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Designing for Sustainable Bicycle Manufacturing

by

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requirements for the degree of Master of Industrial Design

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Designing for Sustainable Bicycle Manufacturing

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Abstract

Currently, with the increase of people moving from one place to another, either to fulfill their daily activities or for recreation, the need has been created to produce a greater amount of means of transportation that can facilitate this action. Many people choose to use vehicles that do not help with the reduction of environmental pollution; among these, we can mention cars, buses, motorcycles, etc. The use of bicycles is predominant in countries with a developed culture and infrastructure focused on bike riding^[1]. Also, where fuel taxes are higher and people care about pollution in their surroundings.

In this project, a design has been developed that focuses on reducing the resources needed to produce a standard bicycle. Focused on developing a sustainable manufacturing design by utilizing additive manufacturing technologies and generative design, we not only aim to find a way to generate a product that is more efficient and friendlier to the environment, but also expects to open a door to new manufacturing possibilities.

Keywords: Sustainability, Bicycle, Additive, Manufacturing, Generative

Introduction

Each day, the number of vehicles providing private and public transportation for people to go to their different destinations increases. The excessive quantity of these vehicles in recent years has consequently increased the air pollution generated by traffic exhaust gases^[2]. There is another type of vehicle with almost no negative environmental impacts; this means of transport is the bicycle.

Bicycles are one of the most common vehicles of all time and are used for a wide variety of activities. Electric motors have been adapted to bicycles to attract a larger number of people and encourage them to use fewer internal combustion vehicles which considerably reduces the pollution generated by them. Electric bikes, by being smaller than another electric type of vehicles require less amount of energy to be used. But this means that it still uses energy, and even if it is in small quantities, it affects the environment^[3].

The bicycle already is a sustainable means of transport that does not consume any type of fuel or produce any kind of emission other than the carbon dioxide produced by our bodies^[4]. Even though bicycles can be aimed at an audience that cares more about the environment, the processes used to manufacture bikes have remained somewhat traditional, which reveals many inefficiencies when compared to current manufacturing trends. Assuming that bicycles are already better in terms of care for the environment, designers and manufacturers have neglected the need for more efficient manufacturing. Improvements can be made using new production methods that use fewer resources to achieve the same or better results, such as additive manufacturing, the use of renewable materials, and the generative design process^[5].

Bicycles and Sustainable Production Methods

Bicycles have been around for a long time and show no signs of disappearing. Over time, this two-wheeled vehicle has evolved from the rigid, big wheeled, not ergonomic machines to long-lasting, eye-pleasing and comfortable rides we know today - a vehicle fit for almost everyone. Kids, grown-ups, and even elders take advantage of the benefits this product offers. For me, a bicycle is perfect for exercise or going from point A to point B, but other people might use it for racing, off-roading, doing tricks or for simple recreation. Also, made from a wide variety of materials and shapes that are adapted to the needs of each user, this makes them optimal for almost any situation.

Every bicycle is made from numerous components that in conjunction work in the most efficient way yet developed. Among the essential elements of a bicycle, we can mention the body of the product, or what we know as a frame, the fork, chain, wheels, rims, brakes, seat, pedals, etc ^[6]. Many of these components have a form and material determined by the type of function they perform, and in the case of bicycles, few decisions are based solely on aesthetics. But having this in mind, the components that are more susceptible to modifications depending on the established requirements are the frame and fork of the bicycle. And we can't talk about the components that form part of what a bicycle is without taking into consideration all the necessary materials used to build one.

The bicycle frame and fork are produced in different materials and shapes that best meet the requirements that are needed, whether it is durability, lightness, hardness, affordability, the type of terrain to be used on, among other things. There is a great variety of materials that are used for this kind of pieces, some weird ones like cardboard or even bones. But we can normally highlight the four most common and efficient materials: steel, aluminum, titanium, and carbon fiber ^[7].

These materials have specific qualities that make them different from each other, for example, steel is the cheapest material among those mentioned above, the manufacturing process is quite simple, is a relatively hard material, and is easy to repair ^[8]. On the other hand, the problem with steel is that it is susceptible to corrosion and is also quite heavy compared to the others.

