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## Sustainably Manufacturing a Bamboo Bicycle in a Container Factory

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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. Container factories could be the answer to reduce costs and increase resource efficiency. In this study, the feasibility of manufacturing bamboo bicycle in shipping containers is investigated. These results are then used to evaluate the sustainability of manufacturing bamboo bicycles in container factories.

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### 1. Introduction

Transportation issues in the rural parts of Sub-Saharan Africa has been a pressing matter over the years, yet the high poverty rate and declining road conditions impose a challenging environment to address these issues. The livelihood of an individual is directly affected by his/her ability to access their jobs and indirectly in terms of access to healthcare, education and social networks where future job opportunities may emerge [1]. Economic growth is a

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necessary condition for the alleviation of poverty in South Africa, but it should be reinforced with the development of the skills of the population in order to sustain the growth and reduce poverty and inequality. Human development and economic growth are thus linked and are mutually reinforcing [2]. This provides a challenge to find a way to address the transportation issues, while at the same time reducing unemployment and poverty through human development. Manufacturing and selling bicycle frames made mainly from bamboo could be a sustainable method to provide rural Africans with a method of transportation, while facilitating skills development and job creation.

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, aluminum and carbon fibre bicycles [3]. 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 bicycles while keeping costs to a minimum [3]. Bamboo is the most versatile and fastest growing plant on the earth. It has played an integral part in millions of lives for the past millennia. In the last few decades it is being exploited with renewed interest to serve as a substitute for timber [4].

There is a paradigm shift occurring in the past years with regard to manufacturing. Manufacturing needs to be more flexible, resource efficient and cost effective. One solution to fulfill these needs could be mini-modular container factories. Container factories is a new way of providing manufacturing solutions close to the market, while proving to be more flexible and inexpensive. Considerations for these factories include the required energy and water to perform the manufacturing steps, as well as the waste produced by the factory [5].

The CassaMobile project is one of the few projects that make use of shipping containers to create a factory on the go. The main goal of the CassaMobile project is to develop a new kind of local, flexible and environmentally friendly production system for highly customized parts based on a combination of different manufacturing processes like 3D printing, CNC-milling and 3D assembly technologies inside an enclosed unit such as a container [6]. This project is just one example showing the possibility of manufacturing a bamboo bicycle in a container factory.

Therefore the research objectives are to:

- Understand shipping containers and container capabilities
- Manufacture a bamboo bicycle
- Evaluate the sustainability of manufacturing bamboo bicycles in container factories

## 2. Shipping Containers

A shipping container is a container with strength suitable to withstand shipment, storage and handling. Freight containers are a reusable transport and storage unit for moving products and raw materials between locations or countries. In addition, for the design use of shipping, the possible applications for shipping containers are almost limitless [7]. Two local South African container companies, Container World and Topshell, are investigated to gain an understanding about these applications and the dimensions which need to be considered for the factory design.

As the market leader in the African container industry, Container World has pioneered the development of the container industry in Africa and continues to maintain their position as the market leader [8]. Their primary activities include the sales, conversions and transport of new and pre-owned marine shipping containers.

Container World has the capability to convert containers into any type of converted unit as requested by its customers. They have provided the sub-Saharan market with specialized container conversions since 1983. Converted containers throughout the world have shown great versatility in solving space requirements. According to Container World [8] these include, but are not limited to:

- Clinics
- Banks
- Mobile Workshops

- Field Kiosks
- Dining and Canteens
- Laundry Units
- Butcheries
- Spaza Shops
- Water and Sewage Treatment Plants

Topshell provides quality products and innovative craftsmanship with regards to shipping containers [9]. They are able to create tailor-made products, which is necessary when designing a container factory. A typical six meter Topshell container is illustrated in Figure 1 below, which includes the dimensions that needs to be considered when designing a container factory.

