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Designing Vehicles for Natural Production: Growing a Velomobile from Bamboo

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Abstract

Sustainability in the field of personal mobility is critical in alleviating social and consumption pressures of mass production processes, which are reliant on steel and petroleum based resources. This paper explores personal mobility in the urban environment, taking into account existing production methods and the environmental impact of raw material consumption. Furthermore, inertia for the uptake of alternative vehicles, specifically bicycles and Human Powered Vehicles (HPVs) is described, together with the current application of alternative production techniques to form these vehicles. The *'Ajiro'* concept has been achieved through the application of 'action research' methodology, whereby active, grown experimentation and observation of bamboo has influenced the shape of the vehicle. This has led to a proposal that explores an agrarian approach to mass production with a process based on plant shape modification, with specific focus on the application of manipulating grown bamboo sections pre-harvesting to describe the structure of the vehicle, thereby avoiding energy intensive post-production processing of the material.

1. Introduction

The social and urban framework of the modern world relies heavily on automotive culture to augment a lifestyle centered on freedom of movement, convenience and prestige (see, for example; Abbott and Wilson 1995, pp. 262-263; Freund, 1993; Litman 2009; Marsh and Collett 1989; Sloman 2006; Urry 2010, pp. 116-130). As an alternative to current automobility, the velomobile is described by Cox and Van de Walle (2007) as a *"…kind of car without an engine"* (p.114) by augmenting some functions of both bicycles (human power, simple drivetrain, no licence) and cars (fairings, cargo capacity). Further diversification of HPVs or velomobile types has been achieved through experimenting with variations of layouts for specialised tasks such as load carrying (see; Cox 2008, pp. 147-149; Papanek 2009, pp. 238-241), commuter proposals (Papanek 2009, p. 264) and racing development (Van de Walle 2004, pp. 45, 62-63, 92), which has unlocked the potential for HPVs *"…tak*[ing] *less energy, go*[ing] *faster…*[the rider being] *safer and more comfortable, provid*[ing] *more weather protection, and even…more manoeuvrable than standard bicycles"* (Abbott and Wilson 1995, pp. 110, 258-259).

Environmentally responsible and sustainable consumption of personal mobility such as automobiles or HPVs could be improved by altering production methods, where conventional mass-production techniques applied to any product[1] requiring fabrication (for example; steel, aluminium) places pressure on achieving low early lifecycle emissions through material sub-processes of mining and refining (Datschefski 2002, p. 10). Comparatively, in the domestic building industry, steps to invigorate sustainable materials were suggested by the Montreal Process Implementation Group for Australia (2008, pp. 112-113), which proposed that *timber*

[1] For example; furniture, transport, general consumer goods or industrial construction could represent marketable products produced with mass-production techniques

from sustainable forests be used *in lieu of steel* – thereby creating an opportunity for biomass[2] production and carbon storage facility till end of life (see; Buchanan and Levine 1999, p. 428; Dias and Pooliyadda 2004, p. 578).

The benefits of natural resource generation for production or construction are investigated by Cattle (2002), through the use of arborsculpture techniques for growing furniture to shape pre-harvest with minimal assembly and a proposal by Joachim (2006) for the *"Fab Tree Hab"*, hypothesising a living architectural housing construction through grafting and manipulating trees to form unified structures. Natural processes such as these rely on tending and caring of the living material to encourage growth, accompanied by an understanding of the natural mechanisms (such as location, climate, soil condition, pests) in supporting trees (see; Hicks and Rosenfeld 2007; Shigo 1991).

Applying *natural materials* to *automobility*, Schlöesser (2004) describes the *interchange* of energy consuming resources (petroleum based, steel) with natural resources, targeting reduction of *"…emissions in production… and generally* [refrain from destroying] *resources."* The manipulation of various plant fibres, for example; sisal, flax, bamboo and other forms of cellulose, can replace glass[3] fibres for certain manufactured parts with low cost and locality of sourcing materials being factors for recommending plant based fibre consumption as forming part of a sustainable manufacturing rationale (see, for example; Eichhorn 2004, pp. 287-288; Okubo, Fujii and Thostenson 2009; Schlöesser 2004, pp. 277, 279, 284; Yamaguchi and Fujii 2004, p. 318). Implementation of plant based materials, as seen in the Mercedes C-class[4] (Schlöesser 2004, p. 284), limit the suitability of these fibres to specific components within the automotive interior, rather than an approach for the *whole* vehicle, or structural parts.

This paper explores some of the reasons why encouraging lifecycle sustainability of natural materials in personal mobility are necessary and which applications may address environmental concerns of mass production processes; the first four sections present an overview of current mobility types, with section 2 outlining the role of mobility and manufacturing barriers for continuing current techniques; section 3 presents an overview of alternatives to automobility through bicycle use, section 4 velomobile uptake and section 5 describes the role of natural materials in production method applications. The hypothesis of a grown bamboo HPV - the *'Ajiro'* – is described in section 6, which postulates that bamboo can be utilised as a cohesive basis for a velomobile frame, formed by linking the diversity of bamboo applications in Asian society (Farrelly 1984, p. 235), architectural and structural uses (Vélez 2000), together with experiments conducted by Hidalgo (2003). These experiments involve growing sections through an enclosed former (Hidalgo 2003, pp. 350-352), i.e., placing removable rectangular moulds over emerging shoots to achieve 'square bamboo' (pp. 353-355). The method applied for creating the *'Ajiro'* differs from both enclosed box and straight tube bamboo deformation described by Hidalgo, by extending the idea to reusable *tubular* formers *with* set compound curves, allowing bamboo to grow pre-harvest to form complex, three dimensional sections for the velomobile frame assembly.

[2] Biomass is referred to as the leaf canopy that a plant produces for photosynthesis

[3] Glass fibres are classified as 'natural', manipulated material based on silica (Wallenberger and Weston 2004, p. 3)

[4] 'Type W203' from 2000, where sisal fibre reinforces the glovebox, in addition to other interior components described in Section 5 of this paper.

2. The conflict between amenity and mobility

The diverse infrastructure of roads, as well as support mechanisms of vehicle repair, and refuelling stations, is seen as aiding the convenience of urban automobile travel (see, for example; Bel Geddes 1940; Holtz Kay 1997, p. 20; Sloman 2006; Urry 2010, pp. 118-119). Furthermore, the 'ideal' metropolis, created through decades of road and highways infrastructure investment as a 'solution' for personal mobility[5], was based around *building a car utopia* or *automobile city* (see; Newman 2003, p. 52, Mees 2010, pp. 5-10; Sloman 2006, p. 44; Urry, 2010, pp. 112-134); and thereby enabling urban expansion with limited transport alternatives to the car (Currie and Senburgs 2007).

An ideal approach towards mobility would encompass diversity of transport alternatives (Mees 2010, p. 66), however, consumption of convenient *personal* mobility should not be discouraged purely because of reliance on *current* models of mass production (see; Liker 2004; Ohno 1988), propulsion (Dennis and Urry 2009, p. 241-245; Ryan and Turton 2007 pp. 3, 38-49) and occupant vehicular packaging (Mitchell, Borroni-Bird and Burns 2010, pp. 54-60; Papanek 2009, p. 262; Parkinson and Reed 2006). The inclusion of HPVs as *'personal mobility'* encourages simple structure vehicles, specialised to fulfil a task. These can be either shop bought or DIY fabricated and assembled using high or low tech materials, and could be completely human powered or pedal electric assisted - without the need for licences or age / disability barriers that would otherwise prevent driving an automobile (See; Zipfel, Olson and Puhlman 2009; Van de Walle 2007, pp. 74-75, 89-91).

2.1 Current automotive production methods

Deemed to be *"one of the most significant landmarks in motoring history"* (Horton 1992, p. 210), the Ford Model T, launched in 1908, implemented the beginnings of 'just-in-time' mass production[6] techniques (Levinson 2002) by 1914, and today, automotive manufacturers such as Toyota follow this form of highly centralised manufacturing, streamlining the business model referred to as *"lean production"* (see; Ellegård et al. 1992, pp. 113-114; Liker 2004; Ohno 1988). Whist this business model allows cost effective management within the repetition of production process, the vast scale of a modern global manufacturing entity, for example, General Motors, leaves its management unable to react with agility to consumer and market vulnerabilities (see; Holstein 2009; Ingrassia 2010; Taylor 2010).

