

14th Global Conference on Sustainable Manufacturing, GCSM 3-5 October 2016, Stellenbosch, South Africa

## Evaluation of resource efficient process chains for secondary manufacturing processes of bamboo bicycles

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### Abstract

In order for manufacturing suppliers to stay competitive in the global market, innovative and resource efficient process chains need to be a part of the manufacturing strategy. Secondary manufacturing process steps entail the assembly and surface treatment manufacturing steps after the primary cutting and shaping of the components. Bicycles have an enormous effect on society, both in terms of socio-economics and of advancing modern industrial processes. In order to manufacture bamboo bicycle frames in South Africa innovative designs and process chains need to be developed. In this study process chains for secondary manufacturing processes of bamboo bicycles were developed and compared. The manual secondary process steps for manufacturing bamboo bicycles in Africa were mapped and compared with developed technological process chains in terms of resource efficiency. The effect on time and cost were evaluated.

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Peer-review under responsibility of the organizing committee of the 14th Global Conference on Sustainable Manufacturing

*Keywords:* Bamboo bicycle frame, Resource efficiency, Process chains, Secondary manufacturing processes

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### 1. Introduction

Designing and manufacturing a new or improved product in modern times has become more and more complicated as technology improves. With the improvement of technology, manufacturing has changed its emphasis from product volume and variety, and these paradigm changes can be seen in Figure 1(a). As more processes become available, choosing the best ones is the most important part. Social manufacturing includes the shared creation, distribution trade, production and consumption of goods, resources and services by different people and

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organisations [1,2,3,4]. This new manufacturing paradigm is already implemented successfully by various businesses.

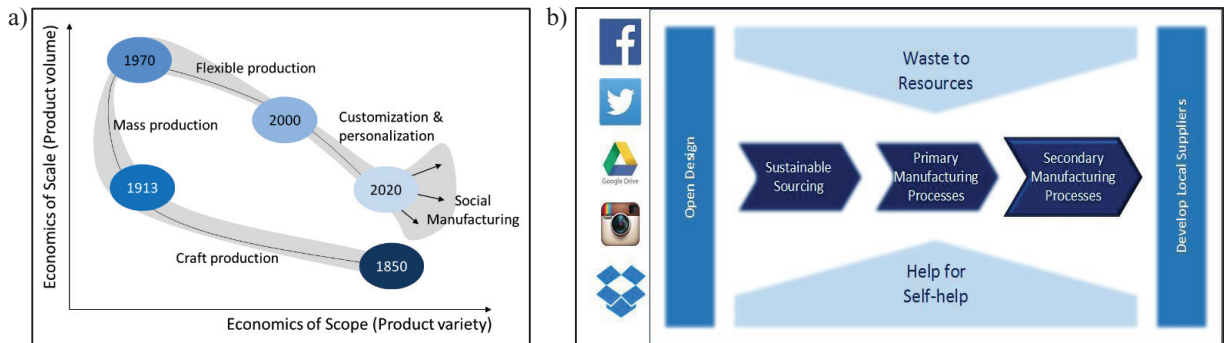


Figure 1: a) Manufacturing paradigm changes and b) the bamboo bicycle project sketch.

When designing a new product one must focus on the standardisation of supply, primary manufacturing processes and secondary manufacturing processes as seen in Figure 1(b). This must be done while also trying to incorporate sustainability by turning waste into a resource. The relationships between these factors are an important part of the manufacturing sketch. The main focus of this paper is on the secondary manufacturing processes.

Manufacturing is defined as an activity that is used to change the form of raw materials in order to create products [5] and is continuously changing due to the improvement of available technologies. While some industries use new and advanced methods, others maintain a highly skilled traditional craftsmanship [6]. Each manufacturing process is generally characterized by some advantages and limitation over the other processes. Primary manufacturing processes involve the initial conversion of the raw materials into the semi-final product stage. The output of primary manufacturing processes is then subjected to secondary manufacturing processes to obtain the final or finished product geometry. Secondary manufacturing processes involve assembly, surface treatment and finishing.