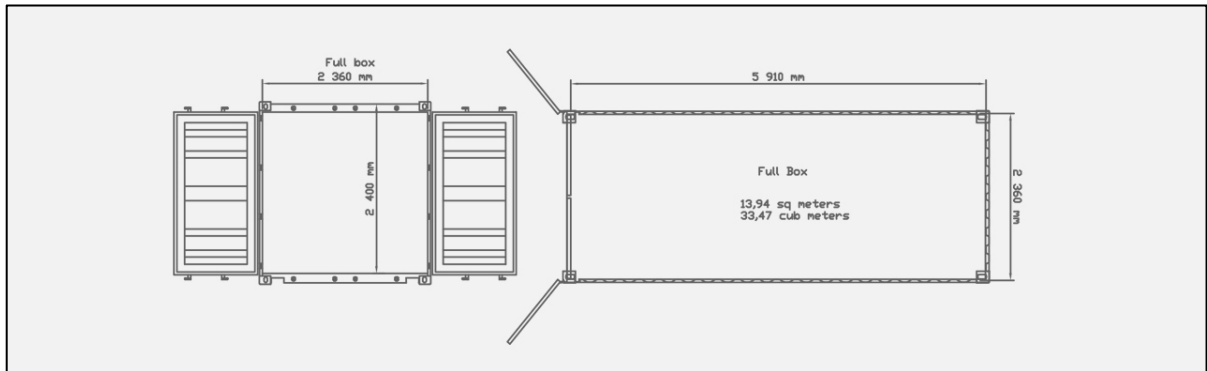


Figure 1: A Topshell container with dimensions.

The manufacturing process steps for a bamboo bicycle need to be performed within the capacity of the container for this to be a sustainable solution. The manufactured bamboo bicycle will be investigated in the next section of this paper.

### 3. Manufacturing a bamboo bicycle

A bamboo bicycle was manufactured at the University of Stellenbosch by a team of postgraduate students at the Department of Industrial Engineering by using social manufacturing [10, 11, 12]. A typical bamboo bicycle frame is illustrated in Figure 2(a) and the manufactured bamboo bicycle is illustrated in Figure 2(b).

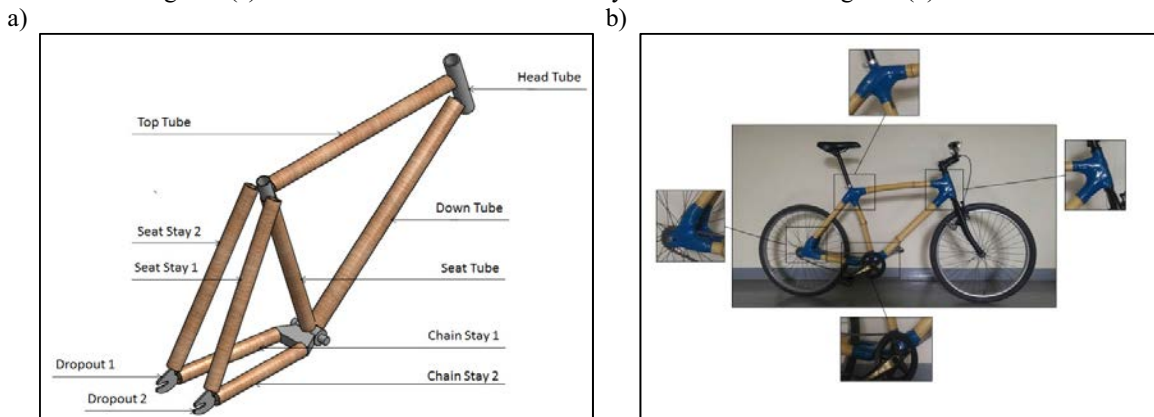


Figure 2: (a) Typical bamboo bicycle frame and (b) the manufactured Bamboo Bicycle.

Only the secondary manufacturing process steps will be performed in the container factory. The primary manufacturing process steps will be performed somewhere else and the parts of the bamboo bicycle delivered as a bamboo bicycle kit to the factory. The Bamboo Bicycle Club and HeroBike are both companies who manufacture bamboo bicycle kits to be sold [13, 14]. However, a locally manufactured kit is less expensive and more resource efficient [15]. The secondary manufacturing process chain steps are illustrated in Figure 3. The container factory must be designed to accommodate these process steps in order to sustainably manufacture the bamboo bicycles.