Globalised manufacturing through the outsourcing of design and individual componentry are intensively used by automobile makers (Mikler 2004, pp. 130-131), however, such a method of production must take into account surplus waste and consider the whole lifecycle of the product, including initial production (Chester 2008, pp. 58-59) and disposal at end-of-life (Davies 2003, p. 2). While current requirements for vehicle reprocessing focus on parts redistribution through the sale and trade of reconditioned and reusable body parts or ancillaries, up to 75% of an automobile can be recycled (p. 4); however, the degree of material processing depends upon an element of *downcycling* (McDonough and Braungart 2002, pp. 56-59), and *'Design for Disassembly'* (Papanek, 1995, pp. 42-43, 238-240).

The very nature of sustaining the current form of mass production relies on goods becoming unserviceable after a period of time – either through mechanical degradation and wear, or through another constructed device used to sell new goods – planned obsolescence (Spielmann and Althaus 2007, p. 1123, 1132; Slade 2006, p. 5). Slade states that, General

[5] Further detail on automobile based city planning is described by Bel Geddes (1940, p. 240, 245)

[6] Directed as a generalisation throughout industry, McDonough and Braungart (2002, p. 43) discusses factors influencing sustainability are directed towards *"… outdated and unintelligent design"* rather than a deliberate *"…morally wrong"* action.

Motors president Alfred P. Sloan (chairman from 1923 to 1956) was credited for annual styling updates introduced in the post war period, whereby:

> *"Through psychological obsolescence, GM's president had guaranteed that his company would remain America's premier automobile producer for decades to come. Having none of his competitor's scruples about product durability, Sloan did his utmost to find new ways to decrease durability and increase obsolescence."* (Slade 2006, p. 43)

Whilst manufacturers tread a fine line with product durability, the notion of planned obsolescence appeals to the consumer through the perceived benefits marketed in the new product. In this respect a 'need versus greed' argument is established in the consumers mind, and it is the challenge of marketing to create the sense of need (Papanek 1995, p. 110-176). Consumers generally see only the finalised item in the showroom, without knowledge of the production processes, or interaction with its artisans. Therefore, production line fabrication and material processing/synthesis remain unseen by the consumer, and any of the environmental consequences (Sloman 2006, p. 82), such as energy intensive mining and smelting steel, become an unknown factor for the consumer (Datschefski 2002, p. 10) who sees the final presentation of the product only in the retail shop. In this case, *consumption*, rather than extending product lifecycles by handing items down through generations, repairing broken items, or DIY culture (Frauenfelder, 2010) may develop an over-reliance on obsolescence to create profit. Where manufacturing efficiency increases the chance of a product becoming disposable, the consumer is encouraged to purchase the newest and latest *"because the future of capitalism depends on it"* (Barber 2007, p. 51).

3. Mobility alternatives – The bicycle

Arranging alternatives for conventional automobility is no easy task, with congestion of the urban landscape, and the pollution they contribute environmentally (see, for example; Alvord 2000; Balish 2006; Holtz Kay 1997; Marsh and Collett 1989; Papanek 2009, p. 262; Sloman 2006) reflecting negatively on their ongoing use. Alvord (2000) maintains that it is possible to live a rich life without automobile dependency, by relying on public transport or bicycle use, nevertheless, it does seem to take considerable effort to maintain methods such as commuter cycling for any extended period, especially when climatic conditions are less favourable (rain, snow, wind), or when topography is hilly, (Parkin, Riley and Jones 2007, p. 80). Yet, in countries such as the Netherlands, bicycle usage is treated as a normal, everyday means of transport, year round, regardless of weather conditions, indicating that the right mix of terrain, infrastructure and ingrained bicycle culture can contribute to successful mobility alternatives (Mapes 2009), whilst density of the urban environment contributes to quick and short commutes (p. 64).

Solutions to the handling of bicycle infrastructure, when promoting cycling as a part of daily life, are many and varied, with Forrester (1993) actively encouraging defiance against separation[7] of cycling and road infrastructure, arguing that cyclists have the 'right to the road' (see; Cox 2008, pp. 149-150, 156-157; Hurst, 2009, pp. 100-102, 136; Mapes, 2009, p. 43). Mapes also cites informal protests such as those through the activist group "Critical Mass" (2009, p. 99) as raising the awareness of cycling to both motorists and the general public.

[7] It is described by Mapes (2009, p. 43) and Abbott & Wilson (1995, p. 259) that Forrester's intention is to create equal rights that a cyclist could use a road along with a motor vehicle driver, without the need for segregating cyclists for protection though physical separation from other forms of transport (through using cycle lanes).

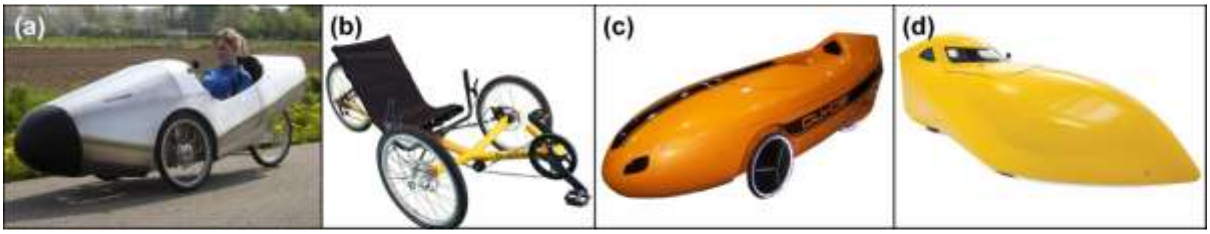
Whilst the bicycle is deemed to be a low cost, quick and clean form of transport (see; Hurst 2009; Mapes 2009; Parkin, Riley and Jones 2007), factors for improvement include comfort and luggage capacity (Cox 2010, pp. 128-129), with flexibility and safety perceptions still a concern and barrier to cycling adoption - and therefore an advantage to automobile culture (Richardson, Vittouris and Rose 2010, pp. 3-4). However, models of bike share systems such as Paris' Vélib, treat public transport not as collective - as would occur in a bus, train or tram, but as individual (Cox 2010), much like the quality found in automobile usage. Furthermore, community acceptance of alternative mobility such as the bicycle may depend on infrastructure investment ahead of current levels of demand, as evidenced during the development of infrastructure in Portland, Oregon, (see; Mapes 2009, pp. 141-168; Dill 2009; Dill and Carr 2003) whereby *creation of* trends may occur, by providing a solid foundation for cultural change, thus increasing public confidence in the promotion of 'everyday' cycling mobility, as it is seen to be officially sanctioned.

4. Velomobile and rickshaw mobility

Cox (2010, p.129) citing Van de Walle (2004), describes the velomobile as being *"…the ultimate level of innovation in human-powered vehicles…which encloses the seated-positioned rider within an integral bodyshell, providing weatherproofing and luggage-carrying capacity"*. Therefore, it would seem that such a vehicle links aspects of attributes from both the bicycle (human power or assisted, manoeuvrability) and the automobile (enhanced occupant protection, luggage capacity) resulting in a hybrid package. Furthermore, diversification within the categories based on bicycle modification has resulted in Velocars – which are two wheeled recumbents (Schmitz 1999-2000), rickshaws and cycle-rickshaws, both of which have been popular in regions in both Asia and India (see, for example; Cox 2010, pp. 165-188; Gallagher 1992; Telfer 2002).

Fuchs (2001), states that the velomobile is a *"…fully faired recumbent vehicle[s] for everyday use"*, however, in terms of recognisable brands for daily urban use, off the shelf solutions consist of a mixture of faired and non-faired recumbent tricycles – which could be modified by the end user adding fairings - from niche makers[8] Alleweder (Figure 1a), TerraTrike (Figure 1b), Greenspeed (Figure 1c) or Trisled (Figure 1d), much of the development of velomobiles is the result of individual D.I.Y contribution (Van De Walle 2004, p. 61).

