Dispatch, 2009) (Rodgers, 2018)

Fortunately, an alternative and less harmful solution for cement has been discovered called fly ash. The material happens to be created from other industrial processes and is a by-product of coal combustion. The U.S federal law now requires power plants to capture this ash to reduce pollution to earth’s atmosphere. The material is not only cheaper than cement, but it has excellent cement like properties, and can produce even higher quality concrete than traditional methods. The fly ash still must be mixed with a small portion of cement, however much less is needed (Federal Information & News Dispatch, 2009).

Another component used to make concrete which can be made more sustainable is aggregate. “Until recently, most of the world's used concrete went into landfills, at enormous environmental cost. But today, some manufacturers, especially in Europe, are crushing used concrete and recycling it for use as an ingredient in new concrete” (Rodgers, 2018). In fact, Switzerland and Austria use RA on a regular basis. Aggregate is traditionally made from crushed rocks and boulders, usually extracted from a quarry. The use of recycled aggregate from debris or demolition waste can provide a sustainable advantage by eliminating the need to mine new materials from quarries, greatly reducing CO2 emissions. Another benefit of using recycled aggregates in concrete production is the advantage it provides in the transport chain. Heavy traffic is greatly reduced, which not only relieves the climate footprint, but other environmental and health risks associated with heavy traffic (noise, dust, etc.)(Rodgers, 2018).

Appendix J – Approval Forms

IDSN 4002 — Humber ITAL / Faculty of Applied Sciences & Technology

Bachelor of Industrial Design / FALL 2020

SENIOR LEVEL THESIS ONE — Catherine Chong / Sandro Zaccolo

Abstract

With climate change becoming an increasingly prominent issue, there is also an increase in the quantity, and magnitude of natural disasters around the world.

El Salvador experiences the effects of these natural disasters on a scale unlike any other country. Due to El Salvador's landscape and geographic location, it experiences frequent occurrences of natural disasters such as hurricanes, floods, earthquakes, landslides, and volcanic eruptions. This results in economic losses and damages to homes, infrastructure, transportation, agriculture, service interruption, and more.

When a disaster occurs, the most affected populations are those from smaller cities or rural towns. Since these small communities are farther away from large and more established cities, they lack access to resources.

Despite this, the communities that reside in these rural areas are active and eager to undertake recovery efforts, without waiting for action by the State.

Examples of this include communities coming together to take on tasks such as removing debris, recovering access roads, building new shelters, and more. This is not an isolated incident but rather a characteristic of the Salvadoran people, who are considered to be very hardworking and resourceful.

The goal of this thesis project is to provide access to the tools and resources necessary for a smoother recovery process for victims in rural areas. The solution will be heavily based on data collection, user observations, and interviews to get more insights into challenges faced by these people. In doing so, it is assumed these communities will then take their own initiative from receiving the following aid solution proposed and incorporate it into their own community how they see fit.

Student Signature(s): [signature]

Date: 04/ 0/2020

Instructor Signature(s): Catherine Chong [signature]

Date: Oct 7 2020

IDSN 4502
SENIOR LEVEL THESIS TWO

Humber ITAL / Faculty of Applied Sciences & Technology
Bachelor of Industrial Design / WINTER 2021
Catherine Chong / Sandro Zaccolo

CRITICAL MILESTONES: APPROVAL FOR CAD DEVELOPMENT & MODEL FABRICATION

Student Name: Cameron Barber Debris

Topic / Thesis Title: Recycling Station

THESIS DESIGN APPROVAL FORM

Thesis design is approved to proceed for the following: [X] **CAD Design and Development Phase**

Comment: Initial CAD progress well as of week #8/March 17th, continue with detailing and refinement.

Thesis design is approved to proceed for the following: [X] **Model Fabrication Including Rapid Prototyping and Model Building Phase**

Comment: Design development progress well as of week #8/March 17th, once CAD is completed, can move forward to model fabrication from week #9 onward.

