Low Cost Bike

For Developing Nations

- Project 10 -

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Team

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Summary

Our team designed and produced an inexpensive yet durable cargo bicycle for developing nations. The bike is designed to allow for easier transportation of goods and people. Our bike was designed to be able to hold 100kg on the saddle and 70kg on the rear rack. Throughout our research, design, and testing stages we have identified components that could be improved to better suit the needs of developing nations

Problem Statement

Our goal is to design and produce a durable and inexpensive bicycle that is marketable in developing countries. By creating this bicycle, we plan to increase the mobility of the target population, while simultaneously allowing the user to transport heavy loads of goods or passengers. We also plan for the bike to promote eco-friendly transportation that will improve the quality of life within communities. Our bike will need to be able to stand up to any abuse, whether it is from the user or the environment. It must be able to withstand poor road quality, while also being sensitive to the cultural needs of the people. In order to achieve our goals, the bicycle needs to be affordable, functional, durable, and desirable by the target market.

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1. Introduction to the Design Problem

This design problem is based on the firsthand experience of our client Dr. Kevin Kochersberger. During his time in Senegal with the Silage design team, he observed an almost complete absence of bicycles, and those that he did see being used were in nearly unusable condition. When looking further into the situation, he found that the most inexpensive bicycle he could find cost the equivalence of 60 US dollars and was in poor condition. In a country where the minimum wage is 40 cents per hour for general laborers, it was unbelievable that one of the most basic forms of human powered transportation would be so financially unreachable for a large portion of the population. It is our client's intention to create an affordable mode of transportation that can be marketed to developing nations around the world. The target price point for our team was initially set 50 US dollars, but in an effort to accommodate the niche market our design team would hone in on the price point was increased to approximately $120.

Designing a bike for the developing world presents a range of unique design challenges. When addressing the specific challenges associated with West Africa, many stem from the cultural considerations we must take into account during our design process. For instance, Dr. Kochersberger observed that many people in Senegal go about their daily business either barefoot or wearing sandals. In addition, both men and women wear long flowing clothing that could interfere with the operation of a bicycle sprocket and chain. Our client has made it clear that while this bike is not intended for use exclusively in West Africa, these considerations are relevant to the cultures of developing countries around the world.

In addition to cultural considerations, our bike design must handle the rigors associated with operating on the roads and in the environment of a developing nation. While in Africa, Dr. Kochersberger noted the state of disrepair of most of Senegal's road infrastructure. While driving on a highway out in the country, it was often necessary to drive off road as the dirt surface was much smoother than the once paved road. This coupled with the heavy rains experienced for much of the year creates almost impassable road conditions for much of the country, especially outside of urban centers. This creates the need for a bicycle that is extremely durable and can operate in a wide range of road surfaces, from paved roads to no roads at all.

With these challenges in mind, it is the goal of this team to deliver a bicycle that can not only improve the mobility of those in developing nations but is also sensitive to their cultural needs. It must be a bike that can stand up to a great deal of user and environmental abuse and still improve the quality of life of its owner, while still maintaining an affordable price.

Through this team project, we expect to gain valuable design experience by conceiving, designing, and producing a marketable product within the design constraints. This product should increase the mobility of the target population, promote eco-friendly transportation, and improve quality of life. We will evaluate the success of this project by the affordability, functionality, and desirability of our final design.

2. Requirements and Specifications

Research and experiences from existing projects. Introducing a broader bicycle culture in developing nations is an idea several organizations are working towards. At the beginning of our design process, we sought out advice from their experiences and recommendations for improvement. Some organizations, such as Bicycles 4 Humanity, take donated bikes and ship them to target regions. Other companies and organizations, such as Kona, are designing a bike, like the Africa bike, specifically for the needs of the population in a target region. Communicating with those organizations revealed that the main usage for these bicycles is within rural areas while traversing long distances as well transporting cargo. Based on information from the organizations, it was recommended that we should focus on designing a cargo bike with ample storage capability and adequate durability while being easily repairable.

In order to meet the customer needs as well as to design a reliable and feasible product, it is essential to identify specific engineering requirements and target performance specifications before generating concepts. Appendix A shows the resulting engineering requirements based on the analysis of the customer needs, research concerning existing bicycle models in developing countries, and basic force calculations. The specific target and threshold values characterizing the engineering requirements describes the testing criteria of the bike. Figure 1 summarizes the engineering requirements in six main fields of interest, ranked by order of importance.

Importance

Durability	**on unpaved roads puncture resistant tires**
Carrying Capacity	**ability to carry heavy loads**
Affordability	**low-cost bike**
Repairability	**easy maintenance**
Cultural adaptability	**women with long dresses**
Comfort	**long difficult rides**

Figure 1. Ranking of the essential engineering requirements regarding importance

Affordability. The main objective of the project was to design an affordable and durable cargo bike. First hand experiences showed that bicycles which are now available in developing countries are often overpriced and not affordable for the indigenous population or do not meet basic requirements regarding durability and strength. Even on the local bicycle market in the US the prize range of cargo bikes starts at over $1000.

Our project started with a final sales price of $50. But ongoing research and design work revealed that we cannot reach this target without lowering our demand of quality. In accordance with our client, we expanded the budget and for the bike and turned functionality and durability of the bike into highest priority of the design process. Affordability remained one of the leading principles but it is not sustainable to purchase a cheap bike which requires frequent maintenance and replacements.

Durability. Another important requirement is the durability of the bicycle and how it responds to environmental conditions. In order to guarantee a long lifetime for the bicycle, it is important to consider the influences of harsh environment on the individual parts of the bike. Furthermore, the bike design must be capable of handling the recurring forces that would be associated with rough conditions and heavy loads.

One particular area that we are focusing on in regards to durability are the wheels and tires which are going to be under constant stress due to the rough roads and the heavy capacity loads. Potholes, which are common in developing nations, can cause pinch flats or even bent rims. These bikes will be used to traverse long distances where locations to repair the bike will be scarce so we want the bike to be as durable as possible. Some concepts that we are investigating in order to minimize the risk of one of these issues occurring, include having foam filled tires to avoid flats and using a rim with internal suspension in order to minimize the risk of bike damage. Having the suspension inside the rim is a fairly new technology, but has proven its durability through use on military Humvees.

Carrying capacity. Bikes in developing countries are not only used as a means of transportation, but also to carry heavy loads such as goods or persons. Therefore, the frame must be capable of supporting the load and provide a loading platform with options to secure the cargo. As with the wheels, the frame must also be able to withstand the cyclical loading caused by rough riding conditions.

Reparability. Another requirement that we felt was important, and that also went hand in hand with affordability, was reparability. We knew that we couldn't just design a bike that was cheap. If something broke it would have to be fixed and we wanted to avoid forcing our customers to have to send away the bike to be fixed or to have to special order parts. We kept our design simple and our components simple and easily repairable. There were, of course, unavoidable parts that would be complicated to replace such as the bike stem, and the brakes.

Cultural Adaptability. When designing our bike we also had to make sure that the design would be adaptable to the culture it would be introduced to. In a lot of developing nations both the men and the women have long flowing dresses. We took this into consideration when designing the bike, opting for a step through frame.

Comfort. Lastly, the bike should be comfortable and easy to handle with multiple goods or persons on one bicycle, which is important but not as essential as the previous performance criteria. The handling and comfort is a result of the overall weight and dimensions of the bike as well as special features like suspension. Furthermore, special cultural habits like barefoot riding or long dresses of women must be considered.

Sustainability Objective. Initially our team had the idea to develop a secondary economy that developed the community by employing people to build and repair the bicycles, which would improve the quality of life and increase the expendable income of the local workers. We also hoped to expand the secondary economy by using as many locally sourced materials as possible. We wanted the majority - if not all- of the manufacturing, assembling, and maintenance to be accomplished locally. To ensure that this goal was attainable we conducted more research about the types of materials available in Africa and the quality of the welding that could take place in developing countries. Researched showed that MIG welding machines are commonly available in developing nations. However, Figure 2 shows a welding example produced in Senegal. The inconsistent and poorly dimensioned weld seam evidently reveals serious weaknesses. As the welds of a bicycle frame need to be of high quality to guarantee the structural integrity of the bike and therefore the safety of the rider, our design team decided that the welding and machining skills we saw in Senegal were not acceptable.

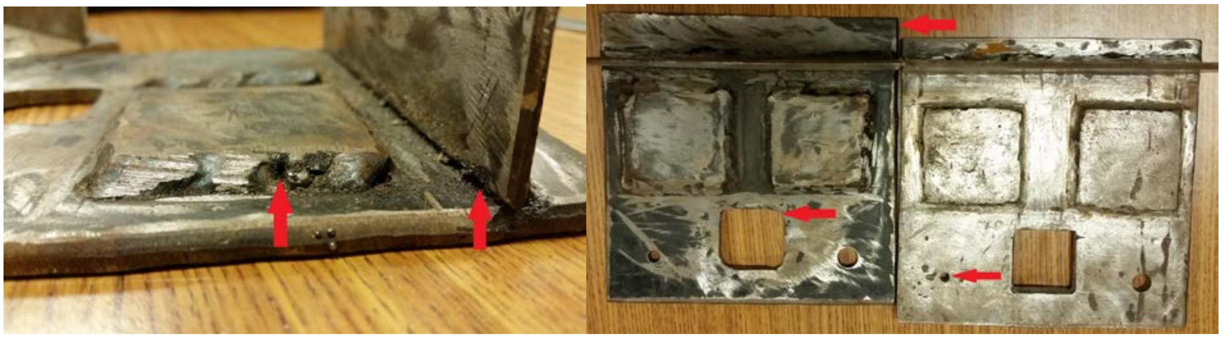

Figure 2. The welding quality in developing nations was of poor quality. The sample on the left shows very rough welding with burs, as well as connection completely missing the welding bead. On the right shows two samples made by different welders that were made from the same specs. The back section has different lengths, the left holes are of different sizes, and the square cutout has different corners.

Consequently, indigenous production was no longer an option. Instead, the design of the bike frame was oriented towards automatized production in China. As a majority of bicycles in the lower price segment are produced there, they have great experience with delivering reliable and replicable weld quality that we require for our design project.

