MONASH University

THESIS ACCEPTED IN SATISFACTION OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Design by research ON 6 Dec 2011

[redacted]

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No Restrictions

The Ajiro Tricycle: Sustainable Natural Production through the Development of a Bamboo Human Powered Vehicle

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Supervisor: Mr Mark Richardson

A thesis submitted for the Master of Design (by Research)

Faculty of Art and Design, Monash University, Melbourne, Australia
July 2011

Statement of Authorship

This documentation contains no material which has been accepted for the award of any other degree or diploma in any university or other institution, and, to the best of my knowledge, contains no material previously published or written by another person, except where due reference or image annotation is made in the text or 'reference' sections in this documentation.

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Mr Alexander Vittouris

July, 2011

Preface

"If at first, the idea is not absurd, then there is no hope for it"
-Albert Einstein

For as long as I can remember, I have had a passionate interest in transportation, particularly the automobile. However, in later years, my thoughts turned to an alternative representation of mainstream transport, and I became involved in the development of Human Powered Vehicles[1]. It became apparent that such vehicles were under represented in consumer modes of transport and could offer a combination of car and bicycle attributes.

The need for balancing both *consumption* and *production* is critical for leaving a lasting legacy of design that transcends styling trends. Whilst visual qualities are vital for communicating product design, qualities such as longevity and complete sustainability are equally important.

Tapping into the ability of utilising a sustainable material to its full potential, is an ethical and moral choice on my part. These altruistic thoughts, whilst tangible, afforded a problem with material selection for the basis of such a design, which would not only fulfil the role of providing strength, but also provide the lightness necessary to allow human energy as the only means of propulsion. After much Investigation, it became evident that bamboo, with its vigorous biomass, was a material that not only had considerable strength, but could also provide a lightweight scaffold frame.

The pursuit of *'growing'* a vehicle presented a somewhat paradoxical answer to consumption, initially, an absurd idea to comprehend. However, the more research that went in to the idea, the more I discovered that humans have been manipulating plants from time immemorial for their own needs, through examples such as arborsculpture, bonsai and viticulture. This reinforced that it could well be entirely possible to grow the basis of a frame using a natural approach to production by linking mass production with farming culture.

1 The term *'Human Powered Vehicle(s)'*, abbreviated as *'HPV(s)'* encompass bicycles and other forms of transport powered by human movement. *'Recumbent'* vehicles referring to a seating/pedalling position whereby *"... the pedalling axis* [is] *substantially in front of the rider"* (Abbott and Wilson 1995, 113). These vehicles may have two, three or four wheels. A *'velomobile'* is typically an *"...HPV designed to do the work of a car"* (Fehlau 2006, 29) which has a partial or full fairing covering or encompassing the structural frame, while a recumbent vehicle usually refers to the frame itself, or the style of seating position.

About the Author

Alexander Vittouris had exposure to velomobile 'Human Powered Vehicle' (HPV) culture, design and construction from as early as 1998 through the *RACV Energy Breakthrough* race held yearly in Maryborough, Victoria, Australia.

In 2008, he completed a Bachelor of Industrial Design (Hons.) at Monash University. With his final year project focusing on alternative construction processes through a flat pack fabric covered vehicle concept, it was determined that further research of socially and environmentally aware transport could provide a valuable contribution to transport design.

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Abstract

In order to alleviate social and consumption pressures of mass production, which are reliant on steel and petroleum based resources, it is important to strive for sustainability in the field of personal transportation.

This thesis explores personal mobility in the urban environment, taking into account existing production methods, infrastructure and the environmental impact of raw material consumption. It discusses inertia for the uptake of alternative vehicles, specifically bicycles and Human Powered Vehicles (HPVs), together with the current application of production techniques to form these vehicles.

The design process of the '*Ajiro*'[2] velomobile concept through the application of 'action research' methodology is then explained, whereby active experimentation with bamboo has influenced the shape of the vehicle. This led to a conceptual proposal that explores an agricultural approach to mass production with a process based on plant shape modification. This focused on literally growing a bamboo velomobile frame, thereby avoiding energy intensive post-production processing of the material.

2 *"Ajiro"* refers to a style of Japanese bamboo twill weaving pattern (Hidalgo 2003, 119-123)

Keywords

Arborsculpture, Automobile, Bamboo, Bicycle, Biomass, Composites, Consumer, Consumption, D.I.Y, Design, Ecosystem, Emissions, Farming, Grafting, Human-powered vehicle, Industrial design, Personal transportation, Manufacturing, Mass-Production, Mobility, Natural materials, Planned obsolescence, Prototype, Recumbent, Styling, Sustainability, Social framework, Transport, Trees, Trike, Tricycle, Velomobile, Weaving

Acknowledgements

This thesis and the accompanying research herein would not have been possible without the sponsorship of 'Nissan Motor Co. (Australia) Pty Ltd.', whose funding assistance allowed the realisation of both the initial materials research, grown experiments, as well as the prototype builds and scale model production.

Secondly, I wish to thank my supervisor, Mr. Mark Richardson, for giving me inspiration, encouragement, and support throughout the candidature and believing in the importance of alternative and sustainable transportation. Furthermore, I appreciate the assistance of both Monash University, and the Faculty of Art and Design, for their faith in design research candidates. Lastly, I would like to thank my parents, Bronwyn and Michael Vittouris, for giving me half the back garden for the bamboo experiments, and their support throughout all stages of the research and development.

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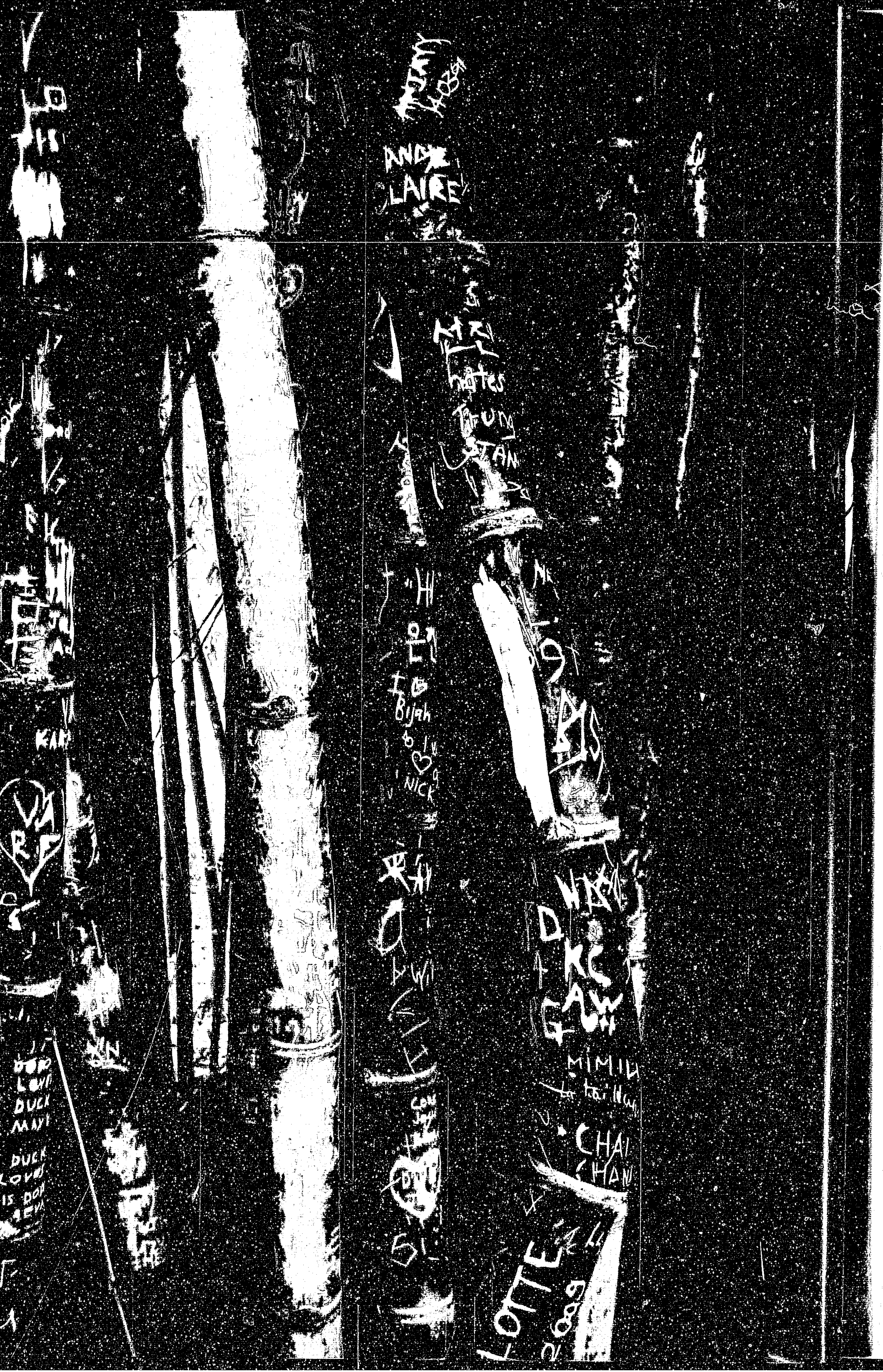
1

An insight into the design rationale, research method and scope of natural design.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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, 262-263; Freund 1993; Litman 2009; Marsh and Collett 1989; Sloman 2006; Urry 2010, 116-130). Historically, governments have investigated policy and future transport planning through measures, such as considering methods for achieving low emissions through systems that involve infrastructural and behavioral change (town planning, carpooling, low emission vehicles and bicycle usage). Whilst these measures are critical for addressing current engine particulate emissions and traffic density, government information on recommending alternative HPV vehicle types beyond bicycles has not been produced at the time of thesis publication[3]. 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"* (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, 147-149; Papanek 2009, 238-241), commuter proposals (Papanek 2009, 264) and racing development (Van de Walle 2004, 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, 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[4] requiring fabrication (for example; steel, aluminium) places pressure on achieving low early lifecycle emissions through material sub-processes of mining and refining (Datschefski 2002,10). Comparatively, in the domestic building industry, steps to invigorate sustainable materials were suggested by the *Montreal Process Implementation Group for Australia* (2008, 112-113), which proposed that *timber* from sustainable forests be used *in lieu of steel* – thereby creating an opportunity for biomass[5] production and carbon storage facility till end of life (see; Buchanan and Levine, 1999, 428; Dias and Pooliyadda, 2004, 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 natural 'living' architectural housing construction through grafting and manipulating trees to form unified, self-supporting structures. Natural processes such as these rely on tending and caring of the living material to encourage growth, accompanied by an

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3 Historical 'Victorian Government' transport planning studies, such as the Victorian Transport Plan (VTP) (2008) and Victorian Transport Study (VTS) (Lonie 1980) focuses on infrastructure, public transport, low emission vehicles and bicycles.

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

5 Biomass is referred to as the leaf canopy that a plant produces for photosynthesis.


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1. Introduction

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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[6] 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, 287-288; Okubo, Fujii and Thostenson 2009; Schlöesser 2004, 277, 279, 284; Yamaguchi and Fujii 2004, 318). Implementation of plant based materials, as seen in the Mercedes C-class[7] (Schlöesser 2004, 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.

> *"If we take action to favour sustainable modes, it will be to the disadvantage of cars,"... "If we act in favour of cars, it will be to the disadvantage of sustainable modes."* (Sloman 2006, 148), Werner Brög survey

This thesis 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, 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, 350-352), i.e., placing removable rectangular moulds over emerging shoots to achieve 'square bamboo' (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.

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

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

1.1 Research Method

The research method used in this project stems from design studio theories which emphasise learning through direct participation (Schön 1987), and diagnosis/evaluation of problems (Susman 1983). Such methodology, called 'Action Research' was developed by Kurt Lewin in the 1940's and interpreted by van der Lugt as *"an intervention in the real world in order to solve a problem"* (van der Lugt 2008, 32). Given the desire to link both the natural object with the manufactured object, it was decided that entry into the field of research should take on an active participation to gain insight into the realistic attributes of bamboo, and how it reacts to conditions and growth patterns.

Van der Lugt (2008), (referring to van der Zwaan 1995) classifies the research strategy as 'action research', whereby *'...it can be considered a field experiment with a practical purpose'*, with:

> *"...the high validity of results through the problem orientated approach; because the intervention takes place in reality, actively involves participants throughout the process and continuously processes their inputs in a step-by-step manner, a high level of learning is created on the spot".* Van der Lugt (2008, 32)

Furthermore, it was deemed beneficial to understand the background of alternative mobility, and consider the motivating factors for change, coupled with seeking to establish the suitability of a natural material for *sustainable* mobility, whereby:

- First, a literature review was conducted, to establish the leaders in the field of natural materials in areas of both production and performance. Additionally, a study of literature describing automobile dominance, consumption, and culturally driven integration of the automobile, was undertaken to provide an understanding in order to establish an alternative approach to production automation and mobility culture. This is where it was established that bamboo could provide fast growing biomass combined with appealing mechanical properties for material harvest over slower growing timbers. (see; ***Section 1, 2, 5, 6***)

- Second, the literature review investigated alternative mobility culture, with focus on personal mobility options of bicycle and HPVs, as well as their respective advantages and disadvantages. (see; ***Section 3, 4***)

- Third, an experimental process combining the research of both bamboo and 'velo' mobility was undertaken, with specific focus on the role that by deforming the growth pattern of bamboo (as described by Hidalgo) it could be possible to produce a harvestable vehicle frame. To appreciate the intricacy of a horticultural field, further investigation regarding material growth behavior was deemed to be valuable to provide empirical knowledge. The experimental growth behavior of the plant was supported by a full size metal frame prototype to verify the proposed vehicle structure. (see; ***Section 7, 8***)

2. The conflict of mobility and amenity

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, 20; Sloman 2006; Urry 2010, 118-119). Furthermore, the 'ideal' metropolis, created through decades of road and highways infrastructure investment as a 'solution' for personal mobility[10], was based around *building a car utopia* or *automobile city* (see; Newman 2003, 52; Mees 2010, 5-10; Sloman 2006, 44; Urry 2010, 112-134); and thereby enabling urban expansion with limited transport alternatives to the car (Currie and Senburgs 2007).

> *"...modernist urban landscapes [that] were built to facilitate automobility and discourage other forms of human movement"*
>
> (Freund 1993, 119).[11]

An ideal approach towards mobility would encompass diversity of transport alternatives (Mees 2010, 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, 241-245; Ryan and Turton 2007, 3, 38-49) and occupant vehicular packaging (Mitchell, Borroni-Bird and Burns 2010, 54-60; Papanek 2009, 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, 74-75, 89-91).

10 Further detail on automobile based city planning is described by Bel Geddes (1940, 240, 245).

11 Factors which may motivate change in transport usage or habits seem to be strongly reliant on energy costs (Pickworth 2007) and general economic outlook (Puentes and Tomer 2008, 3).

The scope of this research is primarily one of material exploration and assembly process development, and this approach results in direct problem solving for the given application, in this case the suitability of bamboo for sustainable mobility. The nature of a practical approach to problem solving takes place through direct observation of the growing material, taking part in experimentation through numerous prototype investigations and consequential failures. Frauenfelder describes the process of D.I.Y. problem solving as a method of trial and error investigation, whereby failures are expected as part of the journey of both discovery and learning, citing that the challenge of 'making' as giving *"...permission to make mistakes, to break things, to fail"* (Frauenfelder 2010, 23), yet also the relative joy and satisfaction gained from approaching any discovery by yourself (217-223). Assessing the failures provides a point of reflection (Cherry 1999) for modification of subsequent prototype revisions, a process which is embedded in the action research approach. This was instinctive, given there was constant prototyping of both plant based and full size steel models.

1.2 Research Objectives and Scope

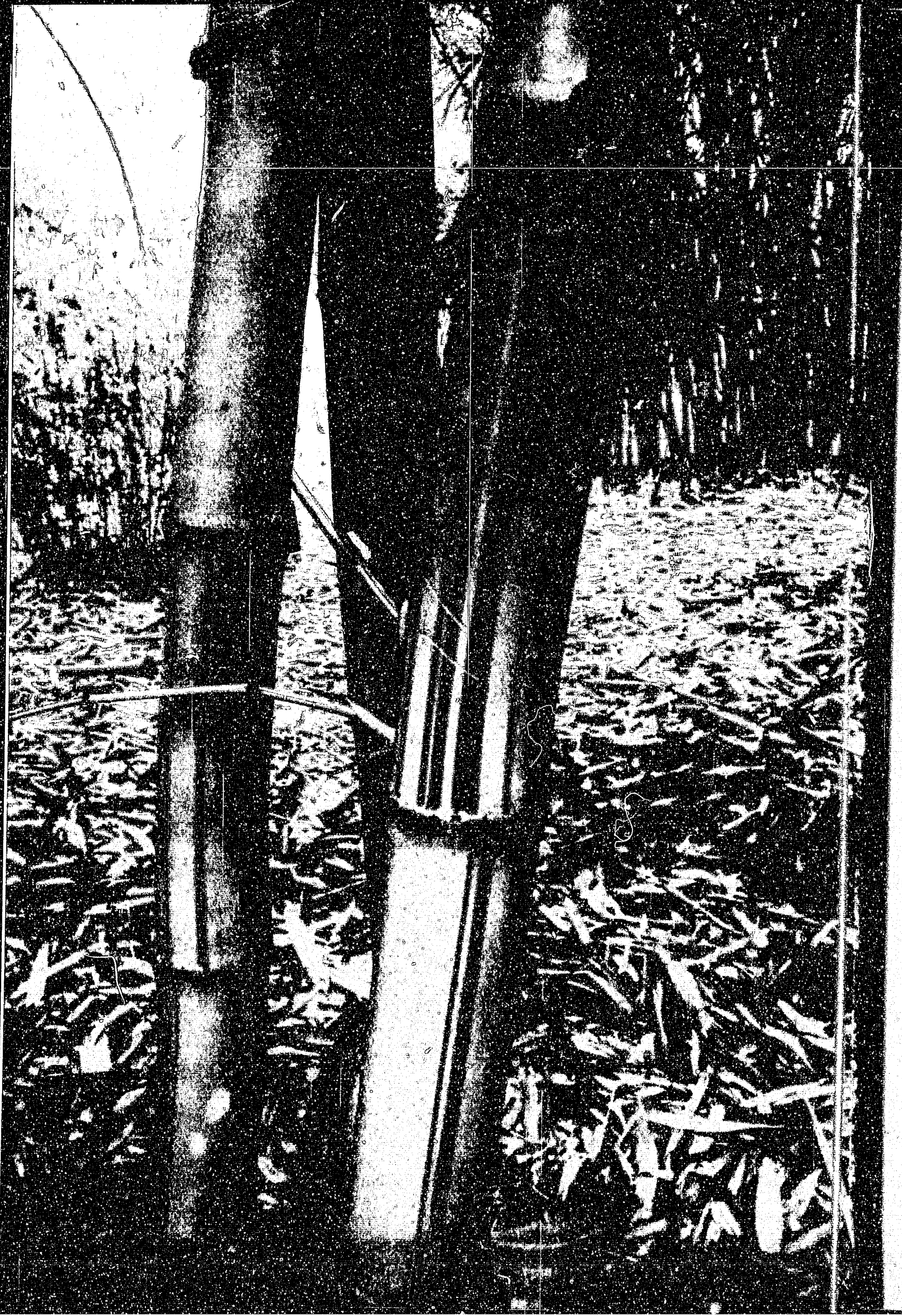
Given the condensed timeframe of the Masters research, the main objective has been to investigate the option of harnessing the natural growth cycle of bamboo and so establish it as a viable material for personal mobility applications. The research aims not to provide a definitive answer to completely recommend the usage of bamboo in personal mobility applications, but rather, to open the discussion for future, focused research. Additionally, bamboo has an unpredictable growth cycle (see; ***Appendix F, G***). It would have been beneficial had a larger number of mature plants been acquired in order to experiment further, however, funding limitations[8] and time for thorough plant establishment[9] resulted in constraints being placed on developing a full sized concept.

The outcomes for the research include:

- To summarise the suitability for urban velomobile usage over the bicycle and automobile
- To undertake material exploration into the suitability of bamboo for the intended purpose of making a velomobile
- To devise and undertake experiments into growing and deforming bamboo, forming complex shapes
- To make a full scale working metal prototype to determine dimensions, structure and functionality
- To make a scale model to represent the intended visual characteristics of the suggested design

8 Mature plants of approximately 1.5 meters (300mm tub) tall had a retail price of approximately $250 each, with larger 4 meter plants costing $500. Larger tub diameters than 60cm incurred additional expense, however, these plants were established for a longer timeframe, and had a higher likelihood to produce new culms.

9 Freedom from constraints such as obtaining expensive bamboo plants may be alleviated by growing seedlings; however, considerable time is needed for the plant seedlings to reach maturity. Seedling experiments are explained further in ***Appendix G.***



2

Current personal mobility, urbanisation and the mass production methods used to create transport.

2.1 Current production methods and responsibilities

> *"...is there a great difference in the car from those puttering little vehicles of the dawn of motoring? The engine works on the same principals, the fuel is the same, the methods of starting, moving and stopping are very similar, the conventional layout is similar, the driver still has the same pedals and levers to manipulate as he did 80 years ago. Are we perhaps still right at the beginning of the business of personal road transport, a minute part of the way along the road of motoring history...?"*
> (Roberts 1983, 128)

Deemed to be "one of the most significant landmarks in motoring history" (Horton 1992, 210), the Ford Model T, launched in 1908, implemented the beginnings of 'just-in-time' mass production[12] 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 what is known as "lean production" (see, for example; Ellegård et al. 1992, 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, for example; Holstein 2009; Ingrassia 2010; Taylor 2010).

Globalised manufacturing through the outsourcing of design and individual componentry are intensively used by automobile makers (Mikler 2004, 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, 58-59) and disposal at end-of-life (Davies 2003, 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 (4); however, the degree of material processing depends upon an element of *downcycling* (McDonough and Braungart 2002, 56-59), and *'Design for Disassembly'* (Papanek 1995, 42-43, 238-240).

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

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, 1123, 1132; Slade 2006, 5). Slade states that, General 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, 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, 110-176). (see; ***Appendix A***) 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, 82), such as energy intensive mining and smelting steel, become an unknown factor for the consumer (Datschefski 2002, 10) who sees the final presentation of the product only in the retail shop.

Describing the engagement of the *creator* with the *product*, Frauenfelder writes of the relative pleasure derived through *experiencing* product creation as a D.I.Y process of active learning and interaction with the item, whereby:

> *"The planning, selection of tools and materials, creation of the workspace, method of construction, documentation, and final product of a DIY project are things to be savoured, not to be thought of as hassles or expenses. The end result of what a DIYer makes is important, but it's also a reminder of an experience that serves as its own reward."*
> (Frauenfelder 2010, 220)

In this case, Frauenfelder's experience is the opposite of the notion that buying more and more items will somehow lead to increased fulfilment (or happiness) in life (26), yet he describes interaction with items that he makes as rewarding, because he gains knowledge of the complete production process, from inception to realisation. *Mass consumption,* rather than extending product lifecycles by handing items down through generations, or repairing broken items, may develop an overreliance on obsolescence to create corporate 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, 51).

3

Alternative personal mobility.
Investigating the current use of bicycles and their infrastructure.

3. Mobility alternatives – The bicycle

> *"If car design had followed the same path [as cycle design], we would be driving Model A cars with titanium frames and the hand crank would be carbon fibre."* (Hadland 1994)

Considering that modern culture regards the automobile as a *"...prized possession that people will strive to retain"* (Lonie 1980, 140)[13], 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, 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[14]. 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), topography is hilly, (Parkin, Riley and Jones 2007, 80), or where transiting links (Mees 2010, 3) and poor, infrequent public transport service hampers commuting reliability [15] (see; Mees 2010, 111; Sexton 2009b). This is where the mechanical speed / power and convenience of the automobile is advantageous in large urban sprawl areas compared to the bicycle, with Sloman (2006), describing that:

> *"If you have one, a car has a lot of obvious advantages. It gets you to places that would be difficult to reach by public transport. It offers the luxury of not having to plan ahead – you can decide to nip into town, and there is no need to wait an hour for the next bus, or to time your trip so you can catch the last one home. If you can afford an expensive model, your car tells other people something about your status....Cars make us feel in control."* (17)

---

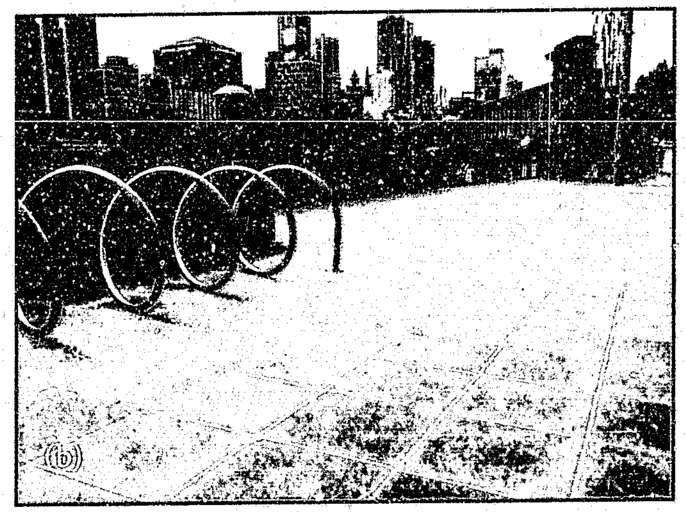
13 Although this report on transport infrastructure dates to 1980, it demonstrates the reliance of road infrastructure in planning, outcomes which have resulted in the development of roads that are in use today ('Monash' M1 Freeway - Melbourne). Usage of the car by individuals is reflected in government roads budgets.

14 The bicycle proposed advantages of personal mobility over those of rail travel by "...freeing cyclists from the train, locality and timetables and generating a sense of autonomous movement and speed" (Urry 2010, 112-113).

15 Linking all the public transport networks (bus, train and tram) with cycle routes and bicycle parking could aid in the convenience of promoting 'park and ride' commuting, expanded through Bicycle Victoria's *'Parkiteer'* secure bicycle parking at selected metropolitan train stations. Rees (2010, 191) does not advocate mass adoption of taking bicycles on-board trains, given space restrictions within carriages.

Figure 1: Cycling infrastructure, comparison: Melbourne, Australia; Amsterdam, The Netherlands

(a)



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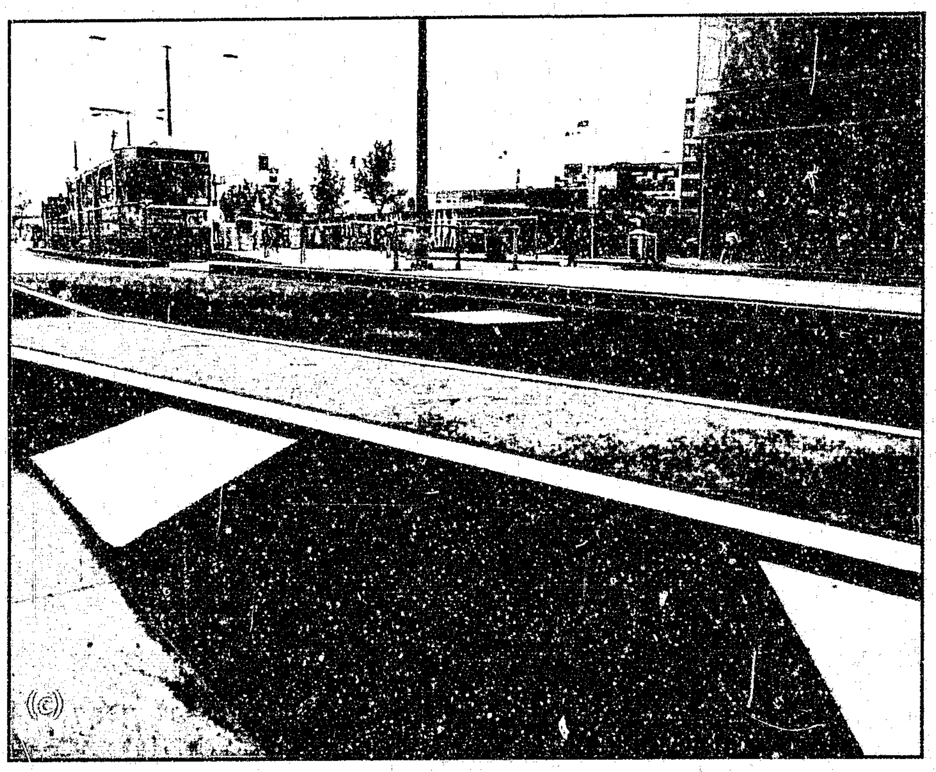
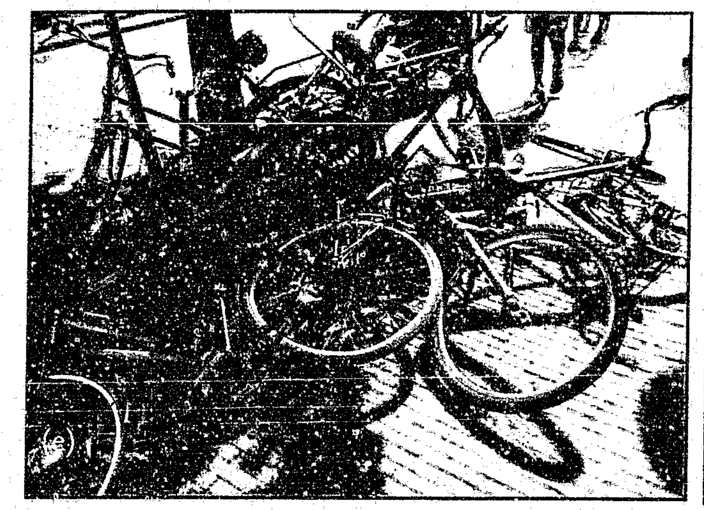
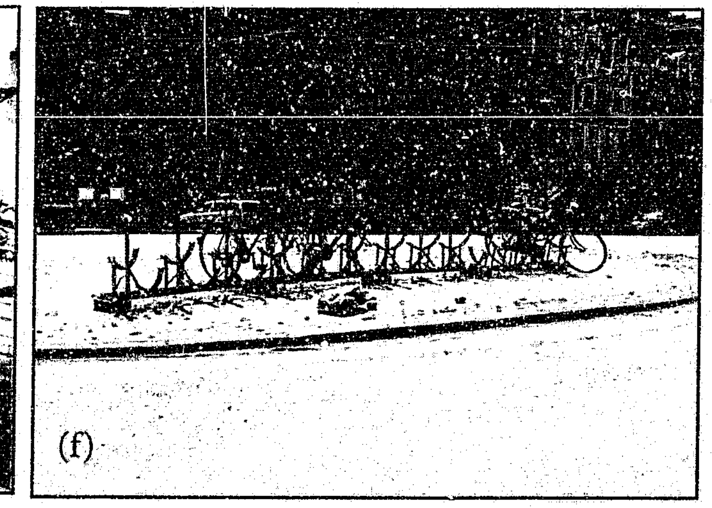


(c)

Figure (a)-(d): Melbourne
(a): Clusters of bicycles locked to 'hoops'
(b): Bicycle parking fixtures in Southbank
(c): Dedicated bicycle lane in Docklands
(d): Shared pedestrian/ bicycle path, Gardiners Creek
Trail, East Malvern

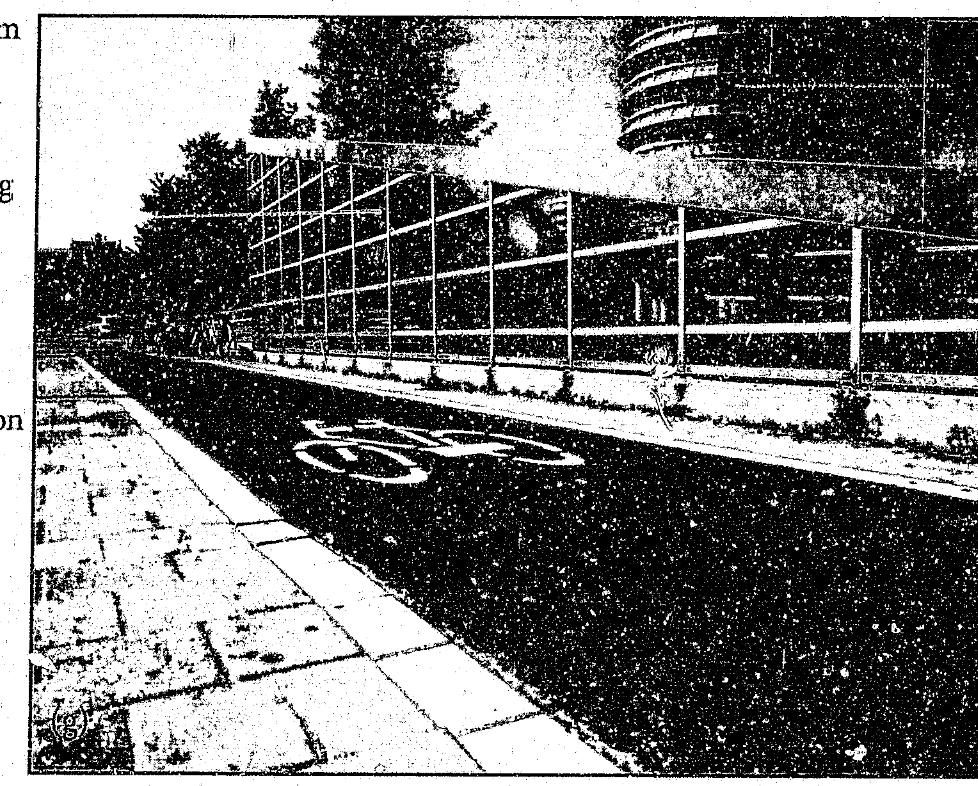
(d)





(f)

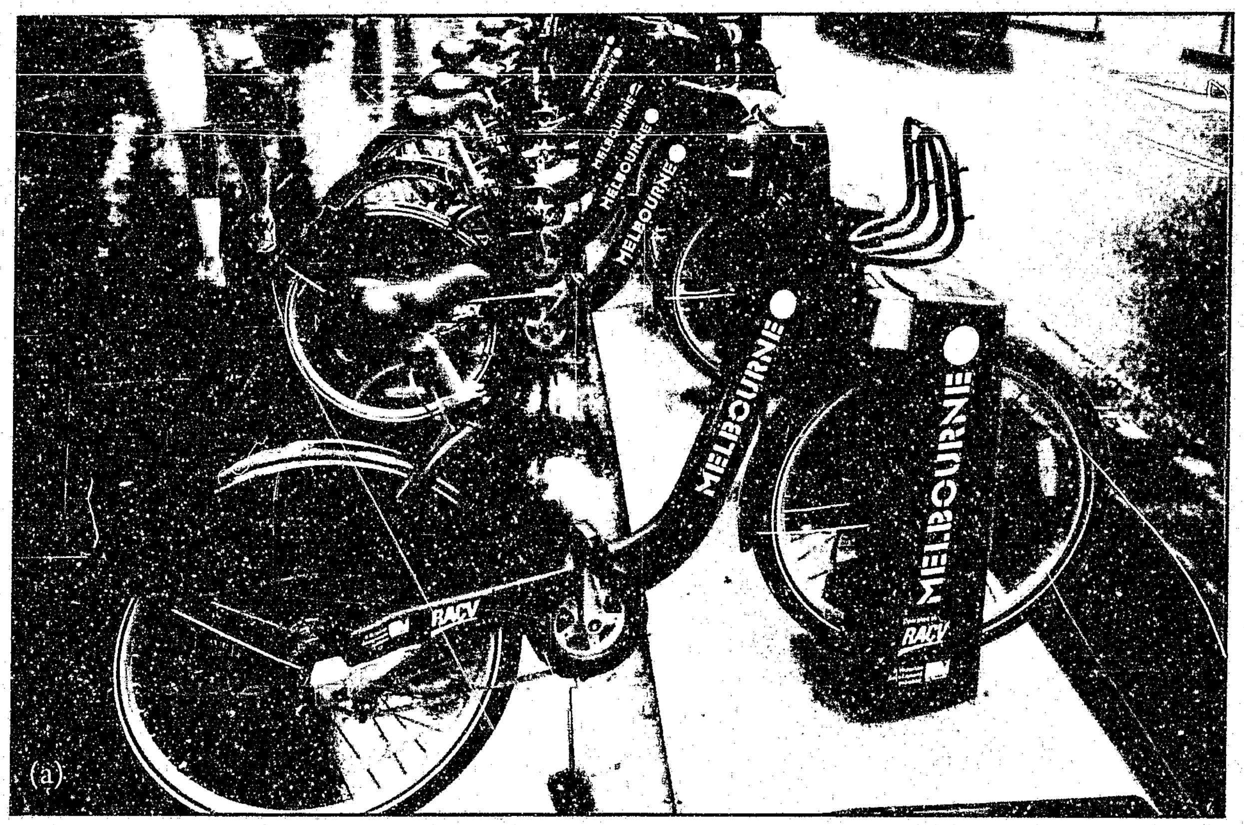
Figure (e)-(h): Amsterdam
(e): Unlocked bicycles randomly clustered
(f): Bicycle parking fixture
(g): Dedicated bicycle lane near Central station
(h): Separated bicycle lane from on street parking



(g)

(h)

Figure 2: Melbourne Bicycle Share Scheme



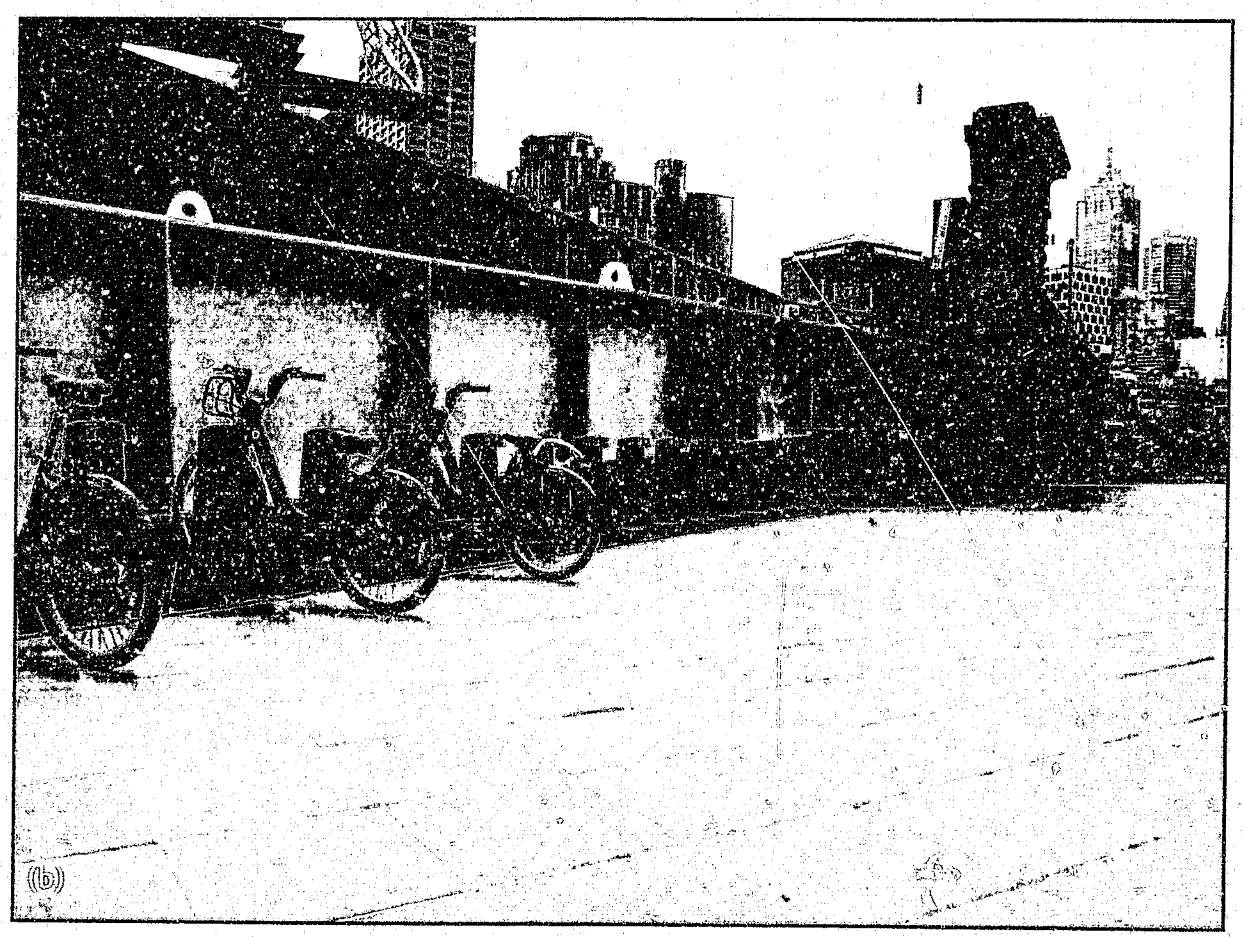
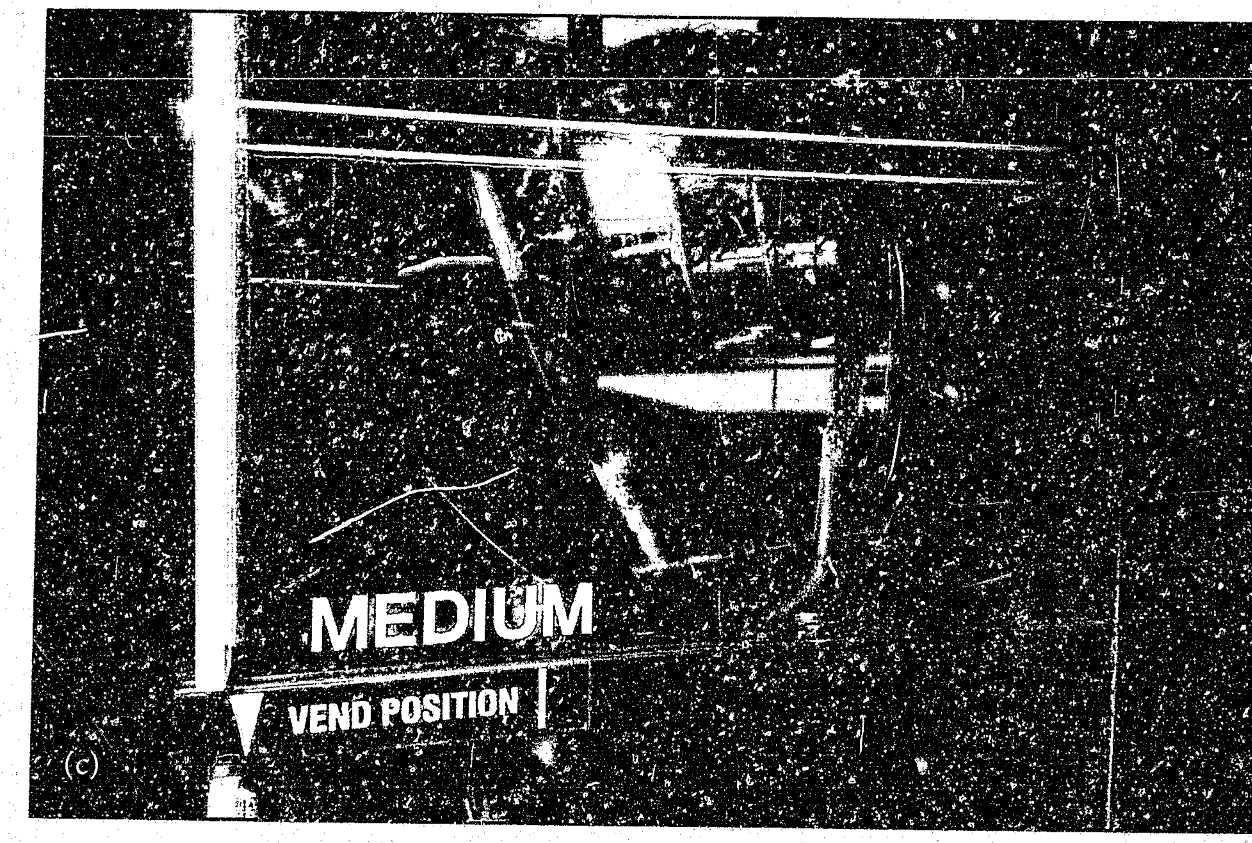


Figure (a)-(b): Vending layout for bicycles in Elizabeth Street (a); Southbank (b)



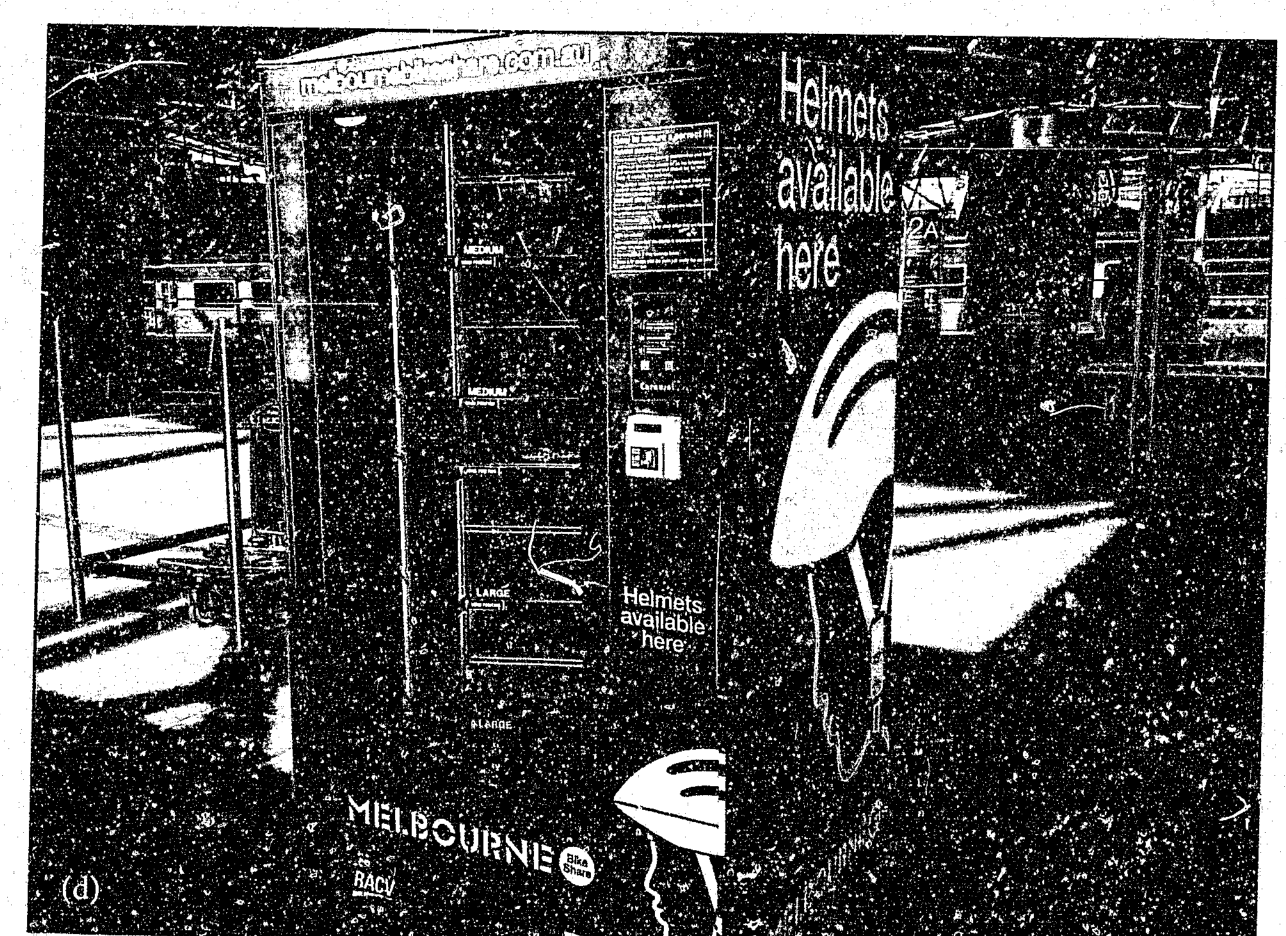


Figure (c)-(d): To comply with compulsory laws, helmets are available through vending machines (pictured here at Southern Cross train station); the helmets are sold for $5, which is taxpayer subsidised.

However, the bicycle also provides a low cost, compact, reliable, and convenient form of transport (see; Mapes 2009; Hurst 2009) in countries such as the Netherlands[16] (see; ***Appendix B***), where the bicycle is treated as a normal, everyday means of transport[17], year round, regardless of weather conditions. Comfort and luggage capacity (Cox 2010, 128-129) together with flexibility and safety perceptions, are areas where improvements could be made. These points remain a concern and barrier to cycling adoption - and therefore an advantage to automobile culture (Richardson, Vittouris, and Rose 2010, 3-4). Factors encouraging usage in this case indicate 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 contribute to quick and short commutes (64) ***(Figure 1a-1h)***.

An example of a successfully integrated public bike share system is found in Paris where the Velib is available free for the first half hour. This system creates a new element in the public transport mix of *individual* (Cox 2010) travel as opposed to the usual *collective* system as we know it in bus, train or tram commute. The local equivalent to the Paris bike hire scheme in Melbourne, Victoria ***(Figure 2a-2d)*** suggests that patronage (at the time of thesis publication) of the scheme is "...*disappointing*" (Preiss 2011), with commuter deterrents such as compulsory helmet laws (The Age, Editorial 2010) contributing to the lack of use for impulsive trips such as short errands or quick links between other modes of transport (train station to tram or bus stop). As such, this would seem to indicate that investment, while worthwhile in transport diversity, can only succeed if public perception is lived up to in the execution of the infrastructure. Evidence of investment ahead of current levels of demand, evident during the development of bicycle infrastructure in Portland, Oregon, (see; Mapes 2009, 141-168; Dill 2009; Dill and Carr 2003) suggests that *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.

Solutions to the handling of bicycle infrastructure, when promoting cycling as a part of daily life, are many and varied, with John Forrester (1993) actively encouraging defiance against separation[18] of cycling and road infrastructure, arguing that cyclists have the "right to the road"[19] (see; Hurst 2009, 100-102, 136; Mapes 2009, 43). Mapes also cites informal protests such as those through the activist group "Critical Mass" (2009, 99) as raising the awareness of cycling to both motorists and the general public.

16 According to Mapes (2009, 84), immigrants to the Netherlands from other European regions are less likely to be cyclists, which possibly indicates immigrants exposure to car culture, or lack of exposure to bicycle culture.

17 Bicycle use is being abandoned in regions of China, whereby *"...60 per cent of Beijing's work force cycled to work in 1998, but only 20 per cent cycled in 2002."* (Gilbert and Perl 2008, 75)

18 It is described by Mapes (2009, 43) and Abbott and Wilson (1995, 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).

19 There has been press discussion that cyclists should pay registration fee for the right to use their bicycles on the road network, which is primarily funded through automobile users. However, as described through a media article written by Sexton (2009a), most bicycle riders also have a drivers licence (and car).

Further discouragement of automobile transport[20] is cited by Gilbert and Perl (2008, 2, 119-136) and Hurst (2009, 134), through the reasoning that making automotive mobility unaffordable through petroleum price increase, will force consideration of modal use. Though forcing the consumer to abandon automobile travel is described as valid for European regions, where *"...the workforce tends to live close to their jobs"* (ibid), the application of such a technique in Australia may set up disadvantage based on where a person lives (Lowe 1990, 5), or their income, as a consequence of factors such as regional job availability, housing affordability in CBD versus outer suburbs, sedentary or active lifestyles (Sloman 2006, 26, 43) and the transport infrastructure available (either car, bicycle or public).

3.1 Distributing bicycles through reuse / D.I.Y.

Addressing transport accessibility to poorer communities could be derived from either diverting obsolete or unwanted bicycles through donation programs such as the African *'Bicycle Empowerment Network'* (Cox 2010, 145) by restoring or rebuilding bicycles for distribution. Furthermore, bicycle recycling programs in western countries, such as *'Re-cycle'*[21] or *'Australian Goodwill Bicycles Abroad'*[22], provide relief from transport inequality with a much more efficient[23] method of travelling long distances than walking (Cox 2010, 142). Initiatives such as Afribike, supported by The World Bank's Rural Travel and Transport Program (see; White, Erlank and Luzolo 2004; Servaas 2000), offer training in bicycle repair and maintenance, and therefore a pathway for employment and supporting the community.

The relative simplicity of the bicycle allows for both low production designs, through developments such as the *'Bamboo bike'*[24] by Craig Calfee ***(Figure 3a)***, and D.I.Y (Do-It-Yourself) bikes; *'OpenCargoBike'* (Moreno and Wagner 2010, 172-173) ***(Figure 3b, 3c)***; *'Berlin Bamboo bikes'*[25] workshop; *'Cognitive Cycles Bamboo Bikes'*[26], or bamboo recumbents made by Klaus Volkmann[27], whereby the traditional, intensely refined ore based materials such as

20 *"Charging for congestion"*, is described by Mees (2010, 44-49) as a possible method of reducing automobile use, however, the model of "road pricing" applied in Singapore appears to make *"...car travel more attractive, especially for those who can afford to pay the charge"* (47)

21 See; http://www.re-cycle.org/

22 See; http://goodwillbicycles.com/

23 The bicycle is said to be 5 times as efficient as walking by Gallagher (1992, 49), because the rider conserves his energy by sitting down and pedalling in a smooth, continuous motion (unlike walking where the feet hit the ground and the body rises and falls). Mees (2010, 38) states that: *"Walking and cycling produce no greenhouse emissions and are the only truly sustainable travel modes. Public transport generally produces lower emissions per passenger than cars, but the difference depends on..."* propulsion energy source (electricity from coal, nuclear, solar...) and occupancy (number of passengers).

24 A similar type of bamboo bicycle is also described by Hidalgo (2003, 534)

25 See; www.berlin-bamboo-bikes.org/ride

26 See; www.bamboobikes.com.au

27 See; http://ecobamboobikes.blogspot.com

steel[28], aluminium or carbon fibre tubular sections, have been replaced by bamboo culms.

Although the bicycle is geometrically simple in its parts (Manzini 1989, 100-101), such methods of construction for bamboo bicycles rely on cutting and joining sections to form the bicycle frame, which is a labour intensive, low volume and skilled process, which is reflected in the retail price for Calfee Designs bicycles, exceeding $4500USD. Part of the issue with asking a premium price for a material which has traditionally had poor 'product associations', is realised through perceptions of bamboo via interviews conducted by van der Lugt:

> *"Because in the past bamboo was used in many low end traditional products of poor quality, bamboo as a resource is commonly associated with these products... product associations [such as] "rustic furniture"... "fences", "basketry", "fishing rods" and "plant supports"...bamboo is commonly associated with China, a country that currently has poor image in sustainability...and quality. In general, people also believe that giant pandas only feed on bamboo and could go extinct because of the mass harvesting of bamboo for material production in China."*
> (van der Lugt 2008, 317)[29]

The case that Calfee presents can be reinterpreted as elevating the prestige of bamboo, as not only being a sustainable material choice, but also one which has unique technical advantages, such as allowing the feel of the bicycle to be fine-tuned through the use of different sub species of bamboo. Advocates for development of bamboo bikes state that the aim of a natural material approach is to utilise a locally obtainable resource, whereby bamboo, as a general material can contribute to the local economy and be utiliesd for a range of different construction purposes (Moktan, et al. 2009), including that of the *'Bamboo Bike Project'*[30]. However, a purely 'bicycle' orientated approach may not be suitable for every application of mobility, such as the need to carry cargo, or for example, transport patients to hospital. Therefore, encouraging diversified structure of the vehicle itself through velomobiles, or rickshaws, could provide an opportunity for specialised and adaptable mobility, with minimal reliance on the automobile.

28 The amount of resources for material refinement is highlighted by Datschefski (2002, 10), whereby a chair has; *"... the steel for the frame...made in Europe from pig iron from ore that had been dug out of huge open-cast mine in Brazil that had originally been forested land. The mining took a lot of energy -- digging, crushing and processing metal ores uses 7% of global energy consumption. The steel mill burned about 20kg of coal to make the steel for my chair."*

29 The relative barriers to Western cultural adoption of bamboo and perceptions are discussed by van der Lugt, van den Dobbelsteen and Abrahams (2003).

30 See; www.bamboobikeproject.org

Figure 3: D.I.Y. creation of bicycles

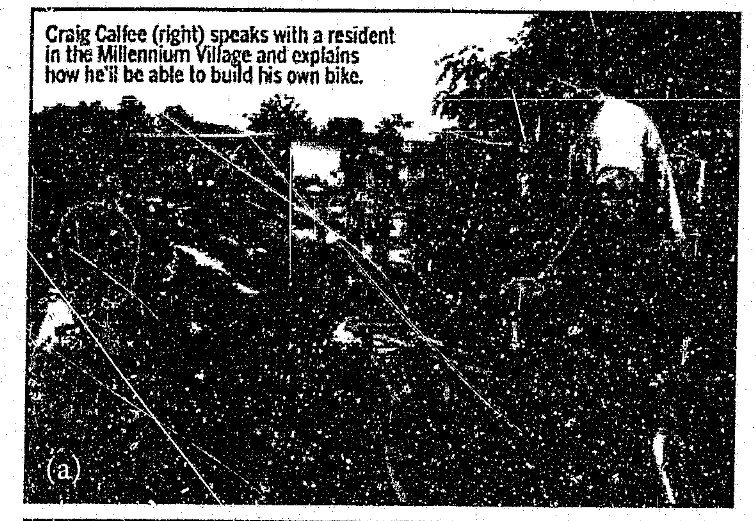


Figure (a): Craig Calfee bamboo bicycle

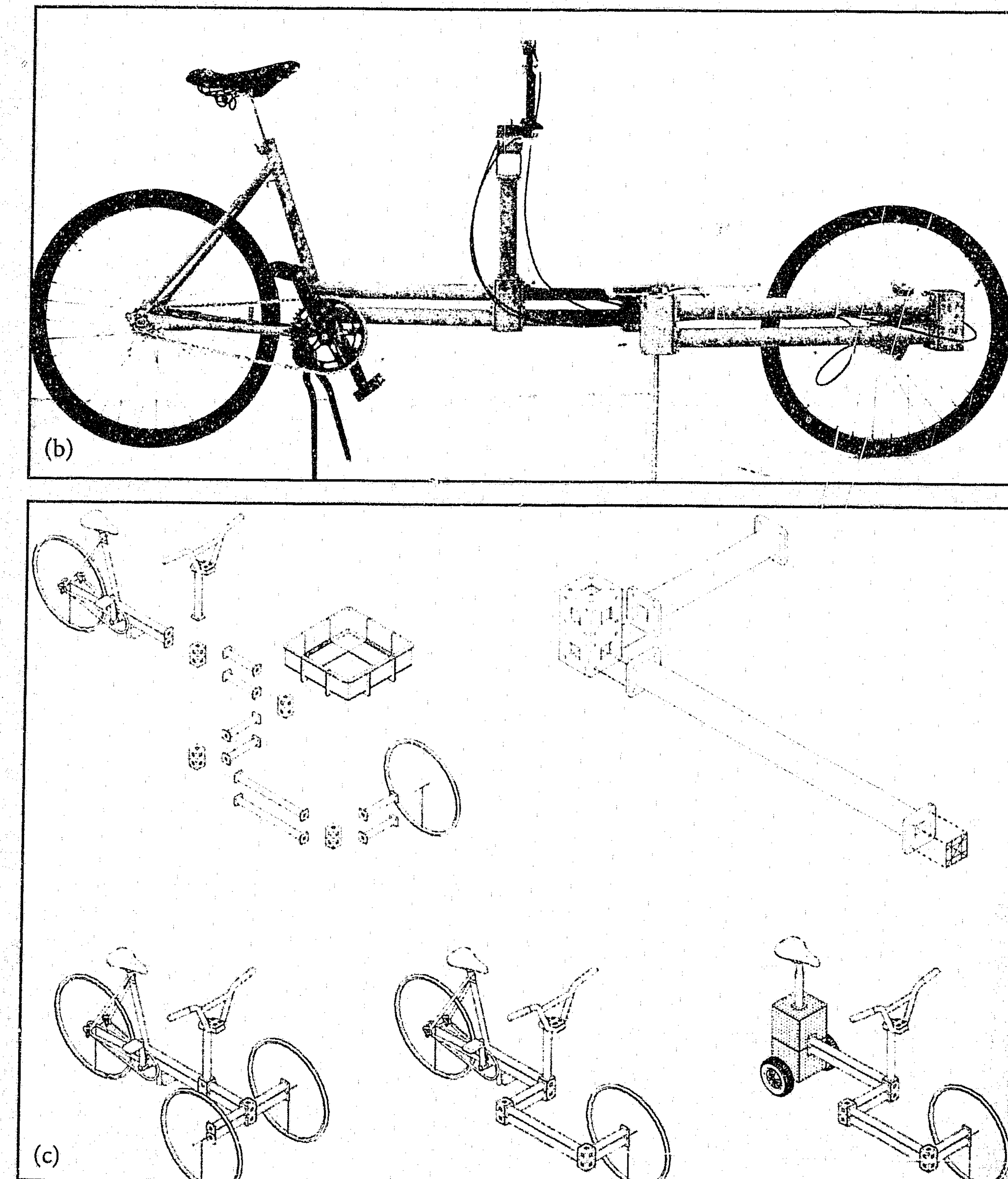


Figure (b)-(c): 'OpenCargoBike' can be reconfigured to suit the user, and uses a number of repeated parts for the frame construction (Moreno and Wagner 2010, 172-173).

4

Human Powered Vehicles (HPV's). Current velomobile usage and the proposal for commuter use.

4. Human-powered vehicle alternatives to the bicycle

The production of the bicycle, when introduced, had an effect of providing *"...autonomy from timetables provided by horse-based travel"* (Urry 2010, 113), an outcome further popularised by automobile use which provided comforts of an enclosed space (see; Marsh and Collett 1989, 11, 25, 53, 156-161; Mees 2010, 13; Sachs 1992, 9).

Early adaptation of bicycles to be enclosed with partial/full fairing was used to create streamlined forms to enhance speed for racing or breaking records (Abbott and Wilson 1995, 99-103). Diversification of human-powered vehicles brought advantages to traditional bicycle culture by: *"...tak*[ing]* less energy, go*[ing]* faster...safer and more comfortable, provid*[ing]* more weather protection, and even are more manoeuvrable than standard bicycles"* (Abbott and Wilson 1995, 110, 258-259). However, there are also 'handicaps' to this form of vehicle, namely additional complexity, package design, weight, maintenance, strange appearance *"...prompting comments from passersby"* (Abbott and Wilson 1995, 111) and road visibility / intergration issues (see; RTA Submission to the Staysafe inquiry into vulnerable road users – Motorcyclists and cyclists 2010, 109-110). It is also noted that barriers towards commuter adoption of HPVs need to be solved through engineering, design, convenience and safety (118, 257):

> *"...HPVs will probably remain a very minor part of the future transportation mix. However, the technology of lightweight high-efficiency, low-energy-consumption vehicles that has been developed for HPVs may have an important impact on future transportation."*
> (Abbott and Wilson 1995, 111)

Recumbent vehicles can come in two main formats, either *semirecumbent*, or *fully recumbent*, whereby the latter is generally only used for racing and speed attempts because vision is obscured from the near horizontal rider position – making it difficult for both rider and other road users (Abbott and Wilson 1995, 113).

The semirecumbent style is noted as being safer than regular bicycles (Abbott and Wilson 1995, 118) because of; low set steering controls reducing handle bar injuries of traditional bicycles; reduced likelihood of pedals touching the ground during cornering; ease of steadying the vehicle during hill descents by applying feet to the ground surface and, relaxed seating which promotes communication with other road users (see; Fehlau 2006, 37, 41-42, 45).[31]

Broadening the HPV category further, are vehicles such as Velomobiles/Velocars – which are three/four wheeled recumbents (Abbott and Wilson 1995, 114-116; Schmitz 1999-2000). These offer the suggestion of automobile alternatives, which can provide storage, fairings and multiple seats in many combinations, while in both Asia and India, rickshaws and cycle-rickshaws, remain popular for passenger and cargo use (see; Cox 2010, 165-188; Gallagher, 1992; Telfer 2002).

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31 Criticisms of recumbents, such as *"...that they can't climb hills, that they're dangerous in traffic... spring from ignorance, and have more to do with fear of the unknown than with reality"* (Fehlau 2006, 1).

4.1 Velomobiles

Cox (2010, 129), citing Van de Walle (2004), describes the velomobile as being *"…the ultimate level of innovation in human-powered vehicles…which encloses the seated* [sic]*-positioned rider within an integral bodyshell, providing weatherproofing and luggage-carrying capacity".* Fehlau (2006, 43) reinforces these points, also describing *"the velomobile* [as] *a vehicle designed to replace a car…They have thorough waterproofing, cargo capacity and safety features – and often full fairings which give them plenty of speed."*

Therefore, it would seem that the velomobile links aspects from *both* the bicycle (human power or assisted propulsion) *and* the automobile, by offering an enclosed space for the occupant and comfort of a seated position, together with luggage capacity[32], resulting in a hybrid package.

Fuchs (2001), states that the velomobile is a *"…fully faired recumbent vehicle for everyday use".*[33] Nevertheless owing to bicycle and road infrastructure, promoting the features of these low volume production HPVs (as well as recumbents and velomobiles) is somewhat difficult as:

> *"…improvements in vehicles* [automobiles] *and roads may increase the use of HPVs somewhat, a large shift in the methods and patterns of transportation would require aligning the costs and benefits of alternative forms of transportation to more closely represent actual economics."* (Abbott and Wilson 1995, 258)

Evolution of design and construction have progressed throughout the years ***(see Appendix C)***, with carbon fibre, fibreglassing and CNC moulding techniques becoming accessible to D.I.Y practitioners ***(Figure 4h)*** for one off or small scale production (Van De Walle 2004, 63). These methods contribute 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 and Van De Walle 2007, 127). Recognisable brands promoted for daily urban use, include off-the-shelf solutions consisting of faired and non-faired recumbent tricycles – which could be modified by the end user - from niche makers[34]: Alleweder ***(Figure 4a)***, TerraTrike ***(Figure 4b)***, Greenspeed ***(Figure 4c)*** or Trisled ***(Figure 4d)***, where much of the development of velomobiles is the result of individual D.I.Y contribution (Van De Walle 2004, 61).

Design concepts which diversify into hybrid electric vehicles such as the Sinclair X-1 ***(Figure 4e)***, Go-One (electric option) ***(Figure 4f)***, Solarlab Solarcab / Rickshaw ***(Figure 4g)***, provide direction for pathways velomobiles could take, yet Cox and Van de Walle describe velomobiles

32 See Fehlau (2006, 124-125)for storage solutions for recumbent vehicles.

33 Fairing design for recumbent vehicles, including discussion of aerodynamics and different materials for their constriction is noted by Fehlau (2006, 140-167).

34 The cost of velomobiles, described by Fusch (2001, 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."*

as having a deficient 'identity' when compared to full size cars. These are compound effects because of relative lack of legal category for classification (Richardson, Vittouris, and Rose 2010, 5), sharing with other vehicles - an issue raised specifically when the electric Sinclair C5 vehicle was released (see; Dale 1985, 168-170). Issues regarding road visibility between the Sinclair C5 and other vehicles prompted criticism from the British Safety Council (Dale 1985, 169), whereby, to date, visibility of recumbents cycles (a category which includes velomobiles) presents an ongoing global problem for debate, while the layout interface and ergonomics integration must be carefully balanced if velomobiles and recumbents are to be recommended for daily use:

> *"..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 De Walle 2007, 126)

Figure 4: Variants of Velomobiles

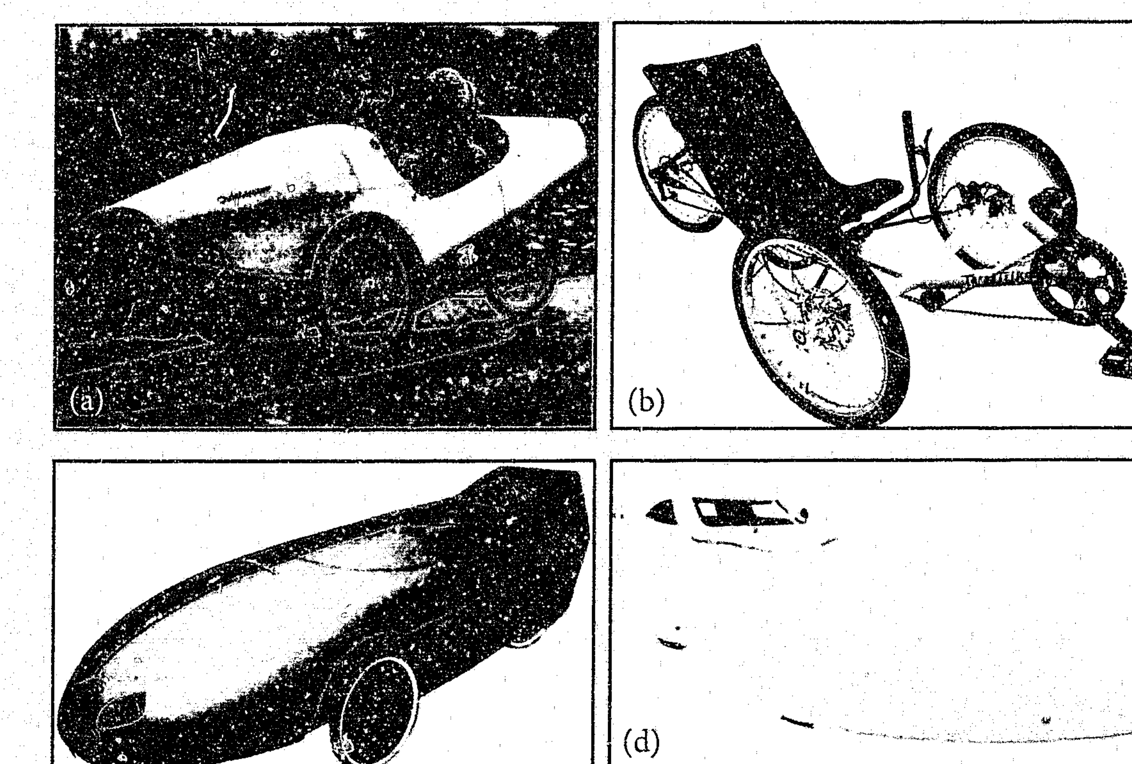


Figure (a): Alleweder
(b): TerraTirke
(c): Greenspeed
(d): Trisled

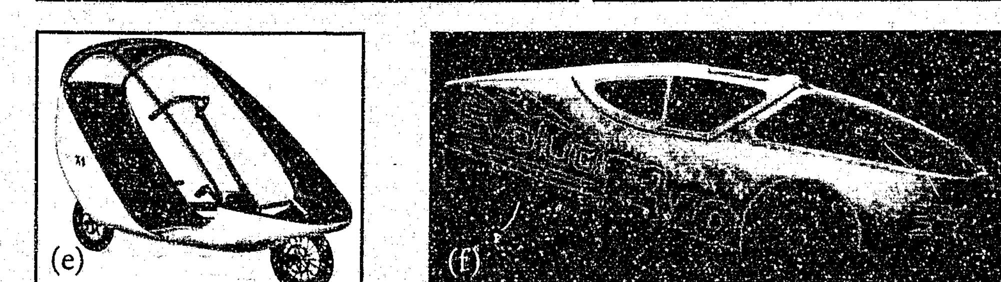
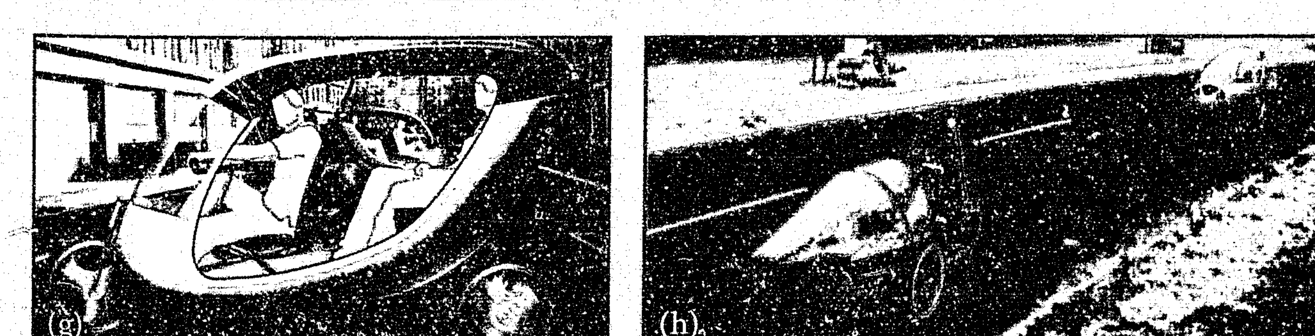


Figure (e): Sinclair X/1
(f): Go-One
(g): Solarlab rickshaw
(h): D.I.Y construction



4.2 Rickshaws for passenger and cargo use

Rickshaws, provide employment for many, in terms of drivers, maintenance, commerce and loads they carry (Gallagher 1992, 6), and 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 dishonorable, yet Gallagher (1992) describes that such a job was no more dishonorable than other forms of manual hard labour (10). Furthermore, the visible imagery of rickshaw pulling was seen to be a representation of an under-developed society. Gallagher also describes that design faults of the rickshaw are mainly the cause of *"...bicycle components* [being] *used in a tricycle role"* (15), with low gear ratios, frame strength issues, brakes and steering inappropriate for the purpose. 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

Alternatives to depleting resources for production through the use of regenerative natural materials.