Bicycles have an enormous effect on society, both in terms of socio-economics and of advancing modern industrial processes. Bamboo bicycles are more sustainable and a less expensive alternative when compared to typical steel, aluminium and carbon fibre bicycles [7]. In order to manufacture bamboo bicycle frames in South Africa innovative designs and process chains need to be developed. A group of final year students from Stellenbosch University's Industrial Engineering Department participated in a tutorial in the Manufacturing Systems 414 module. Using social media as an online community, the students were tasked with open designing a bicycle frame made out of bamboo and marketing their designs on the specified social media platforms [8]. This tutorial provided the Bamboo Bikes for Africa (BBfA) research group with a large pool of designs from which the first prototype could be manufactured.

Therefore, the research objectives are to:

- Understand the secondary processes involved in manufacturing a bamboo bicycle frame through benchmarking
- Manufacture a Bamboo Bicycle prototype
- Compare the current process chain to existing approaches with regards to manufacturing time and cost.

## 2. Manufacturing bamboo bicycles

The popularity of bamboo bicycles have increased over the past few years. In order to expand the market even more in developing countries, it has become important to find the best way of mass producing bamboo bikes while keeping costs to a minimum [7]. Existing methods for building bamboo bike frames have a long manufacturing time and is expensive. The literature will focus on benchmarking existing approaches on building bamboo bike frames. A bamboo bike frame is illustrated in Figure 2(a) and the developed Bamboo Bicycle as prototype in Figure 2(b).

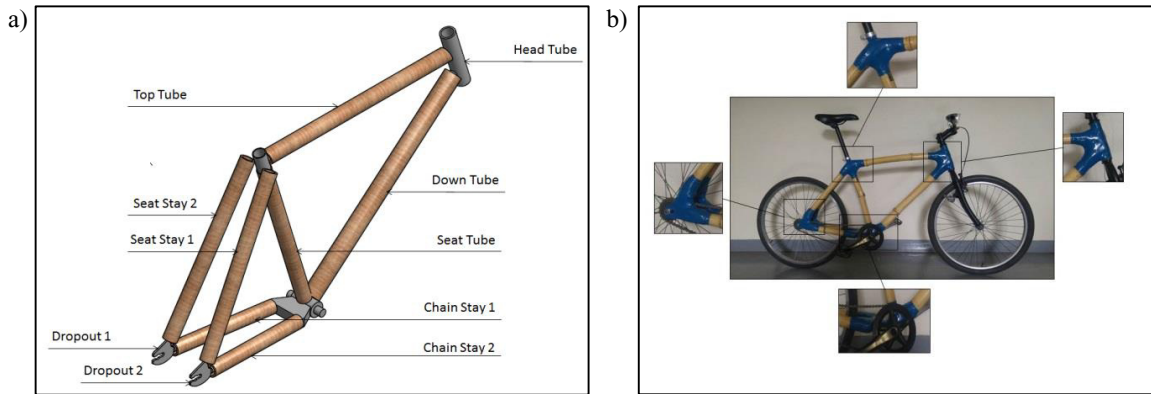


Figure 2: (a) Typical bamboo bicycle frame showing the parts and (b) the developed Bamboo Bicycle as prototype.

Following are benchmark processes from the Bamboo Bicycle Club and HERObike.

### 2.1 Bamboo bicycle club

The Bamboo Bicycle Club London strives to help people who have a passion for cycling to be able to build and ride bamboo bicycles by using their workshops [10]. They provide people with all the necessary parts and tools, as seen in Figure 3(a), to be creative and build their own bamboo bicycle from scratch.