3. Concept Generation and Selection of Overall Design

Concept Generation: Morphological Chart. After further research and idea accumulation we developed a morphological chart, which consists of the main features and their different variations depending on the several designed concepts. This chart is shown in Table 1.

Table 1. Morphological Chart used in concept selection.

Feature	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
Material	Aluminum	Bamboo	Carbon Fiber	Steel	Wood
Frame type	Step Through	Long Frame	Recumbent	BMX Style	Tricycle
Wheel Size	20"	24"	26"	29"	26” X 4”
Wheel Type	Tweel	Conventional Spokes	Solid Wheel	Sprung Metal	Welded Spokes
Brake type	Fixed Gear	V-Brakes	Disc	Coaster	Drag Feet
Drivetrain	Direct Drive	Belt	Chain	Feet	Driveshaft

Concept Selection. For our concept generation process, each member of our team generated 5 unique concepts with differing aspects of each major part of a bike. Out of the 55 concepts that were created, a portion of the team went through and screened each individual concept and found major benefits and flaws of each. We then chose about 18 of the 55 concepts that we found had the most amount of positive aspects and ran them through a secondary screening process. Appendix B shows this process in greater detail. We assessed each of our original customer needs and chose the 10 needs that we found to be the most important for our design to incorporate. We then scored each concept with a “+”, a “0”, or a “-” depending on whether the concept met the need well (+), met the need at all (0), or failed to meet the need (-).

A “+” counted as a positive point, a “0” counted as no points, and a “-” counted as a negative point. Once a concept had been scored for every need used, the total points were counted. Out of the 18 concepts scored, we had only 7 that totaled a positive score. We then took these 7 concepts through a third screening process. Appendix C shows this process in greater detail. In this part of the selection process, each of the 10 customer needs were given a weight corresponding to their overall importance relative to each other. The total weight of all 10 needs was required to be exactly 100%. We then gave each concept a ranking from 1 to 5 (1 being the lowest and 5 being the highest) relative to how well they met each individual need. Once all concepts were scored, the weight percentage of each need was multiplied by the ranking and then summed with the rest of the needs for each individual concept. The final scores can be found in the table. Our data showed that concepts 14, 13, and 12 were the three highest ranking concepts, respectively. Figure 3 shows the combinations of our three highest concepts merged into one.

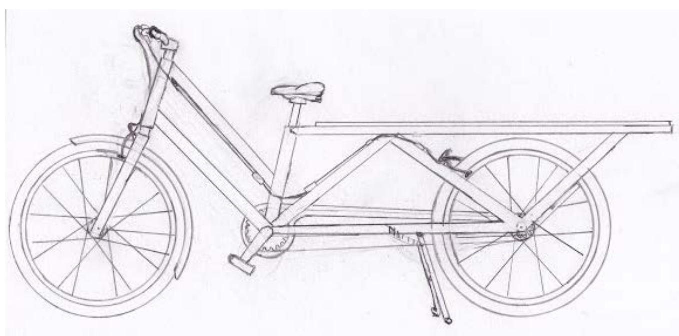

Figure 3. The final concept. A long cargo bike that would allow for items to be carried on the back rack.

4. Frame Design

The frame design was based around several of the engineering requirements that were identified earlier. It would have to be strong, be compatible with the cultures of developing nations, and affordable so that people in developing nations would be able to afford our product.

Initially our team explored 2 options, one of a welded metal frame, and the second built from lengths of bamboo lashed together with natural fiber reinforced with epoxy or resin. Despite the merits of a bamboo frame to include its strength and the environmental benefits associated with using a natural material as opposed to metal, we elected to focus our team's energy pursuing the metal design. The time constraints associated with this project necessitated the use of a material with known and consistent properties that could be sourced in Africa with standardized dimensions. There were also serious concerns with rot, mold, bugs, and maintenance of the bike to prevent other potential hazards such as dry rot from occurring. Due to the complications of testing and evaluating bamboo lashed with fibers as building material for or frame and the unknown availability of bamboo in large quantities and standard sizes especially in Africa, the decision was made to drop the bamboo design concept entirely.

Once the overall bike concept was selected using the concept selection methods outlined in the previous sections of this report the frame sub team was tasked with developing a more detailed design that the other sub teams can begin to work off. As the design for the frame of our bike will dictate many of the design characteristics of the ancillary components, the detail design of the frame was important to complete first. In order to create the frame design our team drew inspiration from a variety of bikes already on the market but lie far beyond our price point. Once general dimensions and proportions were gleaned from these bikes we could move forward developing this bike design to fit our particular engineering requirements. Finally our team utilized the Autodesk Inventor in order to model and evaluate our design. The following section will outline modeling and testing process our team undertook in order to develop the current design for the frame.

To begin the development of our models we had to first create a general idea of how the various members of the frame were to be positioned. This was done by performing a topological optimization using Abacus 6.13-3. By providing Abacus a rough area in which the frame will lie, and constraining that area appropriately, we can gain an approximation of the areas of highest stress, and load paths within the frame area. The following topological optimization is based on a rough outline of the shape of cargo bike selected in the concept selection phase.

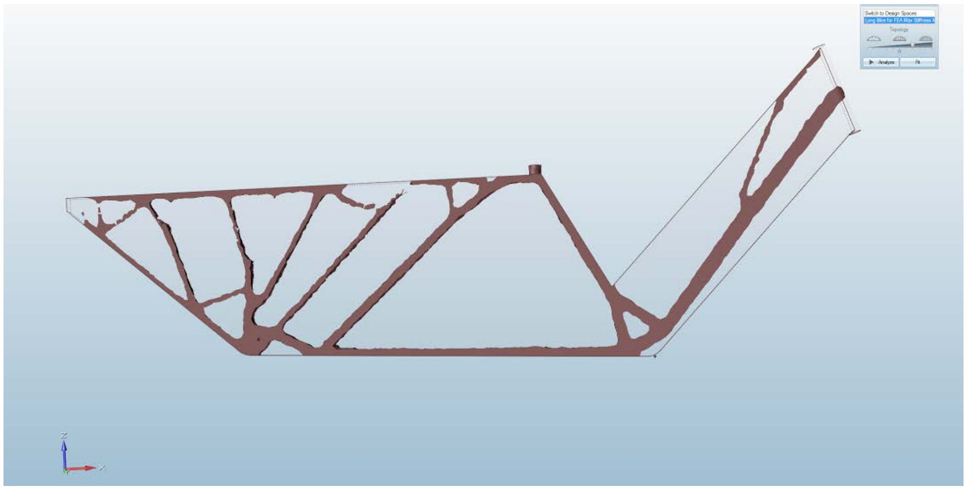

Figure 4. The various load paths, shown in brown, through the area of our frame. Pin constraints were placed at the bottom of the head tube and rear wheel, with a load applied at the seat and a distributed load across the rear rack.

Utilizing the load path data generated from the topological optimization we could begin work on a workable model within Autodesk Inventor. In order to proportion the bike correctly we performed some market research using similar bikes in production. The dimensioning for the front half of the bike to include the head tube, down tube, and top tube were modeled after the Crossroads Sport Step-Through. This is a $500+ bike currently on the market in the United States and around the world. The dimensions for the front half of the bike provide a comfortable upright riding position and good handling.

Figure 5. The Crossroads Sport Step-Through bike.

For the rear half of the bike we based our wheelbase and overall proportioning on the Surly Big Dummy bike. In particular we were interested in the bottom bracket drop, and chainstay length. This bike is designed as a long cargo bike with a load capacity of 90 kg though the retail price online for the frame and fork as pictured below is $950. It was then our challenge to combine aspects from these two designs and modify them to our own needs in order to fulfill our engineering requirements.

Figure 6. Surly Big Dummy long bike.

With general proportions determined we could begin modeling our design in 3D using Autodesk inventor. Over the course of several weeks our CAD model took several different shapes as the design was further modified and optimized as problems became apparent in each revision. Although there were several dozen different versions of the frame design this paper will only discuss the major alterations for the sake of brevity. Our initial model seen in Figure 7 featured an excessively large rear cargo rack which had the capacity to have loads being place well behind the rear wheel, this had the potential the wildly unbalance the bike under certain loading conditions so the decision was made to redimension the rear rack of the bike in order to make the design less unwieldy. In addition there are many complicated joints and welds necessary to assemble this design.

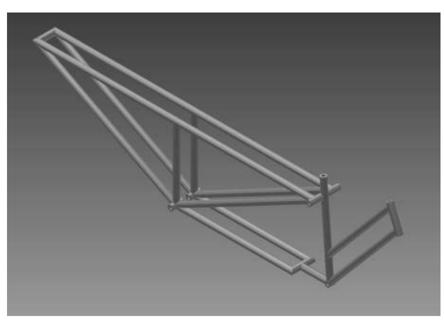

Figure 7. CAD model for revision 1 of the frame design.

Improving on revision 1 of the model our team moved forward developing the bike with a smaller, more manageable rack. In addition it shortened the tubes for the rack so they would not hit the rider's legs while they peddled. Further research into components altered our design for the bottom bracket shell as well. Originally we had a tube with a standard inner diameter. However bottom brackets shell have to be precisely threaded with the right side being a clockwise thread and the left being a counterclockwise thread. This is to ensure that the action of pedaling will help to keep the bottom bracket securely fastened into the bike as opposed to potentially unscrewing it. As it is unlikely that many shops in developing nations have the tools to do this type of machining we opted to use a purchased bottom bracket. This major revision is shown in the Figure 8.

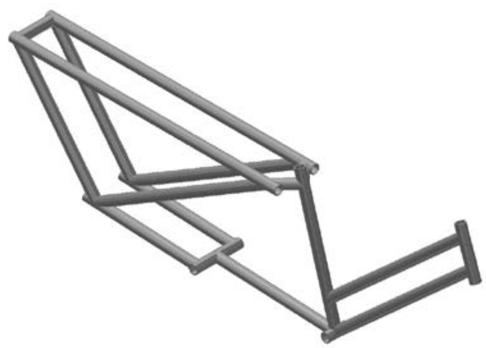

Figure 8. A render of major 2 of the frame.

