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The Feasibility of Wood and its Derivatives as a Bicycle Frame Building Material

Viabilidade da Madeira e dos seus Derivados na Construção de Quadros de Bicicletas

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Figure 1. Xylon Eclipse Bicycle Publicity Photograph – Błaszczyk, Natalia 2008

ABSTRACT

Nicholas Brent Taylor: The Feasibility of Wood and its Derivatives as a Bicycle Frame Building Material

The bicycle is often considered as one of the most important inventions of all time. In addition, it is the most efficient form of human transport in the world. It is non pollutant, uses no fuel other than human power and its carbon footprint is neutralised in a short time. Today, faced with the threat of global warming brought about by fossil fuels, countries such as Denmark, the Netherlands and Columbia actually encourage the use of the bicycle as a viable means of urban transport, and in the city of Paris there are financial incentives for cycling commuters. In China alone there are 450 Million bicycles. The form of the bicycle is universally recognisable, it is easy to use and simple to maintain. However, in spite of its apparent simplicity, the bicycle is made up of numerous components and sub-assemblies.

Over the years these components and sub-assemblies have undergone a succession of changes and modifications. As with the evolution, development, and life cycle of any product, some of the modifications were relatively short lived. Others for various reasons have been adopted almost universally, such as steel ball bearings, the roller chain, pneumatic tires, tension spoked wheels, etc.

In order to more fully understand the bicycle, its advantages, its shortcomings, and its place in the modern world, the first part of this study aims to address the various criteria which apply to bicycle typology, differentiation, use and construction. However, although numerous types of Human Powered Vehicles (HPVs) exist, the initial part of this research is constrained to the evolution and development of the “Safety” type bicycle - attributed to J. K. Starley of Coventry in 1895 – up to the present day, taking into account such factors as; design, material selection, manufacturing technology, and diversity.

The first part of the study is a comprehensive overview of the bicycle which identifies crucial technological aspects and categorises bicycle by type and intended use. Due to the huge quantities and types of bicycles produced worldwide this research identifies generic types of each category irrespective of origin or manufacturer.

The second part of this dissertation is devoted to the study of wooden bicycles and the specific requirements of this type of bicycle such as the use of wood and its derivatives e.g. engineered wood, as a bicycle frame construction material and some of the solutions arrived at and the special parts or components required. Contemporary and historical bicycles made from wood, other organic material and its derivatives have been investigated and conclusions drawn regarding their functionality and purpose.

Part three is dedicated to the Design, Development, and Evaluation of a Wooden Bicycle prototype undertaken by the Author with the assistance of three Industrial Design Students.

Part four describes the design, construction and testing of subsequent prototypes in detail including the fabrication of pre-production bicycles and proposals for manufacture on a commercial level.

Parts five and six outline the empirical findings from the previous section and attempt to define strategies for marketing bicycles manufactured from wood and its derivatives as an alternative to conventional materials with a view to reanimating small local industries which have a strong base of expertise and knowhow working with wood, such as producers of furniture and similar products (broom handles, tool handles, boxes etc.).

Part seven is devoted to the potential diversification of wooden framed bicycles which are electrically assisted. The fabrication of a prototype is discussed but no conclusions were made due to constraints beyond my control.

Keywords: Design, Product, Frame, Bicycle

RESUM

Nicholas Brent Taylor: La Viabilitat de la Fusta i els seus Derivats com Material de Fabricacio de Quadros de Bicicletes

La bicicleta es freqüentment considerada com una de les invencions mes importants de tots els temps. Es tambe una de les formes de transport huma mes eficient en el mon. Hui en dia, per l'amenaça del calfament global provocat per les fonts d'energia no renovellables, països com Dinamarca, Holanda i Colombia animen a usar la bicicleta com un mig de transport urba.

La figura de la bicicleta es universalment reconeguda, es facil d'usar i el seu manteniment es simple.

A pesar de la seua aparent simplicitat, la bicicleta està composta de numerosos components i subconjuntos. A lo llarc dels anys, els subconjuntos patiren una serie de canvis i transformacions. Com en qualsevol evolucio i desenroll, els canvis influixen en el cicle de vida de qualsevol producte, a pesar que algunes d'estos aportaments tingueren una vida efimera. Atres, per raons varies, foren adoptades casi universalment. Entre estes podem citar els rodaments d'esferes d'azor, la cadena, els neumatics, etc.

Per a comprendre millor el producte bicicleta, s'ha considerat com objectiu en la primera part d'este estudi, abordar varis criteris que s'apliquen d'acort en la tipología, diferenciacio, us i construccio de la bicicleta. A pesar d'existir numerosos tipos d'*Human Powered Vehicles* (HPVS), la primera part d'esta investigacio se llimita a l'estudi de l'evaluacio i desenvolupament de la bicicleta “*Safety*” atribuida A J.K. Starley de Coventry UK. 1895, des de la seua aparicio fins nostres dies, prenent en consideracio la seleccio de materials, les tecnologies de fabricacio, el disseny, i l'estat de la bicicleta en la societat.

La segona part d'esta tesis està dedicada per complet a l'estudi de la fusta i els seus derivats com material de construccio de la bicicleta. Bicicletes contemporanees i historiques de fusta i els seus derivats, que han segut investigats i s'han presentat els resultats en relacio a la seua funcionalitat i proposit.

La tercera part descriu en detall el disseny, desenroll i evaluacio d'una bicicleta prototip de fusta, els prototips posteriors i les bicicletes prototip o de PRE-produccio de fusta i els seus derivats fabricats per l'autor en l'ajuda dels Estudiants finalistes del grau de Disseny Industrial (ESTGAD CR, Portugal)

En la quarta part se descriu el disseny, construccio i prova de prototips posteriors en detall, incloent la fabricacio de bicicletes de pre-produccio i propostes per a la fabricacio a nivell comercial.

La quinta i sisè parts resumix els resultats empirics de la seccio anterior i tracta de definir estrategies de *marketing*, per a bicicletes fabricades a partir de la fusta i els seus derivats com una alternativa als materials convencionals, en el fi d'animar a produccio industrial a les menudes industries locals, que posseixen una base solida d'experiencia en el treball en la fusta, com productors de mobles i productes similars.

En l'ultima part, s'ha dedicat a la diversificacio potencial de quadros de bicicletes en fusta que estan assistides electricament. La fabricacio d'un prototip forma part de la discussio i preten ser una proyeccio de futur.

Paraules Clau: Disseny, Producte, Fusta, Bicicleta.

RESUMEN

Nicholas Brent Taylor: La Viabilidad de la Madera y sus Derivados como Material de Fabricación de Cuadros de Bicicletas

La bicicleta es frecuentemente considerada como una de las invenciones más importantes de todos los tiempos. Es también una de las formas de transporte humano más eficiente en el mundo. Hoy en día, por la amenaza del calentamiento global provocado por las fuentes de energía no renovables, países como Dinamarca, Holanda y Colombia animan a usar la bicicleta como un medio de transporte urbano.

La figura de la bicicleta es universalmente reconocida, es fácil de usar y su mantenimiento es simple.

A pesar de su aparente simplicidad, la bicicleta está compuesta de numerosos componentes y subconjuntos. A lo largo de los años, los subconjuntos sufrieron una serie de cambios y transformaciones. Como en cualquier evolución y desarrollo, los cambios influyen en el ciclo de vida de cualquier producto, a pesar que algunas de estas aportaciones tuvieron una vida efímera. Otras, por razones varias, fueron adoptadas casi universalmente. Entre estas podemos citar los rodamientos de esferas de azor, la cadena, los neumáticos, etc.

Para comprender mejor el producto bicicleta, se ha considerado como objetivo en la primera parte de este estudio, abordar varios criterios que se aplican de acuerdo con la tipología, diferenciación, uso y construcción de la bicicleta. A pesar de existir numerosos tipos de Human Powered Vehicles (HPVs), la primera parte de esta investigación se limita al estudio de la evaluación y desenvolvimiento de la bicicleta “Safety” atribuida A J.K. Starley de Coventry UK.1895, desde su aparición hasta nuestros días, tomando en consideración la selección de materiales, las tecnologías de fabricación, el diseño, y el estatus de la bicicleta en la sociedad.

La segunda parte de esta tesis está dedicada por completo al estudio de la madera y sus derivados como material de construcción de la bicicleta. Bicicletas contemporáneas e históricas de madera y sus derivados, que han sido investigados y se han presentado los resultados en relación a su funcionalidad y propósito.

La tercera parte describe con detalle el diseño, desarrollo y evaluación de una bicicleta prototipo de madera, los prototipos posteriores y las bicicletas prototipo o de pre-producción de madera y sus derivados fabricados por el autor con la ayuda de los Estudiantes finalistas del grado de Diseño Industrial (ESTGAD CR, Portugal)

En la cuarta parte se describe el diseño, construcción y prueba de prototipos posteriores en detalle, incluyendo la fabricación de bicicletas de pre-producción y propuestas para la fabricación a nivel comercial.

La quinta y sexto partes resume los resultados empíricos de la sección anterior y trata de definir estrategias de marketing, para bicicletas fabricadas a partir de la madera y sus derivados como una alternativa a los materiales convencionales, con el fin de animar a producción industrial a las pequeñas industrias locales, que poseen una base sólida de experiencia en el trabajo con la madera, como productores de muebles y productos similares.

En la última parte, se ha dedicado a la diversificación potencial de cuadros de bicicletas en madera que están asistidas eléctricamente. La fabricación de un prototipo forma parte de la discusión y pretende ser una proyección de futuro.

Palabras Clave: Diseño, Producto, Madera, Bicicleta.

RESUMO

Nicholas Brent Taylor: Viabilidade da Madeira e dos seus Derivados na Construção de Quadros de Bicicletas

A bicicleta é frequentemente considerada como uma das invenções mais importantes de todos os tempos. É também a forma de transporte humano mais eficiente no mundo. Hoje em dia, perante a ameaça do aquecimento global provocado pelas fontes de energia não renováveis, países como a Dinamarca, a Holanda e a Colômbia, encorajam o uso da bicicleta como um meio de transporte urbano, e actualmente na cidade de Paris existem incentivos financeiros para os cidadãos que usam bicicletas para deslocações urbanas. Nalguns países não Ocidentais, como na China, por exemplo, existem 450 milhões das bicicletas. O formato da bicicleta é universalmente reconhecido, é fácil de usar e a sua manutenção é simples. No entanto, apesar da sua aparente simplicidade, a bicicleta é composta de numerosos componentes e *sub-assemblies*. Ao longo dos anos, estes componentes e *sub-assemblies* sofreram uma sucessão de mudanças e transformações. Como na evolução, desenvolvimento e ciclo de vida de qualquer produto, algumas dessas modificações tiveram uma vida curta. Outras, por razões várias, foram adoptadas quase universalmente, tal como os rolamentos de esferas de aço, o corrente tipo “Renolds”, os pneus pneumáticos, e rodas enraiadas etc.

Para melhor compreender a bicicleta, as suas vantagens e desvantagens e o seu lugar no mundo moderno, o objectivo da primeira parte deste estudo é abordar os vários critérios que se aplicam à tipologia, diferenciação, uso e construção da bicicleta. Mesmo assim, apesar de existirem numerosos tipos de *Human Powered Vehicles* (HPVs), esta investigação limita-se ao estudo da evolução e desenvolvimento da bicicleta tipo “*Safety*” atribuída a J. K. Starley de Coventry UK. 1895, desde a sua aparecimento até aos nossos dias, tomando em consideração o design, a seleção de materiais, as tecnologias de fabrico, diversidade e o estatuto da bicicleta na sociedade.

A primeira parte deste estudo é uma visão abrangente da bicicleta que identifica aspectos tecnológicos cruciais e categoriza bicicleta por tipo e uso pretendido. Devido às enormes quantidades e tipos de bicicletas produzidas em todo o mundo, esta pesquisa identifica os tipos genéricos de cada categoria, independentemente da origem ou do fabricante.

A segunda parte deste trabalho é dedicada ao estudo de bicicletas de madeira e as exigências específicas deste tipo de bicicleta, tais como o uso de madeira e seus derivados, “*engineered wood*” como um material para construir quadros de bicicletas e algumas das soluções encontradas nesta vertente, e também as peças ou componentes especiais e específicos necessários. Também nesta secção, bicicletas históricas e contemporâneas feitas em madeira, outros materiais orgânicos e os seus derivados foram investigados e as conclusões tomadas relativas à sua funcionalidade e finalidade.

A terceira parte é dedicada à concepção, desenvolvimento e avaliação de um protótipo de bicicleta de madeira realizada pelo autor com o apoio de três alunos finalistas de Design Industrial.

A quarta parte descreve o design, projecto, construção e os ensaios dos protótipos subsequentes em pormenor, e além disto a fabricação de bicicletas “pré-produção” e propostas para fabricação semi-industrial.

As secções cinco e seis descrevem os resultados empíricos da secção anterior e as tentativas para definir estratégias de marketing para bicicletas fabricadas a partir de madeira e seus derivados como uma alternativa aos materiais convencionais, com vista a reanimar as pequenas indústrias locais, que têm uma forte base de especialização e conhecimento e que trabalham com madeira, tal como os produtores de mobiliário e produtos similares.

A setima parte é dedicada à diversificação de bicicletas construídas em madeira com o apoio motriz dum motor eléctrico (electricamente assistida). A fabricação de um protótipo é discutida, mas nenhuma conclusão foi tirada, devido a restrições fora do meu controle.

Palavras-chave: Design, Produto, Quadro, Bicicleta

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INTRODUCTION (EN)

The bicycle in its present form has been with us for over a century and it has become an instantly recognisable object. Adapted and refined to better suit the needs of its users, and although not organic in form or material it is an almost perfect extension of the human form. In order to perceive the bicycle and its relationship with its users and manufacturers the objective of this research is to investigate the various criteria which affect to bicycle typology, user interface, and materials and construction methods. Although the bicycle is perceived as a simple object, it is made up of numerous components and sub-assemblies, such as frame, transmission, steering, wheels, brakes etc. as can be seen in the first illustrations of a typical men's and women's bicycles made by Raleigh in the 1950s (Figure 1) These components and sub-assemblies are so well conceived that the bicycle often needs the very minimum of tools and expertise to repair and maintain. However, as the demands of enthusiasts have grown some components and sub-assemblies have undergone a succession of changes and modifications, such as the almost universal adoption of “V” brakes and front suspension on mountain bikes for example and highly sophisticated electronic gear shifting on racing bicycles. However, many components such as steel ball bearings, the roller chain, pneumatic tyres etc. which were designed and developed for early bicycle manufacture were adopted by other industries, such as the automotive, aeronautical, and motorcycle industries. Although the concept of the bicycle as an efficient human powered vehicle is unchallenged, (it is up to 5 times more efficient than walking or running) attempts have been made to complement human power with small engines and electric motors. However these hybrid Human Powered Vehicles (HPVs) still remain relatively insignificant in terms of units sold compared with the millions of bicycles sold worldwide every year.

Therefore this research is based on the idea that a “Bicycle” is a two wheeled vehicle capable of conveying one person by means of their own muscle power. However, in the light of recent developments in bicycle design and use, electrically assisted bicycles have been included.

Following extensive empirical research four essential parts of the bicycle frame have been identified and studied in depth. Having analysed each in turn I have identified them as “Frame/Component Interfaces”. These interfaces, both individually and collectively have been the subject of adaptation and eventual fabrication using non specialised technologies and basic engineering principles. The following examples are existing generic solutions encountered on conventional bicycles.

Justification

The advantages and justification of using bicycles as an environmental friendly means of transport, especially in urban areas, have been widely publicised. Reduced pollution, health benefits, and reduced congestion are just some of the overall benefits. However, there is still a certain reluctance to adopt Human Powered Vehicles for a variety of reasons such as perceived status, safety, and non-user-friendliness. In addition maintenance and upkeep of HPVs is a requirement which is frequently ignored resulting in unsafe bicycles with potentially dangerous consequences for riders and other road users. The objective of this study is to address some of these questions and propose alternative types of bicycles which go some way towards resolving these issues. As a way of attracting new cyclists and providing alternatives for existing cyclists, unconventional and novel uses of materials are proposed for the construction of fully functional bicycle frames. Given the inherent manufacturing skills available in Portugal other than those directly related to bicycle production (such as traditional furniture manufacture and cabinet making which has seen a down turn due to the availability of cheap mass produced furniture by companies such as IKEA) there is an opportunity to capitalise on this expertise and adapt and apply it to new products. The design and development of innovative solutions such as bicycle frames made from wood and its derivatives presents this opportunity. The proposals and solutions outlined in this study seek to define possible areas of development which embody diversification, and differentiation of the bicycle whilst addressing fundamental factors such as function, user-friendliness, safety, and longevity of the eventual product.

Therefore, in Chapter 3, I propose a departure from the existing methods of frame manufacture using materials other than metal based on the diamond frame format and develop a simplified bicycle frame which can be produced with the minimum of specialised technologies or equipment. In order to ascertain the viability of wood as a frame building material a number of designs were developed and tested taking into consideration the following criteria:

- The resultant bicycle frame should perform comparably with existing bicycles made from the same or other materials.
- The useful life of the bicycle should compare favourably or exceed that of existing bicycles.
- The bicycle should be able to be produced with existing woodworking equipment in small workshops already dedicated to producing traditional wood based products, e.g. furniture etc.
- The material used should be easily and readily available and not incur excessive costs.

- The material should be sourced from certified suppliers which are preferably local.
- The need for special components should be kept to a minimum and if required should be able to be produced locally with basic equipment e.g. metal working lathes etc.
- Other materials used in its construction should be eco-friendly.
- The design of the bicycle should take into consideration the properties inherent in wood and its derivatives and use them to its advantage.
- The aesthetics of the bicycle should be appealing to potential users and should embody the visual and tactile qualities of the materials used in its construction e.g. grain pattern, natural colour and “feel”.
- The bicycle should be easily maintained without the need for specialised tools or equipment.
- The bicycle should use easily sourced standard components and not require specialised techniques for fitting them.
- The bicycle should not be considered as a completive to traditional bicycles but rather as an eco-conscious alternative.
- The intended use of the bicycle should not be specific such as Road, MTB, and Randonneur etc. but should be general purpose.
- The size of the bicycle frame should cater for adult users not taking into consideration users with specific disabilities.
- The bicycle should be easy to use.
- The bicycle should be safe to use.
- The bicycle should not require special care.

Statement of the Problem

Having undertaken extensive research regarding wooden bicycles over a period spanning more than a decade, I have found that there is very little published material available. Most references to wooden bicycles are historical and even so, the literature is sketchy and has little relevance to wooden bicycle frames today. Nevertheless searches of the internet revealed an interesting diversity in the use of wood being used for Human Powered Vehicles ranging from primitive wooden two wheeled vehicles used to transport loads in Africa, and “homemade” bicycles of various types made by DIY enthusiasts, Designers, and Design and Engineering students. However, no detailed information was available about the basic Design Concepts, the development of the bicycles, the materials used or the testing of the end result. In addition, due to the very small numbers of wooden bicycles compared to conventional bicycles there is almost nothing written about the solutions to the inherent interface problems associated with bicycle frames made from nonconventional materials. Another factor which has not been addressed is the function and longevity of wooden bicycles frames tested in real time rather than by simulation. This overall lack of research provides the opportunity to address some of the factors empirically and publish the results.

Hypothesis

Is it technologically feasible to use natural wood and/or its derivatives such as engineered wood as a suitable material for the construction of full sized bicycle frames which are comparable in terms of function and performance with bicycles made from more conventional materials?

The following structure will be applied:

- Deduction: Concrete applications or consequences will be deduced from generalised principles and observations in order to arrive at verifiable predictions.
- Predictions: Operational predictions will be made based on the generalized deductions and hope to show the feasibility of the initial hypothesis either in its entirety or in interrelated parts.
- Observation: The results will be observed, critically analysed and tested.
- Test of predictions: The predictions will be tested and if necessary challenged.
- Induction: Strong evidence will be sought for (not absolute proof of) the truth of the conclusion.

Methodology

The title “The Viability of Wood and its Derivatives in Bicycle Frame Construction“ initially derived from the assessment and evaluation of an extracurricular project entitled “A Wooden Bike in a Week “.

My position as lecturer of *Património Tecnológico* “Technological Heritage“ and personal experience and interest in working with wood led me to invite three students to participate in the wooden bicycle project. The aim was to produce a working prototype within 40 hours with the assistance of three final year Industrial Design students, Luis Aniceto, Leonel Mateus, and Sergio Cordeiro from the school formerly known as Escola Superior de Tecnologia, Gestão, Arte e Design (ESTGAD), das Caldas da Rainha, Portugal.(Now ESAD CR).

With the experience and knowhow gained from the extracurricular project the resulting spinoff was the design and development of a series of wooden bicycles which were produced individually by the members working as a team. The detailed account of this initiative and the results are catalogued in Part 5.

Although no formal Design Strategy was stipulated during the initial phase of the “A Wooden Bike in a Week” project, extensive searches for wooden bicycles were made, especially on the internet with the result that very few examples were found other than the Tino Sana wooden bicycle (Figure 113), and the children’s LIKEaBIKE (Figure 121), invented in 1997. Even though the search was made in English, Spanish, German and French only a small number of examples were encountered. Subsequent Design Strategy was based on the Iterative Approach.