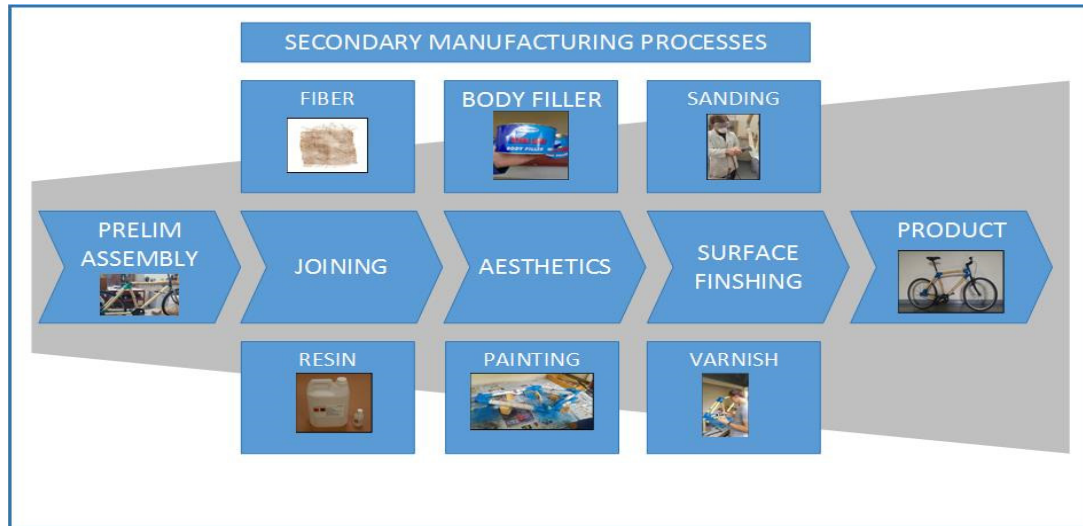


Figure 3: Secondary manufacturing processes of the bamboo bicycle.

As seen in Figure 3, the secondary manufacturing process chain involves three main phases namely joining, aesthetics and surface finishing. Each phase includes two sub-steps.

#### 4. Experimental results and discussion

The secondary manufacturing process chain steps as illustrated in Figure 3 were documented during the actual manufacturing of the bamboo bicycle frame. This data is displayed in Table 1 below and provides the process chain, sub steps, including the time, cost, required energy, water usage and waste of each of these steps.

Table 1: Process chain with the time, cost, required energy, water usage and waste of its sub steps.

Process Chain	Sub Steps	Time [min]	Cost [ZAR]	Energy [kW/h]	Water [Litres]	Waste (%)
<b>1. Joining</b>	Fiber	40	R50	0	0	5
	Resin	64	R83	0	2	20
<b>2. Aesthetics</b>	Body Filler	60	R106	0	1	25
	Painting	25	R50	0	0	15
<b>3. Surface Finishing</b>	Sanding	360	R105	0.55	0	10
	Varnish	45	R101	0	1	0
<b>Total</b>	<b>6</b>	<b>734</b>	<b>R495</b>	<b>0.55</b>	<b>4</b>	<b>12.5*</b>

\*Total waste with regard to the entire process chain

As stated previously, the energy required to power the container factory is one of the most important aspects to design for. Two 100W Bulbs will be sufficient to provide enough light for the necessary manufacturing steps. As seen in Table 1 the process steps require 0.55 kW/h. This increases the total energy required by the container factory to 0.75 kW/h. To keep this container factory sustainable, a 1kW/h solar panel system will be installed on the roof of the container in order to produce the necessary electricity required by the lighting system and the sanding process. Due to the low volume of water required, this falls within the first stage of water usage and is free of charge. The cost model for the bamboo bicycle container factory is illustrated in Table 2. This includes the once-off costs to setup the container factory, as well as the manufacturing cost per bicycle.