One large change we made after inspecting this frame we realized that the joints were overly complicated as we had more than two members meeting at several points. This would require additional machining, tolerancing, and more difficult welds. Therefor the members were adjusted to simplify the connections. At this point we were still designing the bike to be built in the developing nation where it would be used. Because of this we were using a very cheap grade of steel which was weak. We were doing this because we did not want to design something that required stronger steel than they would have on hand as we felt they may build it using a lower grades steel and get hurt. This lead to having extra members added into the frame to produce the necessary strength while maintaining the step through design. This version of the frame is shown in Figure 9.

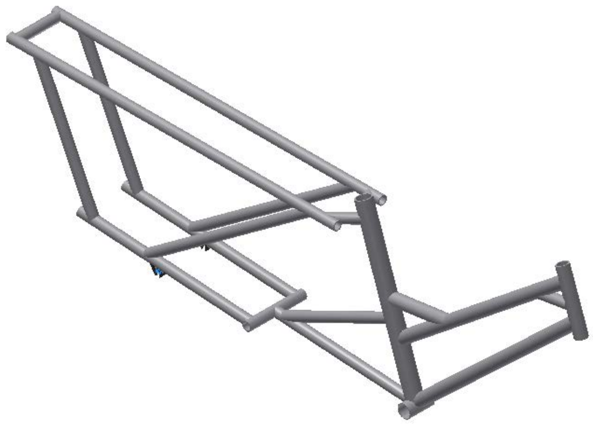

Figure 9. A render of the revision 3 of the frame.

At this point the frame required very large, thick tubes to be structurally sound. This made the frame extremely heavy. Around this time we were also discussing the weld quality we received from Senegal. Due to the dangerously low machining and welding quality we decided that the bikes would need to be built elsewhere. When we decided this it freed us to use a higher grade steel which lead to another major revision in our frame design. It allowed us to thin out the tubes and remove the cross members between the head tube, top tube, seat tube, and chainstay. This required less tube length and utilized thinner tubes providing a much lower weight. This became our final version of the bike and is shown in Figure 10.

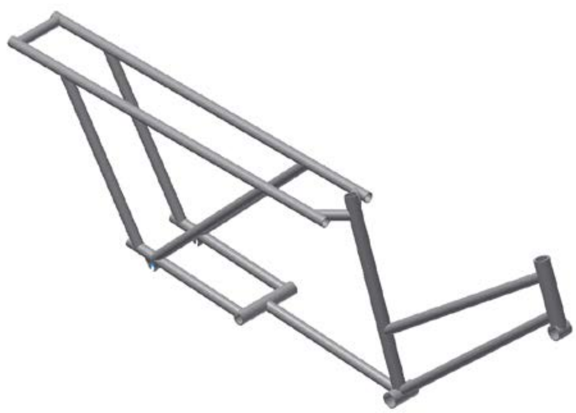

Figure 10. A render of revision 4, our final major revision of the bike frame.

Finite Element Analysis (FEA) was performed to validate our frame. A stand-in piece was added to the frame design on the bottom of the heat tube for FEA purposes only which gave us more realistic loading conditions. For our simulations the value for the endurance limit for our new higher quality steel, ASTM A513 Type 5, using a factor of safety of two was set as the maximum acceptable value. With a factor of safety of two the endurance limit was found to be 74 MPa. The simulation was set up with the full load of 70 kg distributed along the back rack and the full 100 kg on the saddle. The load on the rack was simulated to be experiencing 2 g of acceleration by doubling the force and the saddle load was simulated at 1.5 g in the same manner. This was done to simulate the loads we expected the bike to see fairly constantly while riding on rough roads.

Due to the inability to get the weld function in Inventor to work we had to take some liberties on interpreting the connections between the members. For instance there would be single nodes that were under extremely high load when none of the surrounding nodes were. This lead to inspecting all joints instead of using the maximum value function built into Inventor. With our final design of the bike, excluding errors as mentioned before, the highest stress seen in the frame was 31.1 MPa. We attempted to swap out members for thinner one, in order to lighten the bike, as this is well below our threshold but going any smaller in either outer or inner diameter for any tube shot the maximum stress over 74 MPa. Our FEA results are shown in Figure 11. The final weight for the frame was calculated to be 6.95 kg.

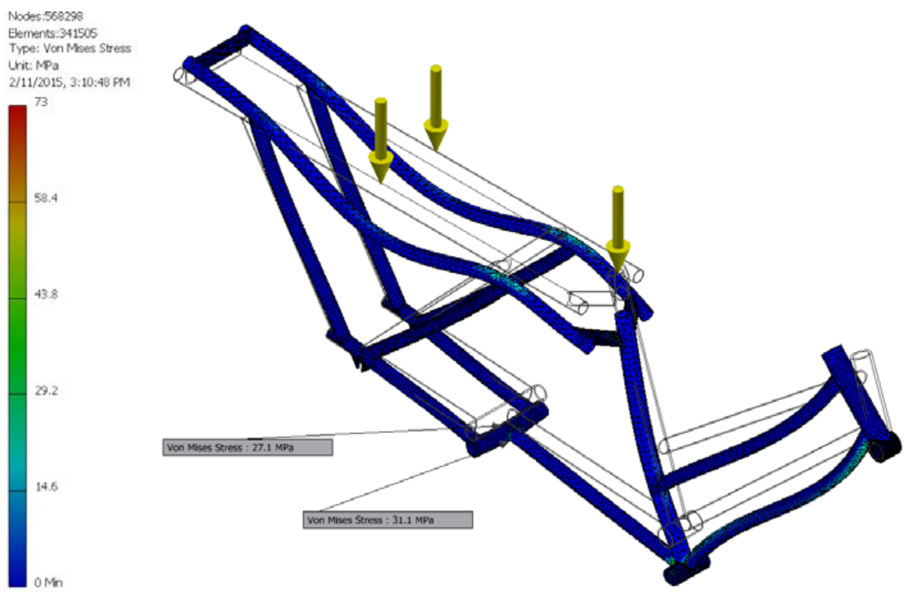

Figure 11. FEA testing results of final frame design.

The fork design was closely defined by the geometry of the wheel and frame designs. The same geometry was kept from the beginning with different tubes being tested to meet the strength requirements while minimizing weight. The final weight was found to be 2.68 kg. FEA was also used to validate the fork using the force found in the frame simulation that was on the support where the fork will be. These were applied at the angle of the headset to make the simulation as accurate as possible. The highest stress in the fork was found to be 68.7 MPa in the final version of the fork which can be seen in Figure 12.

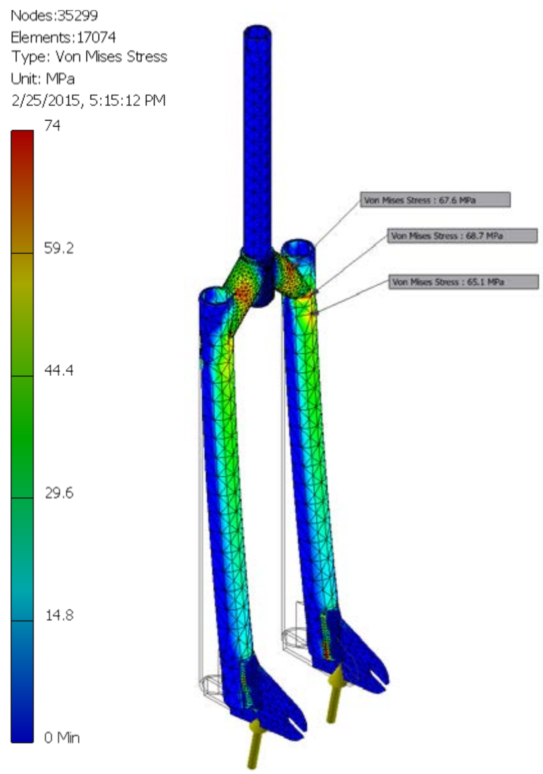

Figure 12. FEA results of final fork design.

5. Wheel Design

General idea. The wheel sub team was tasked with designing, selecting and testing several wheel and tire options which we deemed applicable to out bicycle. We examined two custom manufactured solutions discussed below in comparison to a conventional wheel. Our largest constraints for this aspect of the design were loading capacity, cost, weight, and ease of repair. The result of our initial examination revealed that the two following hand manufactured solutions did not meet our requirements for cost, weight, and ease of repair and as such were dropped as possible alternatives. We then proceeded to test three different manufacturers' budget wheelsets for rigidity to determine the optimal choice for our project. We also tested several alternatives for tires and puncture resistance. Based on previous team evaluation and component team requirements, our rear wheel was expected to have a coaster brake, and feature a free hub. The front wheel was expected to utilize standard rim brakes and have no coaster or freehub. Both wheels were to be 26" in diameter and support 100 kg each. The following sections outline our design, testing, and selection process.

Wheel designs

The two self-designed wheels are created to enable a local manufacturing in Africa; whereas, the conventional spoked wheel would be imported. Thus special design requirements resulting from limited materials, tools and production techniques as well as engineering knowledge must be taken into consideration. The three essential wheel concepts and their main specifications are shown in Table 2.

Table 2. Overview of the different wheel designs

The three different designs for a 26" wheel		
Conventional Wheel	**Disc Wheel**	**6-spoked Wheel**
		
General		
Weight: 1.8 kg Materials: Alloy, steel spokes Cost wheel set: $23.28	Weight: 20kg Material: commercial quality mild steel (S235) Cost: $47.60	Weight: 2.569 kg Material: commercial quality mild steel (S235) Cost wheel set: $32.75

Spoked wheel

Referring to the conventional wheel design, which has been optimized and developed over centuries the 6 spoked wheel is based on the design idea of spokes as main stabilizing construction element. Additionally in order to reduce the complexity and make usage of common welding techniques possible the number of spokes has been adjusted. Instead of the prevalent number of spokes for a 26" wheel which ranges from 24 to 36, the design is composed of just 6 spokes. A drawing including a cross section as well as CAD model pictures of the 6 spoked wheel design are shown in Figure 13. As it is indicated in the cross section of the wheel the spokes have an angle to the vertical axis which is about 2 degrees. This angle has been introduced in order to increase the buckling and bending resistance of the wheel as well as to create space for welds at the hub. Every second spoke is located at the same baseline on the hub and all spokes are welded on the same curve at the rim. Thus three spokes are having the same orientation correlated to the same base curve at the hub.