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, 283). In addition, the natural fibre parts such as Flax/ sisal/wood (door panels), wool fibre moulded material (instrument panel support), and Cotton Fibre (seat backrest panel), save over 22kg in total vehicle weight. Other manufacturers investigating natural materials in automotive usage, such as Mitsubishi Motors[35], developed a similar effect with compression and mixing of fibrous bamboo material with a 'plant based resin', *polybutylene succinate*, and together, both research investigations form the possibility of environmental gain through grown biomass[36], and weight savings which might lead to increased vehicle efficiency.

Global pressures relating to emissions legislation, namely CO_2 production (Smith 2011), indicate that diversity with respect to natural material usage and consumption is critical for offsetting pollution (Montreal Process Implementation Group for Australia 2008, 112).

Whilst the foundation of emissions and legislation regarding limiting carbon dioxide production is still a debate for parliamentary process (Emissions Trading Scheme Discussion Paper, 2008), industry must also be prepared to proactively adjust production habits. For example[37], designers such as Franz von Holzhausen (Tesla Motors) recognise the importance of material diversity stating that:

> *"I think we will no longer see cars made with a majority of steel or aluminium but a hybrid of green* plastics, *metals and environmentally intelligent materials. I would love to see a 100 per cent recycled mass produced vehicle in 20 years and hope to be leading the charge."* (Dominguez 2010)

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 5a)***, promoting bamboo fibre usage through interior componentry ("BamBoo" - the Pure Roots of Mobility), and the Mini Biomoke ***(Figure 5b)*** 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 5c)*** 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).

35 'Plant-based parts', by Terasawa, et al. (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.

36 Carbon sequestration is an additional advantage of using natural materials. Yen and Lee (2011) describe that bamboo has sequestration benefits over timber because of its fast growth and production.

37 Discussed in a media artical, Dominguez (2010) seeks opinions on styling attributes of various vehicles from automotive designers and asks them *"What will cars be made of in 20 years?"*

This shows that ideas concerning material diversification are evident within industry, which hopefully, with further development and practical application, eventuates in consumer variants.

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 6a)***.

> *"I have been thinking for many years about what the best type of body would be for electric vehicles. I thought of wooden structures as Horyuji Temple. With some upkeep, they last more than* [sic] *thousand of years...Wood can be disassembled and reused, and finally it can be burned."* (Fujimoto 2007)

Furthermore, an advocate for natural material use, artisan Kenneth Cobonpue discusses the proposal for natural materials being used for automobiles[38]:

> *"I'm trying to develop a car made out of bamboo and carbon fibre. Is that achievable? I think so, yeah."* (Morris 2009)

An approach to body design which would allow material composting at end of life could be proposed though regeneration of biomass from plants, rather than recycling materials which require further refinement before reuse. Dr Christopher Cattle, a practitioner of grown furniture ***(Figure 6d-6e)***, describes in his dissertation for grown furniture, (Cattle 2002) that natural materials such as timber having an advantage over *the 'extraction and conversion to the raw material'* (14-15) required by ferrous and plastic pressed materials, with natural materials creating the feeding ground for future crops from either their own waste matter (ie. leaf litter, damaged branches decomposing) or their remnants[39]. Green (2006, 20), describes wood as *"...organic, associated with nature in its wild and domesticated forms"*, whereby modification of the natural material, imposed by mass production to create many identical products, can also be simulated through synthetic processes, with:

> *"the plastic replica, wherever it is used, is inescapably the mark of the economically disadvantaged or socially and aesthetically unaware. Captains of industry get real wood in their boardrooms and offices. Foot soldiers do not"* (Green 2006, 22).

Van der Lugt also describes the use of material substitution in the role of replication of materials, with reference to *"steel/plastic chairs mimicking bamboo"* (2008, 309), primarily because of the ability of different types of materials to *"...evoke certain associations and emotions"* (ibid) with steel being – *"clean, cold, precise"* (Ashby and Johnson 2002, 74), and wood *"...naturally*

38 Since this reference has been made, Cobonpue has created a vehicle concept named "Phoenix" using a combination of natural materials (rattan, bamboo), and man-made materials (steel, carbon fibre) (Coxworth 2011) ***(Fugure 6c)***

39 The idea of *"Waste equals food"* is introduced by McDonough and Braungart (2002, 92) whereby natural processes of composting provide the nutrients for growth of future organisms (plants).

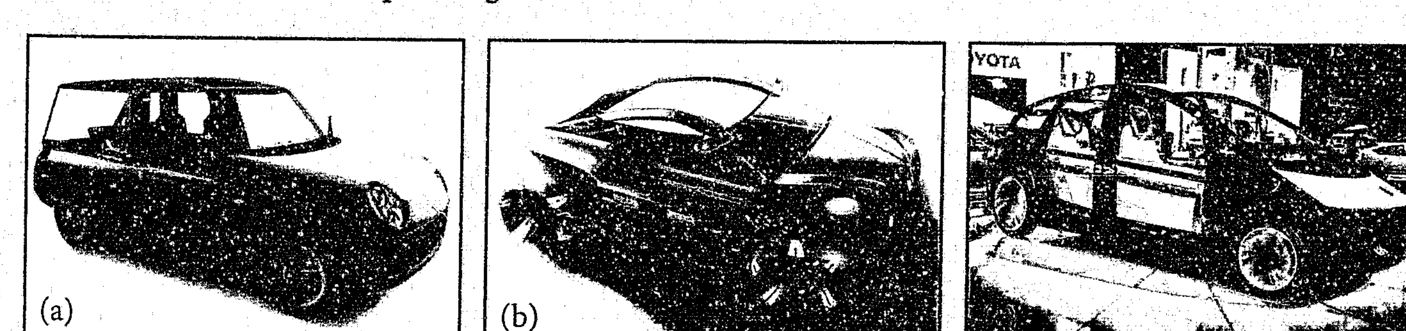
textured, light in weight and feels warm" (108). Natural materials such as wood have a distinct advantage over substitutions, with two levels of appreciation; that of the object in a natural environment (national parks, urban reserves, forests), and the modification of raw material into another form, with sustainable forest timber being used for products such as furniture, transport ***(Figure 6b)*** and building construction. [40] Familiarity and the long history of the human connection with timber indicates that it has been touched, smelt, bent, broken, cut, strained, stressed, dried, wetted, burned and maybe even tasted by most humans (Manzini 1989, 31) - these factors contribute to a catalogue of uses and experience, there isn't much that hasn't been attempted.

Techniques which implement both the living plant, and crafting a product in a single process, is explored in the field of 'Arborsculpture', especially through the formation of both sculpture and furniture, though the technique has been used for both ship building through the formation of shape modified trees or "compass timbers" (Miller 2000, 136-138; Roth 1988, 96) and other large structures.

As described by Watts (2011), plant shape modification of the *Ficus elastica* has been utilised to great effect in suspended structures with the creation of living root bridges (found in Cherrapunji, North-east India) which *"... can support the weight of as many as 50 people at a time"* (129). Cattle (2002) terms the use of plant shape modification as an educational tool to inform people of the effort involved in material production, primarily by illustrating the time taken for timber to become harvestable, stating that:

> *"By showing people, particularly children, how it is possible to produce useful and attractive things by working with the natural process of growth, I'm trying to change their attitudes to their surroundings"*
> Dr Christopher Cattle (Reames 2007, 102)

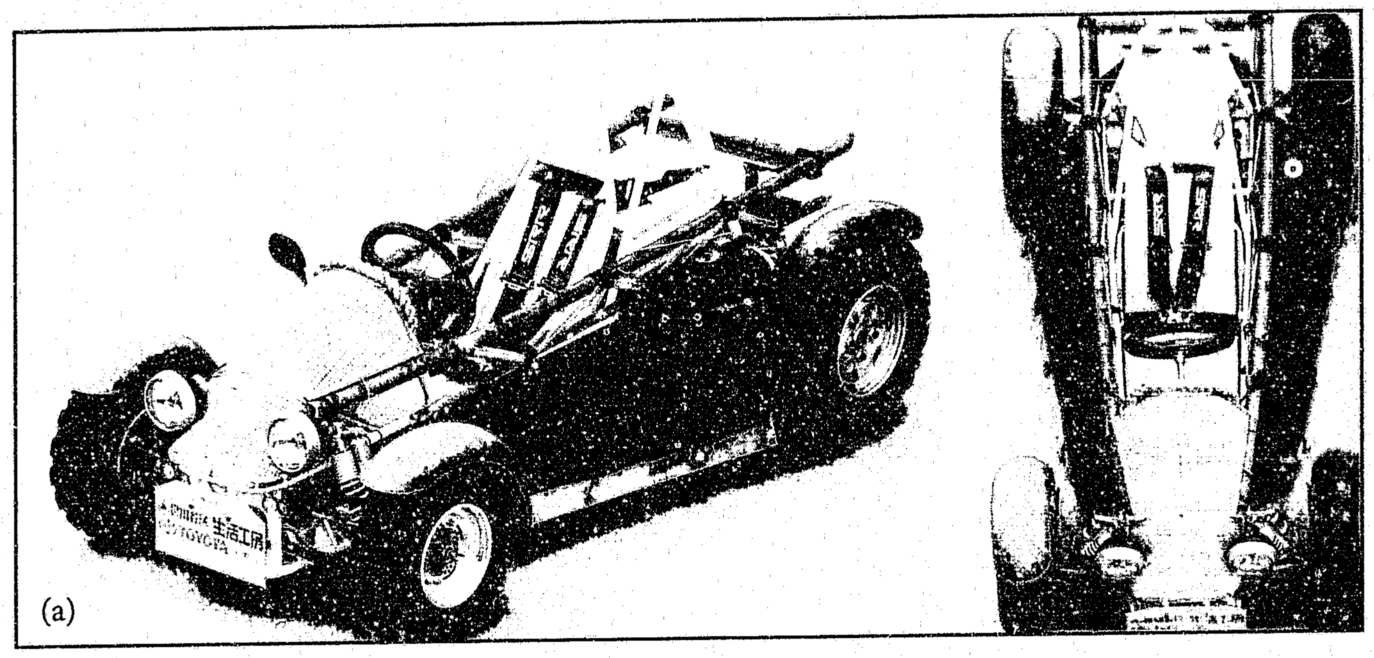
Figure 5: Automobile concepts using natural materials



Conceptual vehicles such as these, present one opportunity for companies to gain feedback regarding market perceptions of new materials or technologies. Conceptual ideas may have merit for diversifying production process, yet, factors such as production costs or immature technology can limit bringing these ideas to volume production.

40 Presenting a solution for sustainable timber use in the building industry, the Montreal Process Implementation Group for Australia (2008, 112-113) describes that forest management impacts of carbon production, noting that: *"...wood products normally require less energy to make and therefore emit less carbon dioxide during manufacture than alternative materials such as steel, concrete and aluminium...New building technologies should soon make it possible to replace greenhouse-gas intensive concrete, steel and aluminium with wooden construction in buildings up to 10 storeys high."*

Figure 6: Natural material use in products



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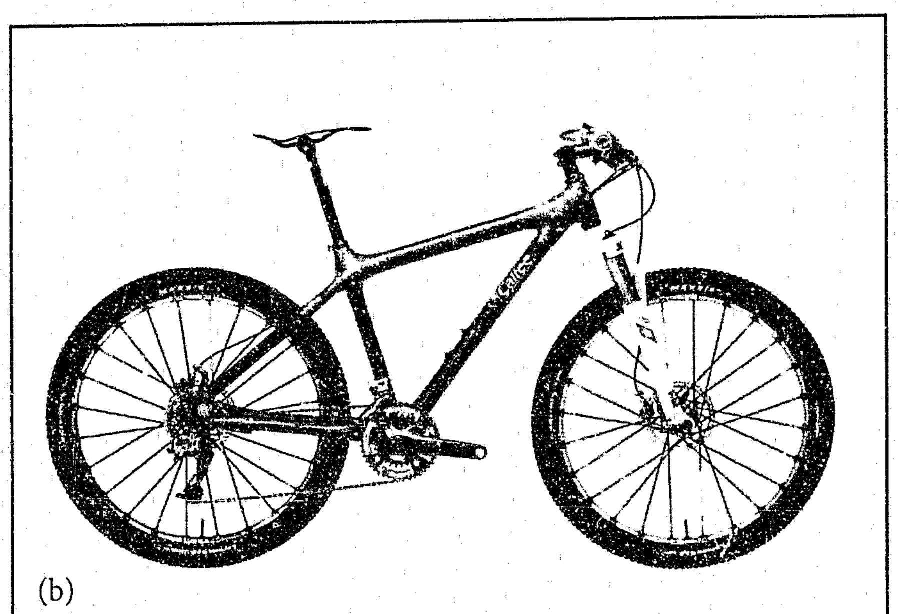

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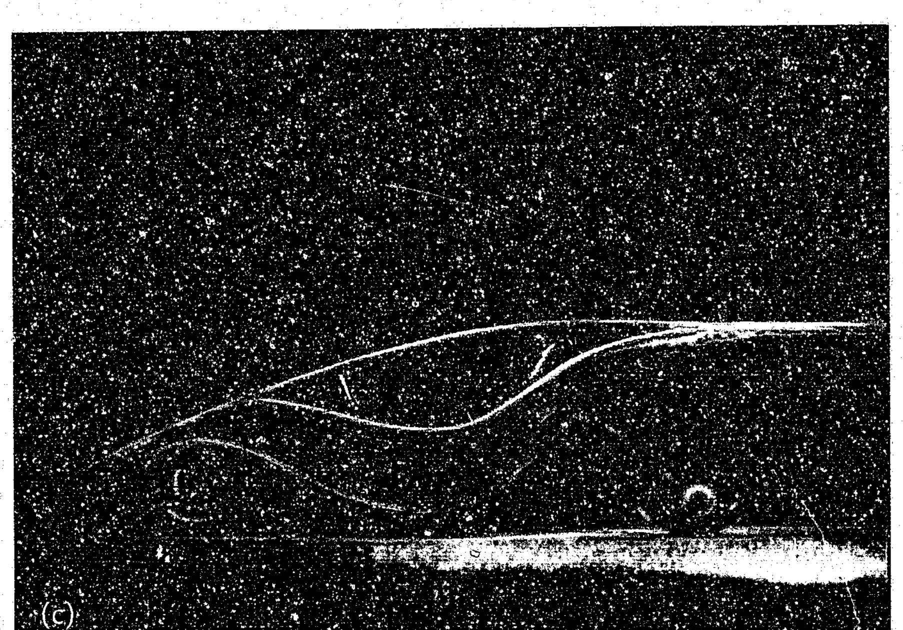
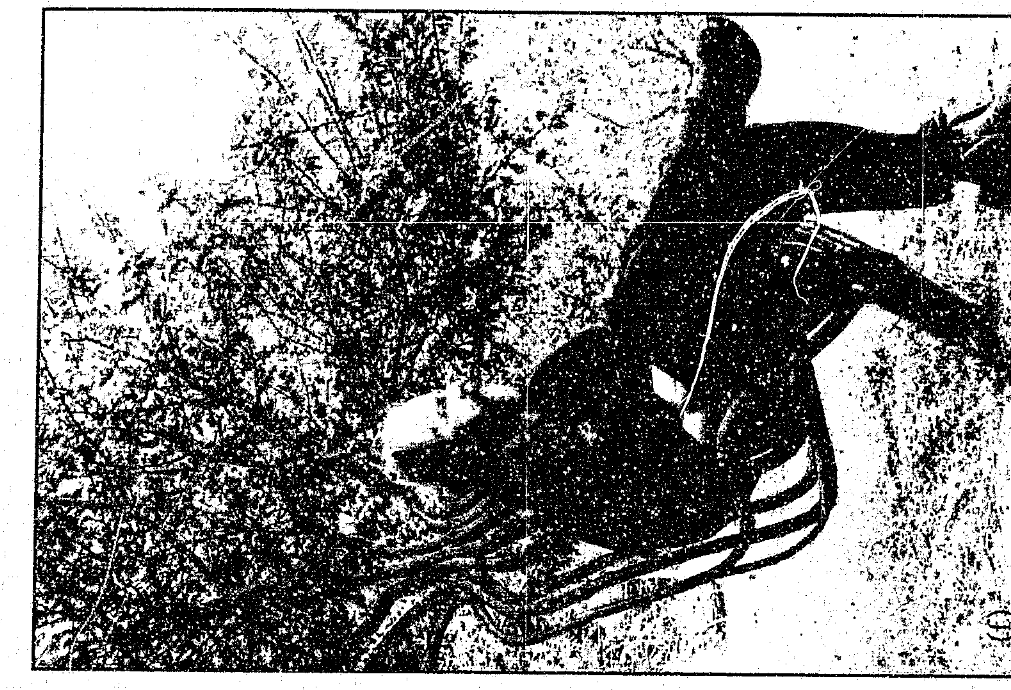


(c)

Figure (a): Setagaya 1
(b): Craig Calfee bamboo bike
(c): Kenneth Cobonpue 'Phoenix'



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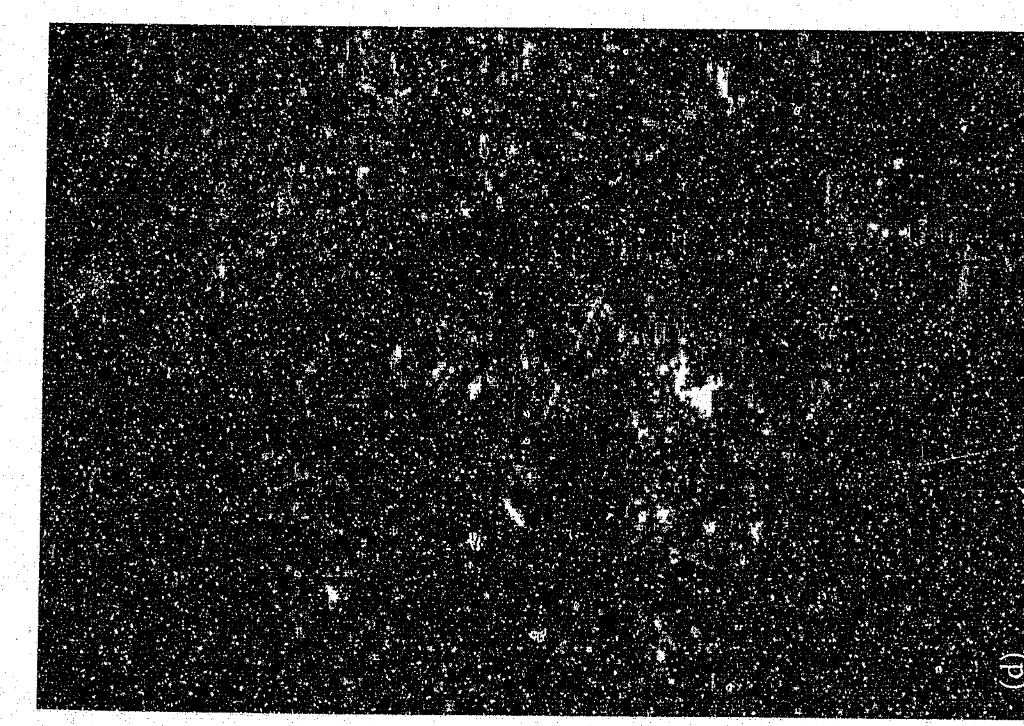


(d)

Figure (d)-(e): Christopher Cattle 'Arborsculpture' grown furniture (Cattle, 2002, 4f/3-5a-1)
(f): Arborsculpture chair with plant growing

6

Bamboo as a monomaterial:

Utilising the unique material properties of bamboo within a wide range of applications.

6. Functional and visual attributes of bamboo

> *"Sustainability requires reliance on renewable resources that can be as available in the future as they are today."* (Gilbert and Perl 2008, 2)

Bamboo was chosen for investigation due its rapid growth when compared to other naturally sourced materials, such as timber (see; Ashby and Johnson 2002, 231; Bess and Wein, 2001; Farrelly 1996; Hidalgo 2003; van der Lugt 2007; 2008; Vogtländer, van der Lugt and Brezet 2010; Yen and Lee 2011) [41]. Growth patterns of bamboo are linked to grasses, such as jute and kenaf, yet bamboo compares well to composites such as glass fibre in mechanical performance[42] tests (Yamaguchi and Fujii 2004, 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"* (151), thus providing industry with access to a sustainable resource which offers rapid regeneration (Oprins and van Trier 2006, 110).

Furthermore, Londoño (2003) refers to a genus related to the more common bamboos of the *bambusa* family, the *Guadua (Guadua angustifolia)* (Farrelly 1984, 122-131; Hidalgo 2003, 36-40) which has a *"...strength/weight ratio which surpasses that of most woods and may even be compared to steel and some high-tech fibres"* (Londoño 2003, 34)[43], showing possibilities for material substitution. The versatility of bamboo permits applications in the form of raw material – culms (Vélez 2000) ***(Figure 7a-7c)***, composites ***(Figure 7d, e, i, j)*** (Hidalgo 2003, 163-175, 199-221; Okubo, Fujii and Yamamoto 2004)[44] and laminates (176-197) ***(Figure 7f)***, with wastage from leaf material forming the basis for livestock fodder ***(Figure 7g)*** (Lewis and Miles 2007, 84-85), or small new shoots (baby culms) harvested for nutritional food (92-105) ***(Figure 7h)***.

Each material 'state' has unique characteristics allowing the creation of cross disciplinary products, while utilising a single material, varying from architectural construction, product design, or artistic practices; for example:

> *"Bamboo's characteristics of lightness, strength, and flexibility, plus its natural sheen, have led to its utility as construction material, rope, fencing, fish and animal traps, bows and arrows, fly fishing rods, farm and garden tools, furniture, kitchen implements, musical instruments, religious articles, and of course, for baskets."* (Coffland 1999, 7)

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

42 Mechanical properties of bamboo, such as tensile and compression strength are discussed in detail by Hidalgo (2003, 79-93), with tensile strength values for different species given (87), strength for scaffolds and structures is also discussed by Chung and Yu (2002).

43 See; Farrelly (1984, 143).

44 Suggested by Huang (2007, 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. 58).

Figure 7: Examples of bamboo applications

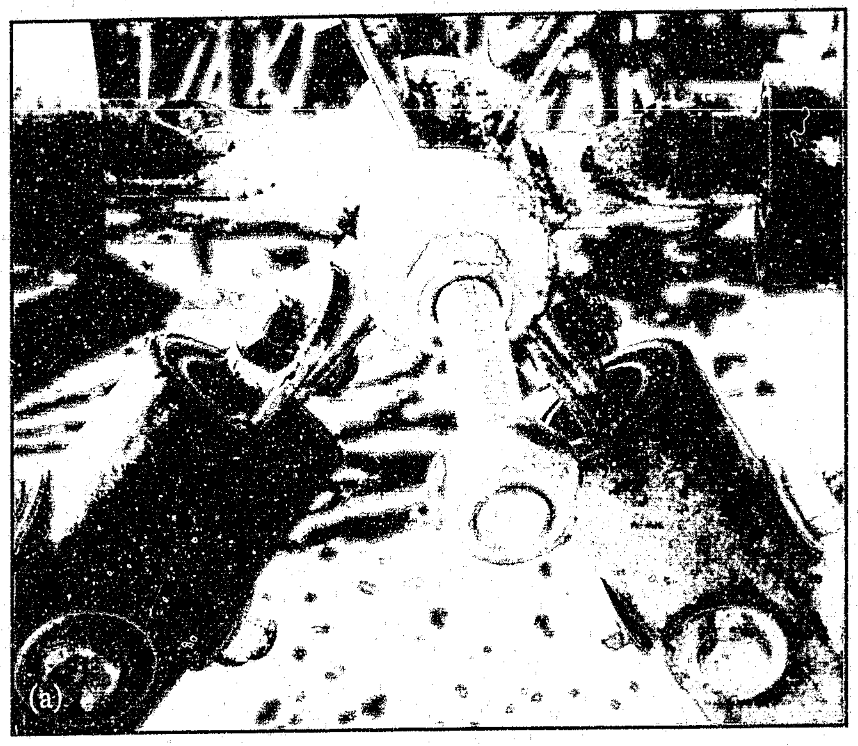
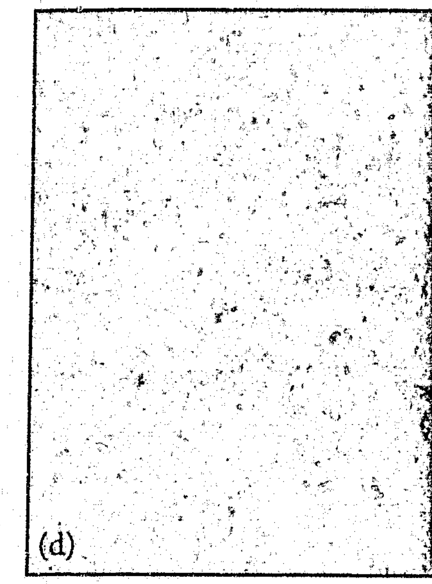
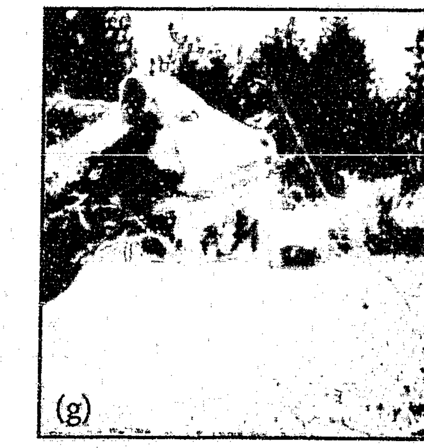


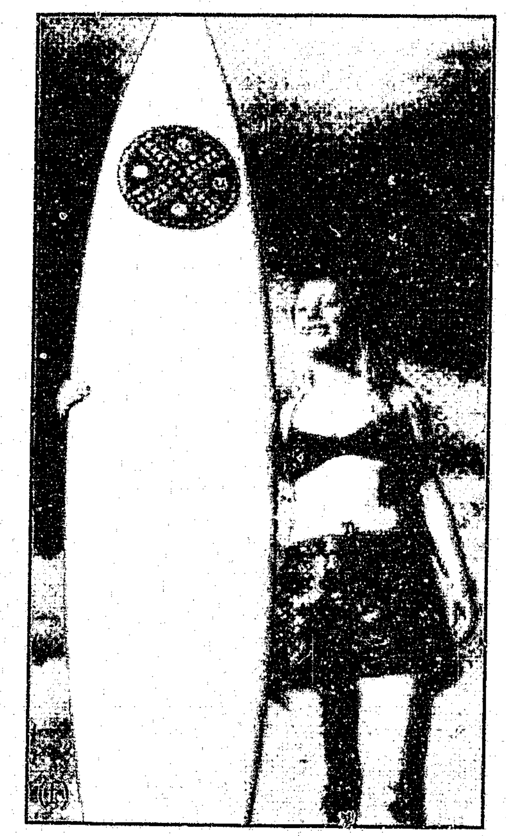
Figure (a)-(c): (Vélez 2000)
(a)Construction uses of bamboo - interface with other materials (108)
(b) Structural usage for housing and shelter (120)
(c) External skeleton structures in the form of scaffold (140)

These examples illustrate the relationship that humans can have with one material, in this case, bamboo. Building structures can be constructed simply from joining sections, whereby at a macro level, the method seems straightforward. However, duplication of simple construction techniques applied over a large scale can sill produce impressive scale.

Figure 7: Examples of bamboo applications







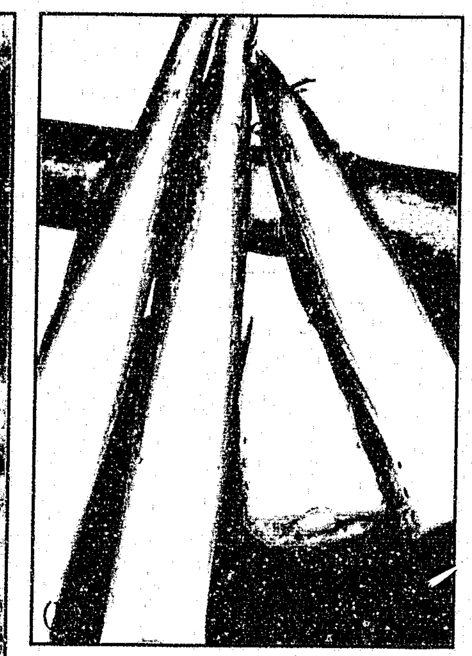
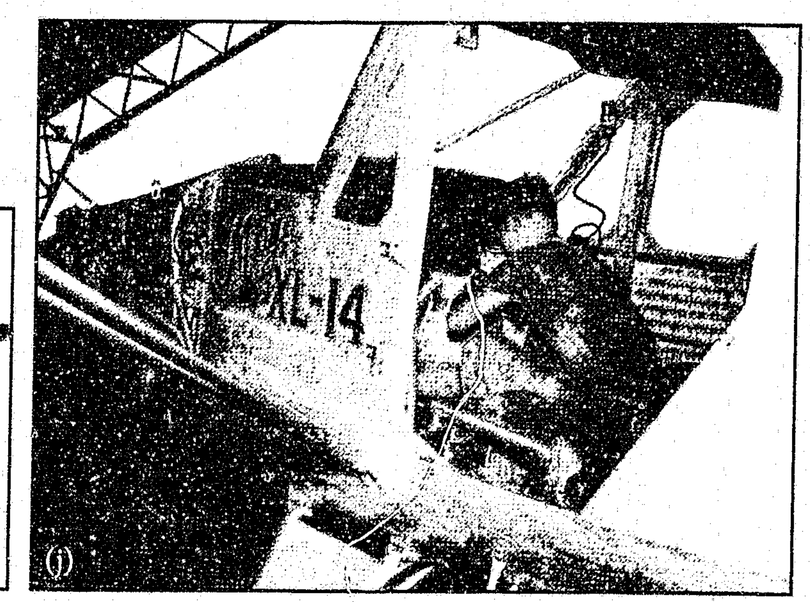


Figure (d)-(e): Composite bamboo through compressed fibres (Hidalgo 2003, 30)
(f): Bamboo laminate surfboard (187)
(g): Li estock feed (Lewis and Miles 2007, 85)
(h): Baby bamboo culms for consumable (edible) purposes (96)
(i)-(j): Aeroplane (XL-14 Maya) made with a bamboo fuselage (Hidalgo 2003, 432)



Monomateriality of bamboo leaves a positive impression that a single material can fulfil the needs of many different industries.

Through the creativity of applications using the raw material, especially in Asian regions such as Japan, utmost respect is given to artisans who dedicate themselves to perfecting bamboo craft, which can take years to master. Learning the craft of Japanese bamboo art requires the formation of 'master-disciple relationships', with Rinne and Okada (2008) specifically mentioning three regions in the country renowned for this system; *"Western Japan, Eastern Japan, and Kyushu"* (15).

Skills following such bamboo crafts also seem to be transferable for other applications, with research by the *Institute of Science and Technology, Manila,* leading to experiments in 'woven bamboo panels' for light aircraft (Farrelly 1984, 16). The application of bamboo in the 'XL-14 Maya' experimental aircraft ***(Figure 7i-7j)*** notes that *"...bamboo mat can readily be used for cantilever and stressed skin construction for all types of light aircraft adapted to wood or plywood frame construction"*, with the woven panels coated in a glue and *"fine soft-wood sawdust"* to seal the surface (Hidalgo 2003, 432-433). The conclusion of the test report is noted by Hidalgo (434) and comments on the feedback from the experimental pilots state:

> *"...good damping characteristics of shock loads as well as good* [sic] *sound-absorption qualities."*

See; ***Appendix E: Visit to "Bamboo Australia" plantation*** for images of a bamboo plantation.

7

Proposing an investigation into production alternatives through using natural materials.

7. Experimental Methodology

Initial phases of the experimental action research, were driven by the desire to seek a unique application using bamboo, and combine this with unorthodox production techniques. Despite the fact that the idea of 'growing a vehicle' could be viewed as fanciful or unconventional, the decision was made to proceed with experiments on the grounds that they would provide a foundation for understanding the capabilities and limitations of bamboo.

This factor of being 'in touch' with the process of experimental making is reinforced by Frauenfelder, who states learning outcomes derived from active making provide:

> "[a]...*sense of control and accomplishment ...from doing something yourself, [through] using your own hands and mind."*
> (Frauenfelder 2010, 30)

7.1 Material Exploration Experiments

The first experiments of material exploration were built upon the idea from Schloesser (2004) relating to the inclusion of natural fibres as a substitute for materials such as fibreglass, together with the product design pieces from designers Eliza Noordhoek, Daan van Rooijen and Jared Huke (van der Lugt 2007, 36-38, 40-43, 121). In these instances, casting or setting of fibre/plant material has been utilised to create form. However, these methods described a process of material substitution (chipboard or compressed fibre already exists using timber pulps), rather than contribution towards a new production method.

Further material experimentation was conducted, and is annotated within ***Appendix D***, whereby:

- Knitting with yarn made from bamboo fibre (or natural materials such as jute), whereby it was proposed that patterns of a vehicle skeleton could produce flat pack sections which would be expanded upon fabrication, and set in resin.
- Bamboo poles were purchased and heat manipulated to gain an understanding of the energy required and the limitations in form complexity.
- Scaled experiments using shape manipulation of growing bamboo plants.
- Manipulating the shape of bamboo culm walls from their natural circular shape through a compression growing method.

8

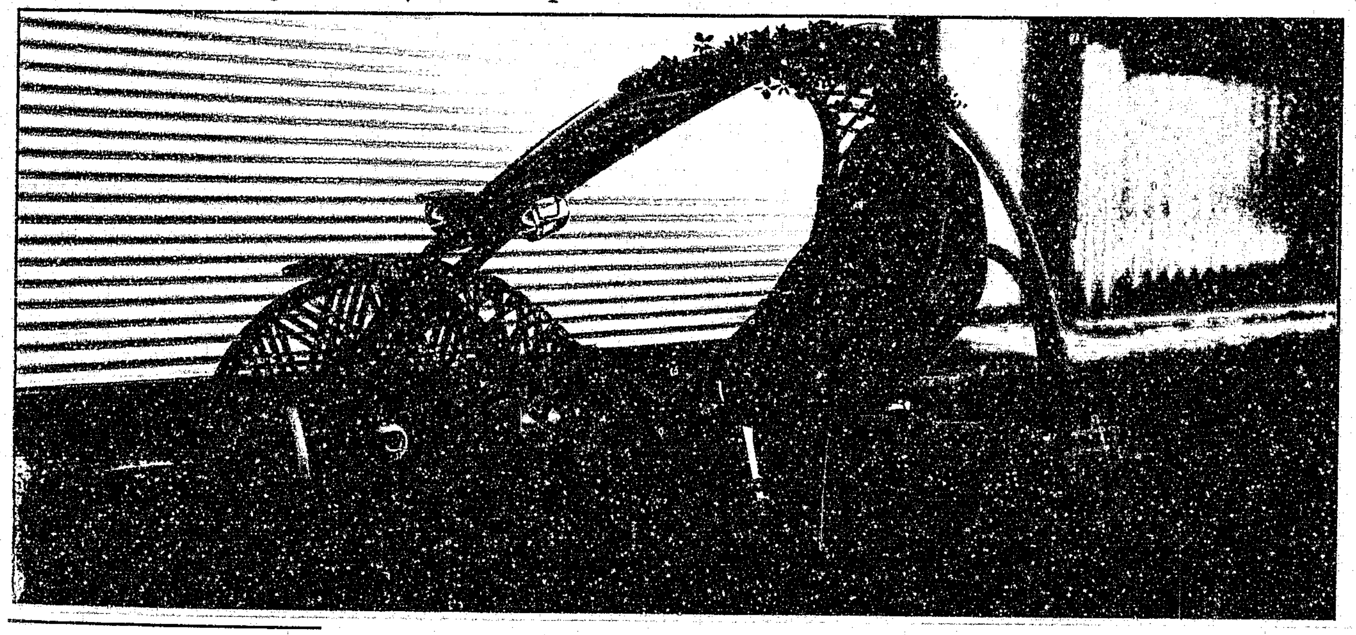
Developing conceptual HPV's by using natural construction as the primary method of fabrication.

8. Development of the 'Ajiro' Human Powered Vehicle

Whilst it can be inferred that following aesthetic parameters in constructed products can be a combined effort between intuition, appealing to the senses, and balanced combination of artistic/engineering principals (Ashby and Johnson 2002, 14-15, 113-114), the response to aesthetic forms in the final concept of the *Ajiro*, represents only *one* of many possible outcomes which could be varied in visual appearance (see; Moore 2008, 20; Hume 1965[45]). Developmental options will be explored to investigate construction methods using bamboo, while taking into account its structural or aesthetic limitations. Bamboo, for example, is unable to form complex angles in shape modified sections, and therefore a sympathetic approach appreciating this fact will be applied, rather than as an exercise which dictates styling to fulfil a preconceived formula which would be unachievable in naturally grown vehicle.

With these considerations in mind, the design concept *'Ajiro'* ***(Figure 8a-d)***, a partial fairing velomobile, was designed using the natural ability of the bamboo to grow while being shape modified pre-harvest, allowing the possibility of 'growing a vehicle'. The height of the vehicle was designed to be significantly taller than current velomobiles (typically under 900mm tall) for greater visibility (see; ***Chapter 4: page 40-41***), through maintaining semi-recumbent seating and extending the roof profile approximately 250mm from head height, while also maintaining 100mm ground clearance (for travelling over speedbumps etc) for a total proposed height of 1135mm. The design of the *Ajiro* frame is primarily based upon experimentation with growing three dimensional compound curves, sketch development ***(Figure 9a-g)*** as well as experimenting with the degree to which bamboo can form tight radii through a growing process without post-production intervention of steam and heat bending ***(Figure 9h)***. Furthermore, the experiments hope to provide insight into how growing bamboo can achieve delicate transitions between curves. The *Ajiro* is representative of one such solution to growing a form, and is not indicative of a limitation with the material, given full investigation is still in its infancy.

Figure 8: Renderings of the 'Ajiro' Concept



[45] "Of The Standard Of Taste" (Hume 1965) by David Hume comments on the parameters which may alter judgement or perception of any visual or audible object.

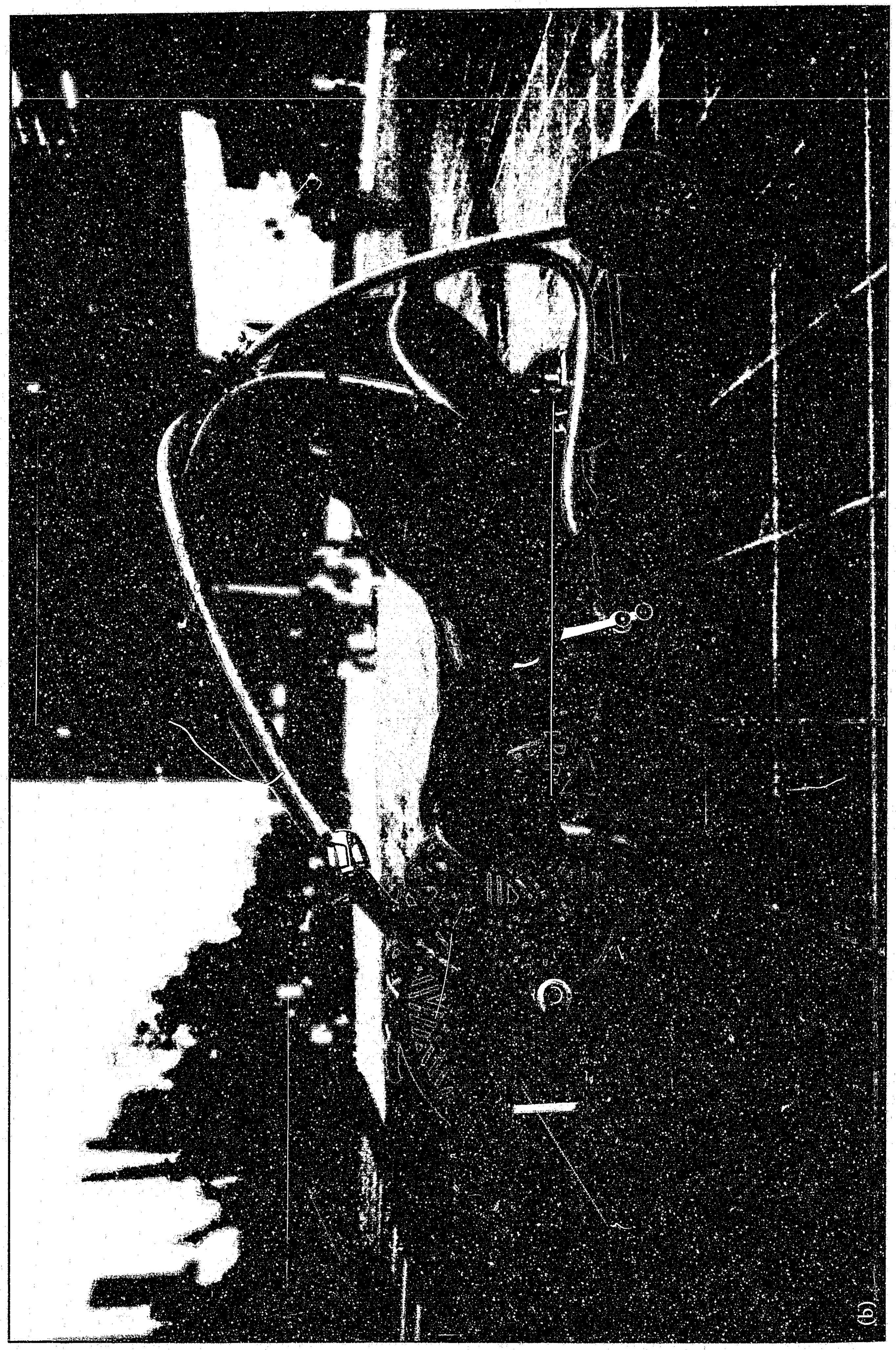
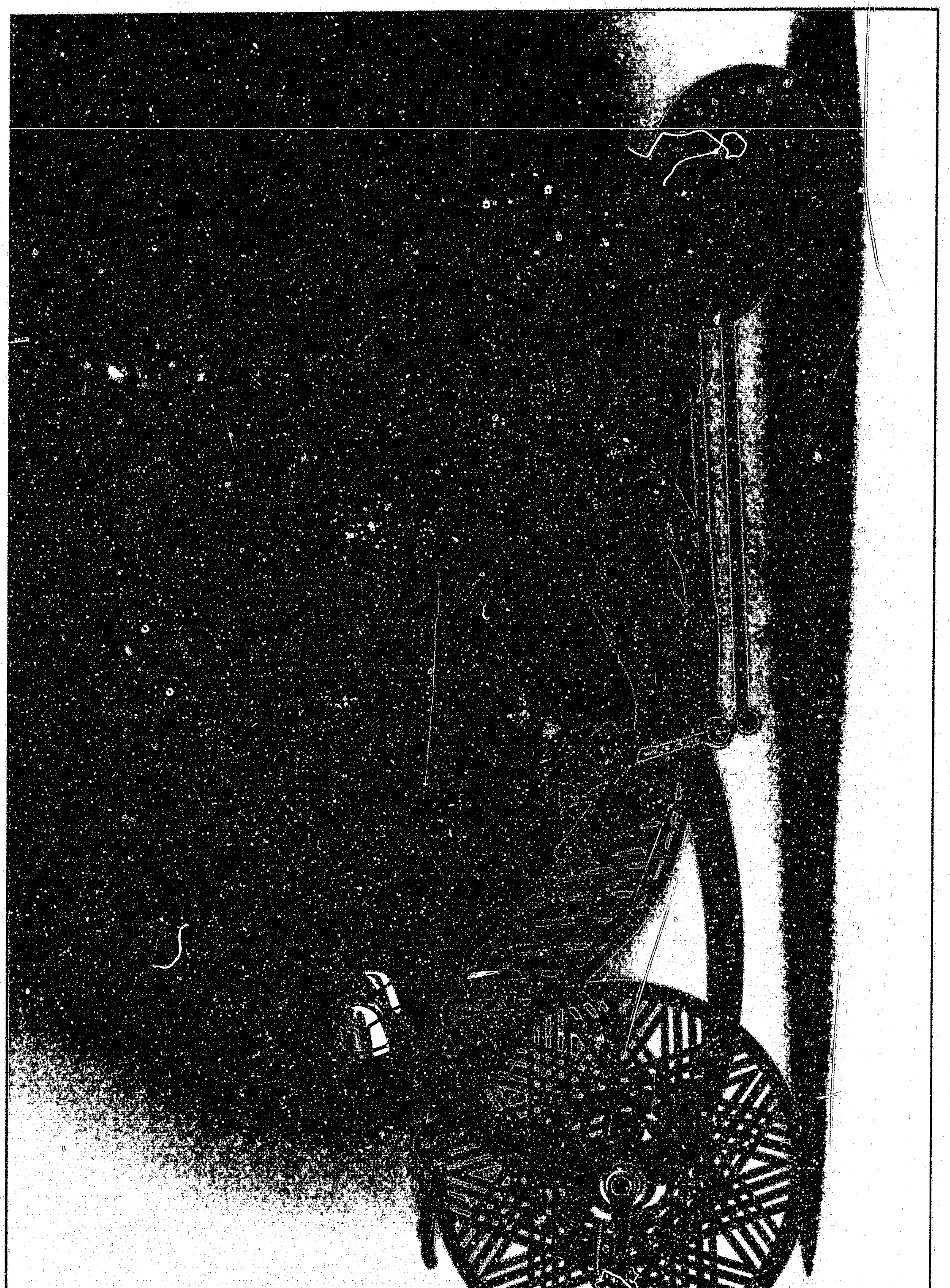


Figure 8: Renderings of the 'Ajiro' Concept



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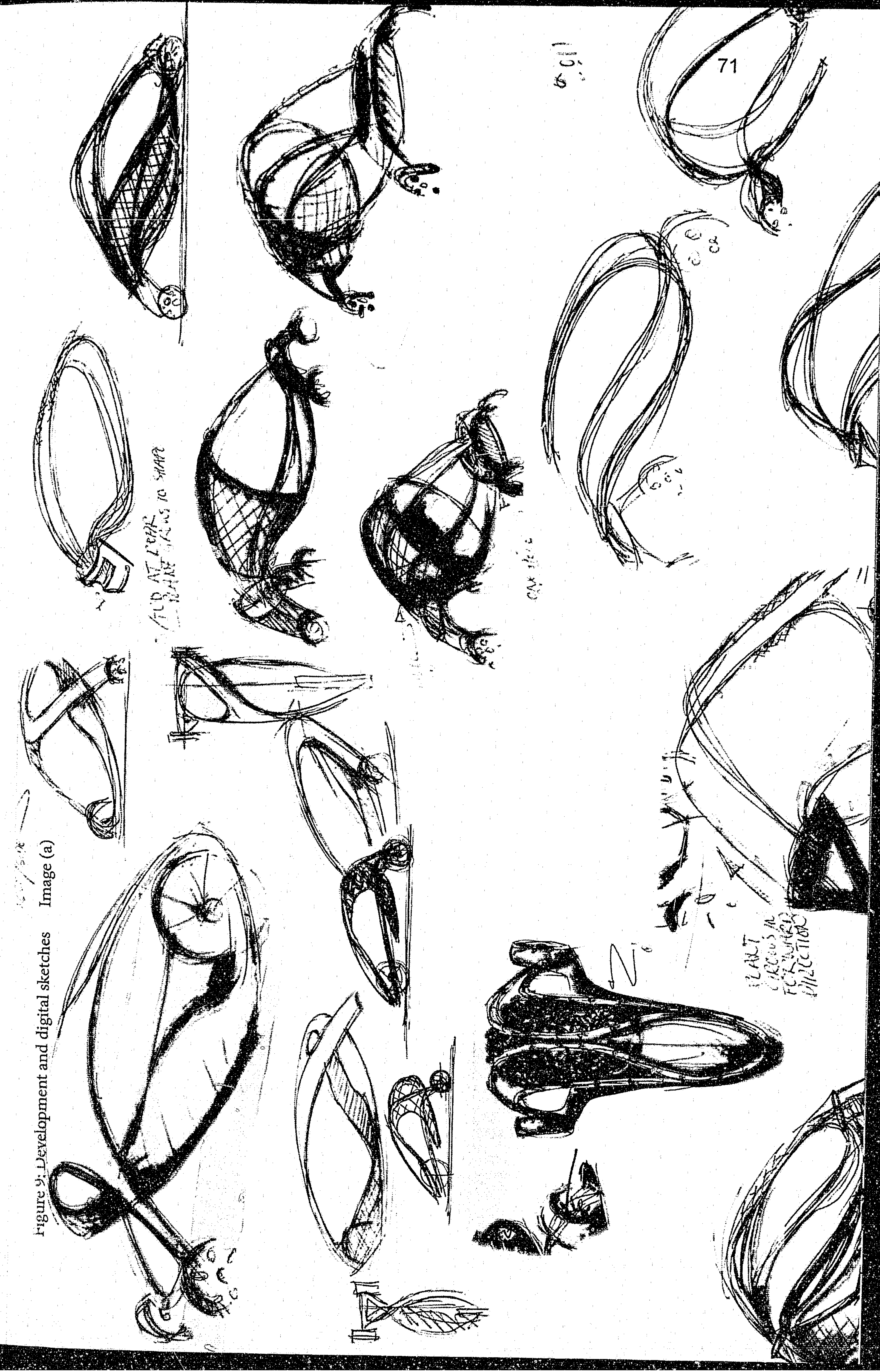


Figure 9: Development and digital sketches Image (a)

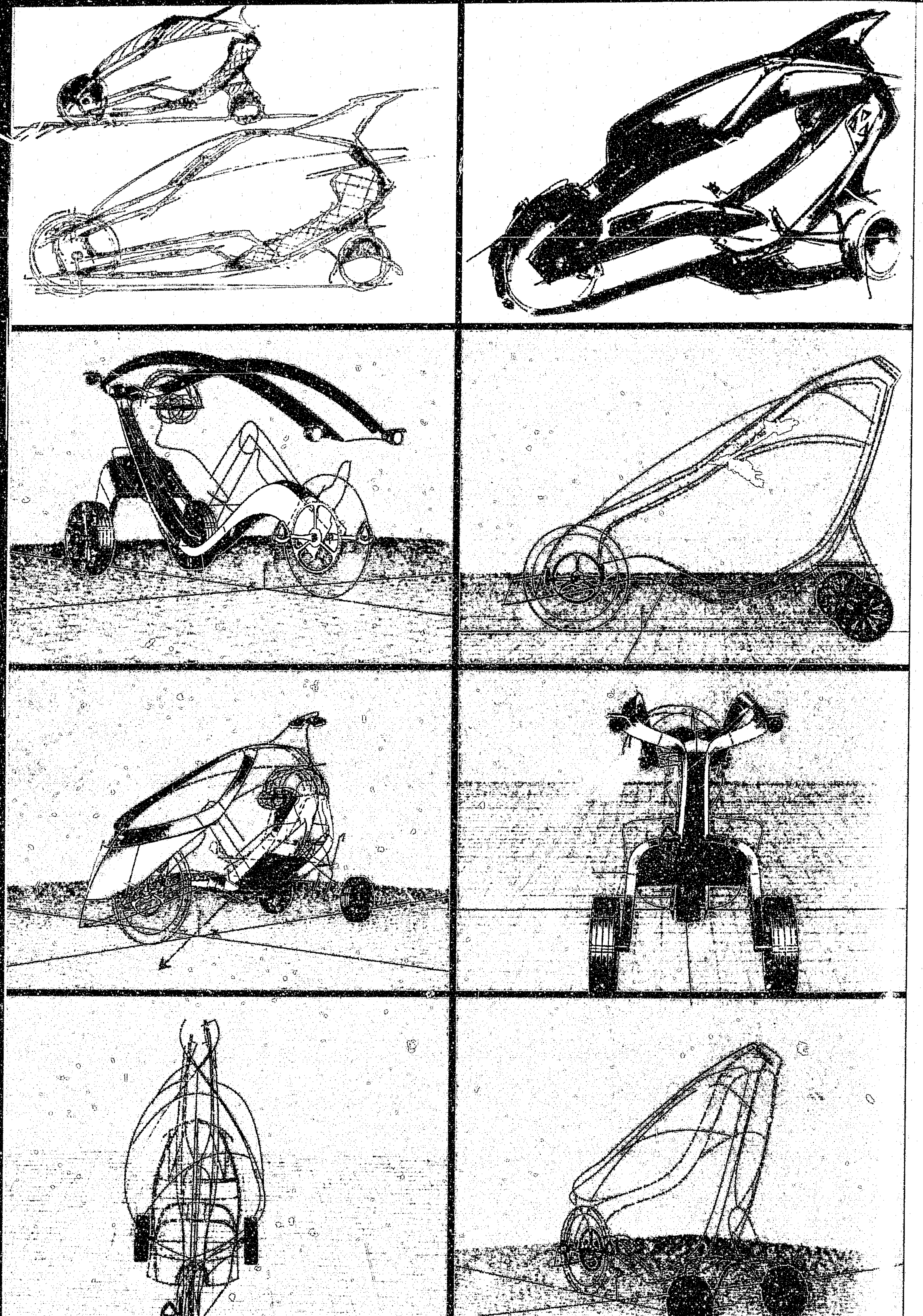


Figure 9: Development and digital sketches Image (b)

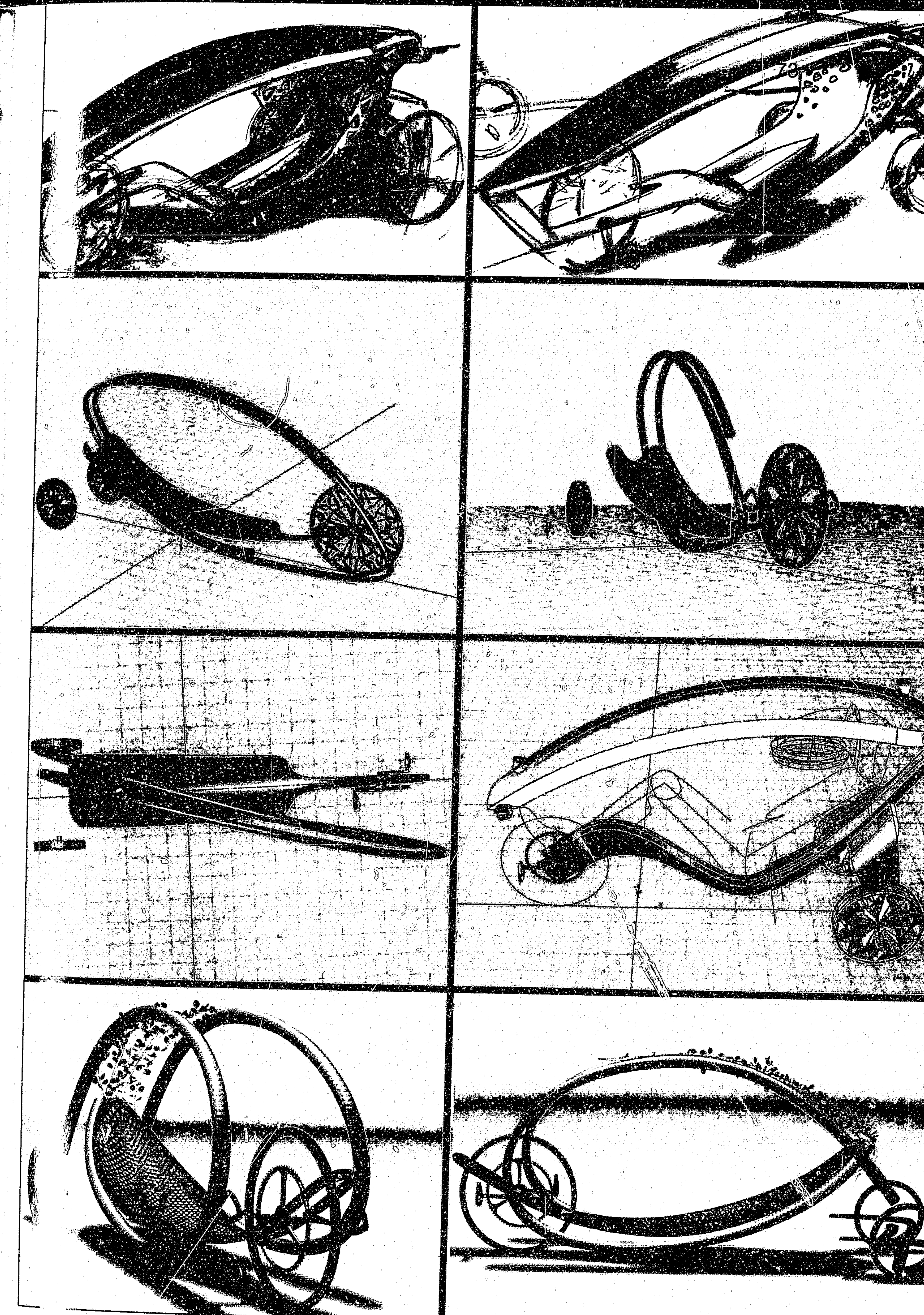
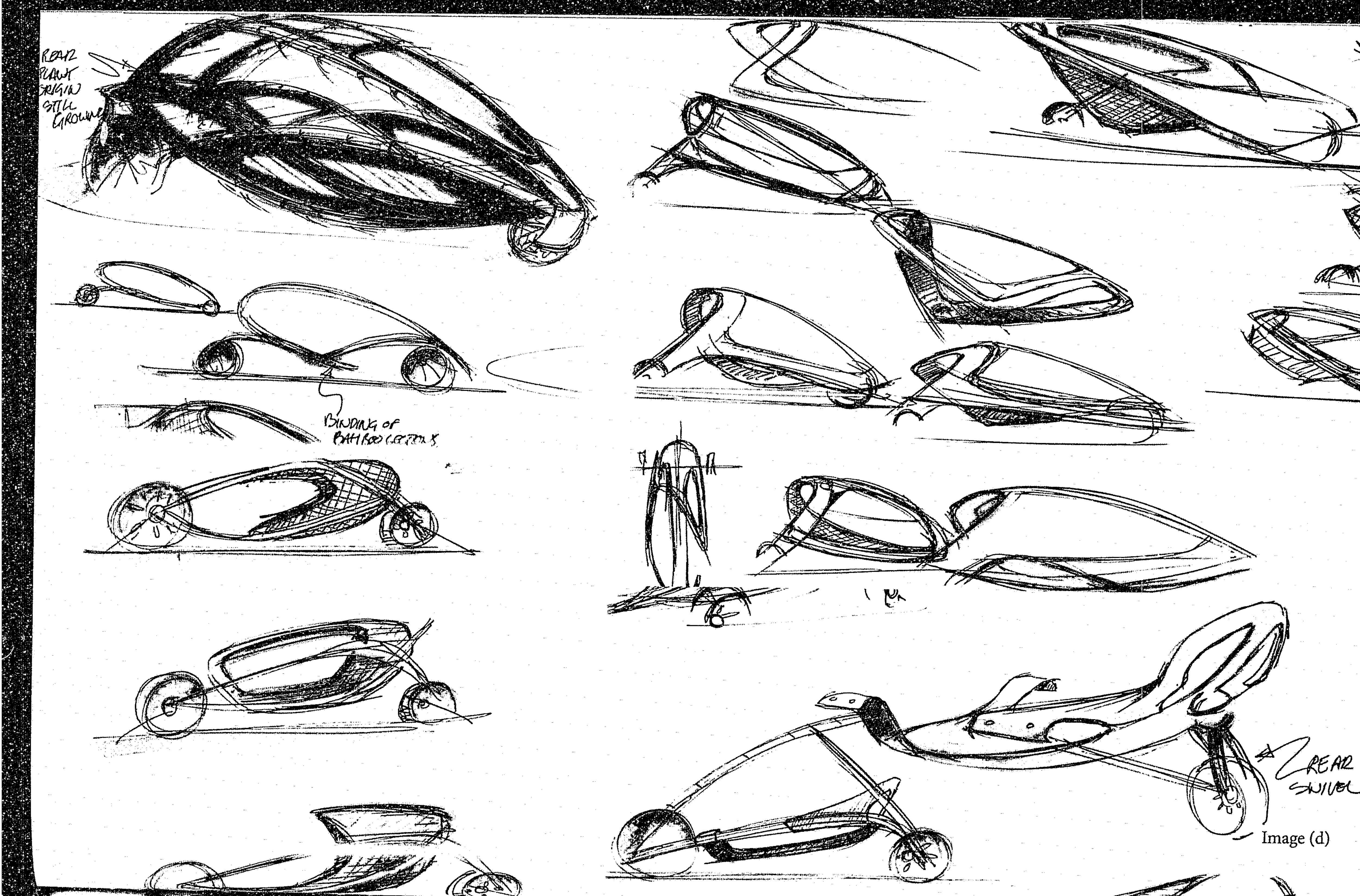


Image (c)



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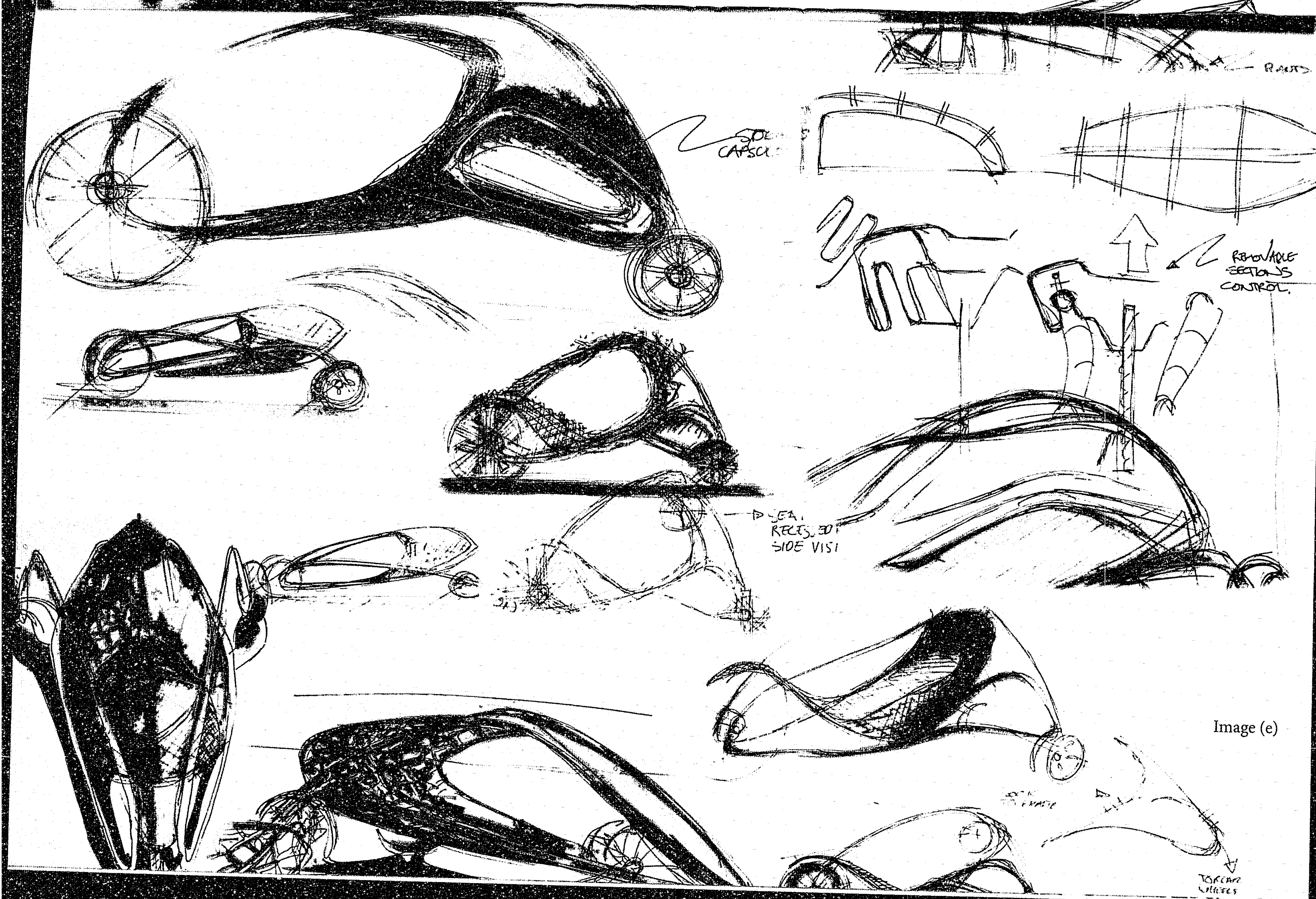


Image (e)

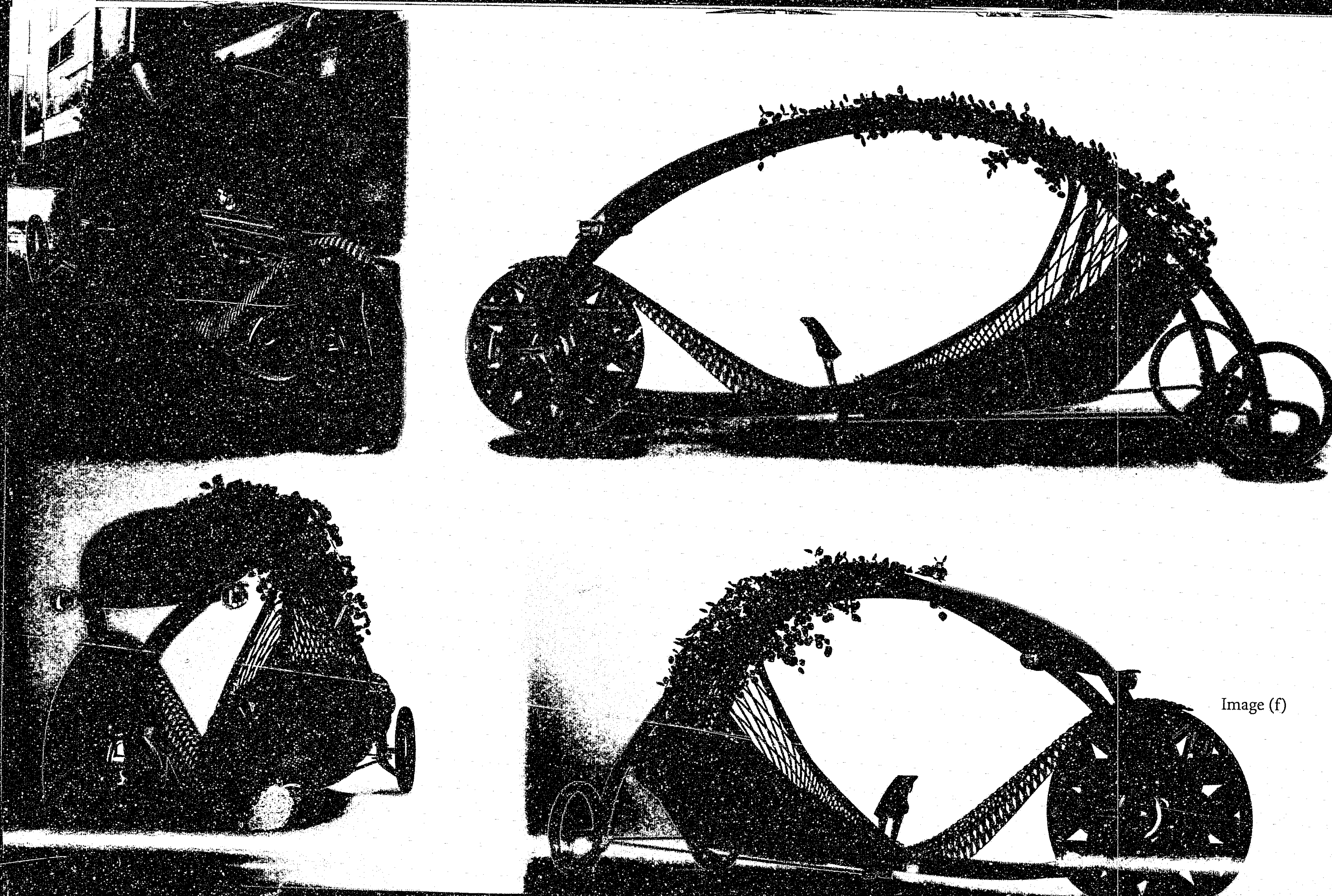


Image (f)

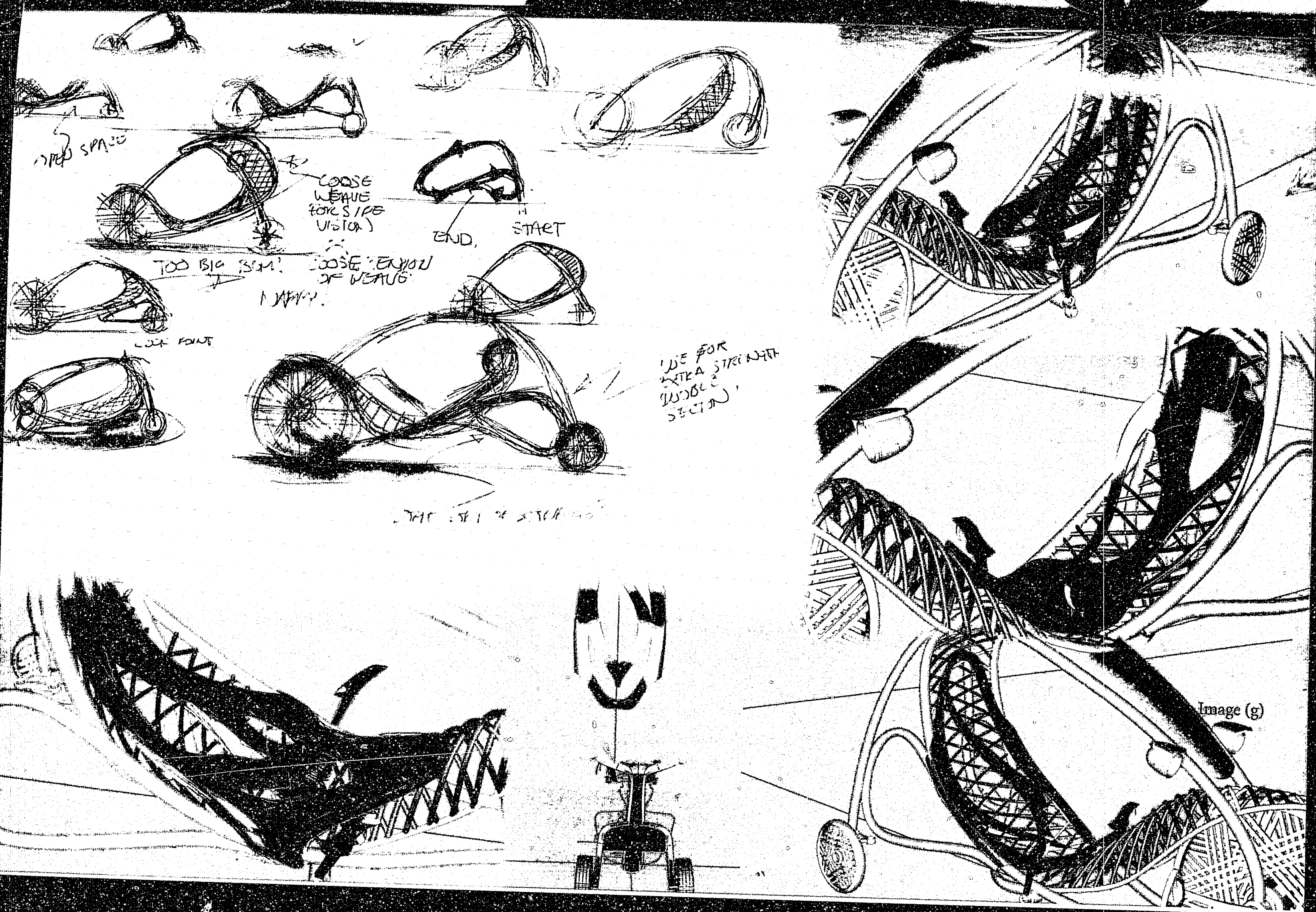
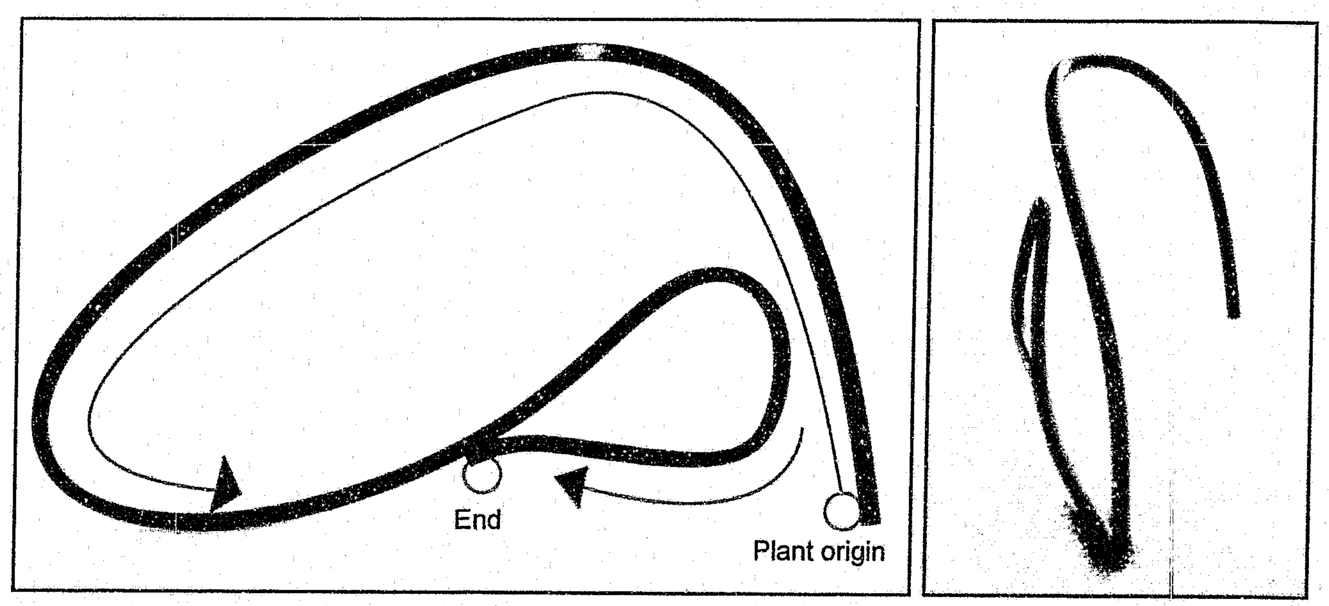
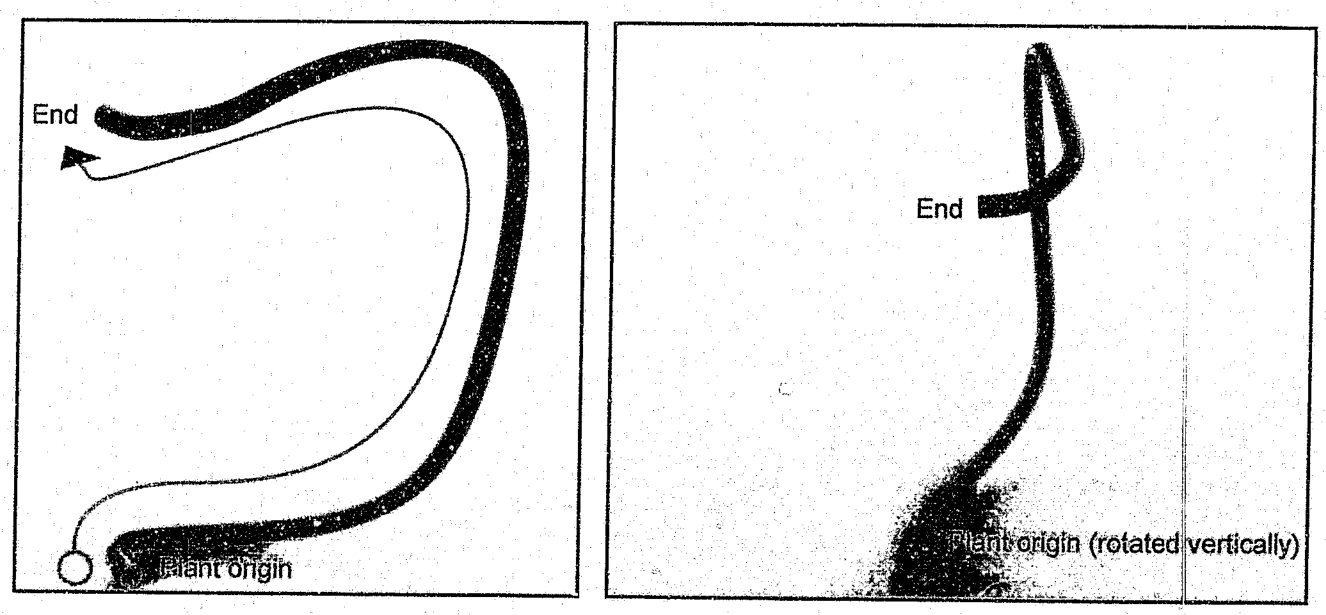


Image (g)

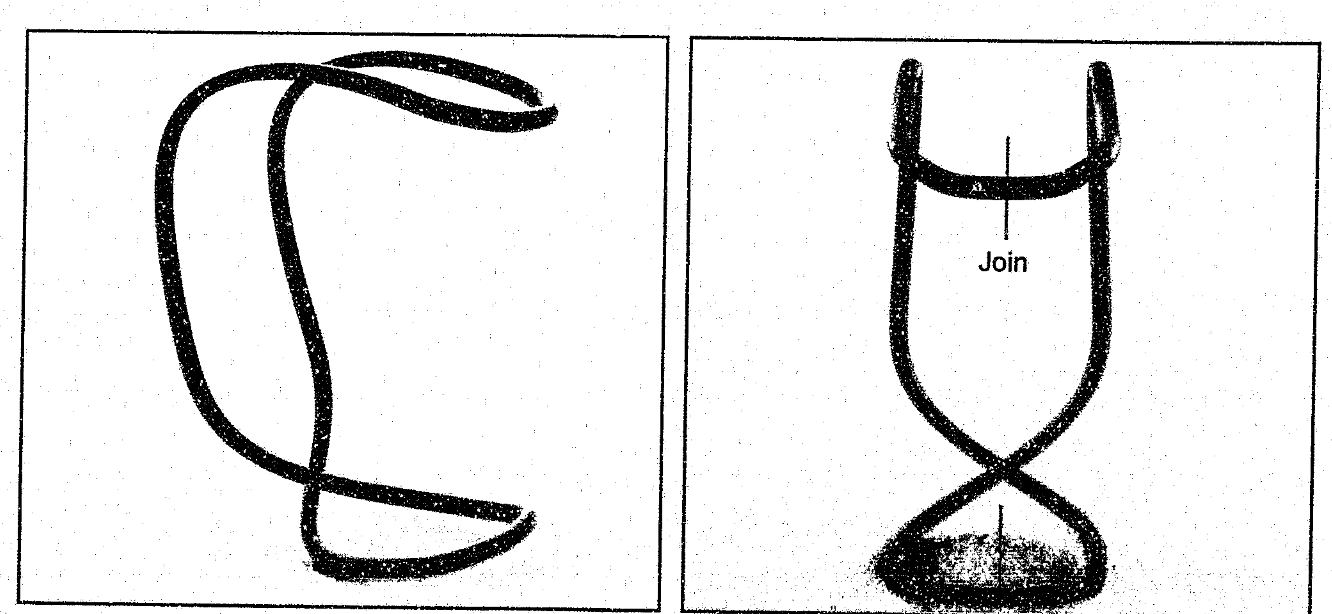
Figure 9: Development and digital sketches (h) - Images grouped



Vehicle frame rationale: One side of the grown frame (one plant), opposing side is a mirror image.