A review of available literature also disclosed very little material other than historical references to early human powered vehicles such as the hobbyhorse and Drainsine *Laufmaschine* (running machine) - the ancestor of the bicycle attributed to Karl Drais and more recently the Whalen and Janssen laminated wood frame bicycle from 1942 (Figure 111), which is part of the “America on the Move” Exhibition in the Smithsonian Museum.

Consequently, due to the absence of contemporary literature on wooden bicycles, the methodology employed in this dissertation is of an intrinsically practical nature based on Empirical Evidence and structured as follows:

In this case, and in the light of no published material or reliable scientific data Empirical Evidence will include measurements or data collected through direct observation and/or experimentation.

Considering the generalised nature and complexity of the hypothesis a Design Methodology is employed which follows the Iterative Approach outlined below with physically fabricated prototypes in real time giving the opportunity to gather and collate feedback to develop the design and prove the initial hypothesis.

Iterative Design Methodology:

- Define – The specific parameters are defined. In this case the initial parameters were solely those perceived by the project title “A Wooden Bike in a Week“
- Ideation – Ideas are generated which are not necessarily strictly defined by the conventional paradigm allowing the opportunity to develop creativity, innovation, and novelty.
- Selection – After evaluation of ideas, select the most appropriate and potentially viable idea and refine it taking into consideration the availability of resources, expertise, and time and establish targets and goals
- Making – Plan the making of full size prototypes or models taking into account the available resources and if necessary, depending on the scope of the work, delegate tasks and establish timing
- Analysis – Having constructed full size prototypes or models, these are subjected to controlled use within defined parameters, tested accordingly and the results analysed.
- Repetition – Depending on the results of the analysis, alterations are made as a whole or to specific elements which in turn may have an effect on the whole which, depending on the complexity of the object may lead to undertaking a holistic approach. The process is then repeated until a viable solution is achieved within the specified time constraints i.e. established deadline.

INTRODUÇÃO (PT)

A bicicleta, na sua forma actual, tem estado connosco por mais de um século e tornou-se um objecto instantaneamente reconhecível. Adaptado e refinado para melhor atender às necessidades dos seus usuários/utentes, e apesar de não seja orgânico na sua forma ou material, é uma extensão quase perfeita do corpo humano. Para perceber a bicicleta e sua relação com seus usuários e fabricantes, o objectivo desta pesquisa é investigar os vários critérios que afectam a sua tipologia, os interfaces com o usuário, e os materiais e métodos de construção.

Embora a bicicleta seja percebida/considerada como um objecto simples, é composta por vários componentes e subconjuntos, tais como o quadro, a transmissão, a direcção, as rodas, e os travões, etc., como pode ser visto na primeira ilustração de bicicletas típicas para homens e mulheres feitas por Raleigh na década de 1950 (Figura 1).

Estes componentes e subconjuntos são tão bem concebidos que geralmente a bicicleta só precisa do mínimo de ferramentas e experiência/conhecimento para reparar e manter. No entanto, como as exigências dos entusiastas têm crescido, alguns componentes e subconjuntos foram submetidos a uma sucessão de alterações e modificações, como por exemplo, a adopção quase universal dos travões tipo "V" e suspensão dianteira em bicicletas de montanha, e até equipamentos electrónicos altamente sofisticados para seleccionar as mudanças em bicicletas de corrida.

Mesmo assim, muitos componentes, tais como os rolamentos de esferas de aço, a corrente, os pneus pneumáticos, etc., que foram concebidos e desenvolvidos para a fabricação das primeiras bicicletas, foram adoptados por outros sectores, como as indústrias automóveis, aeronáuticas e de motas. Embora o conceito da bicicleta como um veículo movido por força humana eficiente seja incontestável (até 5 vezes mais eficiente do que caminhar ou correr), foram feitas tentativas para complementar a força motriz humana com pequenos motores de dois ou quatro tempos e motores eléctricos. No entanto, estes *Human Powered Vehicles* (HPVs) híbridos ainda permanecem relativamente insignificantes em termos de unidades vendidas em comparação com os milhões de bicicletas vendidas em todo o mundo cada ano.

Por isso, esta pesquisa é baseada no conceito de que uma "Bicicleta" é um veículo de duas rodas capaz de transportar uma pessoa por meio da sua própria força muscular. Mesmo assim, à luz dos recentes desenvolvimentos no *design* das bicicletas e das suas utilizações, as bicicletas assistidas electricamente foram incluídas.

Depois da extensa pesquisa e investigação empírica, quatro elementos essenciais do quadro da bicicleta foram identificados e estudados em pormenor. Depois de analisar cada um por sua vez foram identificados como "Quadro/Componente *Interfaces*". Essas *interfaces*, tanto individual como colectivamente, têm sido objecto de adaptação e eventual fabricação utilizando tecnologias não especializados e princípios de engenharia básicos. Ao longo do texto encontrar-se-ão exemplos de soluções genéricas existentes em bicicletas convencionais.

FOREWORD

Four essential frame/component interfaces which are common to almost all bicycles have been identified and defined. These key interfaces are described below (Figure 2).

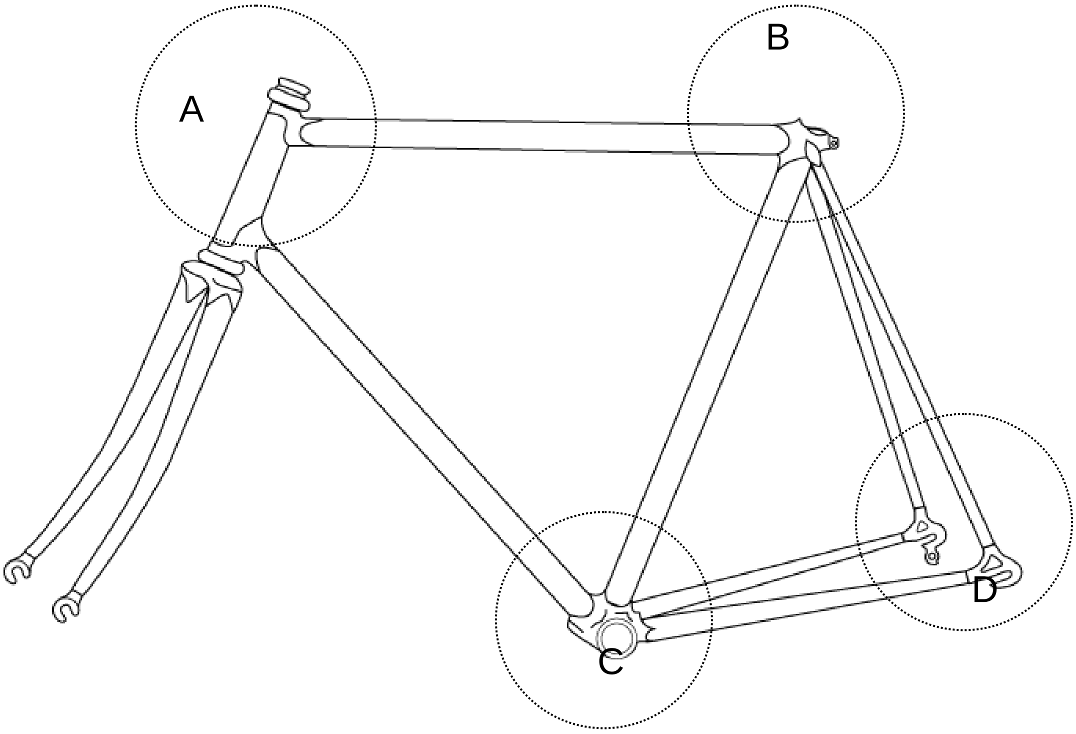

Figure 2. Bicycle frame/component interface. Retrieved from https://law.resource.org/pub/in/bis/S13/is.623.2008.html

Key: A – Head tube, B – Seat tube, C – Bottom bracket, D – Rear Drop outs

Each of these interfaces has evolved over an extended period of time and utilises the frame’s physical characteristics, which in most cases is round metal tube.

The four interfaces have been identified as follows.

A – Head tube

The front forks are attached to the frame at the smooth cylindrical head tube in a way which allows the fork and wheel sub assembly to rotate on bearings which are pressed into the top and bottom of the head tube. The head tube axis is inclined from the vertical by several degrees. (See frame geometry). The forks are connected to the frame in such a way that they are removable if they become damaged. However, the forks rarely require maintenance and they are rarely removed during the life of the bicycle.

B – Seat tube

The seat tube is a smooth cylindrical tube in which the seat post is inserted. The saddle is attached to the seat post which may be raised or lowered to accommodate riders of different stature. The seat post is clamped to the seat tube of the frame with a screw and nut which may incorporate a quickly detachable clamp. In use, the seat post must be fixed in position and neither slip downwards or rotate under force.

NOTE: The seat tube has to have a seamless bore and be a close tolerance fit to create enough surface contact with the seat post, however, depending on the variables of seat tube inner and outer diameter and wall thickness, seat posts are produced in a variety of diameters (Figure 3) starting from 26.0mm, increasing by 0.2mm intervals. The following diameters are relatively common, 26.2mm, 26.4mm, 26.6mm, 28.6mm, 29.4mm, 29.6mm, 26.8mm, 27.0mm, 27.2mm, 29.8mm, 30.2mm 30.6mm, 30.8mm, 31.4mm, 31.6mm, however, the predominant diameter is undoubtedly 27.2mm.

Figure 3. Seat post sizer (www.sheldonbrown.com) Retrieved from http://www.sheldonbrown.com/seatpost-sizes.html

C - Bottom bracket

The bottom bracket is a cylindrical tube which is aligned horizontally and perpendicular to the frame (Figure 4). The bottom bracket is precision machined and threaded to accept the bottom bracket axle to which are attached the crank and chain ring.

Although there are some differences in bottom bracket dimensions the predominant standard is 1.370" diameter with 24 threads to the inch.

D – Rear Dropouts

The rear dropouts (Figure 5) are the part of the frame which attaches the rear wheel. There are a wide variety of types and sizes of rear dropouts but the main dimension which needs to be taken into consideration is the width of the slot or fixing hole which is dependent on the diameter of the rear wheel axle, the distance between the dropouts, i.e. the Over Locknut Dimension (OLD) and their alignment in the horizontal plane.

Standardised bicycle components

Many bicycle components have become standardised which means that parts are easily interchangeable. For example: a typical steel or aluminium bicycle can be upgraded by retrofitting better quality parts than where fitted by the manufacturer. However, manufacturers themselves often produce bicycles with the same frame but with a range of parts of various qualities which are destined for different markets and price levels.

As the objective of this research is to investigate the feasibility of a wooden *framed* bicycle and not to create a bicycle which uses wood for other components, it is proposed that readily available standardised parts used in bicycle manufacture will be used in an unmodified form. Furthermore, although there are various frame configurations, this research is based on the traditional “diamond frame” bicycle configuration which is by far the most common and widely used throughout the world.

During my research, four specific areas were identified where standardised components are used at the bicycle frame/component interface.

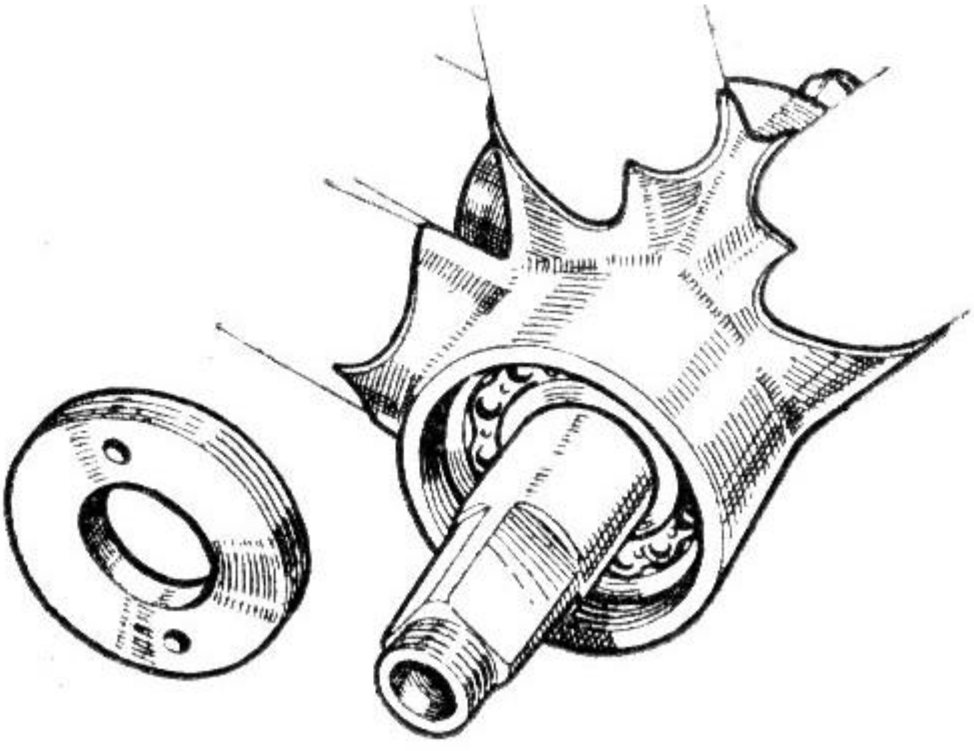

Figure 4. Lugged Bottom Bracket. Rebour, Daniel. Retrieved https://janheine.wordpress.com/2012/05/22/daniel-rebour/

D - Rear wheel dropouts

The rear wheel dropouts comprise a pair of metal plates to which the rear wheel is attached. The dropouts may be designed to allow movement of the rear wheel axle towards the front or rear of the bicycle to tighten or slacken the chain. The rear wheel axle is firmly fixed in the dropouts parallel to the bottom bracket axle. The rear wheel may need to be removed to repair punctures or replace the tyre at regular intervals; therefore the axle is attached by nuts or patented quickly detachable clamping mechanisms (quick release skewers).

Figure 5. Horizontal Rear Dropouts. Retrieved from
http://www.fbmbmx.com/products/frames/steadfast.php

Due to the nature of traditional bicycle frame manufacture and the materials used in its construction (cylindrical metal tubing of various diameters) the interface between the frame and standard components has been resolved through simple machining and turning. For example, the head tube has close tolerance bearing cups press fitted at the top and bottom which rely on friction to remain in position[1].

Frame geometry

Frame geometry is an important factor in frame design and the geometry of the frame depends on the intended use of the bicycle and the physical characteristics of the rider. In traditional bicycle frame manufacture, the length of the tubes and the angles at which they are attached defines the frame geometry. The illustration below shows the critical dimensions and angles of a diamond frame.

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[1] See Appendix iv. Head tube tolerances.

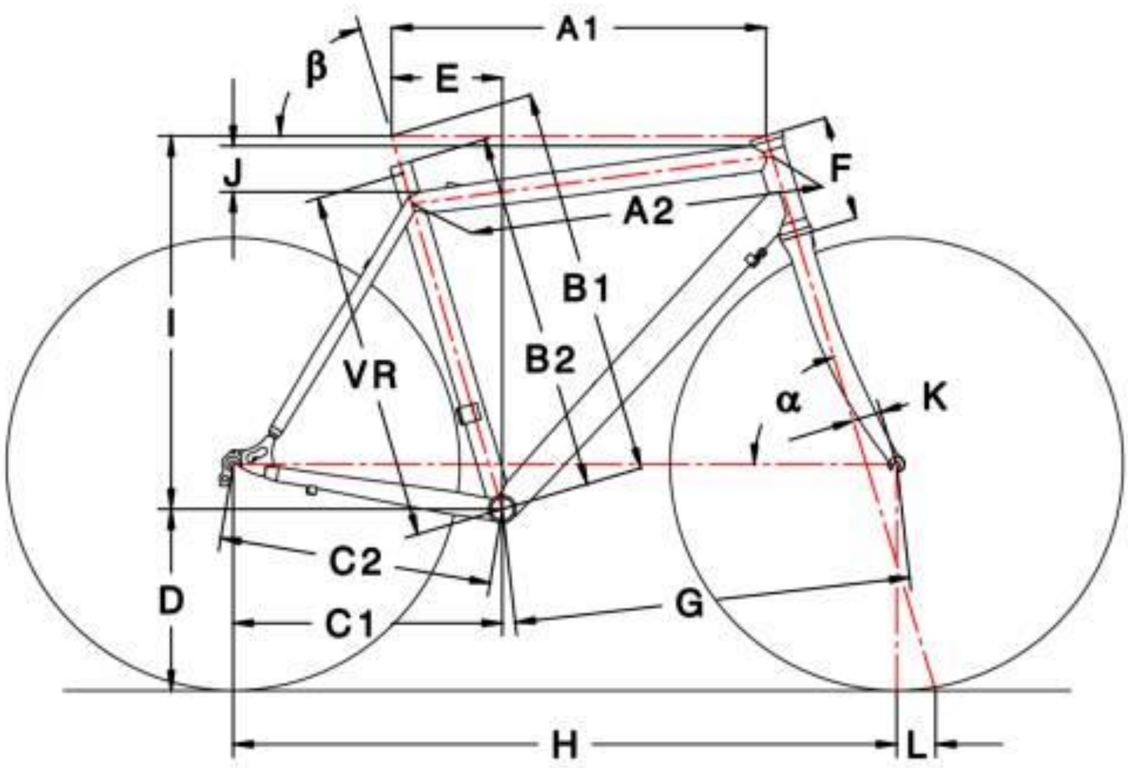

Figure 6. Bicycle Frame Geometry. Retrieved from http://rebelbike.com/download/geometrie_magnetic_t9.pdf

Bicycle frame terminology

A1 - Effective top tube length (measured horizontally)

A2 - Actual top tube length

B1 - Effective seat tube length (including seat stem)

B2 - Seat tube length to top

C1 - Effective chainstay length

C2 - Actual chainstay length

D - Bottom bracket height

E - Seat tube-bottom bracket horizontal

F - Head tube length

G - Freedom of toe (front-centre distance)

H - Wheelbase

I - Maximum height

J - Slope - slope of top tube

K - Fork rake

L - Trail

α - Head tube angle

β - Seat tube angle

Adjustment of components

Although the frame geometry is usually fixed, the rider can adjust the relative positions of some components such as the saddle and handlebars. The following adjustments can be made to suit the rider.

- Saddle height - the distance from the centre of the bottom bracket to the top of the saddle.
- Reach - distance from the saddle to the handlebar.
- Drop - the vertical distance between the top of the saddle to the handlebar.
- Setback - the horizontal distance between the front of the saddle and the centre of the bottom bracket.

For example, a racing bicycle will have the handlebars lower than the saddle and a long reach, resulting in a crouched riding position; however, a comfort or utility bicycle has higher handlebars and a short reach resulting in a more upright, but less aerodynamic riding position. In addition, frame geometry also affects handling characteristics such as oversteer and understeer.

CHAPTER 1

1. Conventional materials and manufacturing techniques employed in bicycle frame manufacture.

A review of existing bicycle frames, materials, parts and components and bicycle sub-types.

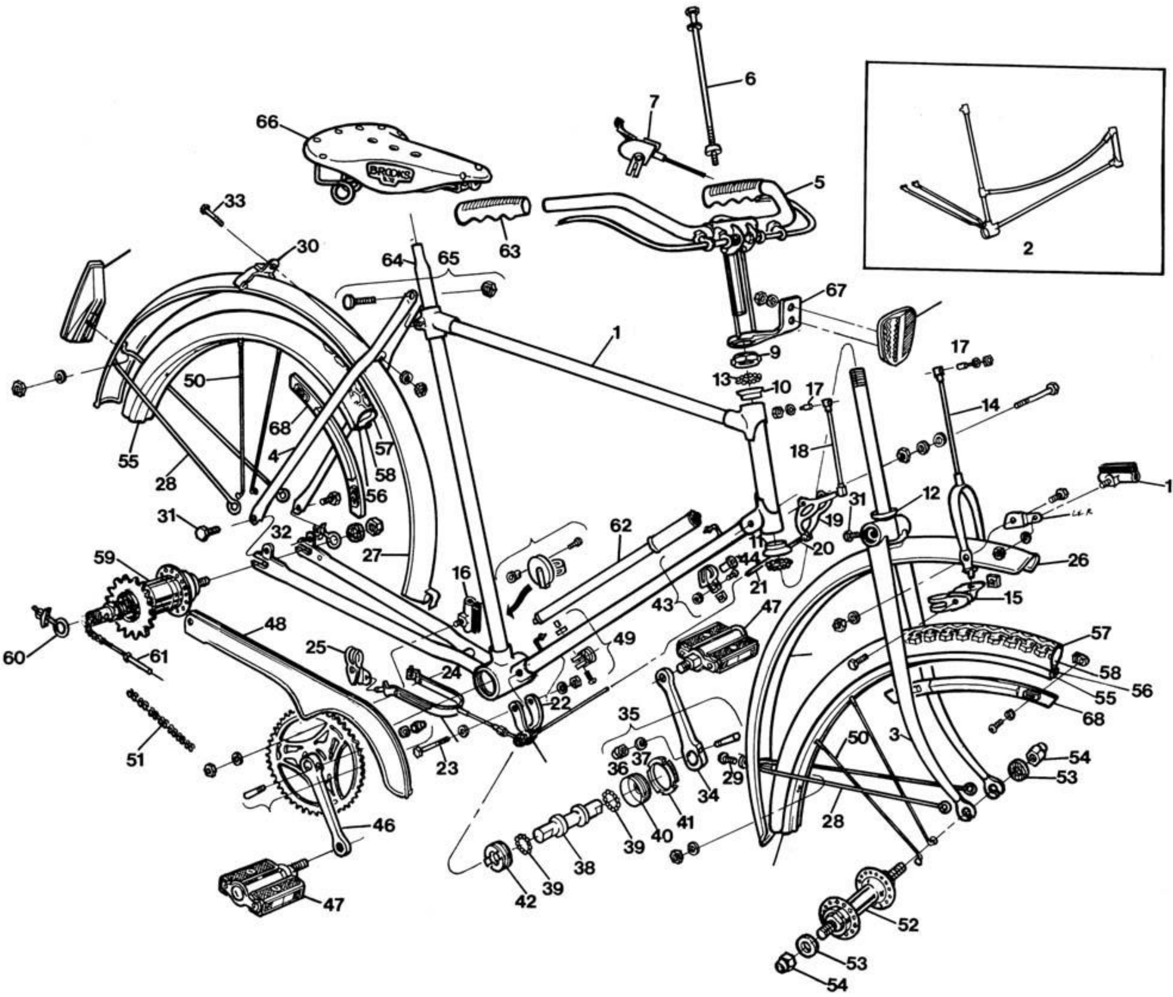

Figure 7. Raleigh D1 bicycle, men's' model circa 1950 (Women's frame inset) Brown S. Retrieved from http://www.sheldonbrown.com/retroraleighs/catalogs/1977-drawings/pages/32-tourist.html

The exploded drawing above shows the parts of the Raleigh Tourist, also known as Dawn Tourist, Tourist-S, Superbe Roadster etc. It is the archetypal diamond frame produced by Raleigh from before WWII with minor cosmetic changes well into the 1980s.[2]

By far the most widely produced type of bicycle frame has been (and still is) the so called "diamond" frame which comprises the following essential components.