Figure 13. Design of the 6 spoke wheel.

In order to maintain the stability and be able to resist the occurring stresses the thickness of the individual spokes is increased. The spokes are made out of steel flats which are composed of the mild steel S235 of commercial quality as it is found in developing countries. These steel flats are then welded on hub and rim. At the beginning of the design process a rectangular steel flat cross section of 15mm x 5mm was planned, but during the Finite Element Analysis, the results of which are shown in Figure 14, this size was increased iteratively since the occurring displacement of the spokes was too high. After several iterations the optimal and thus final size of 30mm x 5mm could be found.

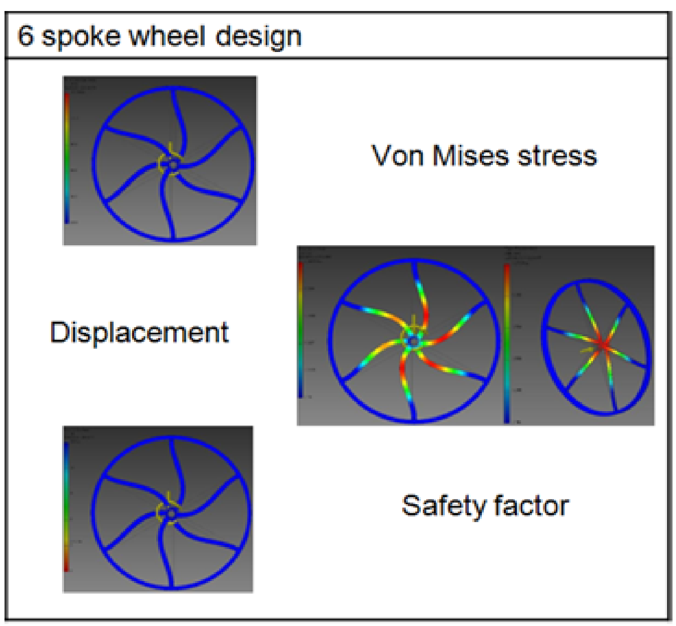

Figure 14. Results of the FEA for the 6 spoked wheel.

However, since the cost of the 6 spoked wheel design, including manufacturing and material costs, is about $33; it exceeds our limits by far. In addition to the significantly higher cost of this wheel design in comparison to a conventional wheel, the 6 spoked wheel also has a weight of approximately 2.6 kg. Furthermore, the realization of the 6 spoked wheel design would require an immense amount of accuracy and preparation during the manufacturing process due to the high number of required measurements. In order to guarantee a convincing result in terms of durability, balance, and roundness, a high amount knowledge as well as experience is needed. Consequently, the idea of manufacturing and testing of the 6 spoked wheel was not pursued. Instead, it was looked further into a simpler design as well as into the requirements for a conventional wheel.

Disk wheel

This design was an attempt at going beyond the conventional spoke system to a system that could both support the required amount of weight while simultaneously making the fabrication process cheaper and simpler. The main motivation for this design is to eliminate the spoke system and replace it with a solid structure. This structure would be comprised of a double circular plate system which could easily be manufactured in mass quantities from sheet metal or another cheap alternative. This plates would be cut to the necessary dimensions and then be pressed into a slight conical shape. They would then be welded at the center to the hub and at the edges to the rim. This is shown in Figure 15 below. Figure 16 shows the FEA analysis run to confirm that this design would effectively meet the standards we set and ensure that the wheels would not fail under maximum loading. The initial plan was to pursue the fabrication of a single set of wheels in order to perform physical testing for comparison. We conducted research into the resources needed to obtain a set of disk wheels. After consulting with multiple third-party facilities including VT Fire and other fabrication companies, we found that the cost to produce one set for our testing purposes went well beyond the amount of funding we still had available. On top of that, the estimated costs for producing mass quantities of this design averaged out to be approximately $47 when including material, fabrication, and welding costs. We decided to scrap the design and continue to focus on obtaining conventional wheels at low cost.

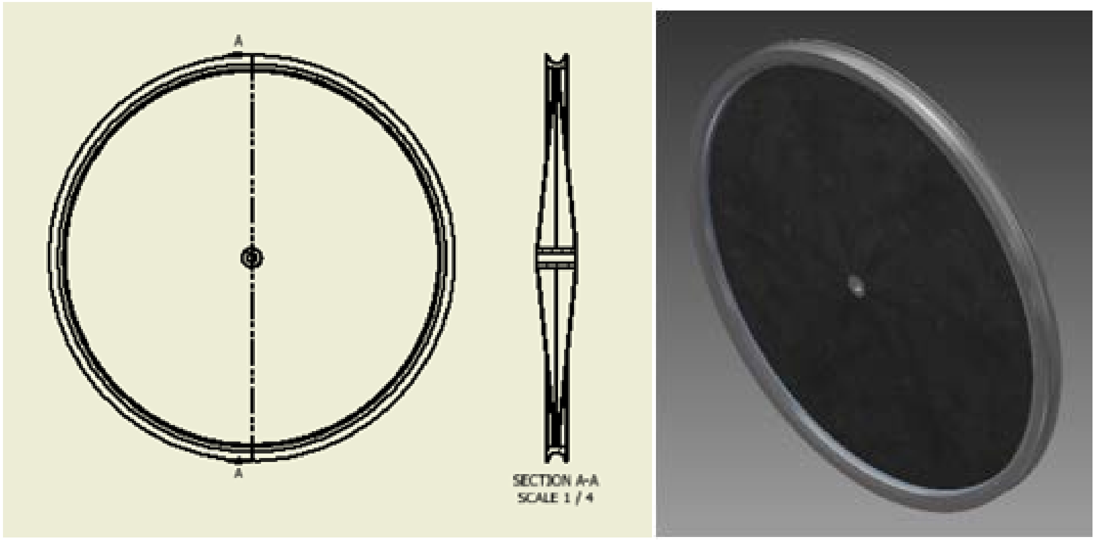

Figure 15: Cross-sectional view of the plate wheel design.

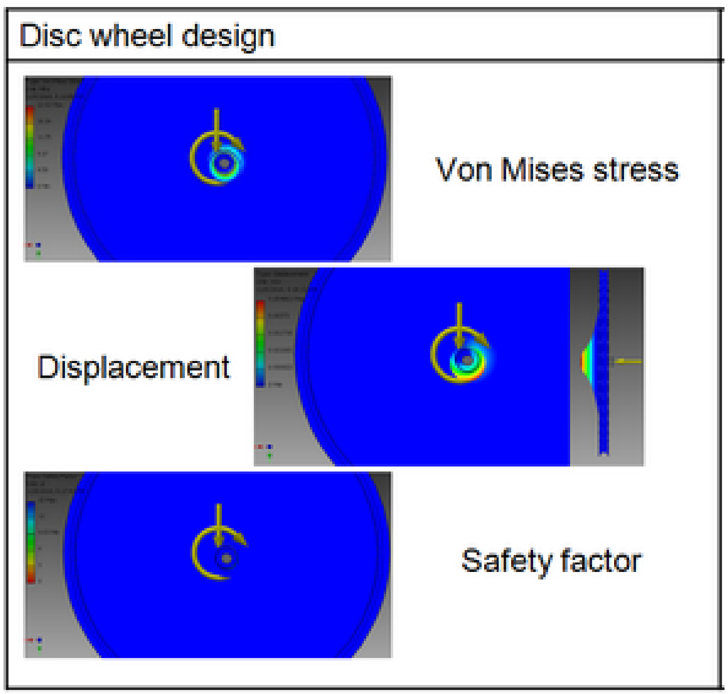

Figure 16. The FEA analysis run on the disk wheel design.

Conventional wheel

The conventional wheel is the wheel you are used to seeing on everyday bikes. The hub in the center of the wheel features sealed bearings and a freehub body to allow the wheel to coast while the user is not pedaling. Attached to the freehub is either a single cog or a set of cogs grouped together as a cassette. The hub may also feature a coaster brake or a disk brake mount. From the hub, the spokes connect to the hub, are laced in a crossing pattern, and connect to the rim through predrilled holes. At the rim side of each spoke a nipple allows for tensioning of each spoke. Adjusting the tension allows a user to easily straighten, or true, a bent wheel. Based on the team's requirements, our rear wheel featured a single cog, and coaster brake. Our only requirement for the front wheel was that it makes use of a rim brake. This was chosen as the wheel type we would pursue for our project based on its high strength to weight ratio, ease of repair, and low cost relative to the other options. We chose the following three wheelsets as our test options as seen in Table 3.

Table 3. The three wheelsets that were chosen to be tested and implemented into our Bike Design.

Brand	Front Wheel Cost ($MSRP)	Rear Wheel Cost ($MSRP)
Avenir	36.90	31.03
WheelMaster	16.08	23.00
StaTrue	33.97	47.58

Tire options

Purchase. Although we examined the option of including our team quickly ruled out the option of manufacturing our own tires. We purchased three different types of tires:

Table 4. Comparison of purchased tires.

Kenda Cyclocross tire	CST Mountain bike tire	Schwalbe Kevlar tire
$14.37 722.9 g (893 g with silicon)	$16.22 638.2 g	$14.99 637.9 g
Sacrifices lower traction for lower rolling resistance	High traction and higher rolling resistance	High rolling resistance and traction, also features a Kevlar shield to prevent punctures

Puncture resistance. We also evaluated possible solutions to prevent tire punctures further. We examined the use of tire slime, alternative tube materials, silicon, and protection strips outside of the tube. Of these, only placing a layer of silicon made it to the final testing stage, at which point we realized that the added weight not only made the wheel heavier, but the tire was also no longer balanced. It showed nothing that suggested it would improve puncture resistance and as such the idea was scrapped. A picture of the silicon filled tire is shown in Figure 17.

Figure 17. Tire filled with silicon. Silicon is colored in blue.

Testing

Tires. For the tire selection, we analyzed puncture resistance, rolling resistance, weight, and cost. All tires were mounted to the same rim with a tube filled to 50 psi. This rim was placed in a custom designed test rig. The rig was then loaded progressively up to 400 pounds with the tire tread placed directly on an upward facing screw. A picture of the testing process is shown in Figure 18. All three tire choices survived this test up to 400 pounds without puncture – the maximum our scale could handle. Therefore, we determined that each tire met our goal for puncture resistance. For added puncture resistance, we looked at several alternatives, however the prohibitive cost of these features caused the team to abandon these. Ultimately, a puncture can be solved with a simple and inexpensive patch kit which, in the United States, can be purchased for $1.99 for 8 patches.