One side of the seat bracing frame (one plant).



Joined seat bracing frame (two plants).

8.1 Exploring grown transportation

The potential for bamboo to fulfil production requirements is based on the characteristics of fast growth and strength advantages over timber (see Section 6). Manzini (1989) describes material characteristics as being a valid reason for its suitability to be integrated into a design, with:

> *"A craftsman's knowledge and skill lie in his ability to integrate a natural component in the artifice he has mastered. He does this not out of an ethical choice due to his respect for nature, but out of pure practical need"* (Manzini 1989, 30)

In the case of the *Ajiro* concept, the use of bamboo may be perceived as ethical, or sustainable due to its biomass qualities (see; Christanty, Mailly and Kimmins 1996; Nath, Das and Das 2009; Scurlock, Dayton and Hames 2000; Yen, Ji and Lee 2010); ability to control salinity; prevent soil erosion through its fibrous root mass (Farrelly 1984, 285-286; Soderstrom and Calderon 1979, 167; White and Childers 1945) and helping to rejuvinate areas of poor soil quality (Singh and Singh 1999). However, the key consideration is that the material *allows* for the ability to promote shape modified vehicle frame parts, pre-harvest, which is the primary *'practical need'* of the design proposal.

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[46] ***(Figure 10a, 10b)***. Factors such as culm circumference, strength of the plant, or genetic mutations of the species (Saporito and Mavition 2010, 7) may contribute to variations while additionally, biological factors such as fungi, borers or termites (see; Farrelly 1984, 226; Hidalgo 2003, 65-69; Lewis and Miles 2007, 56-62) may affect structural integrity of the plant. As described by Janssen (2010, 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.[47]

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

The relative 'defects' of a natural material, are described by Manzini (1989, 28) as obstacles, but also "… *mpt variations"*. This would be similar to a process of grown production, as being described in the *'Ajiro'* concept, ndardization, or perfection of a naturally grown plant will be difficult to continuously replicate.

The selected species of bamboo, *Bambusa Oldhamii,* (Farrelly 1984, 184) ***(Figure 11a)*** and *Bambusa textilis Gracilis* were both chosen for fast growth characteristics. The *Oldhamii* species with a total height of twelve meters is sufficient to form the tubular components of a frame, while also being a clumping bamboo[48]. *Bambusa textilis Gracilis* grows to a height of approximately six meters, whilst being *"one of the hardiest bamboos"* (Farrelly 1984, 185). The total leaf mass and height of the original plant (in this case purchased), 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 (see; Farrelly 1984, 150-153; Hidalgo 2003, 25-31; Janzen 1976) *(See **Appendix F, G** for further discussion).* Soderstrom and Calderon (1979, 165) note that flowering can be 120 years apart, while apparently after flowering, the bamboo plant can die (Farrelly 1984, 149; Bean 1907).

However, seeds from the *Phyllostachys pubescens*[49] species were obtained over the internet from eBay ***(Figure 11b)***, and these were subsequently planted into small pots, each with six seeds which achieved an average of three germinations per tub ***(Figure 11c)***[50]. This leads to the possibility that. given an extended time frame for plant establishment, grown vehicles could technically be produced from seed propagation alone. *(See; **Appendix G** for further discussion on seed growth)*

In contrast to the documented field work which has been undertaken for the development of the *Ajiro*, it became evident, via a press announcement from Mercedes-Benz, that a vehicle concept was being released which purported to represent 'grown transport' - *"a car born from a seed... reciev*[ing] *energy from the trees and develop*[ing] *in a growing medium like an organic being, because it is made of biofibres"* (Cinti 2011, 30).

48 Clumping (Sympodial) bamboos such as *Bambusa Oldhamii*, *Bambusa multiplex*, *Bambusa textilis gracilis* used in this thesis as experiments, tend to keep rhizome spread within several meters of the main plant. Running (Monopodial) bamboos such as *Phyllostachys edulis* (Moso) are bamboos which need to be contained in tubs, otherwise may become invasive (see; Farrelly 1984, 137-138; Hidalgo 2003, 4-8), and therefore more suited to large field establishment for mass planting.

49 Also known as *Phyllostachys edulis* under the common name of 'Moso', this is a popular species of bamboo (Farrelly 1984, 172-174; 226-231). It is capable of growing 20 meters tall, has edible shoots, and the same species can grow up to 1 meter per day once thoroughly established.

50 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."*

The Mercedes-Benz 'Biome' concept ***(Figure 12a, 12b)***, presented at the 2010 Los Angeles motor show, provided fanciful, unsubstantiated claims of 'growing a vehicle' with:

> *"The interior of the BIOME grows from the DNA in the Mercedes star on the front of the vehicle, while the exterior grows from the star on the rear. To accommodate specific customer requirements, the Mercedes star is genetically engineered in each case, and the vehicle grows when the genetic code is combined with the seed capsule."* (Banks 2010) Referencing Mercedes-Benz

However, unlike the *Ajiro*, no experimental, design, scientific support or papers have been published (to date of thesis publication) which support any of the claims provided, let alone any justification in documentation for how such an incubation process would be realistically achievable, nor the method in which 'DNA' would be created for a vehicle , or how individual parts would be controlled, regulated or synthesised to reproduce cells which would form individual vehicle componentry. As such, a mythical approach proposed by Mercedes-Benz, can only be used as method for capturing consumer imagination and fantasy for what a wholly sustainable vehicle *should* achieve, without any substantiation to the technical parameters of the design.

As outlined in the following experiment descriptions, shape modification of bamboo allows a *form*, in this case the frame for the *'Ajiro'* velomobile, to be 'set' into a growing bamboo *form*, with the resulting harvestable shape presenting a basis for further ancillary assembly. Furthermore, the successful germination of bamboo seed allows the theory to be established that growing a plant could eventually result in a vehicle frame, or given the rhizome spread (Farrelly 1984, 208-209) of running bamboos such as ***Phyllostachys pubescens*** (or even clumping bamboo such as ***Bambusa Oldhamii / Bambusa textilis Gracilis***), single successful seed germination could provide the foundation (given plant establishment factors), for the production of many grown vehicle frames within the plants lifespan.

Figure 10: Visual characteristics and variations between bamboo species
(a); Vélez (2000, 158); (b); Vélez (2000, 156)

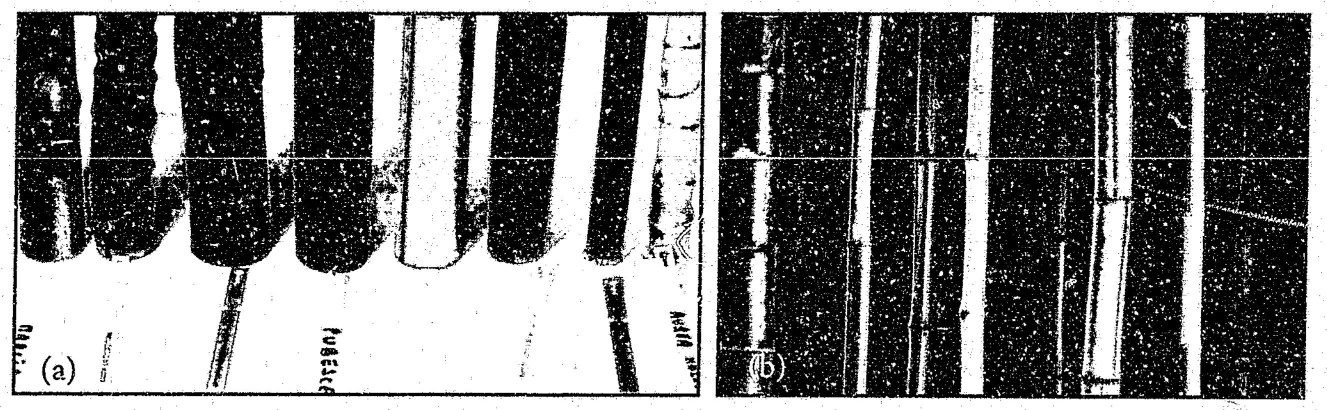


Figure 11: Purchased plants for subframe growing and Phyllostachys pubescenes (Moso) seeds/seedlings

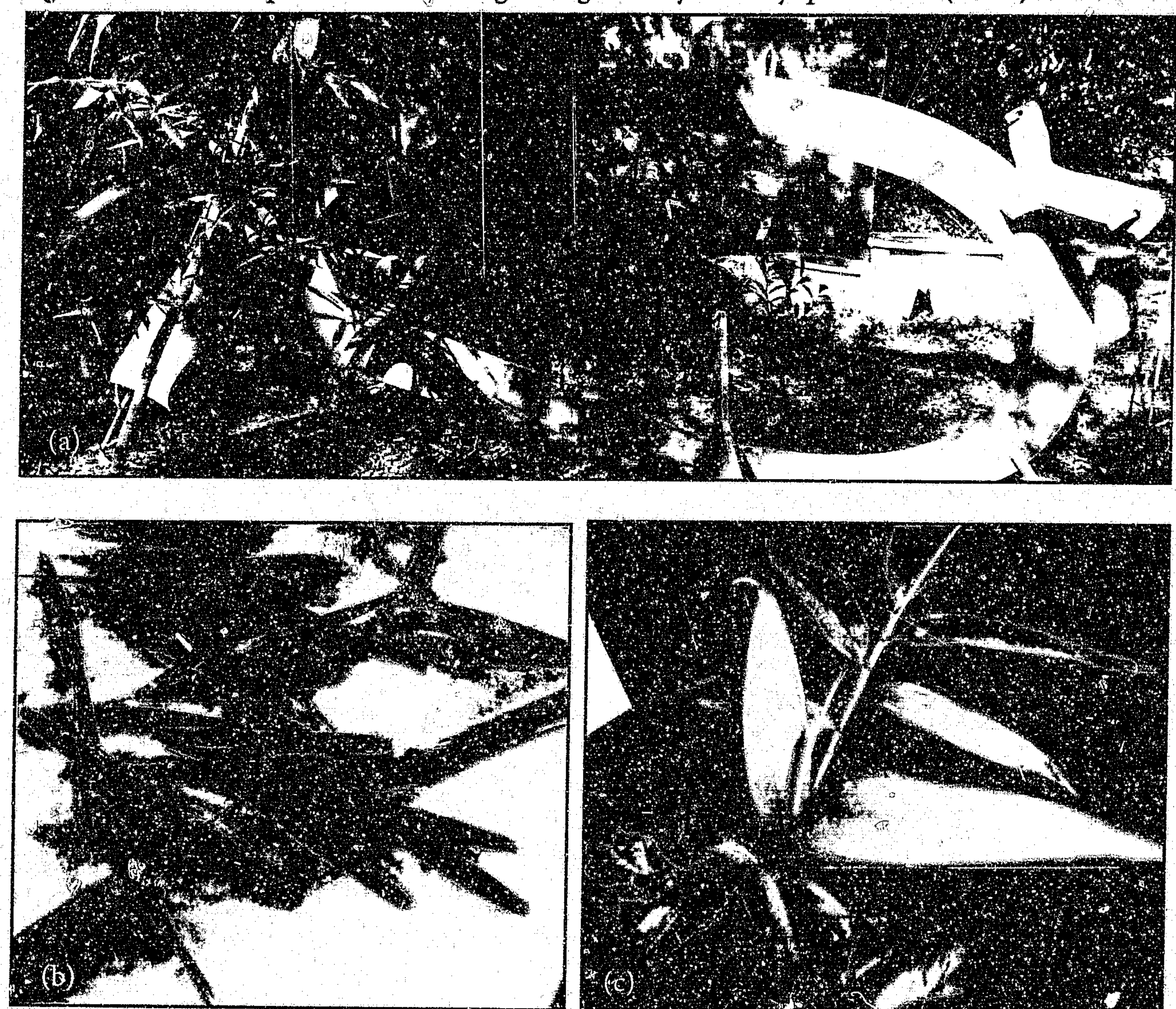


Figure 12: Mercedes "Biome" "grown" concept

8.2 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; Farrelly 1984, 219; Hidalgo 2003, 142-153; Lewis and Miles 2007, 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[51], over such a trellis ***(see; Appendix D: "Growing canopy shelter" Page 176-177)***. 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, 352). This allows structures, including complex compound curves, to be grown seamlessly by only using plant growth control.

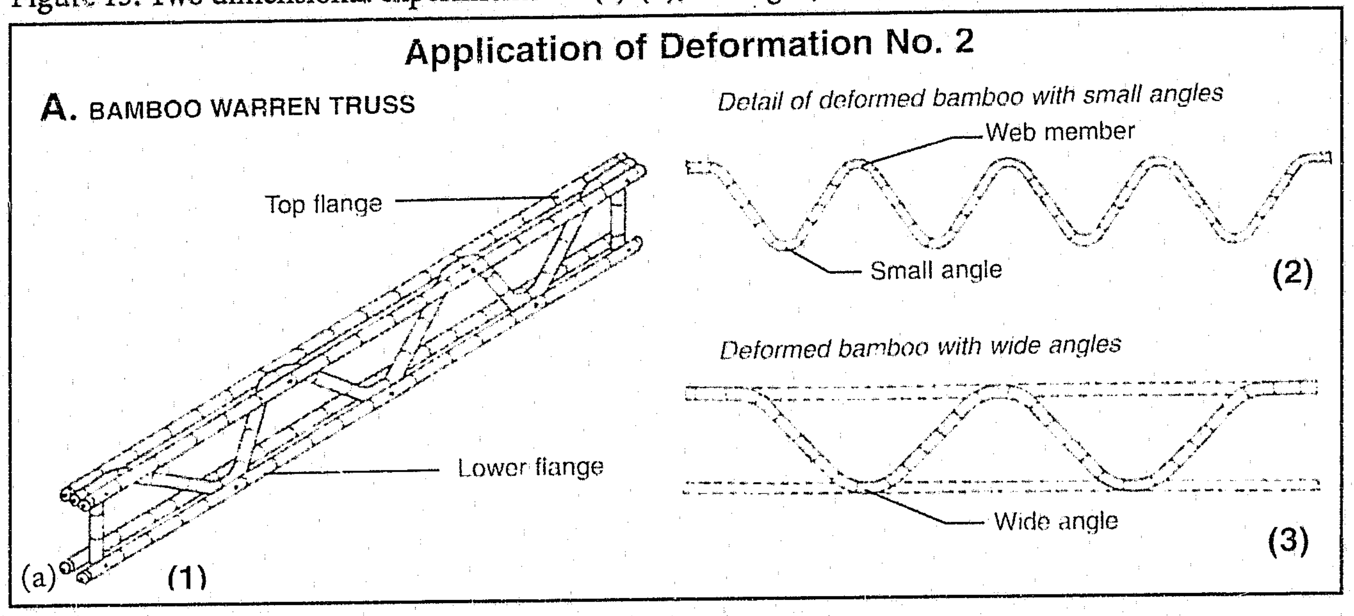
8.2.1 Two dimensional substructures

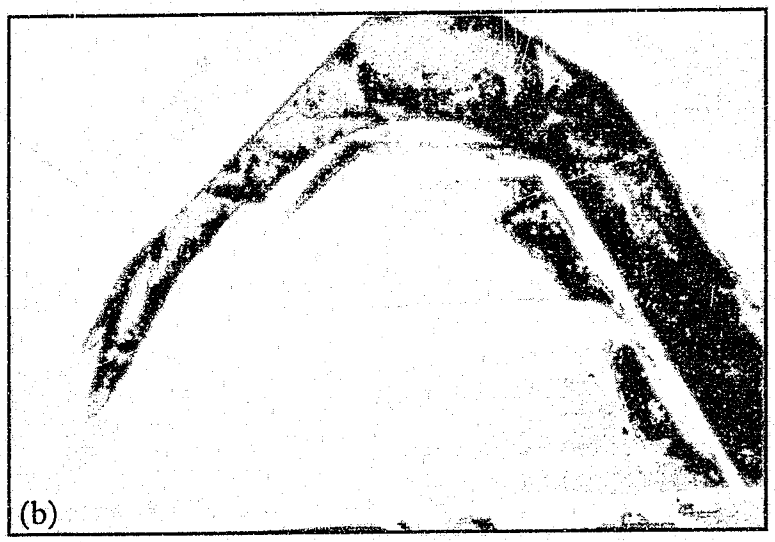
Replicas of the enclosed box growing experiments described by Hidalgo ***(Figure 13a, 13b)***, were conducted in the March 2011 growing period. The experiment was conducted to determine whether, in fact, bamboo could 'find its own way' around a wooden maze fastened to a base board with a hinged cover to check plant growth ***(Figure 13c, 13d)***. This is an ongoing experiment at the time of publication; however, the plant has nearly completed the shape over a small testing section. Hidalgo (2003, 353) discusses methods for creating 'square and rectangular bamboo' ***(Figure 13f)***, and an experiment using this method was conducted ***(Figure 13e)***.

See; ***Appendix D: Early Experiments; Growing square bamboo, Page 178; Growing bamboo inside a maze frame, Page 179-180.***

[51] The need to reduce the distance food travels from growing area to point-of-sale is discussed in a media article by Brendon (2010, 16-17) as one method of increasing food source sustainability.

Figure 13: Two dimensional experiments (a)-(b); Hidalgo (2002, 352)




(b)

These images describe the proposal by Hidalgo regarding structural components being shape modified while growing for architectural purposes. The end result of this process is (at the time of thesis publication) undocumented.


(c)

Image (c):
Section trialed by author.

Note the sudden deformities (bends) in the section just above the culm nodes.

At the time of writing, investigation is being undertaken to determine methods to lessen this effect.

This may include using curves that aren't as tight, or choosing shape modifications towards culms of a certain diameter only.


(d)

Deformities in the bamboo culm whilst performing shape modification experiments in an enclosed box. Despite these deformities, the plant continued to grow.


(e)


(f)

(f); Hidalgo (2002, 353)
Square bamboo shape modifications.

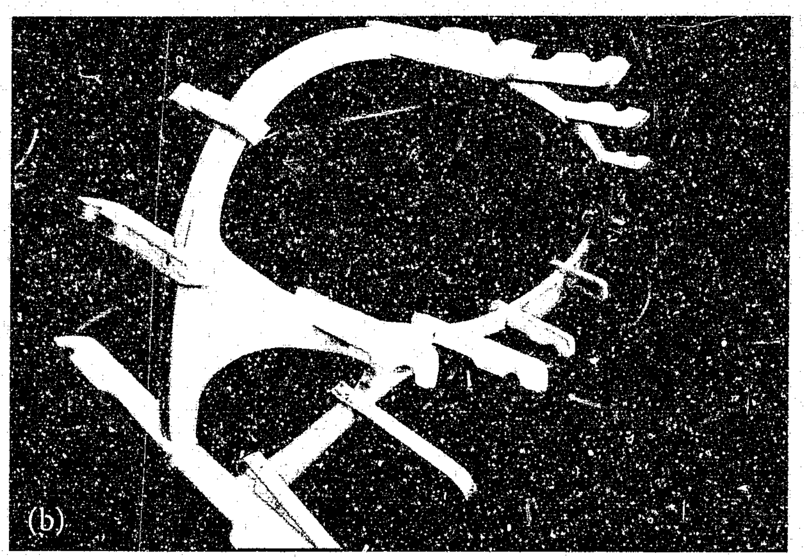
Trial by the author to replicate deformed culm walls in bamboo. The main problem with this trial was the relative unestablished natura of the plant being used for the experiment, with a small diameter. Success may be improved with trials on larger diameter sections.

8.2.2 Direct shape modification over substructures

Experiments involving tensioning the growing bamboo over the frame directly ***(Figure 14a, 14b)*** 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 14c, d, h-k)***, 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'[52] between each section regarding any curve subtleties ***(Figure 14e-g)***, 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 14a***.

Figure 14: Shape substructure experiments

(a)



(b)

Structural supporting frame for deforming bamboo. Frames could be devised to be modular, with removable sections which could be exchanged to other growing culms in a framing scenario.

52 Frame sections, shown in Figure 14a and 14b, have spaces between each tensioned control point. These create jagged stepping between each point where curve coordinates (X,Y,Z) are missing.

(c) (d) (e)

Figure 14: Shape substructure experiments

The profiles did not contain adequate curvature information between the sections to smoothly fulfil the vehicle form.

Figure 14: Shape substructure experiments

Experiments growing bamboo over a scaled substructure frame.

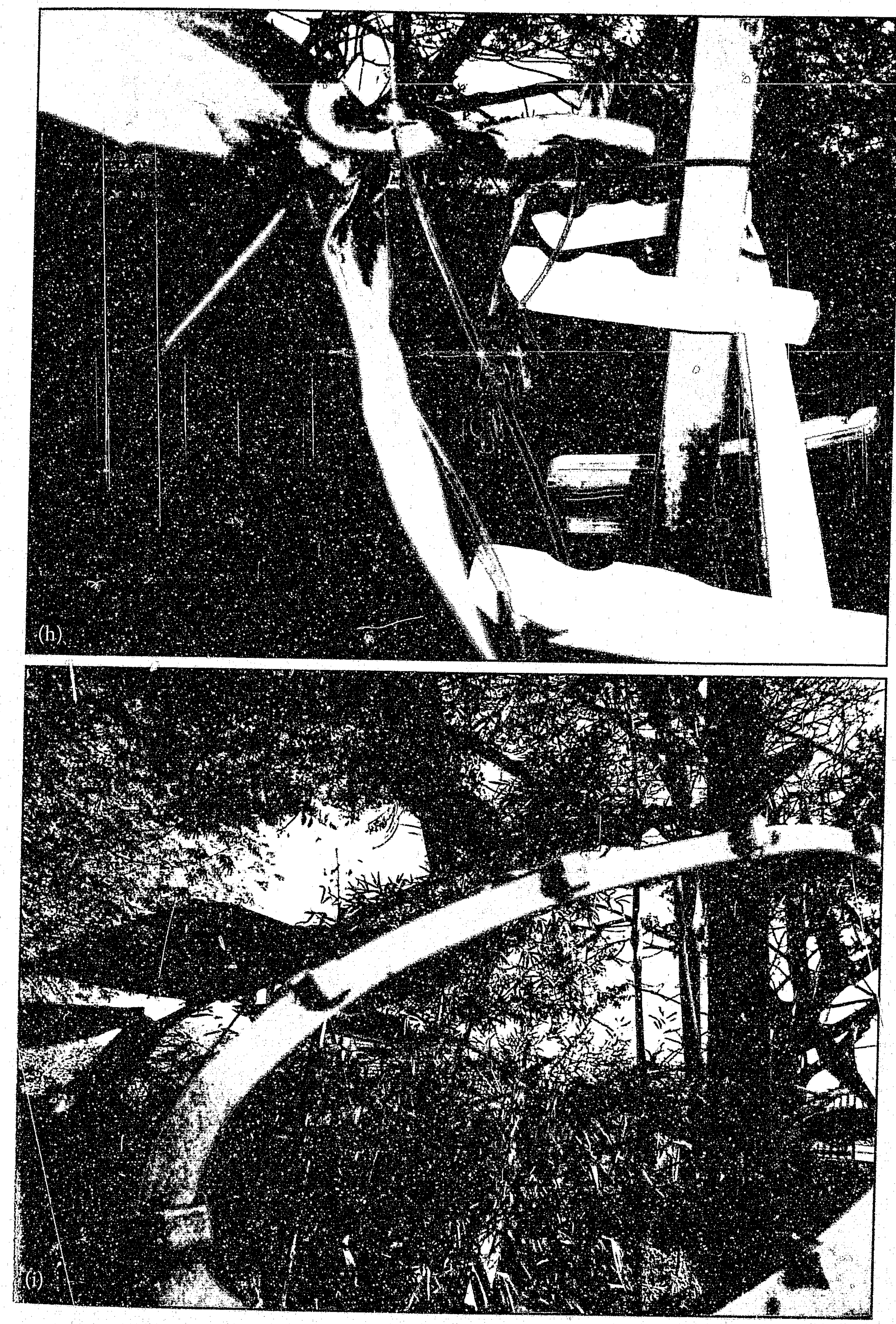
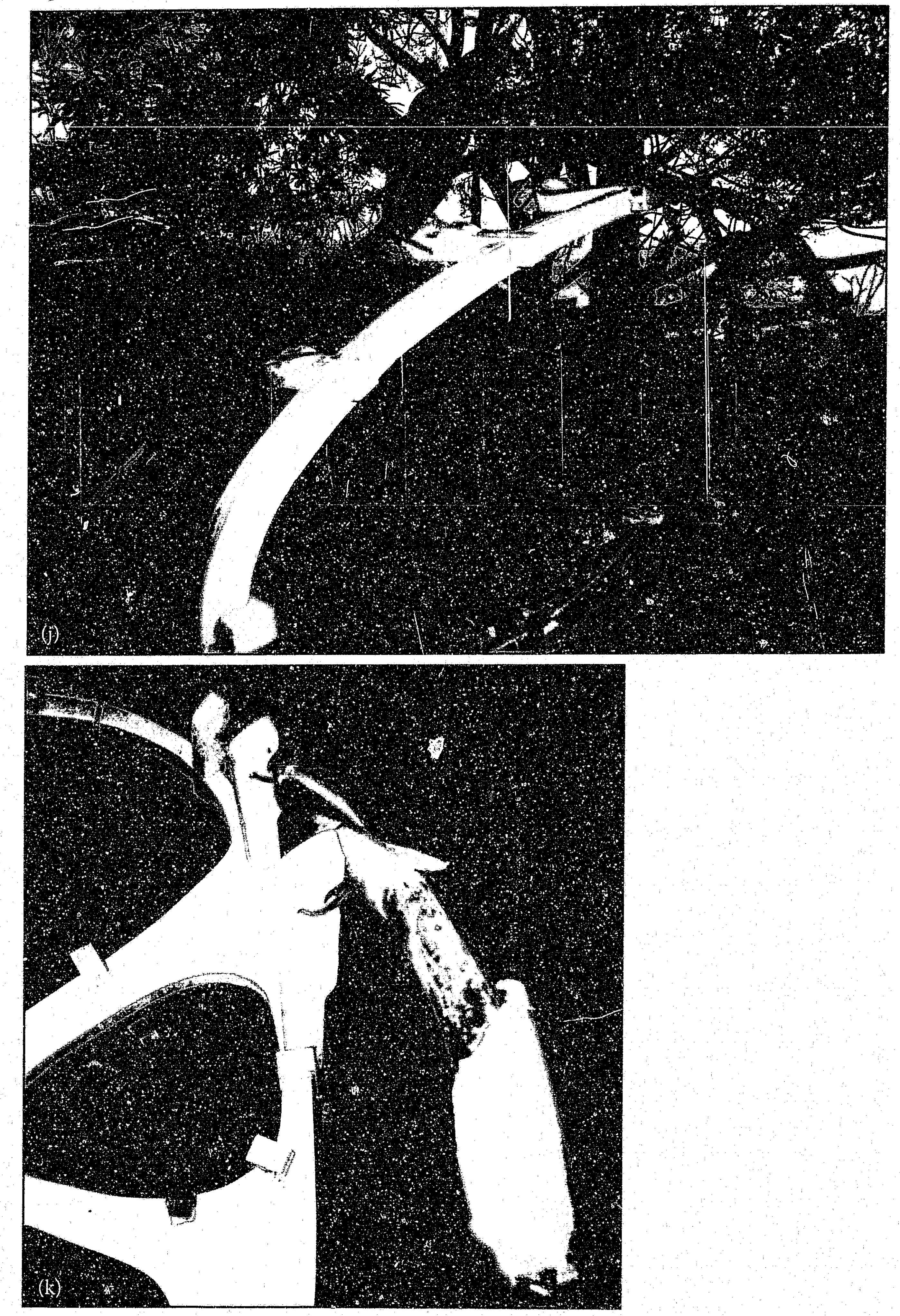


Figure 14: Shape substructure experiments



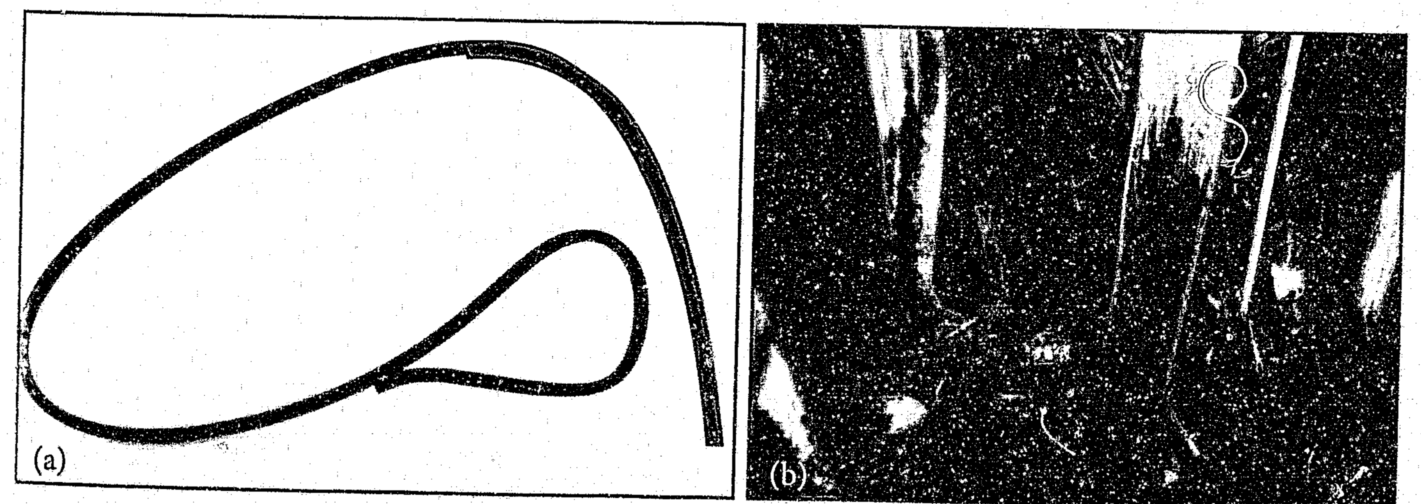
Experiments growing bamboo over a scaled substructure frame.

8.2.3 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 15a-15i)***, as discussed by Hidalgo (2003, 354-355) whereby wooden sections - in this case rectangular wood boards for growing 'square' bamboo - are roped around the emerging culm[53]. This technique, used for decorative and architectural purposes (downspouts for houses) (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[54] 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.

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 (Hidalgo 2003, 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 15: Tubular shape modification experiments



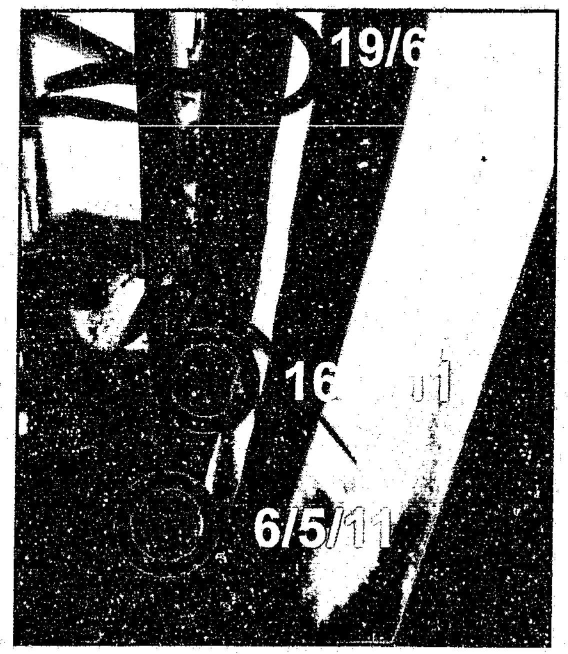
(a): Section grown indicated in red

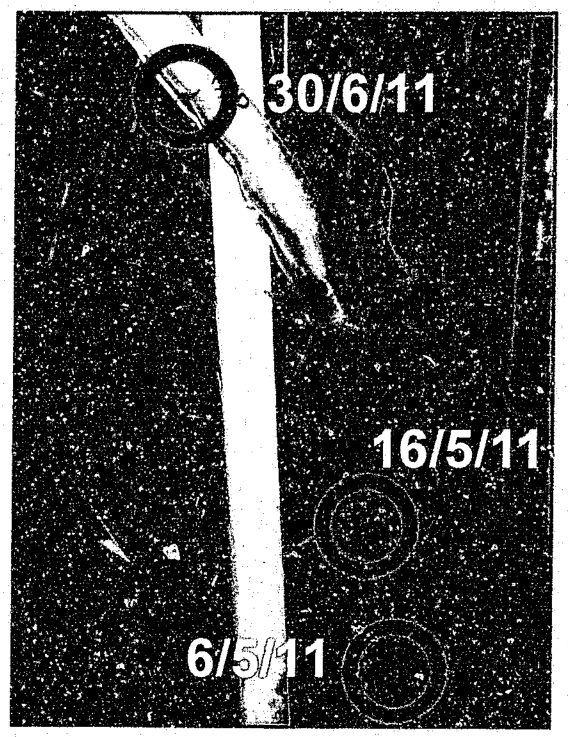
(b): The shaped aluminium tube placed over emerging bamboo culm

53 The technique of plant shape modification through 'guides' is discussed by Watts (2011) regarding the formation of a "Living root bridge" in Cherrapunji, North-east India.

54 PVC was also trialed, and was effectively bent into shapes with minimal heat application from either a hair-dryer, or heat gun (see; ***Figure 15h, Page 100-101***).

Figure 15: Tubular shape modification experiments (c) - Images grouped

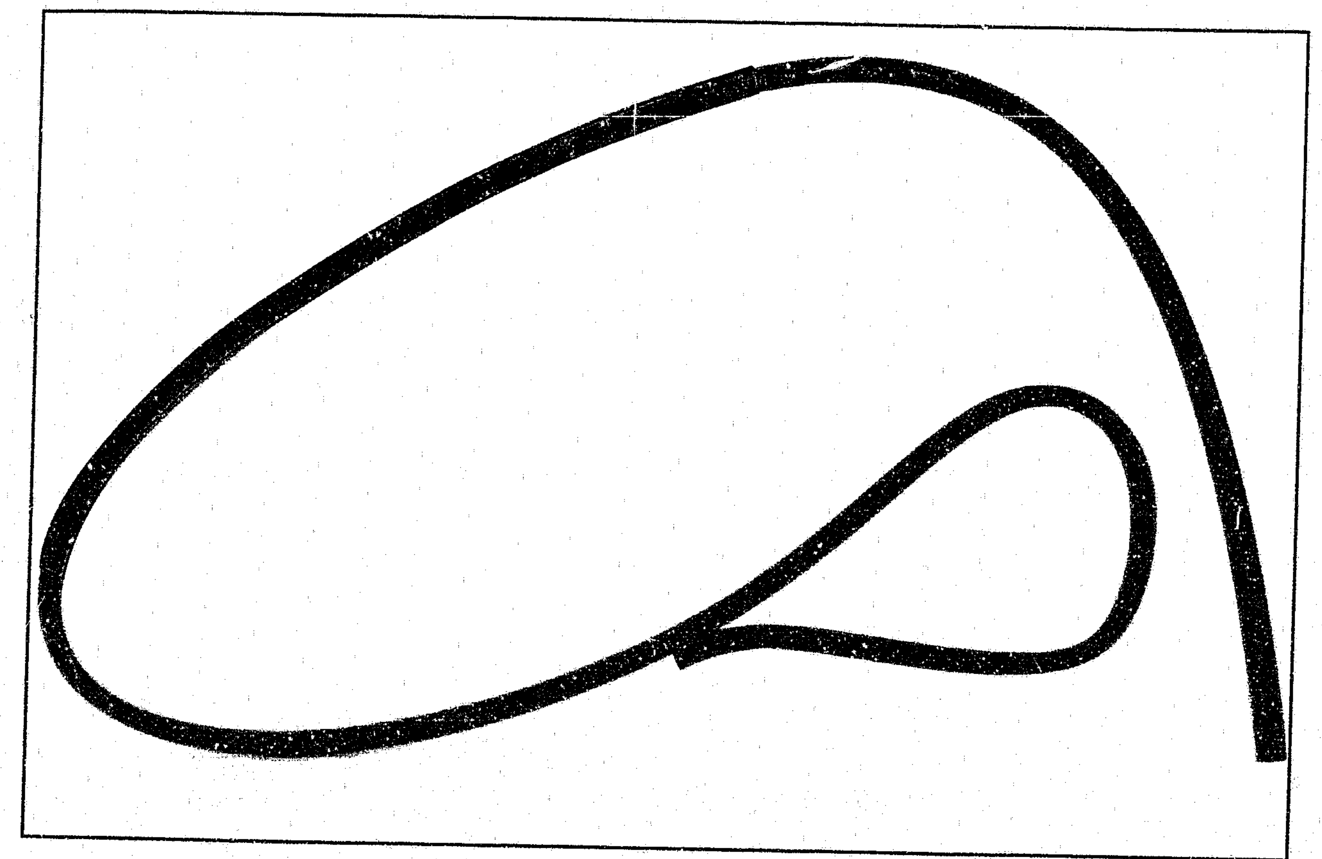




Culm growth progress from ***Figure 15a.*** Indications for the growth pattern were varied. The amount of growth expected over a given timeframe, was inconsistent between all the culms, even those of the same species.

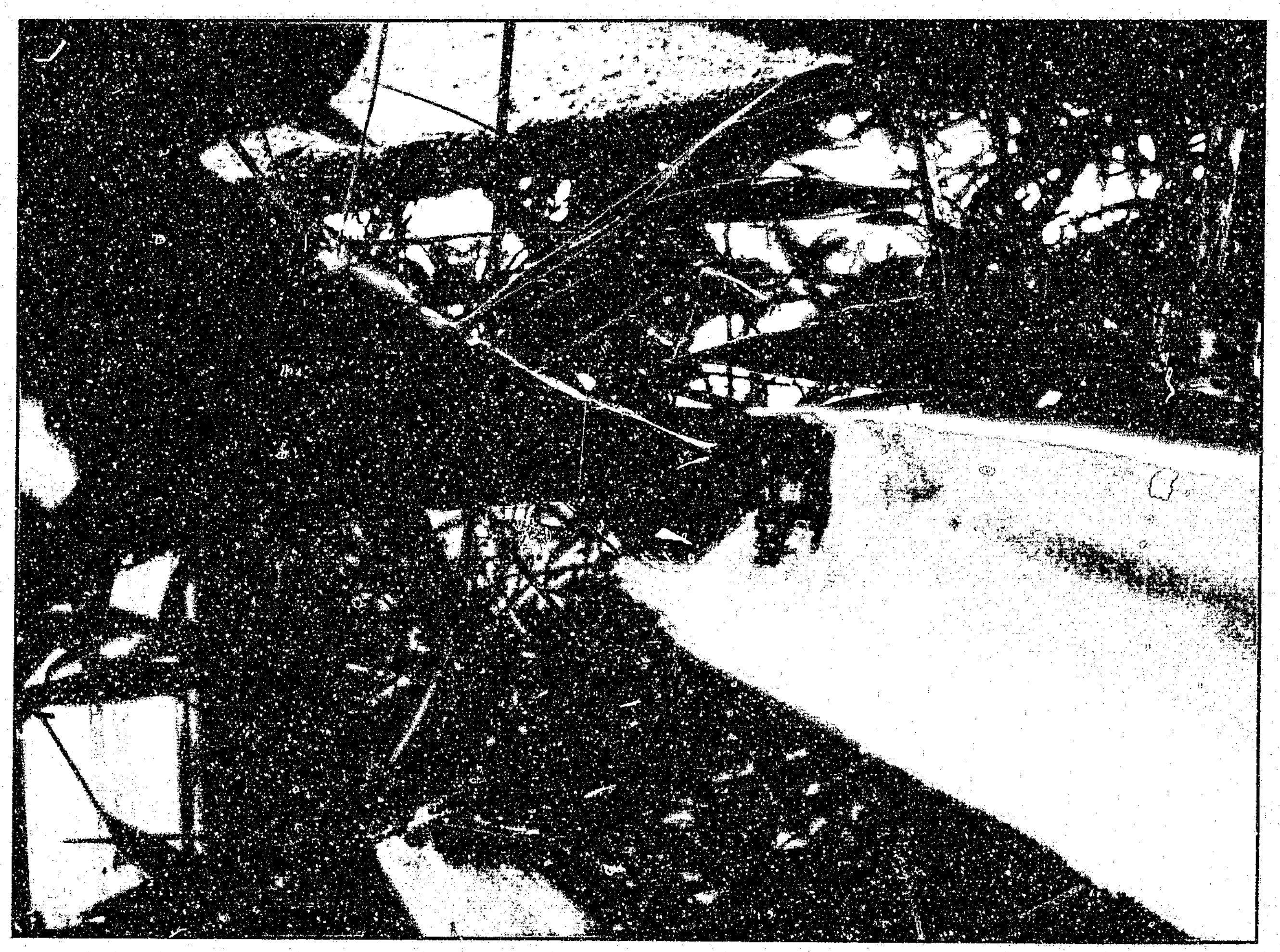
The ability for the plant to follow and maintain gradual curves was particularly impressive.

Figure 15: Tubular shape modification experiments (d) - Images grouped

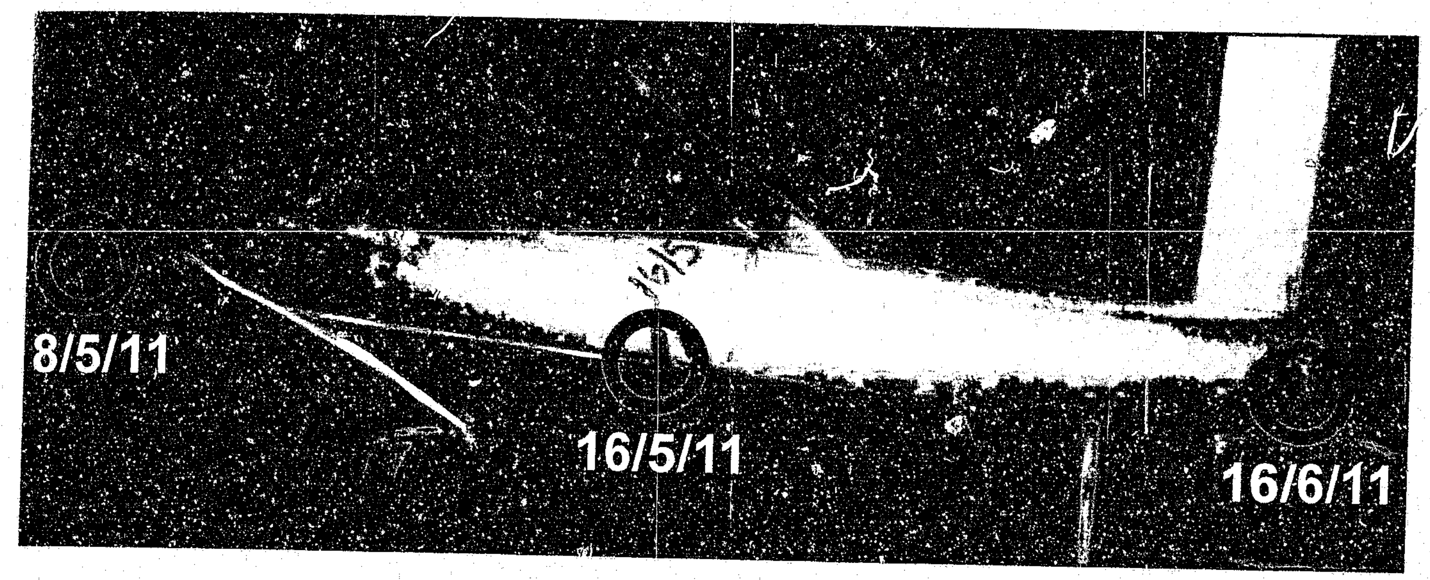


Section grown indicated in red

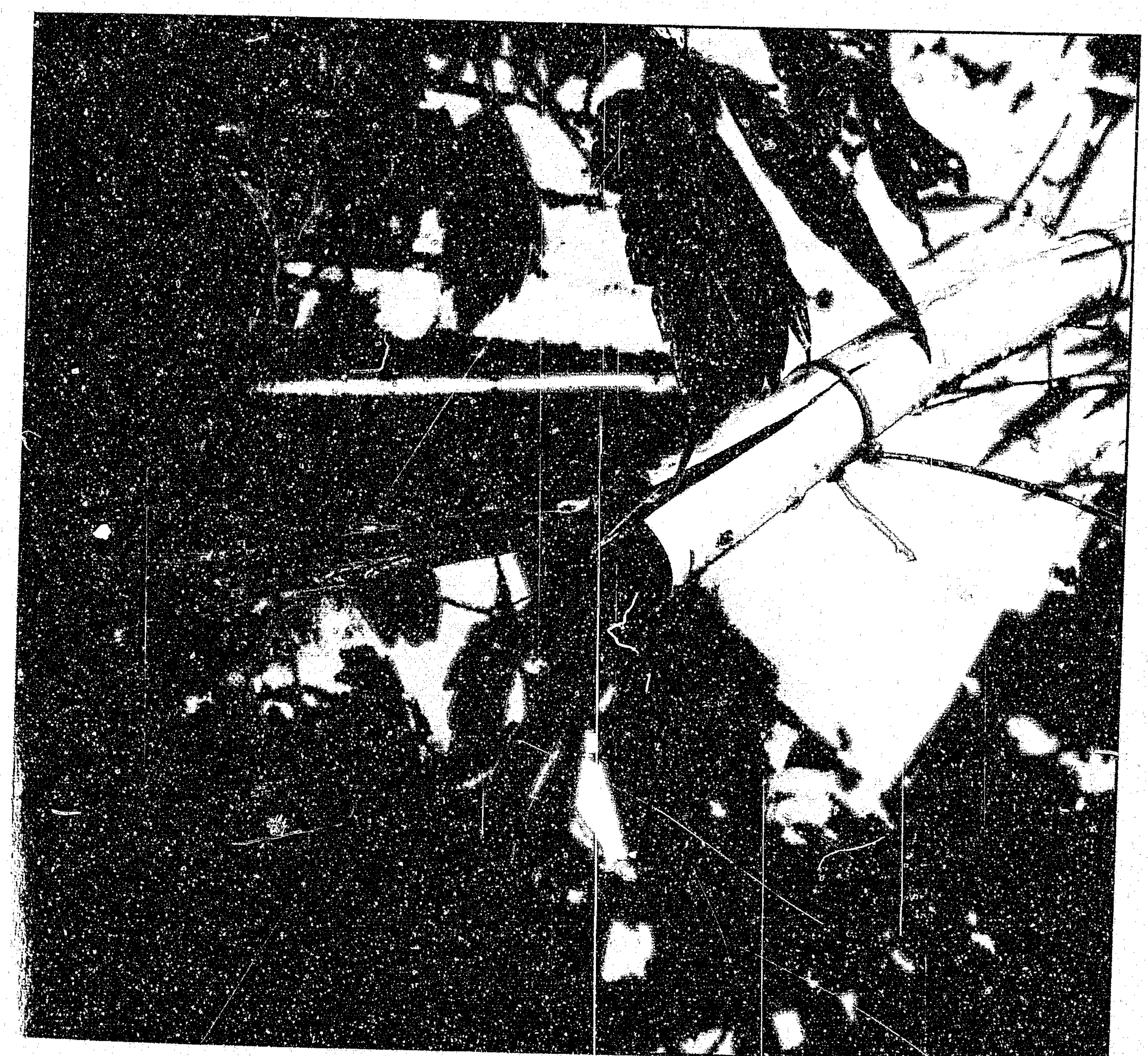
The shaped aluminium tube secured in place



Bamboo culm pushing through the tubing section.

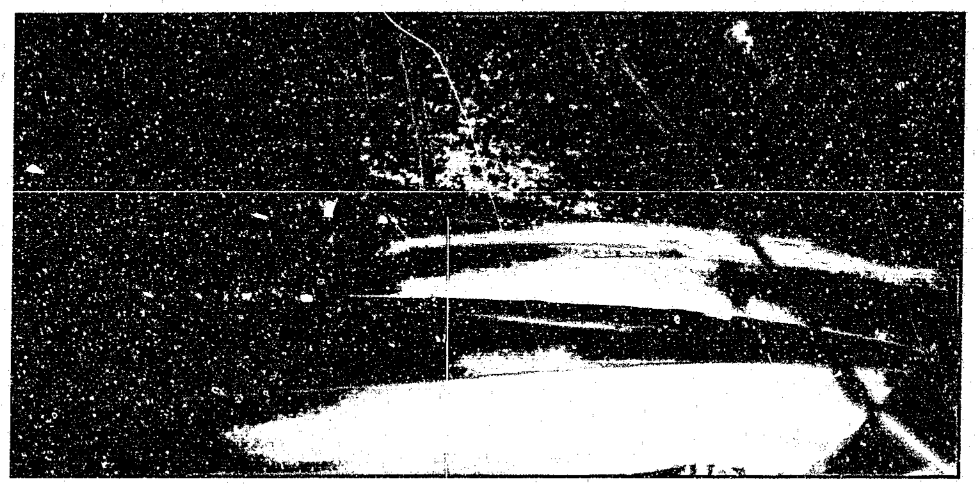


The rate of growth observed may have been due to colder climatic conditions during the winter period.

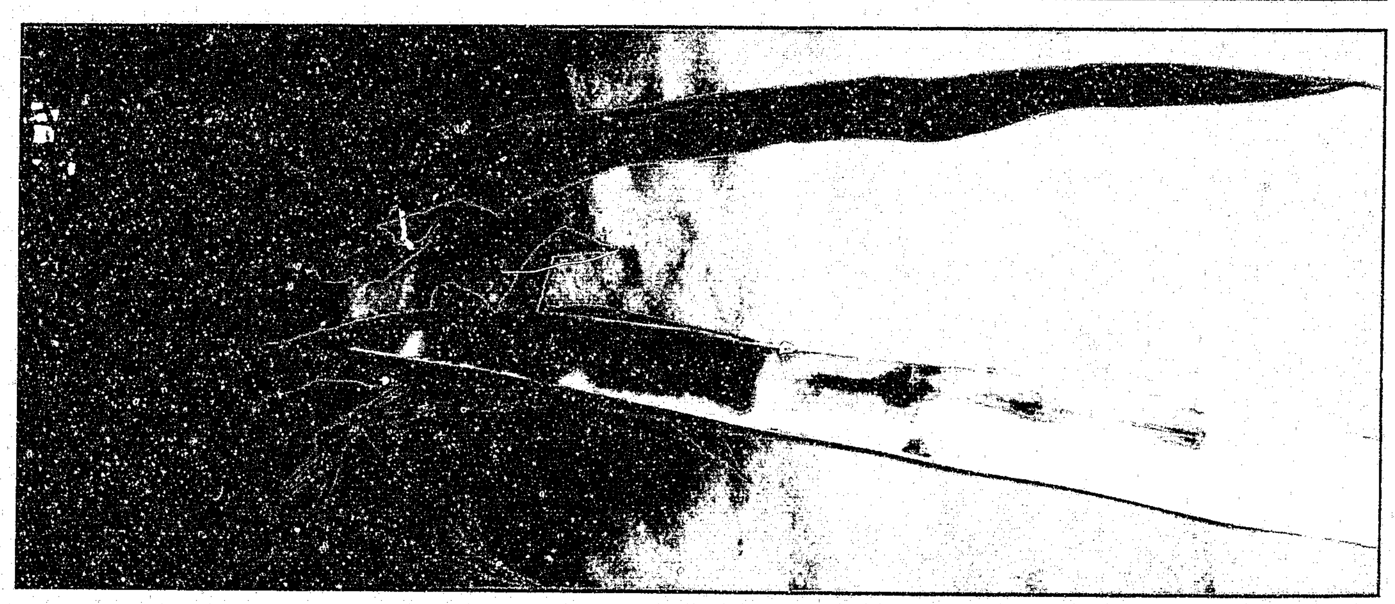


After completion of the shaped section, the bamboo culm continues to grow upwards. It should be noted that from observation, an additional upwards pointing tubular section may have to be added to prevent the culm from bending towards the light at an excessively sharp angle.

Figure 15: Tubular shape modification experiments (e) - Images grouped



Even though the culms are reasonably small, it is apparent that they still maintain a degree of the 'set' shape,although further towards the tip, significantly more 'rebound' is encountered.



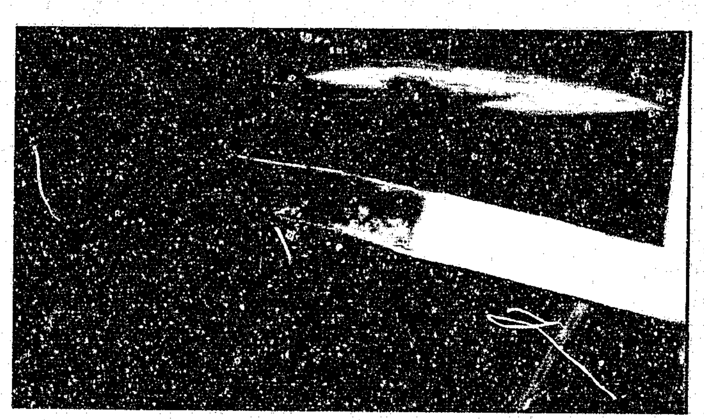
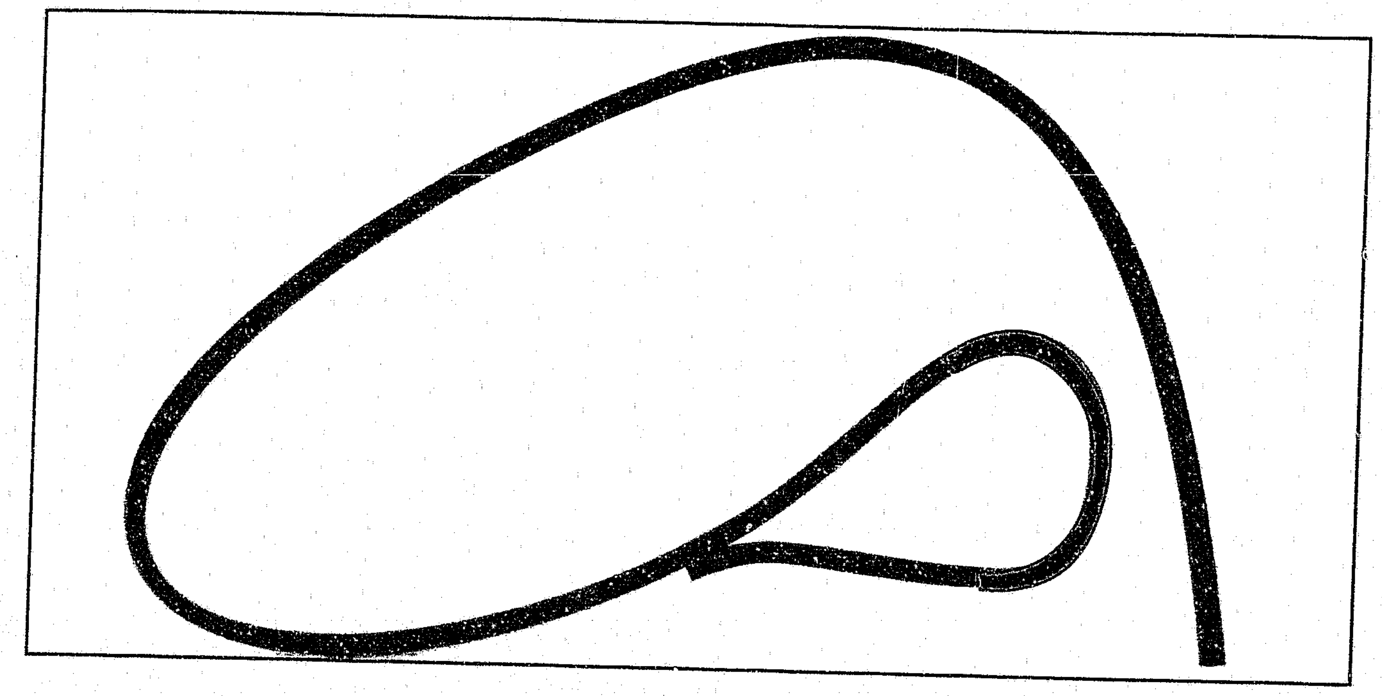
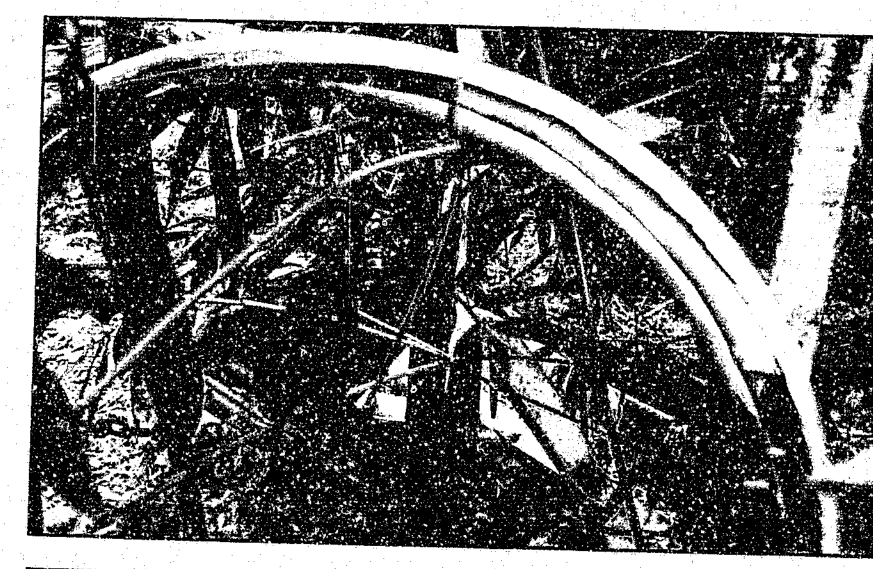


Figure 15: Tubular shape modification experiments (f) - Images grouped

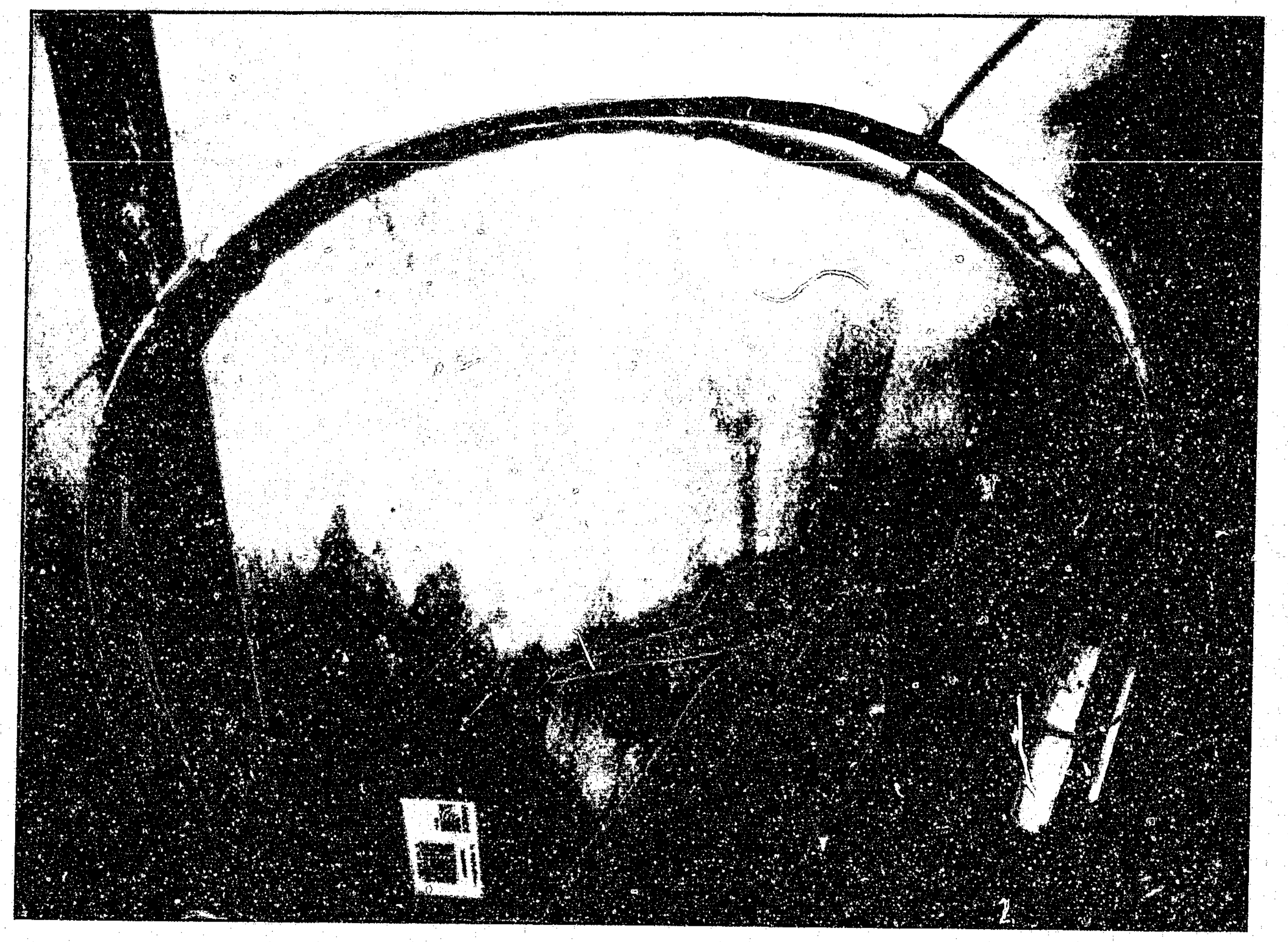


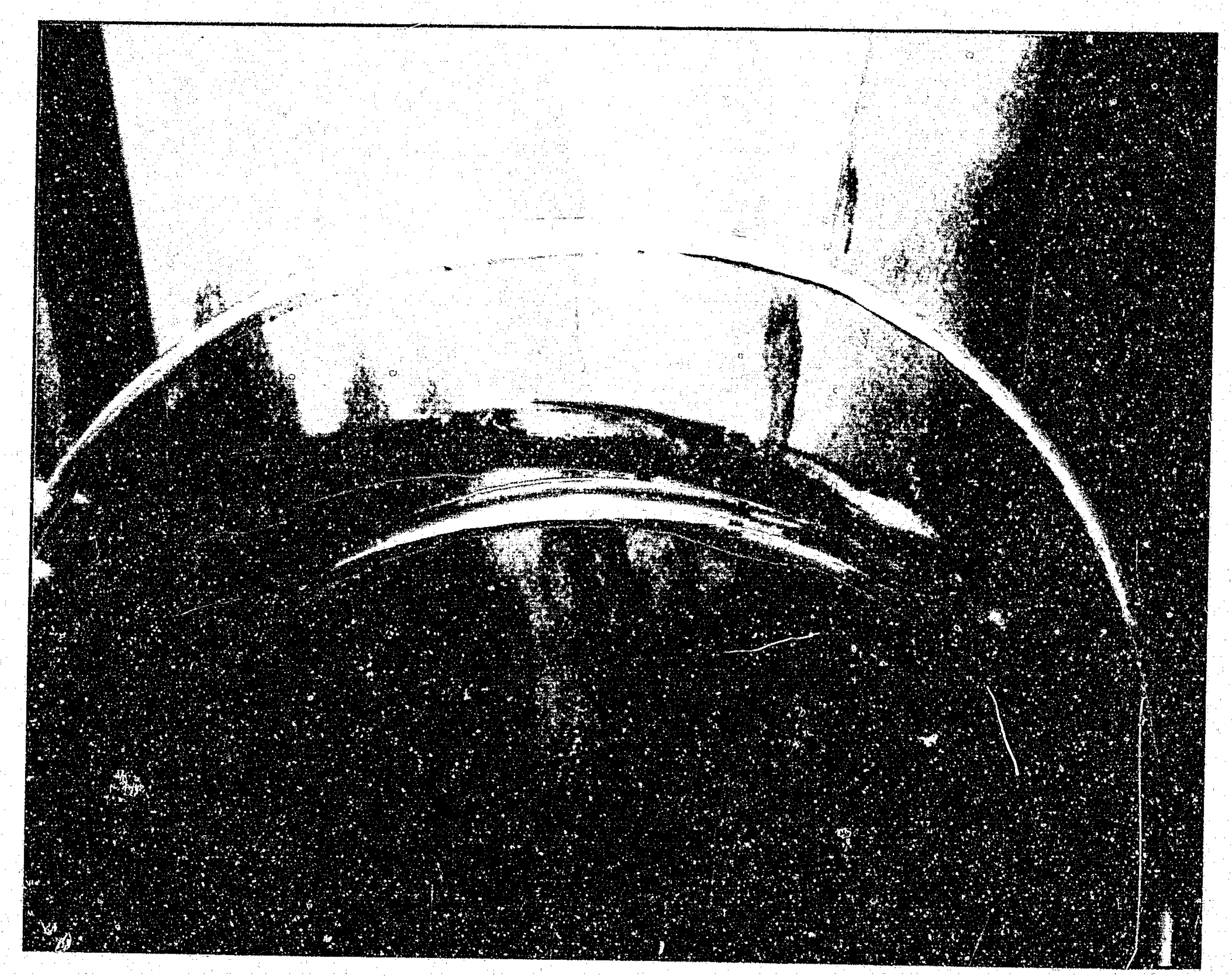


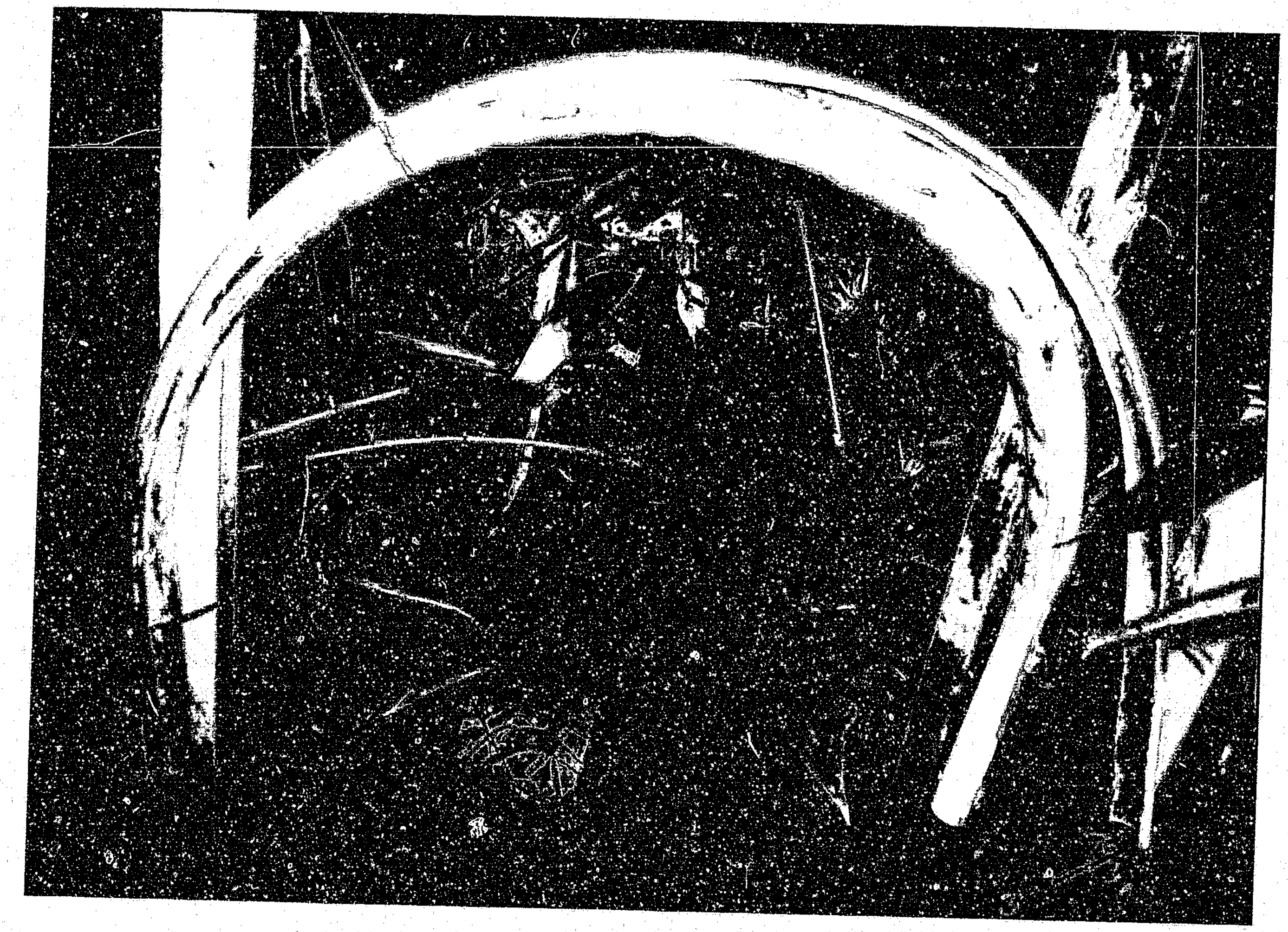
Tight curve radii being grown using ***Oldhamii*** bamboo. The culm is still growing at the time of thesis publication, however, the progress for maintaining such a shape proves extremely promising.