Figure 1: Recumbent vehicles in production



Evolution of design and construction have progressed throughout the years, with carbon fibre becoming accessible to D.I.Y practitioners for one off or small scale production (Van De Walle 2004, p. 63), leading to performance improvements of the parts (strength, wear resistance) and weight savings, with an understanding of aerodynamics contributing to enhanced efficiency of these vehicles (Cox 2008, pp. 153-154; Cox and Van De Walle 2007, p. 127; Kyle and Weaver 2004). Design concepts which diversify into hybrid pedal-electric[9] vehicles such as the Solarlab Solarcab/Rickshaw (Figure 2a), Sinclair X-1 (Figure 2b), Go-

[8] The cost of velomobiles, described by Fusch (2001, p. 22) is a hindrance to market popularity: *"…US$5500.00 is far higher than that of most upright bicycles. The breakthrough would be if everyone could find a velomobile that fits the demands of daily commuting."*

[9] See; Raine and Maxey (1996)

One (electric option) (Figure 2c), provide direction for pathways velomobiles could take, yet Cox and Van de Walle describe velomobiles which have a deficient ‘identity’ when compared to full size cars. This is described as being due to the relative lack of legal category for classification (Richardson, Vittouris and Rose 2010, p. 5), as well as a design integration issue:

> *“..the risk is that a velomobile will be perceived as an expensive, heavy, complex, large and difficult to park bicycle with extra wheel(s) and a body on top….this is the equivalent of expecting a car to embody the benefits of a motorcycle, or calling a car a ‘four-wheeled, streamlined, recumbent motorcycle.”* Cox and van der Walle (2007, p. 126)

Figure 2: Proposed recumbent vehicles

Rickshaws fall into another category of human powered vehicles, and, while providing employment for many, in terms of drivers, maintenance, commerce and loads they carry (Gallagher 1992, p. 6), are seen in a negative light by some, including government as:

> *“Slow-moving vehicles such as pedal-rickshaws, push and pull carts, etc should be gradually eliminated through development of automotive vehicles and training of existing operators for such vehicles.”* Government of Bangladesh (1985)

The justification for removal of such vehicles was that rickshaw pulling was dishonourable, yet Gallagher (1992) describes that such a job was no more dishonourable than other forms of manual hard labour (p. 10). Furthermore, the visible imagery of rickshaw pulling was seen to be a representation of an under-developed society whilst also describing that the rickshaws design faults are mainly the cause *of “…bicycle components [being] used in a tricycle role”*, with low gear ratios, frame strength issues, brakes and steering inappropriate for the purpose (p. 15). Rajvanshi (1999–2000) believes that with modification of the gear system, suspension, aerodynamics and the introduction of a hybrid electric/pedal system, rickshaws can still make a valuable contribution to affordable mobility, and help control pollution, even replacing the autorickshaws that were intended to phase out the cycle rickshaw.

5. Natural material alternatives

Industrial use of natural materials, applied by DaimlerChrysler in production amounts to *“…about 30 different natural fibre reinforced materials…present in the vehicle interior of the C-Class model”* (Schlöesser 2004, p. 283). In addition, the natural fibre parts such as Flax/sisal/wood (Door panels), wool fibre moulded material (Instrument panel support), Cotton Fibre (Seat backrest panel) save over 22kg in total vehicle weight. Other manufacturers investigating natural materials in automotive usage, such as Mitsubishi Motors[10], developed a similar effect with compression and mixing of fibrous bamboo material

[10] *“Plant-based parts”*, by TERASAWA, TSUNEOKA, TAMURA, and TANASE (2008), use *“bamboo-fibre board”* and *“PLA fibre floor mat”* in the Mitsubishi iMiEV, where the *“Life Cycle Assessment”* of bamboo has advantages to Polypropylene components in absorbing CO_2 in the growing phase.

with a 'plant based resin', *polybutylene succinate*, and together, both research investigations form the possibility of both environmental gain through grown biomass, and weight savings which might lead to increased vehicle efficiency.

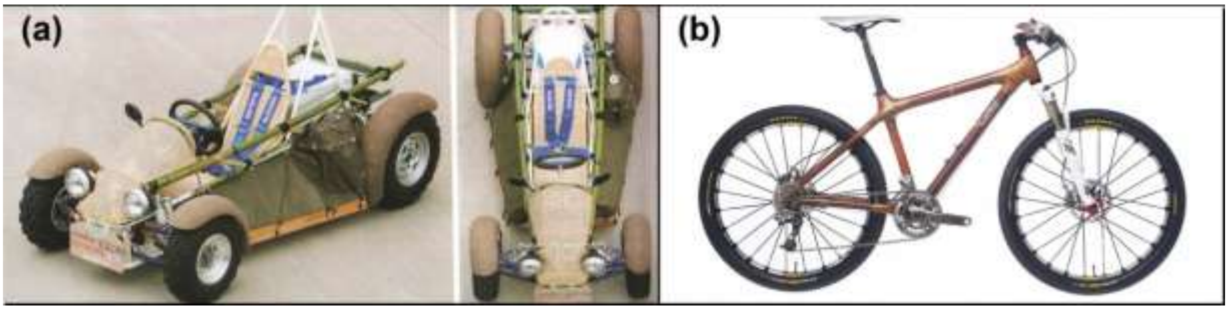
Diversification of material processes combining natural and synthetic materials extend to research and development concept ideation, with some notable examples such as the Rinspeed BamBoo (Figure 3a), promoting bamboo fibre usage through interior componentry ("BamBoo" - the Pure Roots of Mobility), and the Mini Biomoke (Figure 3b) concept utilising material for the body *"…made from a single sheet of biodegradable sandwich panel, implanted with palm tree seeds"* (Blackburn 2006). Other conceptual vehicles such as the Toyota 1/X (Figure 3c) proposes that *"…the roof… made of lightweight bio-plastic manufactured from environmentally responsible materials [is] derived from kenaf and ramie plants"* (Toyota Environmental Update - Forty-ninth issue 2008). This shows that ideas concerning material diversification are evident within industry, which hopefully, with further development and practical application, eventuates in consumer variants.

Figure 3: Automobile concepts using natural materials

Commentary regarding the use of natural materials such as wood in vehicles is presented as a further necessity due to the advent of reliable electric drivetrains, as noted by Tadashi Tateuchi (Fujimoto 2007), in which the longevity of the motor and lithium-ion battery may outlast the vehicle body (including plastic and fibre-reinforced plastic) (Figure 4a). Furthermore, developments such as the 'Bamboo bike' (Figure 4b) by Craig Calfee, and D.I.Y (Do-It-Yourself) bikes such as the "Berlin Bamboo bikes"[11] workshop or Cognitive Cycles "Bamboo Bikes"[12], whereby the traditional materials such as steel, aluminium or carbon fibre tubular sections have been replaced by bamboo culms.

Such methods of construction rely on cutting and joining sections to form the bicycle frame, which is a labour intensive, low volume and skilled process, necessitating a typical price, as in the case of Calfee Designs bicycles, beyond $4500USD. Cases such as these however, demonstrate that material substitution can allow for *enhanced* technical characteristics, in this case allowing the feel of the bicycle to be fine-tuned through the use of different sub species of bamboo.

Figure 4: Bamboo use in mobility



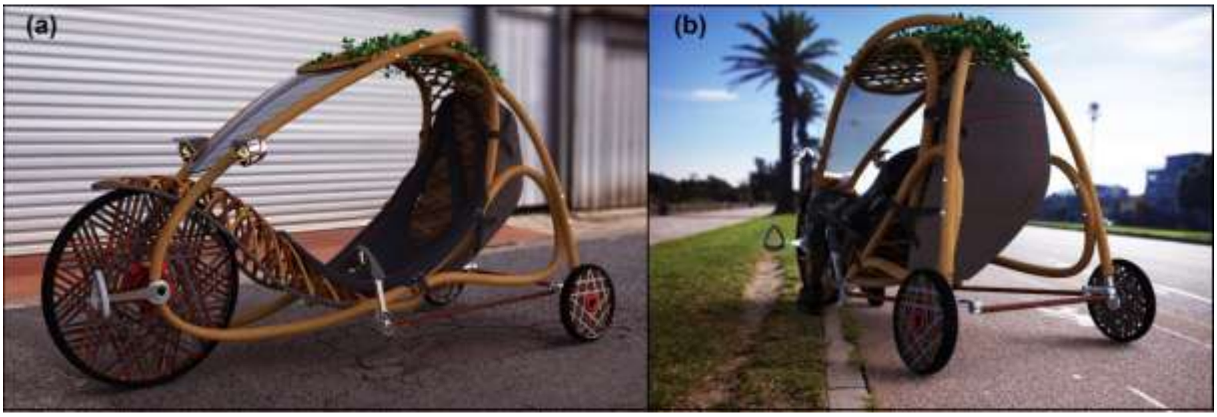
[11] See; www.berlin-bamboo-bikes.org/ride

[12] See; www.bamboobikes.com.au

6. Development of the 'Ajiro' Human Powered Vehicle.

The design concept "Ajiro"[13], a partial fairing velomobile, was derived with simplicity in mind, using the natural ability of the bamboo to grow while being shape modified pre-harvesting, allowing for the possibility of 'growing a vehicle' (Figure 5a and 5b).