1. Head tube (1 piece)
2. Top tube (1 or 2 pieces)
3. Down tube (1 or 2 pieces)
4. Seat tube (1 or 2 pieces)
5. Seat stay (2 pieces)
6. Chainstay (2 pieces)

Other parts which make up the frame are the forks and the Bottom bracket

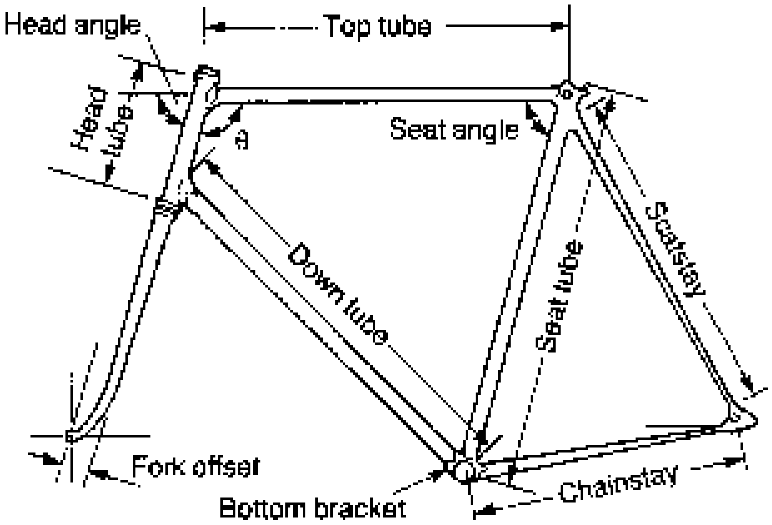

Figure 8. Typical diamond frame bicycle showing the main parts (Easterling K.E.) Retrieved from http://www.tms.org/pubs/journals/jom/9702/froes-9702.html

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[2] Bicycle Design, An Illustrated History. Tony Hadland and Hans-Erhard Lessing. MIT Press.

1.1. Steel Bicycle Frames

The traditional method of building and fabricating this type of high strength to weight frame[3] is by the lugged tube method, the principal components being round section steel tube of various diameters and steel lugs. The principal lugs used in diamond frame construction are defined by their function and position. The internal diameter of the lugs corresponds to the outer diameter of the tubes. The principal lugs are shown in Figure 9:

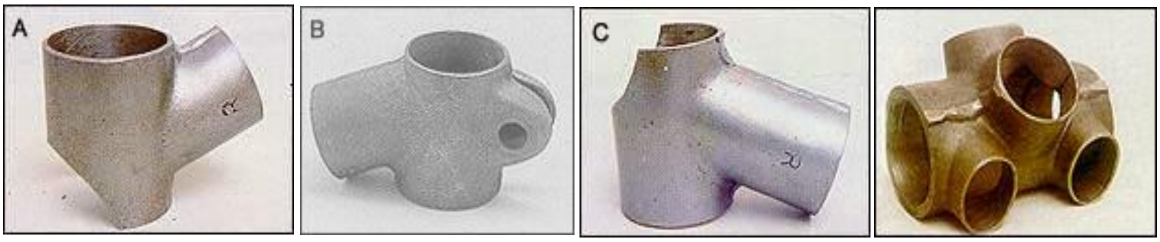

Figure 9. Steel and brass frame lugs
A. Head tube lug. B. Seat tube lug. C. Down tube lug. D. Bottom bracket lug. Retrieved from http://www.indiamart.com/dumaxexports/bicycle-frames.html

1.2. Typical diamond frame configuration

Each junction or joint of the bicycle frame fabricated in this manner uses the aforementioned lugs.

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[3] Handbook of Materials Selection Myer Kutz (Editor) p 1261

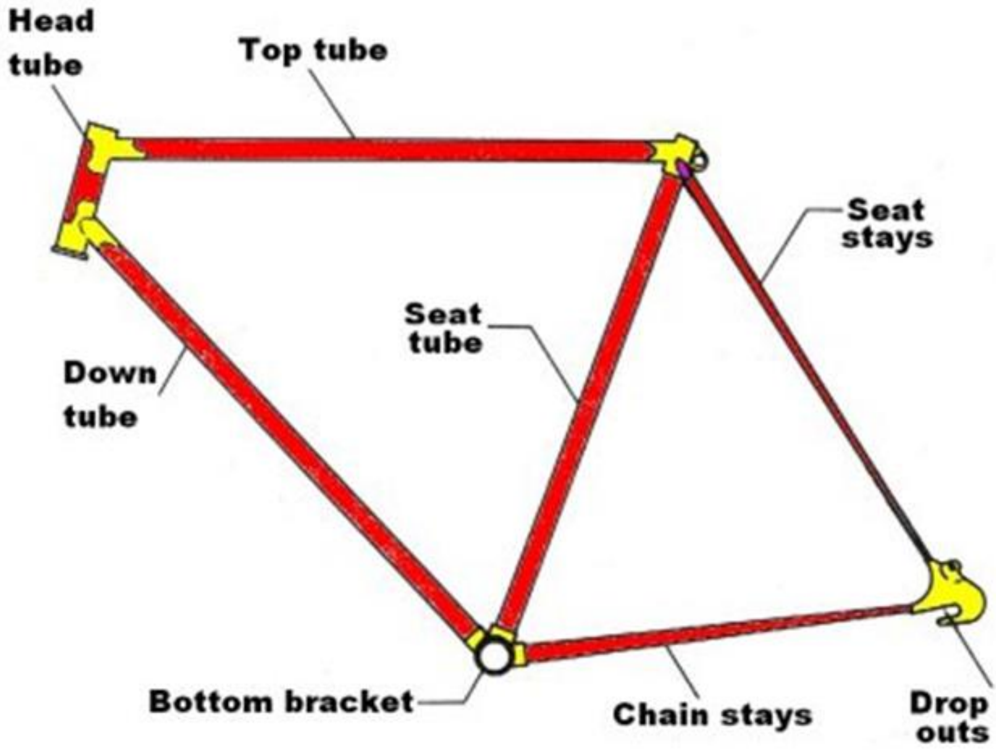

Figure 10. Typical Diamond Frame. Retrieved from https://grabcad.com/library/request-answer-for-mountain-bike-drawing-1

A typical diamond frame configuration would comprise a steering head lug (A), suitably angled to accept the top tube or cross bar and head tube, a lower head tube lug (C) angled to accept the head tube and down tube, a seat tube lug (B) angled to accept the top tube and seat tube, and seat stays, and the bottom bracket.

The bottom bracket is the most complex lug as it typically co-joins four frame tubes, the down tube, the lower end of the seat tube, and two chain stays. In addition to this, the bottom bracket is machined perpendicular to the frame to accept the bottom bracket spindle. The bottom bracket is most often threaded with a left hand and right hand thread to accept the crank spindle bearings and fittings.

Depending on the frame geometry, the angles of the lugs and the length of the frame tubes are predetermined for different sizes and types of frame.

The tolerances involved in cutting the tubes to length are not necessarily very precise as there is a relatively large external surface area of tube in contact with the interior surface of the lug, and when the tube is inserted into the lug, dimensional tolerance is maintained by the assembly jig.

On high quality racing and custom bicycle frames the lugs may be sculpted by the removal of material. This may be done to reduce weight on racing machines or for aesthetic effect on custom machines or a combination of both. The patterns can play a major role in identifying the specific frame maker and are often used as a decorative surface for painted details.

The lugged frame also allows tubes of various qualities and strength characteristics to be employed. For example, a utility bicycle frame would be fabricated with steel tube of constant wall thickness. However a racing bicycle or more expensive touring bicycle frame would be fabricated with steel tube with a variable wall thickness, the tube wall being thicker at the ends than in the middle, in this manner the strength of the frame is maintained but the weight is reduced. This type of steel frame tube is known as butted tube. See Figure 48 – *Reynolds tube*

Further components which are brazed to the frame are the dropouts which are used to position the rear wheel, and various lugs or pins used to affix accessories such as lamp fittings, stand, and pumps etc.

Dropouts are manufactured in a variety of styles depending on the type of frame and may allow rear wheel removal to the rear, downwards or to the front. The rear wheel may be adjusted forwards or backwards to tension the drive chain, or not, if the dropout is vertical.

An essential component in the fitting and brazing of the lugged frame is the jig which maintains the various components in the correct position whilst the frame undergoes the manual or automated brazing process.

1.2.1. Advantages of the lugged frame

Frames can be assembled by relatively unskilled labour at the less expensive end of the market, the tolerances of the tube lengths are not critical. Tube diameters are kept standardised and there is no possibility of incorrect sizing. The frame is mechanically strong and there are few failures at the lugs. Maintenance is minimal other than painting and rust prevention. Although unlikely, in the event of the frame being damaged, the lugs can be unbrazed and the damaged parts replaced, however, this is skilled and labour intensive job which is usually carried out by experts.

1.2.2. Disadvantages of the lugged frame

The manufacture of lugged frames is labour intensive[4] and requires a relatively large number of parts. The lugs are frame-specific depending on the size and frame geometry and are generally not interchangeable thus increasing stock.

1.3. Fillet brazed frames

Fillet brazing is a method used to join steel frame tubes directly to each other without using lugs (Figure 11). The tubes are cut to length, notched (mitred, or shaped) to the required angle, assembled in a suitable jig and brazed. If correctly heated the braze filler joins the tubes at the interface by capillary attraction and fuses with the steel. To

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[4] Bicycles from the Republic of Korea and Taiwan – United States International Trade Commission 1983 p A3

further reinforce the joint a fillet is built up with brass filler and smoothly contoured. This extra material helps to distribute stresses at the joint and gives the characteristic smooth streamlined visual appearance.

Figure 11. Fillet brazed frame joint. Retrieved from http://www.ecovelo.info/2010/01/23/fillet-brazed-frames/

Fillet brazing frames is a skilled, labour intensive and time consuming process and is usually only used on high quality custom frames. In the past, to further enhance the visual aesthetic of the frame the joint was “leaded” with low melting point tin/lead/cadmium solders.

Note: the technique of leading was commonplace in the automotive industry and panel and coachwork repair up until the 1950s when polyester resin filler compounds almost completely replaced the technique.

1.3.1. Advantages of fillet brazed frames

The number of frame parts is reduced to the minimum. There are no lugs with pre-set angles and diameters. Different frame geometry and sizes are possible without special parts. Tube diameters can be varied. The frame is mechanically strong and the fillet reinforces stressed areas. The frame is light weight. Arguably the frame is aesthetically pleasing with a smooth transition between the frame members giving a clean appearance.

1.3.2. Disadvantages of fillet brazed frames

Notching or mitring of the tube requires close tolerances to ensure good contact which is essential for a good brazed joint as the filler metal fuses to the parts through heat and capillary attraction[5]. It is also labour intensive and requires relatively skilled labour. Finishing requires care and is time consuming. If butted or double butted tubing is used, bespoke made to length pieces are required.

1.4. Welded frames

As the effectiveness of welding improved with such methods as TIG and MIG systems as opposed to oxy-acetylene, which relied on relatively highly skilled operatives, welding was employed as a technique to join frame tubes. Essentially the preparation of steel tubes for welded frames is similar to that employed for fillet brazed frames, however, the fine tolerances necessary when notching or mitring for brazing, are not so critical in welded frames.

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[5] Welding Essentials, William Galvery, Industrial Press p 79

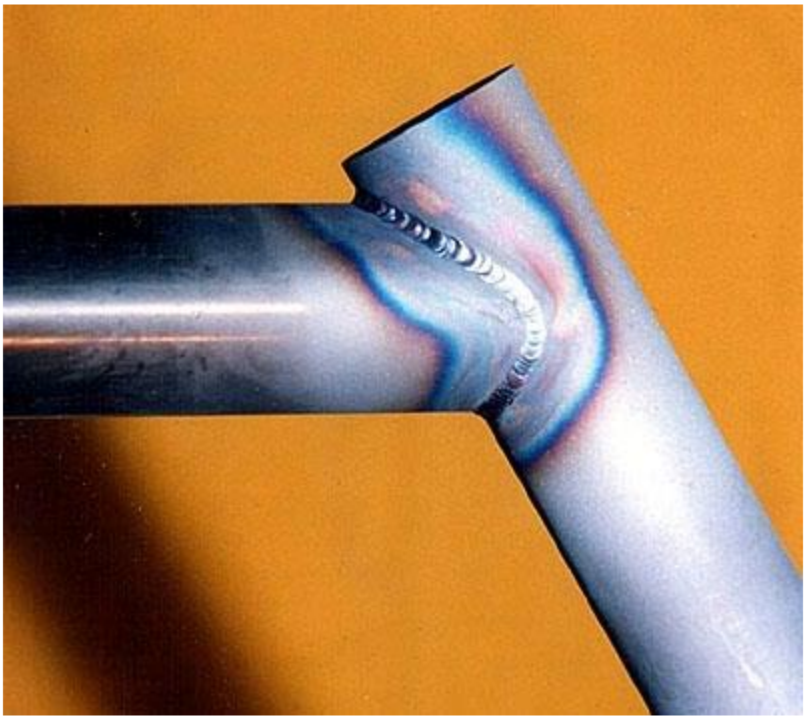

Figure 12. Welded steel tube frame joint. Retrieved from http://www.bikerumor.com/2015/01/16/how-to-build-a-nahbs-bike-part-4-melting-tubes-together/

In a similar fashion to fillet brazed frames, cut and notched lengths of tube are positioned as closely as possible to the subjacent tube (see diagram) in an appropriate jig and welded using whichever of the techniques is most adequate. In the past welded joints were fettled (removal of slag and excess weld) to ensure a smooth even finish prior to painting. However, nowadays in the vast majority of cases (due to the regular consistency of the weld fillet pattern) the joints are left unfettled resulting in the characteristic scales of a welded joint (Figure 12), which have attained their own aesthetic quality.

1.4.1. Advantages of welded frames

As welding technologies are constantly evolving and robot and automated processes are employed, batch production allows large quantities of frames to be fabricated by unskilled labour for the lower end of the market. Due to the now common exposure of the welded joints on other vehicles such as motorcycles, customers now accept the characteristic appearance of a welded joint. Components are reduced to the minimum, and different sized frames are easily accommodated for, as are frames which are made up of different sections of tube such as oval or square section.

1.4.2. Disadvantages of welded frames

Arguably the disadvantages can be categorised as follows.

The dimensional tolerance of the cut tubes needs to be finely controlled as does the contouring of the ends of the tube. The jig must be able to secure all the tubes without the assistance of the mechanical positioning afforded by lugs, and at the same time accommodate differential expansion and contraction of the frame which could cause distortion.

During the welding process the steel tube is brought to very high temperatures to ensure fusion and penetration of the weld fillet. This results in a molecular change at that point which may cause brittleness in the material, leading to structural failure at the interface between the tubes (see figure 12 showing effects of heat around weld). Typically, when there is a failure it is in not at the actual joint but at the interface between the unaltered molecular structure and the altered metal, hence the welded frames have an inherent structural weakness. If the joint is fettled (i.e. filed down), material is removed with a consequent weakening of the joint.

On welded bicycle frames with fettled welds the visual appearance at the joints was an important factor. If the weld was uneven or dirty, the labour intensive fettling served both to disguise poor welding and create a smooth surface for subsequent finishing and painting.

1.5. Frame Design

Since J K Starley developed the “Rover Safety” bicycle in 1885, numerous designs and configurations of bicycle frames have been patented, built and tested. Some were short lived either due to poor design or the use of inappropriate materials but the roughly “diamond” configuration of the frame with two equal sized wheels has remained as the industry standard until the present day. However, some changes were brought about by the diversity of use of the bicycle.

1.5.1. Human factors and differentiation

Although the diamond frame is considered to be one of the most structurally efficient configurations when strength to weight is considered, ironically an important change was made to the bicycle frame which significantly weakened it. The change was brought about due to the increased interest in cycling by women at the end of the 19th century.

Figure 13. Woman on bicycle circa 1900. Retrieved from www.stuhrmuseum.org/

In the 1890s, if a woman was characteristically attired in a long voluminous dress and wanted to ride a bicycle, the top tube impeded the mounting of the diamond frame bicycle and subsequent riding was further inconvenienced by the material of the dress furling on the crossbar. Hence the diamond frame underwent a transformation and the top tube was omitted (Figures 13 & 14).

With one of the principal structural components of the triangulated frame removed, the diamond frame’s rigidity and strength became compromised.

Figure 14. A Royal Sunbeam ladies loop frame bicycle, circa 1910. Retrieved from www.oldbike.eu.

To compensate for this, it was necessary to introduce one or more structural members to redistribute the loads. A wide variety of solutions were employed (Figure 16) ranging from multiple members to single straight or curved members. However, one of the most common configurations was the addition of a curved frame member leading from the seat tube to the head tube. This "loop" frame facilitated mounting and dismounting for skirt wearing riders. To further strengthen the frame the "loop" was attached to the down tube to increase torsional resistance. The completely enclosed chain which prevented the rider's clothes from becoming entangled or soiled is another feature of the bicycle shown on the previous page. A further device was often employed to prevent the rider's skirts catching in the rear wheel spokes (Figure 15). This "skirt-guard" is a common feature on Dutch "*Oma-Fiets*" (Granny Bicycles).

Figure 15. Dutch *Oma-Fiets* circa 2015. Retrieved from http://www.tweedehands.nl

Contemporary Dutch "*Oma-Fiets*" Loop frame bicycle with skirt guard. The differences with the 1910 version are almost indiscernible.

Although the legacy of many bicycle frames is still with us today due to their good design and suitability for use, as would be expected there was a great deal of experimentation carried out on the typical “diamond frame” by the addition of various structural members. The chart of bicycle frame variations from c.1900 illustrates this very well with almost 50 different configurations.

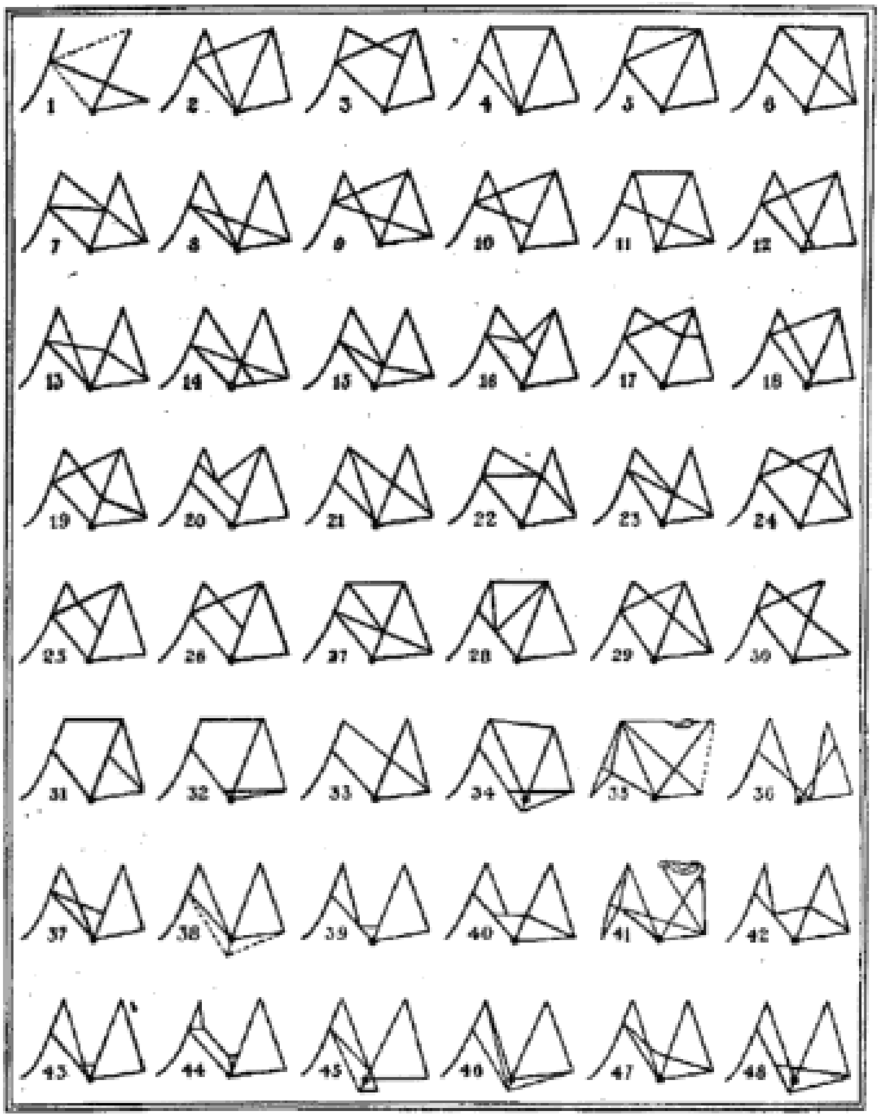

Figure 16. Dutch bicycle frame designs circa 1900. Retrieved from http://www.rijwiel.net/kruisf2e.htm

These modifications were almost entirely employed on lugged frames and by far the most popular of these types of women’s bicycle frames are the loop frames illustrated previously.