Once further plant establishment has taken place, and culms begin to grow to predictable heights, the complete frame would be trialed using a single grown piece.

Figure 15: Tubular shape modification experiments (f) - Images grouped







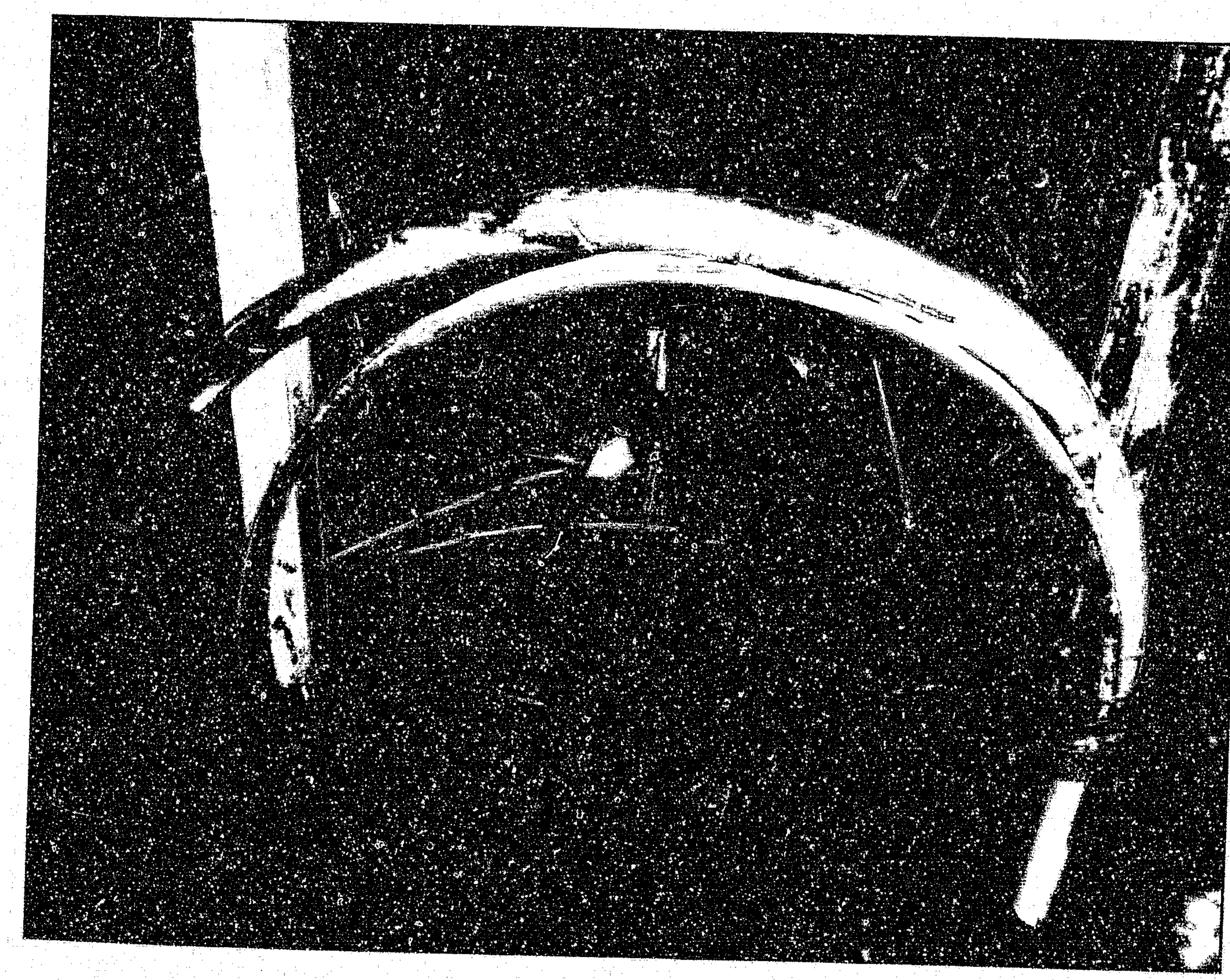


Figure 15: Tubular shape modification experiments (g) - Images grouped

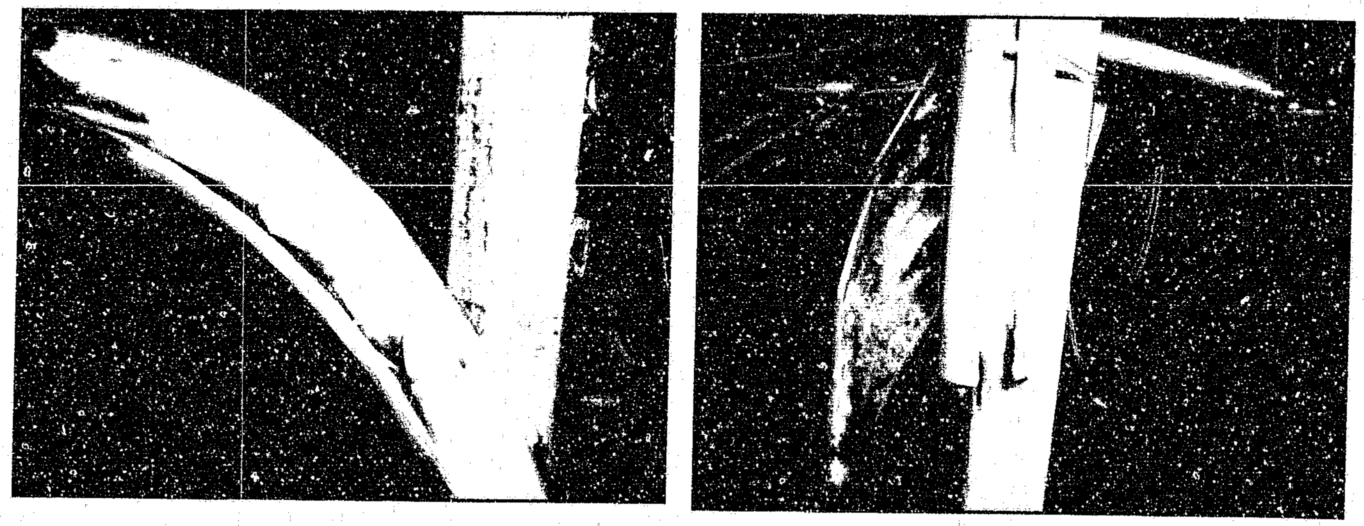
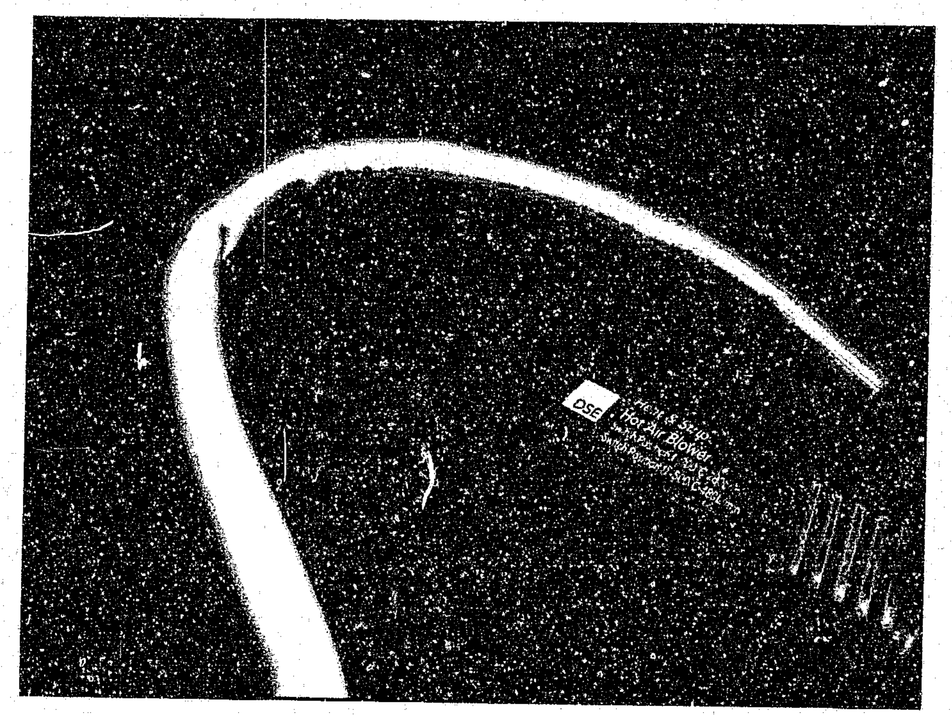
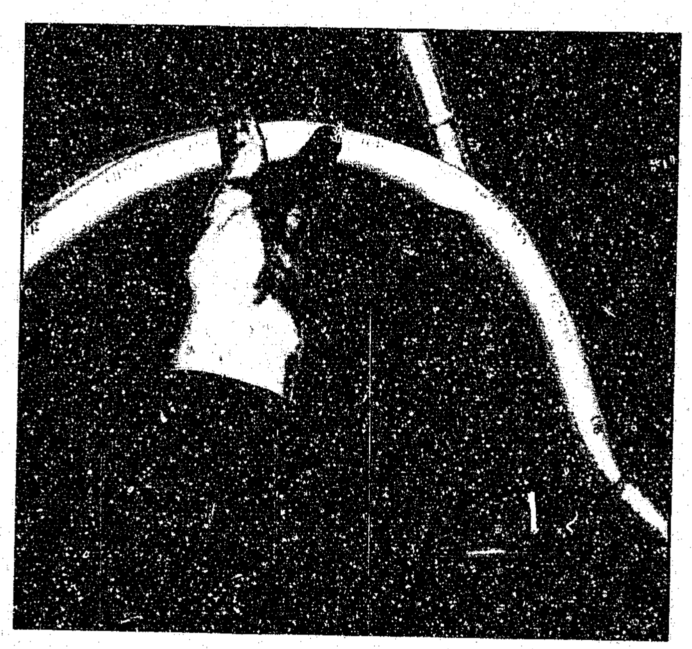


Figure 15: Tubular shape modification experiments (h) - Images grouped



Heat formed PVC pipe could also be used to make initial forming section for the bamboo to grow within.

This plastic material is easier to shape modify, reshape, and is corrosion resistant / UV resistant.



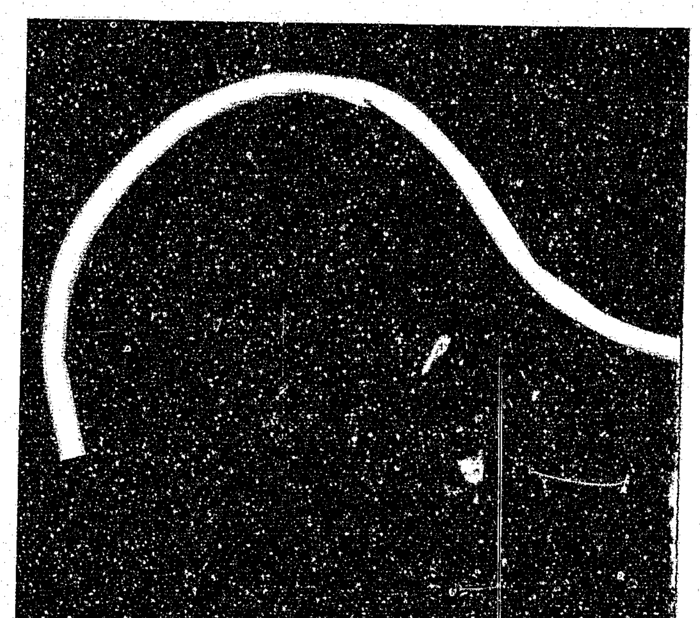
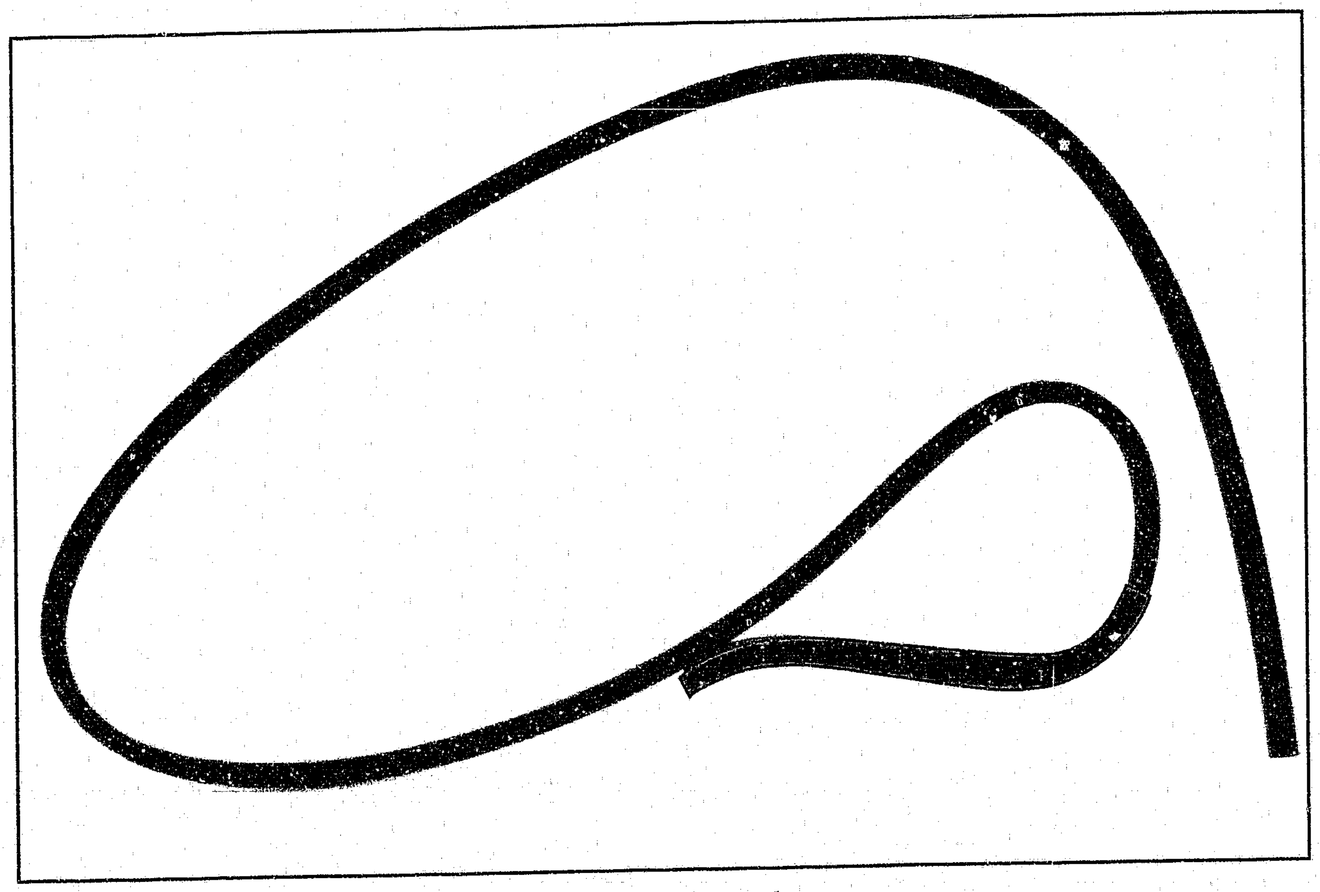


Figure 15: Tubular shape modification experiments (h) - Images grouped

Figure 15: Tubular shape modification experiments (i) - Images grouped



Section profile grown in this experiment is indicated in red.

'S' shaped compound curve set in shape, with the bamboo grown inside aluminium tubing.

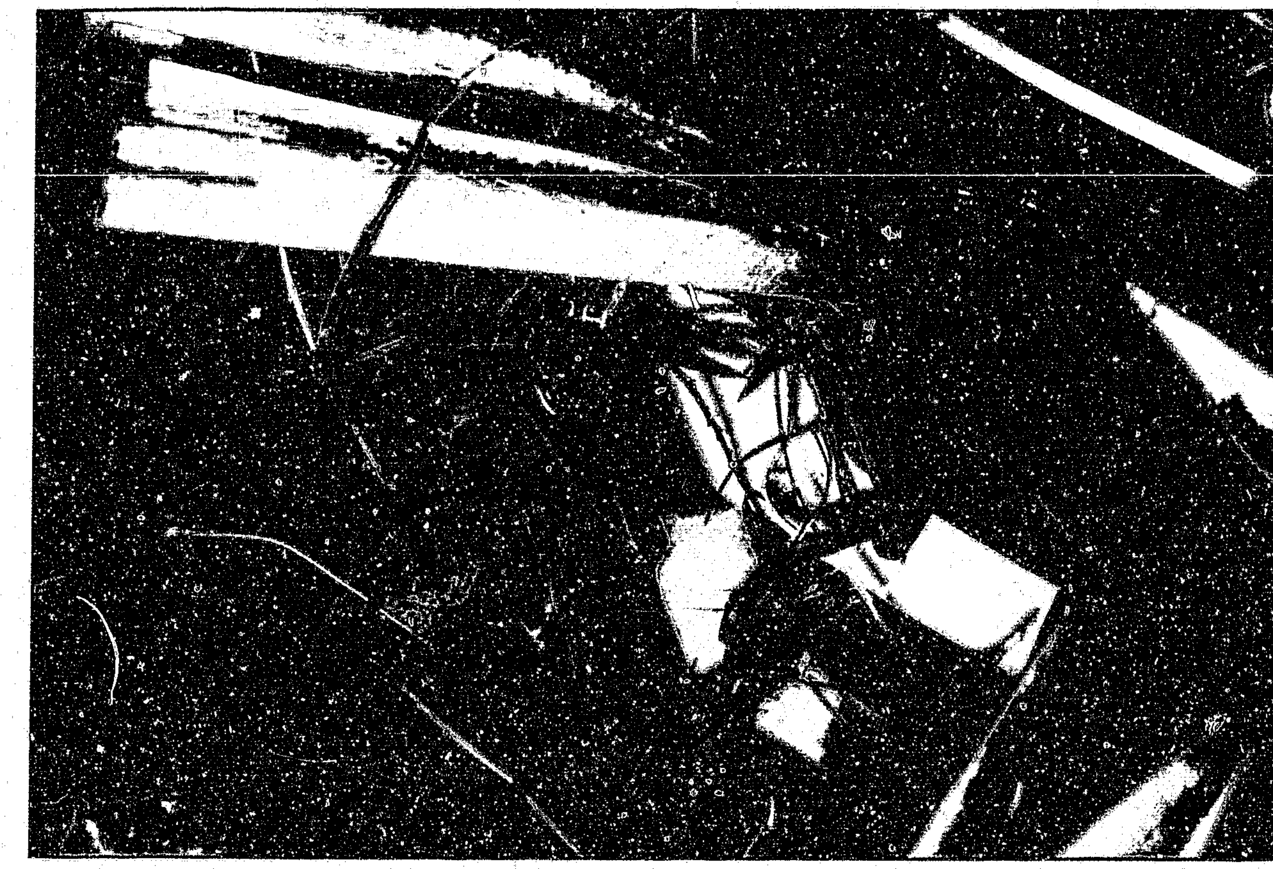
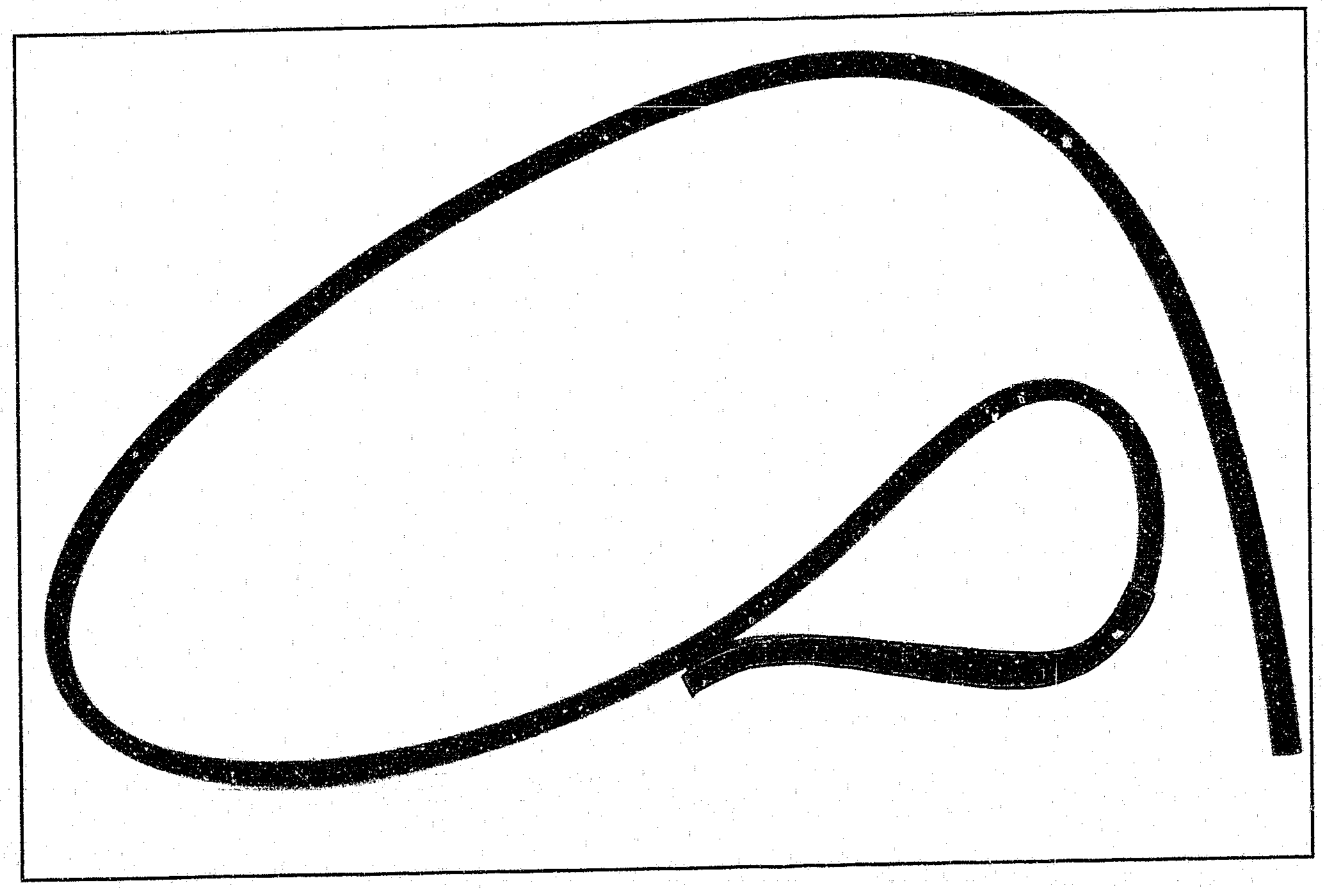


Figure 15: Tubular shape modification experiments (i) - Images grouped

Figure 15: Tubular shape modification experiments (i) - Images grouped



Section profile grown in this experiment is indicated in red.

'S' shaped compound curve set in shape, with the bamboo grown inside aluminium tubing.

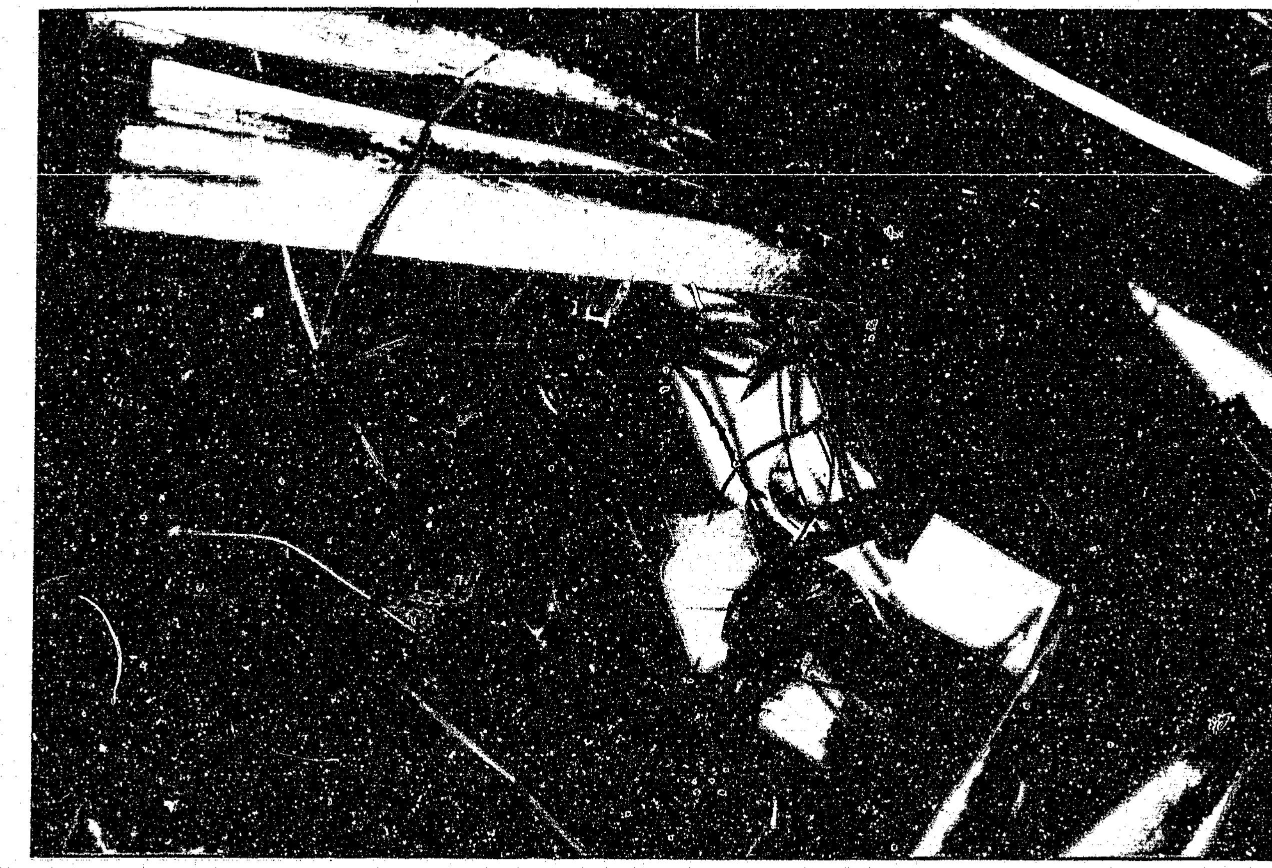


Figure 15: Tubular shape modification experiments (i) - Images grouped

8.3 Prototype testing

Van der Lugt (2008, 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 15a -15i*** (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 16a-16c)***, 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 (see; ***Appendix H, Figure 35j, Page 234***). 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.[55]

(See: ***Appendix H*** for complete list of modifications and trials of the prototyping, ***Appendix I*** for build of the scale model)

55 Modular bicycle structures able to modified for end user requirements are evident in the "OpenCargoBike" (Moreno and Wagner 2010, 172-173) prototype from "OpenStructures" (See; ***Section 3.1, Page 35,*** for an image of this concept)

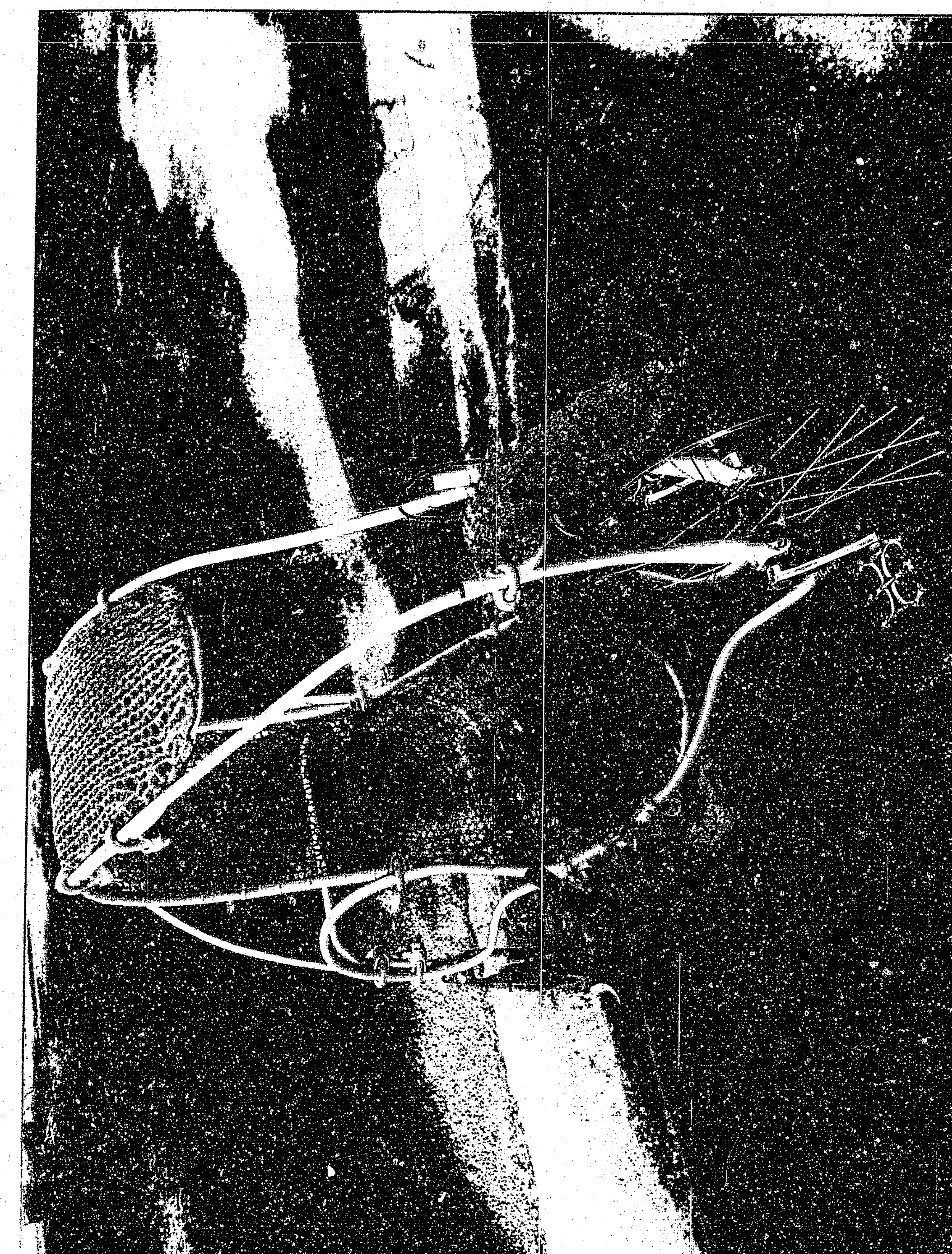
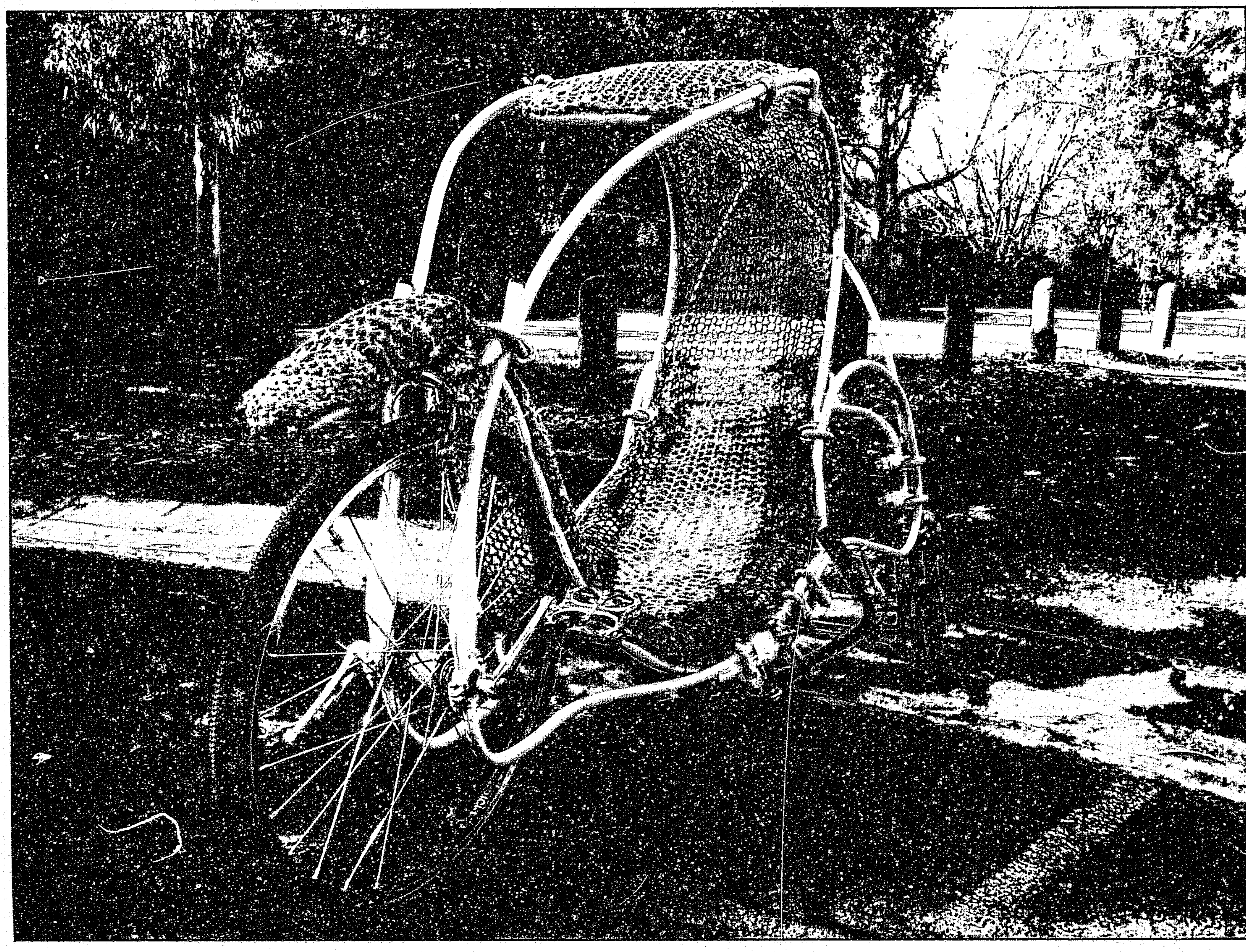


Figure 16: Frame prototype verification

(a) - Images grouped

Figure 16: Frame prototype verification (a) - Images grouped



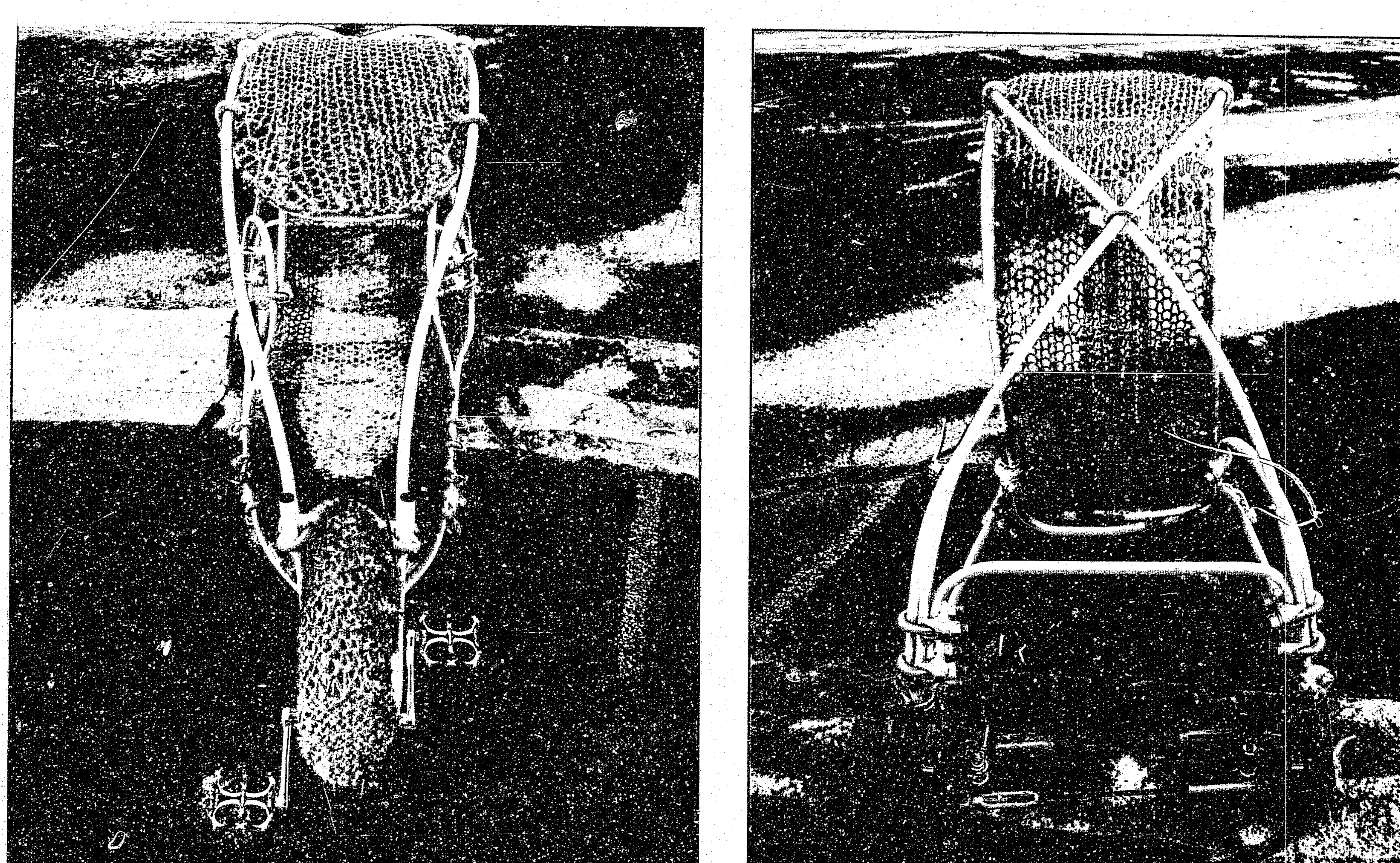


Figure 16: Frame prototype verification (b) - Images grouped

Figure 16: Frame prototype verification (c) - Images grouped

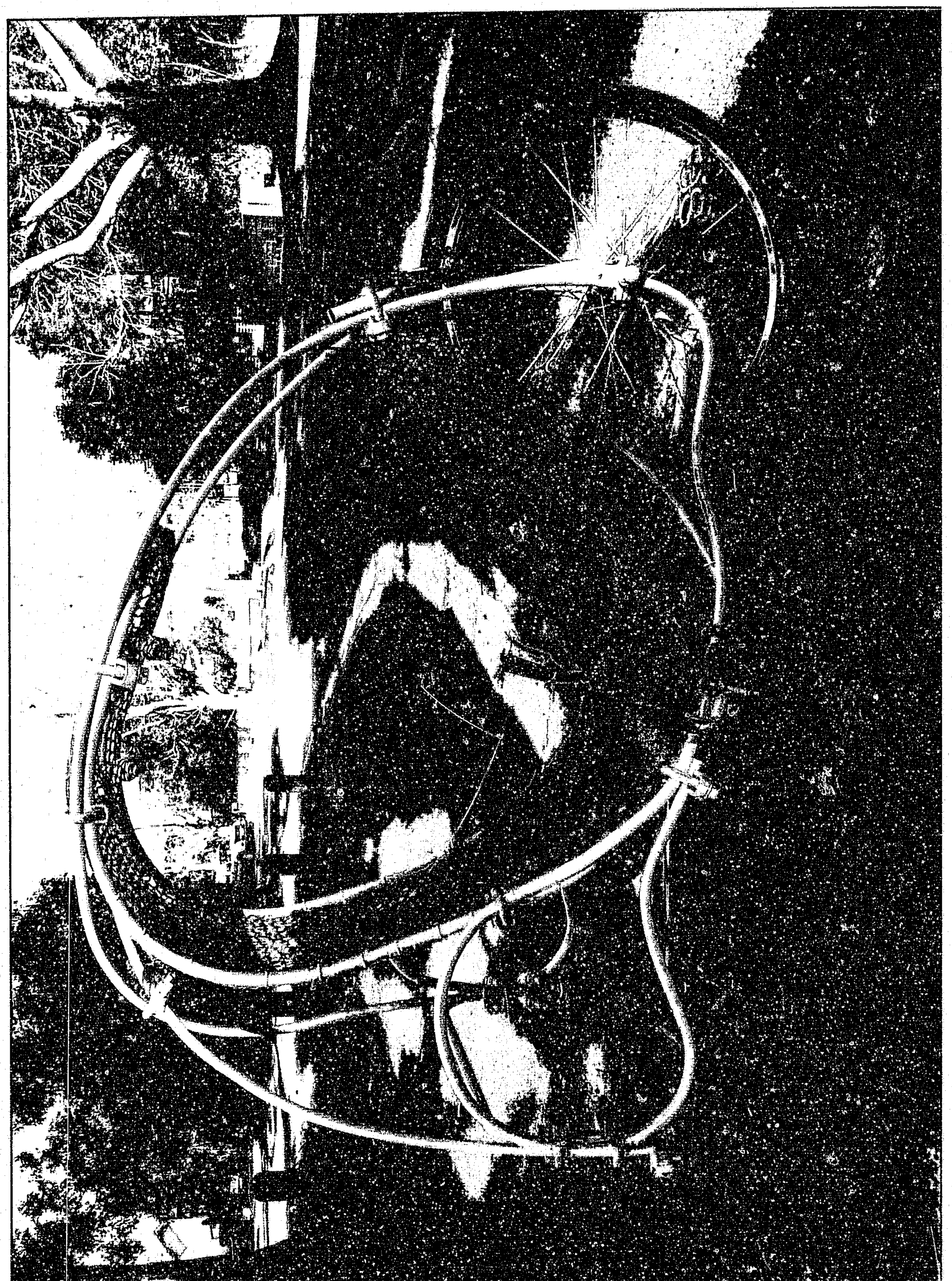
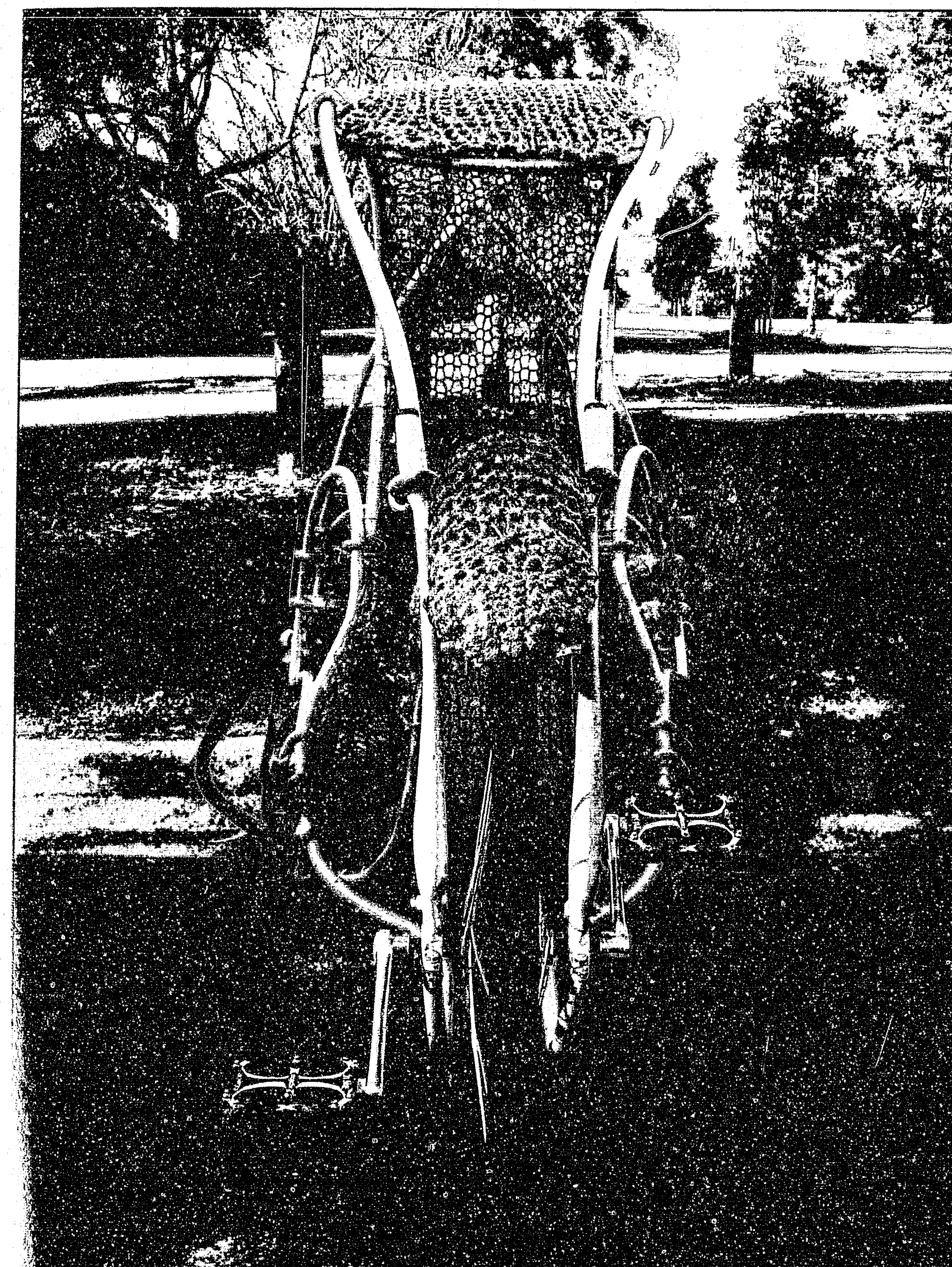


Figure 16: Frame prototype verification (c) - Images grouped



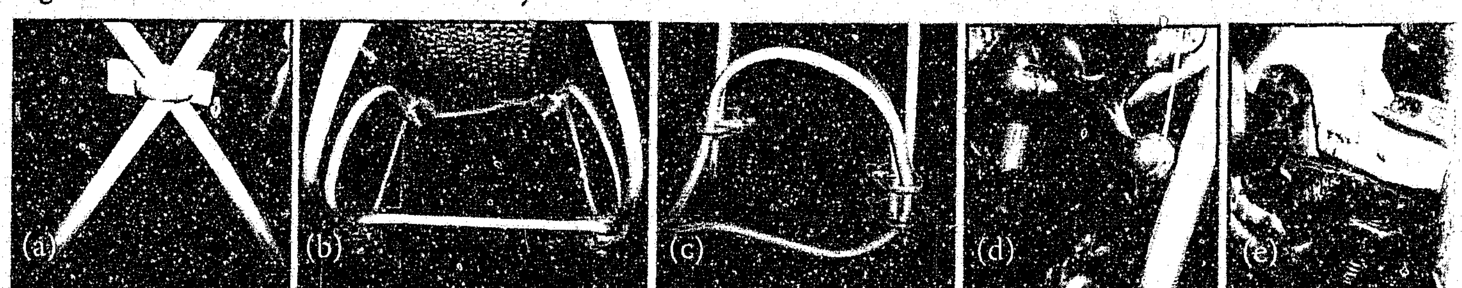
8.4 HPV body and drivetrain description

The reliance on nature to form the vehicle sections allows for simplicity of parts, by forming large amounts of structural components in continuous sections. Furthermore, the investigation into the shape modification on the growing plant enabled experiments which would aim to establish some of the capabilities of bamboo to complete subtle curve transitions and tight radii all within the single growing frame. This has been achieved through the use 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 ***(Figure 17a)***
- Frame canopy structure and wind visor support through opposing roof sections ***(Figure 17b)***
- Stabilising 'loop' for bracing the rear wheels ***(Figure 17c)***
- Routing within the hollow bamboo sections for dynamo wiring and brake cables ***(Figure 17d)***
- Anchor for front wheel hub and pedal assembly ***(Figure 17e)***

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[56], 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.[57]

Figure 17: Structural attributes of the 'Ajiro' frame



56 Front-Wheel-Drive, Front-Steered Recumbents are mentioned by Abbott and Wilson (1995, 126) and Fehlau (2006, 120-121), however, this refers to 'recumbent bicycles', there is no mention of velomobiles.

57 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

9

Discussion of the outcomes from direct experiences in the natural production cycle.

9. Discussion

Mass production, reliant on consumption of raw, unrefined materials (Smith 2011, 79, 190-191) 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 drivetrain function. The basis for the *Ajiro* was reached through harnessing the natural cycle of bamboo production, whereby the sun and soil 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, 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[58] to bamboo must be considered, due to the significant costs of firstly establishing a bamboo plantation (Lewis and Miles 2007, 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 deformed bamboo for architectural applications provided knowledge regarding limitations of bamboo curve formation. This research, together with the culm experiments conducted in tubular pipes, indicate that bamboo is capable of enduring significant deformations through a single intervention during formation. The premise of this project hopes to encourage bamboo use because of its natural strength, rapid growth qualities, monomateriality and biomass benefits of using natural materials.

Regarding the vehicle type recommended in this proposal, safety concerns of recumbent vehicles highlighted by the *"RTA Submission to the Staysafe inquiry into vulnerable road users – Motorcyclists and cyclists"* (2010, 109-110), afford possible consequential benefits for recommending commuter use of velomobiles, by increasing road visibility (Van De Walle 2004, 67, 84), through using fairings / body colours or structures which increase visual bulk and vehicle height. Caution should be taken when mixing HPV's with road traffic such as SUV's, trucks, busses and cars, which expose vulnerabilities / risk towards a HPV riders safety. While HPV's have the right-to-the-road just as much as bicycles, this lawful right does not necessarily translate towards putting the velomobile/HPV rider at ease when on shared roads. Therefore, it is vital to recommend the inclusion of velomobiles and recumbents as integral to existing and future bicycle infrastructure such as cycle lanes and dedicated paths, as well as cultural changes towards the regard for alternative vehicle users on shared roads.

58 Bamboo under three years old is considered immature, according to Hidalgo (2003, 62) with less strength, and not suitable for construction. 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.

10

Concluding remarks from the design, research and prototyping builds.

10. Concluding remarks

The *'Ajiro'* 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, 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.

> *"Human-powered vehicles inhabit the interface where technology impacts human physiology and psychology. Thus, they connect to some of the most serious issues facing humanity: the meaning of life, the future of civilisation, and the impact of humans on the environment..."* (Abbott and Wilson 1995, 265)

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.

This thesis 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'* and *'Bambusa textilis Gracilis'*.

Such exploration of the growth process of bamboo and other plants such as trees by shape modification, may introduce the notion of *'slow design'*[59] - a derivative of the *'slow food'* movement (see; Chrzan 2004; Hayes-Conroy 2010) juxtaposing *'fast food'* production (Miele and Murdoch 2002, 317-318). Therefore, instead of honouring sustainable and local food harvesting, the approach taken in this thesis is to honor *sustainable and local material use in production*, whereby appreciation of the final *grown* design outcome is derived directly from the ability of the plant to achieve the desired form from the natural miracle of growth while providing biomass, and education regarding the origins of materials.

Approaching such a design outcome relies on steadfast determination on the part of the designer and constructor to carry out any project from ideation to completion, given that natural growth cannot be obtained under force, as the growing space within a natural environment

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59 The rationale for slow design process is described by Fuad-Luke (2002) as: *"Slow design is: where designers can experience real freedom; when design improves our lives while simultaneously improving our societies and cultures; when design contributes to restoring the health of our environment."*

is susceptible to any number of variables such as pests, crop failure and climatic conditions . Furthermore, significant forward planning is required to make sure that, if the design is fulfilled to completion, it will not only be fit-for-puropse, but also have adequate resources for continued growth of plants for future versions.

The starting point for research into fulfilling a bamboo culm, shape deformed vehicle frame has been undertaken, with the outcomes for the research as follows include:

- Culm deformation trials which 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.

- The final design of the *"Ajiro"* velomobile which manipulates growing bamboo to form the tricycle frame. 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. These experiments provide the most promising solution for explaining the suitability for deforming bamboo to create shape modified structures. Ongoing trials involving shape modification techniques will allow the bamboo culms to mature into their fixed shape for future harvesting.

- Researching and participating actively in propagation methods of growing bamboo, including dissecting bamboo rhizomes, raising bamboo from seed (using *Phyllostachys pubescens)*, and attempting to grow sections from cuttings (research continuing at time of thesis publication), which support a hypothesis of contained, ongoing production using minimal post production techniques (excluding vehicle ancillaries and drivetrain) once plants have been established. Farming structures from seed may assist in supporting distributed production in other regions or countries, however, growing from seed may also require significant forward planning of the land space and the type of structure (and shape) that is required for the purpose.

- Experimentation with spaceframe design for the velomobile, trialing methods of enhancing the stability of the vehicle, its powertrain, seating and canopy whilst maintaining relative sympathy towards limitations of bamboo shape modification.

- Production of a scale model describing intended visual and proportional attributes of the final design

The experimental research of bamboo plant shape modification, 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 also 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. Rinspeed: http://www.rinspeed.com/pages/cars/bamboo/pre-bamboo.htm (accessed May 20, 2011).

Department of Agriculture, F. a. 2008. *Australia's State of the Forests Report 2008.* Canberra: Australian Government.

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

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

RTA Submission to the Staysafe inquiry into vulnerable road users – Motorcyclists and cyclists. 2010. http://www.parliament.nsw.gov.au/Prod/parlment/committee.nsf/0/c2845253bda84af2ca2577920007b3d8/$FILE/Submission%20No.%2047%20-%20RTA.pdf (accessed May 22, 2011).

Schlumpf - The street hub: Type FS. Schlumpf Innovations: http://www.schlumpf.ch/hp/uni/uni_engl.htm (accessed November 5, 2010).

The Victorian Transport Plan. 2008. Melboune: Victorian Government.

Toyota Environmental Update - Forty-ninth issue. 2008, April. http://www.toyota.com/about/news/environment/2008/01/04-1-2008AprEnvUpdate-49.html (accessed February 6, 2011).

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.

Ashby, M. F. and Johnson, K. 2002. *Materials and Design : The Art and Science of Material Selection in Product Design.* Oxford: Butterworth-Heinemann.

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.

Banks, G. 2010, November 29. *Mercedes-Benz BIOME Concept – could cars be grown in a lab?* Gizmag: http://www.gizmag.com/mercedes-benz-biome-concept/17096/ (accessed January 20, 2011).

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

Bean, W. J. 1907. The Flowering of Cultivated Bamboos. *Bulletin of Miscellaneous Information (Royal Gardens, Kew)* 1907, no. 6: 228-233.

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, November 17. *California dreamin' about being green.* , Sydney Morning Herald: http://smh.drive.com.au/future-cars/california-dreamin-about-being-green-20061117-13zmi.html (accessed January 15, 2011).

Brendon, G. 2010, February 23. Ripe for Harvesting. *The Age: Epicure*, 16-17.

Buchanan, A. H. and Levine, S. 1999. Wood-based building materials and atmospheric carbon emissions. *Environmental Science and Policy* 2, no. 6: 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.

Cherry, N. 1999. *Action Research: a pathway to action, knowledge and learning.* Melbourne: RMIT Publishing.

Christanty, L., Mailly, D. and Kimmins, J. P. 1996, October. "Without bamboo, the land dies": Biomass, litterfall, and soil organic matter dynamics of a Javanese bamboo talun-kebun system. *Forest Ecology and Management* 87, no. 1-3: 75-88.

Chrzan, J. 2004. Slow Food: What, Why, and to Where? *Food, Culture and Society: An International Journal of Multidisciplinary Research* 7, no. 2: 117-132.

Chung, K. F. and Yu, W. K. 2002, April. Mechanical properties of structural bamboo for bamboo scaffoldings. *Engineering Structures* 24, no. 4: 429-442.

Cinti, F. (ed.). 2011, MB Design. *Auto & Design* 186: 30.

Coffland, R. T. 1999. *Contempoary Japanese Bamboo Arts.* Chicargo, IL: Art Media Resources.

Cox, P. 2008. The Role of Human Powered Vehicles in Sustainable Mobility. *Built Environment* 34, no. 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, and P. Cox, *Cycling and Society*, 113-131. Hampshire: Ashgate Publishing Limited.

Coxworth, B. 2011, April 21. *Biodegradable car made from rattan and bamboo.* , Geek.com: http://www.gizmag.com/biodegradable-car-made-from-rattan-and-bamboo/18466/ (accessed May 2, 2011).

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

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

Dale, R. 1985. *The Sinclair story.* London: Gerald Duckworth & Co Ltd.

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

Dennis, K. and Urry, J. 2009. *After the Car.* Cambridge: Polity Press.

Dias, W. P. and Pooliyadda, S. P. 2004. Quality based energy contents and carbon coefficients for building materials: A systems approach. *Energy* 29, no. 4: 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.* Networks, Economics, and Urban Systems (NEXUS) Research Group, Networks and Places: Transportation, Land Use, and Design: http://nexus.umn.edu/Courses/pa8202/Dill.pdf (accessed January 28, 2011).

Dominguez, S. 2010, November 26. *Music to your eyes.* The Age (Drive): http://theage.drive.com.au/motor-news/music-to-your-eyes-20101125-188vg.html (accessed December 2, 2010).

Eichhorn, S. J. 2004. Regenerated Cellulose Reinforced Plastics. In F. T. Wallenberger, and N. E. Weston, *Natural Fibers, Plastics and Composites,* 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 and Production Management* 12, no. 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.

Fehlau, G. 2006. *The recumbent bicycle.* Williamston, MI: Out Your Backdoor.

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.

Freudendal-Pedersen, M. 2009. *Mobility in Daily Life - Between Freedom and Unfreedom.* Surrey: Ashgate Publishing Limited.

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

Fuad-Luke, A. 2002. 'Slow Design': A paradigm shift in design philosophy? *Development by Design Conference* , Bangalore, India. http://www.arts.ulst.ac.uk/artm/courses/jdmm/emotion/slow-des.pdf (accessed March 20, 2011)

Fuchs, J. 2001. Your next vehicle: a velomobile? *Human Power: Technical Journal of the IHPVA,* no. 51: 20-22.

Fujimoto, A. (Ed.). 2007, May. Hybrid Junior High School Student Buggy "SETAGAYA 1". *Car Styling,* no. 178: 92-94.

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

Garnaut, R. 2008. *The Garnaut Climate Change Review.* Melbourne: Cambridge University Press.

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

Gilbert, R., and Perl, A. 2008. *Transport Revolutions - Moving people and freight without oil.* London: Earthscan.

Gillespie, I. 2009, June 5. A world on the brink of environmental disaster. *The Age*: 20.

Green, H. 2006. *Wood – Craft, Culture, History.* Ney York: Penguin Books.

Hadland, T. 1994. *The Spaceframe Moultons* . Coventry: Hadland Books.

Hayes-Conroy. A. 2010. Feeling Slow Food: Visceral fieldwork and empathetic research relations in the alternative food movement. *Geoforum* 41, no. 5: 734–742.

Hicks, I. and Rosenfeld, R. 2007. *Tricks with Trees: Growing, Manipulating and Pruning.* London: Pavilion.

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 and 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.

Hume, D. 1965. *Of The Standard Of Taste, and other essays.* ed. John Lenz. Indianapolis: Bobbs-Merrill

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.

Janzen, D. H. 1976. Why Bamboos Wait so Long to Flower. *Annual Review of Ecology and Systematics* 7: 347-391.

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,* no. 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* 218, no. 3: 141-154.

Leach, G. 1973. *The motor car and natural resources.* Paris: Organisation for Economic Co-operation and Development, Environment Directorate.

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.

Lewis, E. 2005. *Great Brand Stories - Great Ikea! - A Brand for all the People.* Cornwall: TJ International Ltd.

Leys, N. and Gillett, C. 2011, July 14. *Uphill battle to keep share scheme on the road.* Retrieved July 16, 2011, from Herald Sun: http://www.heraldsun.com.au/news/more-news/uphill-battle-to-keep-share-scheme-on-the-road/story-fn7x8me2-1226074540485

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.* eds. J. Conley and A. Tigar McLaren, Surrey, England: Ashgate Publishing.

Londoño, X. 2003. *New Bamboo: Architecture and Design.* ed. B. Villegas. Bogotá: Villegas Editores.

Lonie, W. M. 1980. *Fuel for Transportation - Victorian Transport Study.* Melbourne: Ministry of Transport.

Lowe, M. D. 1990. *Worldwatch Paper 98 – Alternatives to the Automobile: Transport for Livable Cities.* Washington: Worldwatch Institute.

Manzini, E. 1989. *The material of invention" Materials and design.* Cambridge, Massachusetts: The MIT Press.

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 Psychology 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.

Miele, M. and Murdoch, J. The Practical Aesthetics of Traditional Cuisines: Slow Food in Tuscany. *Sociologia Ruralis* 42, no. 4: 312–328.

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

Miller, S. 2000. *Fruitless Trees: Portuguese Conservation and Brazil's Colonial Timber.* Stanford: Stanford University Press.

Mitchell, D. 2008, July. *A Note on Rising Food Prices.* The World Bank: http://www-wds.worldbank.org/external/default/WDSContentServer/IW3P/IB/2008/07/28/000020439_20080728103002/Rendered/PDF/WP4682.pdf (accessed January 9, 2011).

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

Moktan, M., Norbu, L., Dukpa, K., Rai, T., Dorji, R., Dhendup, K. and Gyaltshen, N. 2009. Bamboo and Cane Vulnerability and Income Generation in the Rural Household Subsistence Economy of Bjoka, Zhemgang, Bhutan. *Mountain Research and Development* 29, no. 3: 230-240

Moore, R. 2008. *"Natural Beauty" A Theory of Aesthetics Beyond the Arts.* Ontario,Canada: Broadview Press.

Moreno, S. and Wagner, O. 2010. *Velo: Bicycle Culture and Design, eds* R. Klanten and S. Ehmann, Berlin: Gestalten.

Morris, G. 2009, May 10. His wicker ways. *The Age ('M' Melbourne liftout)*, 18.

Nath, A. J., Das, G. and Das, A. K. 2009, September. Above ground standing biomass and carbon storage in village bamboos in North East India. *Biomass and Bioenergy* 33, no. 9: 1188-1196.

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* (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, March. Development of bamboo-based polymer composites and their mechanical properties. *Composites Part A: Applied Science and Manufacturing* 35, no. 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, no. 4: 469-475.

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

Paine, C. (Director). 2006. *Who Killed the Electric Car?* [Motion Picture].

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

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 *Cycling and Society.* eds. D. Horton, P. Rosen, and P. Cox, 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/

Pickworth, C. 2007, January 27. *Fuel's chain reaction.* The Courier-Mail: http://www.couriermail.com.au/lifestyle/fuels-chain-reaction/story-e6frer4f-1111112889719 (accessed January 25, 2011).

Postrel, V. 2004. *The Substance of Style: how the rise of aesthetic value is remaking commerce, culture, and conciousness.* New York: First Perennial.

Preiss, B. 2011, May 31. *Bike share scheme disappointing.* The Age: http://www.theage.com.au/victoria/bike-share-scheme-disappointing-20110531-1fdto.html (accessed June 1, 2011).

Puentes, R. and Tomer, A. 2008. *The Road…Less Traveled: An Analysis of Vehicle Miles Traveled Trends in the U.S.* The Brookings Institution: http://www.brookings.edu/~/media/Files/rc/reports/2008/1216_transportation_tomer_puentes/vehicle_miles_traveled_report.pdf (accessed June 3, 2011).

Raine, J. K. and Maxey, N. G. 1996. Electrically assisted human-powered vehicles: An option for commuters? *International Journal of Vehicle Design* 17, no. 5-6: 663-680.

Rajvanshi, A. K. 1999–2000. Cycle rickshaws as a sustainable transport systemfor developing countries. *Human Power: Technical Journal of the IHPVA,* no. 49: 15-18.

Rana, L, 2001, What is a Bamboo Cutting? In *The Farmers' Handbook,* eds. Chris Evans and Jakob Jespersen, Kathmandu, Nepal: Format Printing Press

Reames, R. 2007. *Arbosculpture - Solutions for a Small Planet.* Williams, Oregon: Arborsmith Studios.

Rees, W. 2003. Ecological footprints and urban transportation. In *Sustainable transport: Planning for walking and cycling in urban environments*, ed. R. Tolley, 3-19. Cambridge, England: Woodhead Publishing Ltd.

Replogle, M. 1992. *Non-Motorized Vehicles in Asian Cities.* Washington: The International Bank for Reconstruction and Development/The World Bank.

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

Rinne, M. M. and Okada, K. 2008. *Masters of Bamboo.* San Francisco: Asian Art Museum of San Francisco.

Roberts, P. 1983. *The Story of the Car.* London: Treasure Press.

Roth, M. 1988. *Ship Modeling from Stem to Stern.* USA: McGraw-Hill Professional.

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

Sachs, W. 1992. *For Love of the Automobile.* California: University of California Press.

Saporito, R. and Mavition, M. E. 2010, December. Growing Bamboo from Seed. (G. Kyle, Ed.) *Bamboo Bulletin* 12, no. 2: 7-9.

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

Schmitz, A. 1999-2000. Velocar Variations. *Human Power: The technical Journal of the IHPVA,* no. 49: 3-6.

Schön, D. A. 1987. *Educating the reflective practitioner.* San Francisco: Jossey-Bass.

Scurlock, J. M., Dayton, D. C., and Hames, B. 2000, October. Bamboo: an overlooked biomass resource? *Biomass and Bioenergy* 19, no. 4: 229-244.

Servaas, M. 2000, December. *The significance of non-motorised transport for developing countries - Stratigies for policy development.* The World Bank: http://siteresources.worldbank.org/INTURBANTRANSPORT/Resources/non_motor_i-ce.pdf (accessed December 20, 2010)

Sexton, R. 2009a, April 12. *Drivers say it's time cyclists paid a rego fee.* The Age: http://www.theage.com.au/national/drivers-say-its-time-cyclists-paid-a-rego-fee-20090411-a3hg.html (accessed Feburary 3, 2011).

Sexton, R. 2009b, May 17. Waiting, Waiting...welcome to the suburbs where there's always a seat, if you can ever find the bus. *The Age*: 9.

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

Singh, A. N., and Singh, J. S. 1999, June 28. Biomass, net primary production and impact of bamboo plantation on soil redevelopment in a dry tropical region. *Forest Ecology and Management* 119, no. 1-3: 195-207.

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.

Smith, D. 2011. *Dick Smith's Population Crisis - The dangers of unsustainable growth for Australia.* Sydney: Allen and Unwin.

Soderstrom, T. R., and Calderon, C. E. 1979. A Commentary on the Bamboos (Poaceae: Bambusoideae). *Biotropica* 11, no. 3: 161-172.

Spielmann, M. and 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.

Stangler, C. 2002. *The Craft and Art of Bamboo: 30 Elegant Projects to Make for Home and Garden.* New York: Lark Books.

Stein, M. R. 2008. *When Technology Fails: A Manual for Self-Reliance, Sustainability, and Surviving the Long Emergency.* White River Junction, VT, USA: Chelsea Green Publishing Company.

Susman, G. I. 1983. Action Research. A Sociotechnical System Perspective. In *Beyond Method: Strategies for Social Research*, ed. Gareth Morgan, Beverley Hills, USA: Sage.

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*, no. 53: 19.

Terasawa, I., Tsuneoka, K., Tamura, A., and Tanase, M. 2008. *Development of Plant-Based Plastics Technology, 'Green Plastic'.* Mitsubishi Motors: http://www.mitsubishi-motors.com/corporate/about_us/technology/review/e/pdf/2008/20e_16.pdf (accessed September 13, 2010).

The Age, Editorial. 2010, July 24. *Bikes and helmets come to a head.* The Age: http://www.theage.com.au/opinion/editorial/bikes-and-helmets-come-to-a-head-20100723-10ooz.html (accessed May 20, 2011).

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.

van der Lugt, P., van den Dobbelsteen, A. and Abrahams, R. 2003. Bamboo as a building material alternative for Western Europe? A study of the environmental performance, costs and bottlenecks of the use of bamboo (products) in Western Europe. *Journal of Bamboo and Rattan* 2, no. 3: 205-223.

van der Zwaan, A. 1995. *Organisatie Onderzoek.* Assen/Maastricht, The Netherlands: Van Gorcum.

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

Vogtländer, J., van der Lugt, P. and Brezet, H. 2010, September. The sustainability of bamboo products for local and Western European applications. LCAs and land-use. *Journal of Cleaner Production* 18, no. 13: 1260-1269.

Watts, B. 2011. Bettering Biology? *Architectural Design* 81, no. 2: 128-134.

Webb, R. 2006, November 9. *Government assistance to alternative transport fuels.* Parliament of Australia - Parliamentary Library: http://www.aph.gov.au/library/pubs/rn/2006-07/07rn09.htm (accessed February 5, 2010).

White, D. G. and Childers, N. F. 1945. Bamboo for controlling soil erosion. *Journal of the American Society of Agronomy* 37: 839-847.

White, P. S., Erlank, G., and Luzolo, F. 2004, April 14. *The Promotion of Intermediate Means of Transport through a South-South Cooperation.* The World Bank: http://siteresources.worldbank.org/INTGENDERTRANSPORT/Resources/sereport.pdf (accessed November 21, 2010).

Winchell, W. 1991. *Continuous quality improvement: a manufacturing professional's guide.* Dearborn, Michigan: Society of Manufacturing Engineers.

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

Yen, T. M. and Lee, J. S. 2011, March 15. Comparing aboveground carbon sequestration between moso bamboo (Phyllostachys heterocycla) and China fir (Cunninghamia lanceolata) forests based on the allometric model. *Forest Ecology and Management* 261, no. 6: 995-1002.

Yen, T. M., Ji, Y. J. and Lee, J. S. 2010, June 30. Estimating biomass production and carbon storage for a fast-growing makino bamboo (Phyllostachys makinoi) plant based on the diameter distribution model. *Forest Ecology and Management* 260, no. 3: 339-344.

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* 4, no. 2: 119-128.

A

An introduction to product obsolescence derived from consumers.

Appendix A: Industrial Obsolescence and Resource Consumption

Marketing of consumer goods places weight on key *product quality perceptions* such as 'function', 'use features', 'perception features', and 'price' (Winchell 1991, 13), placing responsibility on the consumer to select items which best fulfil their needs. However, rationalising such consumer choice with the marketing technique of planned obsolescence also demonstrates the potential for danger of product renewal out pacing material supply with current consumption being described as *"...the fact that humans are living beyond the sustainable capacity of natural systems"* (Gillespie 2009). The fragility of the economy, with the GFC (Global Financial Crisis) in 2007/2008 as a prime example, indicates the reliance on manufacturing, and, together with the requirement for constant growth as a measure of prosperity (Smith 2011), demonstrates the interdependence of consumer spending with manufacturing profit.

> *"This generation – the first generation to exceed the sustainable productivity of the biosphere – needs as an urgent task of reparation to determine those limits and get our generation's lifestyle back within the limits of natural systems."* (Gillespie 2009)

Whilst attention should be focused on creating a 'low carbon economy', exhaustion of construction materials may force alternatives to be investigated (Garnaut 2008, 70-71), indicating that sustainability of resources (timber, minerals, oil) should be a substantial factor in prolonging resources for future generations (Smith 2011, 18-19, 73-79, 116, 190), *whilst* mitigating pollution from product consumption. The need to seek intervention for balancing *both* production methods and consumption alone may be grounds for pursuing research into sustainable material utilisation, or at the very least, natural material interchangeability.