Figure 5: Renderings of the 'Ajiro' concept



6.1 Attributes of bamboo

Bamboo was chosen for investigation due its rapid growth when compared to other naturally sourced material, such as timber (see, for example; Bess and Wein 2001; Farrelly 1996; Hidalgo 2003; van der Lugt 2007, 2008) [14]. Growth patterns of bamboo are compared to grasses, such as jute and kenaf, yet bamboo compares well to composites such as glass fibre in mechanical performance tests (Yamaguchi & Fujii 2004, p. 306). Vélez (2000) describes that bamboo canes can be used for housing construction purposes after a growing period of three to five (up to eight) years, and that the *"…yield is up to 25 times higher than timber"* (p. 151), thus providing industry with access to a sustainable resource which offers rapid regeneration (Oprins and van Trier 2006, p. 110).

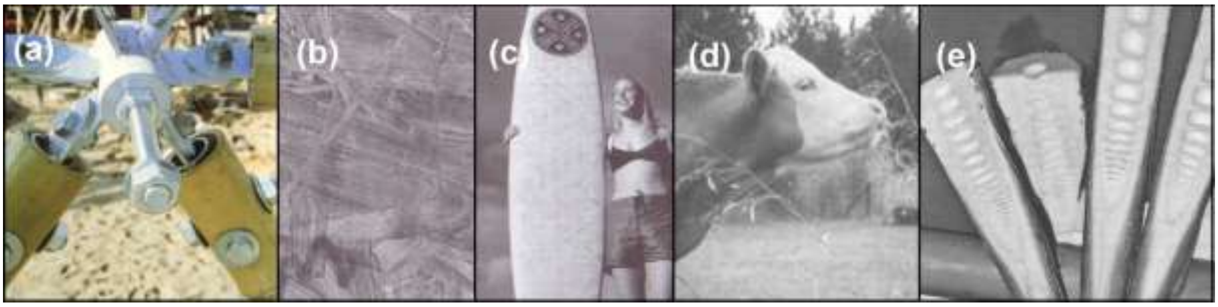
Furthermore, Londoño (2003) refers to a genus related to the more common bamboos of the *bambusa* family, the *Guadua (Guadua angustifolia)* which has a "…strength/weight ratio which surpasses that of most woods and may even be compared to steel and some high-tech fibres" (p. 34) showing possibilities for material substitution. The versatility of bamboo allows applications in the form of raw material – culms (Figure 6a), (Vélez 2000), composites (Figure 6b, 6c) (Hidalgo 2003, pp. 163-175, 199-221; Okubo, Fujii and Yamamoto 2004)[15] and laminates (pp. 176-197), with wastage from leaf material forming the basis for livestock fodder (Figure 6d) (Lewis and Miles 2007, pp. 84-85), or small excess new shoots (baby culms) harvested for nutritional food (Figure 6e) (pp. 92-105).

[13] "Ajiro" refers to a style of Japanese bamboo twill weaving pattern (Hidalgo 2003, pp. 119-123)

[14] Stated by van der Lugt (2007, p. 43) that: *"Bamboo grows nearly five times faster than the average tree"*, (p. 85) *"The record growth for bamboo is 1.22 metre per day (!)…"*

[15] Suggested by Huang (2007, p. 2), bamboo fibres used for biodegradable plastics, state that rapid growth of bamboo could yield frequent harvests for extracting the "micro/nano-sized bamboo fibrils" (fibres); See; Liese (1998, p. 58).

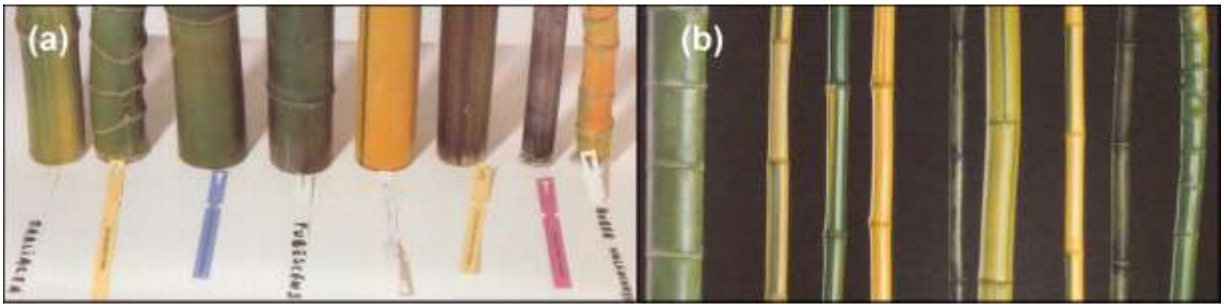
Figure 6: Examples of bamboo applications



6.2 Exploring grown transportation

Natural production in the horticultural field relies on 'part matching', whereby culm comparison between plant species, either at different plant locations, or within the same rhizome parent, is needed for product consistency[16] (Figure 7a and 7b). Factors such as culm circumference, strength of the plant, or genetic mutations of the species (Saporito and Mavition 2010, p. 7) may contribute to variations while additionally, biological factors such as fungi, borers or termites (see, for example; Farrelly 1984, p. 226; Hidalgo 2003, pp. 65-69; Lewis and Miles 2007, pp. 56-62) may affect structural integrity of the plant. As described by Janssen (2010, p. 3): *"Standardization is virtually impossible, because of the variation in sizes. Only in the joins can an attempt to standardization be successful."* , therefore, in order to combat plant mismatching, vehicle parts would be grown separately, and then appropriately paired and graded to another plant within the grove.

Figure 7: Visual characteristics and variations between bamboo species



The selected species of bamboo, *Bambusa Oldhamii* (Figure 8a) was chosen for its fast growth characteristics, and large total height of twelve meters, which is sufficient to form the tubular components of a frame. The total leaf mass and height of the original plant, contributes to the energy offered to new culm growth. This means that a well-established plant will produce offshoots which are more vigorous and stronger than a plant which is only a couple of years old. Another method of generating new plants may be through seed germination, although bamboo species have *"sporadic or irregular flowering"* and *"gregarious or periodical"* flowering patterns (Hidalgo 2003, pp. 25-31). However, seeds from the *Oldhamii* species were obtained over the internet from eBay (Figure 8b), and these were subsequently planted into small pots, each with six seeds which achieved an average of three germinations per pot (Figure 8c)[17]. This leads to the possibility that, given an extended

[16] Mechanical properties and variances between species is noted by Janssen (2010, pp. 12-17).

[17] Noted by Saporito and Mavition (2010), *"Bamboo seeds are your lottery because not every seed is a winner. They're not naturally all supposed to germinate and grow to maturity."*

time frame for plant establishment, grown vehicles could technically be produced from seed propagation alone.

Figure 8: Purchased plants for subframe growing and *Bambusa Oldhamii* seeds/seedlings

6.3 Shape modification experiments

Bamboo has a seasonal growth cycle, and this occurs during the warmer months, in Melbourne late January/February through to May, after which activity is slowed. This means that even the earliest acquisition of the 'parent' plants would require some establishment before new culms can grow. As such, these experiments are still active, and should not be regarded as a finalised outcome, with harvesting depending on species and number of years till culm maturity for structural use (see, for example; Farrelly 1984, p. 219; Hidalgo 2003, pp. 142-153; Lewis and Miles 2007, pp. 78-83).