Table 2 Cost Model for a Bamboo Bicycle Container Factory.

Once-off Costs	Container(12m) + Conversion	R 54 720.00	Manufacturing Cost/Bicycle	Materials	R 1 705.00
	Tools Required (550W Cordless drill)	R 1 200.00		Joining	R 133.00
	1 kWh Solar Panel System	R 17 300.00		Aesthetics	R 156.00
	Shelf	R 1 500.00		Surface Finishing	R 206.00
	Jig	R 400.00	Labour	12 Hours	R 300.00
	Water Tank	R 200.00			
	Buckets	R 150.00			
<b>Total</b>		<b>R 75 470.00</b>			<b>R 2 500.00</b>

The total time required to manufacture a bamboo bicycle frame results to 734 min or 12.23 hours. As set out by the labour law of South Africa the available working time per week amounts to 8hours/day\*5days, which equals 40 hours per week. This means that 3.27 bamboo bicycles could be manufactured within a week. The manufacturing throughput of this container factory for a typical working year in South Africa amounts to 170 bamboo bicycle frames. Taking this into account a break-even analysis is performed in order to illustrate the sustainability of manufacturing bamboo bicycles within container factories. The bamboo bicycles will be sold at a price of R3000, making a R500 profit. Figure4 shows the results of the break-even analysis.

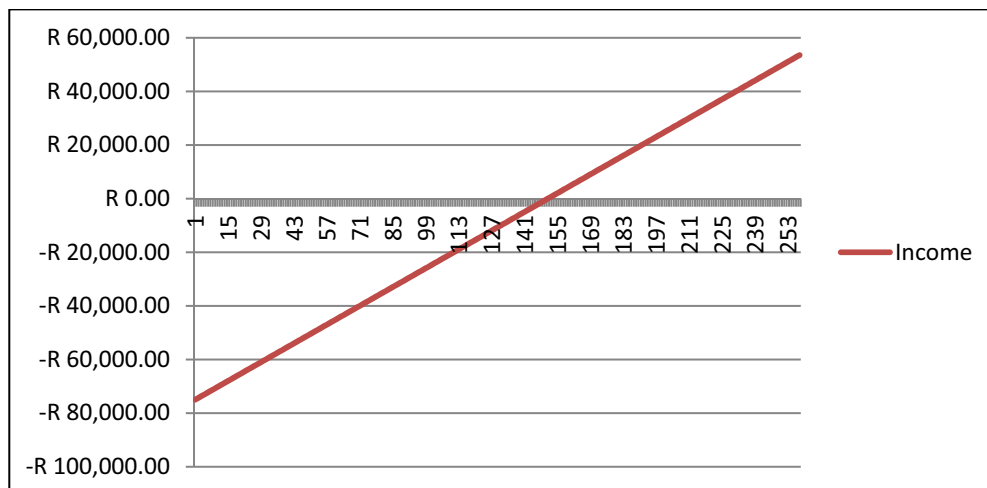


Figure 4: Break-even analysis of the bamboo bicycle container factory.

The break-even point is reached when 151 bamboo bicycles have been sold. As seen in Figure 5 there is no fixed costs due to making use of sustainable energy sources. This results in the bamboo bicycle container factory, with a throughput of 170 bicycles per year, showing profit within the first year. However, this excludes maintenance and tool replacement costs.

## 5. Conclusion

Shipping containers and container manufacturers were investigated to understand the capabilities of containers within the context of South Africa. The most resource efficient process chain to manufacture a bamboo bicycle was identified and manufactured at the University of Stellenbosch subject to availability of the necessary tools and skills. This process chain was documented with regards to time, cost, energy, water usage and waste for each step. A cost model was developed for setting up a bamboo bicycle container factory. The costs were used do a break-even analysis and illustrated the sustainability of manufacturing bamboo bicycles within a container factory. Container factories serve as a low-cost replacement for factories within expensive buildings. Further research could improve the resource efficiency of this secondary manufacturing process chain and a detailed factory layout could be designed.

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