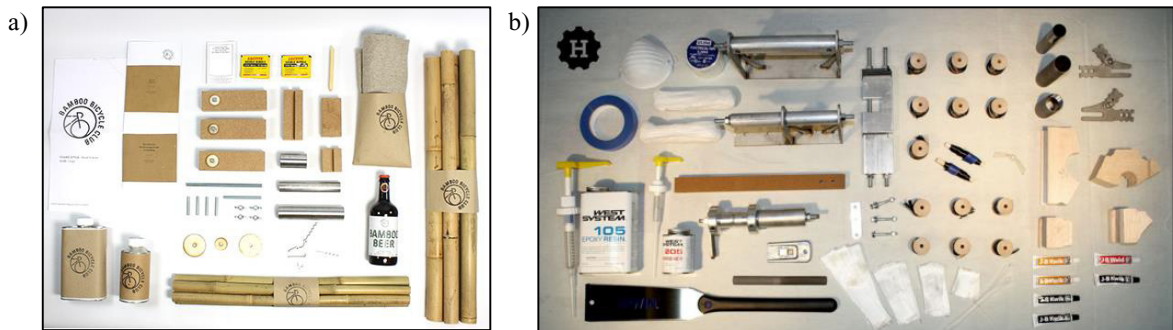


Figure 3: Bamboo bike kit provided by (a) the Bamboo Bicycle Club and (b) HERObike

All their bamboo is sourced from an importer in the UK. They generally use Mos or Tonkin which are two of the most common bamboo species for building bamboo bikes. Both of these species have good environmental performance and excellent strength properties. Bamboo is hand selected and treated at the source. They recommend that the bamboo be coated with a protective layer to prevent movement of moisture and seal the frame against the elements.

The Bamboo Bicycle Club uses a BioFibre for the binding material. This material provides a high level of performance and is easier to process than materials that are glass-reinforced. These materials make use of twistless technology in order to provide a combination of performance, processability and sustainability. BioFibre offers improved environmental impact, reduced weight, vibration damping and safer handling when comparing it to man made fibers. Application is easy enough for beginners while still very effective. The properties of BioFibre are displayed in Table 1 below.

Table 1: Properties of BioFiber

Property	BioFiber
Fiber volume fraction	60%
Density	1.38 g/cm <sup>3</sup>
Tensile Strength	78 MPa
Tensile modulus	9.3 GPa
Flexural strength	195 MPa
Flexural modulus	7 GPa

They also use a glue to hold the frame together. This is a plant based bio resin with a 50% reduction in carbon emissions when comparing it to regular products. The resin shows excellent performance in both compression and tension. They make use of a fast curing resin that allows for roughly 30 minutes of handling time at room temperature. It has a good UV stability and is excellent in all environments.

## 2.2 HERObike

HERO works as a catalyst for community development in the Alabama Black Belt to end rural poverty. HERObike began in 2009 in partnership with HERO, lead by a young designer John Bielenberg. HERObike has grown over the past years with the help of the Bamboo Bike Studio into a widely known manufacturer of bamboo bike kits [11].

HERObike sells a bike kit as seen in figure 3(b), which anyone can use to build their own bamboo bicycle by using a simple set of tools. This process involves 11 steps that can be followed in order to complete the frame of the bamboo bike. The steps involving secondary manufacturing processes are as follow [11]:

Step 1 is to fiberglass the lugs and carbon-wrap the dropouts and involves eight sub-steps, which takes about 1 hour of labour to complete. The goal is to strengthen the lugs and wrap the dropouts. Materials required include fiberglass packets, a mini pump, epoxy resin, epoxy hardener, plastic cups, gloves, safety sleeves, carbon spools, compression tape, a push razor and scissors.

Fiberglass is used to make a basecoat for the lugs. This material is selected because fiberglass can form around the joints in any shape required, which is necessary for the angles and places that are difficult to reach. Fiberglass has a 30-minute handling time after the hardener is added to the epoxy.

The last parts of this step are to carbon-wrap and compress the dropouts. It is important to always remember the four laws of wrapping:

- i) Always completely wet the carbon fiber in epoxy
- ii) Always lay the carbon wide and flat; avoid it twisting
- iii) Always wrap the carbon fiber tight; wrapping it loosely will make your bike weak
- iv) Cross the carbon over itself; do not simply spiral it around the bamboo

Step 2 is to prepare the lugs for wrapping and involves three sub-steps, which takes about 1 hour to complete. The goal is to remove the compression tape and rough the lugs in final preparation for wrapping. Materials used during this step include a rounded file, razor, sandpaper, dust mask, safety goggles and gloves. The aim is to remove all smooth fiberglass surfaces, so that the carbon fiber adheres to the fiberglass. The process is repeated for all the lugs.