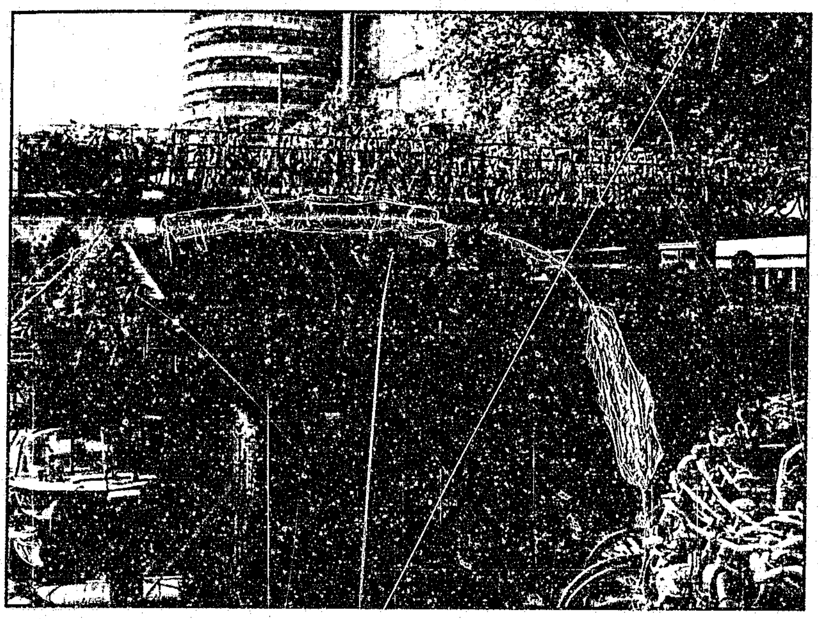
Furthermore, government policy for consumable fuel tax or excise must be considered with the promotion of fuels. Excise exemption, such as LPG, LNG or CNG (Webb 2006), delays the progression of sustainable alternatives by feeding dependence on fossil fuels through promotion of low cost fuels. Leach (1973, 2), discusses the morality of *"..social and energy costs of car ownership"* describing the relative inflammatory effect of reducing taxes on petroleum resources as simply postponing the inevitable shortage (Smith 2011). The written date of such material by Leach (1973) confirms that thoughts relating to fossil fuel resource consumption are hardly a product of our present period, though pressures of current and projected population growth and climate change are described by both Garnaut and Smith as increasing the urgency of discussion for sustainable population and resource consumption.

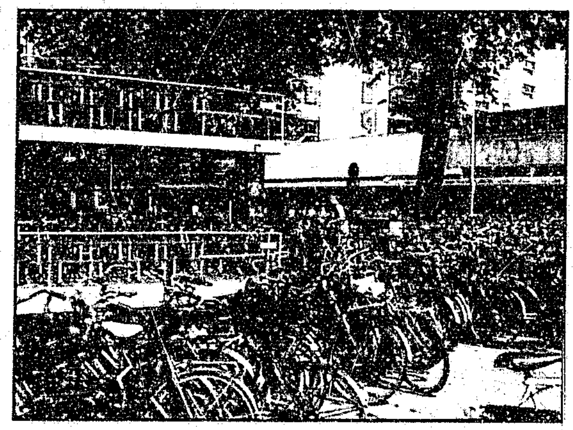
B

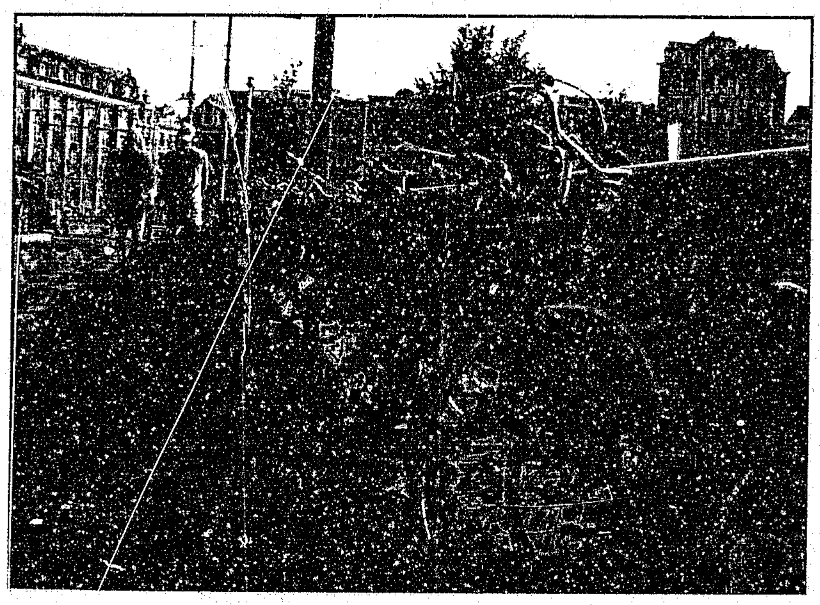
Photos and experiences from a bicycle friendly country: The Netherlands.

Appendix B: Photos from Netherlands regarding bicycle usage

Figure 18: Bicycle infrastructure in The Netherlands (a) - Images grouped





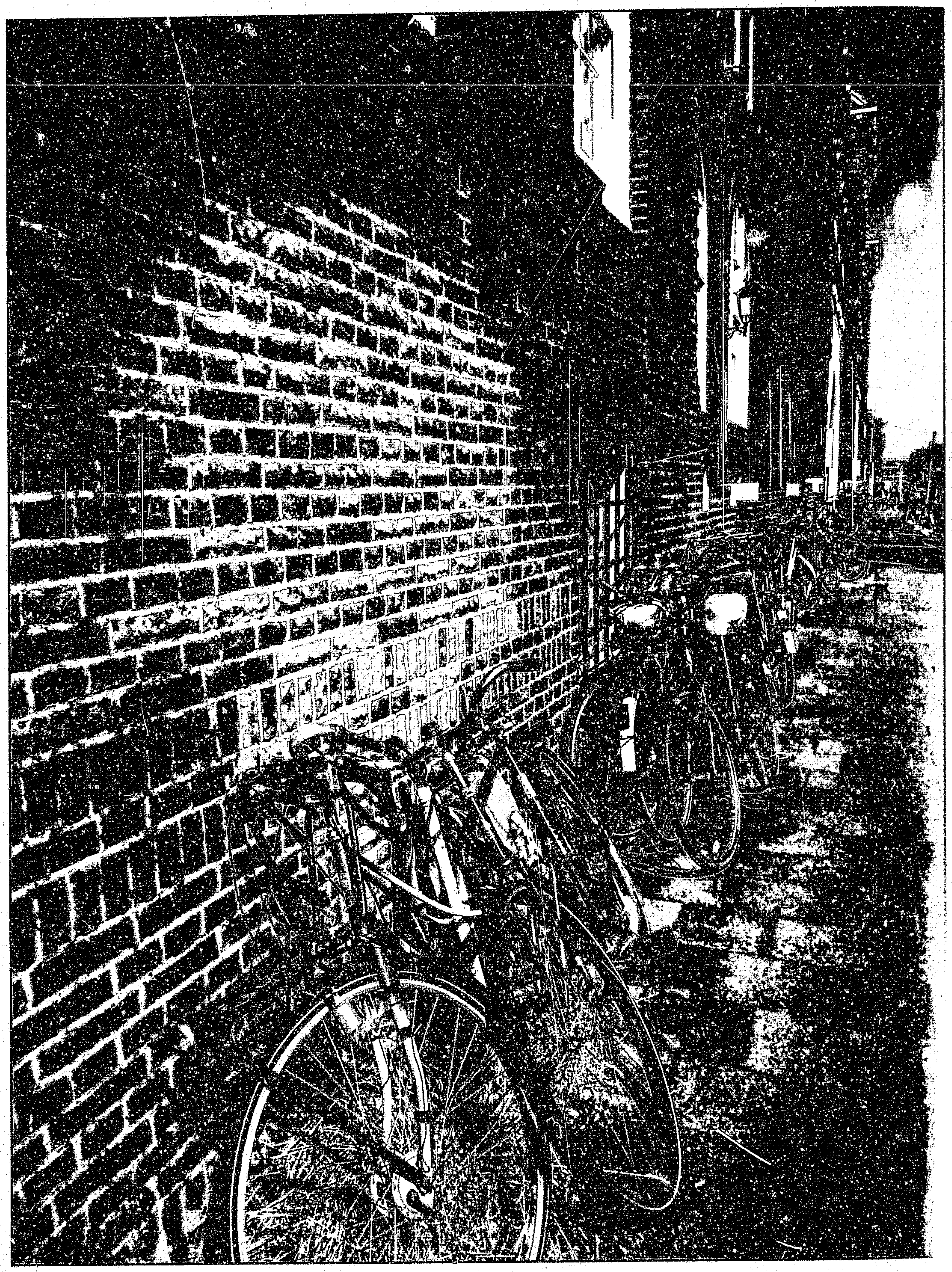


During the authors trip to Stuttgart, Germany for the Automotive Interiors Expo 2010 (guest speaker), a side trip to The Netherlands was undertaken to witness the personal mobility options in a country famous for its bicycle usage and infrastructure (Mapes 2009, 61-88).

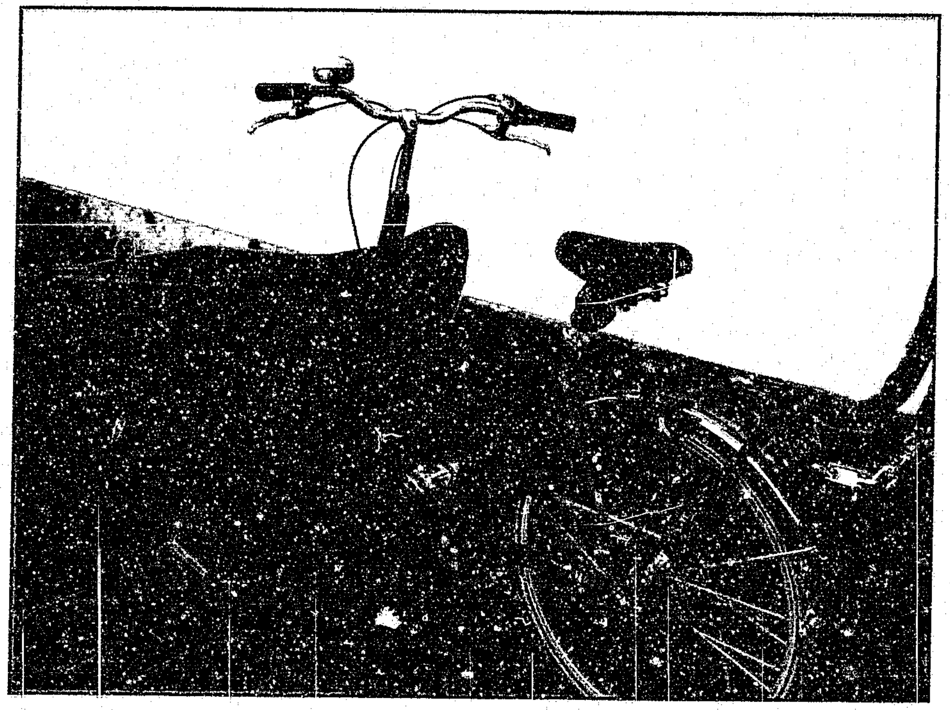
Upon arrival at Central train station in Amsterdam, the bicycle 'carpark' presented an astonishing sight in sheer bicycle volume.

Throughout the rest of the city, bicycle use appeared to be a 'normal' everyday activity. Whilst dedicated cycle lanes were effective, the shared use with noisy and rather fast motorised scooters was disconcerting, and could potentially be viewed as dangerous. The volume of cyclists on the roads perpetuated a safe environment for encouraging cycling on the road.

Figure 18: Bicycle infrastructure in The Netherlands (b) - Images grouped



Bicycles resting against a wall in central Amsterdam indicate not only popularity, but also that the machine is not about a fashion accessory - even though the 'neglected' bikes have a homely, classic feel.



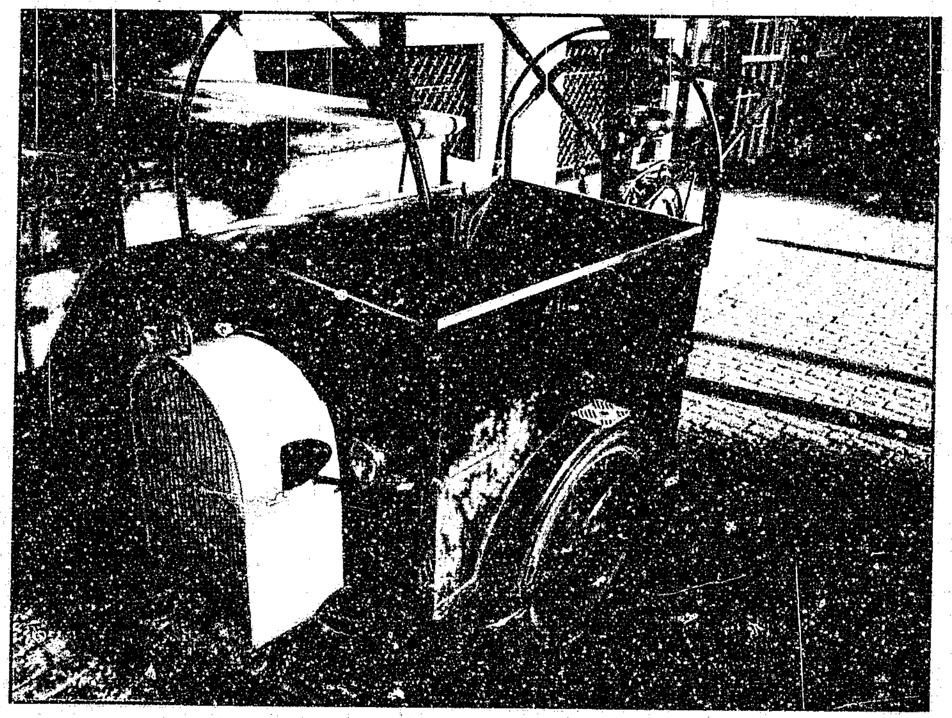
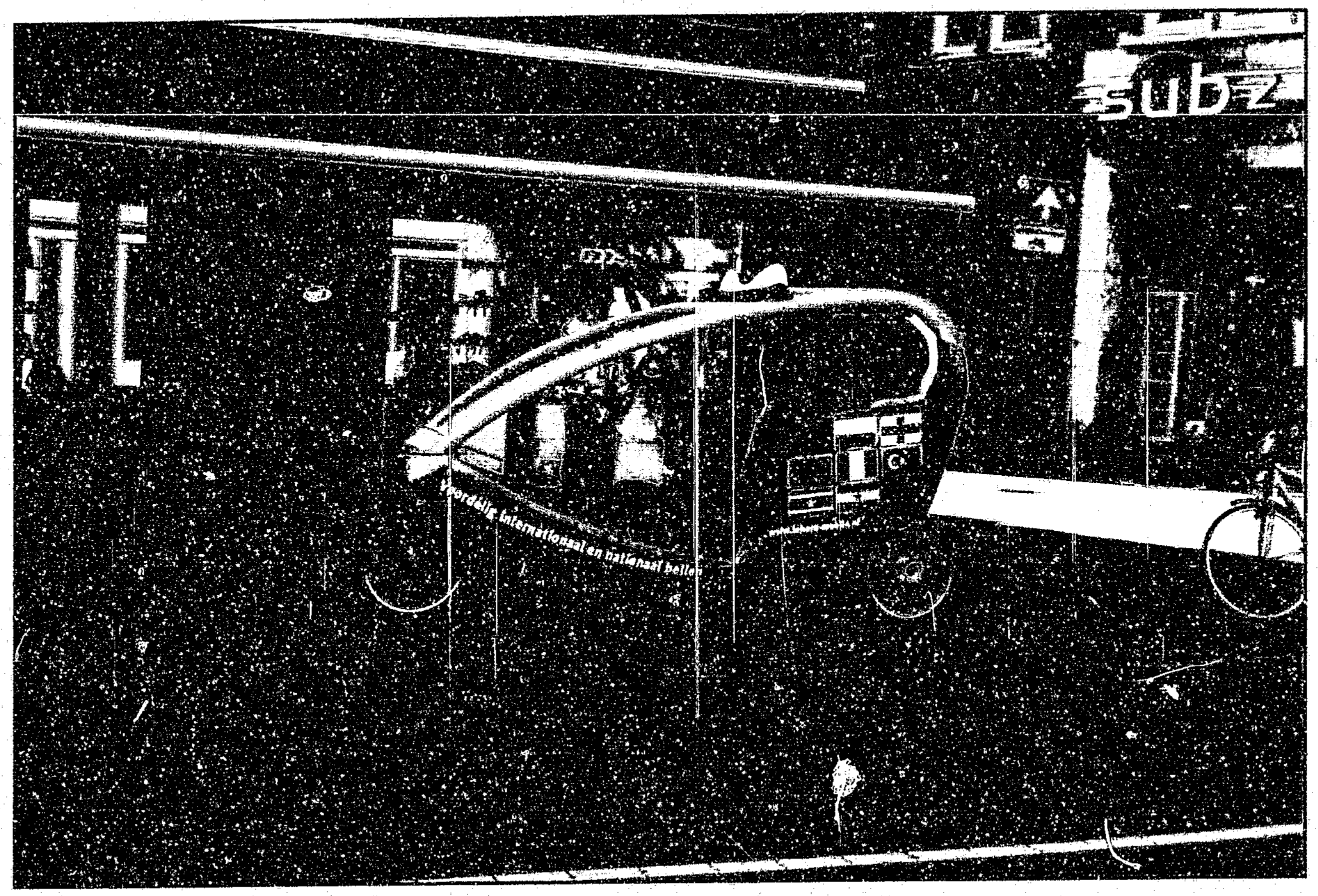


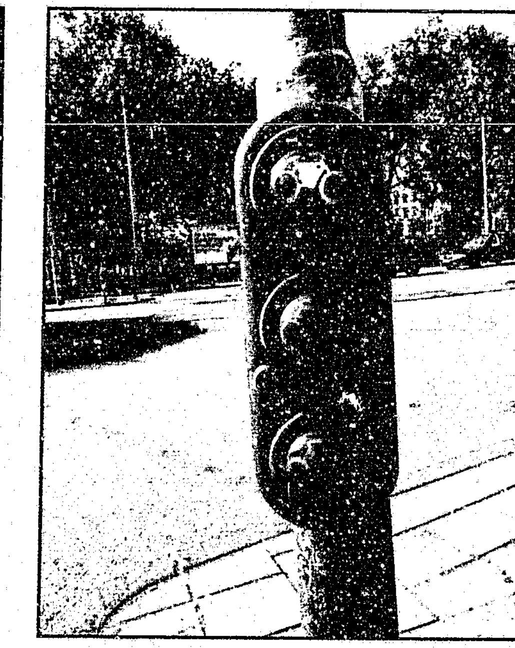
Figure 18: Bicycle infrastructure in The Netherlands (b) - Images grouped



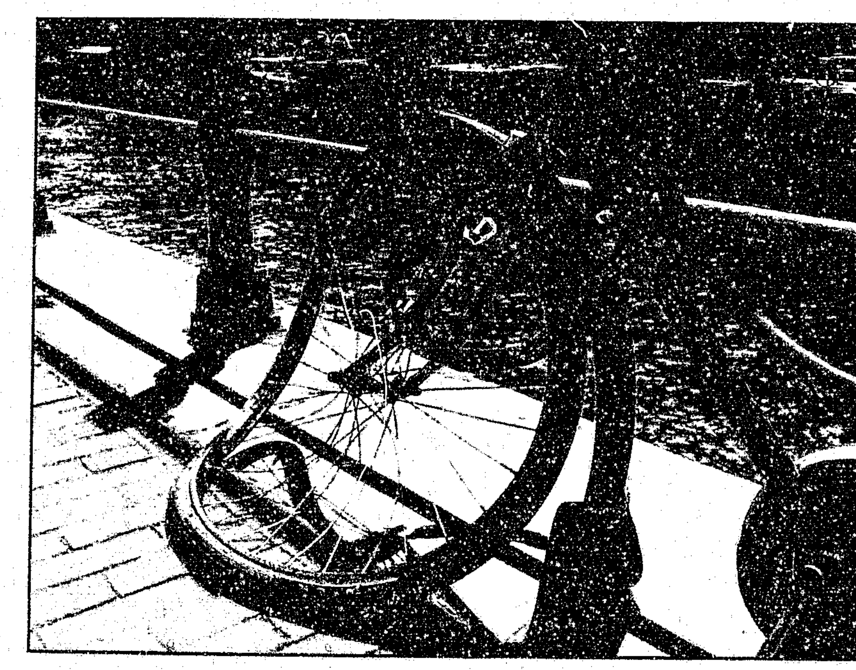
A mix of different sorts of HPVs contributed to fulfilling the wide range of needs by Amsterdam's citizens. Cargo bikes carrying children or parcels were common, as well as three wheel partial fairing velomobiles, which could be classed as rickshaws - these were used as taxis.

Figure 18: Bicycle infrastructure in The Netherlands (c) - Images grouped

Mix of road hazards with bicycle and pedestrian use.



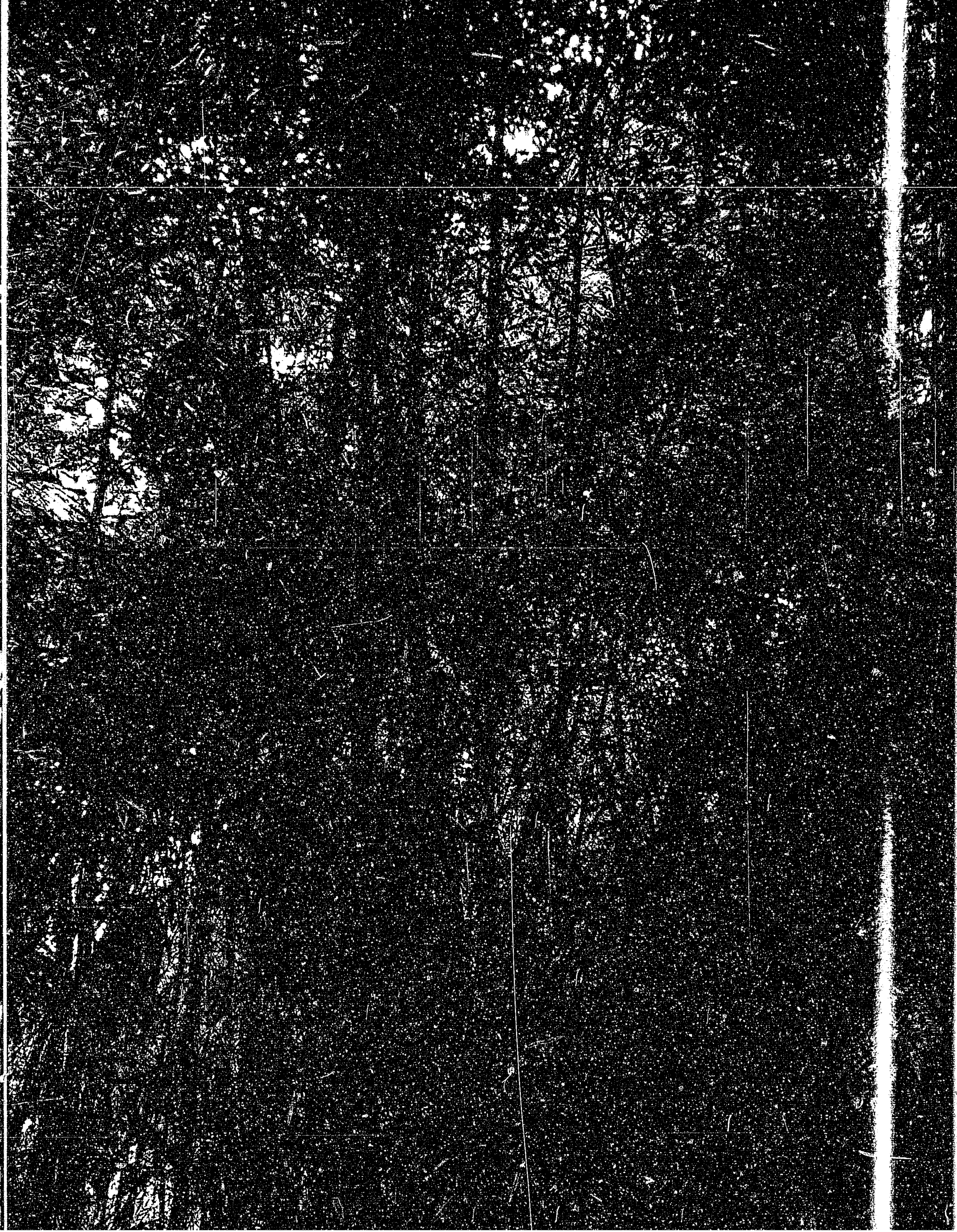
Dedicated cycle crossing lights.



It seems apparent that some bicycles were either abandoned, unused, neglected or perhaps vandalised.

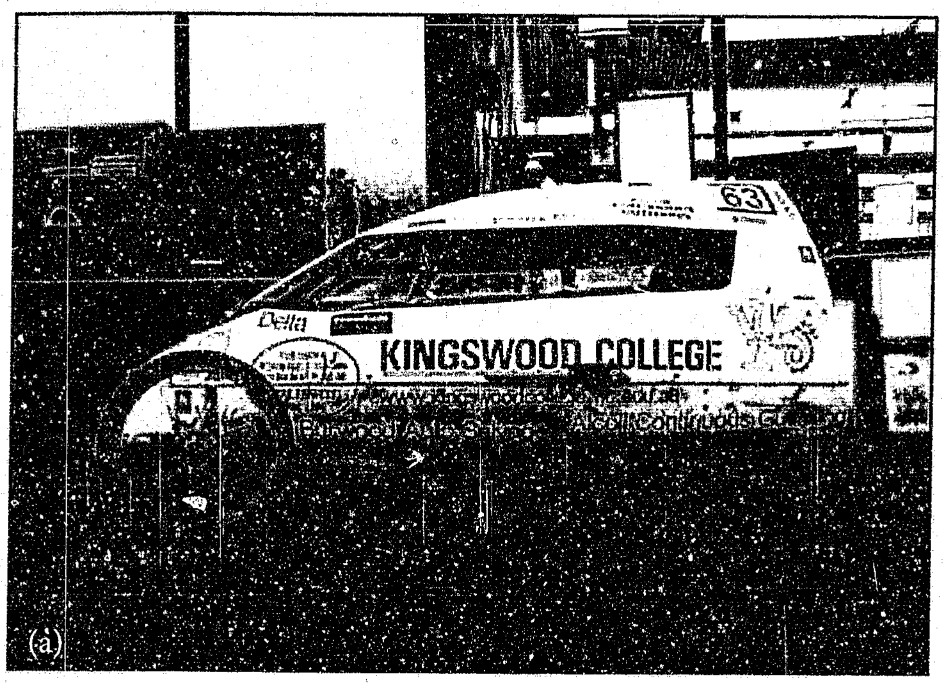
C

Authors experience in velomobile design and construction progress since 1998.



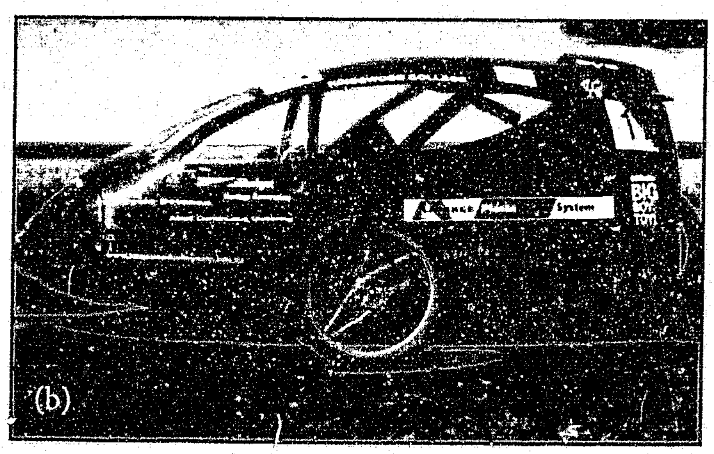
Appendix C: Racing velomobile progress 1998-2010

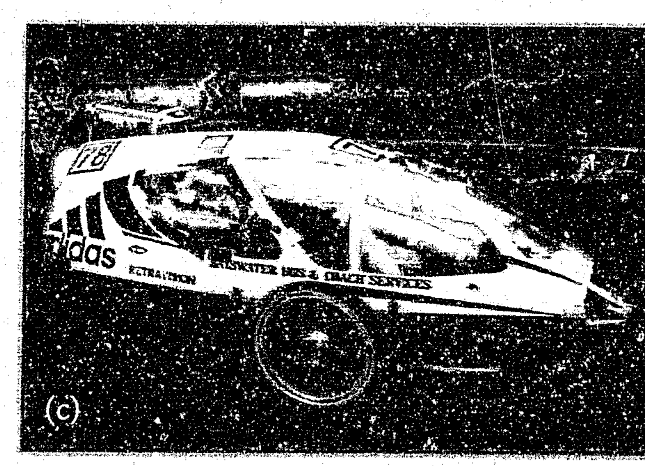
Figure 19: D.I.Y. Velomobiles for racing



This series of images illustrate progress in construction technique, and accessibility of composite materials for D.I.Y project construction.

The first racing velomobile that the author worked on was during 1998/1999. This version was created using a wooden profile subframe, upon which foam sandwich was placed to create a two part shell.





Modifications in 2000/2001 included a complete frame redesign with revised wheelbase for stability. Carbon fibre shell with internal roll bar structure.

Nose cone and wheel damage during the RACV Energy Breakthrough.

The structure of the vehicle had to be compliant with rollover protection, deformable sections and side impact intrusion protection for the 24-hour race conditions.

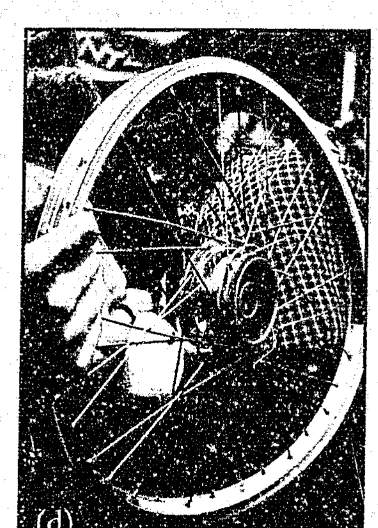
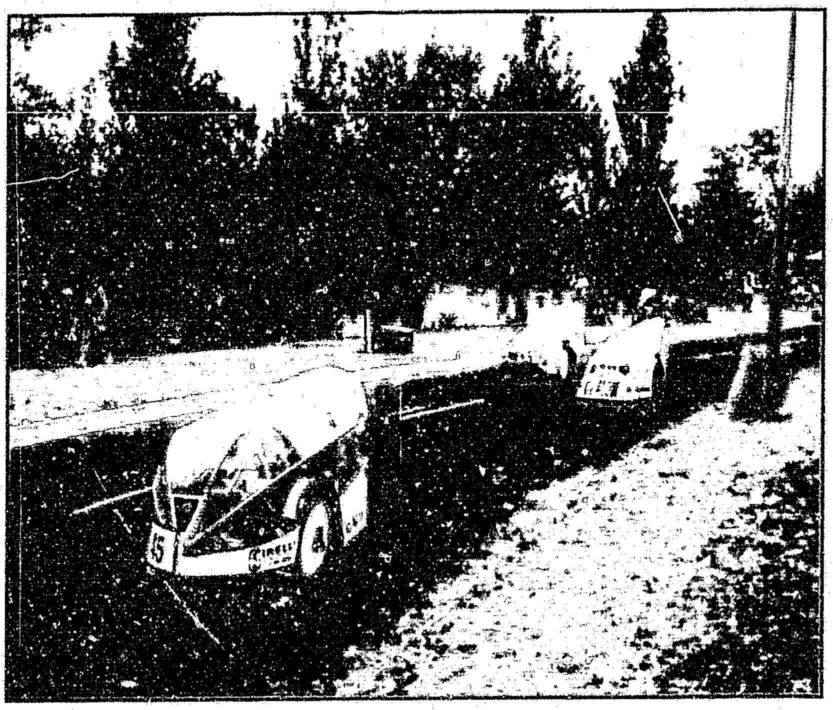
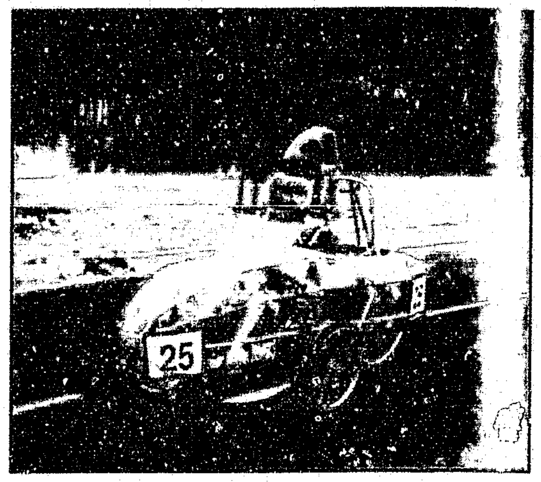
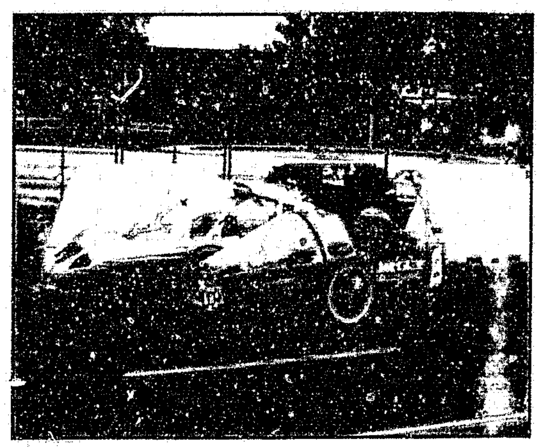
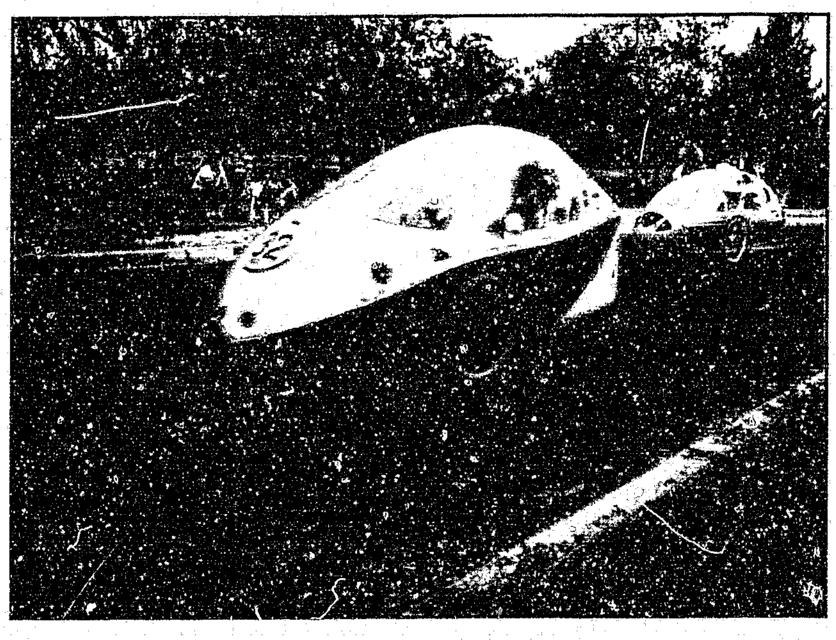


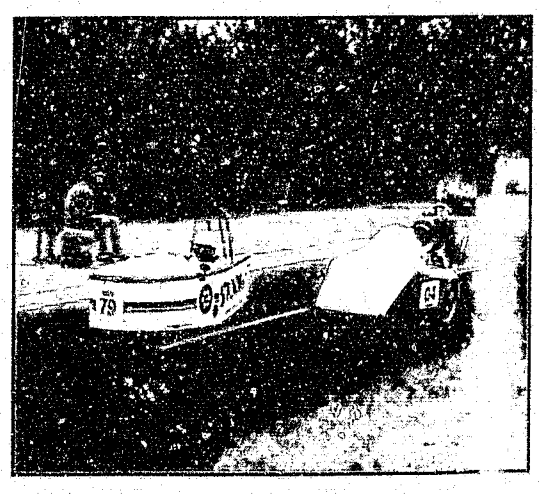
Figure 19: D.I.Y. Velomobiles for racing (f) - Images grouped







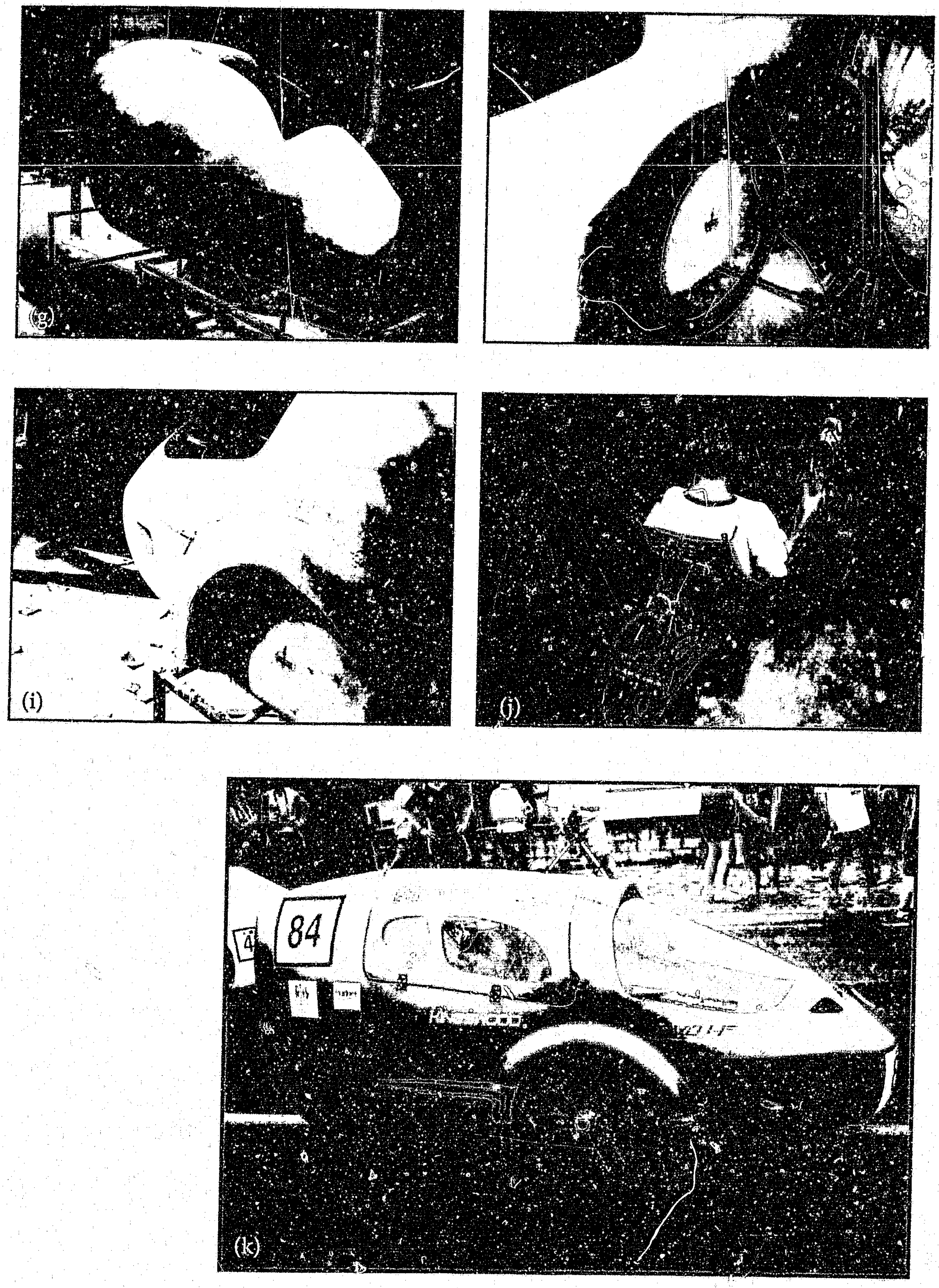




Velomobiles are built for racing purposes using a variety of construction methods and materials, evident in the numerous different fairings.

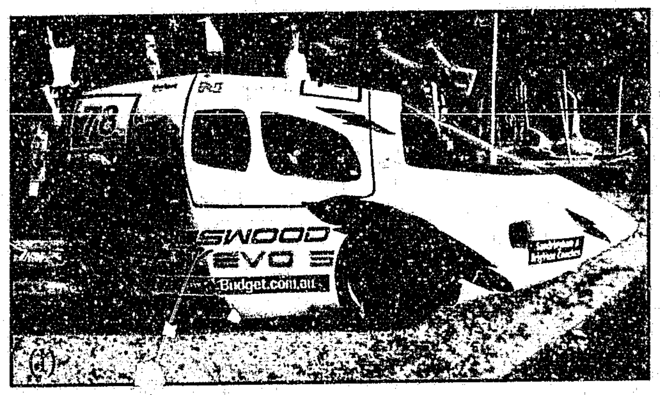
Complexity of the substructure for crank, wheel and seat attachments are reasonably comparable between all versions.

Figure 19: D.I.Y. Velomobiles for racing

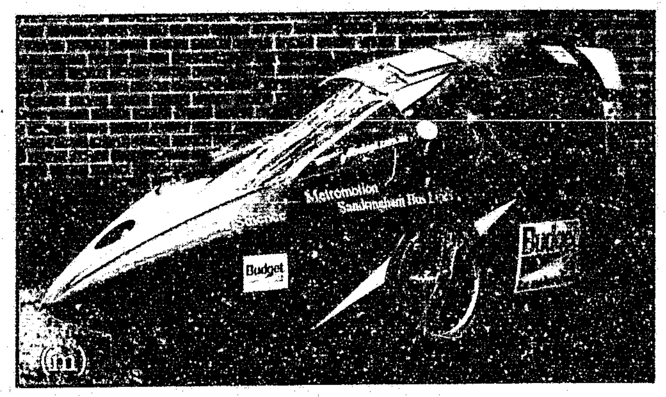


2003/2004 Version. Modifications to subsequent versions began in 2003, and shape alterations could be achieved through reshaping and casting new sections. In this case, modifications were first created in plaster, before casting a new shell in carbon fibre.

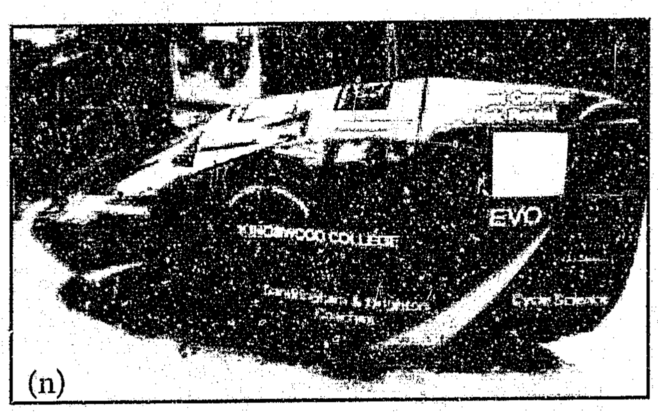
Figure 19: D.I.Y. Velomobiles for racing


(l)

2006 Version

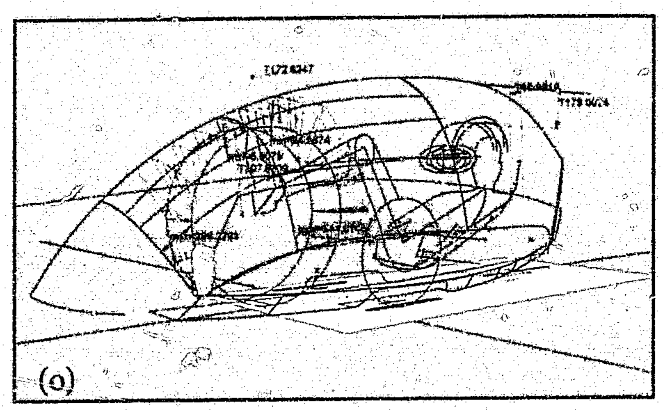

(m)

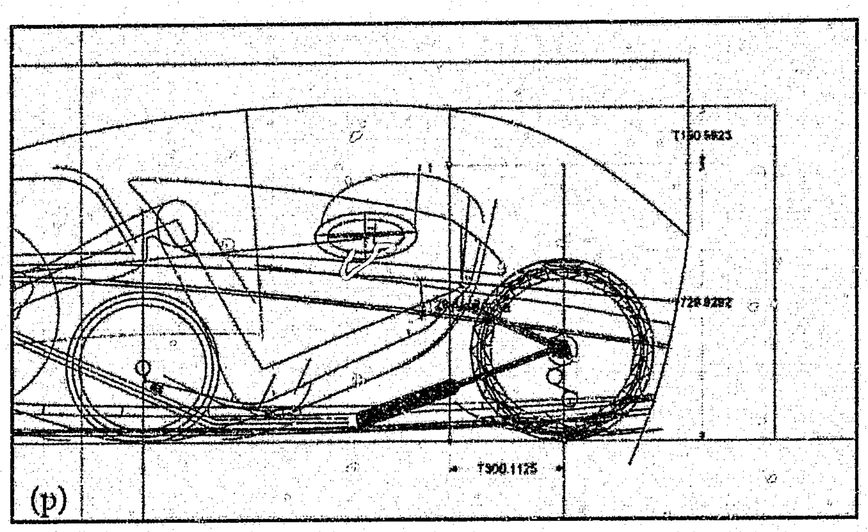
2007 Version



(n)

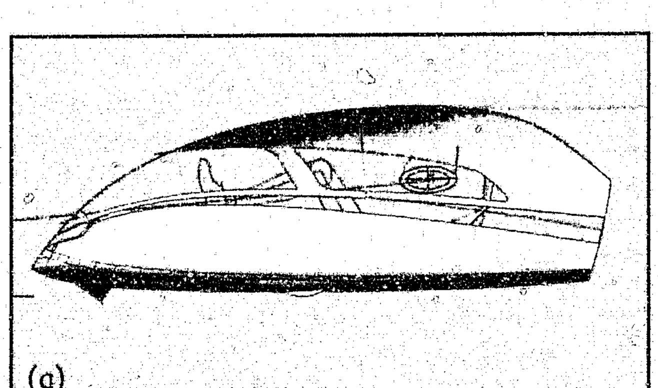
2008 Version


(o)


(p)

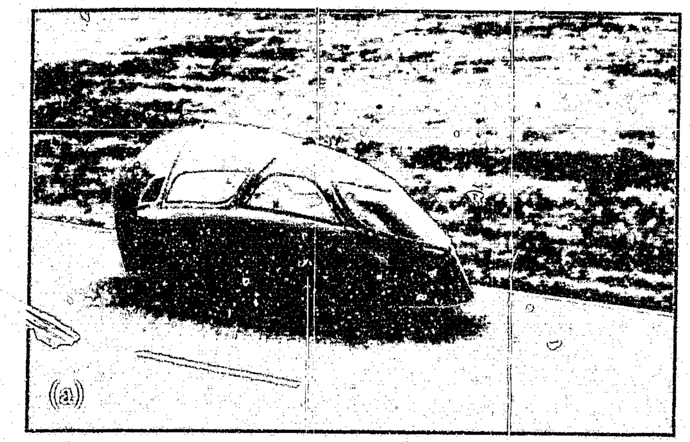
Digital design process could verify all necessary clearances for safety assessment for the next vehicle version, whilst also guaranteeing uniform vehicle appearance.

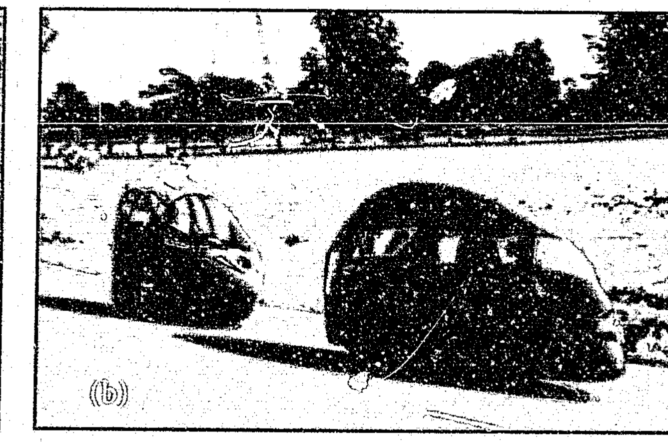
The quality of this process dictates the finial surface finish of the CNC mould, and hence the quality of the carbon finish. This is vital if additional surface fillers are to be minimised.


(q)


(r)

Figure 20: Current progress of carbon fibre velomobiles for racing

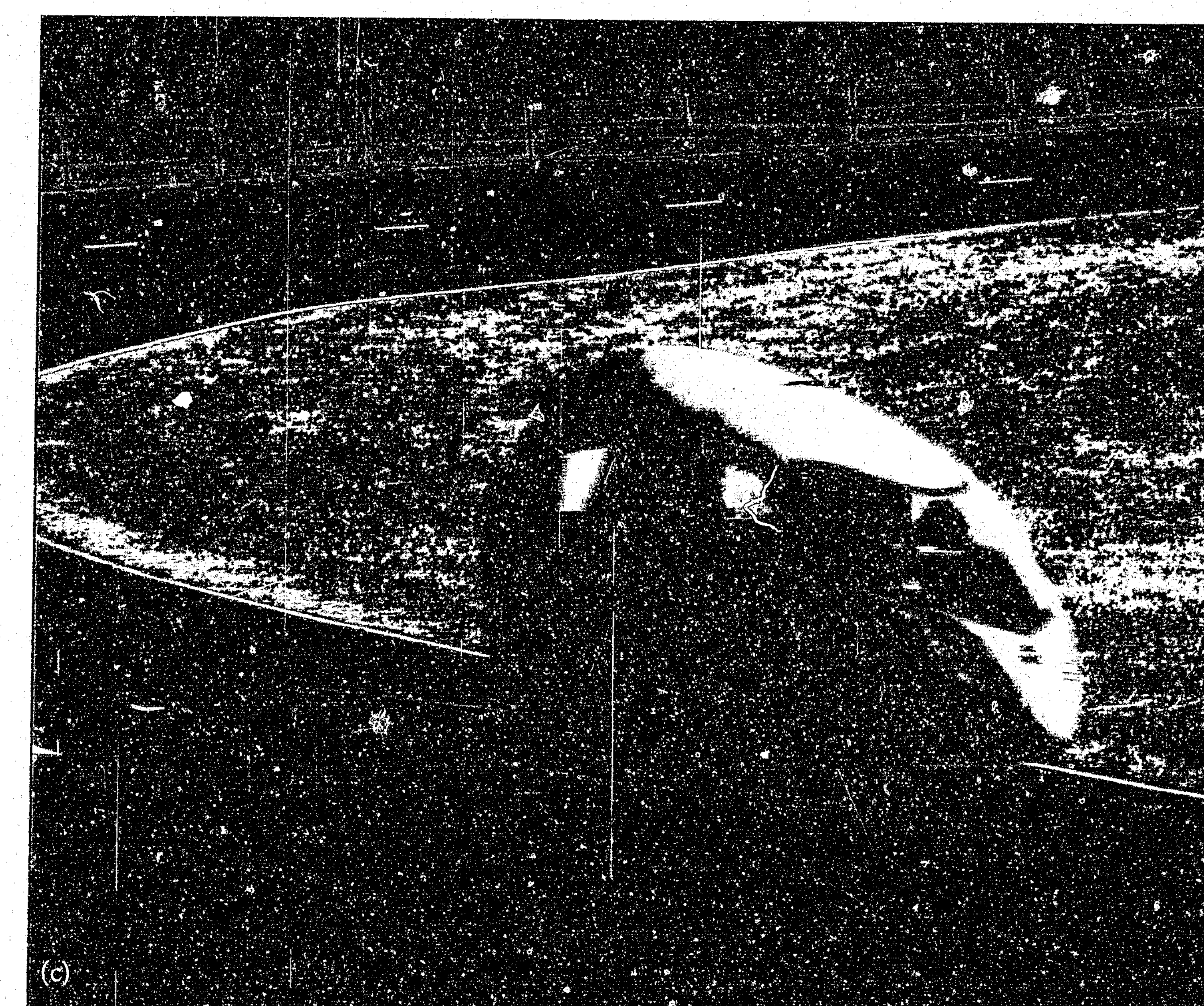

(a)

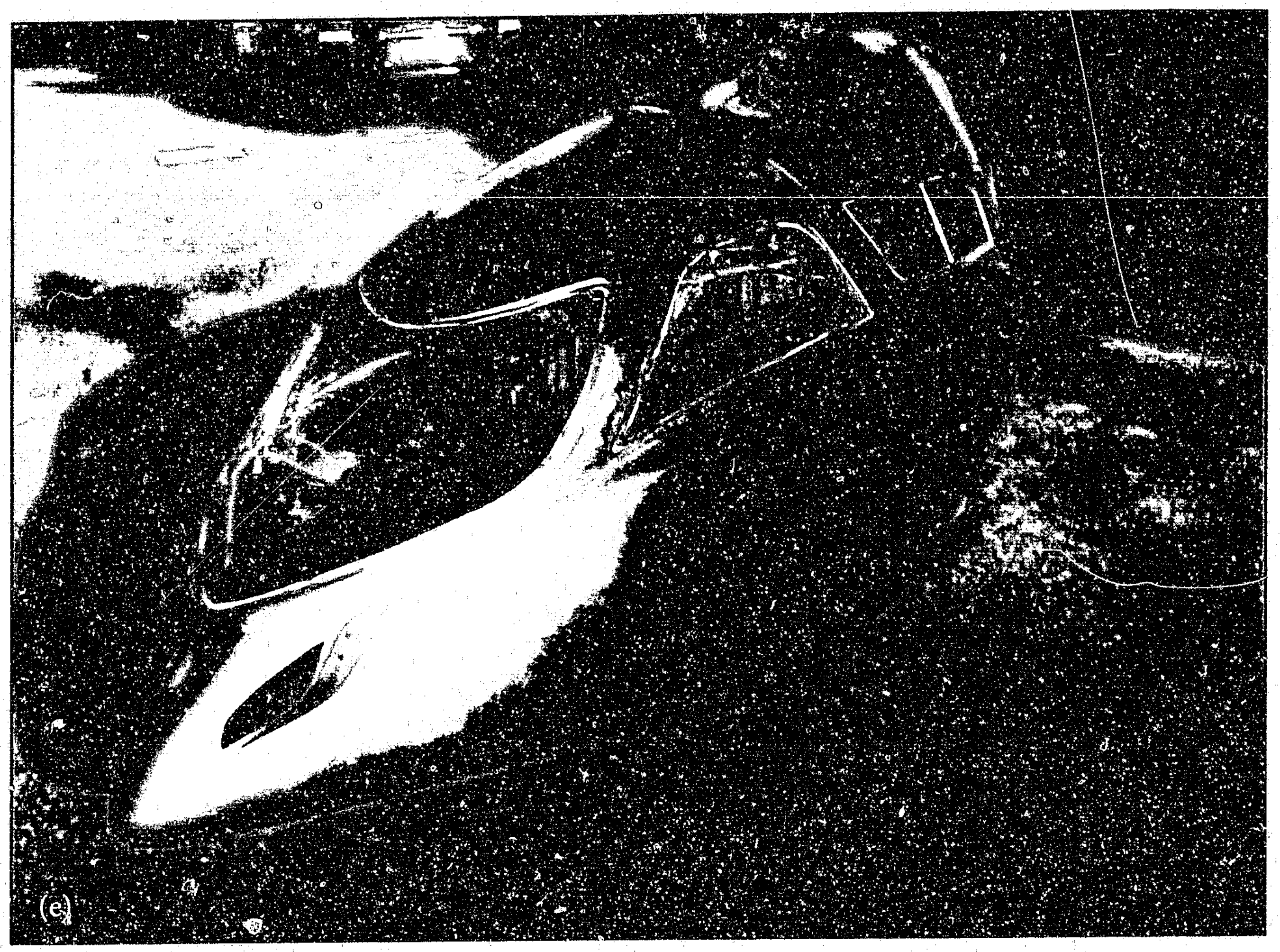

(b)

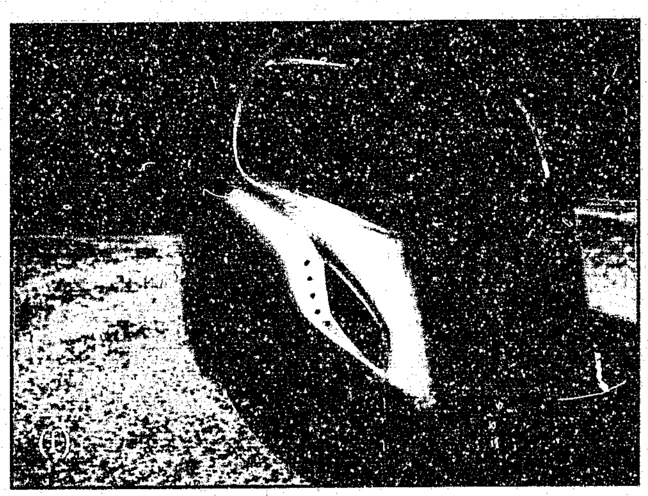
Accessibility of both digital surface creation, validation of clearances, tolerances and sight angles allowed for the 2009/2010/2011 version to be enhanced to meet scrutineering requirements established for racing, whilst aiding aerodynamics and styling.

This version was CNC milled from a foam block, before being cast in carbon fibre and kevlar.

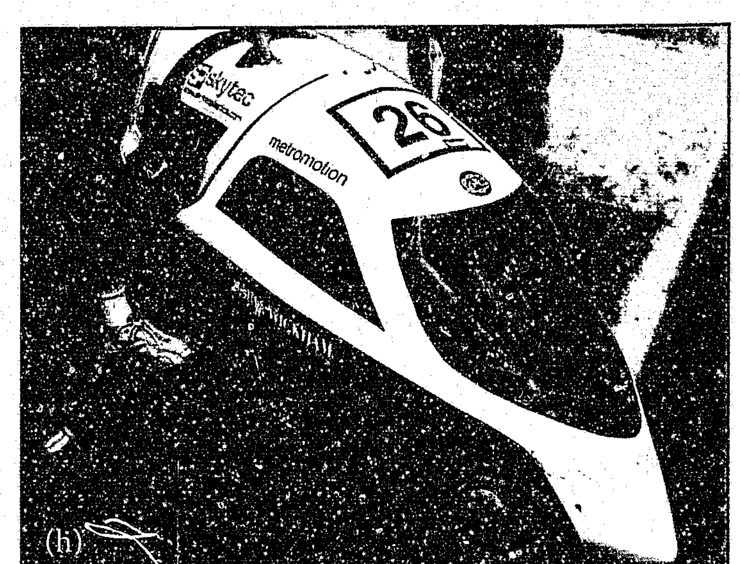
The digital model also allowed for in mould scribing of window profiles and hatch entry to ensure symmetry.


(c)





2009 version.



Race version painted for 2010 RACV energy breakthrough.

The conceptual rendering proves the likeness to the final mould output.

D

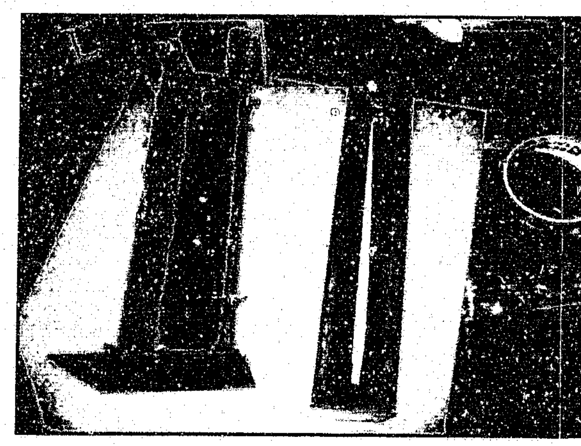
Initial experiments using bamboo as a construction material.

Appendix D: Early Experiments

1. Knitted and resin coated components

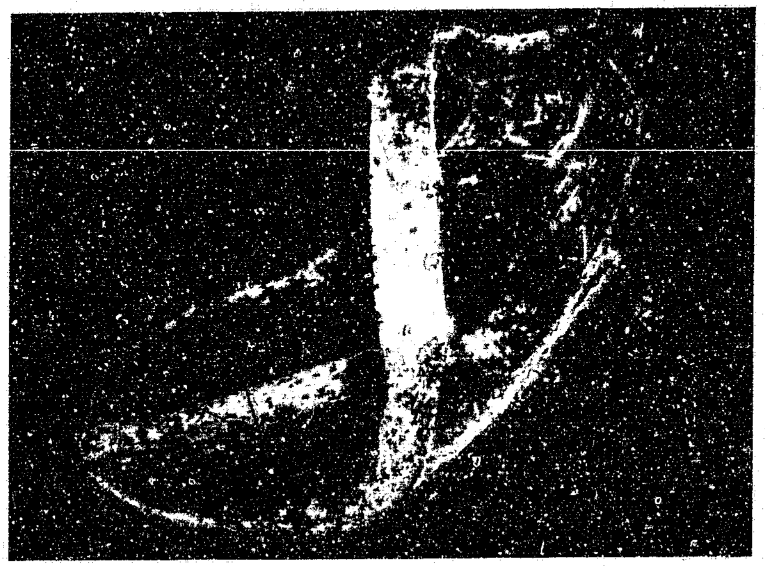
Effects such as specific weaving patterns were investigated for incorporation into sections of the vehicle, such as the seating structure and basket storage. The general goal was to integrate a mono-material into as many aspects of the design approach as possible. From an individual's perspective, such weavings could be localised for regional specificity, ideological or personalised qualities, however, while these factors could be explored further, it was decided to abandon complicated weaving structures and concentrate on a simplified spaceframe structure.

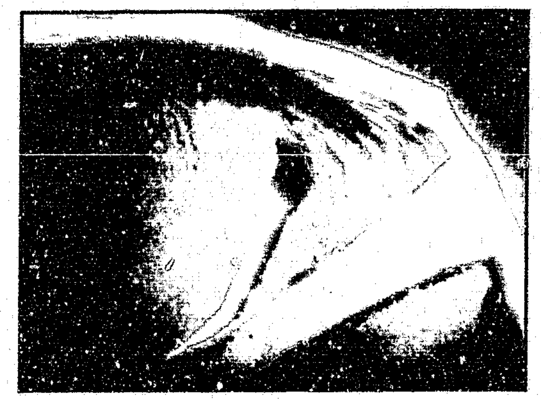
Figure 21: Cast fibre experiment (a) - Images grouped

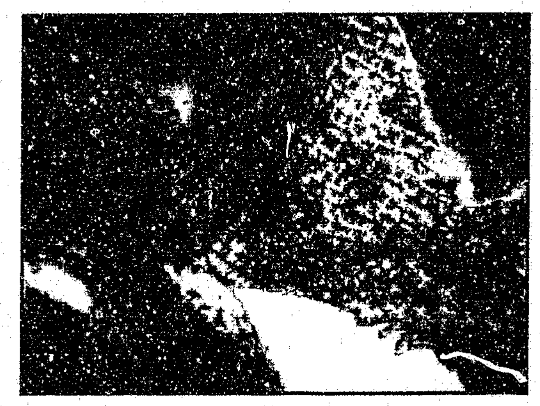


Chopped bamboo, infused in a cast resin two part mould. The bamboo material acts as a filler for the resin. To be effective, increased amounts of material and compression would be needed.

Figure 21: Cast textile experiments (b) - Images grouped

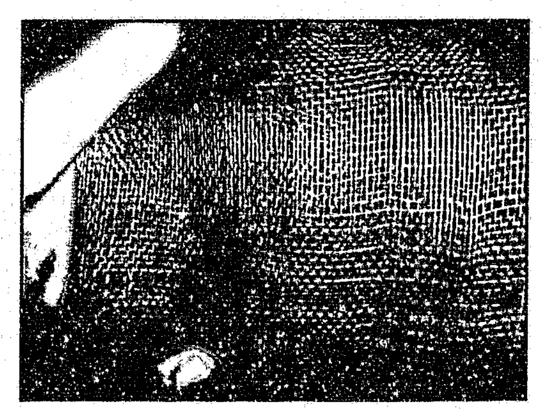


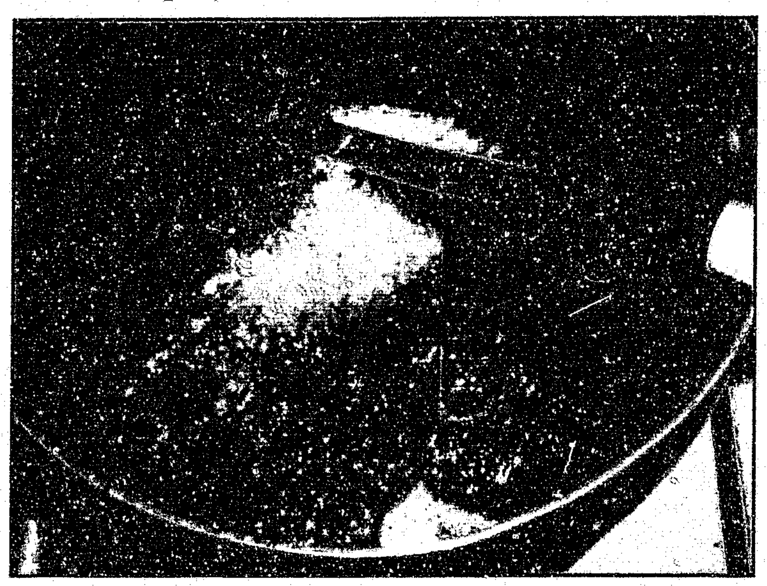




Shape moulding using epoxy resin soaked into Hessian cloth fibre.

PLA resin (polylactide) - made from corn starch - was used as a 'bio' resin, however when melted it was difficult to control and did not infuse the cloth material adequately, unlike the epoxy.





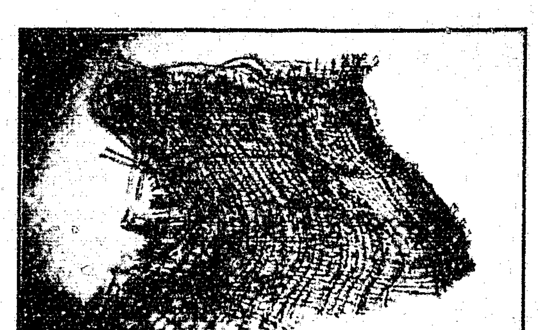
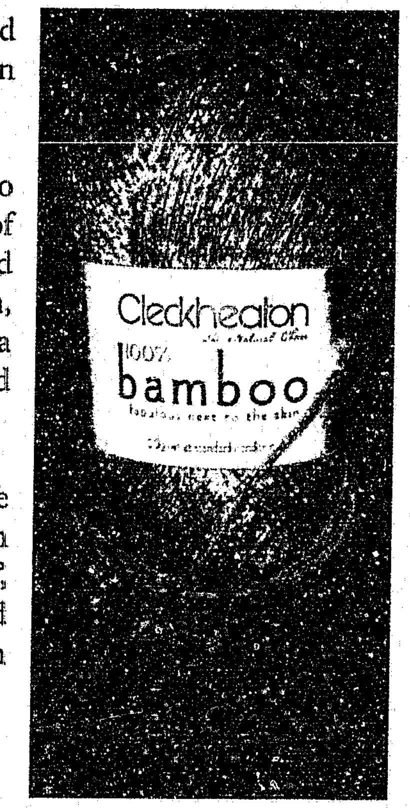


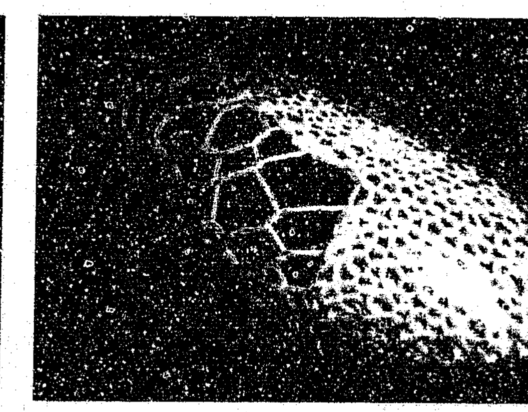
Figure 21: Cast textile experiments (c) - Images grouped

Bamboo yarn and thread was trialed to form a woven surface, infused with epoxy.

The idea behind this was to propose woven sections of a vehicle skin, which could be distributed in flat form, before 'inflating' with a expandable (rubber) air filled former.

Resin could then infuse the expanded form, upon which the former is 'deflated', releasing the mould and leaving a resulting skin surface material.