Figure 18. Puncture Resistance Testing.

Wheels. The wheels and tires were simultaneously tested for durability and reliability. Due to a failure in the shipping department, we were not able to test the Avenir wheel – It did not arrive until two months after we ordered the wheel. The tires were each weighed and the wheels trued before this test took place. The tire was then mounted to a wheel and driven for 20.8 miles loaded up to 208 pounds with 50 psi in each tube (weight was a function of the leverage of our testing rig, which was loaded with 90 pounds). The roads driven on were chosen because they were extremely rough and curvy to simulate road conditions and turning that the wheel would experience under actual use. The vehicle towing the wheel was kept as close to 10 miles per hour as closely as possible. After this, the tires were again weighed to determine the amount of material lost from each tire as a measure of durability. The wheels were trued on a trueing stand. The run out of the wheel was measured in millimeters at each spoke. This information is represented graphically in the two following images. Neither wheel was significantly more out of true than the other, and both posed no problems repairing the damage caused by use. The weight of our tires was measured in ounces, however we later discovered that this unit did not have enough resolution for use. The tires lost less than one ounce from the drive, and time constraints did not allow us to perform a second test to determine the amount of weight lost from each tire.

Conventional biking wisdom encourages placing a gripper, higher tread tire on the front and a smoother, easier rolling tire on the rear. This is because the major function of the front tire is to aid in turning, while the rear wheel focuses on transmitting power to the ground. The meatier tread profiles of the CST and Schwalbe tires meant they were best for the front, while the Kenda’s lower profile tread made it an excellent match for the rear wheel. We tested several combinations on a test bicycle while our final product was being assembled, looking at braking performance, traction, and ease of pedaling. The results from endurance testing are shown in Figure 19.

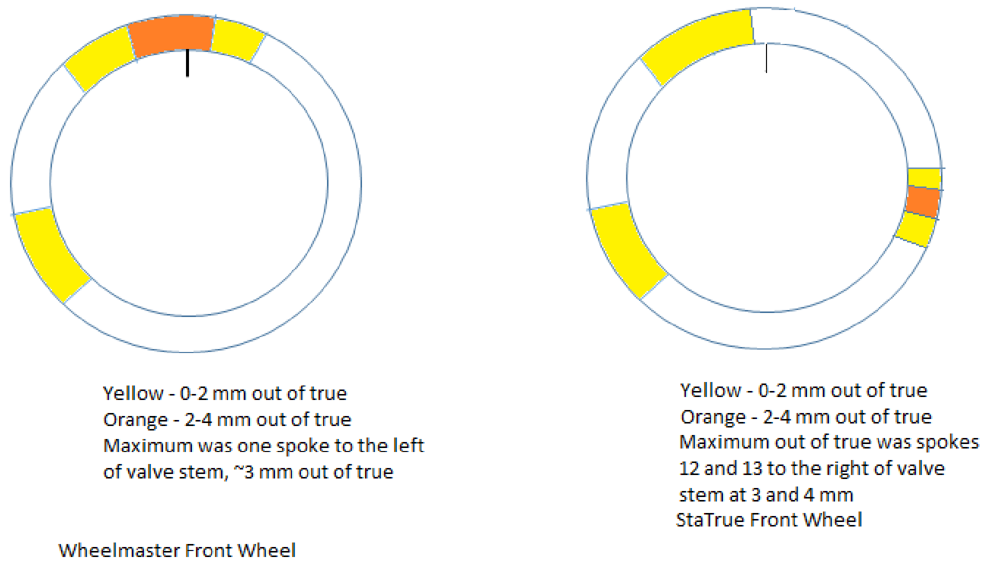

Figure 19. Endurance testing results.

Final Decisions and Conclusions

After testing, our determination was to place the Schwalbe tire in the front. Not only was it less expensive than the CST, but also provided a better turning based on the opinions of our three test riders. This tire also performed the best in braking tests. An added benefit of this was that the Schwalbe tire also featured a Kevlar shield built into the tire. Although we were not able to puncture any of the tires using our test rig, this was the only tire that advertised puncture reduction technology. The Kenda Cyclocross tire was placed on the rear wheel because, again, the test rider panel felt that this tire provided easier pedaling. While tests braking with only the rear wheel showed a decrease in performance while the Kenda was mounted, we found that this difference became insignificant while using both brakes. Further research showed that approximately 70% of braking power on a bike comes from the front wheels.

The wheel was chosen based on performance in the endurance test, since all three wheels survived up to 400 pounds of static loading in our puncture resistance test. The two wheels that we were able to test were the WheelMaster and the StaTrue, and both performed similarly in the endurance test. The WheelMaster, however, was significantly cheaper than the StaTrue. We opted to include the WheelMaster in our final product.

6. Component Design and Selection

The components sub-team was formed to identify, and design or find the parts of the bicycle not directly related to the frame or wheels. During the early portion of the design phase, the sub-team focused on the components necessary for the functioning of the bicycle. This included handlebars, headset, crankset with a bottom bracket, headset, stem, chain, seat post with clamp and saddle, and brakes. After the prototype was manufactured, the components sub-team worked on the back rack, chain guard, fender, and kickstand, as well as revisiting the initial components. The main customer criteria that affected the components selection, were affordability, durability and reparability. Carrying capacity, comfort, and cultural considerations were also considered when deciding optimal component qualities, but affordability was the largest factor, considering our original $50 cost limit. Any individual component could be a design project on its own, but as the entire bicycle was the goal, many components were purchased, as the team new designs would be costly to manufacture, and possibly require new manufacturing processes or elements to be constructed. The cost and time necessary to develop certain new components, not to mention testing, was often considered outside the scope of the team project. A description of each component choice follows, first discussing the items that were eventually purchased, followed by those components designed by the team.

Purchased Components

Crank Set and Bottom Bracket. After the sub-team decided that it was not viable to manufacture our own crankset/bottom bracket, we looked at purchasing common components that would be widely available. The crankset contained a 5 bolt, 110mm BCD and 170mm long crank arms that we attached a 34T chainring to. The 34 tooth chainring gave us the gear ratio (chainring tooth #/cog tooth #) we wanted, which was about 2; this would allow the rider to be able to pedal easily with or without a load on the back rack. The bottom bracket was a standard 68X113mm UN-26 Square taper cartridge that houses all of the bearings needed to turn the crank arms. This would keep the bearings weather proof and would keep maintenance down to almost nothing.

Headset. The headset is what allows the rider to turn the front fork and steer the bike while keeping the fork from sliding up and down. We went with a standard 1” headset that included all of the bearings need to turn the front fork. The headset in combination with the star nut and the stem keeps everything compact and held together.

Chain. We chose a standard single speed chain with a master link that would allow for easy installation and maintenance. In order to create a chain that would reach all the way from the crankset to the cog, we had to attach two chains together by using the masterlink and removing a number of links to allow for the chain to be as tensioned as tightly as possible. After initial installation, we observed the chain was not tensioned properly so we made a makeshift chain tensioner out of a stem and some PVC to keep the chain from popping off.

Stem. The stem is what attaches the handlebar to the front fork and allows the user to steer the bike. Initially, we had a standard solid stem that just extended straight off the head tube, but with the various sizes of riders we had, we decided to switch it out for an adjustable stem that would allow the angle of the stem to be changed. This would allow a larger group of people to ride the bike comfortably.

Seatpost, Seatpost Clamp. The seatpost and seatpost clamp allows for easy vertical adjustment to allow people of all heights to ride the bike. We cut a slit in the steel frame to allow the seatpost clamp to clamp the tube together, which keeps the seatpost in a locked position.

Pedals. Several concepts were generated in an effort to find a simple, cheap design that could use materials already needed for other bicycle sections, the final CAD design can be seen in Figure 20. After construction of a wooden prototype of a pedal design, it was clear the pedal would be heavy, require welding, and still need testing. Furthermore, the team’s client requested bearings, and other structural changes to the design, which made it even less cost effective to manufacture when compared with pedals already on the market. To save money, and considerable testing time, it was decided to purchase a common plastic extrusion pedal (Figure 20, right), which proved to be made of weak material.

Figure 20. The final pedal design on the right, would have cost considerably more to manufacture, especially after bearings and changes were requested. The first pedal that was purchased, on the right, proved unsuitable.

Saddle. Initially, the team was considering designing our own saddle and had generated several viable concepts, but as we presented these ideas to our client, he advised us to purchase a cheap saddle, as designing a saddle would be too time consuming and costly. After looking at different models, we chose a cruiser saddle that is larger than a typical road saddle and more padded to allow for a more comfortable ride. The saddle also features two springs that will help absorb some of the forces as the road conditions will not be ideal in our target location.

Brakes. Initially, we were planning on incorporating two v-brakes with one in the front and one in the back, but we opted against the one in the back as the cable would have to be extremely long and could cause problems. In order to solve this problem, we decided a rear coaster brake would be the best solution as it requires no cables and is naturally weather proof. We also included a v-brake in the front to add more stopping power as the bike would need more if it was loaded in the back. In order to reduce the number of parts included in a V-brake setup, we opted to exclude the brake boss. Instead, a generic screw is welded to the fork. The brake levers are mounted to these with a set of hex nuts and washers on each side. Welding of tabs below the boss provides a surface on which the brake levers can press on. A detailed view of the front brakes is shown in Figure 21. This simple design follows the principle of Design for Manufacturing (DFM), because simple and commonly available bolts replace specialized bike components. Besides favoring easy replacement and maintenance of the breaks, this design favors both the cost and number of pieces involved in our bike.

Figure 21. Front Brakes with modified mounting system.

Designed and Manufactured Components

Throughout the research and design phases of our project, the team identified the following areas in which low cost and effective components could be produced to meet our design goals.