Instructor Signature(s):

CatherineChong Sandro Zaccolo

Date: 17th March 2021

PANEL ON RESEARCH ETHICS
Navigating the ethics of human research

TCPS 2: CORE

Certificate of Completion

This document certifies that

Cameron Barber

has completed the Tri-Council Policy Statement:
Ethical Conduct for Research Involving Humans
Course on Research Ethics (TCPS 2: CORE)

Date of Issue: **1 October, 2020**

Appendix K – Advisor Agreement Forms

IDSN 4002 / 4502
SENIOR LEVEL THESIS ONE & THESIS TWO

HUMBER
Faculty of Applied Sciences & Technology
Bachelor of Industrial Design / FALL 2020 & WINTER 2021

INFORMATION LETTER

Conditions of Participation

- ✓ I understand that I am free to withdraw from the study at any time without any consequences.
- ✓ I understand that my participation in this study is confidential. (i.e. the researcher will know but will not disclose my identity)
- ✓ My identity will be masked.
- ✓ I understand that the data from this study may be published.

☒ **I have read the information presented above and I understand this agreement. I voluntarily agree to take part in this study.**

Nishant Das		9-April-2021
Participant's Name	Participant's Signature	Date

Project Information

Thank you very much for your time and help in making this study possible. If you have any queries or wish to know more about this Senior Level Thesis project, please contact me at the followings:

Phone: **(226) 808-7289**
Email: **cameronbarber@live.com**

My supervisors are:

Prof. Catherine Chong, **catherine.chong@humber.ca**
Prof. Sandro Zaccolo, **sandro.zaccolo@humber.ca**

IDSN 4002 / 4502
SENIOR LEVEL THESIS ONE & THESIS TWO

HUMBER
Faculty of Applied Sciences & Technology
Bachelor of Industrial Design / FALL 2020 & WINTER 2021

PARTICIPANT INFORMED CONSENT FORM

Research Study Topic: Study topic: How may we aid in the aftermath of natural disasters in vulnerable communities?
Investigator: Cameron Barber / cameronbarber@live.com / (226) 808-7289
Courses: IDSN 4002 & IDSN 4502

I, Nishant Das *(First Name/Last Name)*, have carefully read the Information Letter for the project ; How may we aid in the aftermath of natural disasters in vulnerable communities?', led by Cameron Barber. A member of the research team has explained the project to me and has answered all of my questions about it. I understand that if I have additional questions about the project, I can contact Cameron Barber at any time during the project.

I understand that my participation is voluntary and give my consent freely in voice recording, photography and/or videotaping; with the proviso that my identity will be blurred in reports and publications.

Consent for Publication: Add a (X) mark in one of the columns for each activity

ACTIVITY		YES	NO
Publication	I give consent for publication in the Humber Library Digital Repository which is an open access portal available to the public	☒	☐
Review	I give consent for review by the Professor	☒	☐

Privacy
All data gathered is stored anonymously and kept confidential. Only the principle investigator /researcher, Cameron Barber and Prof. Catherine Chong or Prof. Sandro Zaccolo may access and analyze the data. All published data will be coded, so that visual data is not identifiable. Pseudonyms will be used to quote a participant (subject) and data would be aggregated.

I also understand that I may decline or withdraw from participation at any time, without negative consequences.

I understand that I can verify the ethical approval of this study, or raise any concerns I may have by contacting the Humber Research Ethics Board, Dr. Lydia Boyko, REB Chair, 416-675-6622 ext. 79322, **Lydia.Boyko@humber.ca** or Cameron Barber / cameronbarber@live.com / (226) 808-7289

Verification of having read the Informed Consent Form:

☒ I have read the Informed Consent Form.

My signature below verifies that I have read this document and give consent to the use of the data from questionnaires and interviews in research report, publications (if any) and presentations with the proviso that my identity will not be disclosed. I have received a copy of the Information Letter, and that I agree to participate in the research project as it has been described in the Information Letter.

Nishant Das		9-April-2021
Participant's Name	Participant's Signature	Date