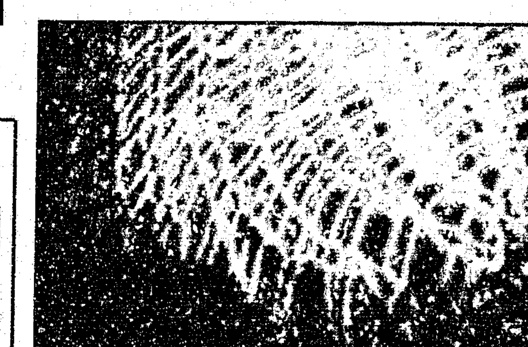
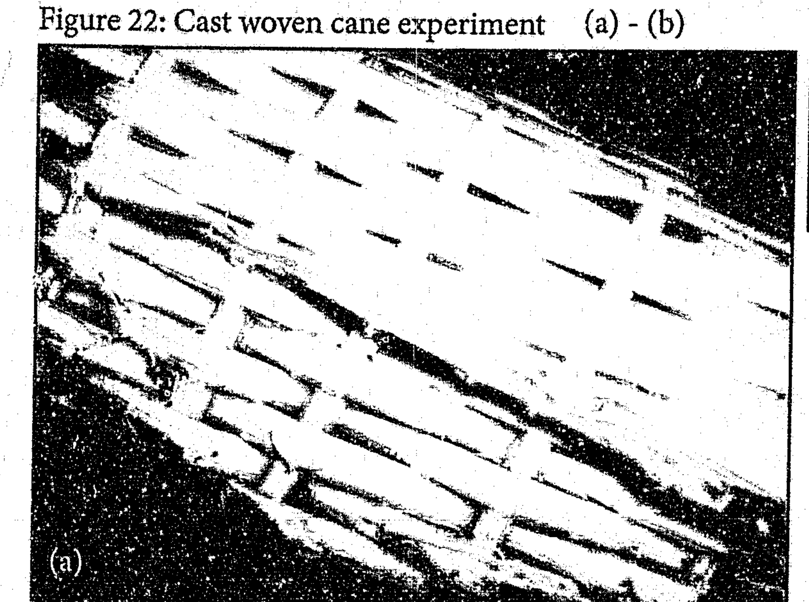


Figure 22: Cast woven cane experiment (a) - (b)



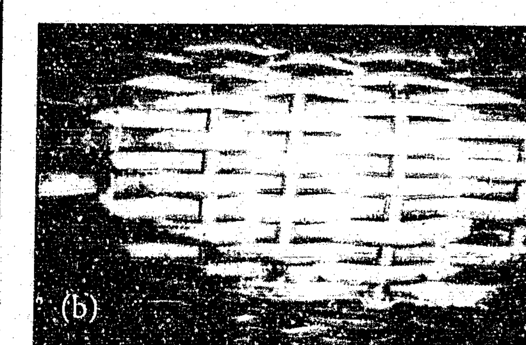
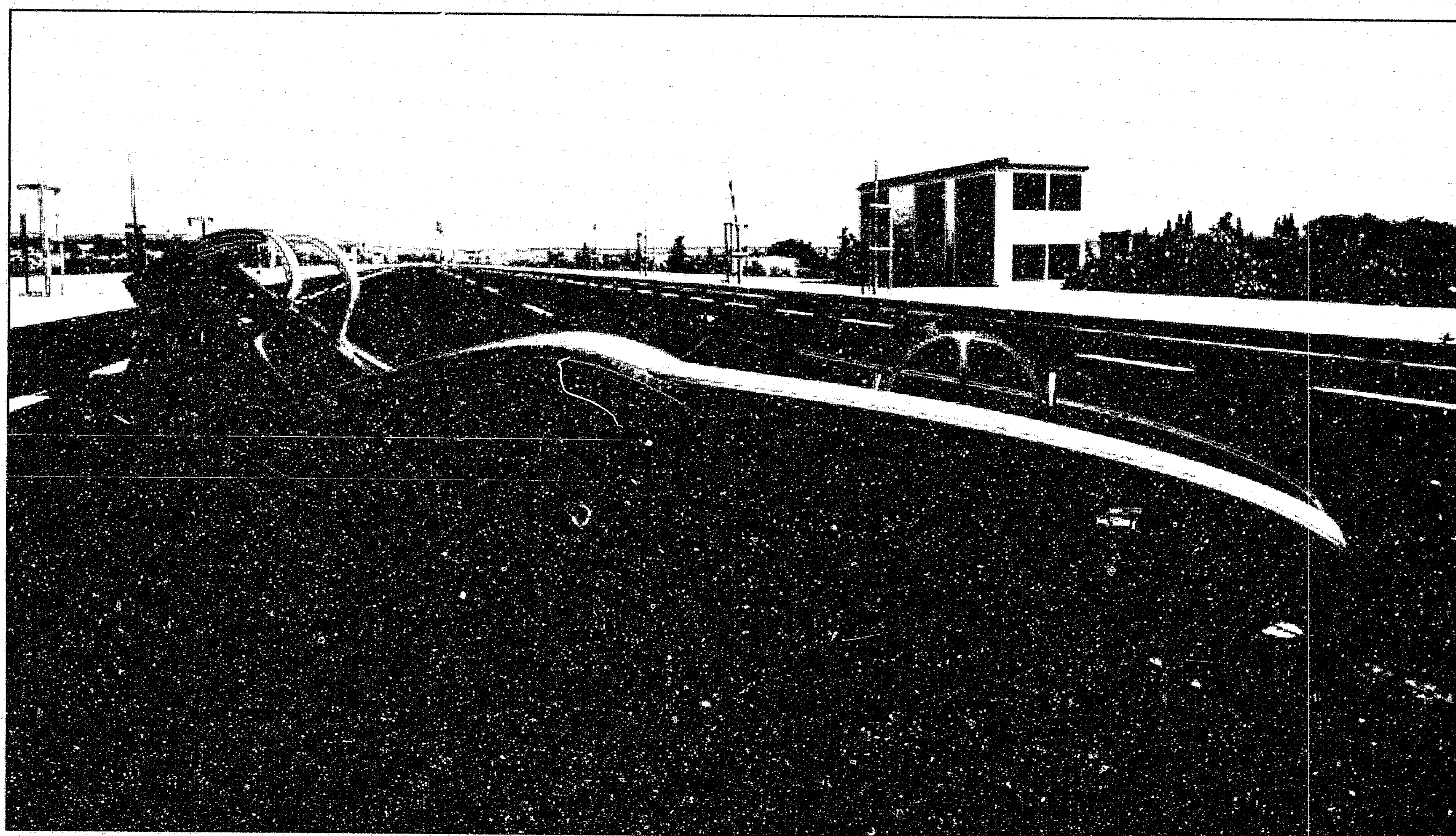
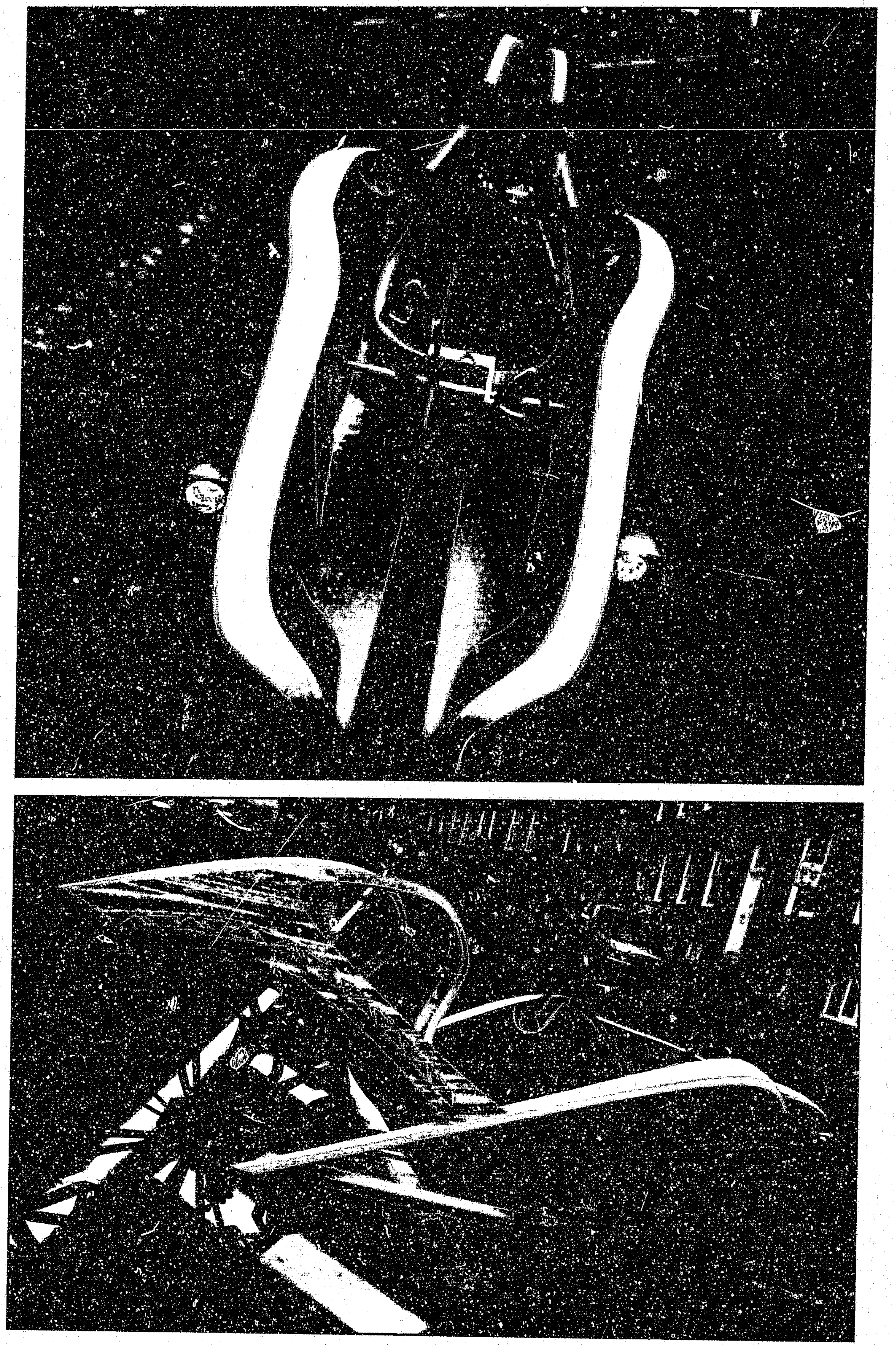


Figure 23: Moulded bamboo fibre 'BamTrike' (a) - Images grouped



The 'Bamtrike' concept reduces the frame section of the HPV to a limited number of core components, forming a unified chassis. The key complexity ifs the production of moulds, and the choice of resin compound for the bamboo fibre.

Figure 23: Moulded bamboo fibre 'BamTrike' (a) - Images grouped



The 'BamTrike' concept was intended to resolve a vehicle from compressed bamboo fibre sections, however, this concept was abandoned due to the complexity of creating bamboo fibre, however, it may be possible to create a similar effect with laminates.

2. Heat manipulated bamboo

To gauge the amount of heat needed to bend 'straight' bamboo, trials were conducted to see the effort needed to be able to form shapes. Hidalgo (2003, 139) describes a process for shaping bamboo post-harvest through using heat from a gas flame - ***Figure 24a***. The method trialed for this experiment differed from that described by Hidalgo - using a 1500W Heat gun as a supplement. As shown in ***Figure 25a, 25b***, shape modification is possible in smaller diameter sections of bamboo, however there seemed to be a limit of achievable radii before breakage. It took several minutes of heating the bamboo before it could be bent. Bending compound curves was unachievable with any degree of precision due to rotation of the section when bending in the opposite direction to a previous bend. Thick sections of bamboo weren't able to be bent using the heat gun, presumably because of the relative low power output. This, however, indicates that post-harvest modification of bamboo would be an energy intensive process.

Figure 24: Heat manipulated bamboo. (a) Hidalgo (2002, 139)

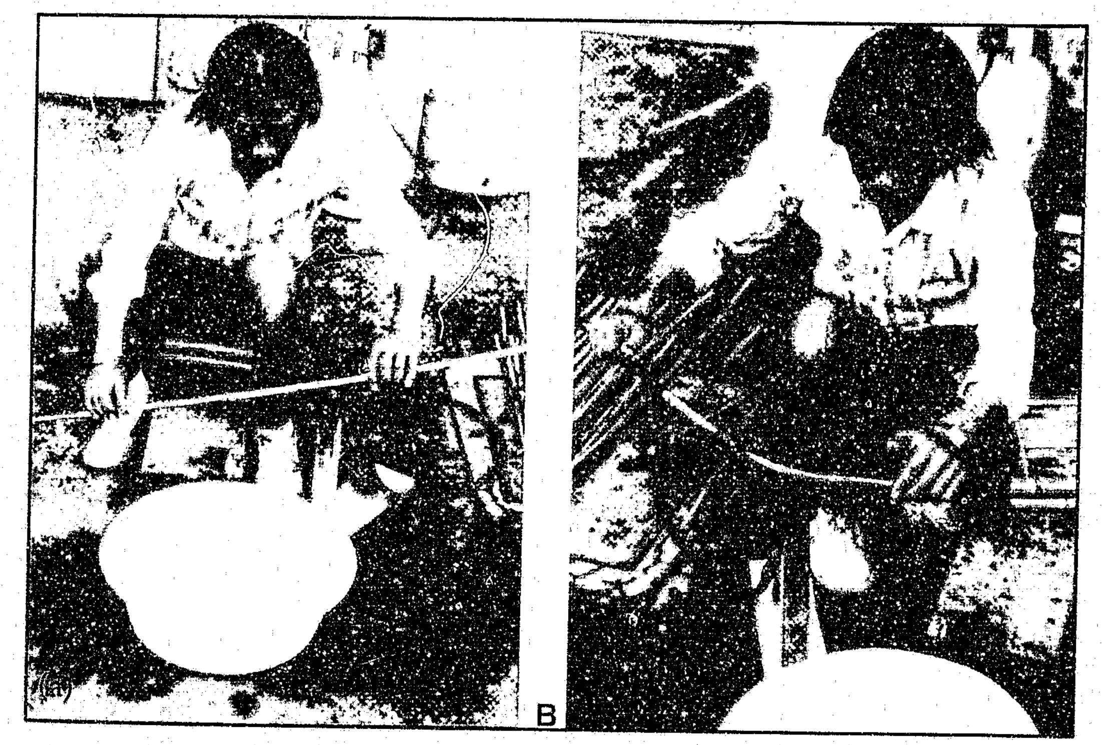
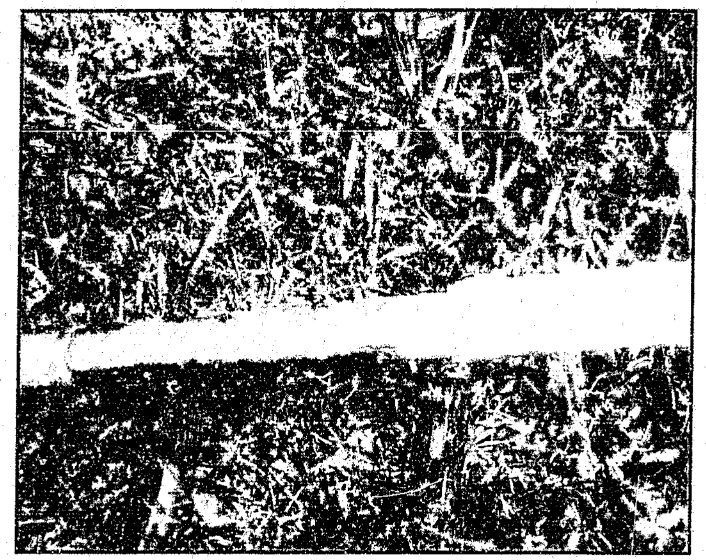
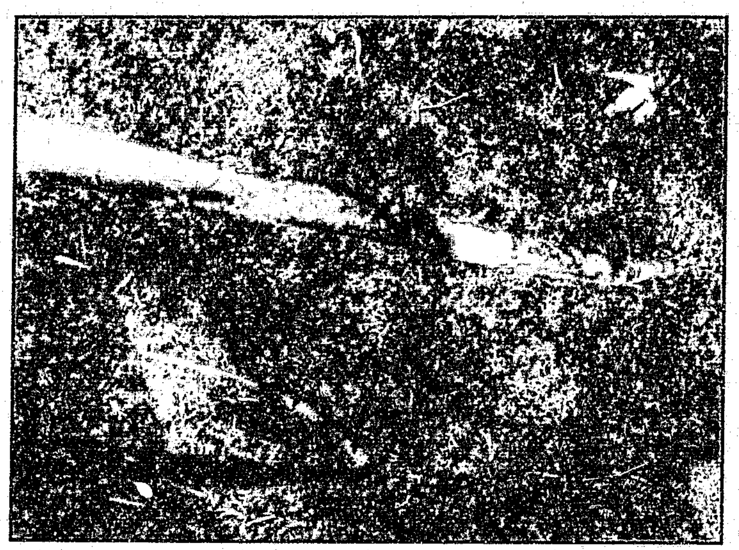


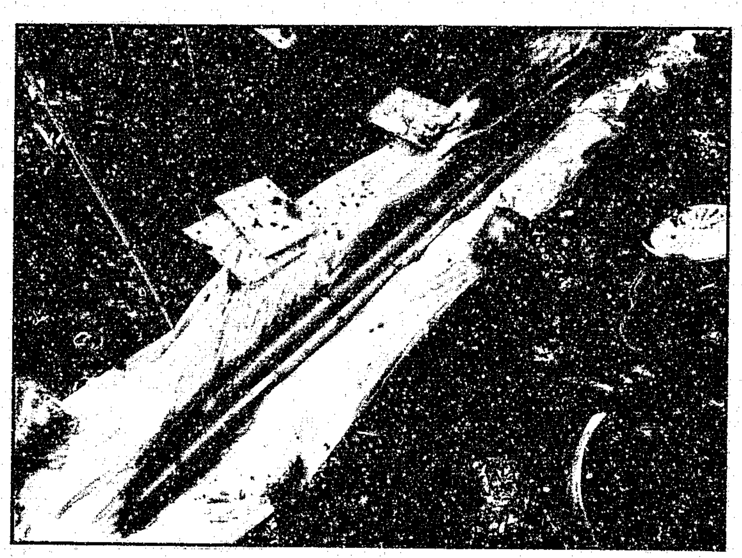
Figure 25: Heat manipulated bamboo experiments

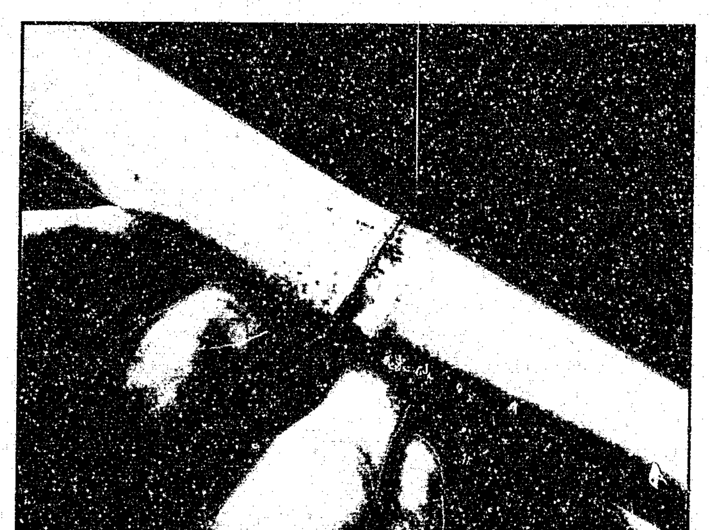
Figure 25: Heat manipulated bamboo experiments (b) - Images grouped



Creating symmetrical shapes takes considerable time - ideally a former would be needed for uniform pieces.







Soaking large diameter culms in water had no effect on the bending ability.

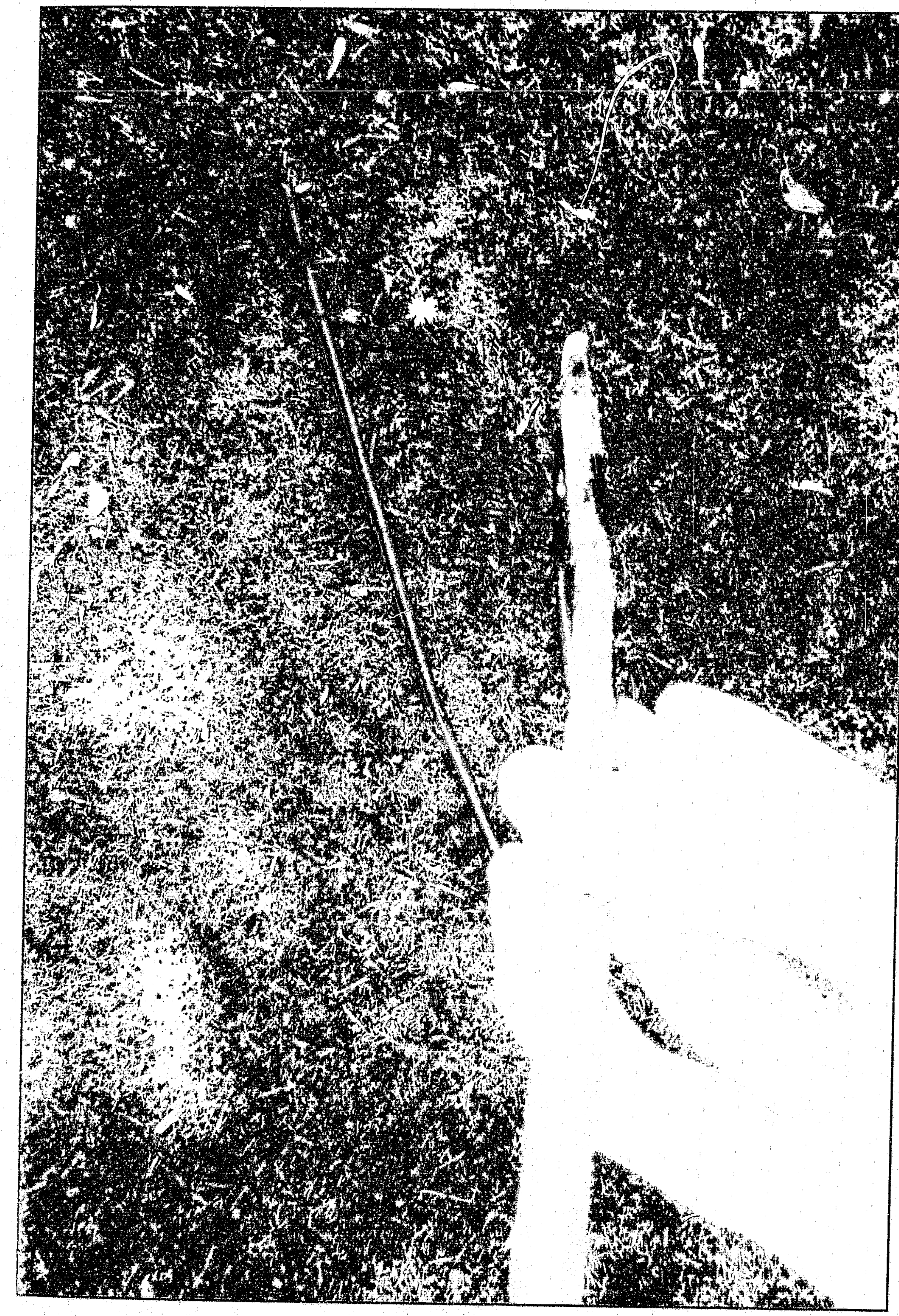


Figure 25: Heat manipulated bamboo experiments (b) - Images grouped

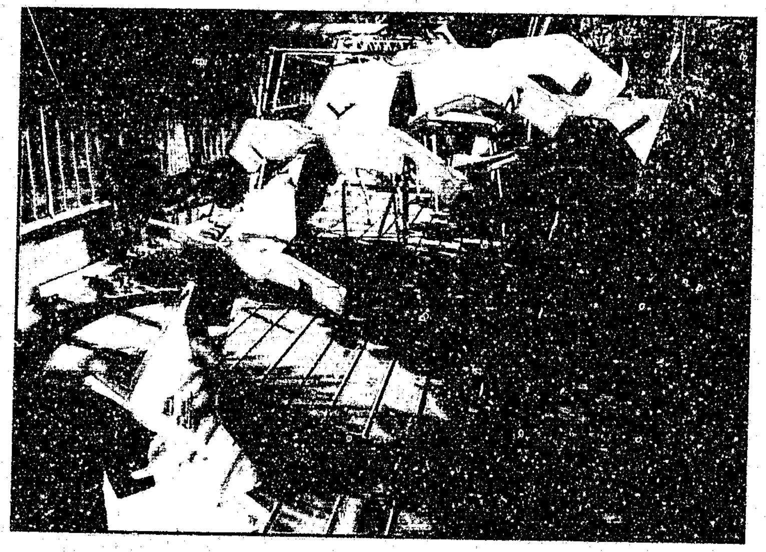
Resulting curves from using a heat gun to shape modify straight bamboo sections. Overheating sections and smoothing the curves create difficulties with this process.

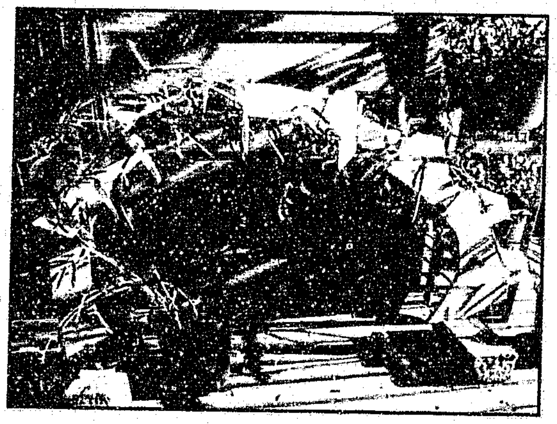
3. Scaled experiments deforming bamboo to a static frame

Experimental version 0.5

This version attempts to explore the fundamental concept of plant shape manipulation on a small, quarter scale size, following extrapolation of the process described by (Hidalgo 2003). Accordingly to fit the scaled down version of a full size proposal, a smaller bamboo species was selected – *Bambusa multiplex (Bambusa glaucescens)* (Farrelly 1984, 183). The grown trial manipulates the flexibility of bamboo culms by attempting to create a 'living rope', by twisting culms around each other, forming a platted effect. The goal of the experiment was to enquire if a multi-strand rope could form a substitute to using a single thick culm. These plants were also slow to establish new culm growth, a problem characterised with bamboos as discussed by Farrelly (1996, 141), and Lewis and Miles (2007, 38). In this case, the rhizomes of the plants were split to form multiple experiment tubs, and establishment and settling of transferred plants takes considerable time.

Figure 26: Substructure experiments (a) - Images grouped



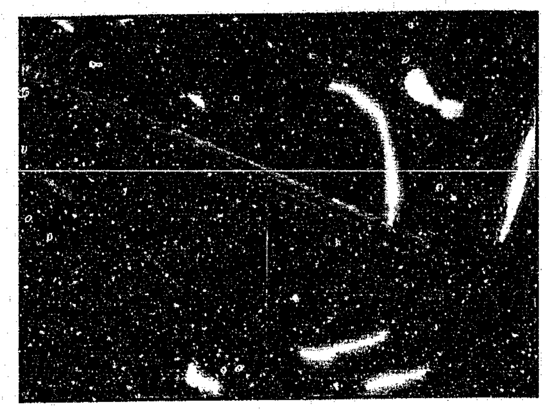


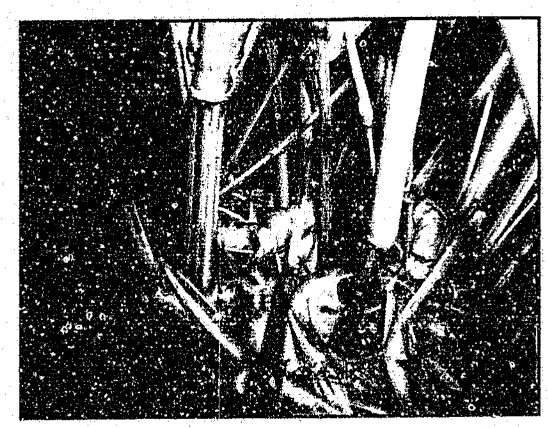
Shape modification was trialed on scale versions using a central 'backbone' former, with left and right sections attached.

The bamboo plants were suitably placed underneath the substructure, and as the sections of the new culms grew, would be affixed to the former profiles along the backbone shape.

Subsequent new culms were interwoven with the old ones to form strands.

Figure 26: Substructure experiments (b) - Images grouped





Whilst this method was effective in displaying a grown shape technique using bamboo, the unpredictable culm growth, particularly over the Summer 2010 period was extremely frustrating.

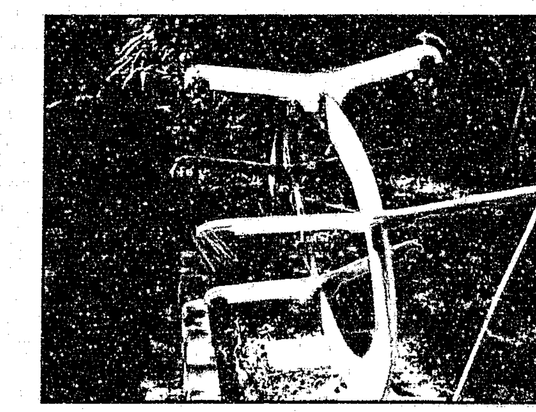
The plant sustained leaf drying during intense hot weather, and took considerable time to re-establish.

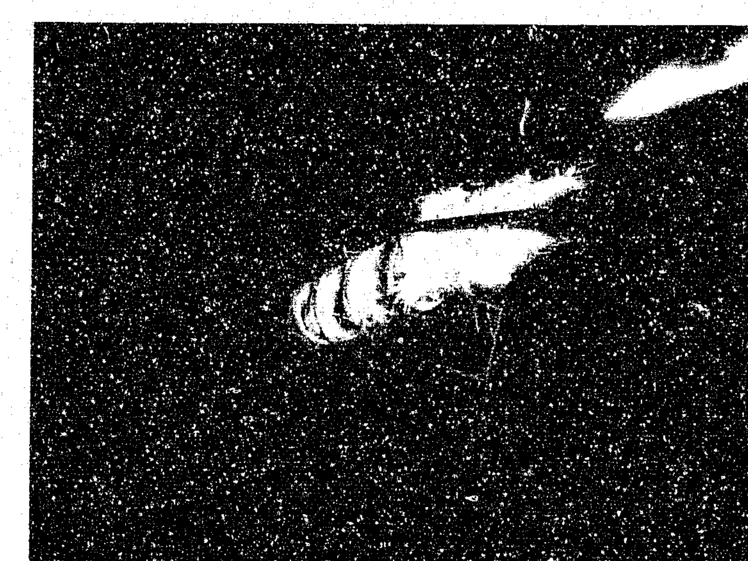
The plants (*Bambusa multiplex)* have sent up new culms, and the experiment to form living, manipulated bamboo rope using culms is still in progress at the time of thesis publication.

Experimental version 1.0

The established culms purchased for experimentation (*Bambusa Oldhamii)* were reasonably small owing to cost constraints at the time. While the plants experienced significant growth during the 2010 spring period, the tips of the growing culms became water logged and rotted. At that stage, it was noted that growth of the culm end ceased, and instead, energy was diverted to producing vigorous side shoots. Since the total leaf mass and height of the original plant contributes to the energy mass that the plant can offer for new culm growth, the side shoot production may enhance the likelihood of the plant sending up new culms, as noted in the Summer 2010/2011 period. This experiment is detailed in ***Figure 27a- c***.

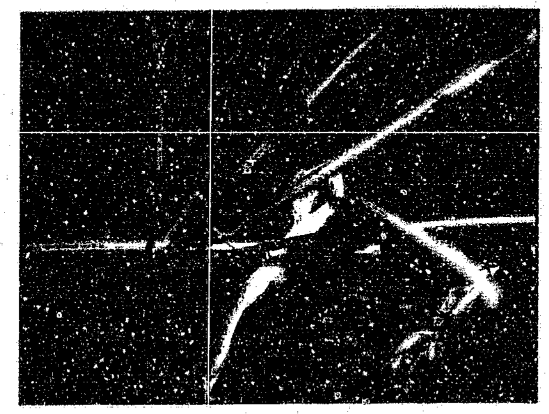
Figure 27: Large substructure experiments (a) - Images grouped

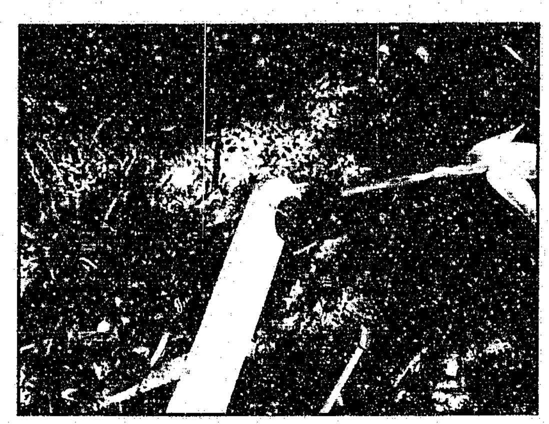




These trials were achieved to form the basis of the shape modification techniques of bamboo for the 'Ajiro' concept. Again, plant quantity and establishment would be needed to further prove the viability of shape modification over substructures.

Figure 27: Large substructure experiments (b) - Images grouped

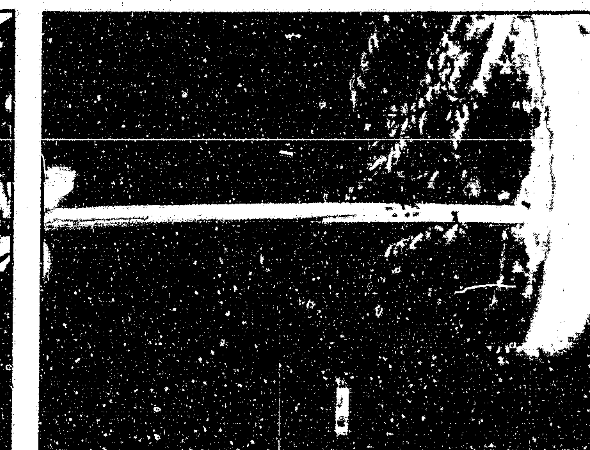


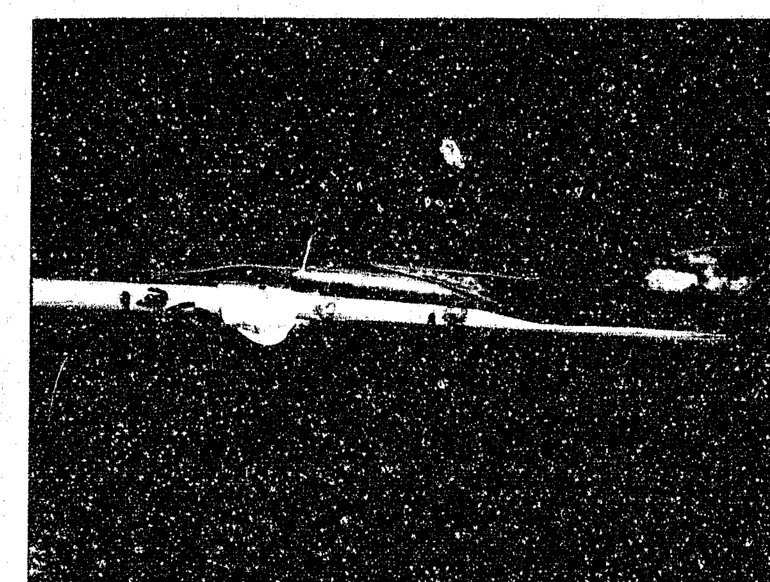


The vigor of growth initially proved quite promising, however, the tips of the culms became damaged during the winter period, and the tip of the culms decayed.

Once this tip damage occurred, growth of the 'main' culm ceased, and the plant instead produced vigorous side shoots. However, such side shoot development may have lead to enhanced development of the plant during Summer 2011, given the extra biomass the plant had.

gure 27: Large substructure experiments (c) - Images grouped





During the warmer summer months, the culms achieved good growth. With added plant establishment, new culms would be vigorous in growth.

New bamboo culm (*Bambusa Oldhamii*).

Experimental version 1.5.

For this case, a different subspecies of bamboo was selected – *Bambusa textilis gracilis*. Whist this plant has different height characteristics to the species used in Version 1.0, specifically a smaller overall growing height of five to six meters, an interesting growth observation was observed, whereby the new culms sent from the established parent plant contain no leaf or side shoot mass. This experiment is detailed in ***Figure 28a-b***.

Figure 28: Large substructure experiments (a) - Images grouped

These experiments used the species Bambusa textilis gracilis to compare the growth of two independent culms - comparing the growth rate. This was reasonably comparable, however, the culm tips also rotted, and the plant produced side shoots. The plant was used for further shape modification experiments during the Summer 2011 period, where the plant has sent up significant numbers of new culms.

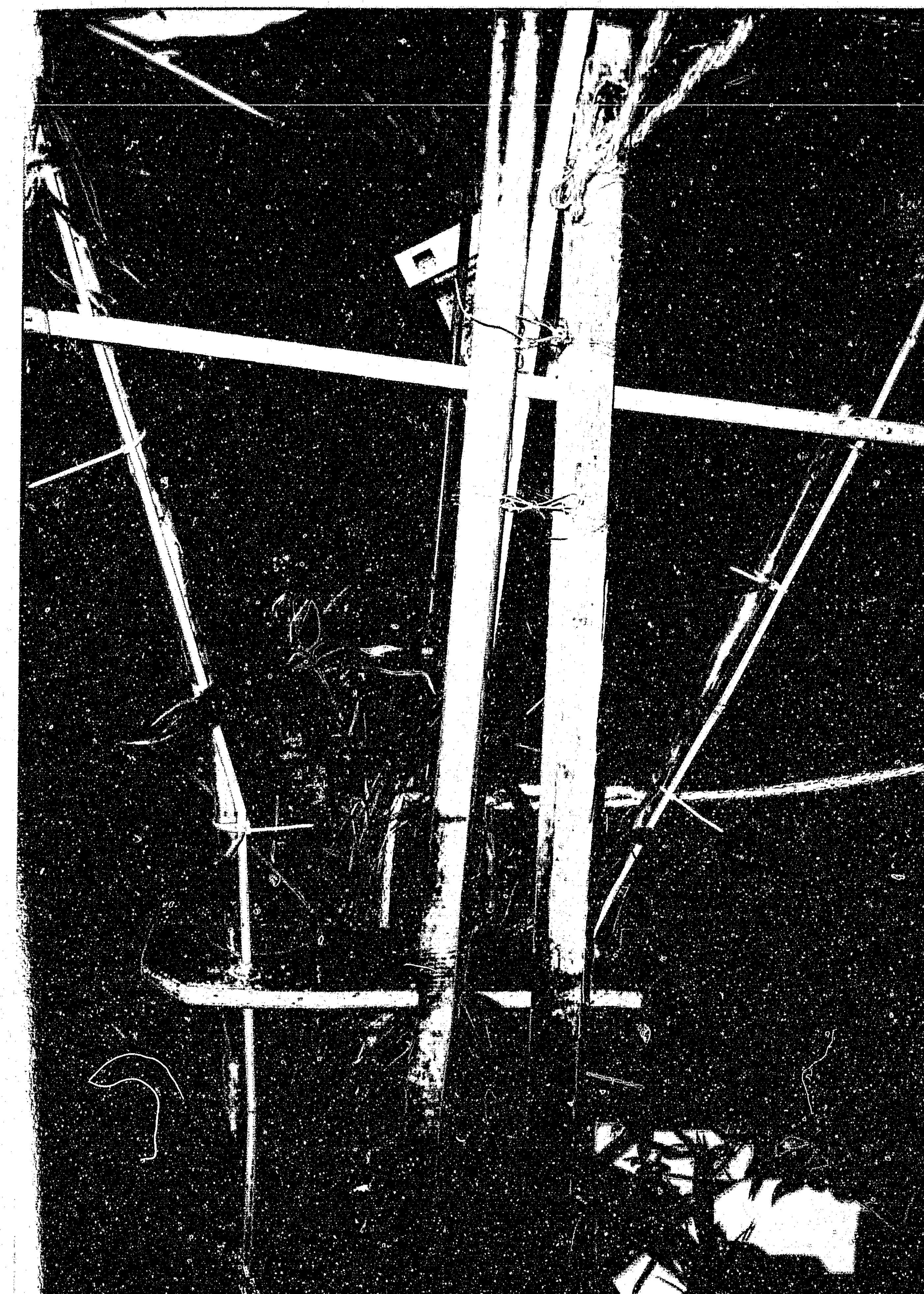


Figure 28: Large substructure experiments (b) - Images grouped

When the culm encountered a restriction, evident in the above pictures, it appears to grow at a tangent to the obstruction, then, once clear, proceeds with a vertical growth pattern.
When the obstruction is removed (bottom picture) the culm maintains the deformed shape.

Growing canopy shelter

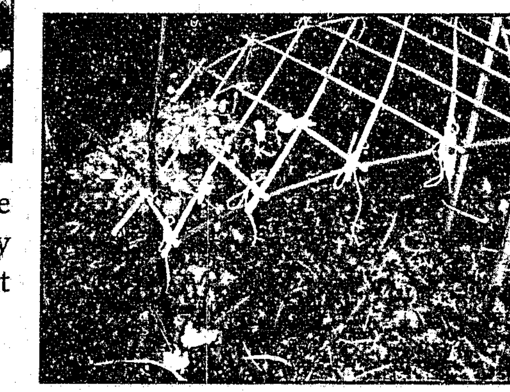
The species ***Pisum sativum*** 'Alderman, Tall Telegraph' pea, has characteristics of fast growth and hardiness. Technically contributing to the particular outcomes in this trial, this species is tall (about two meters total), so can therefore cover a reasonable surface area, whilst the tendrils that the plant produces will savagely cling onto any tubular or other structure – such as the bamboo side shoots. This experiment is detailed in ***Figure 29a-b***.

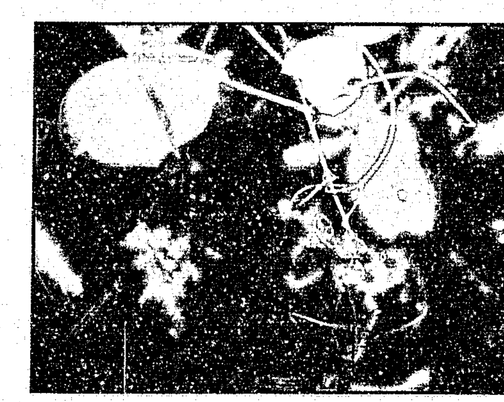
Figure 29: Canopy shelter experiments (a) - Images grouped

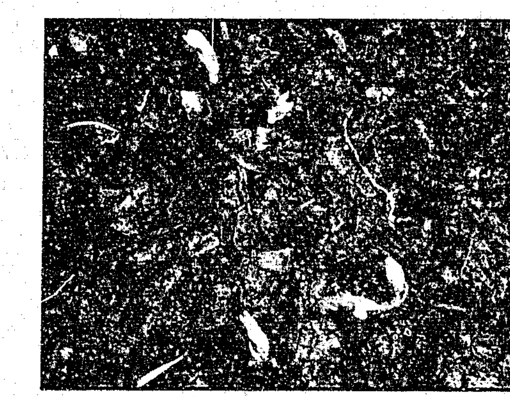
Side shoots or sections of the bamboo could be weaved or tied together to form a loosely interwoven structure. The frame, if dense enough could support climbing vines or plants.

Figure 29: Canopy shelter experiments (b) - Images grouped

The tendrils of the pea wrap around any structure in the way, in this case a bamboo trellis. With increased quantity of 'vine' type plants growing in the 'planter box', significant density of cover could be achieved.



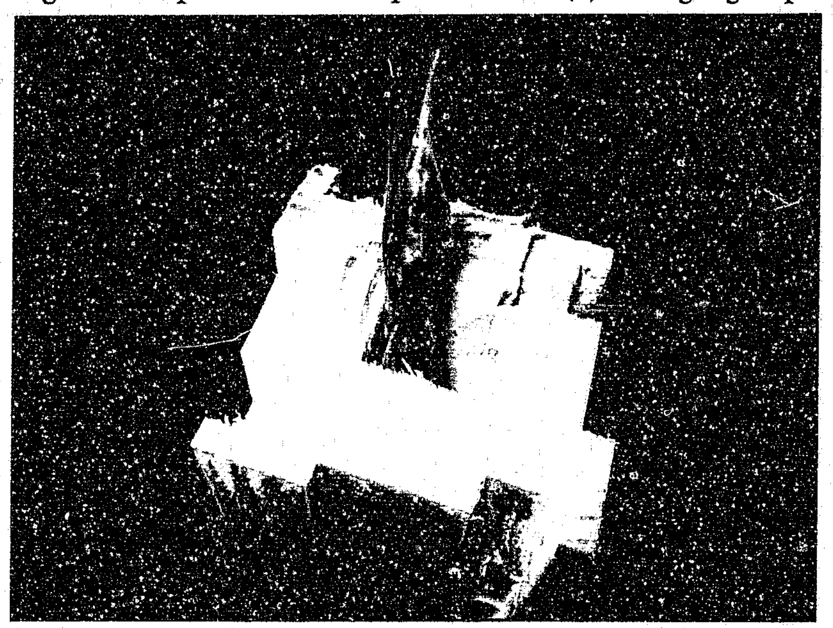




Growing Square Bamboo

Within the growing cycle of the new culms during the season of March 2011, one of the culms was trialed for shape modification through compression of the culm (see; Hidalgo 2003, 353), by forming a fastened square box that would slide over the growing culm section, attempting to create *'square bamboo'*. To date, the experiment is still ongoing, however it is evident that the particular culm is growing at a reasonable rate, and is appearing to put pressure on the enclosing box structure.

Figure 30: Square bamboo experiments (a) - Images grouped



The growing culm emerging from the square restrictor.

Holding a circular template against the deformed section, flattening of the sides indicate the region where the culm has been restricted.

Growing bamboo inside a maze frame

This experiment aims to demonstrate the experiment by Oscar Hidalgo (Hidalgo 2003 352-353) where bamboo was grown in a truss shape within an enclosed wooden box.

The experiment conducted for this thesis is ongoing, however, it is apparent that the spacing of the frame sections might represent curves which the plant cannot achieve naturally by only using the plants resistance (pushing) on the wooden frame sections. As such, it would be desirable to experiment further with variations of angles and spacing in the future. This experiment is detailed in ***Figure 31a-b***.

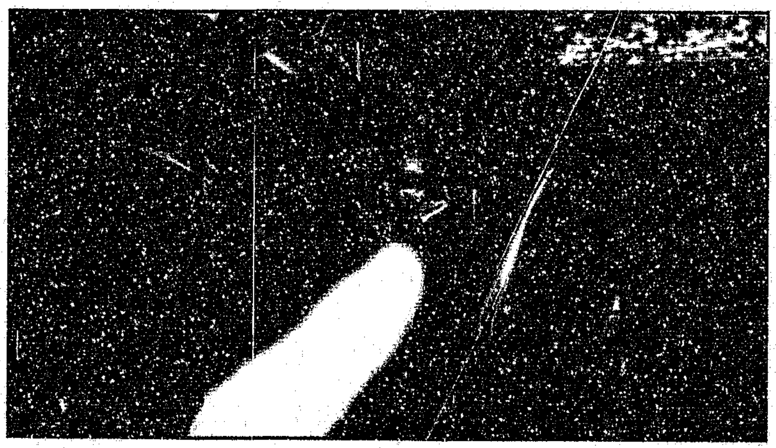
Figure 31: Bamboo growing inside a box frame maze (a) - Images grouped

Culm just starting to push against the box section.

The plant encounters sharp bends in a forceful manner as the culm pushes against the box sections. The angle produced is quite abrupt.

The level of force partially deformed the wooden box, which was quite surprising.

Figure 31: Bamboo growing inside a box frame maze (b) - Images grouped



Shape deformation angles where the growth direction has been restricted. The bend appears to be more pronounced in the region just above the node section.

Note the bump from the section where side shoots will emerge.

E

Visiting a bamboo farm to visually experience the density of bamboo in a farming environment.

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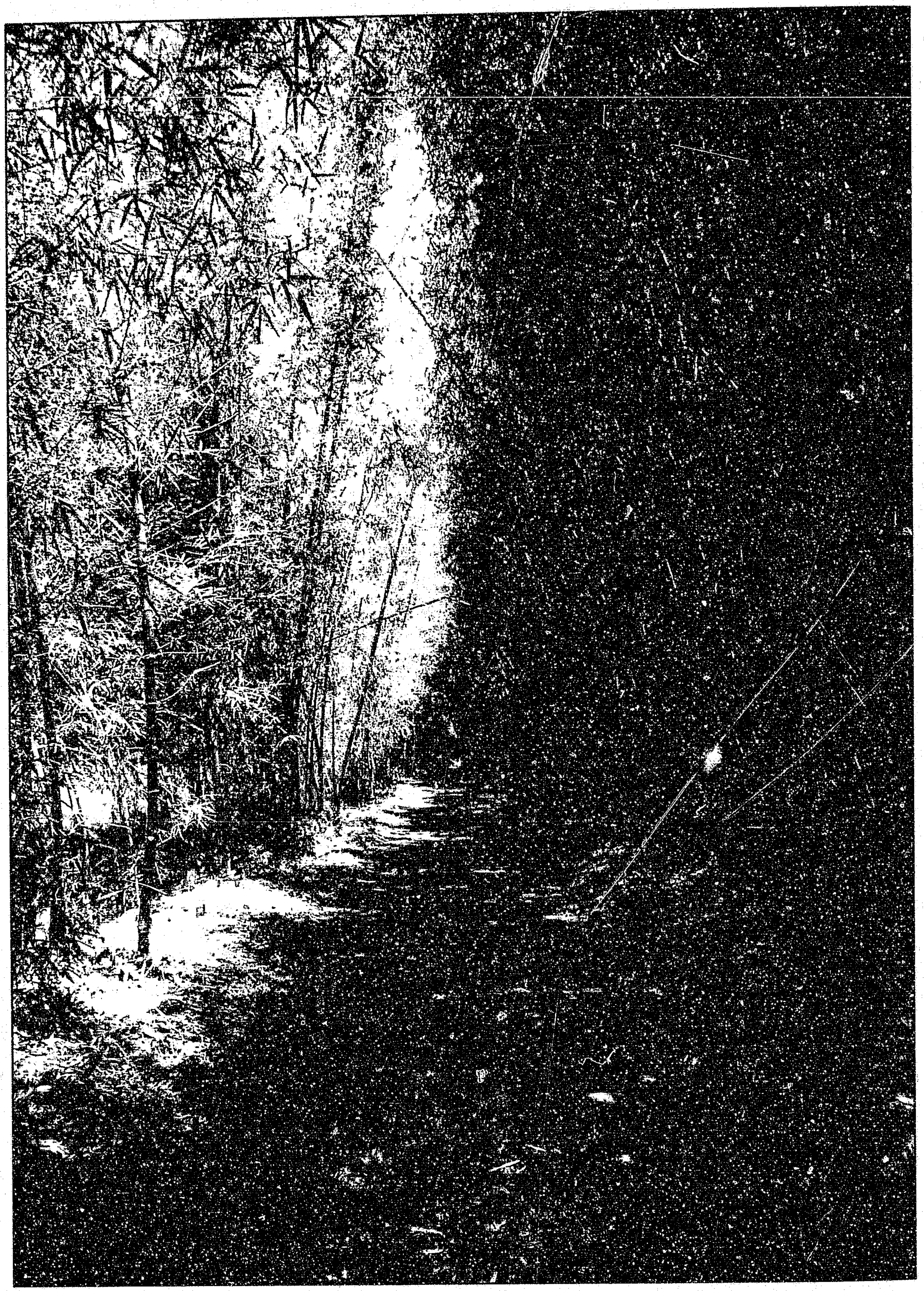
Appendix E: Visit to "Bamboo Australia" plantation

During February 2011, the author visited "Bamboo Australia" plantation in Queensland, Australia. The following collection of images were particularly inspirational, especially witnessing the vigour of the plantations and size of the various bamboo culms.

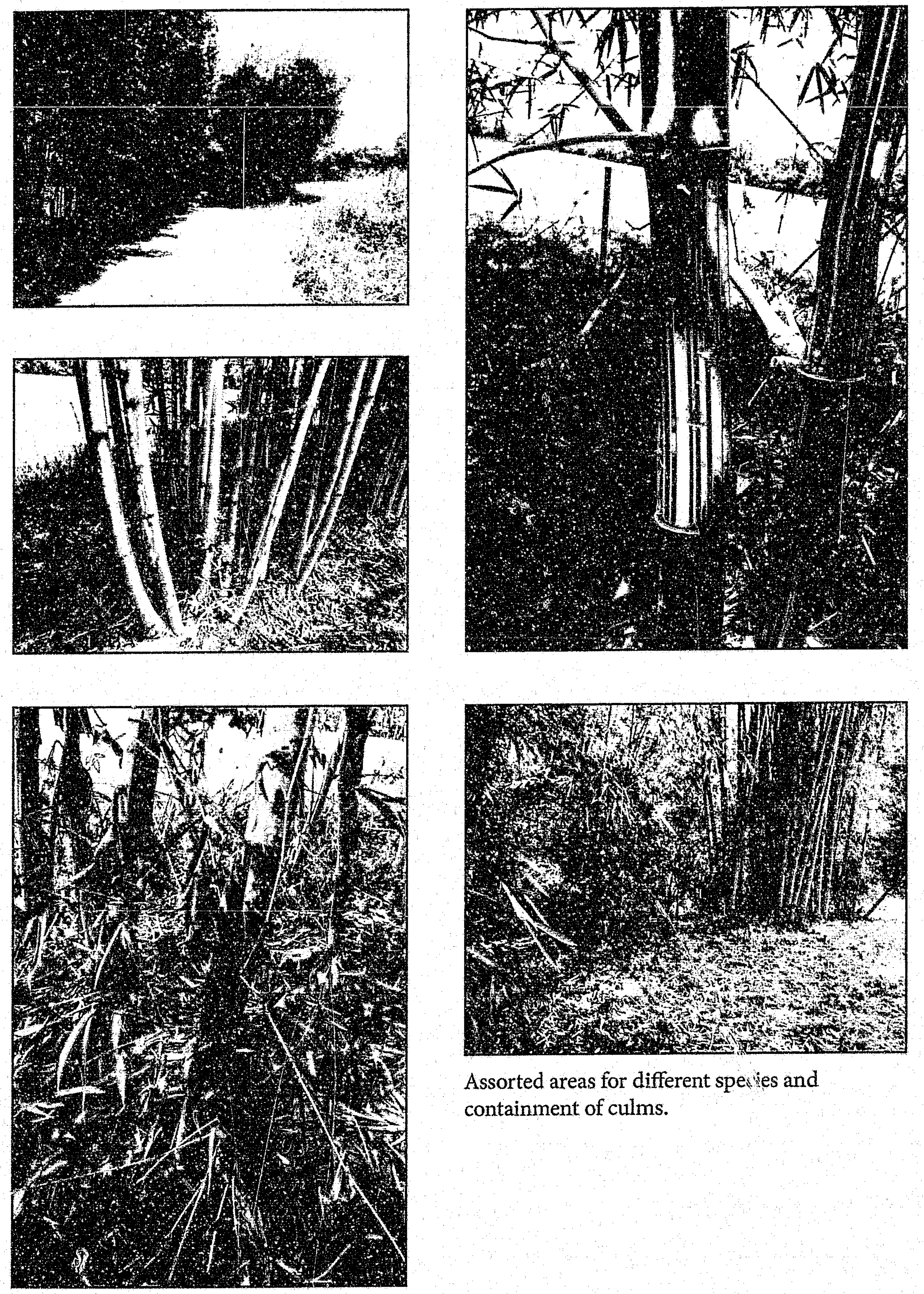
Height, thickness and strength of the massive culms further secured the realisation that bamboo could provide a viable resource for building structures, and was also an excellent indication of the scale and quantity needed for thorough plant establishment for harvesting. These observations are detailed in ***Figure 32a-l***.

Figure 32: Plantation bamboo (a) - Images grouped

Figure 32: Plantation bamboo (b) - Images grouped



Avenue of bamboo. This picture demonstrates the clear lower sections of the plant free from branches.



Assorted areas for different species and containment of culms.

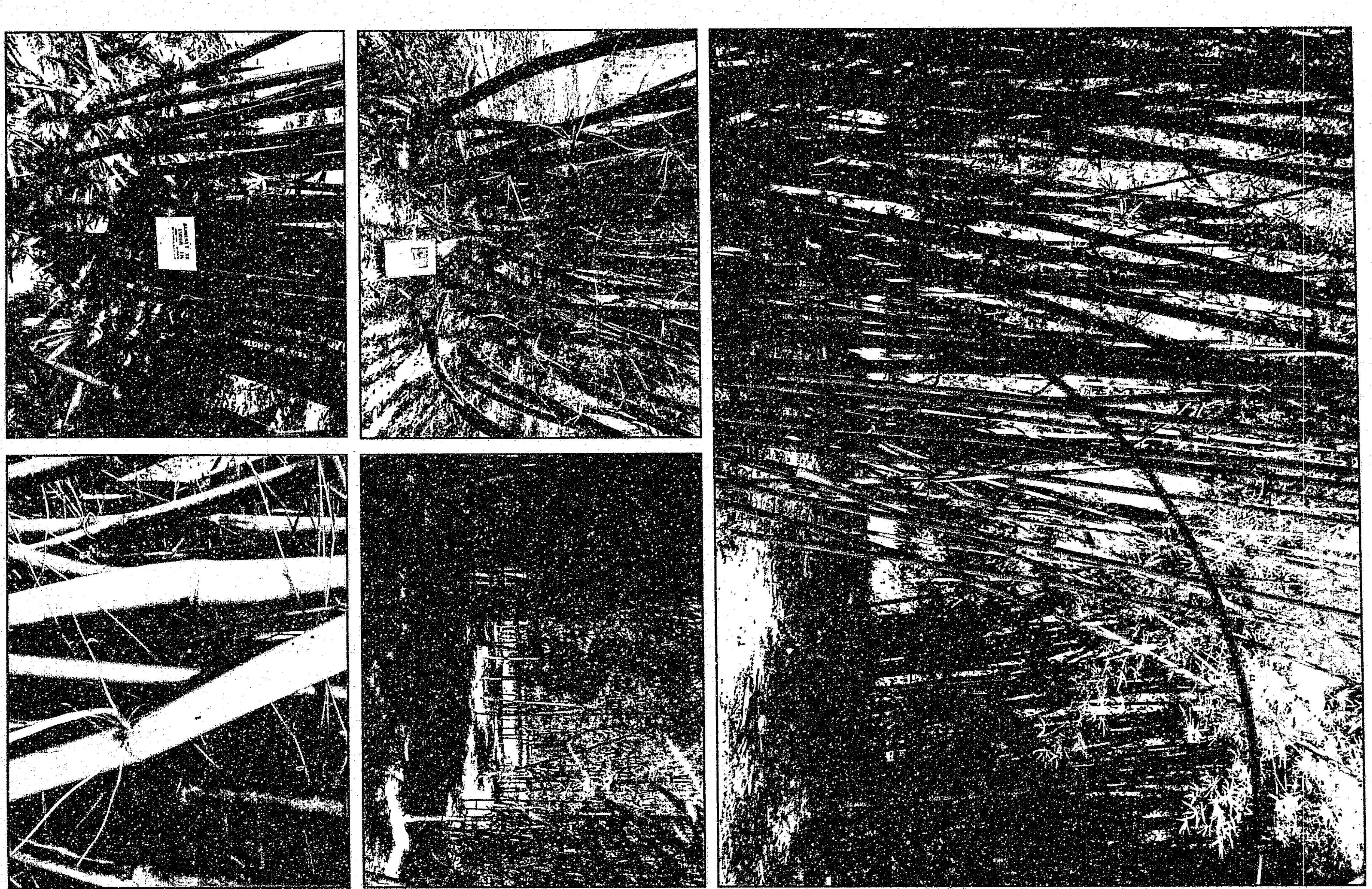
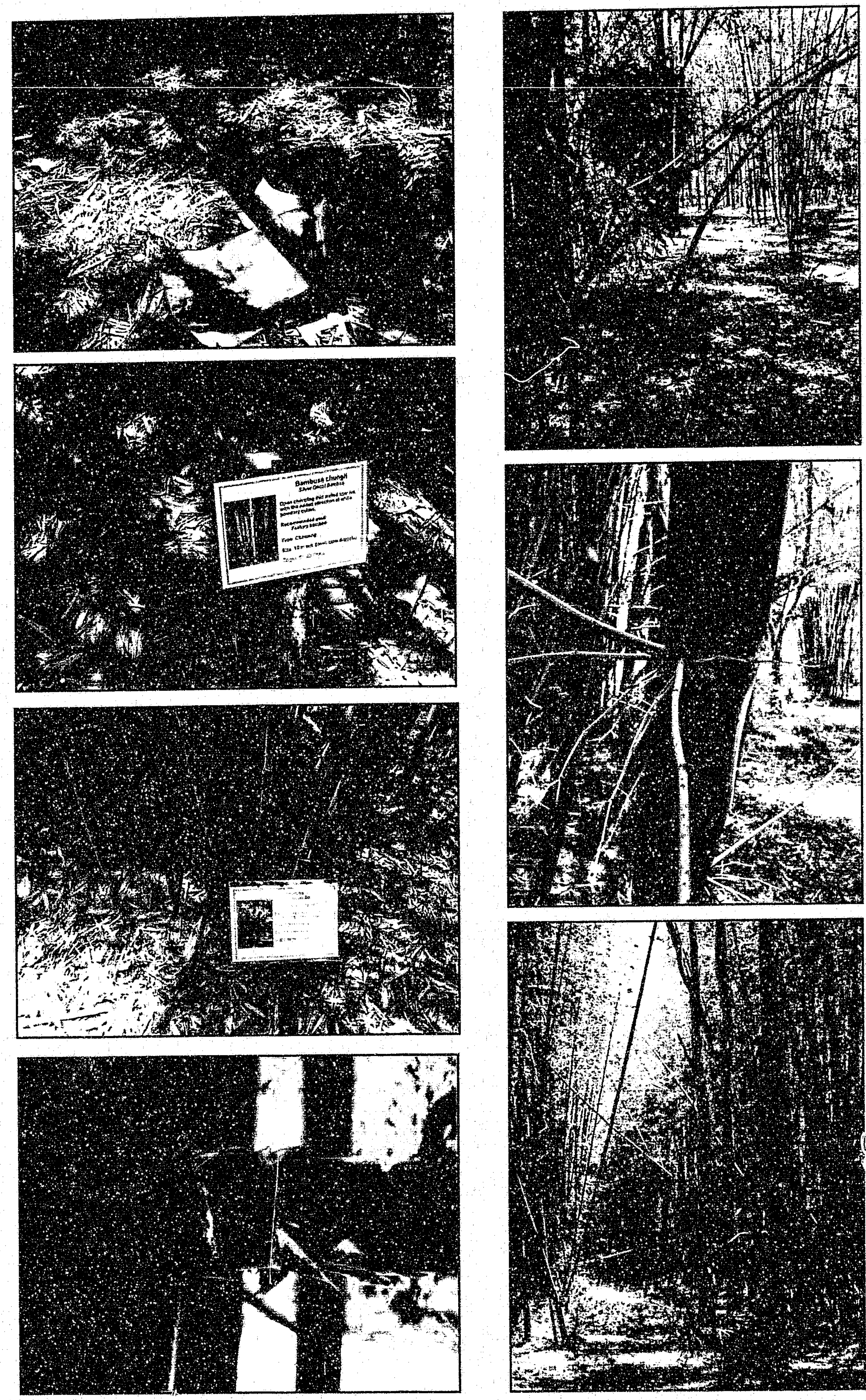


Figure 32: Plantation bamboo (c) - Images grouped

Figure 32: Plantation bamboo (c) - Images grouped

Cluster of culms, the outer most deformed naturally.

Figure 32: Plantation bamboo (d) - Images grouped



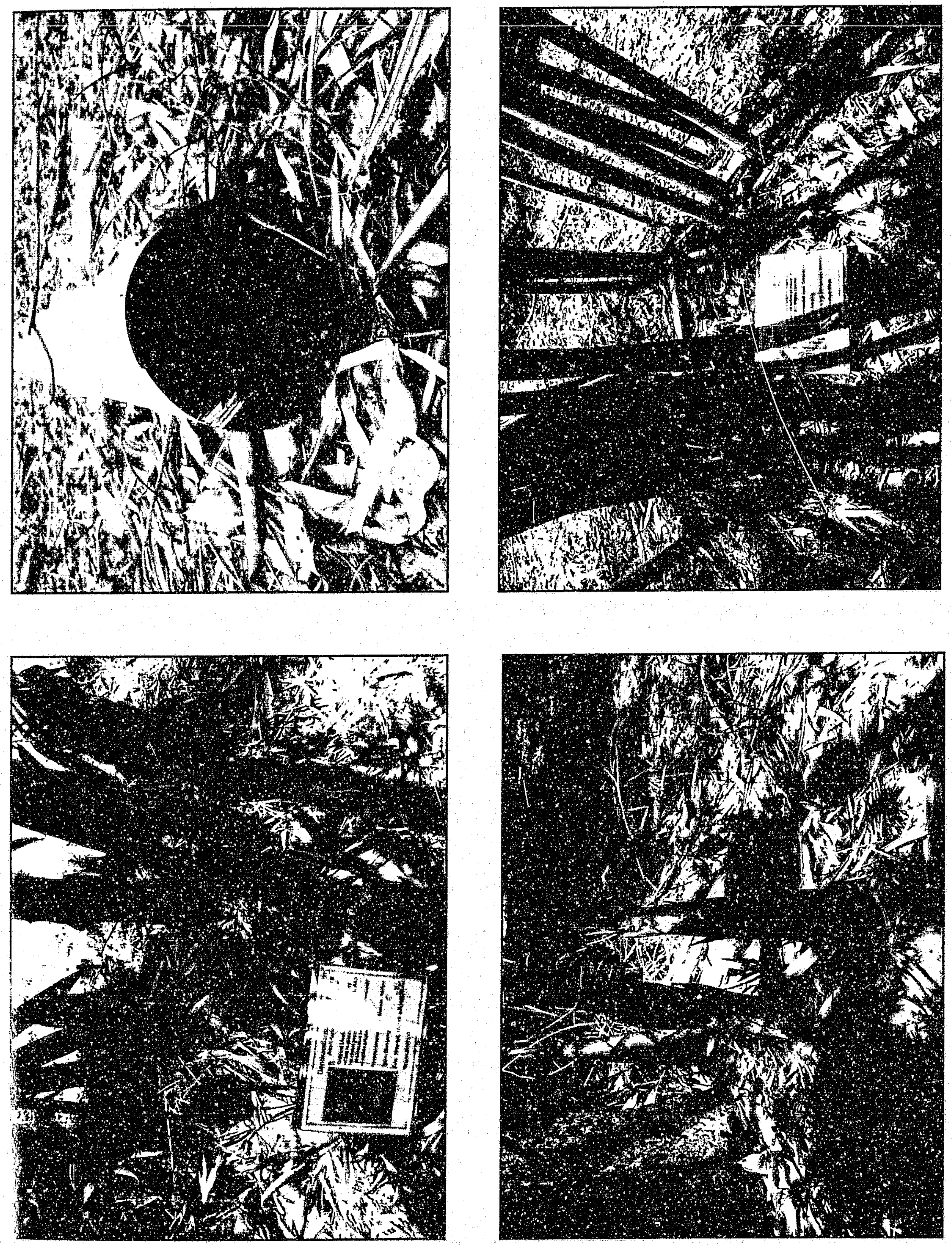


Figure 32: Plantation bamboo (e) - Images grouped

Figure 32: Plantation bamboo (f) - Images grouped

Figure 32: Plantation bamboo (g) - Images grouped

Beautiful canopy and astonishingly straight, clean and tall culms produced.

Figure 32: Plantation bamboo (h) - Images grouped

Natural culm angles in the plantation.

The height and density of the bamboos was particularly impressive. Witnessing the size of such plants aids the realisation that uses could extend beyond construction of simple structures.

The density of the 'green' biomass is contained to the top third of the plant, leaving a clean lower and mid section for use.

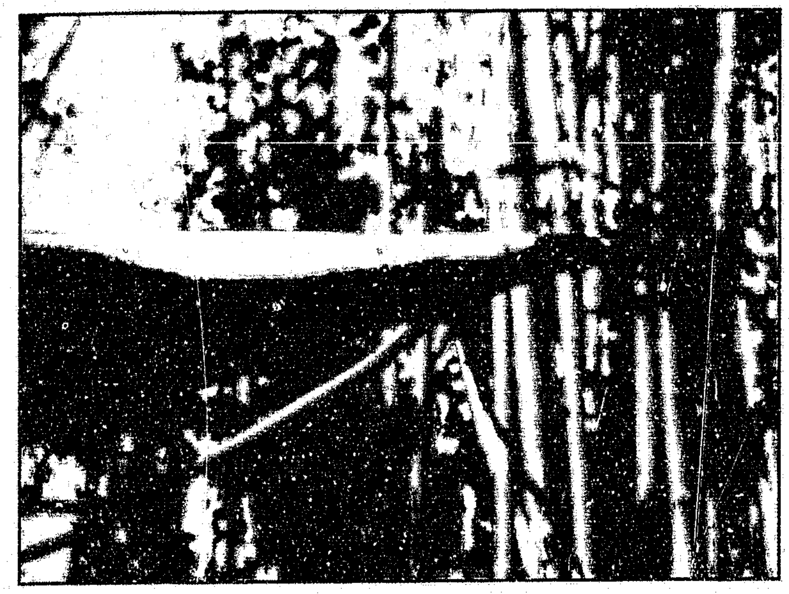
This clean, branch free 'feature' of bamboo is therefore ideally suited to shape modification within enclosed formers, as branches in conventional trees would become trapped. When the bamboo exits the former, it is free to produce its top green biomass canopy, yet leaves the lower sections intact.

Figure 32: Plantation bamboo (i) - Images grouped

Natural shape deformation of bamboos.

Figure 32: Plantation bamboo (j) - Images grouped

An example of uniformity between bamboo culms.



Natural shape deformation of bamboos, particular attention is noted regarding the density of the plantation.

This image demonstrates the straightness along bamboo culms.

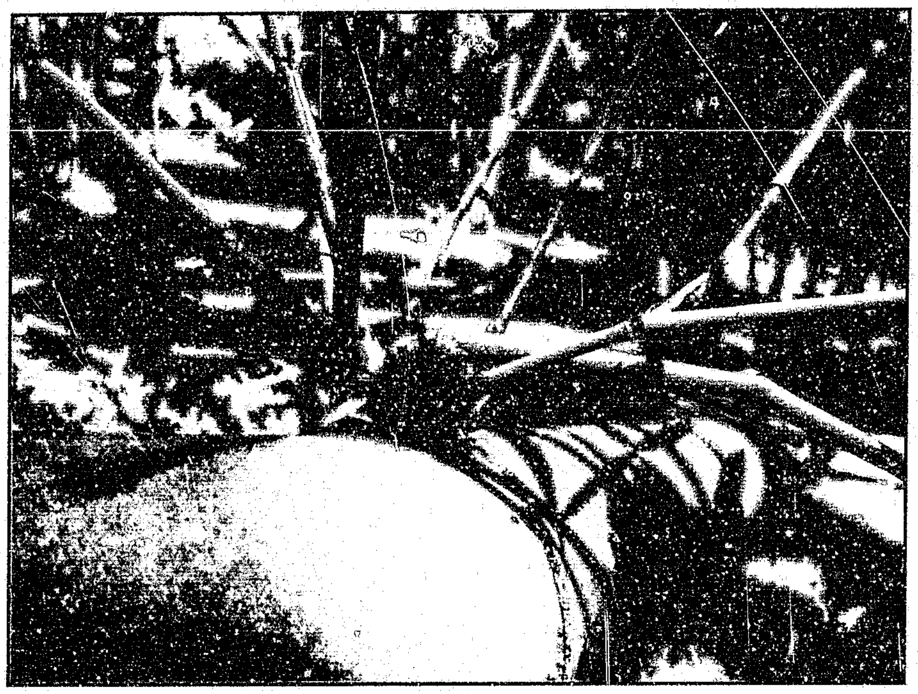
Figure 32: Plantation bamboo (k) - Images grouped

Circumference of the culms was particularly inspirational, coupled with the height, realises the appreciation of the raw material.

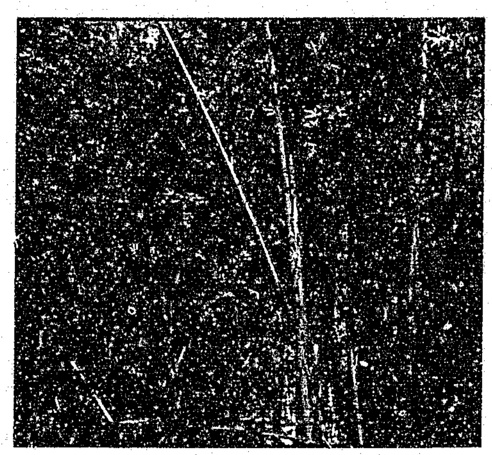
Removed culm shows the relative wall thickness.

The thickness of some of the giant species was extremely impressive.

Figure 32: Plantation bamboo (l) - Images grouped

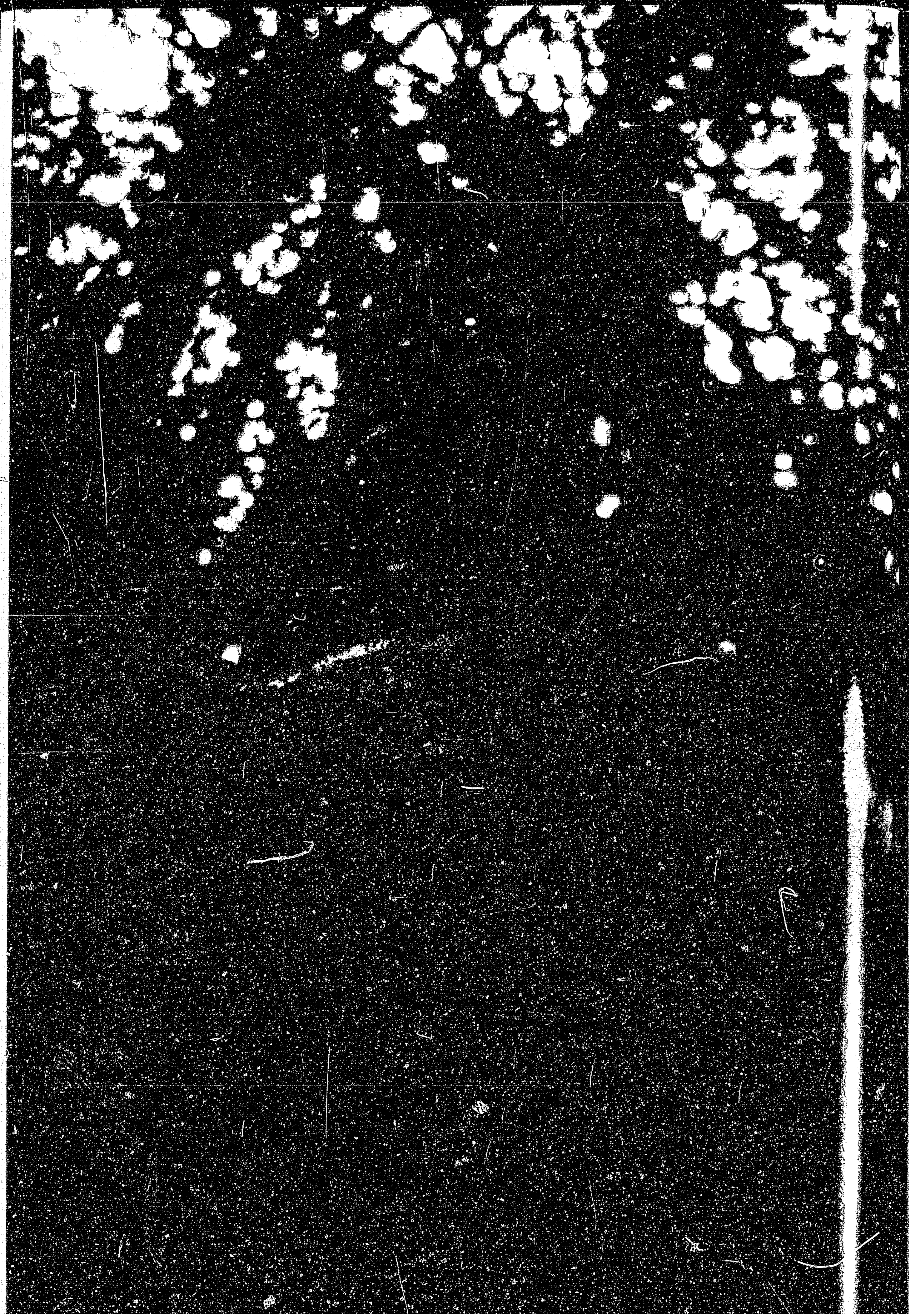


Natural shape deformation in plantation.



F

Issues with recommending a natural production process.



Appendix F: Behaviours Encountered with the Natural Cycle

The variable which determines the overall success of the experiments is reliant on the ability of the bamboo to effectively propagate over an extended period of time. Climatic conditions and plant maturity (such as proper transplanting establishment if up-rating to a larger tub size) are necessary for the ideal growth. Given the restrictive growing conditions in which the research experiments are presently being conducted, the factors for ideal growth are dependent on the wide climatic conditions experienced in Melbourne, Australia.

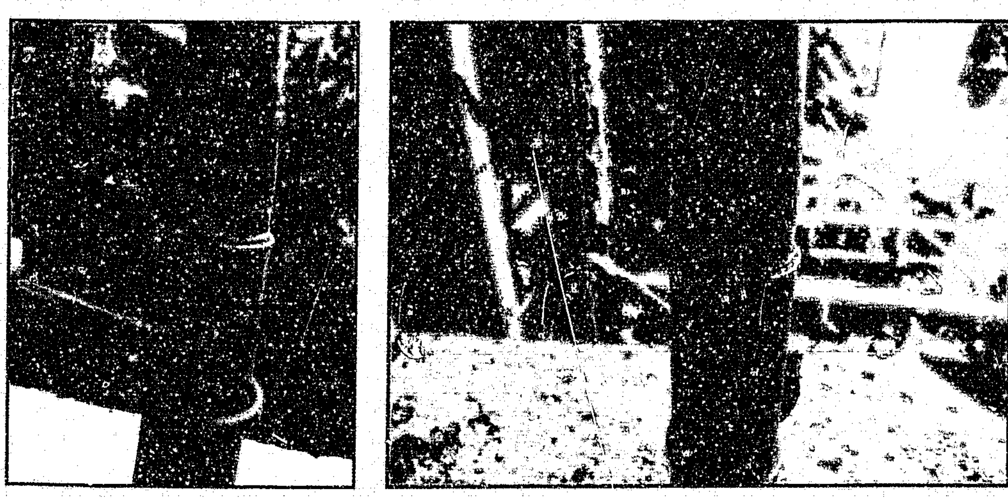
Within the context of the research time constraints and cost factors, the establishment of the obtained plants commenced from mid October 2009. Given the short time frame for growth, the plants have had two growing seasons in which to adjust to being transplanted into larger containers. These stresses have compounded the constraints and establishment of the various experiments. These encounters are detailed in ***Figure 33a-c***.