The diamond frame was also modified into a further variant by the addition of a second crossbar (top tube). Usually affixed parallel to the existing cross bar, the second structural element significantly increased the frame strength and rigidity (Figure 17). It was not uncommon, and in India and China it still is, to see bicycles of this type being used to transport loads of over 50 kilograms such as bags of rice on the crossbar/top tube.

Figure 17. Indian Bicycle with Double Top Tubes. Retrieved from http://www.kwcycles.com/kw-bicycle1.htm

1.5.2. Steering Forks

An integral, but separate part of the bicycle frame is the apparatus which allows the bicycle to be steered. This part of the bicycle is referred to as the forks due to their two pronged appearance. Permitting the bicycle to be steered and manoeuvred, the forks are characteristically mounted at the front of the bicycle and the stem rotate within two sets of bearings at the upper and lower extremities of the head tube. During the course of development of the modern bicycle the diameter of the fork stem has become standardised at a nominal 7/8” (22.2mm) diameter – ISO Standard, however, the length of the tube may vary from between 100mm and 200mm, and even up to 300mm depending on the size and type of frame. (See frame geometry)

The most common method of attaching the fork to the frame is by the threaded headset type in which the “column” of the forks (fork stem) is threaded for a certain distance at its upper portion. These forks are usually manufactured with the maximum length of stem, and the fabricator will cut the threaded portion to the length which best suits the frame head set. Due to the manner in which the top bearing is attached this dimension is critical, if the column is too long the lock nut cannot be tightened, if it is too short, there is insufficient thread to secure the column. This implies that threaded forks are only interchangeable on bicycles with the same length of steering head tube. Possibly for this reason, over the last decade the use of the thread less headsets has become more widespread. As the name implies, the fork column of a threadless headset has no screw thread, but is completely smooth. The column is secured by clamping the steering stem to the column by tightening two screws. As with the threaded fork column, the threadless column is cut to length to suit the frame but the dimensional tolerance is not as critical as any slack can be accommodated by suitable rings or spacers. Final tightening of the threadless headset is accomplished by the top cap and star fangled nut which is a patent self-clamping device inside the fork column.

A number of hybrid threaded and threadless systems also exist and various types of adaptor are required to fit them. With the advent of the mountain bicycle the forks and fork stem was enlarged to 1” (25.4mm) diameter – early examples employed threaded stems and later ones the A-Head or threadless type.

In both threadless and threaded systems the forks themselves can vary from straight, curved, solid, or with suspension depending on the type of bicycle. However, fork design and development invariably goes hand in hand with frame design and development to ensure compatibility between the two regarding handling and riding characteristics.

1.5.3. The lugged frame today

Although produced in smaller numbers than in the past when compared to welded frame fabrication for example, the lugged frame is still mass produced in India and

China and in smaller quantities by bespoke and custom frame builders throughout the world.

The design of the lugs allows differentiation, and high quality manufacturers employ lugs which can be highly decorative. When painted in such a way as to accentuate the lugs the bicycles are easily identified as belonging to a specific frame builder (Figure 18).

The decorative lugs shown in the next image are the “trademark” of Rivendale bicycles.

So as to avoid overheating and distortion of the tubes and lugs when brazing high quality frames, silver solder which has a melting point of about 650-725°C is used rather than bronze which requires temperatures of up to about 900°C. In this way possible weaknesses are avoided.

Figure 18. Contemporary lugged steel frame

Rivendale Bicycles. Retrieved from http://www.rivbike.com/

1.6. Aluminium framed bicycles

In an attempt to reduce the weight of their bicycles, frame builders sought other materials which would provide structural strength combined with lightness. Consequently, lighter aluminium was tested and various alloys combining the required characteristics were found suitable. However, some modifications were necessary to the traditional lugged method of frame fabrication, as in the past brazing could not be employed due to the constraints in brazing aluminium alloys. Methods such as swaging, pinning, and fixing with screws were used to fix aluminium tubes in the cast aluminium lugs (Figure 19).

Figure 19. Caminargent Aluminium Bicycle Frame manufactured by Caminade of Paris circa 1937. Retrieved from http://forums.thepaceline.net

An interesting feature of the Caminade bicycle manufactured in the mid-1930s is the use of heptagonal aluminium tubing. Tubing which is not round section has advantages in this form of construction as the facets permit positive clamping and pegging which resists turning. The choice of 7 sided tubing rather than hexagonal tubing is interesting and was possibly an aesthetic choice rather than a purely functional. Also of note is the seat tube which being seven sided only grips the round seat post on the flats. Nevertheless, even in the 1930s some French and Italian frame manufacturers produced welded aluminium frames with success; however it was not until more efficient methods of aluminium welding became more commonplace that welded aluminium frames began to be produced in increasing numbers. Formerly, welded aluminium frames were fettled to give a clean smooth appearance (Figure 20).

Figure 20. Welded and fettled aluminium bicycle frame by Nicola Barra bicycle built for Garin cycles in 1941. Retrieved from https://vintagebicycle.wordpress.com/2011

However, as the removal of material to create a smooth transition can significantly reduce the strength of the weld, aluminium frames came to be left unfettled and retain the visual characteristics of a welded joint. This evidence of a regular weld bead has come to represent its own visual aesthetic and can be found on many welded aluminium components (Figure 21).

Figure 21. Welded aluminium frame head tube with reinforcement fillets. Guerrilla Gravity Bikes USA. Retrieved from http://ridegg.com/

Due to the heat concentration at welded joints and the resulting potential for fatigue, and subsequent failure, reinforcement was found to be required at some highly stressed parts of aluminium frames, especially those used for completion and radical bicycle sports such as downhill and mountain biking. Subsequently welded fillets are frequently added at points of stress such as at the head tube and downtube.

1.7. Composite bicycle frame construction

With the advent of polymer resins GRP fibreglass composites were used to create mouldable, relatively light weight structures for the automobile and motorcycle market. However GRP was never used as a bicycle frame other than the Bowden Spacelander.

Nevertheless, with advances in reinforcement materials, more specifically carbon fibre, led to its use in the production of bicycles.

Initially the construction methodology of carbon fibre bicycle was very similar to that used for the lugged steel diamond frame. Lugs were fabricated from steel and the tubes were replaced by light weight wound carbon fibre reinforced resin (Figure 22). The tubes were bonded into the lugs by epoxy resin and the result was visually very similar to a conventional frame.

Figure 22. Exxon Carbon Fibre and Steel Graftek frame. Retrieved from http://www.classicrendezvous.com/USA/Graftek.htm

Further development in carbon fibre frame technology and manufacturing techniques led to the use of carbon fibre for the whole frame. The design of the frame is conceived so that resin impregnated carbon fibre can be introduced into a mould of the whole bicycle frame with any metallic components or pieces inserted in the relevant positions then curing takes place and the result is a one piece “monocoque” frame which is light weight, robust, and able to withstand the stresses it is subjected to (Figure 23).

Figure 23. Trek Y Foil Carbon Frame Bicycle 1998. Retrieved from http://www.trekbikes.com

In addition to the advantages of robustness and light weight the carbon composite frame can be designed to take advantage of the mouldability of the carbon composite material which enables frame designers to explore the possibilities without the constraints of building up frames from separate elements in the conventional manner.

1.8. Bicycle Types and Evolution

From its earliest inception, the bicycle has evolved into various divergent types, each one of these types embodying specific characteristics related to their function and use. Although relatively well defined types of bicycle are easily distinguished such as racing bicycles compared to tradesman's bicycles, certain sub-types are more complex to define.

1.8.1. Bicycle sub-type history and evolution

Although certain types of bicycles have a long history, (track bicycles, daily transport, delivery bicycles for example) other bicycle sub-types have appeared relatively recently (Downhill, mountain bike and BMX for example). Throughout the evolution and development of the bicycle, various types and sub-types have evolved and can be divided into the following types as defined by principal use. However, due to continuously evolving trends it is completely reasonable to assume that within the bicycle sub-types mentioned here, that further variations of the particular sub-types will appear.

1.8.2. Bicycle Categories

In the following section the most common types of bicycle are categorised by their function. Each type is broadly defined with no particular consideration given to particular manufacturers or countries of origin.

Road Bicycle

The road or racing bicycle is one of the types of bicycle with the longest history. Aerodynamic riding position, higher gearing and light weight categorised the early racing cycles. These characteristics are still the benchmark for today's road bicycle (Figure 24).

Figure 24. Trek road bicycle. Retrieved from http://www.trekbikes.com

Most of the advances in bicycle technology are the result of improvements made to racing bicycles, especially the use of innovative materials for frame manufacture.

The road/racing bicycle is almost universally characterised by a light weight diamond frame, multiple gearing (up to 30 gears) cable operated centre pivot brakes, dropped handlebars, lightweight saddle, lightweight wheels, and lightweight components. The riding position is designed to maximise the muscular power of the rider and create a low drag coefficient by the rider assuming a "tucked" riding position.

Track Bicycle

The first bicycle velodromes were built in the mid to late 1900s and their sole purpose was to give cyclists the opportunity to attain velocities that would be impossible on the roads of the time due to the uneven surfaces and pot-holes. Nowadays track cycling bicycles are designed for aerodynamic efficiency, lightness, and high speeds (Figure 25).

Figure 25. Track bicycle. Retrieved from http://www.bloomberg.com/ss/08/08/0807_olympic_innovation/13.htm

In many cases the track bicycle still employs a diamond frame format which has the frame elements faired and smoothed to reduce the wind resistance to the absolute minimum. The wheels spokes are frequently replaced with a type of carbon fibre membrane which further reduces drag as shown in the above photograph.

Utility/City Bicycle

As the name implies, utility bicycles are used as a dedicated (sometimes function specific), everyday form of transport. The utility bicycle is characterised by 26” MTB or 26” x $1^{3}/_{8}$” or 28” tyres with a relatively shallow tread pattern, as reduced rolling resistance is an advantage on hard surfaces.

Figure 26. Dutch City Bicycle. Retrieved from http://omafiets.com.au/products/gazelle-medeo-lite-2013-57cm

Comfort and reliability are of prime importance. Weight is not considered an essential factor in design. Millions of utility bicycles are used as everyday transport in countries such as India and China, both of which produce approximately 10 million bicycles for domestic sales and export per year. Single speed, 3 speed hub and 5 or 7 derailleur gears are common. The riding stance is upright and a comfortable saddle, curved back handlebars, front and rear lights, mudguards and carrier are usual components (Figure 26). City bicycles are a common form of transport for commuters and are produced in both male and female versions.

Work or Tradesman's Bicycle

Working or tradesman's bicycles are differentiated by their robust qualities and the provision for carrying loads or cargo. Such bicycles are still used by postal services and in countries where the bicycle is still an essential means of transport in both rural and urban environments, such as in India and China.

Figure 27. Modern delivery bicycle. Dutch Bike Factory Website 2015.Retrieved from http://www.dutchbikefactory.com/pages_eng/home.htm

Recently there has been an increase in the use of “Tradesman’s” bicycles in such countries as Germany, Denmark and Holland as awareness of environmental and economic issues has become more widespread, with such services as moving large objects small distances with specially designed load carrying bicycle or tricycles (Figure 27).

BMX Bicycle

Originally conceived as a children’s bicycle, the BMX (Bicycle Moto Cross) bicycle owes it origins to juvenile cyclists in the 1960s imitating the Moto Cross sport on their bicycles. Certain details characterise the BMX bicycle, the 20” wheel was universally adopted, the frame is the well proven compact diamond frame format, but with the seat tube reduced in length to lower the saddle height (Figure 28).

Figure 28. BMX Bicycle. Retrieved from https://www.harobikes.com/bmx/bikes/2015-freestyle/midway-2015

The BMX bicycle has no gears, but uses a very low gear ration (44:16) with a small number of teeth on the crank wheel , a reinforced one piece or specialised crank, and a front brake arrangement which allows the steering to be rotated or spun through 360º due to a special splitter yoke at the top of the head tube. The 20 inch x 2.25 wheels (ETRTO 37-451, 32-451, and 28- 451) are frequently laced with more than the regular 36 spokes, to give more rigidity, 72 spokes being relatively common.

Mountain Bicycle

Before “mountain bikes” as such, existed, old utility bicycles or “klunkers” were stripped of their mudguards, chain guards, and any other unnecessary accessory and fitted with wide flat handlebars like motorcycle dirt bikes, and the widest knobbliest balloon tyres available.

The mountain bike in its definitive form is an all-terrain bicycle which may be used for recreational off-roading, or competition. The Mountain bike is characterised by 26” MTB studded tyres with a wide track, multiple derailleur gears with very low gear ratios, front and rear suspension, flat handlebars, and the absence of mudguards.

Figure 29. Unusual shaft drive Dynamic Outback mountain bicycle. Retrieved from http://www.dynamicbicycles.com/

Due to the extensive market for Mountain Bikes, frequent changes to the frame design are made, either to increase performance or simply for aesthetic reasons (Figure 29). To a certain extent the “mountain” bike has become the generic style of bicycle which has led them to be sold in a wide variety of retail outlets including supermarkets for relatively low prices. This has led to the production of low quality mass produced bicycles which have been value engineered to the point where safety and function are often compromised. See Appendix ix – Supermarket Bicycles.

Hybrid Bicycle

Hybrid – The so-called hybrid bicycle stems from the aim to fill the need for a bicycle which embodies characteristics of the utility and the road or mountain bike and was first conceived and built by individuals to their own specifications.

Commercially the hybrid bicycle is the response by manufacturers to the perceived need for a bicycle which is sufficiently robust for occasional off road use, and also for road or even commuting. Recognising the potential market for such a bicycle, the hybrid is now produced by almost all major bicycle manufacturers (Figure 30).

Figure 30. Trek Hybrid Bicycle. Retrieved from http://www.trekbikes.com

As the name suggests, there are no specific characteristics of the hybrid bicycle, but rather a combination of various components and configurations suited to the individual's needs.

Factors such as frame type and size, size of wheels, transmission systems, forks, and handlebars are combined or changed to create the required “hybrid”.

Trekking or Touring (Randonneur) Bicycle

The Trekking or formerly touring bicycle is developed for long distance riding with luggage and equipment and is frequently referred to as a *Randonneur* from the French name for the activity.

Figure 31. Touring bicycle. Retrieved from http://www.nordicgroup.us/bikerec/

The characteristics of the *Randonneur* embody robustness, comfort, variable riding position, lightness, large wheels (28 or 700), high pressure tyres, useful gear range for touring, front and rear luggage racks, water bottle holders, lights, etc. (Figure 31).

Comfort Bicycle

For many years, the typical roadster bicycle could be considered as a comfort bicycle where the riders comfort was a prime consideration as opposed to performance. (Vis the racing bicycle) Nowadays comfort bicycles are categorised as bicycles which are easy to mount, due to their low stand over height, have an upright riding position, which puts little strain on the rider’s back, and often allow the rider to place both feet flat on the floor when stationary, or when stopped at traffic lights for instance (Figure 32).

Figure 32. Comfort bicycle with low step-over frame. Retrieved from https://totalwomenscycling.com/commuting/best-dutch-bikes-500-28164/7/#Jus6l0VlIQgYPovl.97

Further details which characterise the comfort bicycle are large diameter wheels which are not as susceptible to road surface irregularities, and swept back, high level handlebars, which put little or no strain on the arms and shoulders. Comfort bicycles are often fitted with small luggage carriers or baskets to facilitate shopping and carrying personal items. Due to the use of higher strength alloys and improved welding techniques, the comfort bicycle frame has undergone considerable changes and modifications, principally in dispensing with the diamond format and even the double tube loop or “swan” frame. The example shown above has a single down-tube with a strengthening tie close to the bottom bracket. As performance is not a primary concern, the frame can be made this way at the expense of added weight, accessories such as mudguards, chain-guard, prop stand and sprung saddles are common on comfort bicycles and contribute to the comfort of the rider. The low step-over height, sometimes combined with a relatively low saddle height allow more elderly riders to stop and remain stationary with the feet flat on the ground and dismounting is facilitated.

Cruiser Bicycle

Conceived and designed to appeal to the younger American generation in the late 1930s and 40s, early cruisers sought to copy the motorcycles of the era, even to the extent that the frame sometimes embodies a “fake” stamped steel petrol tank (Figure 33).

Figure 33. Dayton Streamline 1938. Retrieved from http://www.nostalgic.net/bicycle105

On the better quality models, frame joints were leaded, smoothed, and the frame was painted in “coachwork” style. Wide, swept back handlebars ensured a comfortable riding position. A back pedal (coaster) brake and the absence of a front brake was common, and a sprung saddle and balloon tyres increased ride comfort. Styling reflected the motorcycle and automobile trends of the era with streamlined accessories, such as lamps, grips, emblems, and even handlebar grips etc. No great consideration was given to reducing the weight of Cruiser bicycles as styling was the main objective.

Reproduced below is a section from the Bicycle History Timeline International Bicycle Fund (http://www.ibike.org/index.htm)

> *"Introduced just after the First World War by several manufacturers, such as Mead, Sears Roebuck, and Montgomery Ward, to revitalize the bike industry (Schwinn made its big splash slightly later), these designs, now called "classic", featured automobile and motorcycle elements to appeal to kids who, presumably, would rather have a motor. If ever a bike needed a motor, this was it. These bikes evolved into the most glamorous, fabulous, ostentatious, heavy designs ever. It is unbelievable today that 14-year-old kids could do the tricks that we did on these 65 pound machines! They were built into the middle '50s, by which time they had taken on design elements of jet aircraft and even rockets. By the '60s, they were becoming leaner and simpler".*

Nowadays some modern cruisers feature custom paint schemes and theme logotypes.

Figure 34. Modern Cruiser Bicycle. Retrieved from http://nineplus.com/new-products-beach-cruiser/

The modern cruiser above still makes formal reference to the origins of the type by incorporating the stylised "false" gas tank and "girder" sprung forks (Figure 34). A characteristic of all cruisers is the use of "balloon" tyres fitted to wide rims. Due to the absence of the brakes coming into contact with the wheel rims, the rims can be painted to enhance the aesthetic of the bicycle.

Beach Cruiser Bicycle

The Beach Cruiser, based on the stripped down cruiser bicycles (i.e. fake petrol tank, accessories etc.) is a bicycle with a longer wheelbase than average. More often than not, the typical beach cruiser has no front brake and the rear brake (coaster brake/roller brake) is mounted on the single speed, or internally geared hub.

In terms of styling, the beach cruiser is relatively unique in that almost all of the frame tubes are curved, which gives it a non-aggressive, subtly organic appearance compared to most other bicycle frames. The beach cruiser colour pallet is often in keeping with this non aggressive appearance and colours such as beige, light green, light blue, pink and yellow are common, especially for women's models (Figure 35).

Figure 35. Women's Beach Cruiser Bicycle. Retrieved from http://nineplus.com/new-products-beach-cruiser/

The lack of mudguards, front brake, brake levers, cables, and gears give the Beach Cruiser a clean, uncluttered appearance. As the name implies the Beach Cruiser is a leisure bicycle used for short trips along beach promenades for example where there are hardly any inclines. The climate in California, which is the home of this sub type, is very suitable for beach cruisers and a wide variety of makes and models can be found there.

Figure 36. Man's Beach Cruiser Bicycle. Retrieved from http://nineplus.com/new-products-beach-cruiser/

Beach cruisers have become more widespread and popular in recent years and are often a "lifestyle statement". They are made in both women's and men's models but both maintain the curved frame members (Figure 36).

Figure 37. Customised Paint on a Women's Beach Cruiser Bicycle. Retrieved from http://www.copenhagencyclechic.com/2014/03/laidback-copenhagen-by-bike.html

Folding Bicycle

Almost since the invention of the safety bicycle, there have been numerous attempts at designing and producing folding or compact bicycles. There are many examples of patents from the late 1800s and early 1900s featuring folding or break-down mechanisms for bicycle frames. Although similar, folding and compact bicycles are not synonymous with each other.