Handlebars. The handle bars function as an interaction between the rider and the bicycle to control the direction of travel. Our initial design featured straight cut steel bars for ease of manufacture; if the bars were to break, a new set of handlebars could easily be cut from a straight section of piping. This shape turned out to be uncomfortable, however, and was not ergonomic. With the use of a conduit bender, we produced several different handle bars. Upon testing, we found that the bars that were bent to approximately 7 degrees on each side of the stem provided the most comfortable handling position. These bars still satisfy our design constraints because they are easily manufactured with a cut piece of steel and a conduit bender, a simple tool available in most developing areas.

Kickstand. One of the major functions of the bicycle is for cargo transportation. This made a kickstand a necessary component to enable the loading and unloading of people and goods. When considering design attributes, certain features of normal styles of kickstands proved problematic. The first problem arises from the small area of the kickstand base. The typical design works well on even, hard surfaces. In loose dirt, sand, gravel, mud or grass, this style would sink into the ground with any load. A second greater problem is the location of kickstand mount. Normally, kickstands are mounted close to the ground, but when a load is placed many feet above the mount, a large moment is created which causes excessive torque and can easily tip a bicycle over. To counter these problems, a piece of 1 inch diameter PVC piping was used as a support; the larger diameter of the base would make it less likely to sink into the ground. To counter the possibility of tipping, the kickstand was mounted to the frame of the rack itself, as seen in Figure 22. This placement removes most of the moment about the mount, reducing the inclination of the cargo to cause tipping. Testing showed the kickstand had a tendency to slide out on very smooth surfaces, and also to move horizontally if the ground was not level. To remove the sliding issue, as well as increase the base's resistance to sinking, a rubber foot was attached, which stopped the sliding action. To prevent the horizontal motion, a heavy Velcro strip was used to hold the front brake down when parked, which prevented the unwanted lateral motion. Heavy steel wire was used to affix the kickstand mount to the front of the rack frame, and also to create a cradle (see Figure 22), attached to the rear of the rack frame, to hold the kickstand up during transport.

Figure 22. PVC kickstand design on the left, holding up the load at the rack to greatly reduce the moment compared with typical kickstand placement. The wire cradle attached to the frame can be seen on the right storing the kickstand for transport.

Fender. Fenders are not necessary for the functionality of the bicycle, but to improve comfort by preventing flying dirt, water and stones, a simple and effective design was implemented. A rectangular piece of HDPE plastic was affixed to the frame, over the front wheel with two plastic zip ties. This was found to be effective, although further testing would help to decide an optimal size and shape. The exact fender that was installed on the bike for testing was put there to confirm that it would protect the rider from debris but also to work as a placeholder for an example. In developing countries, people would be able to use any scrap piece of plastic, or possible bamboo, and tie or secure the plastic to the down tube to work as a fender. This simple solution was designed as a secondary economy component, although it would be easy enough for the users to install themselves.

Chainguard. A chainguard was deemed necessary to ensure the long clothing common to many cultures would not catch on the chain and cause damage or safety issues. As there could also be passengers, the chain guard would prevent hanging feet and legs from catching on the chain. The sub-team generated several concepts, and found it would be more cost effective to manufacture a simple chain guard than purchasing one. Initial concepts included bending a common PVC tube heated by a heat gun and bent around a circular form. The goal was to have the chain run through the PVC where possible; enclosing the chain would have reduced maintenance, as less debris would get stuck in the chain, also, less oiling would be necessary. A setback to this design was that heating the PVC caused the plastic to become brittle, and difficult to shape to spec, as can be seen in Figure 23; another negative side effect was that hazardous and toxic gases were released in the heating process. As safety always has a high priority, and considering that many of the simpler components can become part of a secondary economy, we decided not to use this design.

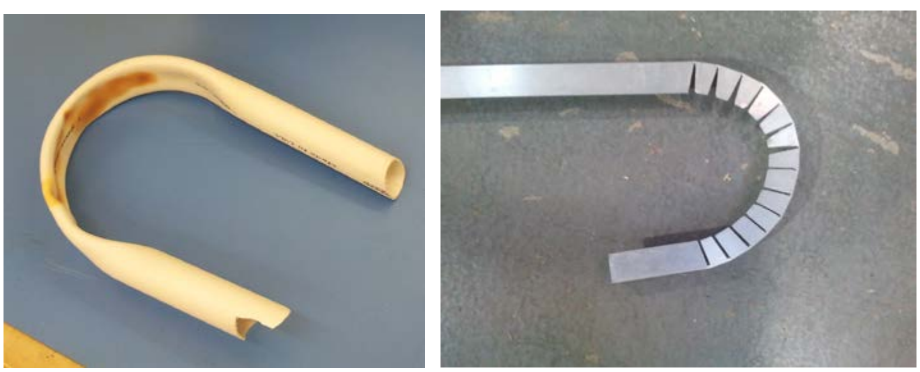

Figure 23. The initial chain guard design with heated and formed PVC tube on the left shows color changes where the heat burnt the plastic, causing brittleness. The final chain guard on the right, was made from aluminum, and formed around a pipe, after grooves were cut.

The final design used a 1 inch by 1 inch length of structural angle made of aluminum. To shape the curve over the front cog, a band saw was used to cut notches on the frontal face, after which it was curled over a pipe section with a similar diameter to the chain ring (Figure 23). The chain guard curves to the bottom of the chain ring, and extends back to cover the top of the rear cog. Two hose clamps were used to attach the chain guard to the frame. This component could be easily constructed from a variety of materials in the target areas; bamboo could be suggested as a useful material to reduce environmental impacts.

Backrack. The rectangular part of the frame that holds the back rack can support a variety of shapes and sizes of racks. Depending on the type of goods or if used to taxi people, the desired dimensions would be very different. For example someone who is transporting flowers would need a large loading platform to avoid stacking them as this might crush the flowers below. A thinner stronger platform would be needed to transport heavy materials such as bricks. The bicycle taxis in east Africa, known as Boda-Boda, would likely want a padded platform with hand holds for their passengers. As the needs were varied, we opted not to include a loading platform with the product, but decided that the rack would be acquired separately, or as an add-on component, but not part of the cargo bicycle initially for sale. We thought this would be a better approach as the customers could then customize the loading area to suit their needs and ensure they are not paying for something they may not need.

The team opted to show one possible design as a demonstration model, seen in Figure 24, using a piece of 7¼" wide, ¾" thick, and 39" long pine board, which was cut to overlap the rack frame. Eight slots were cut in the wood where four hose clamps could then attach the rack to the frame. Two 1" by 4 " slots were also cut towards the front of the rack for handholds for possible riders to hold on to, or that can be used as tie down points. These holes could also be repeated in the middle and the back to provide additional tie down points or more hand holds. If used for goods, a much wider rack would be needed to have a wide base for a stable load.

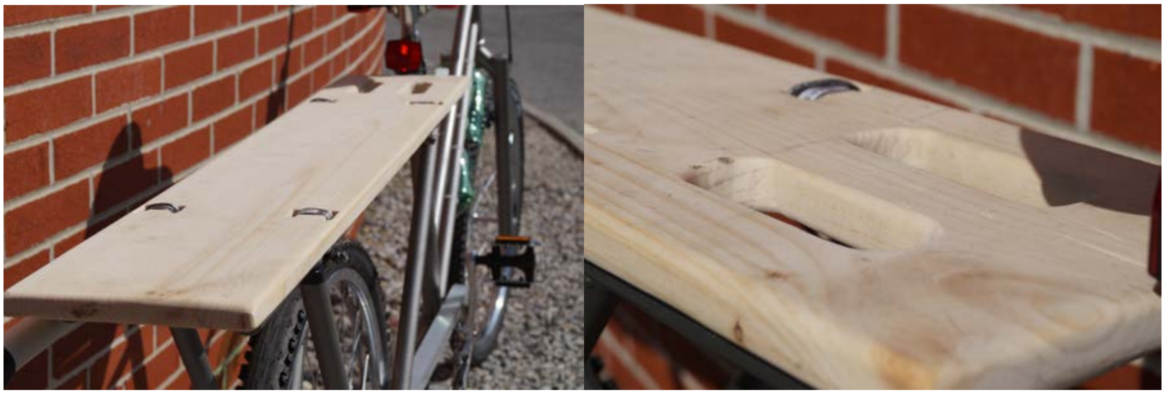

Figure 24. The demonstration platform photo on the right shows where the hose clamps have been used to attach the platform to the frame. The left picture shows the handholds that were cut out.

7. Manufacturing and Assembly

To reach our goals of increased mobility and sustainable transportation in developing nations, mass producing our frame in a low wage country is the most feasible option. It allows us to meet both most important customer needs: affordability and high quality guaranteeing a safe long-time usage. The initial idea of local manufacturing in the area of application fell through, because of the limited welding skills in developing nations do not meet basic standards of security. Therefore, automatized high quality welding in a specialized manufacturing place in a low-wage country justify the expected shipping costs to the target region. Investigating the origin of our selected components revealed that most are manufactured in China anyway.

To implement our bike on a large scale in developing nations, the plan is to ship the components and the frame after their production in China to the customer in the developing nation as an assembly kit. Together with a detailed assembly instruction in their mother tongue, the customer for instance one rural village can purchase one bike as a community investment and assemble it collaboratively. This process will guarantee a high cultural adaptability of the product, because due to the local craftwork it will be seen as cultural imperialism from the developed world. Especially, the modular shape of the product favors this aspect. Depending on the specific needs and the operational field, the customer can adapt the cargo bike design - especially the back rack - as desired. The design of the additional and not safety-related components such as fender, chain guard, back rack allows flexible modifications so that the exact arrangement can be adjusted to the material that are locally available at that point of time.

8. Cost

The cost of the frame, components, and wheels for mass production in a low-wage country were approximated. As recommended by our client, we investigated cost estimations for bulk order of 1000 unit annually. As explained earlier, for safety reason the frame cannot be welded in the developing nations but we decided on manufacture in low-wage countries. Contacting Chinese manufacturing facilities via our Engineering Manager Yang Chen gave us reliable cost estimations on the welding which is around $5 for the frame and the steel supply of around $10 for one bike. Table 5 shows detailed cost information for the frame and the fork.

For the purchased components, we investigated the retailer markup typical for the bike market. Unfortunately, due to confidentiality policies, several retailers could not provide us information how they build their prices. However, Quality Bicycle Product let us know that we can reduce retail prices by approximately 50% to 70%.