Notable natural complexities include:

- Heat stress due to intense sunlight during the summer period, resulting in significant leaf drying, from which the plant failed to recover.
- Winter factors such as frost and rain, caused the tip of the culm to become water logged, resulting in rotting.
- Drying of soil during wind events (especially during winter), or excessive sunlight/heat (summer period is of primary concern, however, this can occur during other months if no rain events have been recorded for a while) resulting in leaf curling and leaf shedding.
- Permanent plant damage (leaf shredding) resulting from a significant hailstorm (March 2010) event.
- Insect damage and culm decay.

The main concern with progression of the various experiments was with the significant dormant period which the plant encounters during the winter months.

Figure 33: Bamboo culm damage (a) - Images grouped

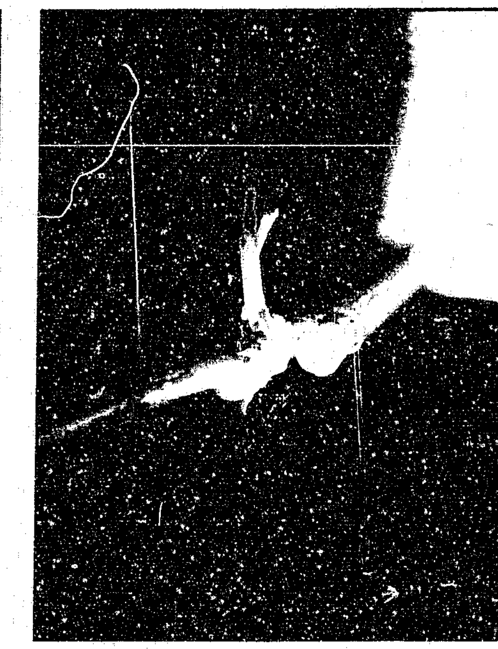


Decay in one of the culms. Although damaged, the rest of the culm remained healthy. Despite enquiries, the source of the damage remains a mystery.

Figure 33: Bamboo culm damage (b) - Images grouped

Images of other damaged culms which were observed in the bamboos grown by the author.

Figure 33: Bamboo culm damage (c) - Images grouped



When the tips of the bamboo culm become damaged, it does not grow any taller. Instead, energy is directed into sending out vigorous side shoots at the 'nodes'.

Note the shoot growth off the side of the culm wall, even through the main culm has been damaged.

G

Documented experiences with growing bamboo from seed.

Appendix G: Behaviours encountered when growing bamboo from seeds and cuttings.

Further observation towards the natural process of growth and plant establishment was gained through the growing of bamboo from seed. This method seems feasible, given commentary by Farrelly (1984, 1996), Hidalgo (2003) and Oprins and van Trier (2006, 34-35). Investigation was also undertaken to experiment with a method for propagation from cuttings, as discussed by Rana (2001), see: **Figure 34h**.

The reason for growing bamboo from seed was to explore possible ways of liberating the design from constraints of relying on specialised suppliers to source mature plants. Growing from seed may allow for closed loop production, whereby reliance is developed for the plants to self-seed, or obtain mass seed stock from other locations.[60]

Predicting the flowering of bamboos can be problematic, with Farrelly describing that some species may take *"several lifetimes"* before spontaneously flowering (Farrelly 1984, 149), and that *"some species of Phyllostachys* [having a flowering] *cycle of eighty years or more"* (Oprins and van Trier 2006, 35). Furthermore, Oprins and van Trier note that mass flowering may occur *"...simultaneously over large areas"*, where the trigger for flowering remains *"...one of the greatest mysteries in the plant kingdom"* (ibid) and *"the flowering cycle of bamboos is one of their most unusual, disputed, and botanically mysterious characteristics"* (Farrelly 1984, 148). The mechanisms for flowering, therefore, remain the source of various hypothesis. Janzen (1976, 369), proposes that bamboo plants have an internal calendar or "alarm clock" (Soderstrom and Calderon 1979) and the *"...same stock bloom at the same time, regardless of geographic locations or climatic conditions"* (165). Farrelly (1984, 149) also describes the relative mechanism for flowering as unknown with the plant being *"...alerted by some unriddled mechanism in the cells"*.

The seeds for the propagation experiments were obtained from two different sources from eBay to ascertain if there is an effect with quality. Each packet contained fifty seeds of ***Phyllostachys pubescens (Moso)***, and these were planted at a ratio of six seeds per tub. The species ***Dendrocalamus giganteus*** was also planted, however, only one seedling emerged, and later died. It averaged that three ***Moso*** seeds would germinate although given the fragile nature of the seedlings; it seems that the success rate further diminishes over time.[61] ***Phyllostachys pubescens (Moso)***, is referred to as a running bamboo, which can be invasive if it's planted in a small area. Therefore, managing such a plant highlights the opportunity for the plants to be grown in large barrels, or tubs, however, establishment will take considerable time. As such, the experiments in growing seeds were undertaken to evaluate the viability of seed germination within an Oceanic environment (Melbourne, Victoria).

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60 Other methods of propagation described by Oprins and van Trier (2006) include propagation from cuttings (36-38) and "Micropropagation through tissue culture" (38-44), at the time of publication, these methods have not been trialed in the development of *"Ajiro"*.

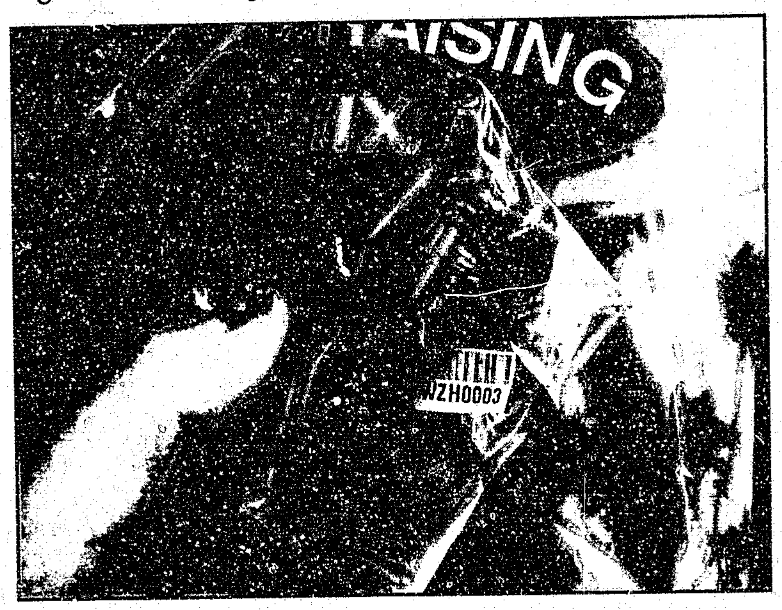
61 Further discussion relating to growing bamboo from seed is referenced in (Lewis and Miles 2007, 30-31), Saporito and Mavition (2010, 7-9)

The following apparent factors which contributed to a seedlings success or failure were encountered during the observations of the germination process:

- Temperature conditions, the germination appeared to occur most vigorously during humid days.
- Some seedlings failed for no obvious reason, or one seedling failed in a container where the remaining seedlings were healthy.
- Rainfall – too much rain resulted in over saturated tubs, which seemed to rot the seed material, greenhouse tests where the seedlings were covered with cling wrap resulted in an over moist condition, when fresh air was introduced, the seedlings rotted.
- Soil quality – the peat pellet germination mixture appeared effective for initial germination, however sustaining the plants in this mixture alone resulted in some seedlings forming a nutrient deficiency, evident in the yellowing of the leaves.
- Pests – some seedlings obtained mite infestation, resulting in erosion of the chlorophyll from the leaves.

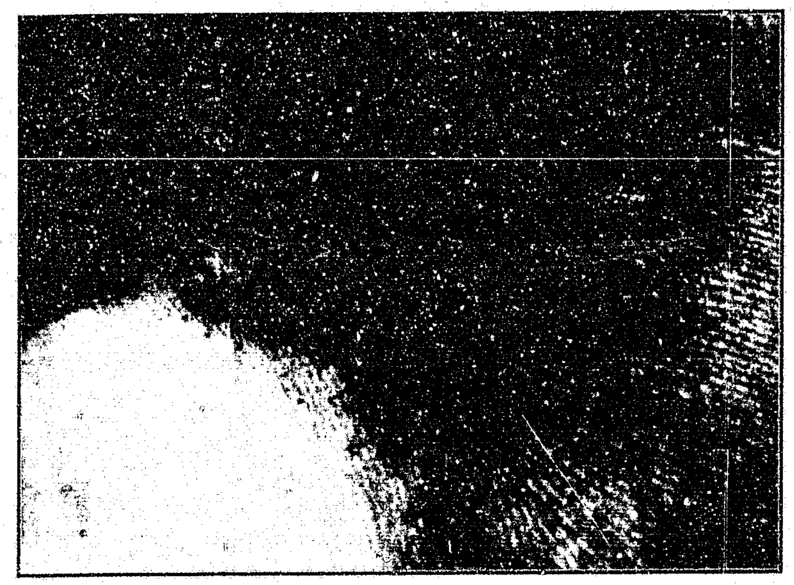
Encounters from seed and cutting propagation are detailed in ***Figure 34a-h***.

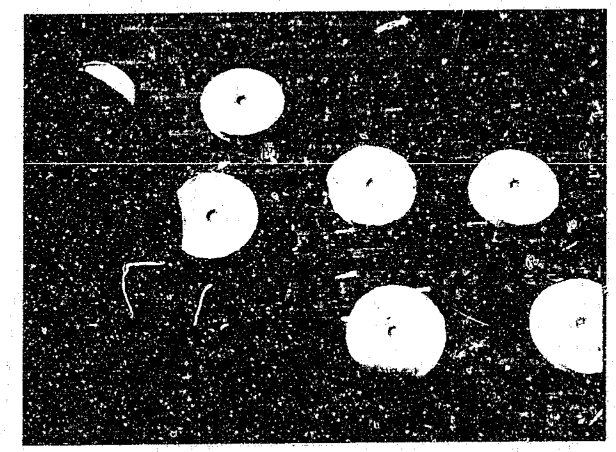
Figure 34: Growing bamboo from seed (a) - Images grouped

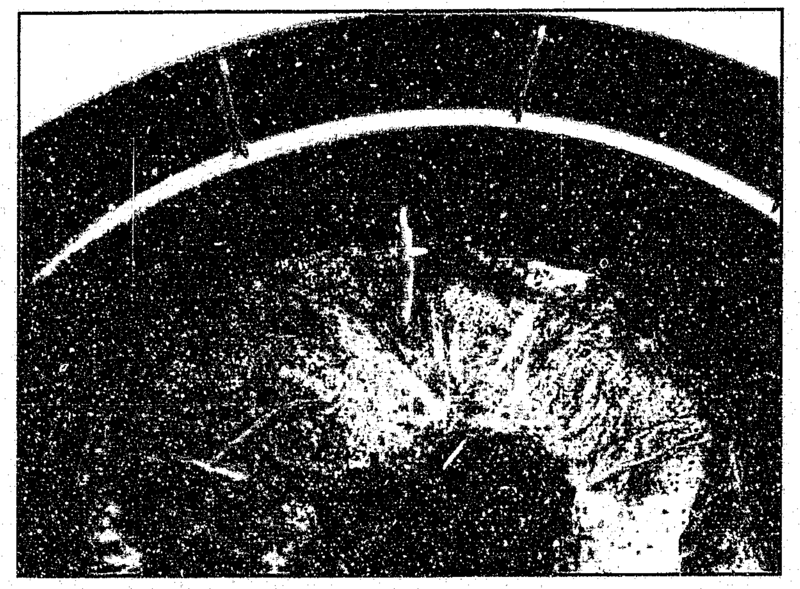


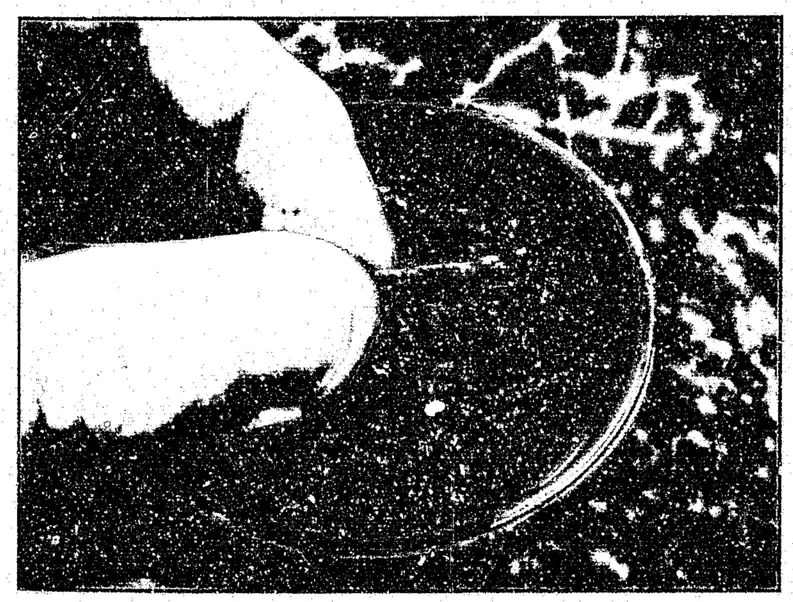
The packet of seeds from eBay source. The seeds were soaked for a period of 5 minutes in salt water, as per instructions included for seed raising. The seeds were planted in 'Peat Pellets' to serve as initial tubs. These compressed peat tubs expand when water is poured over them.

Figure 34: Growing bamboo from seed (b) - Images grouped



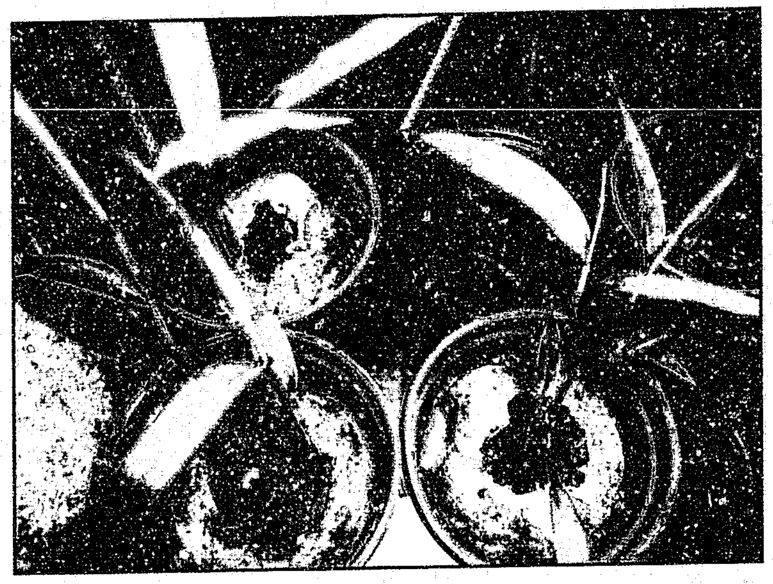


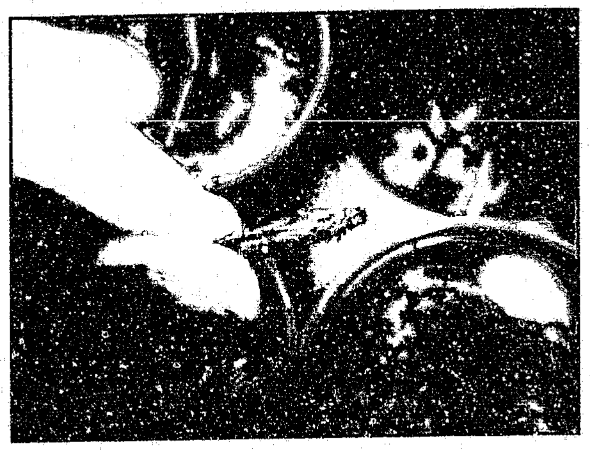


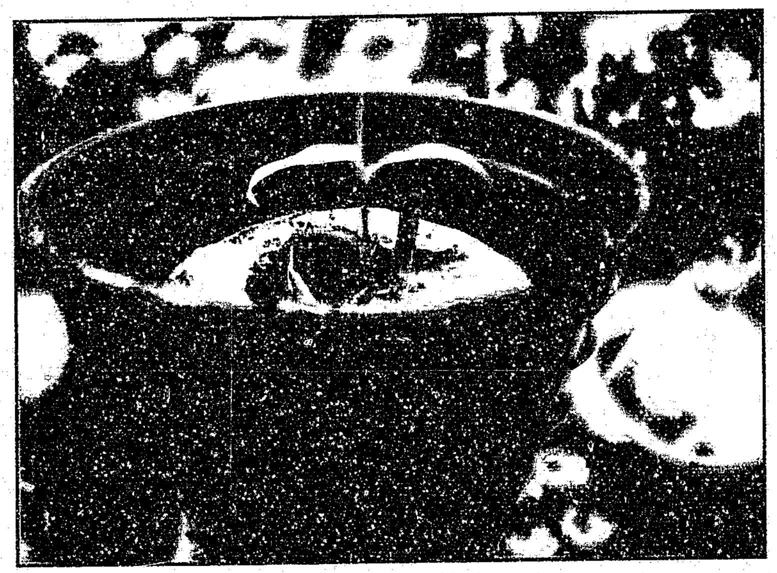


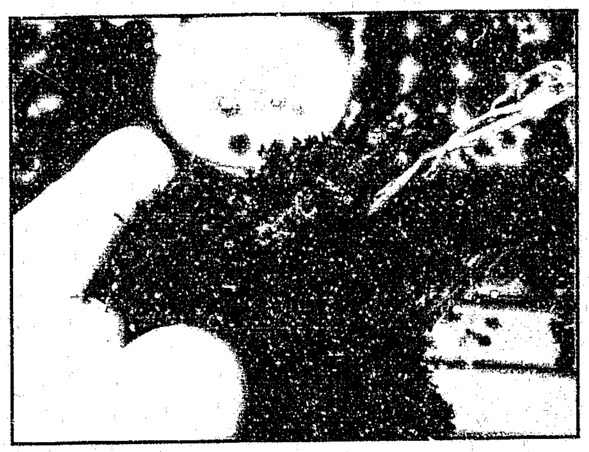
Examples showing Moso bamboo seedlings. Notice the emerging root from the seed, and the small new seedling emerging through the fibrous material on the peat pellets.

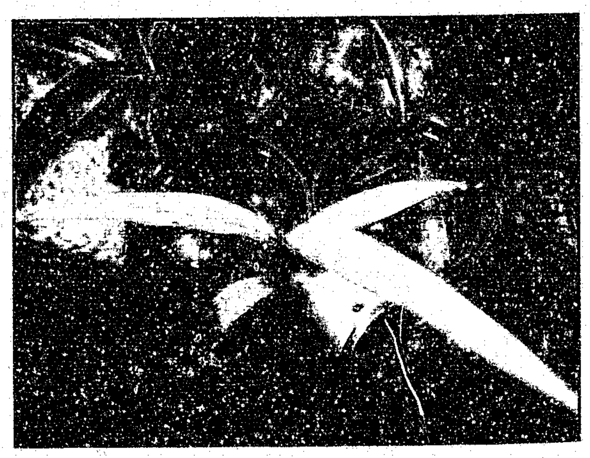
Figure 34: Growing bamboo from seed (c) - Images grouped







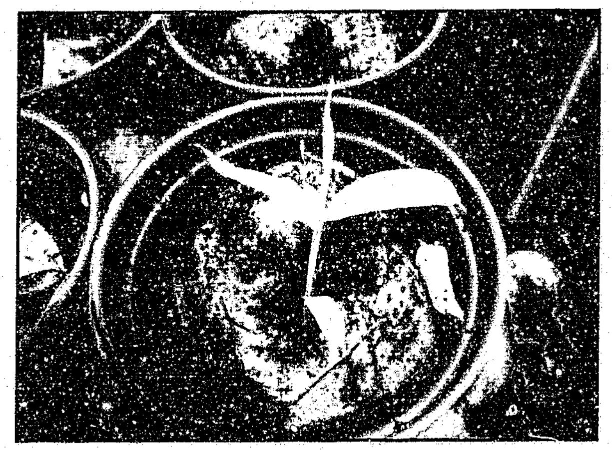


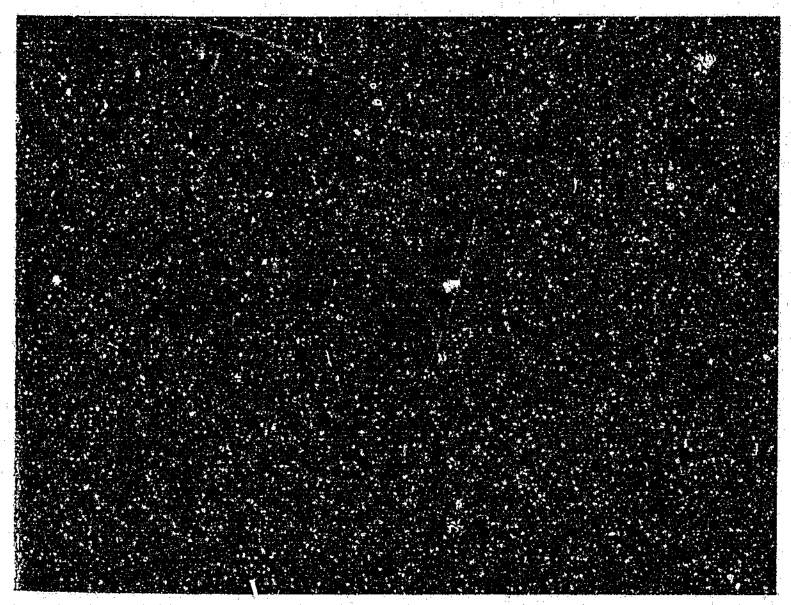


These images illustrate some of the complications that arose in seed propagation of ***Moso*** and ***Dendrocalamus giganteus.*** Complications included seed rot, fungal attack, mite infestation attacking leaves, and nutritional problems.

Other seeds appeared to fail without any of these factors.

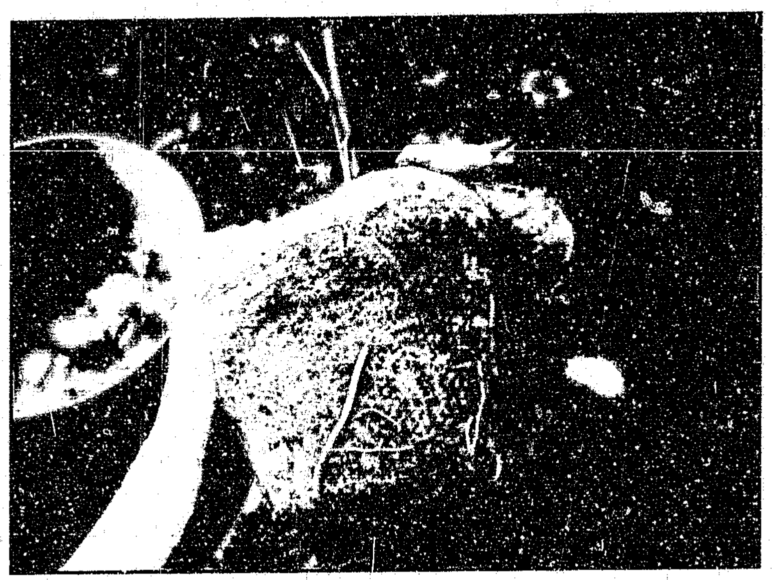
Figure 34: Growing bamboo from seed (d) - Images grouped

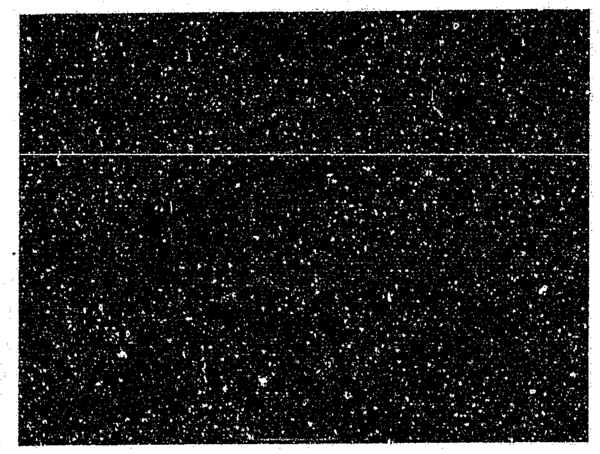


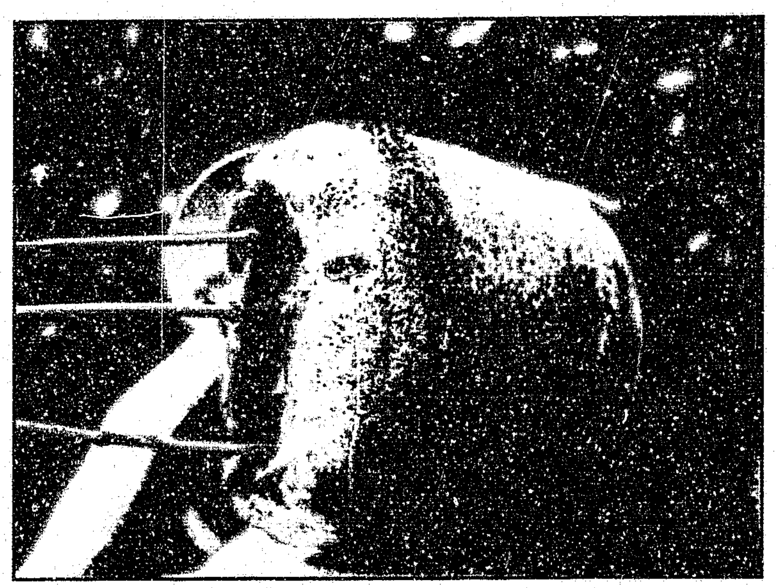


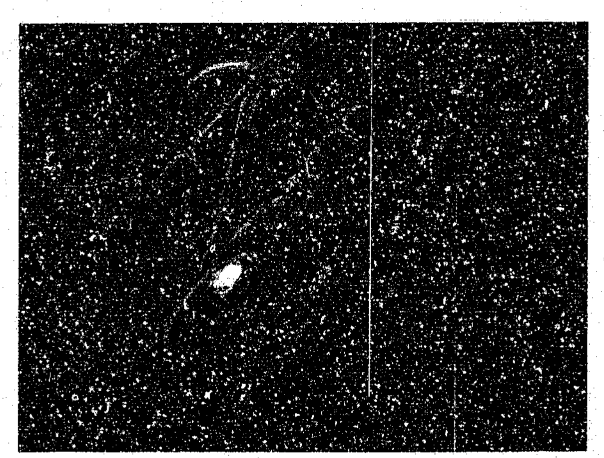
Leaf yellowing of ***Moso*** bamboo seeds. Success and failure of these seeds present a challenge for recommending the natural process for early material growth, yet also highlight the fragility of nature, which humans can control successfully only to a certain degree.

Figure 34: Growing bamboo from seed (e) - Images grouped





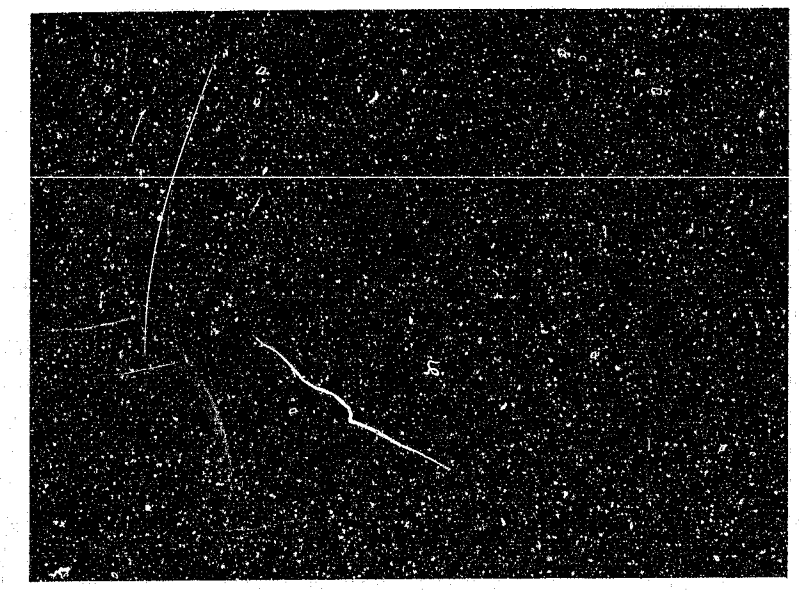




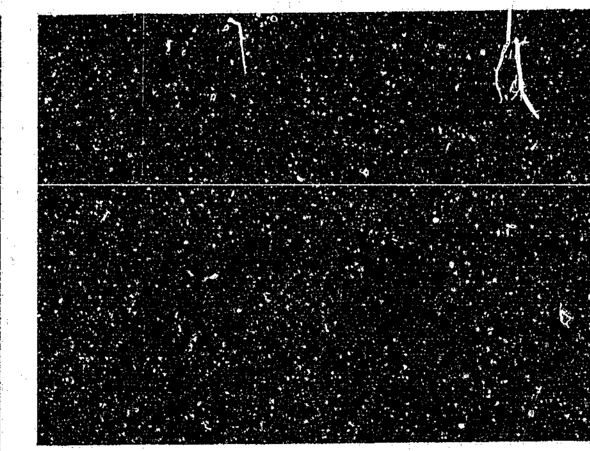
Plants that died during the seedling trials.

The roots of the seedlings were vigorous, and soon outgrew the original peat pellet tubs.

Figure 34: Growing bamboo from seed (f) - Images grouped



Leaf burning during hot weather in Summer 2011.



Pest infestations.

Leaf erosion due to mite infestation during warmer months.

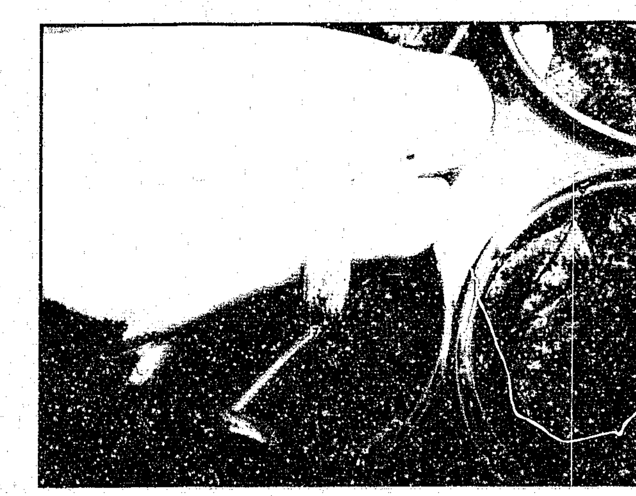
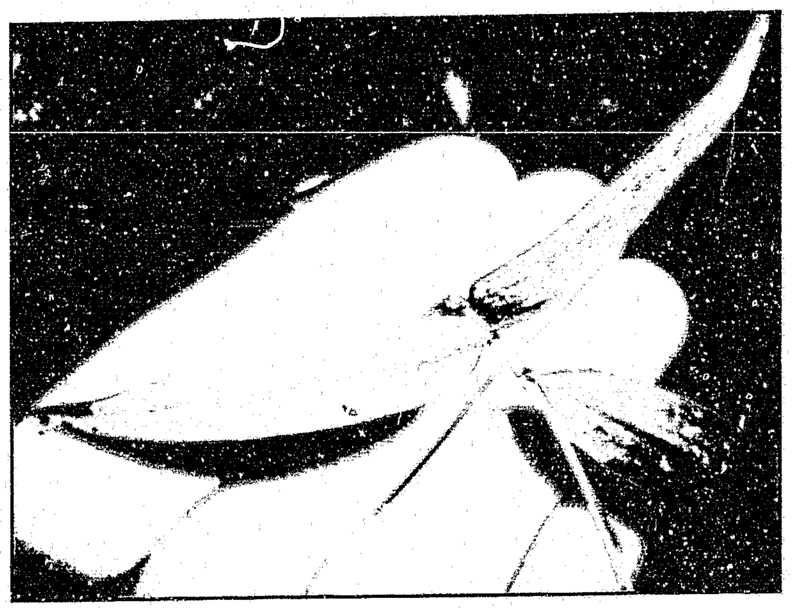


Figure 34: Growing bamboo from seed (g) - Images grouped



Parasite infestation had to be treated with Bayer Confidor insecticide.

Splitting rhizomes of ***Bambusa Multiplex*** (originally 2 plants, after splitting, 4 plants).

New culms emerging from seedlings. Every new culm that emerges appears to be thicker and stronger than the previous.

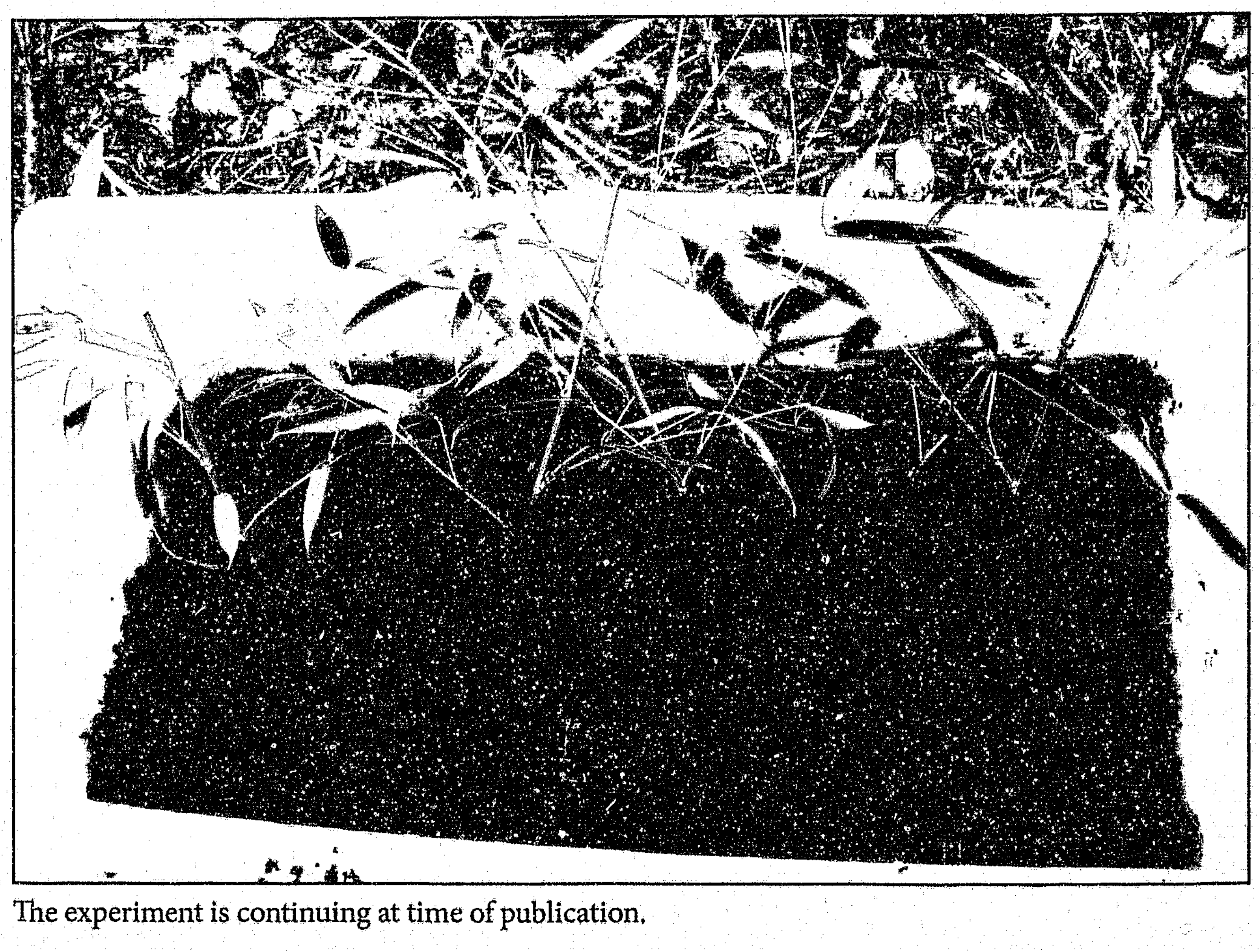
Figure 35: Propagation by bamboo cuttings (a) - Images grouped

Cutting section and preparing for propagation. This method is described in detail by Rana (2001).

Filling culm ends either side of the node with soil.

Figure 35: Propagation by bamboo cuttings (a) - Images grouped

Rana (2001) recommends sealing the ends with fresh cow dung, however I have substituted this with plasticine.



The experiment is continuing at time of publication.

Bamboo
Taiwan

H

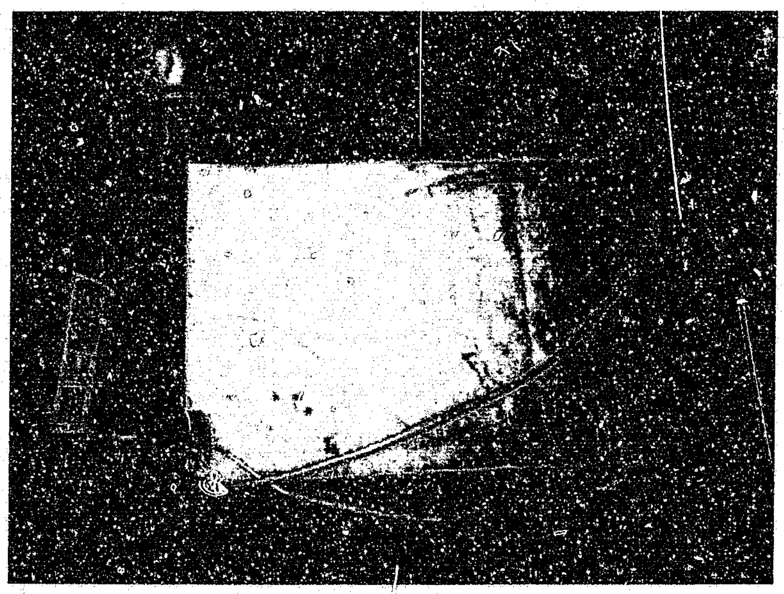
Development of a prototype to support the visual and functional attributes of the hypothesis.

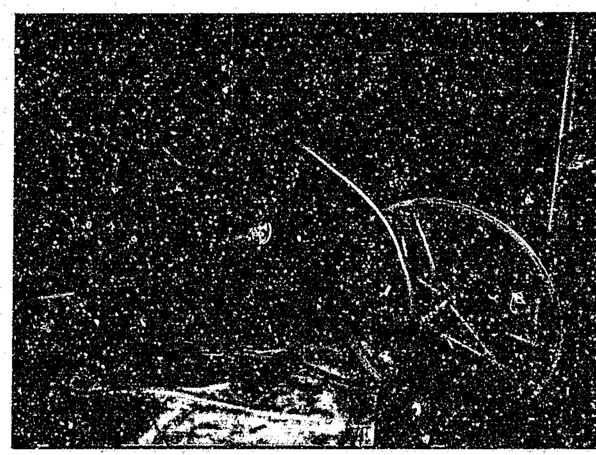
Appendix H: Prototyping development of "Ajiro" concept

The following section describes the logs of the prototype builds, and the resulting modifications ***(Figure 36a-p)***.

- Initial shape testing performed in 12 and 16mm aluminium tubing. Bent using hand manipulated pipe bender to dimensions specified by the CAD output.
    - After the initial full size build, it was established that the structural qualities of aluminium would not be sufficient to adequately evaluate the structure. The amount of flex at the rear wheel attachment was significant when full body weight (51kg) was applied to the midpoint of the frame.

Figure 36: Prototyping development (a) - Images grouped





Aluminium version bent with small hand pipe bender, relative to proportion initially developed in 1:1 2D CAD drawings. This version was used to gain general proportions, and refine how the structure would be self-supporting.

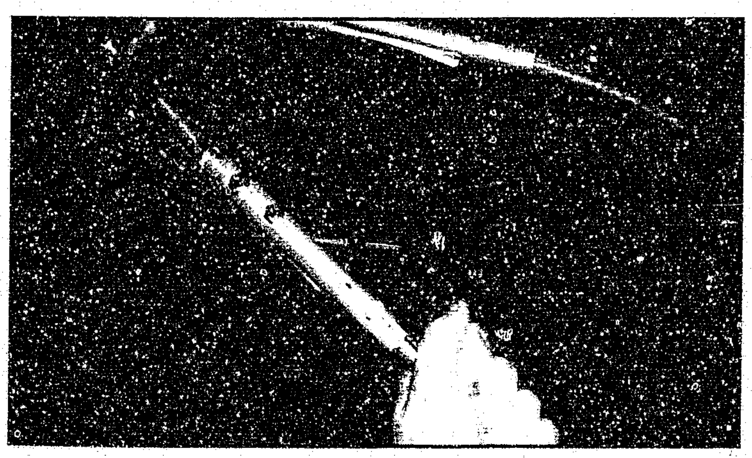
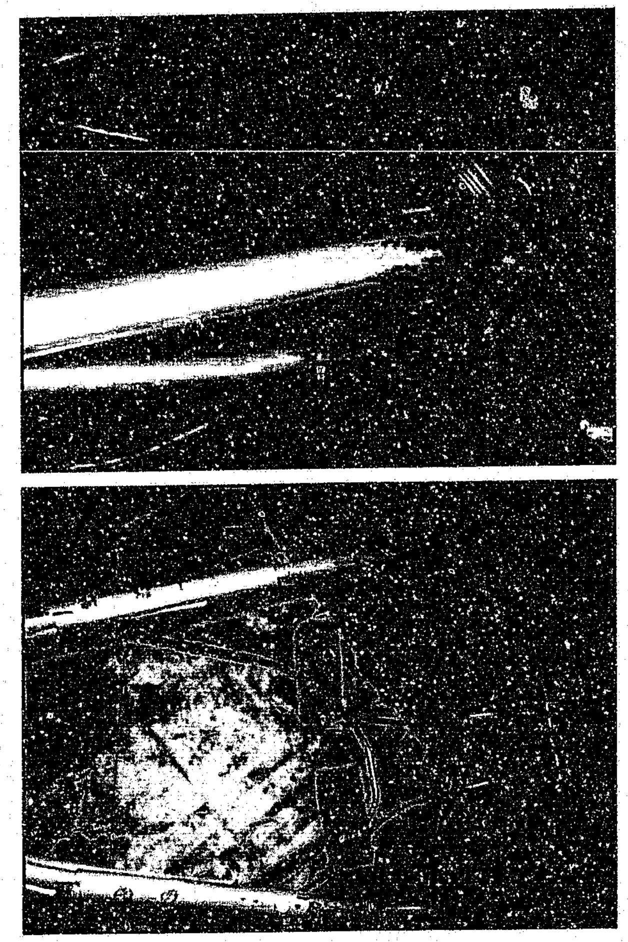


Figure 36: Prototyping development (b) - Images grouped



Front windscreen section profile in aluminium, bolted, slip over joins using larger diameter aluminium tubing.

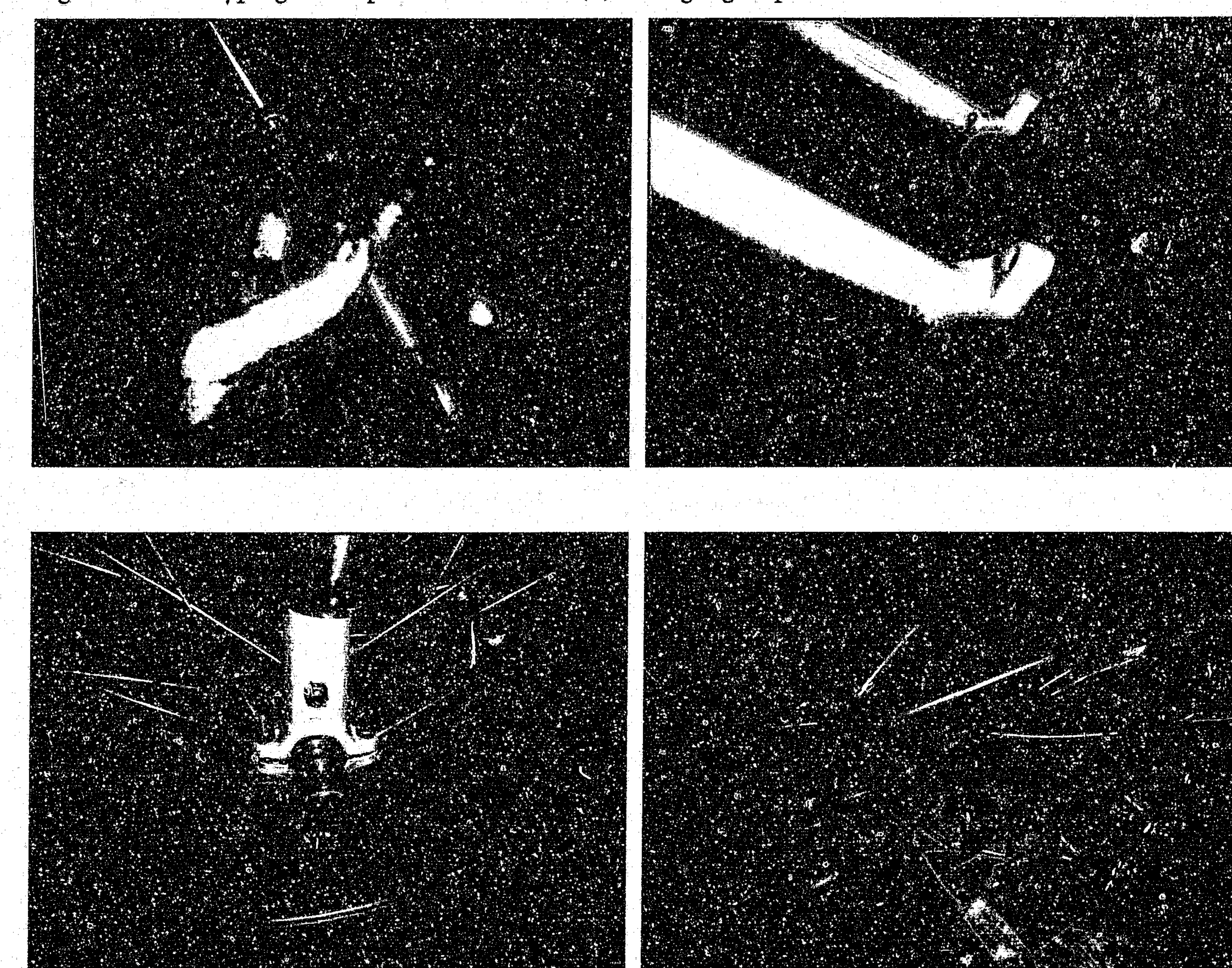
- Revision of rear end dimensions to bring rear wheels inboard.
    - The rear wheel section becomes permanently deformed easily when the wheels are at a significant side angle. By straightening the rear wheel section, there seems to be less flex in rear

Figure 36: Prototyping development (c) - Images grouped

Wheelchair wheel attachment directly to hollow pipe frame.

- Modification of small rear wheels to facilitate the steering mechanism for the rear.
    - The nature of the available manufactured castor wheel parts seems to permit several design issues. It appears that the offset nature of the wheel axel being different from the top mounted wheel pivot, allows 'self- centering' of the wheel assembly, but when performing unintended modifications to the unit by adding a steering mechanism, the wheel does not pivot in a satisfactory manner. Pivoting on one side produces a different wheel angle to the opposite side.
- Sourcing of front wheel attachment method – using fork from a unicycle
    - To facilitate the simple drivetrain specification, sourcing the wheel of a unicycle fulfils the general specification of containing the drive in a self-contained unit. Whilst lacking in multiple ratios, the fixed drive should adequately describe if the vehicle is able to be moved through the pedalling action.
- Revision to make parts out of steel

Figure 36: Prototyping development (d) - Images grouped



Unicycle direct drive front wheel fork and attachment.

Authors notes from trial of vehicle:

The integrity of the vehicle seems to be reasonable in supporting full body weight. The alternating sections of steel, e.g. 19mm/16mm/19mm – allow for a degree of adjustment in the one meter sections. The U-bolt joins between the sections adequately compress the tubular steel pipe to the other sections; however, the sections are troublesome to align correctly.

The 'on road' trial, conducted on a bicycle path, demonstrates that the rear track of the vehicle easily fits within the lane width on the track. Whilst the tracking of the vehicle follows a reasonably straight path, the steering mechanism with the pull/push lever, is prone to unwanted movement with any corrugations in the road surface. It seems that any bumps are easily transmitted to the linkage, and cause the vehicle to veer off course. Correction of such phenomenon requires very slight and precise movements of the lever, which is very difficult to achieve smoothly.

The sensation of the rear wheel steering proves to be an interesting factor with the cornering. The sensation produced is somewhat 'out of control', yet the vehicle doesn't physically appear so. It is apparent that the stability of the vehicle can be a little tipsy if attempting to corner at a speed greater than an average walking pace.

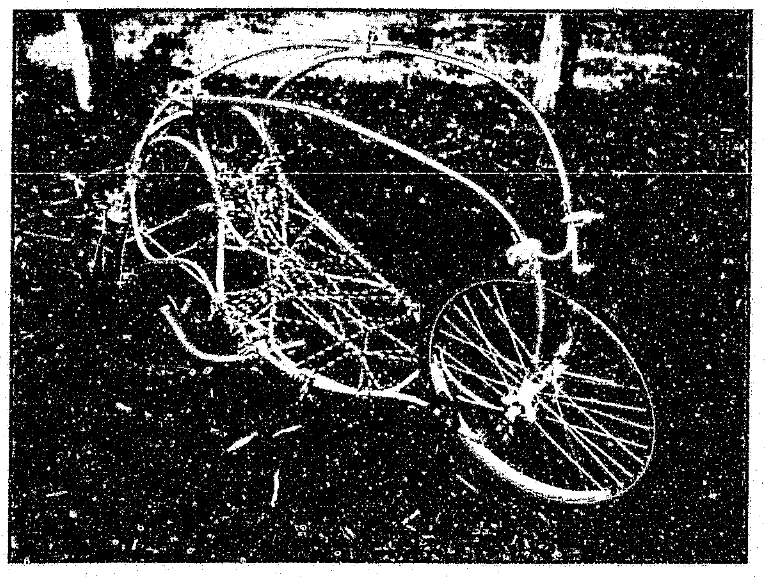
It could be advantageous to trial a wider rear track, or altering the rear wheel camber to seek improvement. Attachment of the front wheel to the side rails proves problematic. The bracket which clamps the front wheel bearing is difficult to attach. Presently, the solution is somewhat ad-hoc, using formed sheet metal to form a t-shaped union which is then compressed onto the tubular metal sides with small U-bolts.

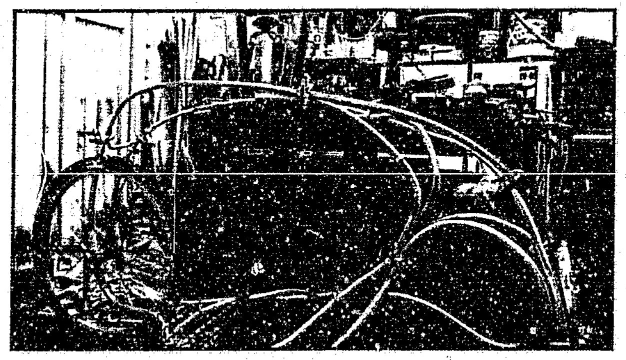
The difficulty with this method is the small U-bolts cause physical interference with the front wheel spokes and present a challenge for proper compression to the tubular sections. This method results in some wheel wobble when applying power to the front wheel – especially evident upon climbing gradients.

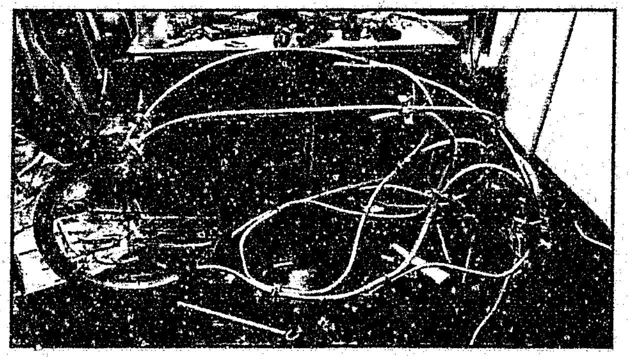
The clearance relative to the pedals causes some rubbing, and it has become apparent that sourcing a front axle with increased dimensions could be troublesome.

The overall power from the vehicle is quite impressive. In the trials conducted, power from standing start could easily be applied and small gradients could be climbed. Given the large wheel diameter of 24", the average speed is reasonable, approximating 14km/h when cruising with reasonable pedal speed.

Figure 36: Prototyping development (e) - Images grouped

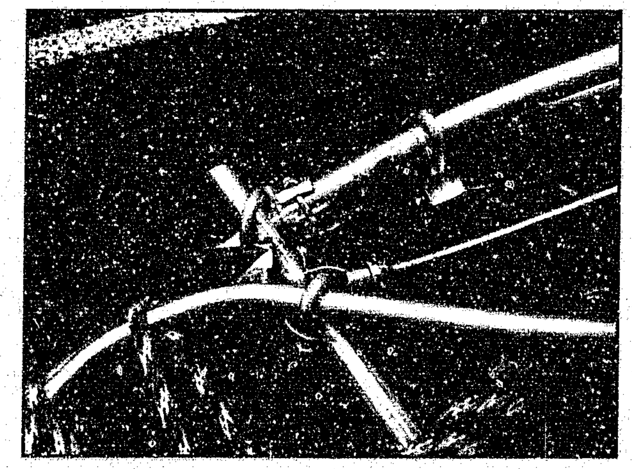


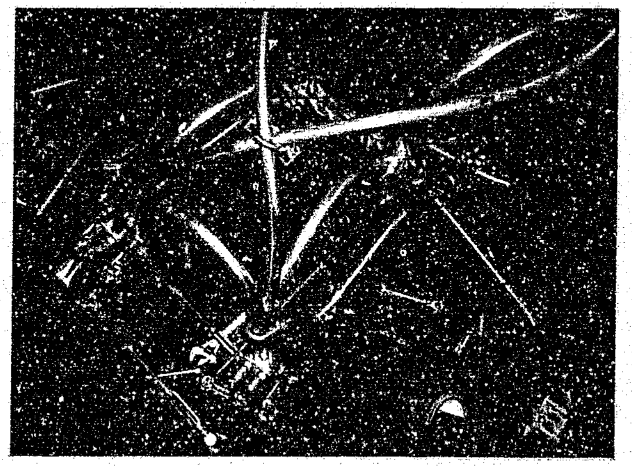




Steel version with U-bolt clamps joining the sections. This method allowed parts to be swapped and reshaped by hand easily.

Complex or long sections were extremely difficult to manipulate in the hand operated , hydraulic pipe bender.





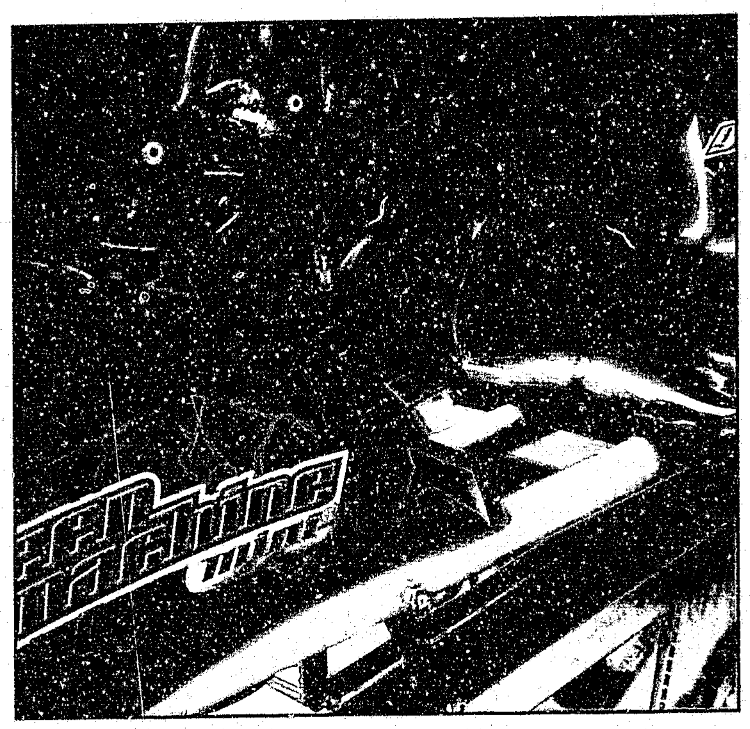
Steering attachment.

Front wheel attachment bolted to frame.

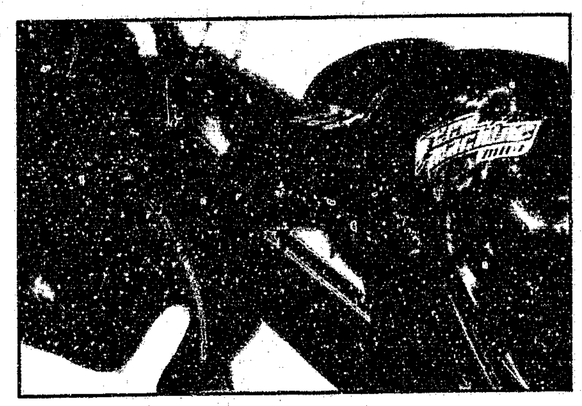
Rear bracing loop, bridging seat structure and rear end of the vehicle.

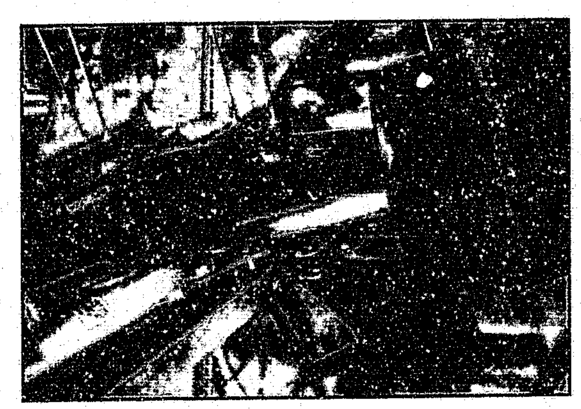
The elements of the 'rear wheel steering' mechanism are reflected in the ***"Huffy Green Machine"*** linkage setup whereby the pivot is placed in the middle of the vehicle spine. Another variant of the Green Machine uses pivots on both sides of the vehicle. This setup would be ideal as the bamboo could act as the linkage for a swivel bearing to be pressed in.
Twin pivot steering linkages were noticed on a ride-on lawn mower as well.

Figure 36: Prototyping development (f) - Images grouped

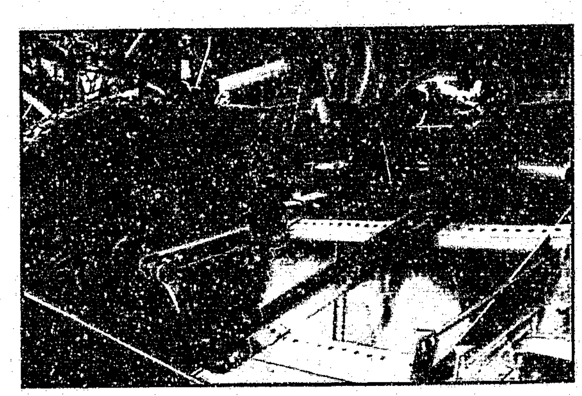


Huffy Green Machine rear wheel steering, with push-pull linkage mechanism



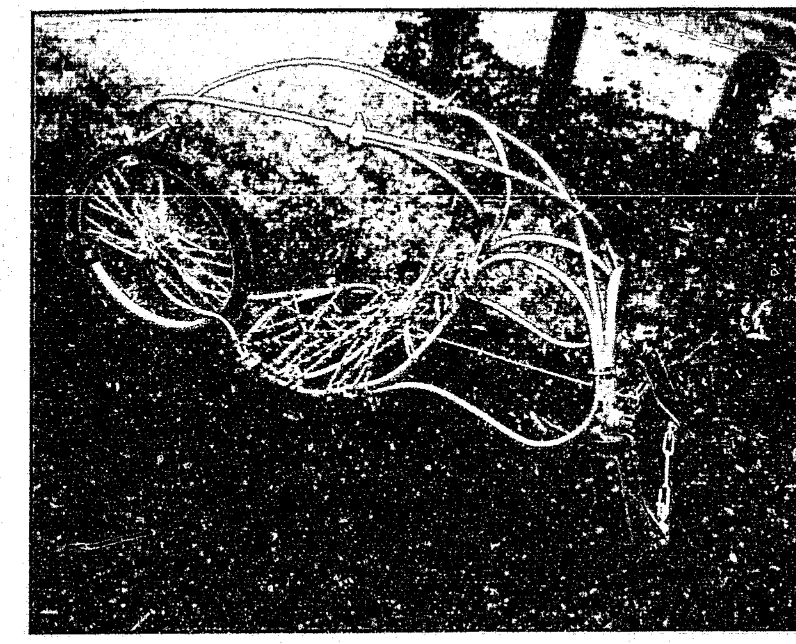


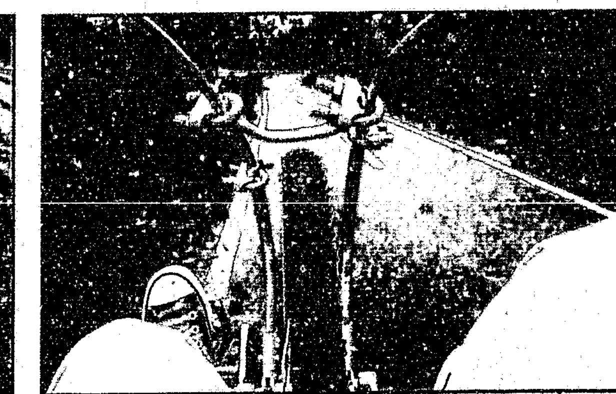
Ride on lawn mower twin bar pivot linkage steering mechanism.



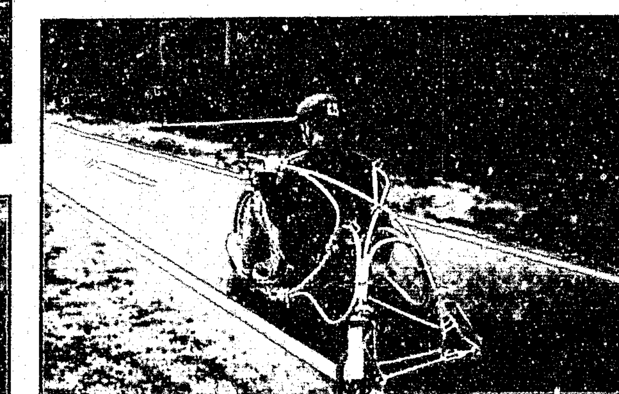
Alternative rear wheel steering trike, with separately pivoting rear wheel linkage.

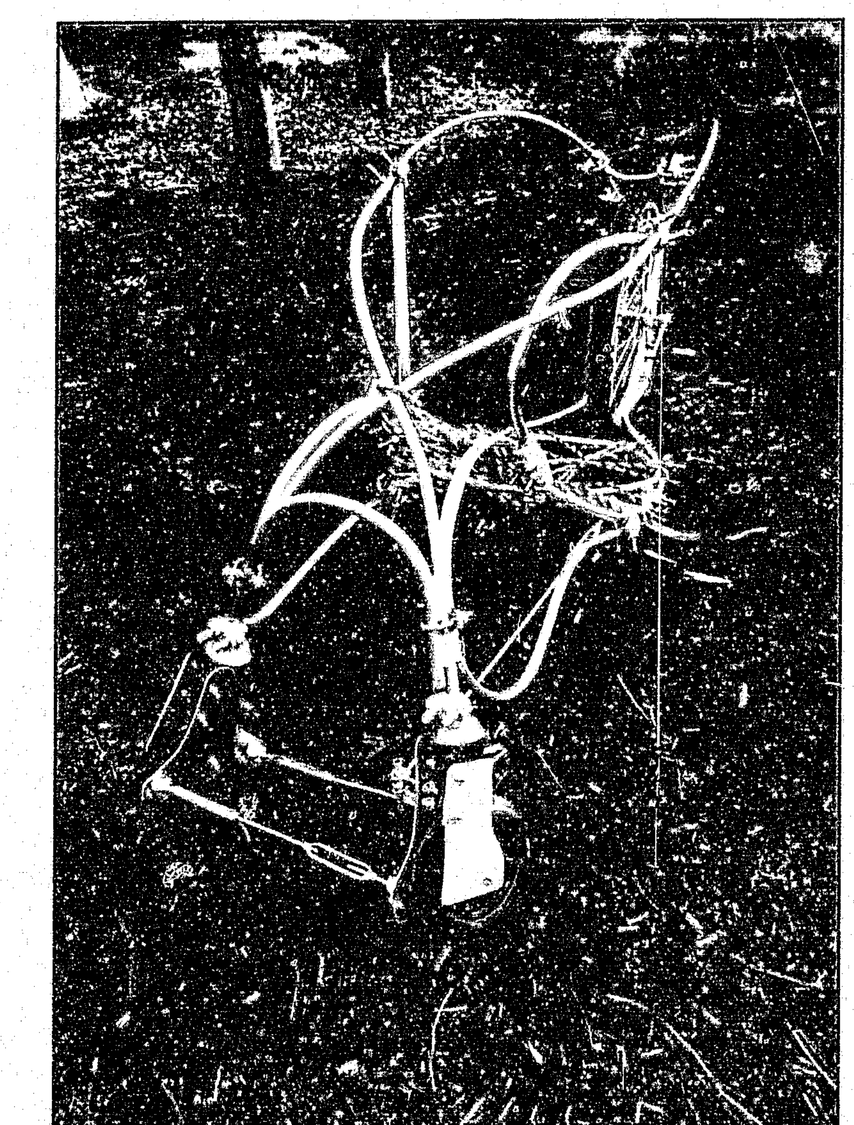
Figure 36: Prototyping development (g) - Images grouped

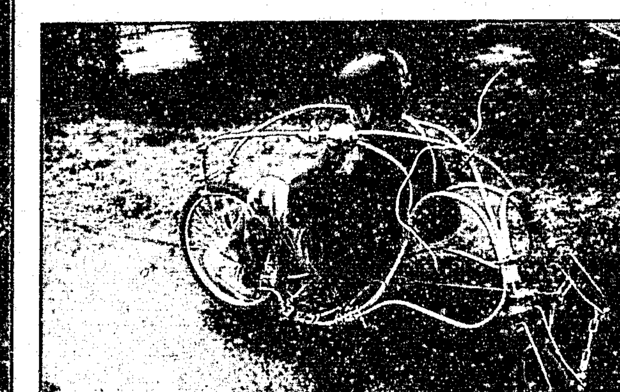


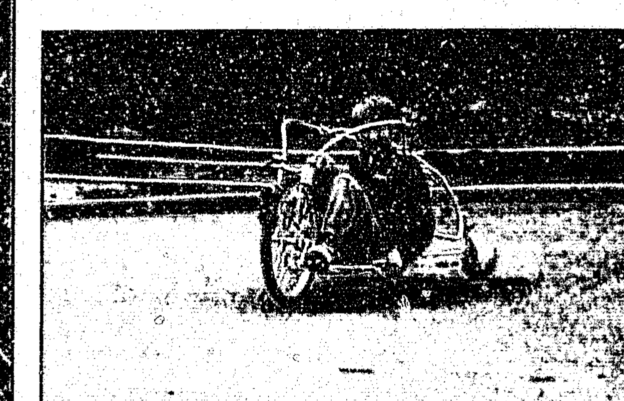


View from front wheel.









Demonstration trials of rebuilt version from steel. The seat threading tension was varied in order to find a suitable riding position.

- Revision of rear section to take body weight over rear wheels to reduce flex
- Revision in body clearance from ground
- Revision of cross over point in seat section
- Revision of vehicle height to allow more head clearance
- Revision to steering mechanism
- Revision to vehicle width

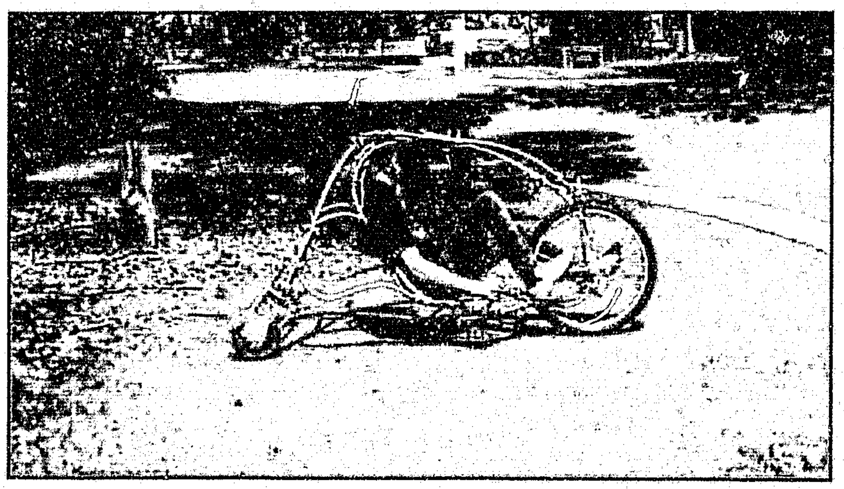
Authors notes on vehicle prototype test:

The revisions to the steering mechanism have proved to increase the confidence of the riding experience. While the spring setup provides little 'return' feedback, or self- centring, the tension of the springs provides resistance to the lever moving when set to straight ahead. From trialing some cornering, this resistance allows finer control of small movements and the lever isn't as prone to jarring movements from road corrugations.

Even with the increased width, stability is still a reasonable concern, though aided by leaning in the opposite direction of the steering input.

The height of the vehicle, whilst increased over the previous revision, needs an additional 10cm of clearance to cope with helmet size.

Figure 36: Prototyping development (h) - Images grouped



Rebuild with enhanced clearance, proportions and realigned steering mechanism and pivot points.