Another material we normally find is aluminum, the most common material used in bicycles, which, compared to steel, is much lighter and resistant to rust, also, its manufacturing process is relatively easy. The problem with aluminum is that it is very difficult to repair and the material fatigues over time which leads to a failure in the structure. The next material would be titanium, which is as light as aluminum, as hard as steel, it is durable and resistant to corrosion, the problem is that it is the most expensive material of all due to the specialized machinery that it requires and the conditions in which the material must be maintained. Finally, we have carbon fiber, the only non-ferrous material on the list. Carbon fiber offers characteristics like other materials but at the same time has unique qualities. Like aluminum and titanium, this material is quite light, provides excellent rigidity compared to weight, is resistant to corrosion, while, on the other hand, it does not expand easily with heat, is practically never fatigued and can be molded in a variety of non-regular shapes. The problem with carbon fiber is that it is difficult to produce and repair and is susceptible to fractures ^[9].

In some instances, different materials are used to achieve different types of results, whether aesthetic, functional or cost effective. Some people have used materials such as wood or another which is less orthodox but probably a lot more useful, bamboo. Regardless of the reason for their use, these are materials that have been proven structurally functional for the performance of a bicycle. But as we mentioned, not only materials play an important role when we talk about the sustainability of bicycles, we must also consider the resources used for the production of these. These resources can be things such as water, electricity, the amount of material used, among other things.

A study done to the bicycle company SPECIALIZED®, carried out by students of Duke University, in North Carolina, in which they analyzed the environmental impact of the bicycle industry, shows the different resources used to produce frames and forks of their bicycles. The analysis is based on the Allez (aluminum) and Roubaix (carbon fiber) models, which are the most sold models and the materials most requested by users ^[9].

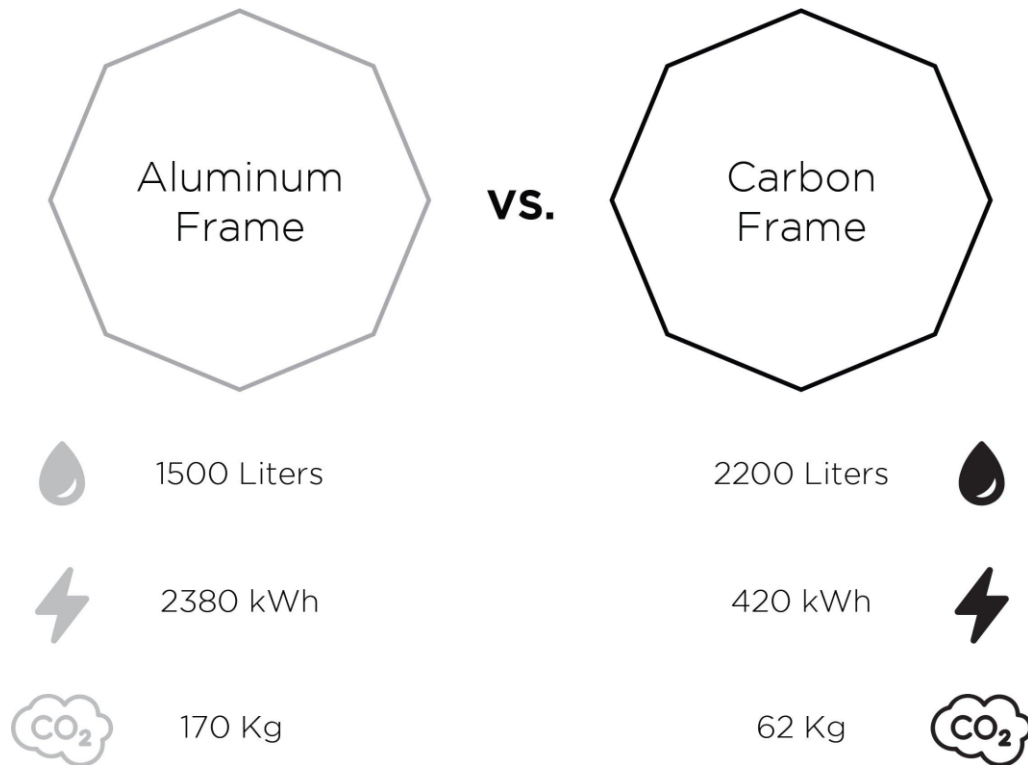


Figure (1) Data recollection took from Duke University students report. Shows the resources used and emission created in the manufacturing of the Specialized® bike frames.