Figure 38. Italian Alpine troops with folding bicycles early 20th Century. Retrieved from http://www.oldbike.eu/museum/world-war-one/bianchi-military-folding-bicycle-model-1912/

Originally the folding bicycle was a variant of the typical diamond frame large wheel bicycle, having an articulated frame which allowed it to be more easily transported in difficult terrain where it was impossible to ride, as can be seen in the photograph of the of the two Italian Bersaglieri Alpine troops (Figure 38). However, when small wheels became more popular the compact bicycle appeared in many guises and became more sought after as it could be integrated into the lifestyle of the commuter/driver/cyclist (Figures 39 & 40).

Figure 39. Montague Paratrooper Folding Bicycle (Folded) Retrieved from http://www.montaguebikes.com/

Figure 40. Montague Paratrooper Folding Bicycle (Ready to Ride). Retrieved from http://www.montaguebikes.com/

Compact bicycles

“Full size” 26” wheel folding bicycles are relatively uncommon. However due to trends in small wheel bicycle development the Compact bicycle is today one of the types of bicycle which is sought after by urban users who live in apartments, or houses with limited space. A large range of products are available from low cost compact bicycles to “designer” bikes and fully equipped models such as the Brompton (Figure 42).

Figure 41. Strida compact folding bicycle. Retrieved from http://www.strida.com

Figure 42. Modern Brompton folding compact bicycle. Retrieved from http://www.brompton.com/

The small wheel is the fundamental component of the compact bicycle and sizes as low as 16 inches diameter and less have been used (Figure 41).

The compact bicycle is an object of compromise and a delight for designers. It must be functional to ride (for limited distances) and it must be compact. It is a difficult task to conciliate these two parameters as undoubtedly one or the other will gain predominance over the other.

Decisions as to where the frame or other parts must fold lead to structural and safety issues, as well as the ease that the bicycle can be folded and opened. In addition clamps, clips, and fasteners must resist repeated use. One of the products to appear which was directly related to the development of the compact bicycle was the folding pedal which reduces the width of the compact bicycle considerably.

1.9. Typology and Differentiation - Review

Considering the great diversity and number of bicycle types currently available it is worth reviewing the original differentiation criteria and the subsequent evolution of the sub-types.

The original “safety bicycles” were conceived as a safer and more stable alternative to the “ordinary” or “penny farthing” large wheel machine. With the safety’s lower centre of gravity, chain driven rear wheel and smaller wheels of similar diameters front and rear, the safety bicycle may be considered as the ontological standard of two wheeled transport. In the late 1880s a number of safety bicycles were available from different manufacturers. However, the innovative Rover safety bicycle, designed by J. K. Starley of Coventry in 1885 is probably the best known, and coined the term “diamond frame”

The introduction of the pneumatic tyre at the same time also led to the increased popularity of the new machines. By the end of the 19th century or the beginning of the 20th century the “safety” bicycle had become the universal norm of two wheeled pedal transport and as a consequence the term “safety” which differentiated it from the “ordinary” became less and less employed and eventually fell into disuse, with simply the term bicycle being employed .

To give an example of the popularity of the bicycle at this time, production of bicycles in the United States increased by a factor of ten in less than a decade, with 200,000 examples recorded in 1889 compared to 2,000,000 in 1897

Differentiation of the safety bicycle in the late 1880s and 1890s was categorised by:

- The absence or lowering of the top frame tube which clearly differentiated the woman’s from the man’s model, - a practice which has continued to the present day.
- dropped handlebars on racing bicycles for lessened wind resistance and drag
- different gear ratios (crank and sprocket sizes) for specific activities such as everyday riding, touring, or track events
- skirt guards on women’s’ models
- reduced scale children’s models (Figure 43)

Figure 43. Child's safety bicycle circa 1897,

Smithsonian Institute – America on the Move. Bicycle Collection. Retrieved from http://amhistory.si.edu/onthemove/collection/object_316.html

The child's safety bicycle shown above has been manufactured using exactly the same methods used for adult bicycles of the time, i.e. lugged frame construction.

1.10. Children's Bicycle

Due to the diverse nature of children's bicycles their analysis is beyond the scope of this work.

1.11. Characterisation by wheel size

Throughout of the course of the evolution of the bicycle, the size of the wheels underwent a number of changes in its development. The first boneshakers employed similar sized front and rear wheels whose dimensions were probably dictated by the riders' stature. The Ordinary or penny farthing (named after two coins of significantly differing sizes) employed a front wheel which could have a diameter equal to or greater than the average height the rider and a rear wheel which was generally no greater than knee height.

Due to the inherent instability of the ordinary and its replacement by the safety, wheel sizes reduced to dimensions that varied from to 28” to 30” tyre size diameter.

Most probably it was the initiative to produce children’s versions of adult bicycles that gave rise to the manufacture of small scale versions of bicycle types with the consequent reduction in wheel size.

However, the size of adult bicycle wheels from 1900 onwards became virtually standardized possibly due in part to the restricted availability of the pneumatic tyres which had replaced the previous solid rubber ones. See Appendix iii – Wheel sizes.

1.12. Tyre standards

Prior to the tyre and rim standards being set by the European Tyre and Rim Technical Organization (**ETRTO**) which was adopted around 1970 by the International Standards Organization (**ISO**), manufacturers in different countries produced their own tire and rim sizes.

The majority of tyre and rim sizes are nominal; which means that their actual measurements are within certain dimensional limits. The Bead Seat Circumference (BSC), or Bead Seat Diameter (BSD) (where the tire bead seats in the wheel rim), is the most accurate measurement. French Metric tyres are measured by diameter in millimetres, and by width in letters - A for narrow (20mm) to D for wide (50mm). An exception came with narrow 700-size clincher tires designated as C. Fractional Inches tire sizes usually fit wheels with European straight-bead rims and British wired-on rims. 'Decimal Inches' tire sizes, usually fit America hook-bead rims. Narrow width tires (18cm to 25cm or 1-1/4" to 7/8") usually fit hook-bead rims. See: Appendix iii Wheel Sizing Chart.

1.13. Wheel manufacture

In order to reduce weight, increase shock absorbing qualities and facilitate production, the metal, wire spoked wheel was developed. Early wheels were radially spoked with steel rims. Later the tangential spoked wheel was developed with steel, or wooden rims in some cases to reduce weight and increase stiffness. As with frame manufacturers, it was not long before wheel makers recognised the advantages of aluminium alloys as a light weight alternative to steel. And the first aluminium bicycle wheel rim was produced in France by MAVIC (Manufacture d'Articles Vélocipediques Idoux et Chanel) in 1926. Ref. velo-retro.com

The large wheel (26" or 28") almost exclusively dominated bicycle production until Alex Moulton launched his small wheel bicycle in the sixties[6].

1.14. Transmission typology

One of the essential characteristics which determined the format of the bicycle was the method of propulsion. Early boneshaker "riders" straddled the machine and literally strode or walked whilst sitting. Macmillan's velocipede employed a mechanism that was operated by treadles and the ordinary (bicycle) by a crank moved by pedals.

Due to technological developments, more specifically the perfection of the roller chain by Renolds, the most common type of transmission to be adopted was the roller chain and toothed sprocket. Eventually the *pitch* (distance between links) of the chain was standardised for virtually all bicycle transmissions. However, although the pitch has been standard for over a century there are currently two width variants of the chain, denominated "wide" - 3/16th" and "narrow" - 1/8th", the narrow being used on bicycles fitted with derailleurs where the space between the sprockets is reduced to accommodate up to 9 or 10 separate sprockets. The wide chain is invariably used on single speed bicycles, children's bicycles and bicycles fitted with internally geared hubs and or coater/roller brakes. The wide chain is also exclusively used on BMX bicycles as it offers more strength. Narrow chain is used on bicycles with derailleur gears, such as Mountain bikes and racing bicycles (Figure 44). When correctly maintained and tensioned the roller chain can attain a level of efficiency of up to 98%[7] in ideal conditions (i.e. clean, suitably lubricated, and not excessively worn or "stretched" which is in fact a misnomer as any lengthening is due to wear on the rollers creating excessive play.

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[6] The Biography of the Modern Bike: The Ultimate History of Bike Design. Chris Boardman. Cassell 2015. P 108

[7] http://pages.jh.edu/news_info/news/home99/aug99/bike.html John Hopkins University

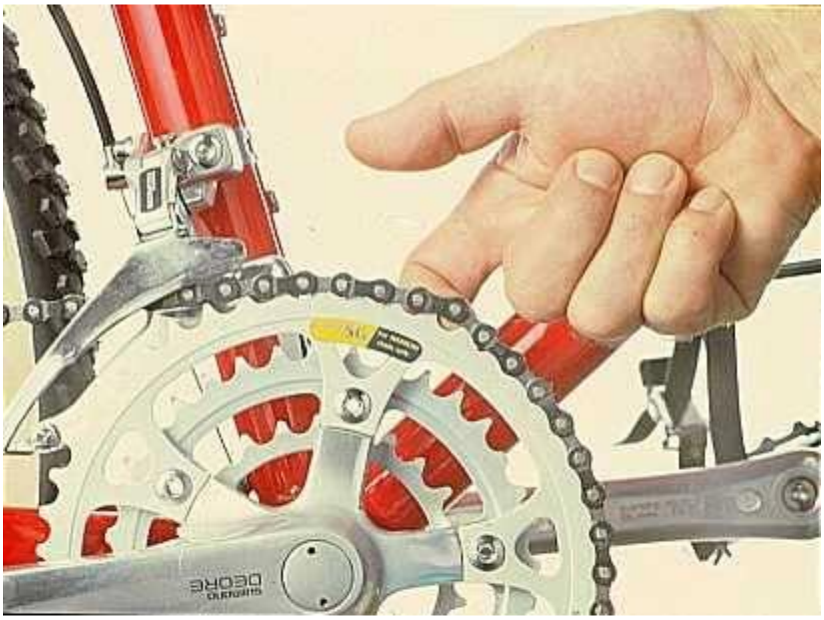

Figure 44. Chain and front sprocket with front derailleur. Retrieved from http://oldtenspeedgallery.com/

It was recognised from early in the bicycles history that in order to maintain this efficiency, the chain requires regular preventative maintenance and lubrication. This led to the invention and the widespread use of the totally enclosed chain guard which not only protected the chain from accumulating road dirt but also protected the riders clothing which was an important consideration as unprotected sprockets and chains can also snag the users clothing.

1.14.1. Other types of transmission

The precursors of the bicycle such as the Draisine, the Hobbyhorse, and *Lauf-maschine* (literally running machine) had no form of transmission other than the rider thrusting their feet against the ground to provide the impulse required to propel the vehicle forwards. However, with the advent of various transmission of movement mechanisms being used in agricultural and industrial machines, a number of these mechanisms were adapted to the bicycle.

Shaft drive

Although the predominant method of transmission since the early days of the bicycle has been by chain, other ways of transmitting the power of the rider to the rear wheel were tried. A logical step was the adoption of the cardan or shaft drive. The first example of shaft drive being used on a bicycle was in 1895 (Figure 45); however some sources cite 1901 as the date when Edoardo Bianchi presented the first bicycle featuring a *cardan* (universal joint transmission).

Figure 45. Shaft drive bicycle circa. 1897. Retrieved from https://oldbike.wordpress.com/

The Tribune bicycle, 1903 (Figure 46) was claimed to be more efficient than contemporary chain transmissions, which is possibly true as early chains were not as efficient as modern day ones. A characteristic of the shaft driven bicycle is its “clean” appearance, the torque tube replacing one of the chain stays. Gearing could be effected either by epicyclic gearing at the cranks or an internally geared rear wheel hub such as the Sturmey Archer.

Today, shaft drive bicycles are still in the minority but a number of manufactures such as Biomega are strong supporters of the system and produce several models.

Figure 46. Tribune Shaft drive Bicycle 1903. Retrieved from http://collection.rydjor.com/bikecollection/1903tri.htm

Toothed belt

Although the Renolds type chain drive is efficient and relatively cheap due to mass production, there are some inherent disadvantages in its use. Lubrication is necessary and the chain accumulates dirt which can be transferred to the riders clothing, and causes wear to the chain and sprockets. The toothed belt which is used in many mechanical and automotive applications is a method of transmitting power to the rear wheel (Figure 47) via a specially profiled crank wheel, with a similarly contoured rear wheel “sprocket”, the flexible toothed belt engages the crank and rear wheel[8].

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[8] Bicycling Science, Third Edition, David Gordon Wilson, MIT Press p 324

Figure 47. Toothed belt rear hub – Bridgestone Picnica Folding Bike c. 2000. Retrieved from http://bikecult.com/works/archive/04bicycles/picnicaF.html

As the belt is continuous with no method of lengthening or shortening it, unlike a chain which can be lengthened or shortened by adding or removing links, this type of drive can only be used on bicycles with raised chain stays, removable seat stays, or some similar artifice. Tensioners which act on the belt cannot be employed, due to their increased friction; neither can Derailleur type gearing be used with this type of drive. Consequently belt drive bicycles have to employ single speed or internally geared rear hubs. Belt tensioning is effected either by an eccentric bottom bracket (see Figure 136), which is rotated in the bottom bracket housing and most often used on tandems and is quite unusual and costly, or the more common method of slotted dropouts which permit the rear wheel to be moved forwards or backwards thus increasing or reducing the tension on the belt.

Treadle

Although the treadle mechanism was one of the first to be used to propel HPVs, the development of the roller chain and sprocket drive soon became the norm and few treadle systems have been commercially produced. This is probably due to the inherent problem of treadle mechanisms being unable to supply a sustained and constant force without the use of a flywheel type device being incorporated. Also the types of linkage required tend to require a larger number of moving parts than a chain and sprocket drive (Figure 48). The treadle transmission is not a viable option for bicycles.

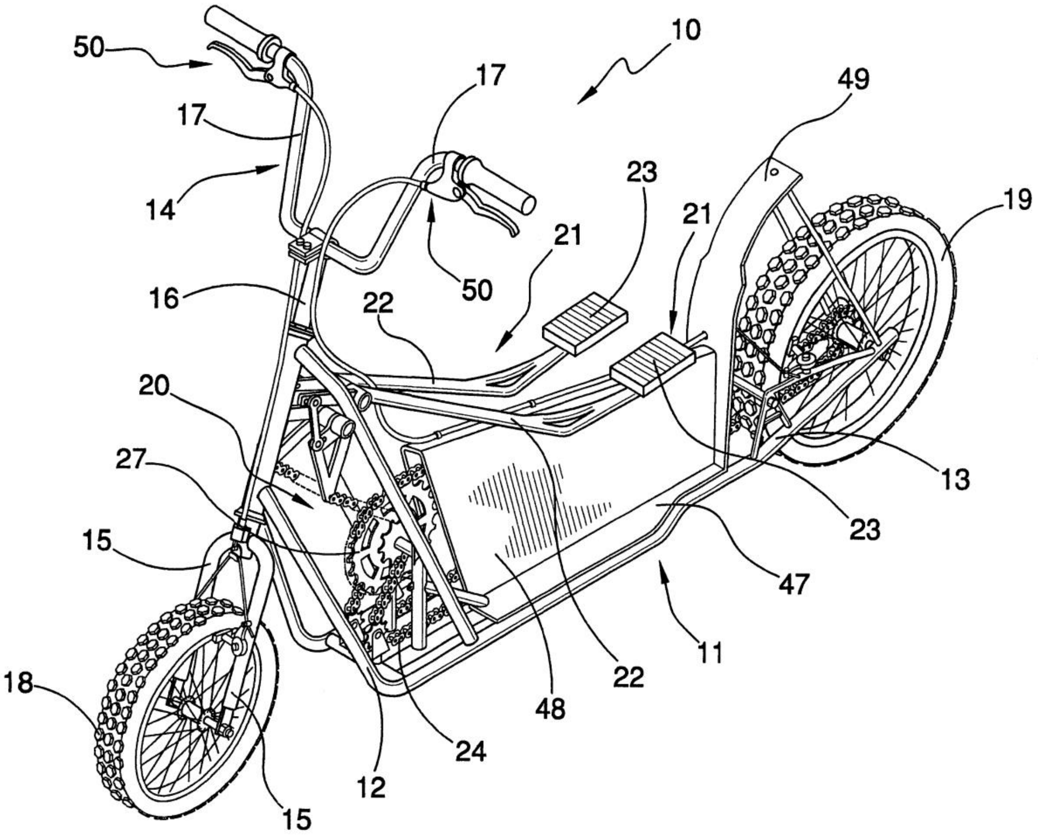

Figure 48. Drawing from patent application for treadle drive vehicle. Retrieved from http://www.google.com/patents/US8128111

1.15. Frame strength and testing criteria

The performance of a bicycle frame is not confined to structural strength alone. Other criteria are also considered such as factors which govern the way in which the bicycle performs or behaves in certain conditions. (See ASTM International - Standard Classification for Bicycle Usage)[9]. For example, flexing is one of the characteristics of the bicycle frame which needs to be taken into consideration as it not only relates to frame strength but also the riding experience. However, the testing procedure for flexing is more often than not, undertaken on frames which do not have the other components such as wheels, saddle, cranks and handlebars fitted.

For example: in terms of rider/bicycle/road interfaces the variation in components is further conditioned by type of tyre, tyre pressure, inclination of road surface etc. which introduce factors which are not simulated in frame tests alone.

A further consideration in frame testing is aging and fatigue.

1.16. Five main factors considered in bicycle frame construction:

NOTE: These factors are applied to conventional bicycle frame construction and are not necessarily valid when applied to the wooden frames discussed later.

1. Material Density
2. Stiffness of the material employed
3. Yield strength
4. Elongation
5. Fatigue and Endurance limits

Material Density and Stiffness of material determine how heavy the bike will be and also the comfort of the ride. Yield strength and Elongation are related to with how well the frame will behave during use and in a crash. Fatigue and Endurance limits are associated with how much normal wear and tear the frame material can handle before failure or breakage.

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[9] http://www.astm.org/Standards/F2043.htm

1.17. Frame materials compared

Initially, when metal was used to replace wood as the frame material for early Human Powered Vehicles, the most commonly available material was wrought iron. However, when steel alloys became an economic alternative, the production of wrought iron frames ceased almost entirely. Nevertheless, even though steel was the material of choice of many bicycle manufacturers other materials were experimented with.

1.17.1. Steel

Steel frames have always been, and still are, widely used in bicycle manufacture. In fact the majority of bicycle frames are made from steel tube which is welded into the required frame format. Higher quality steel frames are constructed from “chromoly” which is a steel alloyed with chromium and molybdenum, it is a dense (heavy) material. However, steel is not as stiff as some other materials, and therefore it provides a smoother ride as small vibrations are absorbed by flexion. Strong forces are needed to deform steel. (Depending on the thickness). In bicycle frame applications, steel has virtually unlimited fatigue and endurance limits. However, it should be noted that at points where the frame members are welded there may be a tendency for failure from heating during the welding process which may lead to brittleness in the proximity (but not the weld itself) of the weld bead.

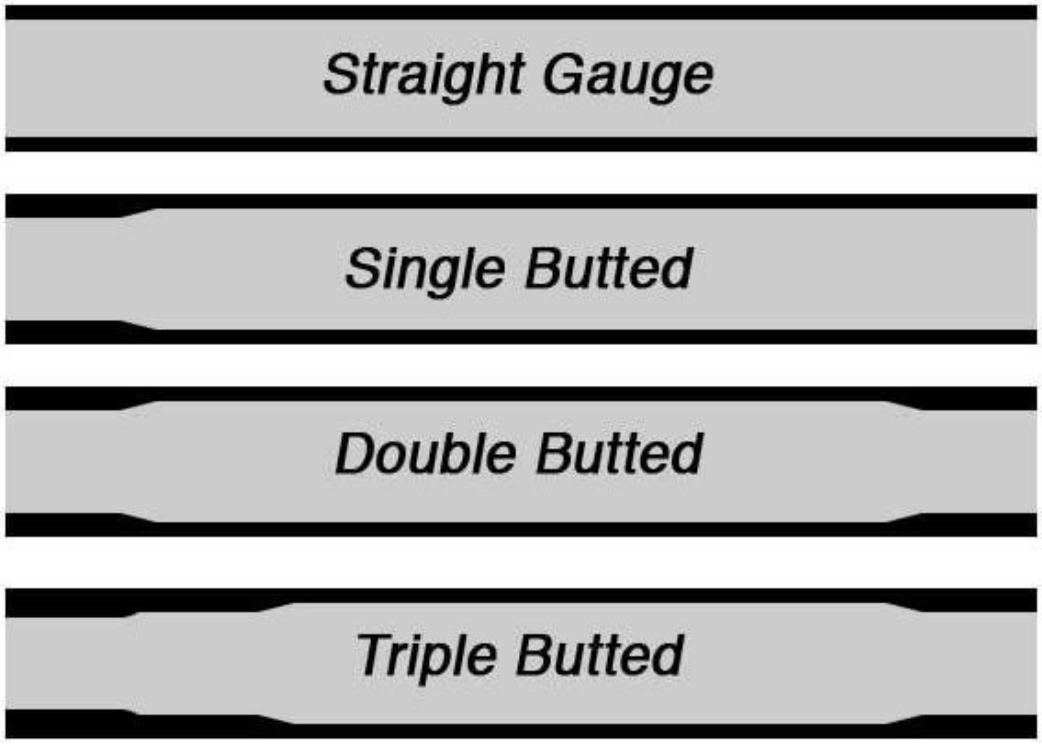

Figure 49. Comparison of Straight, Single, Double, and Triple Butted Steel Tubes. Retrieved from http://www.reynoldstechnology.biz/

One of the great advances in steel frame technology was the invention of “butted tube” by Reynolds as far back as the 1930s (Figure 49).