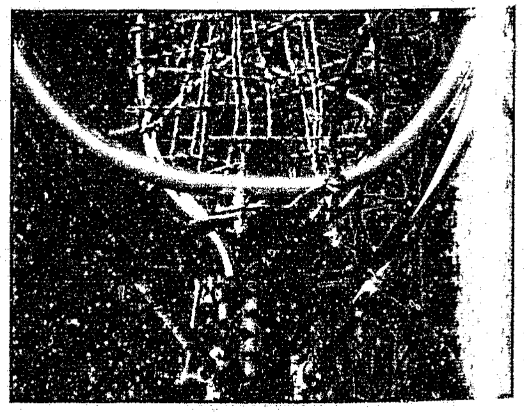
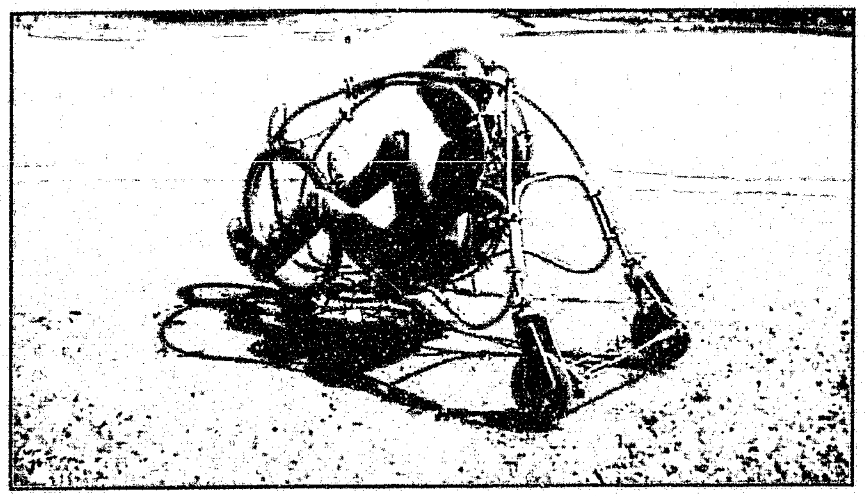
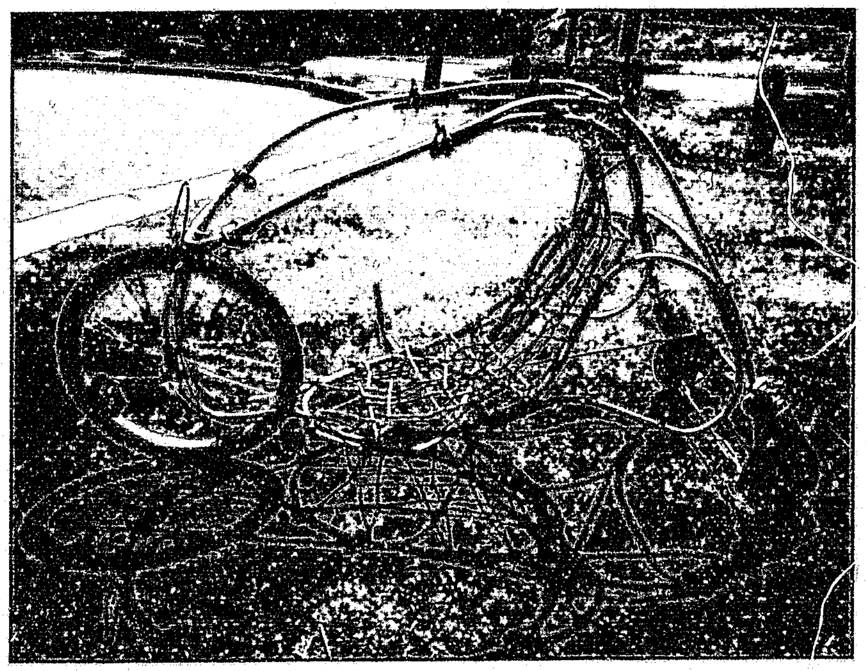
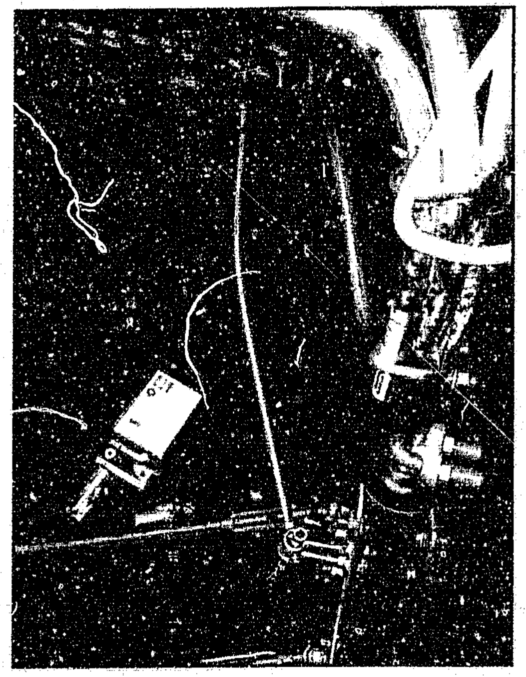


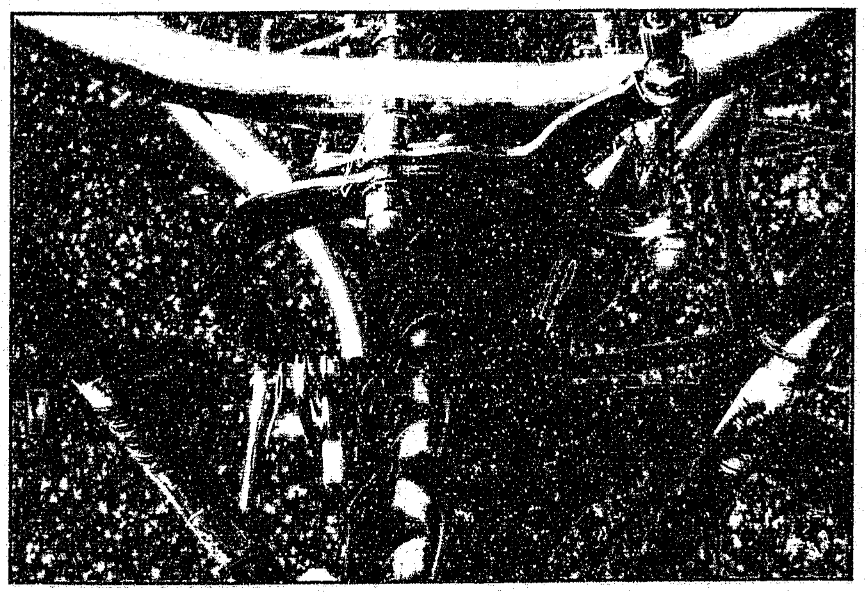
Figure 36: Prototyping development (i) - Images grouped





Steering mechanism deformed under stress from testing. Revision was made to reinforce the link with an external metal sheath.





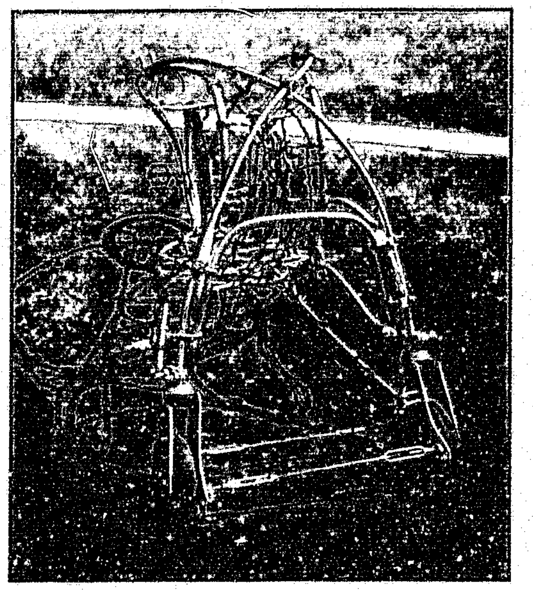
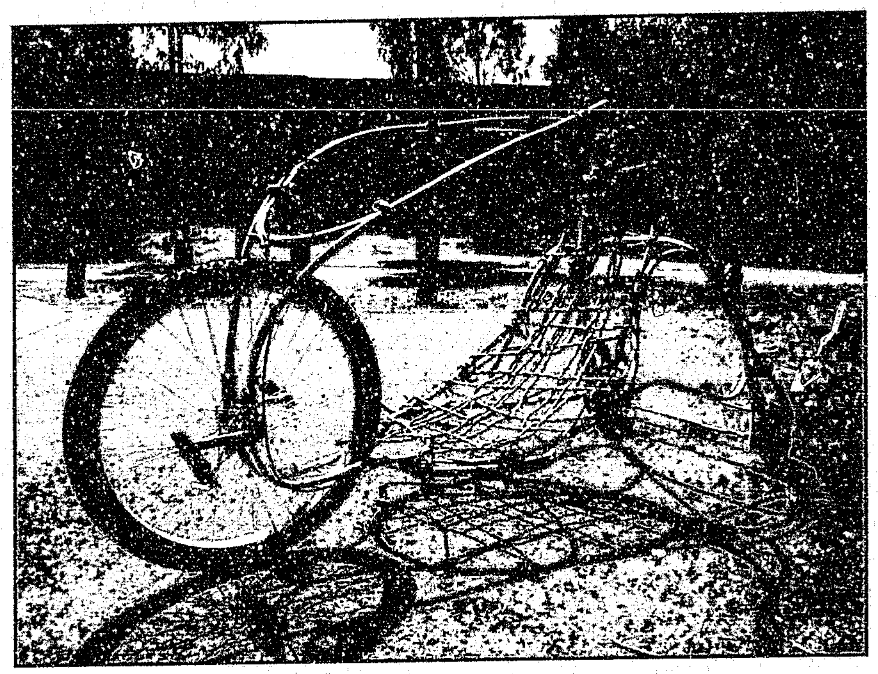
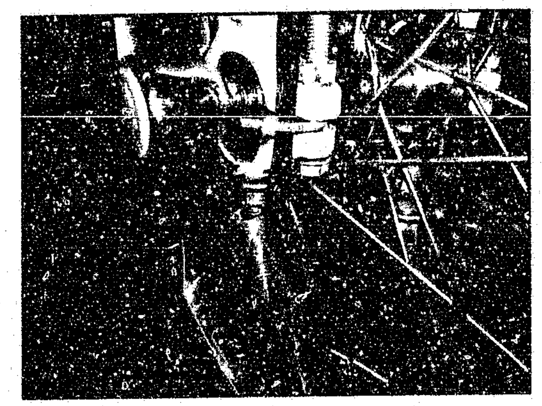
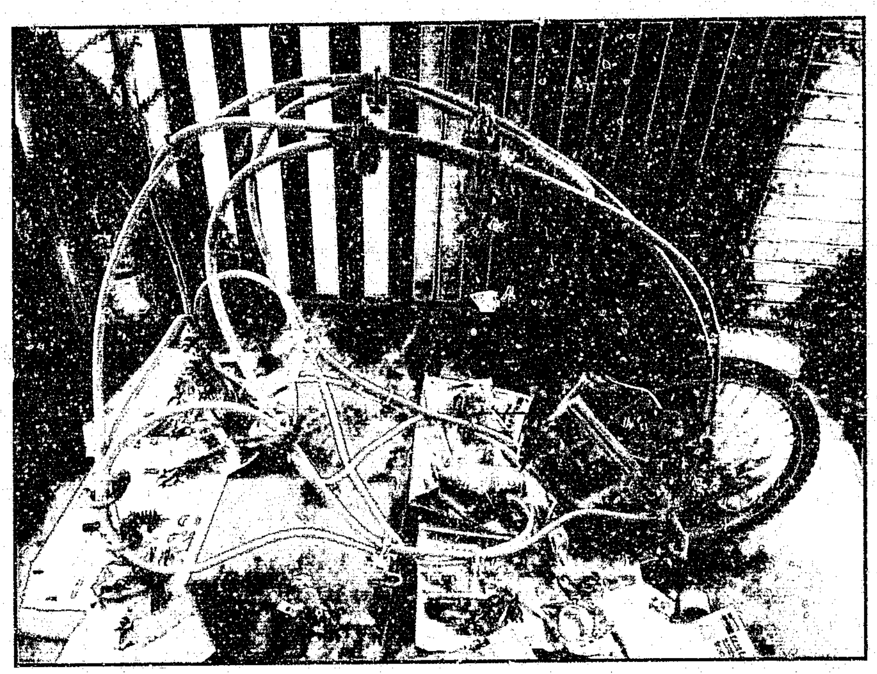
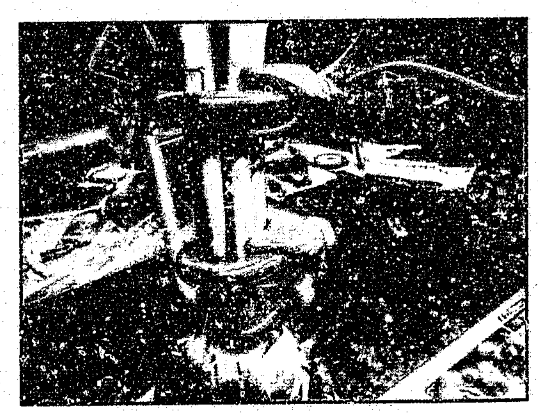


Figure 36: Prototyping development (j) - Images grouped



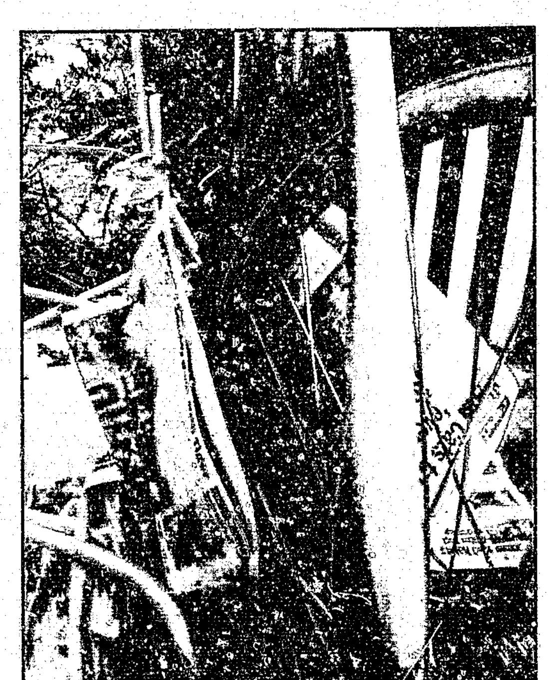






U-Bolts/wire rope grips were powder coated for uniform appearance and to prevent corrosion. The process is able to recover wasted powder for filtering and recycling, creating little wastage.

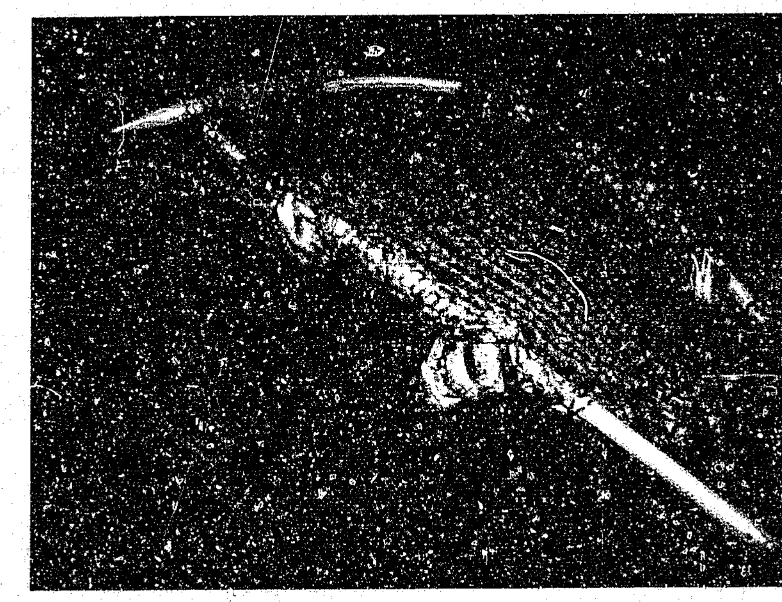
The revised frame was painted to provide similar protection of the surface and provide reasonable likeness to the intended bamboo proposal.

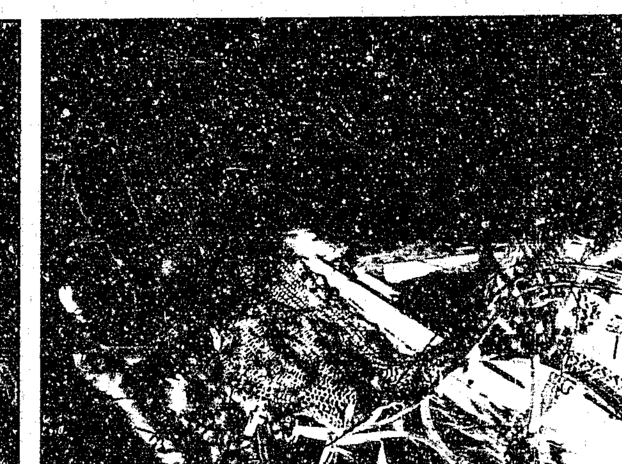


The crank set casing was blended into the steel frame with woven fibreglass mat and epoxy resin after a bolt was secured through the tubing to minimise unwanted alignment changes. A similar composite wrapping method could be used to attach metal parts to bamboo - a technique demonstrated in other bamboo bicycles.

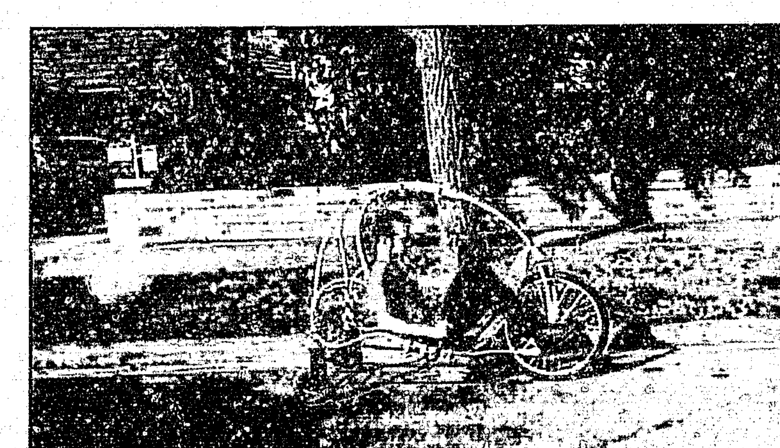
- Revised attachment method of front wheel, bolted and fibreglass wrapped
- Unicycle brackets welded to side frame sections, rear section from one long steel pipe, added additional height to the vehicle
- Seat and canopy moulding made from knitted jute yarn

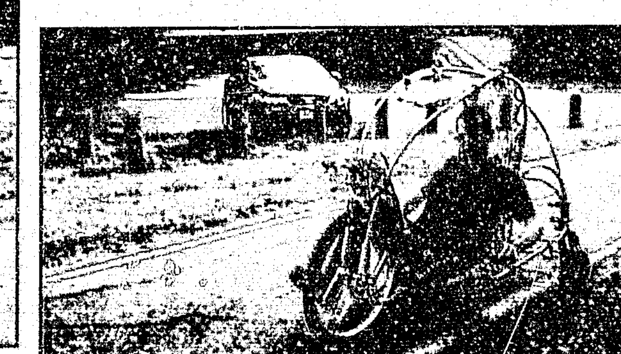
Figure 36: Prototyping development (k) - Images grouped





Roof canopy base in the form of a knitted substructure was measured to conform to the shape of the roof and seat width variations.

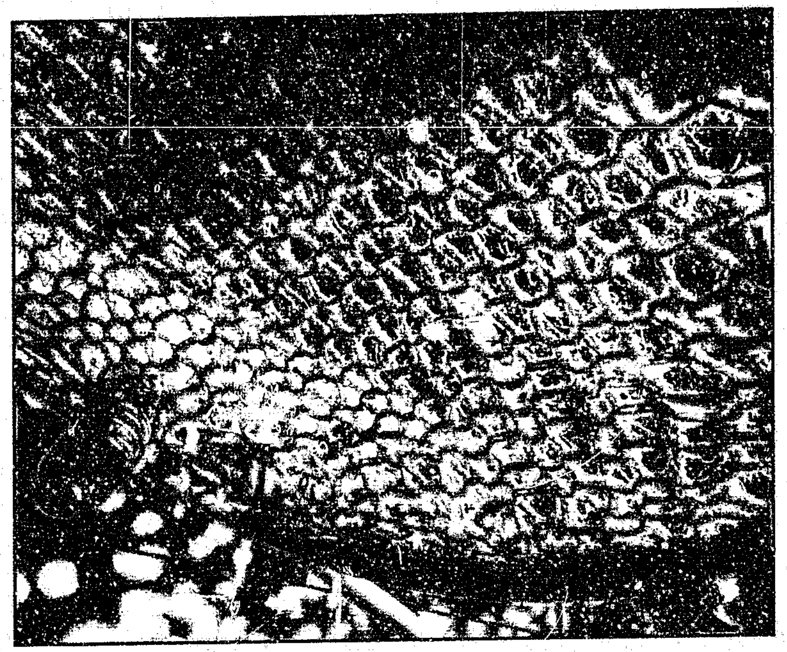
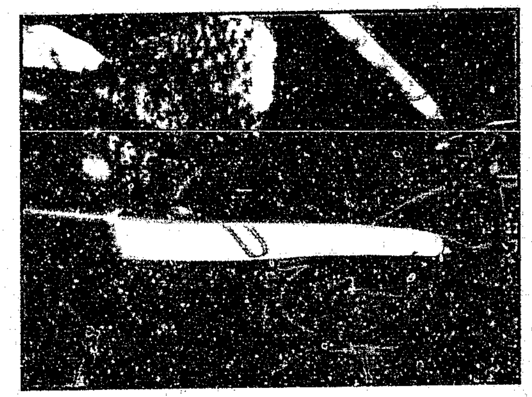


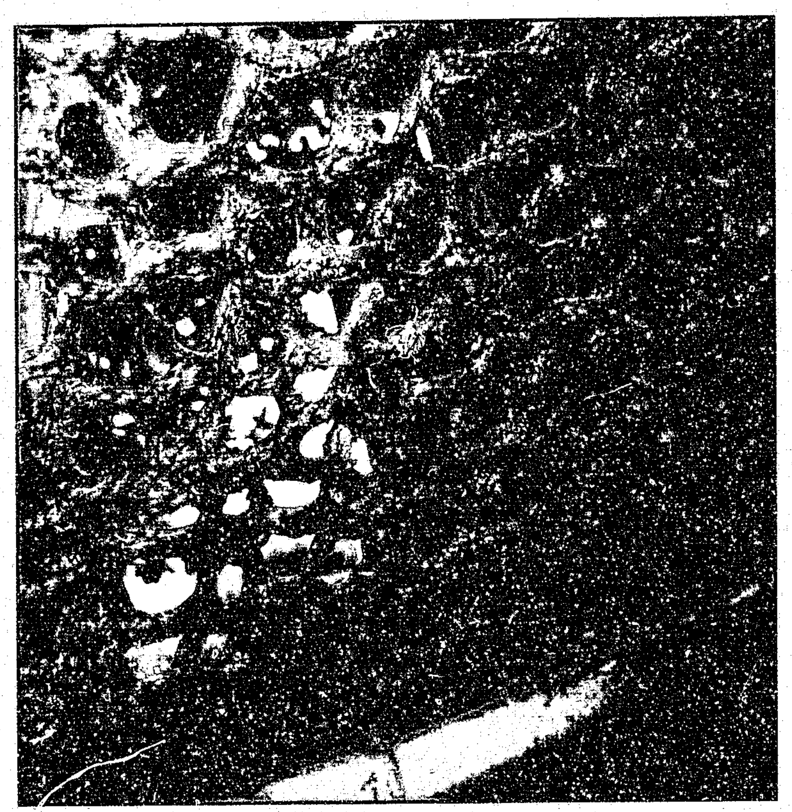
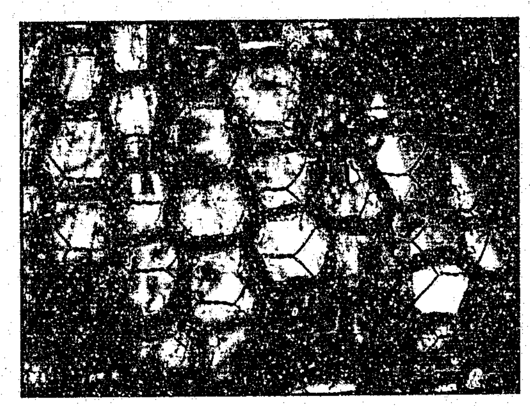
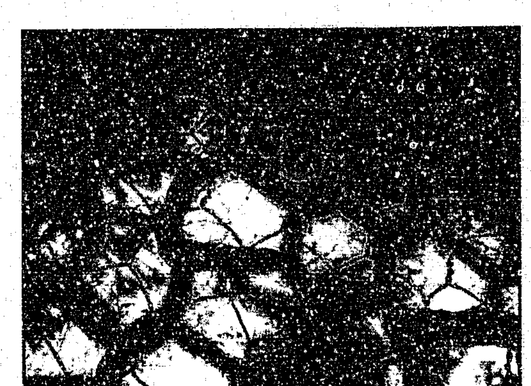


Knitted canopy cover from jute formed the front wheel guard, seat and roofing cover in a single piece.

The revised rear wheel pivot and 'upright' linkage seemed to reduce bending angle stress from seated weight.

Figure 36: Prototyping development (l) - Images grouped

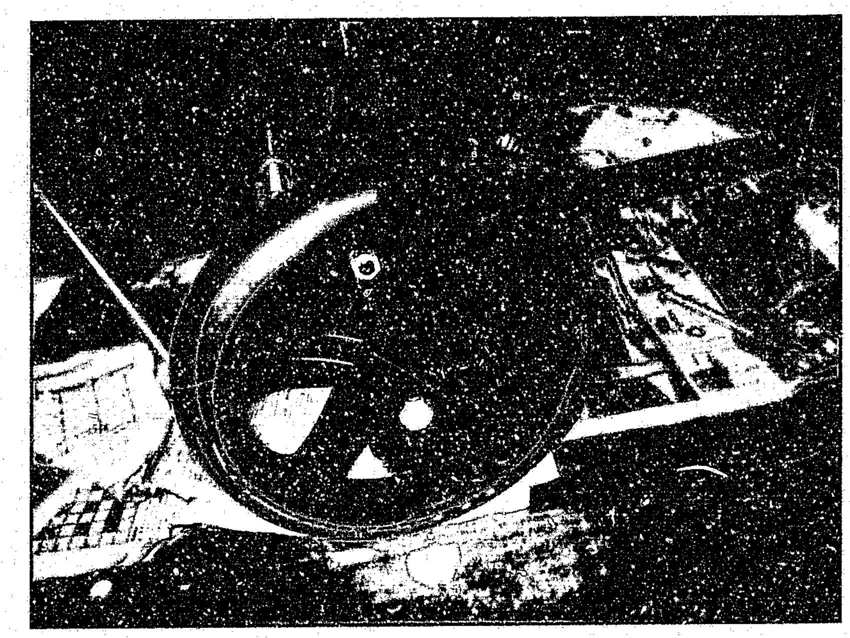




The knitted canopy developed a tendency to sag over a period of time, due to dampness from storage outside. To create a 'fuller', and shapely cover, a chicken wire mesh was added underneath, with a grease proof paper separator included between the knitted fabric and the wire. Epoxy resin was brushed over the fabric and allowed to soak in, before forming a hardened layer.

Removing the wire mesh allows for a shape to be set into the fabric, while heating the surface significantly with a 'heat gun' allows the shape to be re-moulded, and the set again using a cool, damp cloth.

- Revising wheels to use lighter 10" polyurethane scooter wheel
- Revised front wheel with freewheel mechanism, respoked from 20" Huffy Green Machine wheel to a 24" rim.
- Testing of new revision; vehicle showed improved stability with tighter steering return spring and steering axis running through the centre of the rear wheels.

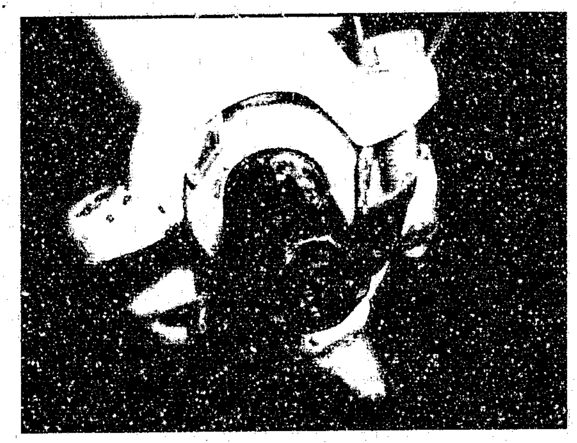
Figure 36: Prototyping development (m) - Images grouped

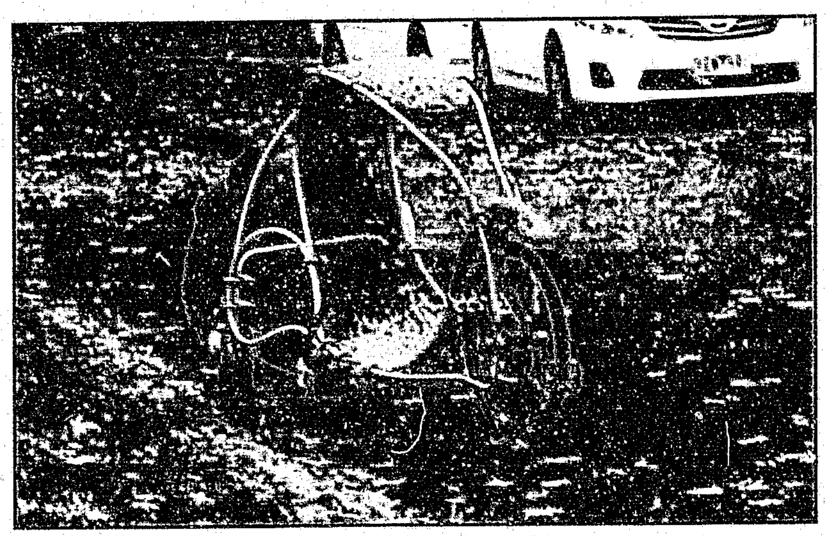


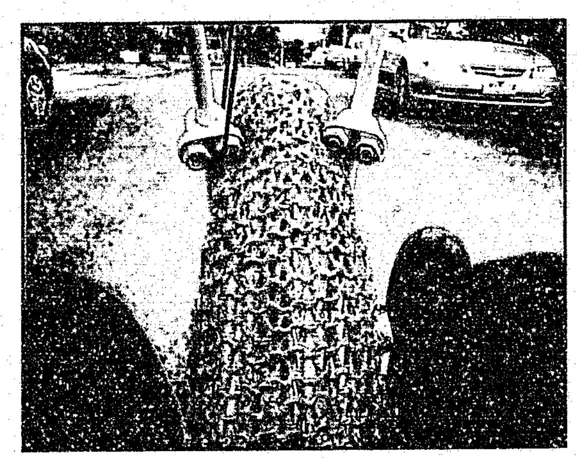


New 10" scooter wheels were lighter than the previous wheel chair wheels, and the hard nature of the material seemed to provide better steering response in testing, with a trade off of higher levels of road surface (bumps, undulations, and loose gravel/dirt) transmission to the rider through the frame linkage.

Figure 36: Prototyping development (n) - Images grouped

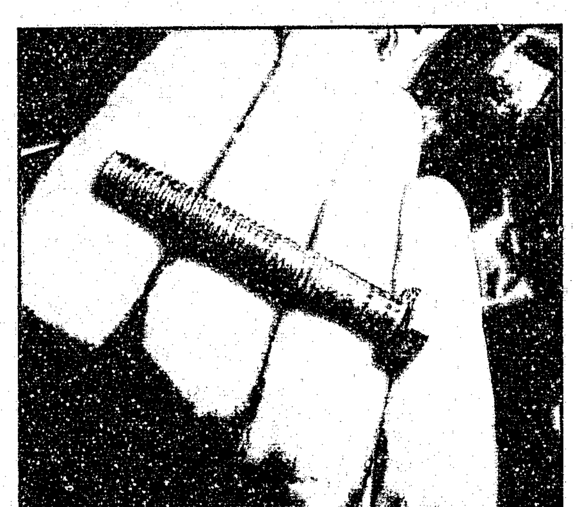






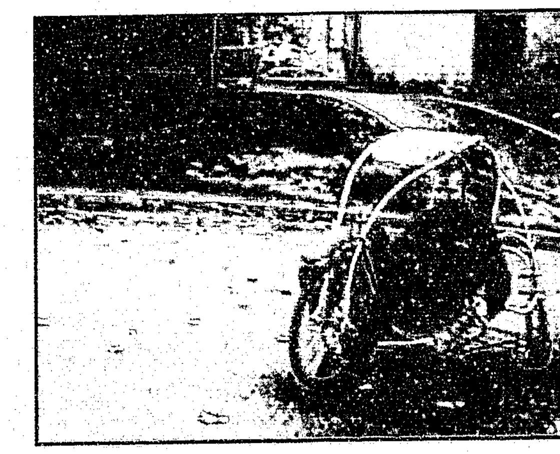
Some materials available commercially through hardware stores proved inadequate for 'industrial' use under stress.

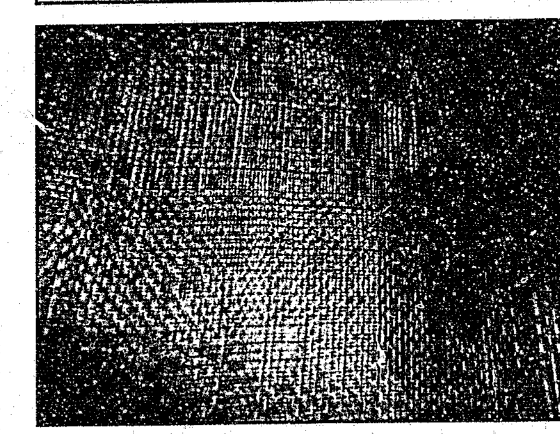
The quality of the metal used had an effect on how many times the part could be removed/retensioned before wear (such as thread stripping on bolts) or complete failure (bolts deforming and breaking under stress - especially in the rear wheel attachments).



- Rear basket for plant canopy
- Apply more resin to seat; introduce greater curvature to seat base and lip for seat sides
- Revised and repainted vehicle due to wear and markings from the ridden trials.

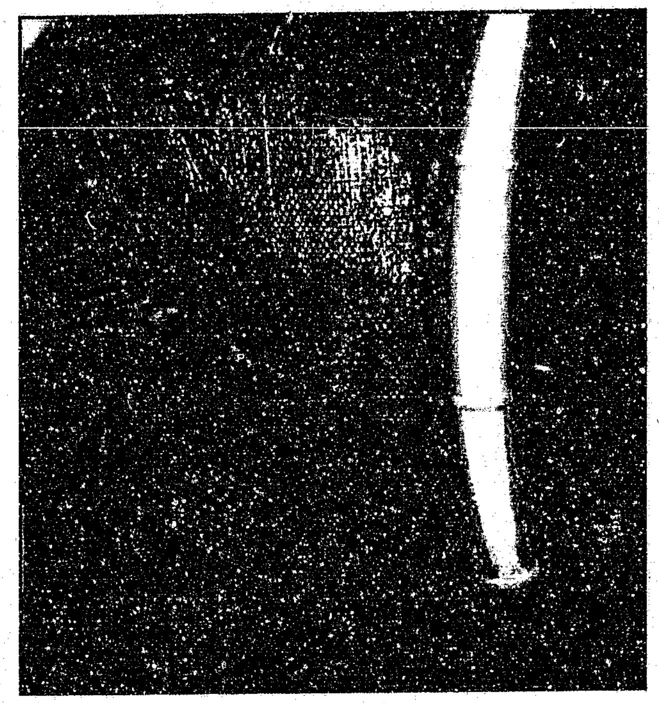
Figure 36: Prototyping development (o) - Images grouped

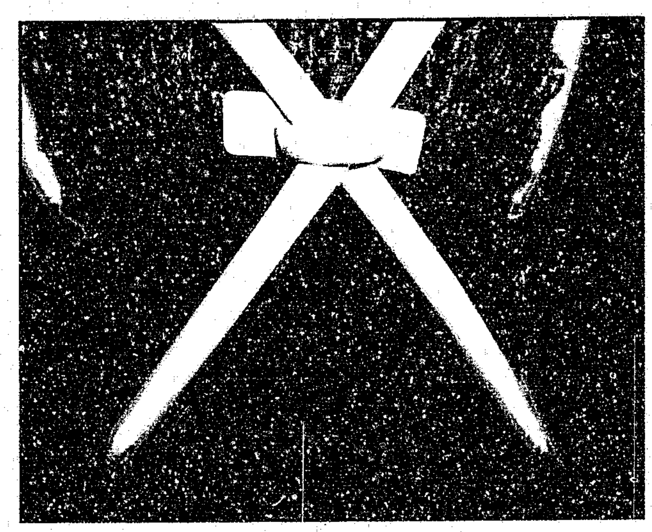


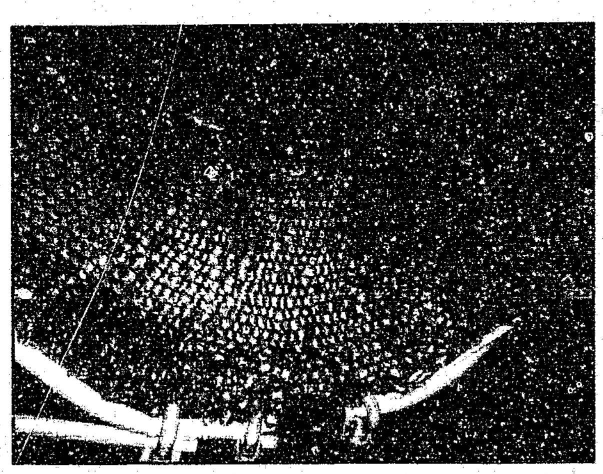


Firstly, the desired shape was formed in cardboard, hot glued at the edges, then covered with greaseproof paper to act as a mould release for the epoxy resin, which would coat the banana leaf fibre woven cloth material.

Figure 36: Prototyping development (p) - Images grouped

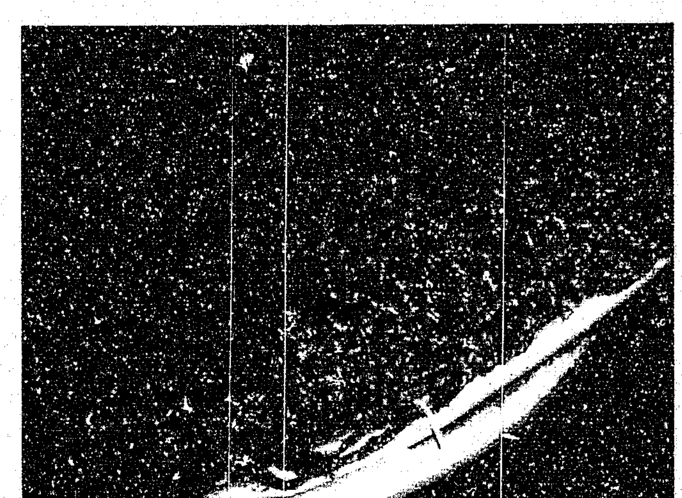






Resin applied to side regions of the seat to offer a more contoured shape. Once 'set' the final shape could be manipulated by warming the region with a heat gun, then using a damp cloth to re-harden the area.

The idea for the plant container is a draft representation, the banana leaf fibre cloth hardens quite well with resin application, but doesn't appear to 'soak' the cloth mesh as readily as traditional fibreglass.



Details of the fabrication process for a scale model to represent the intended design outcome.

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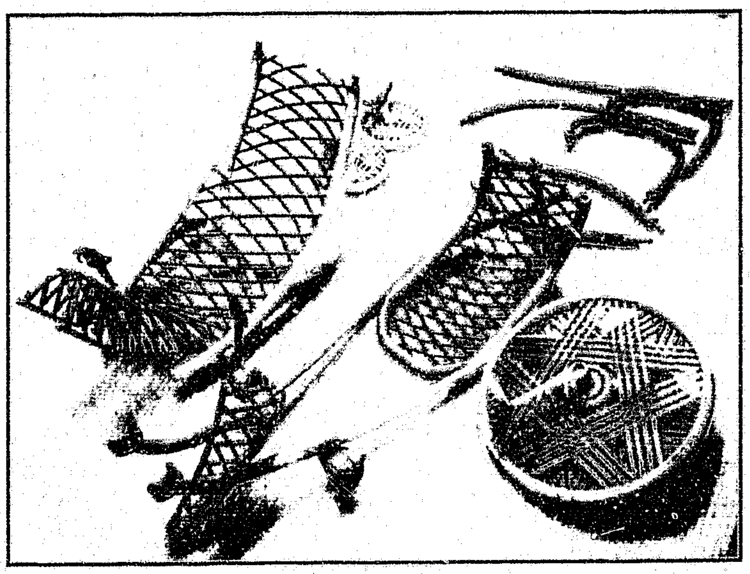
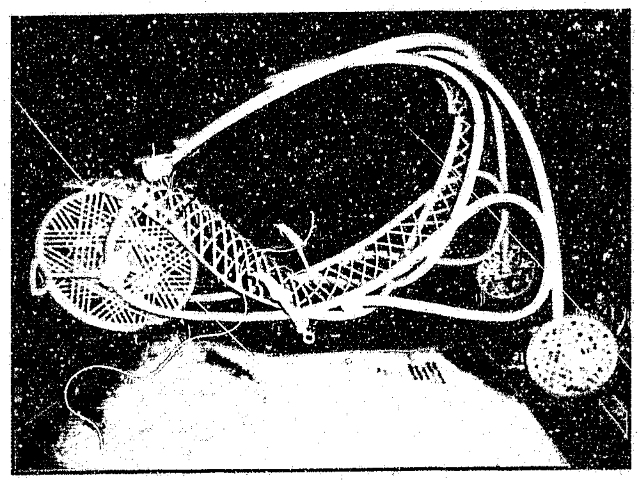
Appendix I: Fabrication of Scale Model

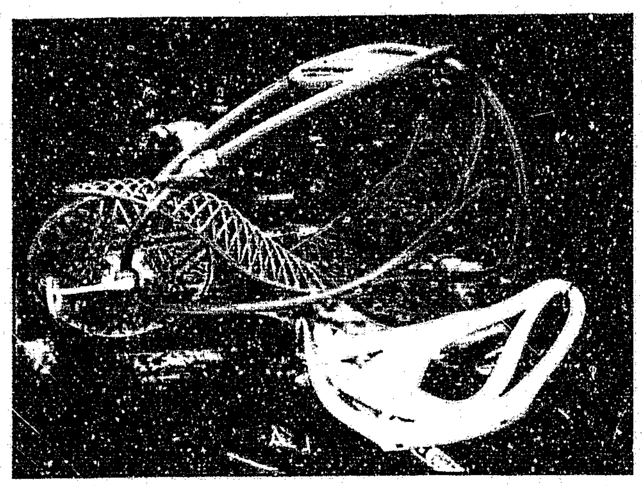
To provide a suitable indication of the intended resolution of the 'Ajiro' project, a scale model was produced ***(Figure 37a-d)***. The full size 1:1 parts were reduced to 1/4 scale, and produced used a rapid prototyping process. Due to the open nature of the design, it would have been inappropriate and costly to produce the vehicle as a single, as the printed parts require support material to surround the hardened, core parts. Therefore, the parts were split into sections, with oval shaped keyed connectors to accurately join and align the parts. Suitable offset of 0.2mm was included on both side of the part keys, to facilitate adequate amounts of adhesive (JB-Weld epoxy).

Figure 37: Scale model (a) - Images grouped





Individual parts with keyed connectors.



Once joined with adhesive, the connected sections were filled with spot putty, and primed. Once wet sanded, the body was masked off and painted. The wheels were painted separately, then attached to the main frame during final stages of assembly.

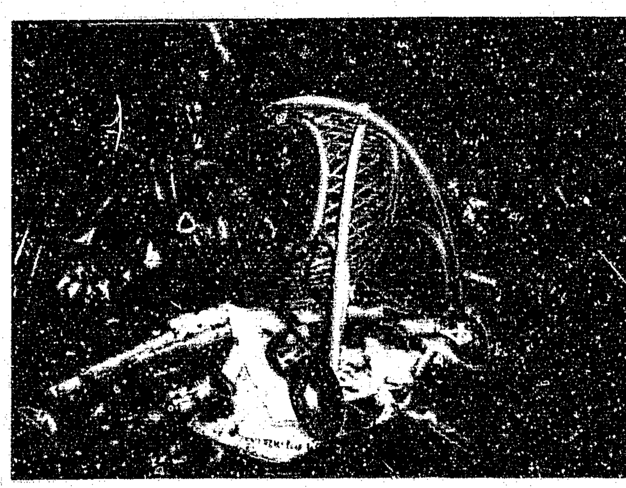
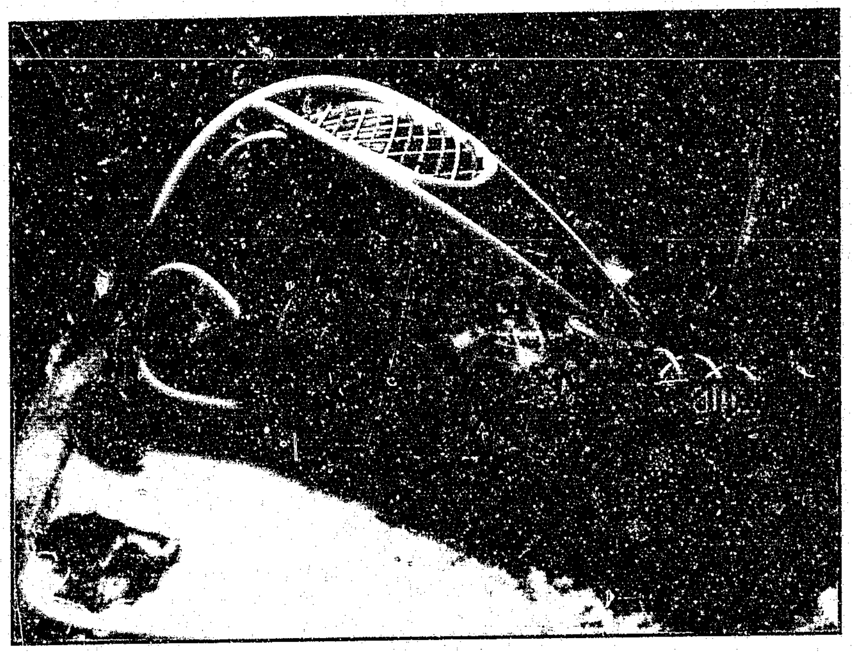
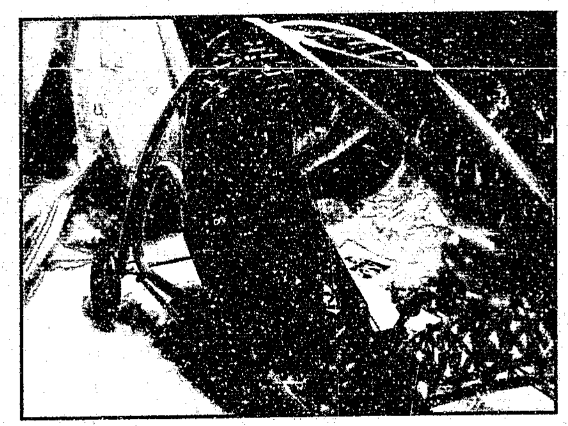
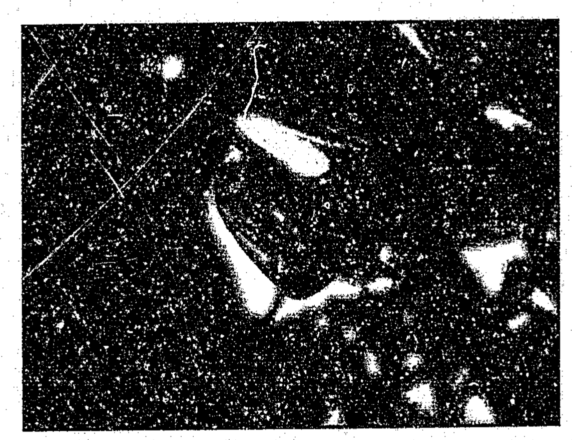


Figure 37: Scale model (b) - Images grouped





The rider seat was sprayed with textured paint to provide a finish intended to represent the proposed fabric covering.



Parts such as the headlights and steering linkages were masked separately. Lense inserts were created for the headlights using hand shaped and polished acrylic.

The frame was painted in a custom colour matched to that of dried bamboo. The finish of the acrylic lacquer paint allowed for intentional brush marks to be formed in the paint surface, by running a dry brush through the applied paint.

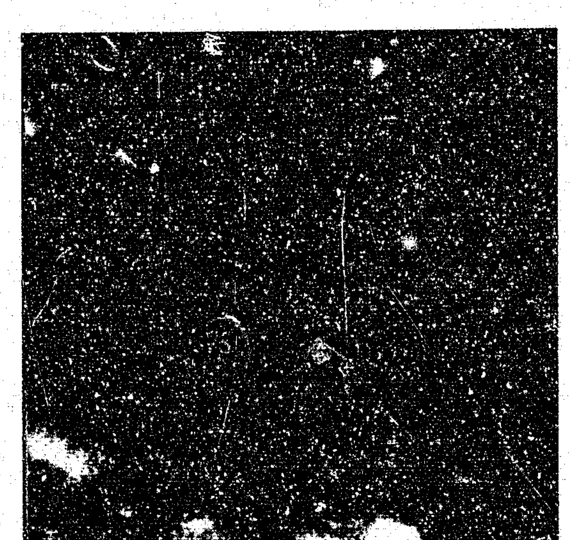
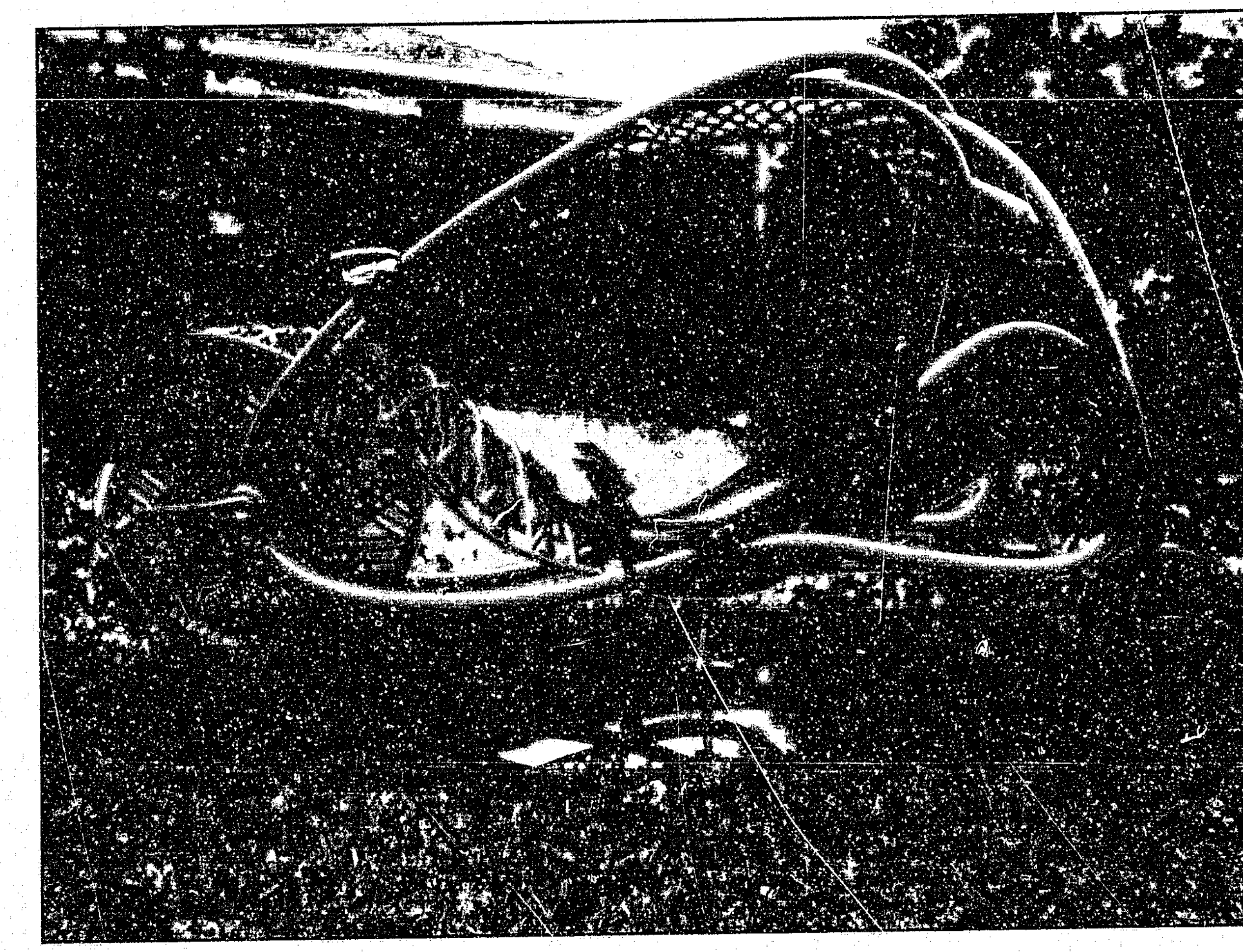
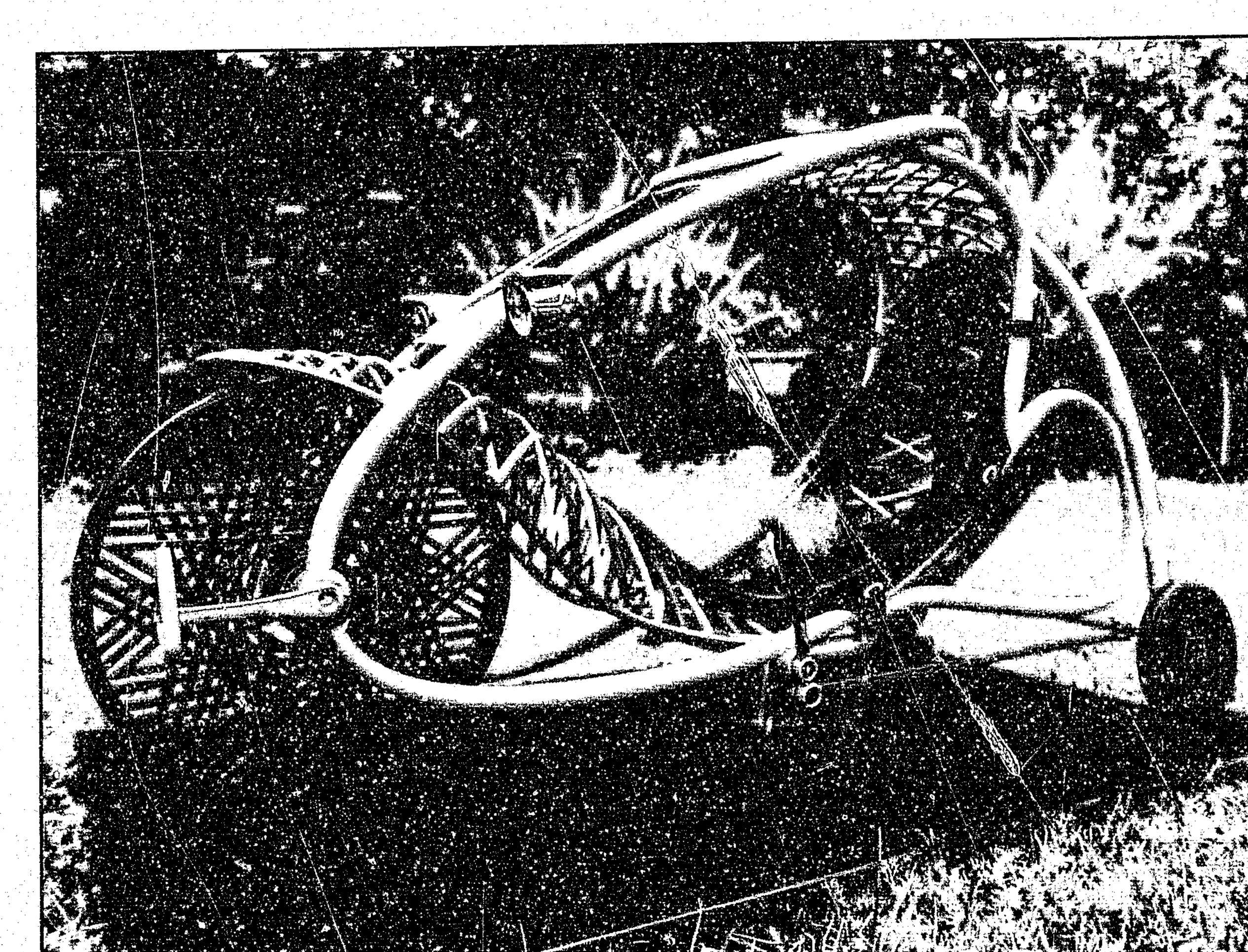


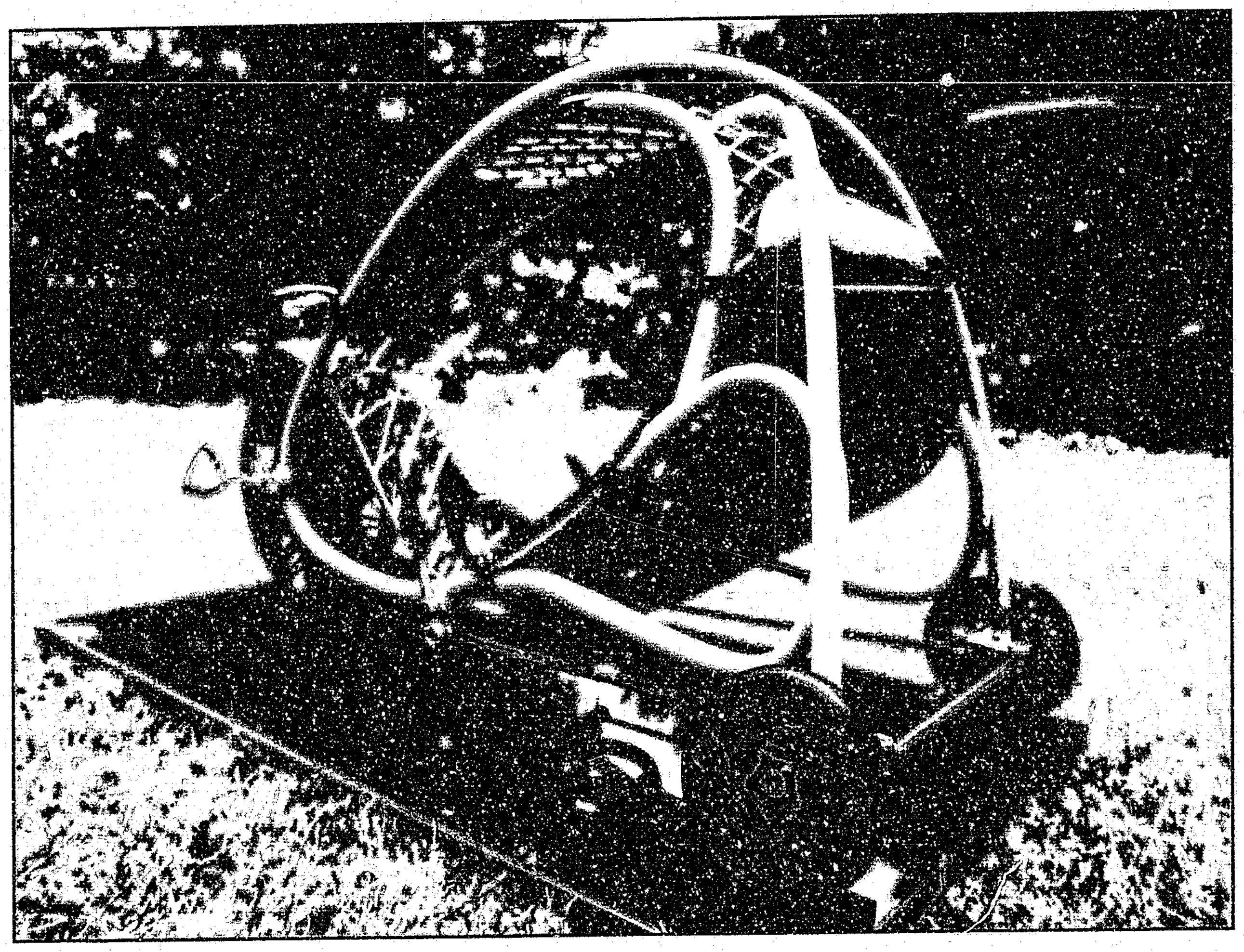
Figure 37: Scale model (c) - Images grouped

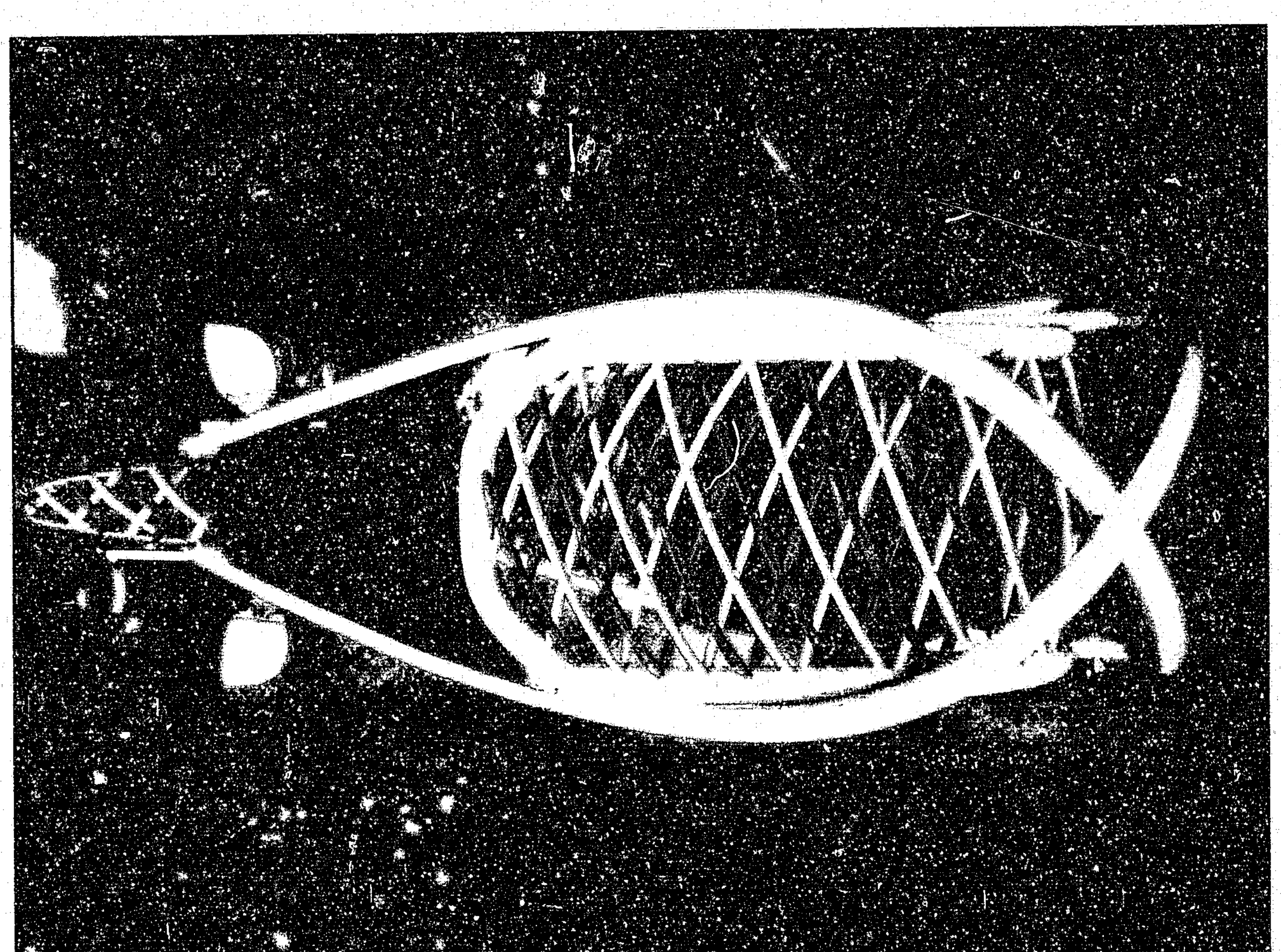




Conceptual scale model resolution.

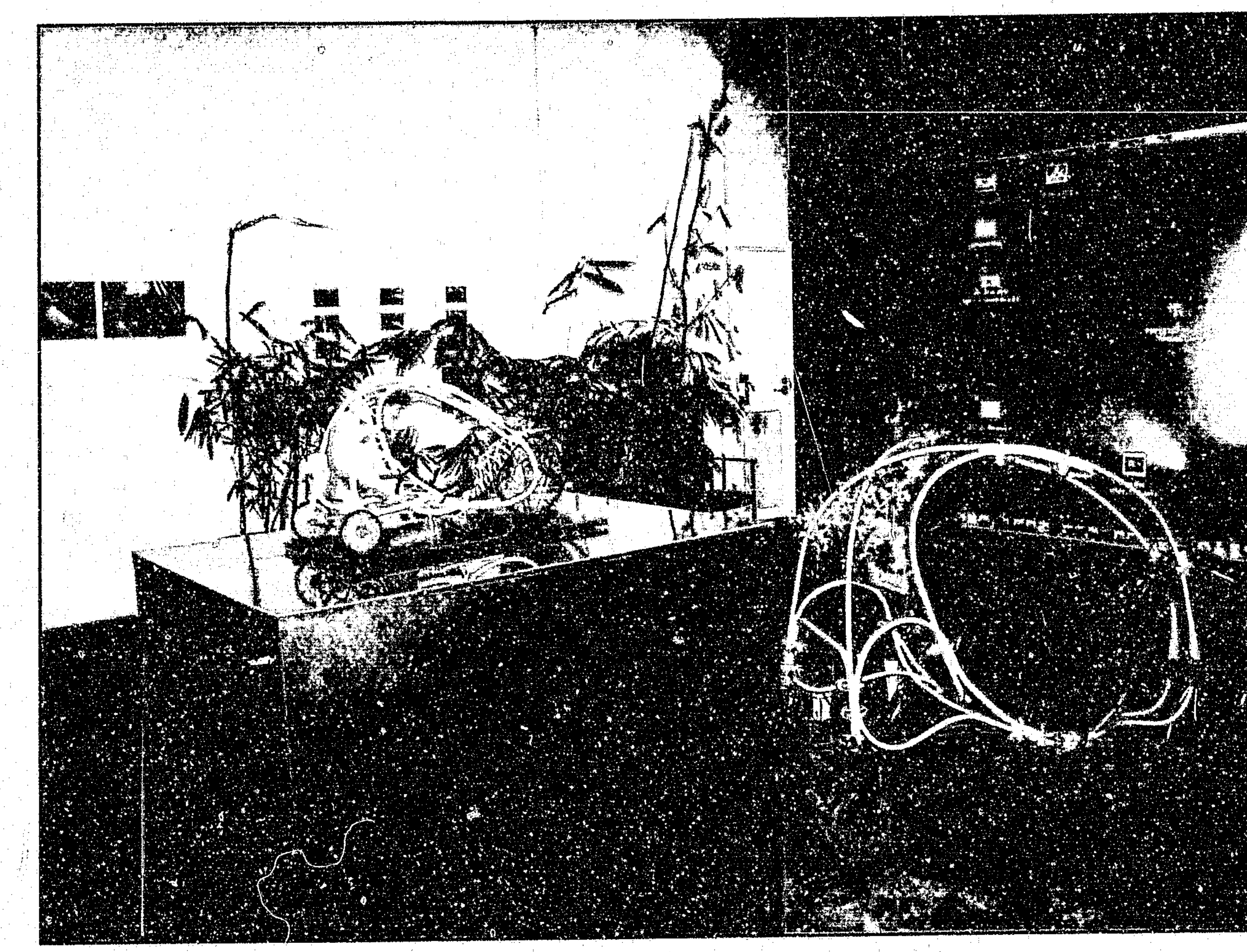
Figure 37: Scale model (c) - Images grouped



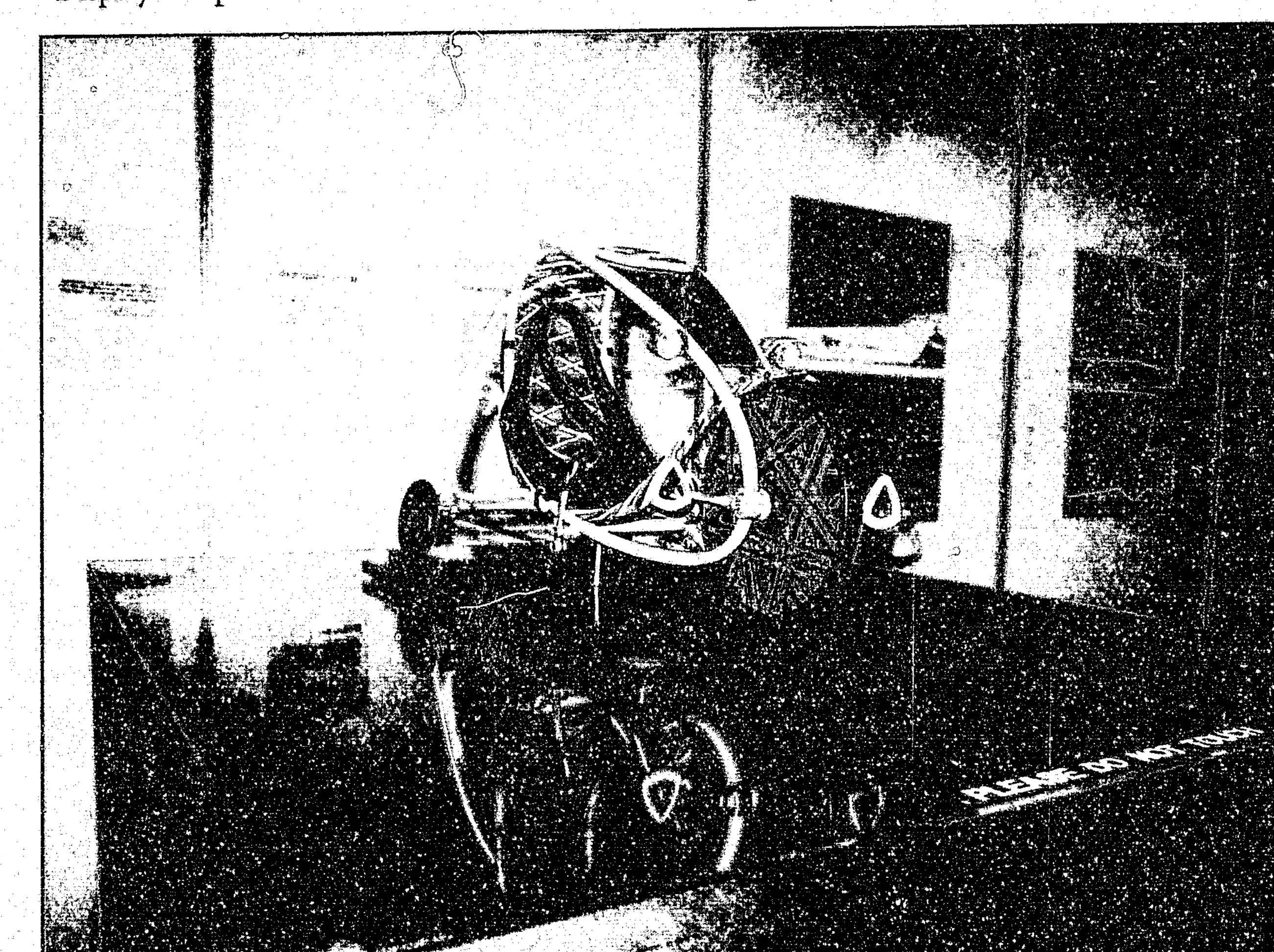


Conceptual scale model resolution.

Figure 37: Scale model (d) - Images grouped (Amendum inserted October 2011)

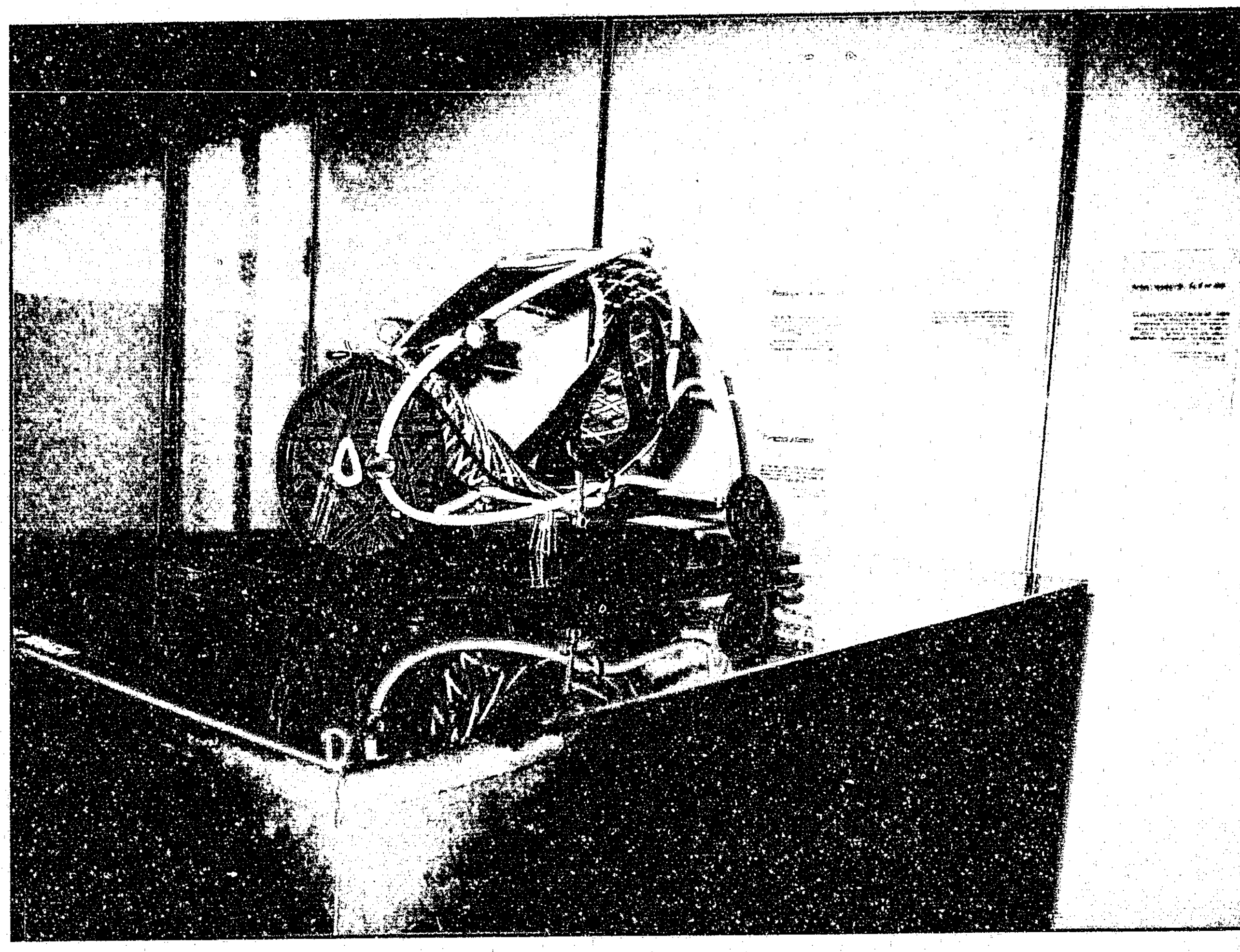


Display comparison between scale model and full size prototype.



Setup display for exhibition. Presentation amongst explanatory literature and relevant quotations.

Figure 37: Scale model (d) - Images grouped (Amendum inserted October 2011)



Setup display for exhibition. Explanatory plant experiments in background.