The company uses approximately 2200 liters of fresh water to make a kilogram of carbon fiber frame while it takes about 1500 liters to produce one kg of the aluminum frame. However, the aluminum frame consumes much more electrical power than any of the other pieces, approximately 2,380 kilowatt-hours per kg of aluminum. Finally, the CO₂ generated when producing the different parts. Producing 1 kg of carbon fiber for a Roubaix frame makes 60 times more that amount in CO₂, but an Allez frame triples the figure, reaching about 170 kilograms of carbon dioxide. The high energy consumption and CO₂ generation in Allez models are because aluminum must be cut and welded, and the machinery used for this requires a high use of electrical energy^[10].

According to this research, we must observe that two essential things are needed to design a more sustainable bicycle frame: a material that requires fewer resources to be worked, and a process that uses less energy and generates less CO₂. Integrating these two requirements is not an easy task, how can we design components that take in consideration these important aspects?

Emerging technologies might have the answer to this question and part of the solution of what we are trying to accomplish. It is in this kind of situation, where we need an innovative manufacturing method, where the technology known as additive manufacturing might become convenient. Before proceeding, we need to answer some questions: What is additive manufacturing? And how can it help to design a more sustainable bike?

Additive Manufacturing and its Utility

Additive manufacturing, better known as 3D printing, is one of the greatest advances in manufacturing technology of the 21st century. It is defined as the process in which materials are joined to form a three-dimensional part or component, usually layer by layer ^[11]. This process, except for assemblies or mechanisms, does not necessarily need to be worked on so that the piece can function adequately since the impressions can be created on one step no matter the complexity of them. This allows for the creation of very intrinsical shapes and geometries that are simply marvelous.

Diverse types of technologies used for 3D printing have allowed many companies to implement parts manufactured in this way to be part of the current market. Starting with materials like ABS or PLA, which are the most common polymers used as raw material for 3D print. These plastics are very cheap and allow printers to work fast as they have relatively low melting points, but every good thing comes with a price. PLA and ABS aren't recognized either by their surface finish or their durability and strength. Other printing technologies have been becoming more and more famous, such as SLA (Stereolithography) which uses photopolymer resins and UV light to solidify layers and create a more accurate piece. Sadly, even if can be stronger than PLA or ABS, they are susceptible to fatigue and applied forces and probably won't withstand the conditions a standard bike would have to go through. On the other hand, photopolymer resins are not recyclable, which doesn't go with our sustainable scope ^[12].

Printers that are capable of printing with metal increase the utility of this type of manufacturing since they allow the production of a greater number of pieces or products on diverse areas such as transportation, aeronautics, technology, etc.



Figure (2) Image taken from 3Dprint.com. Markforged Metal X 3D printer.

With 3D printing, many of the components needed to build a bicycle could be produced with a single step, even making the print of a complete frame is a possibility. However, this would only ensure the reduction of manufacturing steps. Any frame created would be just one click away from turning a 3D computer model to a physical piece. The use of energy and material is something that still needs to be checked. We must also take into consideration, 3D printers that can manufacture components as big as a bicycle frame, have a high acquisition cost.

So how can we use 3D printing to improve the bicycle manufacturing process? The ability of 3D printers to generate shapes that cannot be carried out with traditional methods allows the formation of more complex structures that can eliminate the unnecessary use of material and increase structural efficiency ^[13]. On the other hand, when a piece is produced with a single action like it's done with additive manufacturing, processes like the welding used to join the metal parts or the application of resin to make pieces in carbon fiber can be eliminated.

Additive manufacturing can be combined with another technology which uses artificial intelligence to create a countless number of variants that meet predetermined parameters, a process known as generative design.

Generative Design Role

Generative design programs use the parameters established by the designer and engineers to propose various solutions that can solve any given structural problem in the most efficient way that is possible for the software. Using material or reinforcement on the areas that are needed the most helps to minimize material waste and at the same time creating structures that the human brain is not capable of thinking. In most cases, the structures generated by these programs are extraordinarily complex and hard to make or may not be possible to manufacture using traditional methods, but utilizing 3D printing, this can be possible [14].