Whilst retaining most of its strength, butted tube is thinner in the middle than at the ends. The above illustration clearly shows the difference between

- straight gauge tube where the wall thickness is constant (based on the minimum thickness which can be brazed without distortion)
- Single butted where just one end of the tube is butted or thickened.
- Double butted tube where both ends are thicker
- And triple butted which has both ends butted but one or both ends are butted in steps.

1.17.2. Aluminium

Aluminium is not as dense or as strong as steel. Hence aluminium frames are lighter (approximately three times lighter per equal volume) and easier to deform when compared to steel. However, aluminium is much stiffer. This can affect the rider experience, and means that the ride can be more jarring and possibly uncomfortable. Compared to steel, aluminium *does* have a notable fatigue and endurance limit. Nevertheless, the time before failure is within the projected “lifecycle” of the bicycle. There are advantages to aluminium over steel as a frame material from the point of view of corrosion. Aluminium is usually lacquered to prevent surface oxidation, but scratches and scrapes which leave the aluminium unprotected do not “rust” in the same way as steel does, but form aluminium oxide to form a less reactive material.

As aluminium is a less dense and softer metal than steel it is also prone to damage from incorrectly fitted parts. For example the bottom bracket housing thread can be damaged relatively easily if the bottom bracket is cross threaded or erroneously fitted.

Also the dropouts can suffer damage if wheels are frequently removed and refitted.

1.17.3. Titanium

Titanium frames are considered by some to be the “state of the art” bicycle frames. Titanium is light, with a density about half that of steel: 4.43 g/cm^3 compared to 8.00 g/cm^3 which is typical for steel) and it is very strong (specific strength of 288 kNm/kg as compared to 254 kNm/kg for steel for example). As with other frames constructed from metal tubes, tube diameter as well as design determines the stiffness of the frame. In common with steel, titanium’s characteristics almost guarantee an extended riding life. The main disadvantage of titanium is its elevated cost compared to other materials and considerable care is required when machining and welding the material in order to ensure flawless joints.

The three materials (metals) referred to above all fall into a specific category whereby the frame is “constructed” from various components which are joined together by methods such as welding, brazing, or soldering. However, by varying the construction methodology other materials may be employed.

1.17.4. Plastics

Plastics and composites have been employed in bicycle components in various formats, however, plastic as a frame material is less common. An example of a full size plastic framed bicycle which entered full scale production is the Itera Plastic Bicycle, produced in collaboration with the Volvo Motor Company in Sweden.

The Itera Plastic Bicycle

In Sweden, a bicycle manufactured from plastic went into production in 1974. Not only was the frame made from glass fibre reinforced plastic, but the wheels, handlebars and forks were also injection moulded from the same material (Figure 50).

Figure 50. Itera Plastic Bicycle – Sweden. Retrieved from http://twwhlspls.com/itera/

The innovative project was heavily subsidised by the Swedish government and the Volvo automotive company. The apparent economic advantages of injection moulding the frame were an important factor. In fact, it was one of the first revolutionary and major deviations from traditional bicycle manufacturing methods to have occurred in over 80 years. The frame was a one piece moulding and employed strengthening ribs externally and strengthening webs internally and was designed to be injection moulded in glass reinforced plastic. The forks featured longitudinal strengthening ribs and the handlebars were also moulded. The 27 inch eight spoke wheels were moulded in one piece. The saddle post seems to have been a standard (metal tube) component, as was the saddle itself, which was fixed with some form of clamping device integrated in the frame (Figure 51).

Figure 51. Itera Plastic Bicycle Fitted with Conventional Dropped Handlebars. Retrieved from http://twwhlspls.com/itera/

Even the pedal cranks which are the part of a bicycle which are subjected to great stress were injection moulded; the internal webs can be clearly seen in the above photograph. Probably the most striking thing about the Itera bicycle is its appearance. Compared to almost all contemporary bicycles of the time, although it was made from plastic, it looked rather heavy. Not only did the frame appear to be heavy to the onlooker, but also the wheels, which, when compared with wire spoked wheels which are almost universally used on bicycles, had an almost primitive “cartwheel” appearance in spite of being moulded from plastic. The angular appearance was also quite unusual, as was the low step over height, (although increased by the moulded strengthening tie) there also appear to have been very few, if any, advantages to the user. The Itera weighed the same as a normal bicycle, and was less rigid, resulting in a “wobbly” ride which did not inspire confidence in its structural integrity. Following the results my own experiments with wooden frames, the latter is a fundamental flaw in the design of this and any other bicycle, and the perceived weakness of plastic compared to metal was reinforced by the feeling of insecurity. It is not known how the plastic rims compared to metal rims with regard to braking in dry and wet conditions, or what the resulting wear was.

When observed in its entirety, there does not appear to be a great deal of visual cohesion of the frame and wheels. There seems to be a conflict between the linear design of the frame and the curves of the wheels which is surprising given that the plastic injection moulding process and design of moulded parts benefits from flowing curves and absence of angular changes of direction which can structurally compromise the parts. There is also no visual integrity to the saddle and seat-post which appear to be from a different bicycle. Another factor which appears not to have been addressed is the choice of colour. The conservative tones of beige and light blue that were used did not take advantage of the possibility of making the bicycle more attractive and “fun” by using other brighter colours.

Remarkably given the “volume” of the frame compared to a standard bicycle, there was also hardly any attempt at “hidden” cable routing, the cables being visible externally with the exception of a partially routed rear brake cable. In terms of longevity there is no information available regarding this, however, given that bicycles spend most of their lives outdoors, there is the possibility of Ultra Violet breakdown of the plastic as can be observed in things as plastic outdoor furniture after a number of years of exposure. However, most remarkably, contrary to the evolutionary process of rationalisation and standardisation that had occurred over the decades regarding bicycle parts, the Itera designers appear to have "reinvented" almost every component of the plastic bicycle with the result that, to carry out repairs or replace parts or components, only those manufactured by the bicycle manufacturer themselves were compatible, with the result that, bicycles in need of repair were returned or never repaired at all. At the time (1980) and selling for 1,500 SEK the bicycle was more expensive than a standard equivalent bicycle which sold for 1,200 SEK, and similar to IKEA products nowadays it was marketed as a "flat-pack" for home assembly.

Abstract from "The Itera Plastic Bicycle"[10]

> *"The bicycle boom which followed in the wake of the 1974 oil crisis inspired a small group of engineers in Gothenburg to develop a bicycle in fibre composite plastics. All essential parts, such as frame, wheels, fork and handlebar, were designed to be produced by automatic injection moulding, requiring very little subsequent finishing. Substantial grants and loans were obtained to start full-scale production in 1982. In spite of intense advertising and unusually high interest in the media, the new bicycle was never accepted in the marketplace. The bicycle boom was already fading out, and few people were prepared to pay the relatively high price at which it was marketed. The bicycle was just as heavy as a standard bicycle, but it was slightly more flexible, which gave some people a sense of insecurity. The appearance deviated from the archetypal shape of a bicycle, and this is believed to have been the major reason for its rejection".*

From The Itera Plastic Bicycle, Jan Hult, *Social Studies of Science*, Vol. 22, No. 2, Symposium on 'Failed Innovations' (May, 1992), pp. 373-385.

Commercially, the Itera Plastic Bicycle was not a success. Approximately 30,000 Itera bicycles were manufactured and production of the Itera bicycle ended in 1985. A few surviving models can still be found, mainly as curiosities on E-bay, they do not command very high prices as collectors' items, but they are a reminder of the diverse circumstances which can lead to a product's success or failure.

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[10] Social Studies of Science, Vol. 22, No. 2, Symposium on 'Failed Innovations' (May, 1992), pp. 373-385 .Jan Hult. The itera Plastic Bicycle

However, plastic as a frame material has been used more recently in the following example. The Frii recycled plastic bicycle (Figure 52) designed by Israeli industrial design student Dror Peleg embraces the qualities of plastic in its design and goes some way towards resolving the problems inherent in a plastic bicycle regarding its visual aspect. The Frii has the appearance of a large child's bicycle and features brightly coloured wheels and structural ribs which are visibly an inherent part of the design. However, its childish appearance may also be to its disadvantage as potential consumers may not take it seriously. Also it does not appear to use any standard bicycle parts which would potentially make it a disposable object and consequently not a very sustainable design.

Figure 52. Frij recycled Plastic Bicycle – Dror Pelag. Retrieved from http://www.designboom.com/design/dror-peleg-frii-plastic-bike/

A more traditional format has been proposed by Matt Clark. The Innervision (IV) plastic bicycle concept comprises an inner structural frame and two outer halves. Manufactured from polypropylene and reinforced polypropylene the frames parts are thermoformed and ultrasonic and hot air welded together. All other components such as the forks, bottom bracket, cranks, wheels etc. appear to be standard bicycle type components. The proposed manufacturing process appears to provide opportunity for a creative approach without compromising structural integrity (Figure 53). Externally the frame shows no evidence of reinforcement such as ribs and webs and lends itself to be used as a surface for stickers, decals, and other applied graphics.

Figure 53. Innervision Plastic Bicycle – Matt Clark. Retrieved from http://www.wired.com/2008/08/the-innervision/

The metal seatstay and chainstay reinforcement bars can clearly be seen in the photograph above which may lead one to question the need for the plastic shrouding.

1.17.5. Carbon fibre

Carbon fibre frames are a relatively recent addition to bicycle construction, the first non-lugged (i.e. monocoque rather than using carbon fibre tubes) carbon frame being manufactured by Aegis in the United States 1986. Source: Aegis website.

Carbon (and graphite) reinforced frames are lightweight and can be quite stiff. However, carbon fibre frames are not as impact resistant as metal frames.

Nevertheless, the advantage of carbon fibre is that the frame can be designed to incorporate reinforcement where it is most required during manufacture.[11]

1.18. Additional components and accessories

The bicycle frame can vary in complexity and design depending on the intended use, however, apart from the essential component interfaces, other components which are non-essential to the direct function of riding, such as luggage rack fitments, water bottle holders, and illumination brackets may be incorporated in the frame. Where the bicycle frame is made from steel, these fittings can be brazed onto the frame, where the frame is aluminium, these and other parts such as cable stops and rear carrier lugs can be welded to the frame. The frame may also be drilled to accept fittings or they may be simply bolted or screwed on by means of clamps. For example many bicycles have a series of holes incorporated on the front fork dropout and the rear dropouts for the attachment of mudguards; however, the majority of mountain bicycles are not factory fitted with mudguards and this practice has been phased out on many bicycle frames and forks.

1.18.1. Suspension

The need for some method of making the ride more comfortable was identified early on in the bicycle's development. Although the adoption of the pneumatic tyre absorbed shocks and smoothed the ride, uneven road surfaces caused vibrations to travel through the frame, saddle, and handlebars to the rider. As a consequence, the saddle itself was manufactured incorporating padding and metal springs (Figure 54).

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[11] VeloNews article - Metallurgy for Cyclists I: The Basics by Scot Nicol

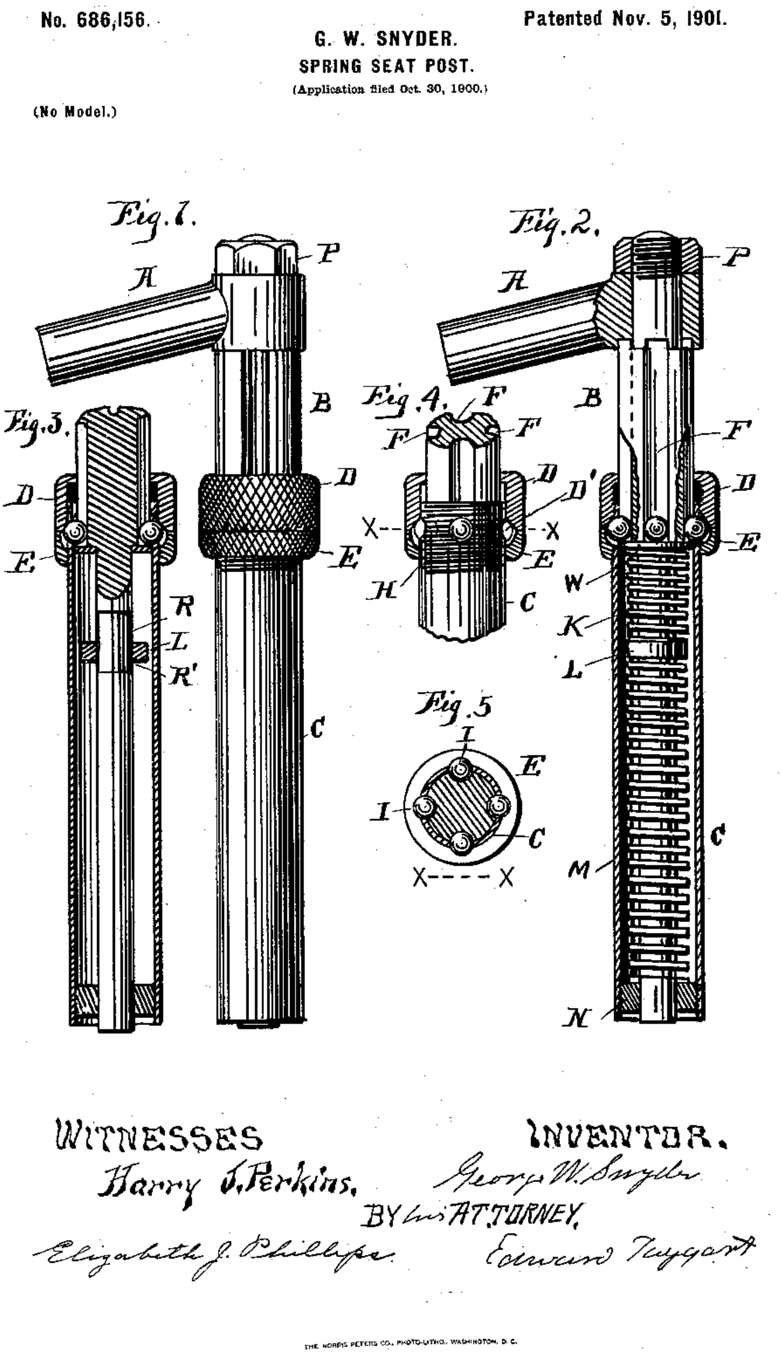
Figure 54. Brooks leather saddles:– B

Brooks Leather Saddles. Retrieved from http://www.brooksengland.com/

The complexity and configuration of the sprung saddle depended on the intended use and the manufacturer with some sprung leather saddles being fabricated from as many as 25 components, and lightweight racing saddles comprising the minimum of material and parts.

If the sprung saddle did not manage to soften the ride, many patents were taken out for various types of devices that would act as shock absorbers. The patent application on the following page shows such a device. The seat post is allowed to move in the vertical direction like a telescopic tube with an internal coil spring to dampen the movement (Figure 55).

However, due to the physical limitation of vertical shock absorption of the saddle itself various attempts were made to introduce vertical shock absorbing into the stem of the saddle and there are patents applied for such devices from the early 1900s.



No. 686,156. Patented Nov. 5, 1901.

G. W. SNYDER.
SPRING SEAT POST.
(Application filed Oct. 30, 1900.)

(No Model.)

WITNESSES
Harry J. Perkins,
Elizabeth J. Phillips.

INVENTOR.
George W. Snyder
BY his ATTORNEY,
Edward Taggart

THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.

Figure 55. Telescopic Sprung Seat Post Patent Application 1901. Retrieved from http://www.google.com/patents/US2644504

Other attempts were made to introduce suspension into the bicycle saddle employing linkages, springs and polymers. Bodyfloat® produces a seat post which incorporates a telescopic spring and shock absorber (Figure 56).

Figure 56. BodyFloat Bike Suspension Seat Post. Retrieved from http://www.cirruscycles.com/

1.19. Standardisation of components

1.19.1. Standardisation of components and systems

Although bicycle frames vary in size (dependant on wheel size for example) and type, certain components and parts have become standardised. The advantage of standardised parts allows the bicycle industry and individual bicycle builders the freedom to experiment with various configurations without recourse to designing completely new systems.

Bottom Bracket

The bottom bracket is basically a subset of conjoined pieces where the crank set is located. The principal frame component is the bottom bracket lug (Figure 57). For example, bottom bracket dimensions such as width, diameter and thread size, and the adoption of left and right hand threads (to avoid undesirable loosening of the components when the torque is applied clockwise on the right hand side of the bicycle, and anti-clockwise on the left hand side of the bicycle) became almost universal.

Figure 57. Bottom bracket – lugged frame. Retrieved from http://www.henryjames.com/bicyle-parts/bike-bottom-bracket-shells.html

This meant that that the bottom bracket axle and ball bearings were interchangeable between many different makes and types.

The bottom bracket shell traditionally used cottered cranks and cup and cone ball bearings (Figure 58). Cottered cranks are attached to the bottom bracket axle by flat tapered cotter pins that are tapped into place and secured with a nut. No special equipment is required for their removal, as they can be tapped out with a hammer and drift, although there was a tendency for them to become loose over time the nut can be tightened to eliminate any play.

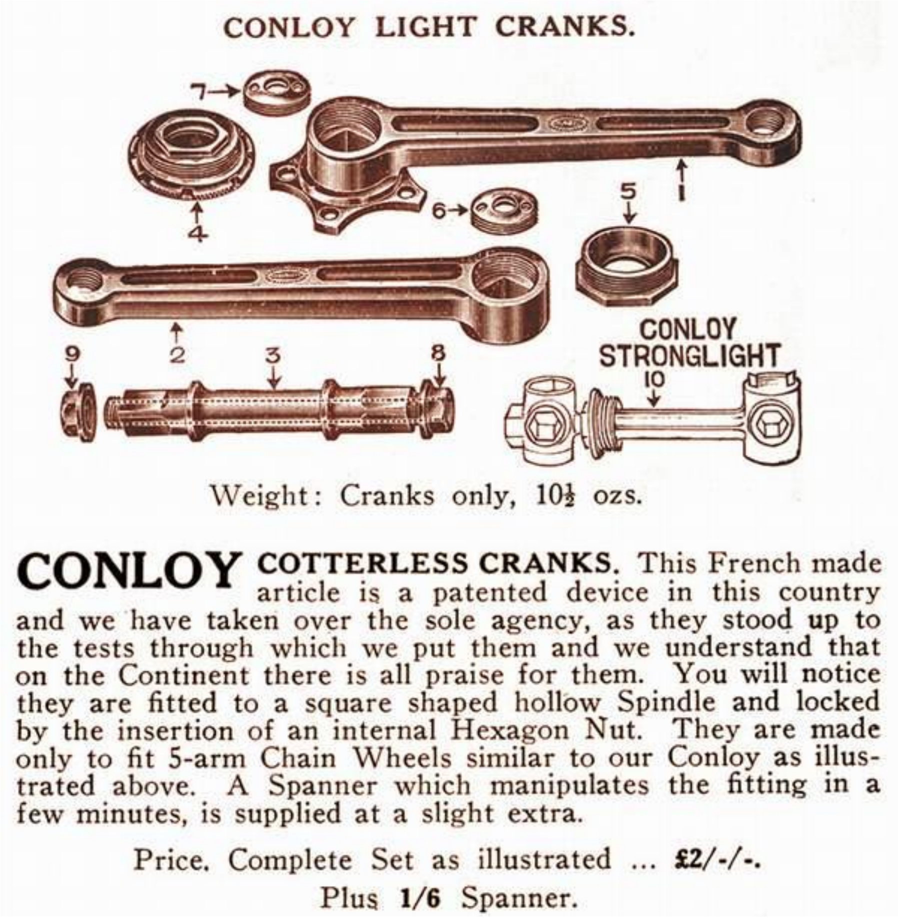
Figure 58. Cottered Bottom Bracket Spindle with Bearing Cups. Retrieved from http://www.velobase.com/ViewComponent.aspx?ID=9fec2064-d0db-4338-be80-dbfb7ab90d18&Enum=119

Eventually the cotter will wear as it is deliberately manufactured from a softer material than the hardened bottom bracket axle. When no further adjustment can be made; the simple remedy is to replace the inexpensive cotter with a new one. (Figure 59)

Figure 59. 9.5mm Crank Cotter. Retrieved from http://www.velobase.com/ViewComponent.aspx?ID=9fec2064-d0db-4338-be80-dbfb7ab90d18&Enum=119

Figure 60. Cottered cranks on a 1970s bicycle. Retrieved from oldtenspeedgallery.com

A system which superseded the cottered crank was the square taper bottom bracket axle. However, the adjustable cup and cone bearing system was retained for many years as the bearing method. Square taper crank axles rely on the friction between the tapered axle and the square hole in the crank to remain firm. To avoid loosening, a hexagonal screw pulls the crank tight onto the taper. The illustration shows the spindle which, instead of being tapped internally has a threaded portion and nuts to secure the cranks (Figure 61).



CONLOY LIGHT CRANKS.

Weight: Cranks only, 10½ ozs.