Step 3 is to carbon-wrap the lugs and involves eight sub-steps, which takes about 1 hour of labour to complete. The goal is to carbon-wrap and compress the main lugs. Materials used during this step include gloves, scissors, a mini pump, carbon fiber spools, epoxy resin, epoxy hardener, carbon fiber patches, safety sleeves, plastic container,

mixing stick and compression tape.

Once you start wrapping a lug, it is important to make sure you finish wrapping the lug and compress it before taking a break. The dried resin should be as smooth as possible. There should be no sharp pieces of resin that will act as stress concentrators in the lug. The fingers are used to smooth out any lumps in the lug. It is advised to use more carbon spools for heavier people. Make use of your hands to compress the lug and squeeze out any extra resin.

Step 4 is to finish the lugs and involves two sub-steps, which takes more than 4 hours to complete. The goal is to smooth the lugs and clean up the transitions from carbon to bamboo. This step also completes the building of the bike frame. Materials used during this step include safety goggles, mask, safety sleeves, file, sandpaper, gloves, epoxy resin, epoxy hardener, a mini pump, plastic container, mixing stick, razor, scissors, damp paper towel, two adjustable wrenches and Tung oil. For this step the bike is removed from the jig. The aim is to remove all bumps, bulges and divots in order to remove all stress concentrators. One must be careful not to remove too much carbon. The paper towel is dipped in Tung oil and rubbed into the bamboo to keep the bike weather resistant and make it shine.

### 3. Research methodology

Firstly a bamboo bicycle had to be designed, as there were no previous projects at the University of Stellenbosch involving a bamboo bicycle. The bicycle was built by using the processes and materials available at the University. The secondary manufacturing processes were compared to benchmarks in order to determine whether there are better options. The process and steps followed can be observed in Figure 4 below.

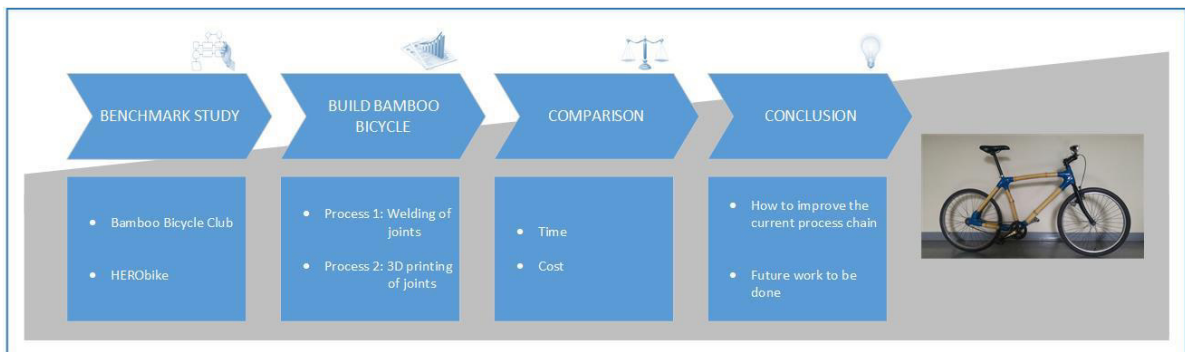


Figure 4: Research Process Steps to Evaluate resource efficient process chains for secondary manufacturing processes of bamboo bicycles.

## 4. Experimental results and discussions

### 4.1 Benchmark study

Two different organisations, Bamboo Bicycle Club and HERObike, were investigated and their secondary manufacturing process steps for building a bamboo bicycle frame documented. These process chains are illustrated in Figure 5(a) and 5(b) respectively. This serves as valuable information to compare to the process steps that were followed during this project.