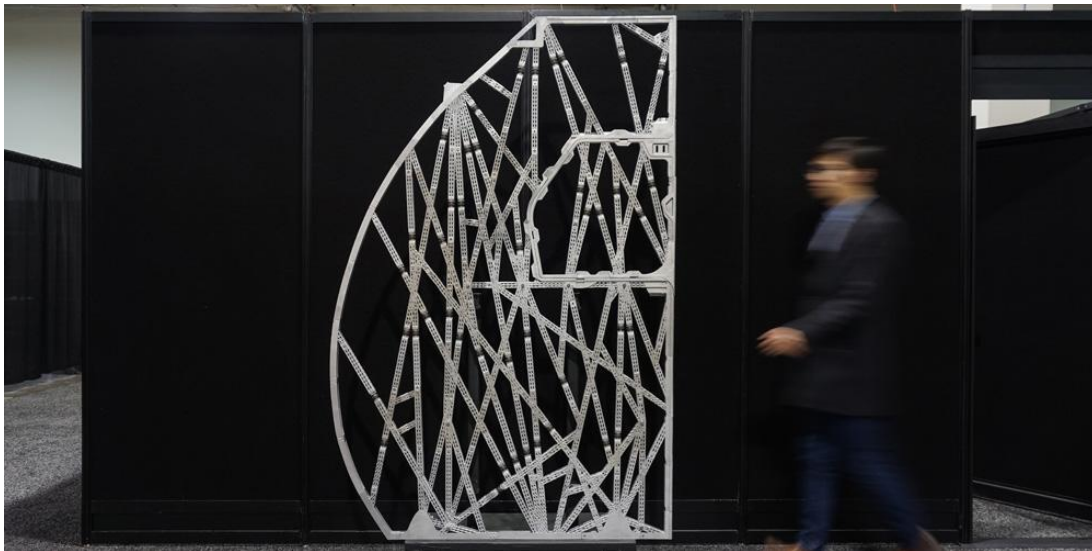


Figure (3) Image taken from www.aec.at. Largest 3D printed aircraft component made of metal utilizing generative design for its creation.

Using generative design to come up with a new concept for bike frames that use less material and have the same or better strength as any other structures are one of the possibilities that needed to be explored, either addressing the whole frame or just the joints of it.

Autodesk® offers different products that allow the user to implement the generative design into their concepts. These include Dreamcatcher, Within and Netfabb, which use different types of logistics to come up with procedurally generated structures but all trying to accomplish the same result: improve shape. One program that has been on the market for a longer time is Grasshopper for Rhinoceros which works with visual algorithms generating an

extensive number of iterations. This certainly one of the most used, if not the most well-known software that offers this type of tools.

Also, Fusion 360 with its shape optimization tool can take the user close to the desired results, and this can be used as a testing tool to later implement more in-depth ones.

Design Concept

After researching about the bicycle manufacturability, sustainable materials, top-notch building processes and testing different shape iterations and product architectures. A final concept came to life.

The final design concept combines the aforementioned technologies to achieve a product that meets the quality of being produced with sustainable materials and more energy efficient processes than those currently implemented in the market.



Figure (4) Frame model, shows proportions and number of components.



Figure (5) Bike render, shows the desired materials and interaction with other components.

The design of this bicycle frame focuses on reducing the amount of energy used to produce frames of aluminum or other metals, a high consumption that can usually be attributed to the soldering done to assemble the parts. With the implementation of 3D printing to produce connections that eliminate the use of welding we can generate a unified piece that will connect with the rest of the structure. These connections must be built or printed on a 3D printer capable of working with aluminum or titanium. These materials, unlike the most common plastics in additive manufacturing, provide greater strength and resistance that ensures that the frame can withstand the different forces applied; such as weight, impact, and fatigue.

Each joint or connection is designed for a specific bicycle size that can be customized for any type of user. With the user's measurements, changes can be made in the dimensions of the frame and print an appropriate size for the person.