Table 5. This table shows the items that were used to manufacture the frame and fork and their cost estimates.

Items	**Cost (Dollars)**
Headset	5.75
Handlebar	1.60
Stem	7.60
Seat Post	3.85
Seat Clamp	2.00
Steel Tubes	7.80 - 13.92
Weldment	4.80 - 6.40
Total	**33.40 - 41.12**

Table 6. This table shows the components that were incorporated in our bike and their cost estimates.

Item	**Cost (Dollars)**
Bottom Bracket	7.10 - 7.60
Bottom Bracket Shell	4.51
Chains	2.95
Chainring	3.30 - 10.70
Crank arm	8.99
Brakes, Cables with Housing, Levers	4.50 + 0.60 + 3.00 = 8.10
Saddle, Handlebar Tape	6.50 + 0.66 = 7.16
Pedals	4.00 - 6.00
Total	**46.11 - 54.01**

Table 7. This table shows the items that are composing the wheel and their cost estimates.

Item	**Cost (Dollars)**
Rear Wheels with Coaster Brake	11.00 - 18.00 per wheel
Front Wheel	9.00 - 12.00 per wheel
Tires	.80 - 2.90 per tire
Tubes	0.34 - 0.65 per tube
Total	**21.15 - 33.55 per wheel set**

After the cost analysis for each sub-categories was performed, we were able to determine the total cost estimate for the whole bike as shown below in Figure 25. Components took the largest portion of total cost which was about 44% and wheels took the least portion of total cost which was about 24%.

The entire bike will be produced for $114. This low price for cargo bike with innovative step through frame and highest specifications regarding durability, sufficiently meets the project target of designing a low cost cargo bike for developing nations.

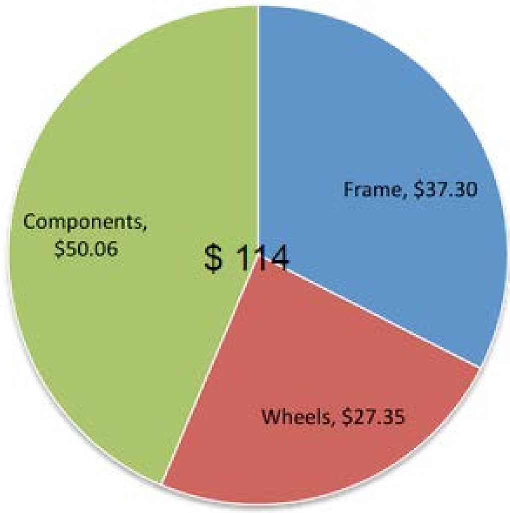

Figure 25. Total cost estimate is broken down to each sub-categories.

8. Overall Bike Testing and Results

Once we had acquired a working prototype of our cargo bike design, we initiated the implementation of our testing plan. We included items such as stopping distance with and without load, turning radius with and without load, and general bike integrity and comfort. The testing criteria and results can be found in Figure 26 and in the Acceptance Criteria section of this report.

Our tests were chosen based on the initial criteria set by the customer needs. Perhaps the most important of these regarded durability - we wanted to ensure most of all that the bike could stand up to the regular abuse from the rough terrain of our target environments. Therefore, we spent a good amount of time testing the integrity of the bike while both loaded and unloaded. The backrack loading is illustrated in Figure 27. Another very important aspect we felt should be quantified was the average stopping distance when both loaded and unloaded. It is critical that the rider has a safe amount of time to stop the bike should something go wrong or an obstacle appears. We conducted this test on both flat and angled paths with and without a full load. Lastly, we determined that the length of the turning radius was important to quantify as well. We wanted to ensure that the bike's maneuverability met average standards. We would have wanted to conduct more endurance testing to further ensure the integrity of our design was safe and durable enough to warrant mass production, but we had neither the time nor the resources to do so.

1	Testing Method	Testing Criteria	Experimental Value	
2				
3	Ride on Huck	Comfort	8	
4				
5	Simple gravel/dirt trail	Bike Integrity	Pass	
6		Comfort	8	
7	Simple gravel/dirt trail with full payload	Bike Integrity	Pass	
8		Comfort	6	
9				
10	Shallow stairs in front of D2 (technically against school polocy)	Bike Integrity	Pass	
11				
12	Ride on Huckleberry Trail / Road in front of Smith Landing	Stopping Distance (Flat) @20 kph	4.8	m
13		Stopping Distance (Downhill) @20 kph	7.15	m
14				
15	Ride on Huckleberry Trail / Road in front of Smith Landing while fully loaded	Stopping Distance (Flat) @20 kph	9.22	m
16		Stopping Distance (Downhill) @20 kph	11.7	m
17				
18	slow speed turn radius unloaded	Manuverability	1.56	m
19	" " With Braking		1.185	m
20	slow speed turn radius fully loaded	Manuverability	2.23	m
21	" " With Braking		1.935	m

Figure 26. The testing methods and experimental results.

Figure 27. Demonstration of the Backrack Loading.

9. Comparison to Existing Bikes

In order to determine if our project would be viable in today's market, we compared our product to bikes that are already on the market and readily available. In the beginning of the project, we bought an $80 bike from Walmart to see the quality that a bike in our price range would hold up to our tests. We quickly figured out, after just riding it around campus, that this bike would not meet our standards as the plastic pedal broke after 30 miles of riding and the wheel was damaged making it completely unride-able. The Walmart bike, even though it was not a cargo bike, was a good starting point to see the quality of a regular cheap bicycle.

Next, since we were building a cargo bike for our project, we looked at some of the top cargo models that are on the market. We researched three models that we would use to compare to out bike. Those models are the Kona Ute Cargo Bike, the Surly Big Dummy, and the Yuba Mundo. All three bikes cost well over the $114 projected cost to produce our bike with the Kona being $1300, the Yuba being $1250, and the Big Dummy at $2500. Those prices are with the basic attachments only. Some of the bikes add on extra cost for fenders, chain guards, etc. All of the cargo bikes shown in table 8 are around the 45 lb. mark with the exception being the Kona Ute bike with it being at 35 lbs. Our cargo bike is designed to hold a 100 kg rider and an extra 70 kg of load on the back rack which equates to approximately 375 lbs. total. The three cargo bikes all have a higher max hauling cap, but at a much greater cost. Also, with our research at the beginning of the year, we do not think that our target market will need more than 70 kg of loading on the back rack.

Table 8. Our final design compared to the retail price point, weight, and carrying capacity of comparable long bike designs.

	Kona Ute	Yuba Mundo	Surly Big Dummy	Our Bike
Base Price	$1300	$1250	$2450	~$114
Weight	35 lbs.	48 lbs.	45 lbs.	47 lbs.
Loading Capacity	300 lbs. + rider	440 lbs. + rider	400 lbs. total	375 lbs. total

As you can see, our bike was able to stand up to three of the top cargo bikes on the market. Our cost, which was the prime focus of this project, is considerably lower than the three competitors, but it comes with the downside that the rider will not be able to haul as much load on the back rack as other bikes. However, we do not believe that our target market will need a higher loading capacity for the loads they will be carrying.

10. Acceptance Criteria

Once finishing our tests for our bike, we compared out results and findings to our initial acceptance criteria which was determined previously. The results from our testing trials were paired with our acceptance criteria which is shown in Table 9 below. Our acceptance criteria consists of testing for integrity of the bike with and without a load, the comfort, stopping distance with and without a load, turning radius with and without a load, and the tire tread.

Table 9. Shown in the table below are the findings from our tests and acceptance criteria.

Testing plan	Testing Criteria	Target	Experimental result
Integrity: No Loading	Damaged/Undamaged	Undamaged	Undamaged
Integrity: With Loading	Damaged/Undamaged	Undamaged	Undamaged
Comfort	Scale: 1-10	5	7
Stopping distance	Flat @20 km/h Downhill @20 km/h	5 m 8 m	4.8 m 7.2 m
Stopping distance w/ load	Flat @20 km/h Downhill @20 km/h	10 m 13 m	9.2 m 11.7 m
Turning radius w/ and w/o braking	Diameter	4 m 45 m	2.4 m 3.2 m
Turning radius w/ load w/and w/o braking	Diameter	5 m 6 m	3.9 m 4.9 m
Tire Tread	Visible tears in sidewall or tread	No Tears	No Tears

We found that our bike passed all of the acceptance criteria that we were able to test. Our team would like to continue our testing to do a complete endurance test until failure. We were not able to test the bike to failure due to the amount of hours it would take to finish a failure test for our bike.

11. Improvements and Technology Readiness Level

After completely our testing trials and collecting results, we found that there were a few features of our bike that we would like to change in order to improve certain features about our frame. Some of these improvements we were able to implement into our bike immediately. One of the features we changed was the brake lever. The brake lever we originally used proved to be problematic and would release tension from the front brake cable and would result in a complete loss of braking power. We implemented a more robust front brake lever in order to guarantee the secure connection between the brake lever and brake cable, shown in Figure 28 are both the original and new brake lever.

Figure 28. Shown above are the original and new brake lever.

When we installed the new brake lever, it was apparent immediately that the new lever worked much more efficiently. The new brake lever created a greater cable tension which increase the stopping power without having to pull the lever as hard and the cable did not fall out once. The next part we decided to improve was the pedal. Our first pedal choice was a cheaper plastic framed pedal that shattered into pieces after thirty miles of testing. We quickly decided to install a metal framed pedal to increase the lifespan of our pedals even though it would increase the costs slightly, shown in Figure 29.

Figure 29. Shown above are the original and new pedal.

Next, we decided to use an adjustable stem to allow our bike to quickly change the angle of the stem for more people to be able to ride the bike, shown in Figure 30.

Figure 30. Shown above is the new stem.

Our original stem worked as expected but we decided that with an adjustable stem, more people would be able to ride the bike therefore making the bike more adaptable to all sorts of riders. Lastly, our team decided to remove the steering damper that was on the bike in the beginning. The steering damper was supposed to improve the bikes handling ability and keep the front wheel facing forward while in motion, but during our testing we found that the steering damper actual made it more difficult to maneuver the bike, specifically in our turning radius and bike control testing. We also found that the steering damper was approximately 12% of our bikes costs, so by removing the steering damper we were able to reduce our overall costs.