CONLOY **COTTERLESS CRANKS.** This French made article is a patented device in this country and we have taken over the sole agency, as they stood **up** to the tests through which we put them and we understand that on the Continent there is all praise for them. You will notice they are fitted to a square shaped hollow Spindle and locked by the insertion of an internal Hexagon Nut. They are made only to fit 5-arm Chain Wheels similar to our Conloy as illustrated above. A Spanner which manipulates the fitting in a few minutes, is supplied at a slight extra.

Price. Complete Set as illustrated ... **£2/-/-.**
Plus **1/6** Spanner.

Figure 61. Advertisement for Conloy Cotterless Cranks 1937. Retrieved from http://www.oldbike.eu/museum/

Unlike cottered cranks which can be removed with the aid of a spanner and a hammer, removal of square tapered cranks can only be effected with a special extractor tool (Figure 62).

Figure 62. Park Tools Universal Crank Puller for Square Taper and Splined Cranks. Retrieved from http://www.parktool.com/

In the 1990s sealed bottom bracket one-piece cartridges (Figure 63) were introduced to replace the adjustable cups and cones. This meant that the bearing could not be serviced or adjusted; as they contained no serviceable parts, the whole unit is discarded when worn.

Figure 63. Bottom Bracket Axle Sealed Cartridge. Retrieved from http://www.parktool.com/

Although the standard dimension for the bottom bracket housing is 68mm or 72mm, the actual axle may protrude different distances from either side of the unit to accommodate for frame or crank differences, such as multiple chain-sets, and single chain-sets.

Pedals

Further examples of standardisation may be seen in the choice of size and screw thread of pedal to crank attachment. This is not to say that all pedals are the same. There is a huge variation in size, profile, material, pattern and colour etc. which differentiate pedals destined for racing bicycles, children’s bicycles, utility bicycles etc.

Figure 64. Bicycle pedals with rubber inserts and reflectors. Retrieved from http://www.sjscycles.co.uk/mks-comfort-lite-pedals-prod23663/

High quality bicycle pedals are equipped with two sets of small ball bearings at each end of the pedal shaft, as their smooth rotation with the minimum of friction is essential (Figure 64). However, in order to reduce costs, low quality bicycles often have pedals which have no ball bearings. The plastic of the pedal body is in direct contact with the pedal shaft, and due to the differing materials the friction is reduced. Although suitable for light use where no great force is exerted on the pedals, the plastic is prone to rapid wear which results in premature failure. As a result, pedals are one of the components which are replaced with most frequently.

In Europe and Great Britain and India , typically, the screw thread size for the majority of pedals is English standard, 9/16” x 20 TPI (Note: there are left and right hand threaded pedals) however, some examples of pedal may be manufactured to the old USA standard of 1/2”x 20 TPI. Consequently, as the pedals are not a direct fit onto the frame but onto the crank arms, the type of fitment has no bearing on frame design, other than the Ashtabula one piece crank which used the smaller diameter pedal thread, as do BMX bicycles.

Care must be taken when tightening the pedals to the crank arms so that the threads are not mixed or crossed. In the majority of cases the pedal is stamped with “R” or “L” to identify which side they fit. Due to the elevated forces and stresses applied to the pedals, especially when standing and applying downward thrust, insufficiently tightened or cross threaded pedals can rapidly destroy the treaded portion of the crank arm, especially if it is made from aluminium with the result that the crank arm is rendered economically unserviceable and needs to be scrapped and replaced. The left hand pedal fails more frequently than the right or chain side pedal. However, pedals are almost invariably sold in pairs.

Handlebars

Another component which underwent a series of changes in shape and form was the handlebar. Ergonomic considerations were the main factor, handlebars being curved downwards and backwards on racing bicycles or upwards and outwards on utility bicycles. However, the diameter of the handlebar itself remained almost constant at 22mm (7/8”) with an increase in diameter to 25.4mm (1”) in the centre where it is clamped to the quill stem; consequently this enabled the use of homologation of handlebar grips with a standard internal diameter.

Figure 65. Nitto “Moustache” Handlebar. Retrieved from http://www.rivbike.com/Nitto-Handlebars-s/107.htm

The Nitto “moustache” handlebar (Figure 65) can be used in either the “dropped” or “raised” position.

Currently the majority of Mountain bikes use almost flat or slightly raised handlebars. This tendency has led to an almost universal adoption of this type of bar for a wide range of bicycles whether they are Mountain bikes or not.

The material used for handlebar manufacture is predominantly steel tube. However, when suitable alloys are employed, aluminium may also be used, this is especially the case with racing/road bicycle “dropped” handlebars.[12]

Figure 66. Aluminium Dropped handlebar wound with Leather tape. Retrieved from http://www.rivbike.com/Nitto-Handlebars-s/107.htm

Steel handlebars are often chromium plated but there is a tendency to paint handlebars on low quality bicycles as a cost saving. Aluminium handlebars are more often than not anodised which allows the bars to be coloured as well as natural aluminium colour.

“Dropped” handlebars are frequently taped along their length with fabric, polymer tape, or cork composites (Figure 66).

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[12] The Bicycling Guide to Complete Bicycle Maintenance & Repair: For Road & Mountain Bikes Paperback – September 28, 2010 by Todd Downs (Author) p316

Figure 67. Laminated and curved Wooden Handlebars. Retrieved from https://www.flickr.com/photos/kolb-rahmenbau/6347546756

Recently there has been a resurgence in the interest in wooden handlebars. Wooden handlebars can be made from solid wood or laminated. Laminated wooden bars lend themselves to the use of different coloured woods to give an exclusively decorative effect (Figure 67). The laminations also overcome the problems associated with splitting and potential failure of solid wooden handlebars.

Handlebar Grips

There has been a great diversity of handlebar grips throughout the evolution of the bicycle. Probably the material most used initially was wood as it gave the handlebars a warmer more comfortable feeling than just the metal. However it is interesting to note that as early as 1900 plastic handlebar grips were manufactured in celluloid.

Figure 68. Vintage Japanese celluloid bicycle grips. Retrieved from http://chikutakurinrin.cocolog-nifty.com

The examples above show the diversity of detail, shape, and colour of some early Japanese celluloid grips (Figure 68). The manufacture of celluloid grips continued into the 1950s. Other materials were also used, including leather, cork, rubber and plastic.

Nowadays, there is a wide range of handlebar grips available to the consumer, and they are a common upgrade part. The quality and price of handlebar grips varies greatly. In order to function correctly and safely, handlebar grips must be firmly secured on the handlebar. In fact, removal can be difficult, and in many cases in order to replace grips the old ones have to be cut off and destroyed in the process. This is not a problem if the grips are not going to be reused, but in some cases, the grips need to be removed in order to replace other parts such as shifters and brake levers.

When destroying the handlebar grips is undesirable, removal may be accomplished by directing a concentrated jet of compressed air between the grip and the handlebar and twisting and easing the grip off.

This situation has been recognised by some manufacturers and grips are produced which clamp on to the handlebar making their removal a simple and non-destructive procedure.

Headsets

The steerer tube, which can be defined as the frame member into which the fork stem is inserted were produced in diameters (threaded headset type) that became virtually standard for many years, consequently the diameter of the fork quill at either 22mm (7/8") or 25.4mm (1") also became standardised.

Figure 69. Headset for threaded forks – Sheldon Brown. Retrieved from http://www.sheldonbrown.com/headsets.html

The previous figure shows the parts of a typical headset for threaded forks (Figure 69).

Quill Stem

The quill stem attaches the handlebars to the forks and is a snug fit in the steerer tube. Various methods of securing it are used but the most common is the wedge system which is tightened by a long bolt at the top of the quill (Figure 70). Prior to the adoption of method, the stem was slotted and a threaded cone drawn into the stem by the long bot.

On older bicycles the long bot has a hexagon head, more recently this has been replaced by an inset socket cap Allen bolt.

Figure 70. 22mm Diameter Quill Stems. Retrieved from http://sheldonbrown.com/harris/stems/index.html#onethreadstems

Since the 1990s there has been a move to threadless headsets. In effect there is no quill; the stem (Figure 71) is clamped directly to the unthreaded steerer tube of the forks.

Figure 71. Threadless Aluminium Stem. Retrieved from http://store.velo-orange.com/index.php/components/stems.html

The steerer tube is either 1" diameter or 1 1/8" diameter. The stem may be adjustable allowing the angle to be changed and can vary in length.

Seat post

Although there was a move towards standardisation of the majority of components, one component that became standardised to a certain degree, but at the same time offered a wide variation of diverse sizes was the saddle or seat post (Figure 72).

Figure 72. Seat post detail – Campagnolo equipped bicycle. Retrieved from velofinds.com

The seat post is a tube which is attached to the saddle in such a way as to allow the saddle to be raised, lowered or in some cases tilted. Generally the old style seat post tube narrows at the top. As a rule the part which attaches to the saddle or seat clamp (tapered portion) became standardised at 22mm (7/8”) and in many cases the diameter of the post itself was almost universal as the seat tube diameter was more or less constant among manufactures.

Figure 73. Three, (left) two, (centre) and single (right) rail saddle clamps for 22mm seat post - Brooks saddles. Retrieved from http://www.brooksengland.com/catalogue-and-shop/spareparts/saddle+clamps/

But as manufactures diversified, the diameter of the seat tube depended on the structural characteristics of each frame type. As a result seat post diameter may vary from 25.4mm (1” Imperial) to 31.6mm (1 ¼”) in increments of 0.2mm resulting in over 20 different diameter seat post sizes.

In spite of this diversity, Italian and British steel frames almost invariably use 28.6mm ($1^{1/8”}$) seat tubes. But one size eventually predominated across the board, the majority of bicycle frames using 27.2 mm which is by far the most common size.

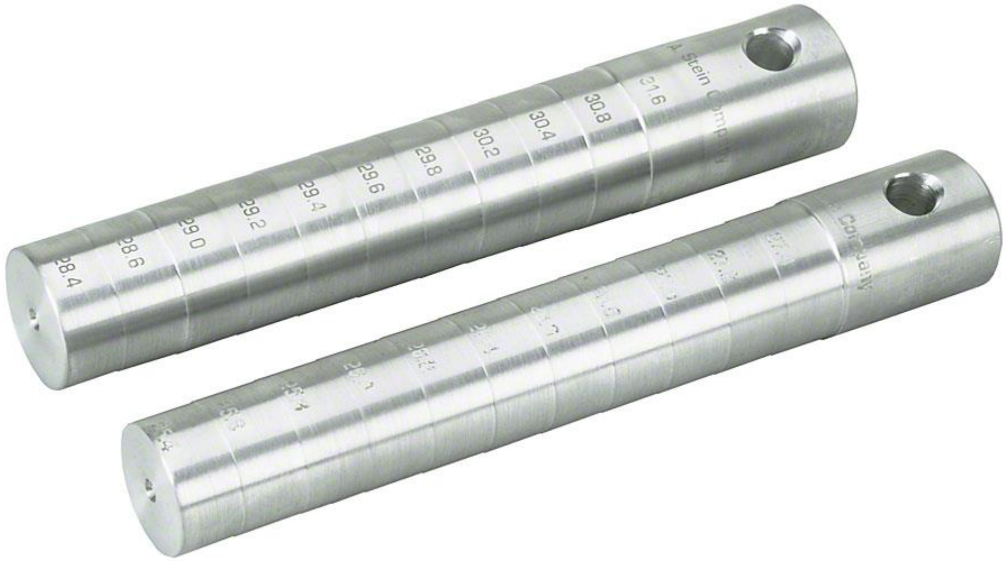

Figure 74. Stein Seat-post Sizing Rod Set – Stein. Retrieved from http://www.jensonusa.com/!mhSNz4Bj02JWAD-b0tON0g!/Stein-Seatpost-Sizing-Rods

Shown above is a seat post sizer gauge (Figure 74). For the post-fitting of seat tubes it is necessary to obtain the correct size to within 0.2mm (manufacturers' incremental sizes) However, the actual clearance tolerance should be as small as – 0.05mm + 0.00mm. In other words the seat post diameter may not be greater than the inside diameter (bore) of the frame seat tube.

Racing or track bicycles are made of thinner tubing, so the inside diameter will be greater if the outside diameter remains the same. As a rule, a larger diameter seat-post size is an indication of a better quality bicycle. Currently 27.2mm diameter is used for high quality bicycles that have 1 1/8" O.D. - 28.5 mm (Outside Diameter) seat tubes.

Figure 75. Surly Constrictor Seat Post Clamp – Surly. Retrieved from http://surlybikes.com/parts/small_parts/constrictor

Seat post clamping

The seat-post clamp is a device which is used to firmly clamp the seat-post in the seat tube to avoid downwards movement of the seat post and also to prevent turning. A poorly clamped seat post is dangerous and unwanted movement can lead to loss of control of the bicycle. Generally, on the majority of bicycles the clamping system was permanently attached to the seat tube, i.e. a slot is machined in the seat tube near the top and a brazed on collar or brazed on lugs are drawn together to squeeze or clamp the seat tube around it by the use of a patent screw. However, design developments have led to the adoption of separate seat post clamps which are not an integral part of the frame (Figure 75).

Seat post clamps come in various sizes based on the outside diameter of the seat-tube. They are generally made from machined aluminium but in some cases from titanium. The finish can be natural or anodised; in the case of titanium seat-post clamps a variety of colours are possible. The seat post clamp may be fitted with a quick release toggle mechanism similar to quick release skewers, however, this has some drawbacks as it makes it very easy to steal the seat-post and saddle, nevertheless this can be turned to advantage as the seat-post and saddle can be removed by the owner rendering the bicycle difficult to ride by would-be thieves and can act as a deterrent to theft. This preventative method is becoming increasingly popular where bicycles are fitted with expensive saddles such as the Brooks B17 Standard leather saddle which retails for about 110 Euros, and the Brooks B17 Titanium which retails at 230 Euros.

1.19.2. Non-standard or so called "Oversized" Components

In recent years, due to the some components failing under the extreme competition conditions which are demanded of them, such as mountain bike trials, downhill, and road racing, reinforced or strengthened "oversized" components have been developed. However, due to the highly specialized and specific nature of these components they are beyond the scope of this study.

1.20. Examples of significant changes in bicycle frame design and manufacture

As has been mentioned previously, the bicycle frame has been the subject of extensive redesign, modification, and development. The basis for such changes are diverse and include efficiency, style, manufacturing methods, and economics. Although there are thousands of registered patents related to the changes made to the bicycle over the decades, only references of some of the benchmark changes that occurred in bicycle development and the reasons behind them are discussed here.

1.20.1. The Dursley Pedersen Bicycle

One of the first significant authors of a bicycle which was both unconventional and visionary was Mikael Pedersen, a Danish engineer who, whilst living in England designed and developed his own concept for a bicycle. As it was produced in Dursley in Gloucestershire, it became known as the Dursely Pederson

Mikael Pedersen was one of the first bicycle builders to create an innovative "spaceframe" of tubular steel components with tensioned "ties" which gave a comfortable ride incorporating lightweight and strength (Figure 76). The Dursley Pedersen is still produced today in limited quantities.

Figure 76. Dursley Pedersen Bicycle 1902. Retrieved from http://www.yesterdays.nl/dursley-pedersen-1903-featherweight-p-471.html

1.20.2. Moulton small wheel bicycle

The diamond frame, with minor differences and modifications, and the loop frame dominated the bicycle market for more than 60 years. However, in the late 1950s Alex Moulton, an automotive engineer and recreational cyclist, asked the question “Why *had* the bicycle hardly changed in its design since the adoption of the diamond frame safety bicycle?”

"Engines of our Ingenuity KUHF-FM Houston "
"No. 1231: AUTOMOBILE ADVERTISING"
<http://www.uh.edu/engines/epi1231.htm>

Figure 77. Model T Ford circa 1910. Retrieved from http://www.uh.edu/engines/epil231%20htm

As a result he re-evaluated the bicycle, returning to first principles and analysed every detail. One of the factors that he addressed was bicycle wheel diameter had remained ostensibly the same for over 50 years, whilst other vehicle wheels had undergone a gradual reduction in size over the years, as was evident in motor cars, and locomotives. (But not motorcycles, with the exception of the Vespa and Lambretta scooters which are a specific example of using small wheels as part of a design philosophy)

Figure 78. BMC “Mini” circa 1961. Retrieved from http://www.aronline.co.uk/blogs/cars/mini-classic/the-cars-mini-development-history-part-1/

As a result of his studies and five years of development Alex Moulton concluded that smaller wheels can be stronger and lighter than large ones, create less drag, and due to less inertia can be accelerated with less effort. In addition, if small wheels are fitted with high pressure tyres, rolling resistance is no greater than for the traditional large wheels. (High pressure tyres – 100 PSI and above - were used on racing bicycles) Alex Moulton proposed that the ideal wheel size should be 16” to 17” (200mm – 225mm) diameter.

However, there *were* some disadvantages associated with the adoption of small wheels – the ride was bumpier on uneven road surfaces, especially with high pressure tyres which provide little or no shock absorption.

Figure 79. Standard Moulton bicycle circa 1965. Retrieved from http://www.flickriver.com/photos/anglepoise/popular-interesting/

Therefore it became necessary to develop a suspension system. After dozens of prototypes were produced and tested, the following characteristics differentiated the Moulton range of bicycles (Figure 79) from their contemporaries.[13]

- The so called “F frame” Moulton bicycle had a low step over height which made mounting easier for both men and women riders and especially older riders of either sex.
- The luggage carriers were mounted lower, thus lowering the centre of gravity
- The single main frame member permitted the bicycle to be conveniently hinged for easy and compact storage in the boot of a car for example.
- The bicycle “looked” modern compared with all the other contemporary bicycles

Moulton’s bicycle was a revolutionary concept, and in the mid-sixties it came at a time when the public wanted something new, fashionable and “different”. As a result, Moulton became the largest bicycle manufacturer in the UK.

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[13] The F-Frame Moultons (Bicycle Science), Tony Hadland, LIT Verlag p 43

In fact, the “Moulton” was so successful that the Raleigh Bicycle Company virtually copied the idea and produced the RSW 16 (Raleigh Small Wheel – 16” diameter) (Figure 80).

So as not to infringe Moulton’s patent, the RSW did *not* have the Moulton patented suspension and high pressure tyres but used “balloon” tyres instead.[14] Unfortunately, the adoption of balloon tyres ironically increased the rolling resistance that Moulton had sought to reduce with his high pressure tyres. Also, for some reason (probably as the RSW 16 was aimed at female riders) the bicycle was effectively scaled down to 90%. Due to the popularity of the small wheeled bicycle and as a direct result of the success enjoyed by the Moulton and to a lesser degree, the RSW, the use of smaller wheels became commonplace in compact bicycle design, with many manufacturers producing their own versions throughout the world.

Figure 80. Raleigh RSW 16 – 1967. Retrieved from http://www.veloscene.net/2013/12/raleigh-rsw-16-deluxe-flamenco-red.html

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[14] The Spaceframe Moultons (Bicycle Science) Tony Hadland p 4

One particular wheel size that became very popular as a spin-off of the Moulton and RSW 16 was the 20”. In England in the mid-60s Dawes manufactured the Dawes “Kingpin” and the separable “Newpin” which was a take apart compact bicycle, and Raleigh responded with the “Raleigh 20” and the “Raleigh 20 Folder”. As a result of the popularity of the 20” wheel size many clones were produced worldwide and nowadays the 20” bicycle makes up an appreciable quantity of overall bicycle sales. However, in spite of the innovations incorporated in Moulton’s bicycles and subsequent similar designs, in the main part bicycle manufactures still relied upon the tried and tested production methods and produced diamond frames bicycles from steel tube in the conventional manner.

1.21. The use of non-conventional materials in bicycle frame manufacture

In addition to developing and testing numerous variations on the diamond frame bicycle fabricated from steel tubing, a more innovative approach was made over the years where non-conventional materials were used to fabricate bicycle frames. The reasons for using non-conventional materials are varied and may be driven by economic factors, availability of materials, perceived improvements, fashion and trends, and less objectively, simply the desire to create something “different” and explore the properties of materials rarely used in bicycle manufacture.

1.21.1. Plastics

The post war era evidenced a boom in the use of plastics (polymers). And in the early 1950s the Glaspar G2, the first all plastic (fibreglass reinforced plastic – FRP or GRP) production car body was manufactured. However, in spite of various patents being taken out for bicycle frame manufacturing techniques using other materials such as plastics, very few were actually put into production. One example which *was* produced was designed by Benjamin G. Bowden, a noted English automotive engineer. To raise morale after the war, Bowden and other designers were asked by the British Council of Industrial Design to submit designs to the 1946 "Britain Can Make It" exhibition which was conceived as a way of showcasing modern design and innovation in the austere post war economic climate.