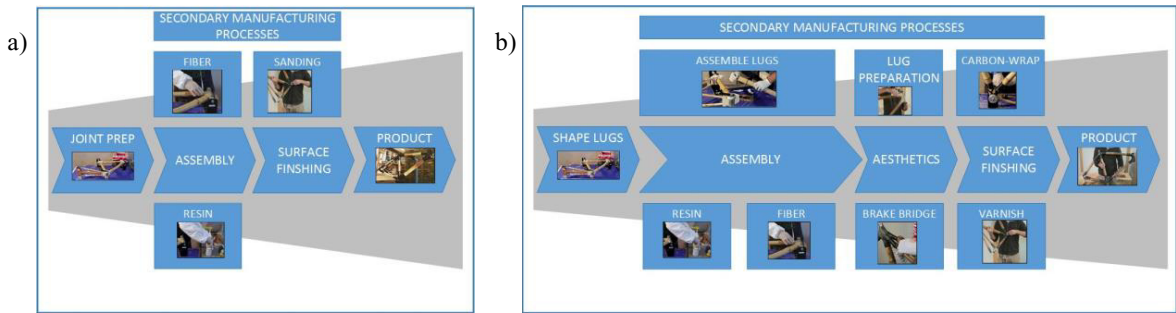


Figure 5: Secondary manufacturing process chain for developing a bamboo bicycle frame of (a) the Bamboo Bicycle Club and (b) HERObike

#### 4.2 Manufacture bamboo bicycle

An actual bamboo bicycle was built in order to understand the challenges and constraints associated with such a project. The processes used were determined by the availability of machinery and tools. This limits the options and therefore may contribute to the fact that the bicycle might not be of the best quality and/or standard. These processes were modelled in a process chain similar to those illustrated in the benchmarks that were researched earlier and illustrated in figure 6(a).

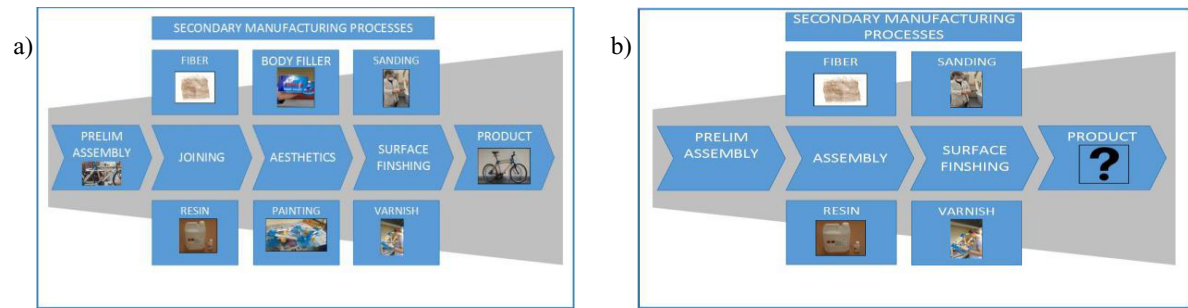


Figure 6: (a) Process chain 1 used to manufacture a bamboo bicycle frame and a (b) proposed process chain 2

A proposed process chain 2, as illustrated in Figure 6(b), was developed in order to use in the comparison for the next step. This process will make use of 3D printing to manufacture the joints. The secondary manufacturing process steps are similar to process chain 1, which make it possible to determine the time and cost associated with each step. The manufactured joints will result in a reduction of the number of steps required in the process chain and therefore this could be an improvement from process chain 1.

#### 4.3 Comparison

The time and cost of each process was documented in order to compare our approaches to the benchmark approaches of the Bamboo Bicycle Club (BBC) and HERObike. The material used, time and cost for each step of each secondary manufacturing process chain can be seen in Table 2 below.

Table 2: All the secondary manufacturing process steps including the material, time and cost for developed process chains and benchmarks

Process Steps	Process chain 1	Process chain 2	BBC	HERObike
Assemble lugs	NA	NA	NA	Balsa wood 30 min R120

Process Steps	Process chain 1	Process chain 2	BBC	HERObike
Apply resin	Laminating resin	Laminating resin	Bio resin	Resin/epoxy
	104 min	104 min	120 min	60 min
	R114	R114	R120	R90
Lug preparation	NA	NA	NA	Sandpaper
				60 min
				R100
Carbon-wrap	NA	NA	NA	Carbon fiber
				60 min
				R210
Filler	Luxor ultra light	NA	NA	NA
	60 min			
	R106			
Sanding	Air tool	Air tool	Sanding aid	NA
	360 min	60 min	300 min	
	R105	R60	R30	
Install brake bridge	NA	NA	NA	Brake bridge
				60 min
				R50
Painting	DayGlow spray	NA	NA	NA
	25 min			
	R50			
Varnish	Exterior wood	Exterior wood	NA	Tung oil
	45 min	45 min		240 min
	R101	R101		R400
Total steps	6	4	3	7