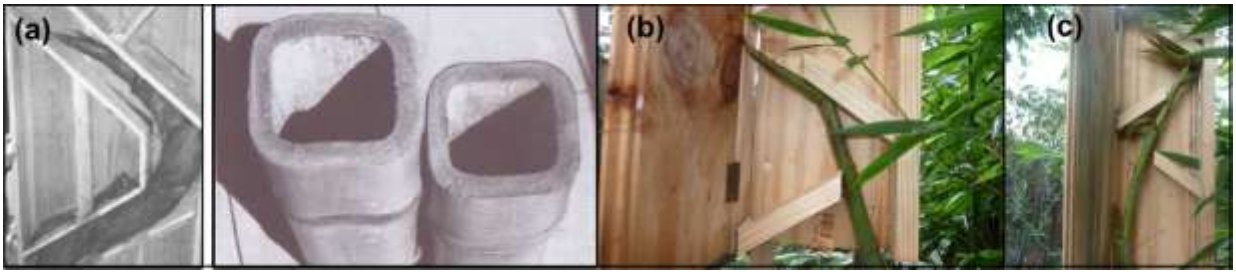
Observation of the current plants note that side shoots propagate outwards from the main growth stem, especially once maximum culm height is reached, or when the tip has been damaged. Using side shoots, which would normally be discarded, could work towards deriving an even greater amount of value from the material growth process - the eventual goal would be to use the shoots to provide patterns or weavings directly onto the grown sections, creating a frame for a canopy trellis. Experiments have been successfully conducted by growing the *Pisum sativum* 'Alderman Tall Telegraph Pea', which has characteristics of fast growth and hardiness, over such a trellis. Creating a living shelter could be justified further by turning redundant space on the vehicle into biomass for photosynthesis as the vehicle is used, whilst also providing a potentially edible resource.

The advantage of utilising the entire material, including both the side shoots and raw culms is, that when the bamboo is removed from the forming tool after the completed growing cycle, the material will hold a contorted shape, (Hidalgo 2003, p. 352). This allows structures, including complex compound curves, to be grown seamlessly by only using plant growth control.

6.3.1 Two dimensional substructures

Replicas of the enclosed box growing experiments described by Hidalgo (Figure 9a), were conducted in the March 2011 growing period. The experiment was conducted to determine whether, in fact, bamboo could 'find its own way' around a wooden maze fastened to a base board with a hinged cover to check plant growth (Figure 9b and 9c). This is an ongoing experiment at the time of publication; however, the plant has nearly completed the shape over a small testing section.

Figure 9: Manipulating the shape of bamboo pre-harvesting



6.3.2 Direct shape modification over substructures

Experiments involving tensioning the growing bamboo over the frame directly (Figure 10a) were initially thought to be reasonable in controlling the plant. It was soon apparent that with increased culm circumference, limitations arose as to the amount of tension which could be applied to the growing tip - not evident in earlier testing, as spindly, more pliable plants were used. Thicker culms required higher tension to keep the plant from growing vertically (Figure 10b), and if too much pressure was applied to the bamboo tip, it was likely to break, not grow any taller and only send out side shoots. The spacing of the subframe profiles contained 'missing information'[18] between each section regarding any curve subtleties (Figure 10c), and this, coupled with frame distortion from inclement weather and the bending force of the growing plant, resulted in severe disfigurement of the shape from that desired in Figure 10a.

Figure 10: Bamboo shape modification over substructures

6.3.3 Shape modification of bamboo through tubular sections

With the high frame tension needed at every profile point in the earlier experiments, it was established that a finer degree of control would be needed to subtly 'push' the bamboo into shape, rather than a series of sharp applications of tension. Direct control of the plant by growing the culms through tubing (Figure 11a -11f), as discussed by Hidalgo (2003, pp. 354-355) whereby wooden sections - in this case rectangular wood boards for growing 'square' bamboo - are roped around the emerging plant. This technique, used for decorative and architectural purposes (downspouts for houses) (p. 354), needed to be modified to include curved tubular sections for growing the subtle curves required for giving the vehicle a refined aesthetic appearance. Initially, the experiments conducted utilised aluminium tubing due to its non-corroding nature when exposed to damp conditions, while the pliability allowed for ease of bending to shape. Achieving a tight, smooth radii proved very difficult without kinking the tubing , however, trial pieces were produced and sectioned in half (a procedure necessary to ensure a clean outcome during removal from the culm). These halves were then attached, with cable ties, to an emerging culm which then proceeded to grow in the desired shape inside the former.

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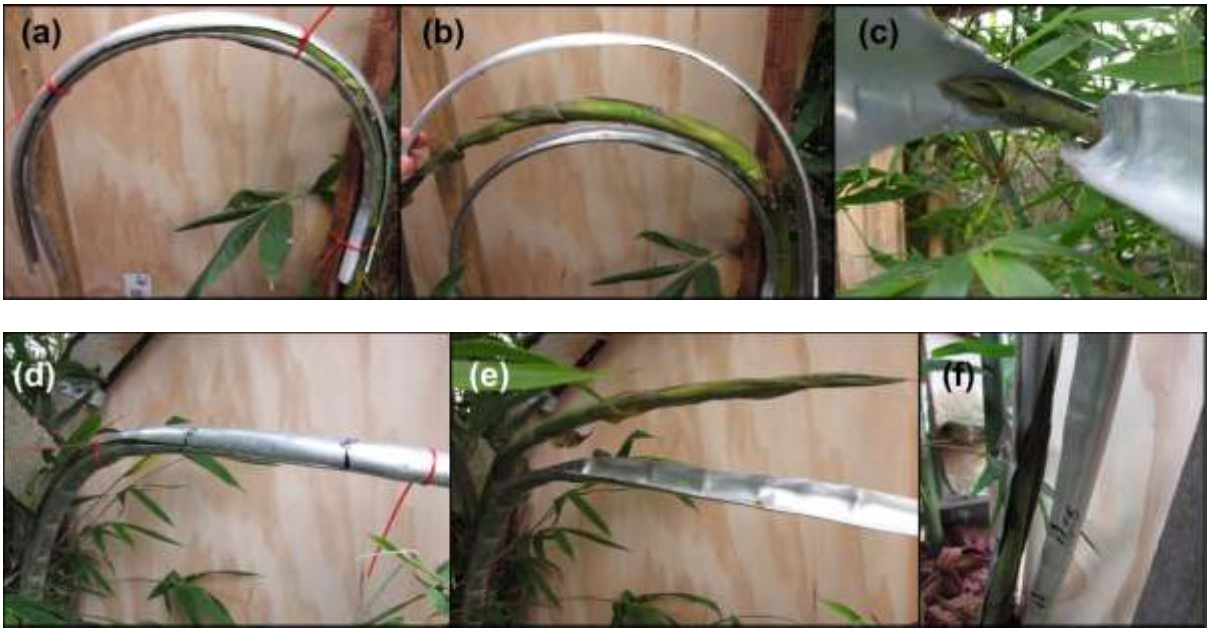
[18] Frame sections, shown in Figure 10a and 10b, have spaces between each tensioned control point. These create jagged stepping between each point where curve co-ordinates (X,Y,Z) are missing.

Although these experiments are ongoing, they are providing promising results, as smooth gradual curves can be formed. Furthermore, Hidalgo postulates that culm growth can still occur in a totally dark, sealed environment, as the plant will seek a pathway to light (p. 352). The ultimate goal of such an approach would allow some of the finalised shaped bamboo sections to themselves become facilitators, in the form of tubes (cut in half), in which new generations of culms would grow, thereby helping to create a completely closed loop natural production process.

Figure 11: Bamboo shape modification through tubes



6.4 Prototype testing

Van der Lugt (2008, p. 32) refers to ‘action research’ methodology as being useful when working with natural materials, whereby the design process is directly influenced by field experiments. Linking both the *natural* object with the *manufactured* object, research and evaluation should directly contribute to each other, with material capabilities, gained through experiments directly influencing the design, without the design pre-judging or imposing impossible or impractical techniques (such as extremely tight radii and large structural spans without reinforcement).