Including the parts which we were able to implement into our bike currently, our team found that there were a couple other features which we would improve in our bike during fabrication. The most important aspect that our team would improve was a problem created from the lack of chain tension. The dropouts on our bike were not machined out far enough back to allow for the adjustment of the rear wheel. This resulted in the lack of chain tension which then caused the chain to jump off the cog on the rear wheel during testing, shown in Figure 31.

Figure 31. Shown above is the chain that does not have proper chain tension due to the dropouts not being long enough.

For future bikes, we would have the dropouts extended back during fabrication. We would also like to add a chain slap guard to the member which the chain crosses in order to prevent the paint from chipping when the chain would bounce of it while riding. We would like to reduce the chance of the paint chipping to prevent the formation of rust where bare steel is exposed, an example is shown in Figure 32.

Figure 32. Shown above is the chain slap guard that was installed to protect the paint.

Lastly, we would change the steel tubing size for the head tube from 1 inch to 1 ⅛ inch to allow for more common sizing headsets to be used. When building out bike, we found that 1 inch threadless headsets are less common compared to a 1 ⅛ inch headset, and we would like our bike to use easier to get parts so the headset can be replaced more conveniently.

Our team evaluated our technology readiness level, and concluded that our design is currently at a TRL of 8. We came to this conclusion because our bike and product is completely ready and tested to begin production and implementation to developing nations. Although we would like to conduct a further endurance test to run the bike until complete failure, the bike is exactly as it would be fabricated.

12. Conclusion

In conclusion our design team was extremely successful developing an affordable multi-use cargo vehicle for the developing world. At a price point of $114 the utility of this bike is leaps and bounds ahead of the recycled, worn out, and barely functional bicycles sold for $60 our client described during his trip to Senegal. Our product would be an important capital investment for any rural farmer, just as a truck would be for a rural family farm in America. Not only does our product facilitate the transport of goods to market, it greatly increases personal mobility. With bicycle taxis in mind our design allows for passengers to sit astride the long rear rack. We envision our bicycle to be used in a wide range of capacities and fully expect it to be applied to tasks we have never imagined.

Through the results of our testing program we are confident that our design can stand up to the rigors of nonconventional use and will help to increase the quality of life of our customers and their communities. Moving forward we intend to ship our prototype to Africa this summer with the help of Dr. Kochersberger to fully evaluate its performance and receive feedback from our target customers. The information gathered on this trip would be invaluable to a future design team to further refine our design. We made an effort to make this design as useful to as many cultures as possible but moving forward our work can be used as a basis for a range of design projects targeting different parts of the globe.

13. Appendices

Appendix A. Engineering requirements and specifications
Appendix B. Concept Selection Tier 2
Appendix C. Concept Selection Tier 3
Appendix D. Bill of Materials

Appendix A. Engineering requirements and specifications with specific threshold and target values

Eng. Requirement	Category	Specification	Threshold	Target
Resistant to Environmental Influences	Wheels	Tire Temperature	-10°C to 50°C	-20°C to 60°C
	Tires	Average Miles Travelled Before Puncture	2000 km	5500 km
Rolling Resistance	Wheels	Required Power at 20 kph and 85 kg Bike & Rider	250 W	205 W
Shall be Capable of Sustaining Forces	Wheels	Vertical Forces	2.5 kN	5.0 kN
	Wheels	Rolling Resistance	50 N	30 N
	Wheels	Torque	80 Nm	100 Nm
Financial Feasibility	Overall	Cost	$85	$50
Environmentally Sustainable	Overall	Recyclable Material	60%	90%
	Overall	Production Waste	40%	10%
Carrying Capacity	Back rack	Carrying Capacity	100 kg	150 kg
	Saddle	Carrying Capacity	80 kg	100 kg
Functional Geometry	Frame	Persons of Height	150 - 170 cm	120 - 190 cm
Durability	Frame	Lifetime	7 Years	15 Years
	Component	Lifetime	3 Years	6 Years
	Wheels	Lifetime	2 Years	3 Years
Repairability	Frame	Number of Tools Required	5	2
	Wheel	Number of Tools Required	3	1
	Components	Number of Tools Required	3	1
Cultural Awareness	Frame	Type of Frame	Standard	Step Through
	Components	Pedals	Standard	Barefoot
Security	Components	Locking Mechanism	None	Included
Handling	Overall	Weight	40kg	15kg

Appendix B. Shown in the table below is the second tier of concept selection. The greyed out boxes are the seven designs that were continued to the next tier of the design phase.

	Concepts																	
Potential Solution Selection Criteria	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Adequate F.S.	-	0	0	0	-	+	0	0	+	0	0	+	+	0	+	+	+	-
Liftetime	-	0	0	0	-	+	0	-	+	0	0	+	+	0	+	+	+	-
Repairability	+	0	0	0	-	-	0	0	0	+	0	0	0	+	+	0	0	0
Carrying Capacity	-	0	+	+	+	+	+	+	0	0	0	0	0	0	+	-	+	0
Lightweight	+	0	0	-	+	-	-	0	-	0	0	+	+	+	-	+	0	+
Number of Components	+	0	-	-	0	-	0	0	+	+	+	+	+	+	0	0	0	+
Comfortable	-	0	0	0	0	+	-	-	0	+	+	+	+	0	+	-	0	0
Security	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Low Cost	+	0	0	0	+	-	-	0	0	+	-	0	+	+	0	+	0	-
Adjustable Seat Height	-	-	-	+	+	+	+	-	+	-	-	-	+	+	-	0	+	-
Sum +'s	4	0	1	2	4	5	2	1	4	4	2	5	7	5	5	4	4	2
Sum 0's	1	8	6	5	2	0	4	5	4	4	5	3	2	4	2	3	5	3
Sum -'s	6	2	3	3	4	5	4	4	2	2	3	2	1	1	3	3	1	5
Net Score	-2	-2	-2	-1	0	0	-2	-3	2	2	-1	3	6	4	2	1	3	-3
Rank	13	13	13	11	9	9	13	17	5	5	11	3	1	2	5	8	3	17
Continue?	no	no	no	no	no	no	no	no	yes	yes	no	yes	yes	yes	yes	no	yes	no

Appendix C. The third and final tier of concept selection. Narrowed down our seven designs to one concept that we would work with further.

		Concept 9		Concept 10		Concept 12		Concept 13		Concept 14		Concept 15		Concept 17	
Objectives	**Weight (%)**	**Score**	**W.S.**	**Score**	**W.S.**	**Score**	**W.S**	**Score**	**W.S**	**Score**	**W.S**	**Score**	**W.S**	**Score**	**W.S**
Adequate F.S.	10%	3	0.3	3	0.3	3	0.3	5	0.5	5	0.5	4	0.4	4	0.4
Liftetime	10%	3	0.3	3	0.3	3	0.3	4	0.4	4	0.4	3	0.3	4	0.4
Repairability	15%	2	0.3	4	0.6	4	0.6	4	0.6	5	0.75	3	0.45	3	0.45
Carrying Capacity	15%	3	0.45	2	0.3	3	0.45	2	0.3	3	0.45	5	0.75	4	0.6
Lightweight	5%	3	0.15	4	0.2	5	0.25	4	0.2	4	0.2	2	0.1	2	0.1
Number of Components	10%	4	0.4	4	0.4	4	0.4	4	0.4	4	0.4	3	0.3	3	0.3
Comfortable	10%	2	0.2	3	0.3	4	0.4	4	0.4	3	0.3	3	0.3	4	0.4
Security	5%	1	0.05	1	0.05	1	0.05	1	0.05	1	0.05	1	0.05	1	0.05
Low Cost	15%	3	0.45	3	0.45	4	0.6	4	0.6	4	0.6	2	0.3	2	0.3
Adjustable Seat Height	5%	4	0.2	2	0.1	2	0.1	4	0.2	5	0.25	1	0.05	4	0.2
	100%	**2.8**		**3**		**3.45**		**3.65**		**3.9**		**3**		**3.2**	
Rank:		**7**		**5**		**3**		**2**		**1**		**5**		**4**	

Appendix D. Part One: Bill of materials

Bill of Materials (Wheels and Components)			
Item #	Description		Quantity
1	Crank arms 170mm 110 BCD		2
2	Chainring 34T 110BCD		1
3	BB-UN26 Square Taper Cartridge Bottom Bracket 68x113mm		1
4	½”x⅛” single speed chain		2
5	Coaster Brake		1
6	Handlebar Grips		2
7	Headset 1”		1
8	Starnut		1
9	Brake Levers		1
10	Brake Cable		1
11	Brakes w/pads		1
12	Seatpost		1
13	Seat Clamp		1
14	Cruiser saddle		1
15	Adjustable stem		1
16	Stem (for chain tensioner)		1
17	PVC for kickstand		1
18	Wire for kickstand		1
19	WheelMaster ⅜” front wheel		1
20	WheelMaster ⅜” rear wheel		1
21	Schwalbe Black Jack Tire		1
22	Kenda Kross Tire		1
23	Bicycle tube		2

Appendix D. Part Two: Frame and Fork Bill of Materials

Member	ID #	Length (mm)	Size (DO,wall in)
seat tube	82	490	1.25,0.12
top tube	84	625	1,0.065
down tube	85	640	1,0.065
right diag	86	90	0.875,0.049
left diag	87	90	0.875,0.049
tail	88	135	0.875,0.049
right rack	89	990	0.875,0.049
left rack	91	990	0.875,0.049
single chainstay	92	400	1,0.065
cross bar	102	170	1.25,0.12
rear left support	94	440	0.875,0.049
rear right support	95	440	0.875,0.049
right mid support	96	510	0.875,0.049
left mid support	97	510	0.875,0.049
right chainstay	98	350	0.875,0.049
left chainstay	99	350	0.875,0.049
head tube	100	175	1.5,0.188

Member	ID #	Length (mm)	Size (DO,wall in)
Steerer		305	1,0.083
right blade		443	1.25,.095
left blade		443	1.25,.095
right angle		77	1.25,.095
left angle		77	1.25,.095
collar		55	1.25,0.12
Handlebars		720	0.875,0.049
spacer		50	1,0.065