From Table 2 it is clear that the process from HERObike involves the most steps, as it has seven steps in total. Bamboo Bicycle Club only makes use of three steps and could be the reason for their low manufacturing time. In order to compare the manufacturing time of the bamboo bicycle frame, the total time for each of the four approaches are displayed in Figure 7(a).

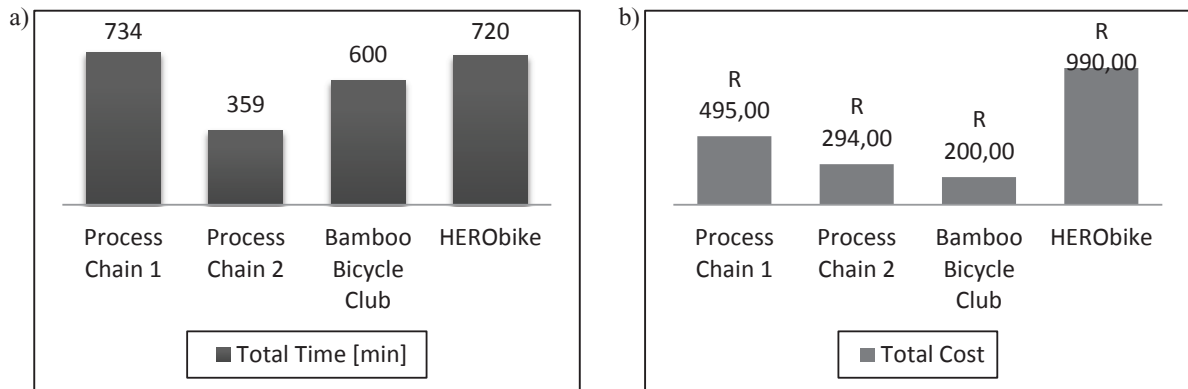


Figure 7: (a) The total time for the four approaches in minutes; (b) The total cost for the four approaches in Rands

From the comparison in Figure 7(a), it can be observed that the proposed Process chain 2 has the fastest manufacturing time. Process chain 1 has the slowest manufacturing time.

In order to compare the cost of building a bamboo bicycle frame the total costs for each of the four approaches are displayed in Figure 7(b). From Figure 7(b) we observe that the Bamboo Bicycle Club has the lowest cost, while HERObike has the highest cost for building a bamboo bicycle frame.

## 5 Conclusion

In this study the resource efficiency of different secondary manufacturing process chains for manufacturing a bamboo bicycle were evaluated by comparing the manufacturing time and cost. The process chains evaluated include two benchmark approaches from the Bamboo Bicycle Club and HERObike, a process chain used to manufacture a bamboo bicycle at the University of Stellenbosch and a proposed process chain for a future prototype.

From the experimental results, it is clear that the Bamboo Bicycle Club has the best existing approach for building a bamboo bicycle as they have the second fastest manufacturing time, as well as the lowest cost. It was expected that process chain 1 would not be the best approach, because of the fact that this was the first prototype. Although process chain 2 is just a proposed approach, the time and cost improves due to the lessons learnt from process chain 1. When executing process chain 2, the fiberglass step will be performed by professionals, which will deem the filler step unnecessary and reduce the sanding time. This results in a faster manufacturing time and a reduction of costs for manufacturing the bamboo bicycle frame.

It has to be noted that this study is only done on the secondary manufacturing processes and that the primary manufacturing processes could tell a very different story. By combining the results from these two process chains, the results may differ. Bamboo bicycles have endless possibilities and are by far more environmentally friendly than current materials. Therefore there exists a lot of future work that are still to be done in order to improve the secondary manufacturing process chain for manufacturing bamboo bicycles.

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