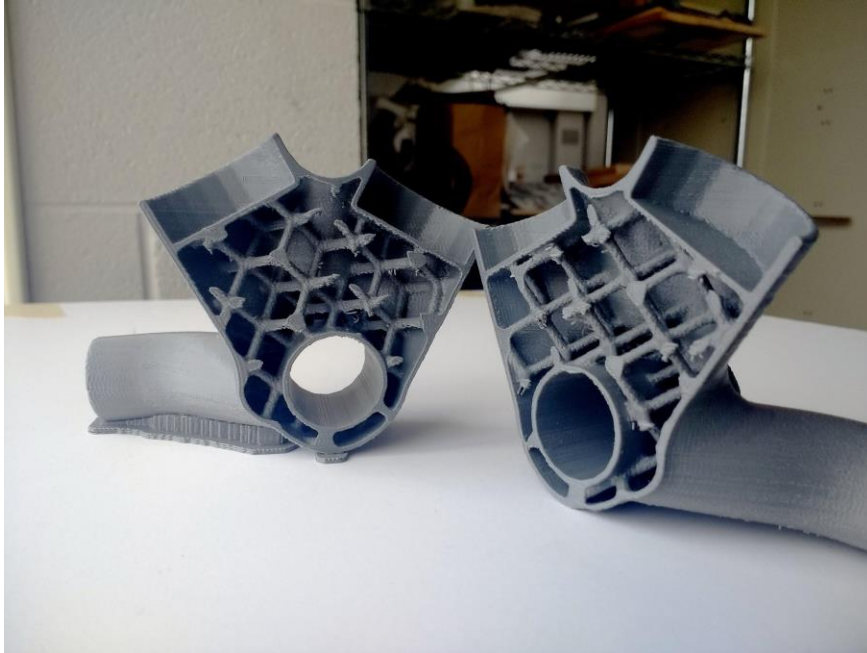


Figure (6) Section view of one of the connections showing internal lattice structure that supports the piece.

Each of these pieces is designed to use the least volume of material, for which it was necessary to use programs that would oversee the reduction of the internal density and reinforcing the structures.

Because the largest part of generative design programs does not offer student versions and have a high acquisition price, it was necessary to resort to another option. Using the Meshmixer program, a lattice structure was generated which strengthens the internal part of each piece while requiring less material. The infill structures of the 3D printers were discarded since they are not designed to increase the strength of the piece but to support the internal walls so that the impression does not collapse.

Taking as reference one of the most common 3D metal printers on the market today, the Markforged Metal X, the machine uses 2400 Watts of energy to run the printing process. According to the production tests carried out with FDM printers, the total printing time of the 5 pieces of the printing makes a total of 56 hours. These values would give us a total of 135 W

that approximately 20 times less than welding an aluminum frame, therefore, we can also assume a reduction in the production of CO₂. This of course if the pieces are printed one by one. Arranging them so all the pieces can be printed simultaneously, would divide the production time exactly by 5, making it a total 10 hours of production time approximately. The more we can fit in a printing bed, the more pieces per print we could generate. Another benefit is that printers that work by laser sintering, spend the same amount of time per layer regardless of the size of the print ^[15].

Each connection is linked to the other using bamboo. Why bamboo? Bamboo is an organic material with great resistance to fractures, bending, and weight. These characteristics have led bamboo to be considered a great material when in the need of sustainable components. Another positive factor is that this plant has a harvest time of fewer than 5 years, some bamboos reaching 4 feet in height in just 24 hours. Bicycles made with this material already exist in the market, but they use welded metal connections or are covered with resin to make "organic" connections, which defeats the purpose of being friendly to the environment ^[16].

Market

Since the design does not focus on the optimization of weight, aerodynamics or performance, we must rule out its competitive or enthusiastic use since these markets do not focus on obtaining a bicycle that is sustainable but one that offers the best performance in extreme conditions. On the other hand, the fact that this is one of the first iterations of the product, a product such as mountain bikes are also ruled out since the complexity and factors that must be considered exceed the scope of this project.

By focusing on the design of the frame on a road bike style, we can concentrate on a more general public that uses bicycles whether for recreation, exercise or commute. Like this, we can maintain a simple architecture where the materials are the ones that play the most important role, both structural and aesthetic.

The primary users of this design are people who care about the environment and want to have a means of transport that really offers a sustainable option, people who choose to move from one place to another through a transport that does not generate emissions that pollute the

environment. This includes the way the product gets manufactured and how the production process affects our surroundings.

Lastly, the modular structure of the design allows the user to replace any part that gets damaged with minimum effort. Printing the joints or cutting down the piece of bamboo needed for the structure can be handled by any enthusiast or mid-level craftsman. This allows the user to get the most out of the product.

Conclusion

Emerging technologies can affect our understanding of products we are used to interacting with every day in ways that go beyond our imagination. As time passes, how can these processes and technologies improve the things that we think are already at their “best”?

Developing a bicycle frame that brings two different scopes, such as manufacturability and sustainability, and fuses them to generate a new kind of product that expresses the best of both worlds. With this design, we can see that it is possible to redefine a product we don't think could be modified. Something with simple functionality, such as a bicycle, can be assumed to be at its full potential.

Is it possible to approach other products in a similar way? What new possibilities will this approach create? Everything will depend on how much designers are willing to create products that focus more on the environmental aspect and how they will bend technologies to work in this way.

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