While the plant experiments provide insight into the material capabilities of bamboo, further verification of the design was directly influenced by hands-on prototyping using tubular aluminium pipe. Early experiments using a hand manipulated pipe bender were conducted to compare the form to paper 1:1 printouts of top, front side proportions. The limitations of aluminium was quickly realised once weight was placed on the structure, especially in the vulnerable rear wheel attachment section, where most of the rider weight rested, causing significant flex in the wheel alignment. Learning from this particular material failure however, allowed further investigation into the best approach for triangulating and bracing the rear section of the frame against such flex. Given that it would be undesirable to include additional extraneous sections to the form, since the goal was to grow as much of the frame as possible in one piece, a ‘bracing loop’ was created (grown in the frame profile). This links the seat frame, bottom of the chassis and rear wheels together, fastening the rear end of the vehicle to the wheel attachment (formed by the opposing ’X’ crossover in the frame), while the grown experiments in Figure 11a through to 11f (conducted during the later stages of prototyping), show that thick culms can achieve the tight radius expected in this region.

Subsequent testing relied on steel as a substitute for bamboo (Figure 12a and 12b), whereby flexibility of the frame was essential to allow changes to be made without altering the whole vehicle. Modular sections of metal tubing bent to the appropriate shape simulates the growth pattern presented by the concept whereby standard length (1 meter or 3 meter) tubular steel were then joined through the use of wire rope grips / u-bolts (Figure 12c). As such, modification of the prototype is now easily achieved for future alterations, while presenting a rideable solution for testing steering, seating position and vehicle stability.

Figure 12: Frame prototype verification

6.5 HPV body and drivetrain description

The reliance on nature to form the vehicle sections allows for simplicity of parts, by forming large amounts of structural components in continuous sections. This has been achieved through using of two primary, continuous crossover grown bamboo sections, which form the following structural attributes:

- Overlapping cross point 'X' attaches and suspends the two lateral sides
- Frame canopy structure and wind visor support through opposing roof sections
- Stabilising 'loop' for bracing the rear wheels
- Routing within the hollow bamboo sections for dynamo wiring and brake cables
- Anchor for front wheel hub and pedal assembly

Supported by a smaller, grown sub-section which attaches the vehicles 'roof' to the 'floor', the primary crossover plant growth begins at the 'rear' of the vehicle. Utilising rear-wheel-steering, the swivel attachment bearings could be pressed into the naturally hollow bamboo sections. Such a method differs from traditional recumbent vehicles, removing the chain drive, derailleur and cassette sprockets, and instead, integrates gears into a front wheel hub, saving vehicle weight. Although a multi-speed direct drive hub is not presently available for recumbent vehicles, Kretschmer (1999-2000) describes his invention for up to eleven gears contained in a direct drive hub, stating that it offers ease of maintenance with "…no cogs or chain-rings to wear out." The commercial derivative of this hub is the HK-Schlumpf sold for unicycles, which offers a 1:1 ratio with an overdrive feature; however, given the high retail price of one thousand Euros, using such an item for testing is prohibitive within the funding of Masters research.[19]

[19] Prices of the geared hub are based from the website information obtained from: http://www.schlumpf.ch/hp/uni/uni_engl_preise.htm , detailed specifications on the "HK- (Schlumpf - The street hub: Type FS)" available from: www.schlumpf.ch/hp/uni/uni_engl_standard.htm

7. Discussion

Mass production, reliant on consumption of raw, unrefined materials to synthesise into products, differs from the approach taken while designing the 'Ajiro', where a sustainable cycle of product growth, use, and composting, utilises minimal components - excluding those needed for the drivetrain function. The conceptual basis for the Ajiro was reached through harnessing the natural cycle of bamboo production, whereby the sun and soil both serve to provide an energy facilitator. These methods of energy conversion are already utilised for commercial energy production (solar, geothermal and hydro), but transference to this research utilises the bamboo and its comprising elements (leaves, rhizomes, and roots) as both a *converter* and *conveyer* of natural energy, rather than electrical substations and industrial machinery.

While the research is still in its infancy for transference from steel to a full size bamboo version, the approach for this concept is based on the reliability of natural processes (such as harvest yield, soil quality, climate variations and pests and insects), whereby the formation of multiple bamboo plants would be required to establish the success rate of growing completed forms. Although such a concept could be applied over a distributed growing network, the viability of applying farming and harvesting techniques[20] to bamboo must be considered, due to the significant costs of firstly establishing a bamboo plantation (Lewis & Miles 2007, pp. 29-34), and secondly, obtaining hands-on labour to control the grove production.

The research experiments (to date of publication), reference the work of bamboo practitioner Oscar Hidalgo, whose experiments with pre-harvest shape modified bamboo for architectural applications provided valuable knowledge regarding the limitations of bamboo curve formation. This research, together with the culm experiments conducted in tubular metals, indicate that bamboo is capable of enduring and maintaining significant deformations during its establishment through a 'once-off' intervention process. The premise of this project hopes to encourage the use of bamboo because of its natural strength, rapid growth qualities, monomateriality and biomass benefits of using natural materials.

8. Concluding remarks

The 'Ajiro' Human Powered Vehicle (HPV) aims to provide wholly sustainable urban mobility, by considering the product lifecycle and existing production methods as a natural growth process through agricultural techniques of plant modification.

Concerns over raw material consumption for personal mobility production and propulsion, together with extensive development and investment in the urban road network, indicate the reliance on personal mobility in the form of an automobile. While bicycles and HPVs offer the ability to diversify the transport mix on the roads, many commercial techniques for the production and assembly of such vehicles are derived from processes used for automobile production (excluding D.I.Y. or low volume runs). Furthermore, bamboo used for bicycle production currently requires the growth of straight culm sections, joined in laborious binding techniques. Much like the bicycle, recumbent vehicle technology stems from utilising the human body, an efficient power source, to propel recreational or urban transportation. With proposed storage and canopy shelter, the 'Ajiro' concept establishes that spaceframe construction of HPVs presents an alternative for 'body on frame' techniques presently used by velomobiles.

[20] Bamboo under three years old is considered immature, according to Hidalgo (2003, p. 62) with less strength, and not suitable for construction. Therefore, it could be advantageous to have multiple sets of bamboo plants growing in a crop rotation method, whereby each plant is at a different stage of maturity.

This paper has discussed the pressures of conventional mass production, and presented a concept study supported by grown shape modification experiments, utilising the bamboo species *'Bambusa Oldhamii'*. Culm deformation trials were performed through adding tension to growing sections, however, these were considered visually undesirable, due to the unrefined curve caused by the inflexibility of thick bamboo culms. Further experiments were conducted whereby culms were grown within moulded tubing, thus allowing structural formations to be achieved 'pre-harvesting' with smooth curve transitions by gradually encouraging the plant to grow to the desired form. Ongoing trials involving shape modification techniques will allow the bamboo culms to mature into their fixed shape for future harvesting.

The experimental research connects *'personal mobility'* with *'grown mobility'*. Benefits obtained through making the adaptability of bamboo work for us, can create sustainable mobility through plant regeneration, whilst exploiting the alluring characteristics of fast growth, structural resilience and, potentially, localised production through sub-species selection and farming.

References

BamBoo - the Pure Roots of Mobility. (n.d.) Retrieved from Rinspeed: http://www.rinspeed.com/pages/cars/bamboo/pre-bamboo.htm

Toyota Environmental Update - Forty-ninth issue (2008) Retrieved February 6, 2011, from Toyota Motor North America, Inc.: http://www.toyota.com/about/news/environment/2008/01/04-1-2008AprEnvUpdate-49.html

Abbott, A V and Wilson, D G (1995) *Human-powered vehicles.* Champaign, IL: Human Kinetics.

Alvord, K (2000) *Divorce Your Car! : Ending the Love Affair with the Automobile.* BC, Canada: New Society Publishers.

Balish, C (2006) *How to Live Well Without Owning a Car: Save Money, Breathe Easier, and Get More Mileage Out of Life.* Berkely: Ten Speed Press.

Barber, B R (2007) *Con$umed : how markets corrupt children, infantilize adults, and swallow citizens whole.* New York: W.W. Norton & Co.

Bel Geddes, N (1940) *Magic Motorways.* New York: Random House.

Bess, N M and Wein, B (2001) *Bamboo in Japan.* Tokyo: Kodansha International.

Blackburn, R (2006) *California dreamin' about being green.* Retrieved January 15, 2011, from Sydney Morning Herald: http://smh.drive.com.au/future-cars/california-dreamin-about-being-green-20061117-13zmi.html

Buchanan, A H and Levine, S (1999) Wood-based building materials and atmospheric carbon emissions. *Environmental Science & Policy*(2), 427-437.

Cattle, C (2002) *Grown Furniture - A move towards design for sustainability.* Faculty of Design, The Buckingshire Chilterns University College; Brunel University.

Chester, M V (2008) *Life-cycle Environmental Inventory of Passenger Transportation in the United States.* Berkeley: University of California.

Cox, P (2008) The Role of Human Powered Vehicles in Sustainable Mobility. *Built Environment*, Vol. 34, (2), 140-160

Cox, P (2010) *Moving People; Sustainable Transport Development.* London; New York; Cape Town, South Africa; New York: Zed Books; UCT Press; Palgrave Macmillan.

Cox, P and Van De Walle, F (2007) Bicycles Don't Evolve: Velomobiles and the Modelling of Transport Technologies. In D. Horton, P. Rosen, & P. Cox, *Cycling and Society* (pp. 113-131). Hampshire: Ashgate Publishing Limited.

Currie, G and Senbergs, Z (2007) *Exploring forced car ownership in metropolitan Melbourne*, 30th Australasian Transport Research Forum, Melbourne

Datschefski, E (2002) *Sustainable Products - Using Nature's cyclic|solar|safe Protocol for Design, Manufacturing and Procurement.* Retrieved January 15, 2011, from BioThinking International: http://www.biothinking.com/sustainable_products1.pdf

Davies, G (2003) *Materials for Automotive Bodies.* Oxford: Butterworth-Heinemann.

Dennis, K and Urry, J (2009) Post-Car Mobilities, *Car Troubles* (J. Conley, & A. Tigar McLaren, Eds.) Surrey, England: Ashgate Publishing.

Dias, W P and Pooliyadda, S P (2004). Quality based energy contents and carbon coefficients for building materials: A systems approach. *Energy*(29), 561-580.

Dill, J (2009) Bicycling for Transportation and Health: The Role of Infrastructure. *Journal of Public Health Policy*, (30), 95-110.

Dill, J and Carr, T (2003) *Bicycle Commuting and Facilities in Major U.S. Cities: If You Build Them, Commuters Will Use Them – Another Look.* Retrieved January 28, 2011, from Networks, Economics, and Urban Systems (NEXUS) Research Group, Networks and Places: Transportation, Land Use, and Design: http://nexus.umn.edu/Courses/pa8202/Dill.pdf

Eichhorn, S J (2004) Regenerated Cellulose Reinforced Plastics. In F. T. Wallenberger, & N. E. Weston, *Natural Fibers, Plastics and Composites* (pp. 275-285). USA: Kluwer Academic Publishers.

Ellegård, K; Engström, T; Johansson, B; Johansson, M I; Jonsson, D and Medbo, L (1992) Reflective Production in the Final Assembly of Motor Vehicles – An Emerging Swedish Challenge, *International Journal of Operations & Production Management*, vol. 12, (7-8), 109-125

Farrelly, D (1984) *The Book of Bamboo.* San Francisco: Sierra Club.

Farrelly, D (1996) *The Book of Bamboo - A comprehensive guide to this remarkable plant, its uses and its history.* London: Thames and Hudson Ltd.

Forrester, J (1993) *Effective Cycling.* Cambridge, Massachusetts: MIT Press.

Frauenfelder, M (2010) *Made by hand: my year of finding meaning in a throwaway world.* New York: Portfolio

Freund, P (1993). *The Ecology of the Automobile.* Montreal; New York: Black Rose Books

Fuchs, J (2001), YOUR NEXT VEHICLE: A VELOMOBILE? *Human Power: Technical Journal of the IHPVA*, (51), 20-22.

Fujimoto, A (Ed.) (2007), Hybrid Junior High School Student Buggy "SETAGAYA 1". *Car Styling*, (178), 92-94.

Gallagher, R (1992) *The Rickshaws of Bangladesh.* Dhaka, Bangladesh: The University Press Limited.

Geddes, N B (1940) *Magic Motorways.* New York: Random House.

Government of Bangladesh (1985) *The Thrid Five Year Plan, 1985-1990.* Dhaka.

Hidalgo, O L (2003) *Bamboo - The gift of the gods.* Columbia: D'VINNI LTDA.

Holstein, W J (2009) *Why GM matters : inside the race to transform an American icon.* New York: Walker & Company.

Holtz Kay, J (1997) *Asphalt nation: how the automobile took over America, and how we can take it back.* New York: Crown Publishers.

Horton, C (1992) *Encyclopedia of Cars.* Surrey: Colour Library Books Ltd.

Huang, X (2007) *Preparation and Investigation of Soy Protein Based Environmentally Friendly Plastics and Composites.* Cornell University.

Hurst, R (2009) *Cyclist's manifesto : the case for riding on two wheels instead of four.* Connecticut: Falcon Guides.

Ingrassia, P (2010) *Crash course : the American automobile industry's road from glory to disaster.* New York: Random House.

Janssen, D J (2010) *Building with Bamboo - A handbook.* Warwickshire, UK: Practical Action Publishing Ltd.

Joachim, M W (2006) *Ecotransology : integrated design for urban mobility.* Massachusetts: Massachusetts Institute of Technology.

Kenworthy, J and Laube, F (1997) *Automobile dependence in cities: An international comparison of urban transport and land usage patterns with implications for sustainability.* Perth: Institute for Science and Technology Policy, Murdoch University.

Kretschmer, T (1999–2000) DIRECT-DRIVE (CHAINLESS) RECUMBENT BICYCLES. *Human Power: Technical Journal of the IHPVA*, (49), 11-14.

Kyle, C R and Weaver, M D (2004) Aerodynamics of human-powered vehicles. Proceedings of the Institution of Mechanical Engineers*, Part A: Journal of Power and Energy*, Vol. 218, (3), 141-154

Levinson, W A (2002) *Henry Ford's Lean Vision: Enduring Principles from the First Ford Motor Plant.* New York: Productivity Press.

Lewis, D and Miles, C (2007) *Farming Bamboo - Increase Farm Income by Growing Bamboo.* Lulu Press.

Liese, W (1998) *The anatomy of bamboo culms.* Brill.

Liker, J K (2004) *The Toyota way : 14 management principles from the world's greatest manufacturer.* New York: McGraw-Hill.

Litman, T (2009). Mobility as a Positional Good: Implications for Transport Policy and Planning, *Car Troubles.* (J. Conley, & A. Tigar McLaren, Eds.) Surrey, England: Ashgate Publishing.

Londoño, X (2003) New Bamboo: Architecture and Design. In B. Villegas (Ed.). Bogotá: Villegas Editores.

Mapes, J (2009) *Pedaling Revolution - How Cyclists are Changing American Cities.* Corvallis, Oregon: Oregon State University Press.

Marsh, P and Collett, P (1989) *Driving Passion: The Psycology of the Car.* Winchester, MA: Faber and Faber.

McDonough, W and Braungart, M (2002) *Cradle to cradle: remaking the way we make things.* New York: North Point Press.

Mees, P (2010) *Transport for suburbia : beyond the automobile age.* London: Earthscan.

Mikler, J (2004) The International Car Industry and Environmental Sustainability: Moving Beoynd 'Green Washing'? *Sustainablity and Social Science Round Table Proceedings* (pp. 125-158). The Institute for Sustainable Futures, Sydney; CSIRO Minerals, Melbourne.

Mitchell, W, Borroni-Bird, C and Burns, L (2010) Reinventing the automobile: personal urban mobility for the 21st century, MIT Press

Montreal Process Implementation Group for Australia (2008) *Australia's State of the Forests Report 2008.* Canberra: Bureau of Rural Sciences.

Newman, P (2003) Walking in a historical, international and contemporary context. In R. ed. Tolley, *Sustainable transport: Planning for walking and cycling in urban environments* (pp. 47-58). Cambridge, England: Woodhead Publishing Ltd.

Ohno, T (1988) *Toyota Production System: Beyond Large-Scale Production.* New York: Productivity Press.

Okubo, K, Fujii, T and Yamamoto, Y (2004) Development of bamboo-based polymer composites and their mechanical properties. *Composites Part A: Applied Science and Manufacturing, 35*(3), 377-383.

Okubo, K; Fujii, T and Thostenson, E T (2009, April) Multi-scale hybrid biocomposite: Processing and mechanical characterization. *Composites Part A: Applied Science and Manufacturing, 40*(4), 469-475.

Oprins, J and van Trier, H (2006) *Bamboo - A material for landscape and garden design.* Basel, Switzerland: Birkhäuser Architecture.

Papanek, V (1995) *The Green Imperative – Natural Design for the Real World*, Thames and Hudson, New York

Papanek, V (2009) *Design for the real world: Human ecology and social change.* Chicago: Academy Chicago Publishers.

Parkin, J, Riley, T and Jones, T (2007) Barriers to Cycling; An Exploration of Quantitive Analyses. In D. Edited by Horton, P. Rosen, & P. Cox, *Cycling and Society.* Burlington: Ashgate Publishing Company.

Parkinson, M and Reed, M (2006) Optimizing Vehicle Occupant Packaging. *2006 SAE World Congress*, Detroit, Michigan; http://papers.sae.org/2006-01-0961/

Rajvanshi, A. K (1999–2000) CYCLE RICKSHAWS AS A SUSTAINABLE TRANSPORT SYSTEM FOR DEVELOPING COUNTRIES. *Human Power: Technical Journal of the IHPVA*, (49), 15-18.

Richardson, M; Vittouris, A and Rose, G (2010) Socialised transport: Increasing travel mode diversity through open-source vehicle design,upcycling, natural production and distributed production methods. *Australasian Transport Research Forum 2010 Proceedings.* Canberra: http://www.patrec.org/web_docs/atrf/papers/2010/1950_093%20-%20Richardson%20Vittouris%20Rose.pdf.

Raine, J K and Maxey, N G (1996) Electrically assisted human-powered vehicles: An option for commuters? *International Journal of Vehicle Design*, Vol.17, (5-6), 663-680.

Ryan, L and Turton, H (2007) *Sustainable Automobile Transport - Shaping Climate Change Policy*. Cheltenham, UK; Northhampton, MA, USA: Edward Elgar.

Saporito, R and Mavition, M E (2010) December, Growing Bamboo from Seed. (G. Kyle, Ed.) *Bamboo Bulletin,* Vol. 12, (2), 7-9.

Schlöesser, T P (2004) Natural Fiber Reinforced Automotive Parts. In F. T. Wallenberger, & N. E. Weston, *Natural Fibers, Plastics and Composites* (pp. 275-285). USA: Kluwer Academic Publishers.

Schlumpf - The street hub: Type FS. (n.d.) Retrieved from Schlumpf Innovations: http://www.schlumpf.ch/hp/uni/uni_engl.htm

Schmitz, A (1999-2000) Velocar Variations. *Human Power: The technical Journal of the IHPVA*, (49), 3-6.

Shigo, A L (1991) *Modern Arboriculture: A Systems Approach to the Care of Trees and Their Associates*. Snohomish, WA, USA: Shigo & Trees Assoc.

Slade, G (2006) *Made to Break - Technology and Obsolescence in America.* Massachusetts: Harvard University Press.

Sloman, L (2006) *Car Sick - Solutions for our Car-addicted Culture.* White River Junction, VT, USA: Chelsea Green Publishing Company.

Spielmann, M; Althaus, H J (2007) Can a prolonged use of a passenger car reduce environmental burdens? Life Cycle analysis of Swiss passenger cars, *Journal of Cleaner Production*, (15), 1122-1134

Taylor, A (2010) *Sixty to zero : an inside look at the collapse of General Motors - and the Detroit auto industry.* New Haven [Conn.]: Yale University Press.

Telfer, B (2002) Demise of the rickshaws in the orient. *Human Power: The Technical Journal of the IHPVA*, (53), 19.

Terasawa, I; Tsuneoka, K; Tamura, A and Tanase, M (2008) *Development of Plant-Based Plastics Technology, 'Green Plastic'.* Retrieved from Mitsubishi Motors: http://www.mitsubishi-motors.com/corporate/about_us/technology/review/e/pdf/2008/20e_16.pdf

Urry, J (2010) *Mobilities.* Cambridge, UK; Malden, MA, USA: Polity Press.

Van De Walle, F (2004) *The Velomobile as a Vehicle for more Sustainable Transportation: Reshaping the social construction of cycling technology.* Stockholm, Sweden: Royal Institute of Technology, Department for infrastructure.

van der Lugt, P (2007) *Dutch design meets bamboo.* Eindhoven: [Z]OO producties.

van der Lugt, P (2008) *Design Interventions for Stimulating Bamboo Commercialization - Dutch Design meets Bamboo as a Replicable Model.* Delft: VSSD.

Vélez, S (2000) *Grow your own house : Simón Vélez und die Bambusarchitektur = Simón Vélez and bamboo architecture.* Zeri: Vitra Design Museum.

Wallenberger, F T and Weston, N E (2004) Science and Technology. In F T Wallenberger, and N E Weston, *Natural Fibers, Plastics and Composites* (pp. 3-7). Boston, Mass.; London: Kluwer Academic Publishers.

Yamaguchi, H and Fujii, T (2004) Bamboo Fiber reinforced Plastics. In Wallenberger, F T and Weston, N E, *Natural Fibers, Plastics and Composites* (pp. 305-319). Boston, Mass. ; London: Kluwer Academic Publishers.

Zipfel, E; Olson, J and Puhlman, J C (2009, March). Design of a custom racing hand-cycle: Review and analysis. *Disability and Rehabilitation: Assistive Technology*, Vol. 4, (2), 119-128.

Image References

Figure 1a, Alleweder
http://dutchrecumbenttrike.com/sites/default/files/styles/uc_product_full/public/velomobilekv4kit_0.jpg

Figure 1b, TerraTrike

http://www.velocityracers.com/j/images/VR/trikes/path.jpg

Figure 1c, Greenspeed

http://www.greenspeed.com.au/gs_glyde_sm.png

Figure 1d, Trisled Avatar

http://www.trisled.com.au/images_content/avatar_spec_photo_02.png

Figure 2a, Solarlab Rickshaw

http://www.dodevice.com/wp-content/uploads/solar-rickshaw.jpg

Figure 2b, Sinclair X-1

http://www.sinclairzx.com/i/x-1-spec.jpg

Figure 2c, Go-One

http://www.go-one.us/wp-content/uploads/2010/12/evo21.jpg

Figure 3a, Rinspeed BamBoo

http://www.egmcartech.com/wp-content/uploads/2010/12/rinspeed_bamboo_concept_images_001.jpg

Figure 3b, Mini Biomoke

http://images.theage.com.au/2010/08/04/1740425/MINI_02_L_m-600x400.jpg

Figure 3c, Toyota 1/X

http://4.bp.blogspot.com/_cLWqMZQ1CPk/TO3p3KF90jI/AAAAAAAAEls/C7kovcn7Y-U/s640/toyota_1_x_0_430.jpg

Figure 4a, Setagaya 1

Hybrid Junior High School Student Buggy "SETAGAYA 1". (2007, May). *Car Styling, 178*, p. 93

Figure 4b, Craig Calfee bamboo bike

http://eco-artware-notes.com/wp-content/uploads/2011/02/feb10-calfee-bamboo-bike.jpg

Figure 5a-b, Authors own images

Figure 6a, “Bamboo connection in metal by Japanese architect Shoei Yoh”

Vélez (2000, p. 108)

Figure 6b, “Bamboo particle board panels made with flakes”

Hidalgo (2003, p. 183)

Figure 6c, “Surfboard manufactured with epoxy resin reinforced with bamboo orthogonal mats by Gary Young in Hawaii”

Hidalgo (2003, p. 187)

Figure 6d, “A beef cow stripping leaves, twigs and small branches from a harvested bamboo pole at Garold Nelson’s RKR farm in Coquille, Oregon”

Lewis and Miles (2007, p. 85)

Figure 6e, “Henon bamboo shoots sliced lengthwise showing the decorative pattern of the nodes and internodes. Moisture oozes from the butt ends”

Lewis and Miles (2007, p. 96)

Figure 7a, Bamboo species

Vélez (2000, p. 158)

Figure 7b, “Various types of phyllostachys bamboo”

Vélez (2000, p. 156)

Figure 8a-8c, Authors own images.

Figure 9a,”The bamboo shoot growing inside the short wooden form.”, “Square *Guadua angustifolia”*
Hidalgo (2003, pp. 352- 353).

Figure 9b-12c, Authors own images