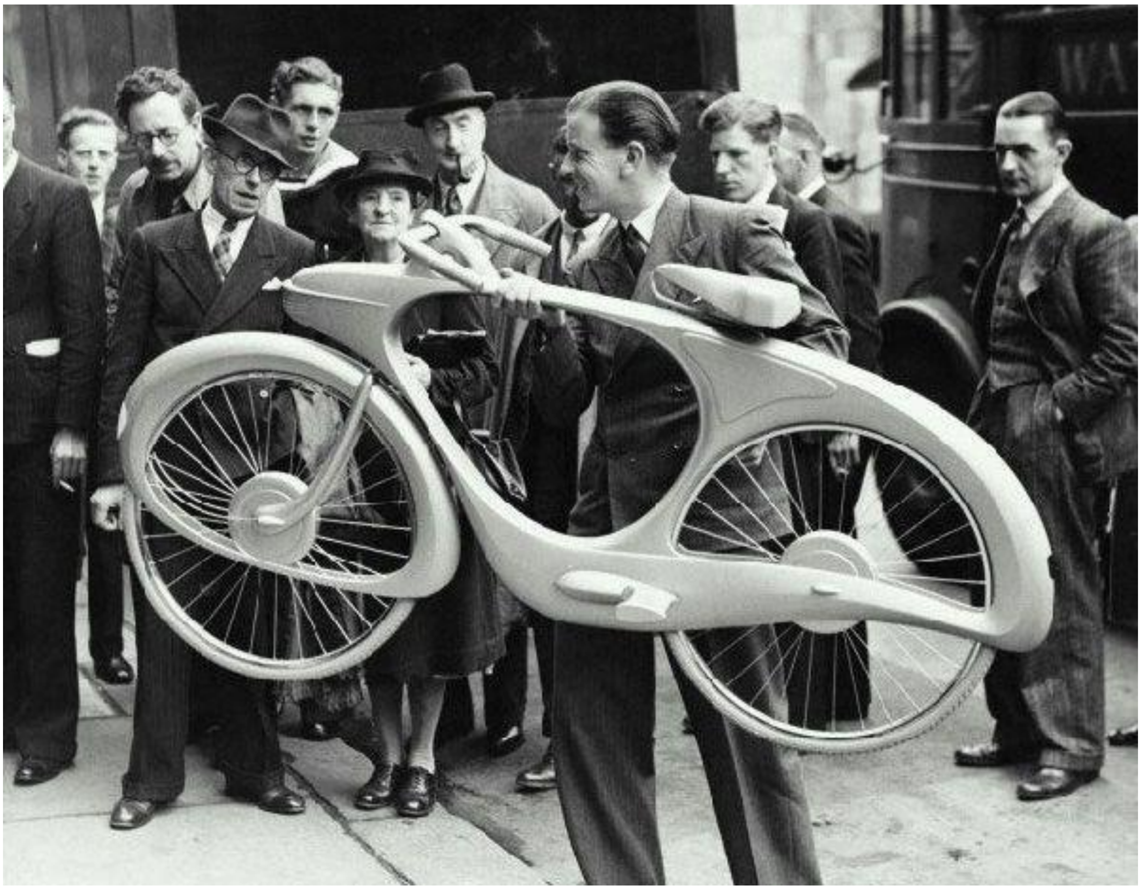

Figure 81. Bowden Spacelander 1946. Retrieved from http://www.nostalgic.net/1946-bowden-spacelander-prototype

Bowden designed a “radically different” shaft driven bicycle with a highly stylized frame made of two aluminium halves bonded together (Figure 81). Unfortunately, manufacture was complicated and the Bowden Spacelander (which nowadays would be regarded as a “Concept Bike”) was only put into production almost 15 years later using Glass Reinforced Plastic, which marks it as one of the pioneers in “composite” bicycle frame manufacture. The bicycle embodies many of what were called at the time, “Space-age” type design features with flowing streamlined curves and enclosed mechanics (the version shown below has a chain drive rather than shaft drive). It is interesting to note that the production Spacelanders still retained many standard components; notably the wheels and tyres. From a design point of view there is a strong visual incompatibility between the saddle, the handlebars, and the rest of the bicycle giving it the appearance of a “”dressed up” normal bicycle (Figure 82).

Figure 82. Bowden Spacelander Bicycle. Retrieved from http://www.nostalgic.net/1946-bowden-spacelander-prototype

Somewhere in the region of 500 Spacelanders were produced, and today they are still manufactured in limited quantities.

Although the Spacelander was supposedly intended to be a “production model” bicycle, sales were very limited (for whatever reasons – conservatism, non-acceptance, cost, manufacturing issues) and it would not be until the 1980s that a serious commercial proposal for a “radically” different bicycle was developed in the form of the Itera “all plastic bicycle” in Sweden (Figure 83).

Figure 83. Itera Plastic Bicycle, Sweden 1980. Retrieved from http://www.cyclechat.net/threads/for-sale-itera-plastic-bike.179841/

However, for various reasons as mentioned previously in "The Itera Plastic BIcycle" by Jan Hult, on page 83 (of this work) the Itera bicycle was not a commercial success.

1.21.2. Wood

In the 1800s the ‘Hobbyhorse’ or ‘Draisienne’ attributed to Baron Von Drais de Sauerbrun used contemporary technology developed for horse-drawn wagons and featured a wooden frame and wooden wheels. In 1861 Pierre Michaux added pedals to the front wheel of a French hobby horse and made the boneshaker which had a solid iron frame with wooden wheels with iron tyres like a wagon wheel.

From the late 1800s wood was replaced by iron or steel. However, some attempts were made to produce bicycles with wooden frames, employing the available wood technology of the day. Bicycle frames either used wood as a direct replacement for straight steel or iron tube, or in some cases used the "bent wood" furniture technique to create integrated frames (Figure 84). This technique was also employed successfully to produce lightweight and shock resistant handlebars and wheel rims.

Figure 84. 'SOUPLETTE' Bicycle with bent wood frame France circa 1898. Retrieved from http://www.sterba-bike.cz/album/659/category/the-gallery?lang=EN

From the early 1900s wood was replaced by steel and there are few examples of wooden bikes. Recently however, a small number of bicycles have been successfully produced in wood. The example on the following page is fitted with various accessories and wheels made in wood (Figure 85).

Figure 85. Contemporary wooden bicycle – Unknown Author. Retrieved from http://www.ecovelo.info/2009/03/10/yaneks-photo-contest-entries/

1.21.3. Bamboo

In 1896 The Bamboo Cycle Company of Holbourne, London, based in Wolverhampton manufactured their frames made of bamboo because it was strong, lightweight and from corrosion free (Figure 86). However, steel was considered be a better material and only a few bamboo bikes were made. Later the company disguised the steel tube to have the appearance of bamboo by painting it.

Figure 86. Lady’s Bamboo bicycle, National Cycle Collection – Llandrindod Wells. Retrieved from http://www.cyclemuseum.org.uk/

Recently there has been a resurgence in the interest in bamboo as a frame material and a number of bicycles are available commercially from Greenstar Bikes, Boo Bicycles and Calfee Design (Figure 87).

Figure 87. Contemporary Bamboo Bicycle Frame – Calfee D Published June 20, 2014. Retrieved from http://calfeedesign.com/

1.22. Overview

Over a period spanning more than a century, various materials have been used successfully in the construction of bicycle frames, the materials being chosen for their mechanical properties and methods of manufacture. During the course of bicycle development, advances in materials technology have lifted the constraints imposed on frame design, opening new avenues for innovative design and manufacture. Thanks to sports enthusiasts, independent designers, and engineers, the market for specialised bicycle types has expanded, and manufactures, recognising this, have increased their product range to cater for more specific needs of cyclists.

Other objectives have also been considered in the bicycle industry such as reducing manufacturing and material costs through aggressive value engineering, to the point where the resultant bicycle barely serves it purpose as a means of transport, but can be purchased for as little as 40 Euros in supermarket stores. At the other end of the scale, athletes are constantly searching by for lighter and stronger frames employing state of the art technology and costing thousands of Euros, which are obsolete after one season. The most recent developments in frame construction are in the use of graphite and carbon fibre composites and monocoque construction, but even so, as a lasting tribute to the early pioneers of cycling, the diamond frame still dominates the field whether in steel, carbon and graphite composites, aluminium alloys or titanium.

However, in spite of the technological advances in wood technology, wood and its derivatives such as plywood have been, on the whole, markedly absent in bicycle frame design. Therefore, the objective of this study is to evaluate the small number of wooden framed bicycles that do exist and explore the feasibility of wood as a potential bicycle frame building material.

CHAPTER 2

2. Wooden bicycles compared

As the typology of bicycles in general has been discussed previously, this section deals specifically with the various approaches to wooden bicycle frame design in more detail.

Possibly the most logical, if not original approach, is to substitute the traditional frame members with wood. This method has been employed for over a century in various guises and some of the results are discussed here.

Notwithstanding the success or failure of these attempts, the wooden framed bicycle has never been produced in large quantities and has never made any serious inroads in the established bicycle market.

2.1. Types of wooden framed bicycles – A comparative survey

Wooden bicycles are unusual and rare compared with conventional bicycles and reliable figures regarding the quantities produced are difficult to source. Nevertheless there is a certain diversity to the design and manufacture of wooden bicycle frames.

2.1.1. Wood and bamboo

As the typology of bicycles in general has been discussed previously, this section deals with the various approaches to wooden bicycle frame design, construction, and manufacture.

Compared to a decade ago, research reveals a relatively large number of wooden bicycles, (although compared to traditional bicycles the number is quite insignificant) ranging from unique models made by craftsmen, do-it-yourself enthusiasts, and design students, to production models, limited editions, and promotional types.

The aim of this comparative study of wooden framed bicycles is primarily to identify the types of bicycle and attribute a nomenclature to bicycles which fit within certain criteria rather than attempt a comprehensive survey of all the wooden framed bicycles that exist.

As a starting point for this comparative study, possibly the most logical, albeit not the most original approach, is to consider bicycle frames which substitute the frame members with their counterparts in wood or its derivatives, i.e. wooden diamond frame bicycles.

As has been mentioned previously, wooden or bamboo framed bicycle have been around for more than a century. For whatever reason, whether it was the weight of steel or iron tubing, the quality of the tubing, a desire to use a different material and explore its qualities, or to avoid production methods requiring brazing or soldering, round section structural frame members made from organic material have been experimented with and have led to a number of designs which are even to the present day still being made and tested.

2.1.1.1. Bamboo

Bamboo was probably the first material used to substitute steel tubing in bicycle frame manufacture (See Bamboo Bicycle Company) Quick growing, abundant, and uniformly round in section, with good strength to weight characteristics and with regular fibres running longitudinally, bamboo is flexible in long lengths but quite stiff in short sections compared to its diameter (when used in lengths approximately equating to the length of a bicycle top tube for example). When combined with the use of lugs similar to those found on almost all bicycles at the end of the 1800s, it was a relatively logical step to use the material or turned solid wooden pieces for frame construction.

Figure 88. Contemporary Bamboo Bicycle. Retrieved from http://www.actionhub.com/stories/2015/08/06/3-bikes-youve-got-to-see/

Modern bamboo bicycles however have adapted a different approach to frame construction. With the availability of polyester resins and carbon fibre reinforcement the lugs have been replaced by wound joints which have the appearance of a bandage.

Consequently the bamboo frame is virtually a “composite” frame where the separate parts cannot be removed or replaced (Figure 88). The practicalities of this approach imply that if the frame is seriously damaged it may not be able to repaired.

It is too early in the life of bamboo composite bicycle frames to hypothesise regarding longevity and there is little information available regarding reliability or failure.

Figure 89. Wood and metal framed bicycle circa 1910 – Sterba Bike CZ. Retrieved from http://www.sterba-bike.cz/en/

The resulting need to fix the parts firmly, as brazing or soldering was not an option, led to adaptations and alterations of the lugs such as can be seen in the photograph above (Figure 89). The turned wooden frame members are snugly inserted into the bottom bracket lug and are clamped by nuts and bolts. In fact, in this example the bottom bracket itself is clamped into the lug in a similar fashion. However, a form of structural compromise has been used here as the chainstays are permanently fixed to the bottom bracket lug in the traditional way. Although detailed information is not available, it looks as though the wooden parts are relatively new and are replacements, as the bike is over 100 years old.

Another way of fixing the wood or bamboo frame members to the lugs was by the use of pins or dowels. It is not known whether any form of adhesive or resin was used in addition to the pins or clamps, but as a simple precaution against the infiltration of water or humidity it would have been a wise decision to use some form of mastic or caulking at the wood/bamboo/lug interface such as bitumen or tar.

2.1.1.2. Rattan Cane (Also known as Malacca Cane)

Although there is no evidence to suggest that Rattan cane (Figure 90) was ever used in bicycle frame manufacture, from the point of view of strength and structural properties it would appear to be an ideal material. Used extensively on the manufacture of baskets and furniture where a structural armature is required, solid rattan cane is strong and bendable with steam. Other uses are for the handles of wooden mallets as it has good shock absorbing properties, and drain and chimney cleaning rods as long lengths are quite flexible (unlike shorter lengths) .

Figure 90. Stripped and Unstripped Batang Cane. Retrieved from http://www.rattan.cc/drum_stick.htm

Rattan cane is available up to 34mm diameter and therefore would be an ideal substitute for metal tube of a similar diameter in the construction of a diamond framed bicycle.

In the above photograph, the Batang cane on the left is stripped and sanded to a uniform diameter; whilst the cane on the right still has its skin intact clearly showing the nodes.

The material is commercially available and the specifications that follow are from a supplier’s catalogue:

> *"Polished Pole Cane: Sizing 10/12mm – 32/34mm diameters. Polished Pole Cane is the description given to all canes that have had their outer skin removed and the cane has then gone through a sanding process to produce a smooth finish. As the skin has been removed from the cane, the cane will now absorb a stain and this cane is therefore ideal for using in furniture that is going to be stained a darker colour. There are three different species of cane in this category, namely Batang, Manau and Tohiti. There is very little difference between the three canes and all types are interchangeable".*

It is clear from the supplier's description that peeled and sanded cane absorbs liquids. Whether this potentially undesirable property (as there is a need to seal the cane) is possibly a reason not to employ the material needs to be researched. However, correctly sealed or deployed with the "skin" not stripped off, this problem could be overcome. Batang cane can be easily bent to shape by the use of steam or heating and on cooling retains its shape.

2.1.1.3. Wood and bent wood

Although still using lugs and wood, the women's bicycle below shows a different approach to simple straight structural frame members. Made of hickory, which is hard, stiff, dense, and resistant to shock, the loop frame is possibly laminated and steam bent to shape, and the lugs are very ornate, bearing intricate perforated decoration (Figure 91).

Figure 91. Hickory loop framed bicycle circa 1910. Retrieved from http://www.sterba-bike.cz/produkt/old-hickory-lady-wood-bicycle-1898?lang=EN

The opportunity to apply this form of ornate decoration to the bicycle is not surprising as during the period when this bicycle was manufactured, Art Nouveau was very much in vogue as can be evidenced in the Alphonse Mucha designed poster for Perfecta Bicycles (Figure 92), and Thonet's bent wood furniture[15] was very popular.

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[15] Thonet: One Hundred Fifty Years of Furniture – November, 1980 Christopher Wilk p 10

Figure 92. Alfons Mucha Publicity Poster – Perfecta Cycles. Retrieved from https://commons.wikimedia.org/wiki/File:Alfons_Mucha_-_1902_-_Cycles_Perfecta.jpg

The photograph on the following page (Figure 93) shows a man's bicycle which is constructed in a similar manner to the one previously described, however the frame members are unbent. As with the women's model the lugs are lightened and ornately decorated, the handlebars are made of wood also, and so are the wheel rims, which was quite a common way of producing light-weight wheels in beech wood prior to the now extensive use of aluminium.

Figure 93. Hickory Diamond framed Bicycle circa 1910. Retrieved from http://www.sterba-bike.cz/produkt/old-hickory-lady-wood-bicycle-1898?lang=EN

2.1.1.4. Frames made from sheet material (Engineered Wood)

A good example of a contemporary wooden frame bicycle which has gained popularity and commercial success is the “LIKEaBIKE” (Figure 94). Designed for children to learn to keep their balance (also known as a Balance-Bike) and ride a bicycle without the problem of concentrating on pedalling, the LIKEaBIKE was one of the first wooden bikes to be commercialised successfully.

Figure 94. Plywood Childs “LIKEaBIKE”. Retrieved from http://www.likeabike.co.uk/

Following the acceptance and success of the LIKEaBIKE many clones have been produced and the term “Balance Bike” and “LIKEaBIKE” are virtually synonymous.

The wooden balance-bike is constructed from beech plywood and is robust and hardwearing. The wooden material is very user-friendly and any damage is less evident than on a metal framed child’s bicycle as scratches and scrapes can be touched up with clear varnish.

However, the use of engineered wood is not confined solely to the manufacture of children's bicycles. Adult bicycles which are also constructed from sheet material are manufactured by Flatframesysytems. A women's model made by this company is shown on the following page (Figure 95).

Figure 95. Flatframesystems Women's Bicycle. Retrieved from http://flatframesystems.com/

An interesting design concept incorporated in the frames of both the LIKEaBIKE and the Flatframestystems bicycle is the orientation of different parts of the frame. For instance, in the "LIKEaBIKE" the front forks are made with the orientation of the material running perpendicular to the rest of the frame. In the Flatframesystems bicycle the same technique is used for the seat stays and the chainstays. These decisions are based on the flexion of these components and the resistance to bending in the lateral orientation.

2.1.1.5. Flat panel bicycle frame

Building bicycle frames from flat panels has its advantages. Parts can be cut from sheet material and very little or no post forming is required.[16] Also this method permits the most economical way of using standard sized sheets of engineered wood.

Figure 96. Flat Panel Bicycle – Paulus Maringka. Retrieved from http://www.tuvie.com/greencycle-eco-uses-pre-fabricated-bamboo-as-its-main-material/

The previous illustration shows a suite of metal parts used to construct the wooden bicycle made up from flat sheet stock (Figure 96). The quantity and complexity of the parts leads the conclusion that there are few advantages to this approach especially as the frame design will lack torsional stability, and there will be excessive flexion at every part of the frame making it possibly unridable.

The two bottom bracket housing flanges are similar to those developed for the Xylonbikes frames featured in this study.

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[16] Forest Products Laboratory (U.S.) U.S. Dept. of Agriculture, Forest Service, Forest Products Laboratory, 1961 p 41

2.1.1.6. The Sandwich Bike

A particularly attractive challenge for designers in this era of IKEA product philosophy regarding the packaging and marketing of products is the design of a “flat-pack” bicycle (Figure 98) which is intended to be assembled at home by the purchaser with the minimum of complicated tools or equipment. The selling price of a basic model Sandwich Bike (Figure 97) is 1200 €.

Figure 97. The Sandwich Bike. Retrieved from http://www.sandwichbikes.com/pages/story-of-the-sandwichbike

This “assemble your bicycle at home” idea has been attempted before by the Itera Plastic bicycle company, and the venture was a commercial failure for the reasons previously stated.

Figure 98. The Sandwich Bike flat pack by Pedalfactory. Retrieved from http://www.sandwichbikes.com/pages/story-of-the-sandwichbike

As a Flat packed assemble it yourself product, the sandwich bike has been designed as a kit. Wheels, crankset, and saddle are standard bicycle parts but the frame is a significant departure from a traditional bicycle frame.

The frame is assembled with screw fasteners and no gluing is required.

The company states:

> *"Developed in Germany by Pedalfactory, 'Sandwichbike' is a flat-pack bicycle made out of two beech plywood plates that users can build on their own. Delivered in a compact cardboard box, the concept can be assembled at home with a few basic tools: the cruiser comes fully equipped with everything you need to get on two-wheels within 30 minutes. From the frame to the pedals, each piece is securely held together by a series of carefully milled aluminium parts. Composed out of nineteen components, the fixed gear features a distinctive silhouette reminiscent of heavy duty construction materials. The 'sandwichbike' was extensively tested by compressing the seat, structure and wheels,*

> *and bottom bracket up to 100,000 times, simulating the wear and tear from life on the road".*

Unfortunately, one of the major problems with a product such as a bicycle which is assembled by the purchaser who may or may not have the necessary mechanical aptitudes or training is the question of safety. Unlike a piece of furniture which is usually a static object which can only possibly cause injury by collapsing or falling over onto a person, a bicycle on the other hand is, by its very nature, a dynamic object. This undoubtedly raises a number of questionable issues such as the competence of the purchaser, their ability to follow instructions which are probably graphic rather than written, and their capacity to carry out the assembly of the bicycle efficiently, effectively, correctly and safely (Figure 99).

Having personally surveyed at first-hand, bicycles which are sold in supermarkets and which are put together by supposedly trained staff, that have pedals that are not tightened sufficiently and eventually strip the crank threads and fall off, handlebars that are mounted back-to-front, and in addition, bottom brackets that have been cross-threaded at the factory, the possibility of incorrect assembly at the hands of the purchaser is almost certain to occur in some cases.

This also begs the question as to who is legally responsible for the rider's safety. If on riding the assembled bicycle there is a safety issue which may result in injury to the owner or third parties is it the manufacturer of the product who is liable, or Is it the purchaser/assembler?

A further concern regarding the flat-pack bicycle is the availability of aftersales service, repair and maintenance.

Traditional bicycle shops are generally reluctant to provide service for bicycles that have not been purchased from them and consequently have not been subject to their professional scrutiny regarding quality of work, assembly etc. As a consequence they may charge, what may appear to purchaser, a relatively exorbitant sum for carrying out work on the customer's bicycle.

NOTE: I have personally recorded a bicycle shop quoting the cost of repairs and parts for a bicycle that was more than the original cost of the bicycle which had been purchased from a supermarket. (See Appendix viii Supermarket Bikes)

Also there is undoubtedly a certain reticence on the part of trained bicycle mechanics to undertake work on a bicycle which falls outside their sphere of knowledge and understanding especially when their reputation and the possible threat to life and limb of their client are at stake.

This also calls into question the possible repair and replacement of the non-standard bicycle parts which make up the kit bike.

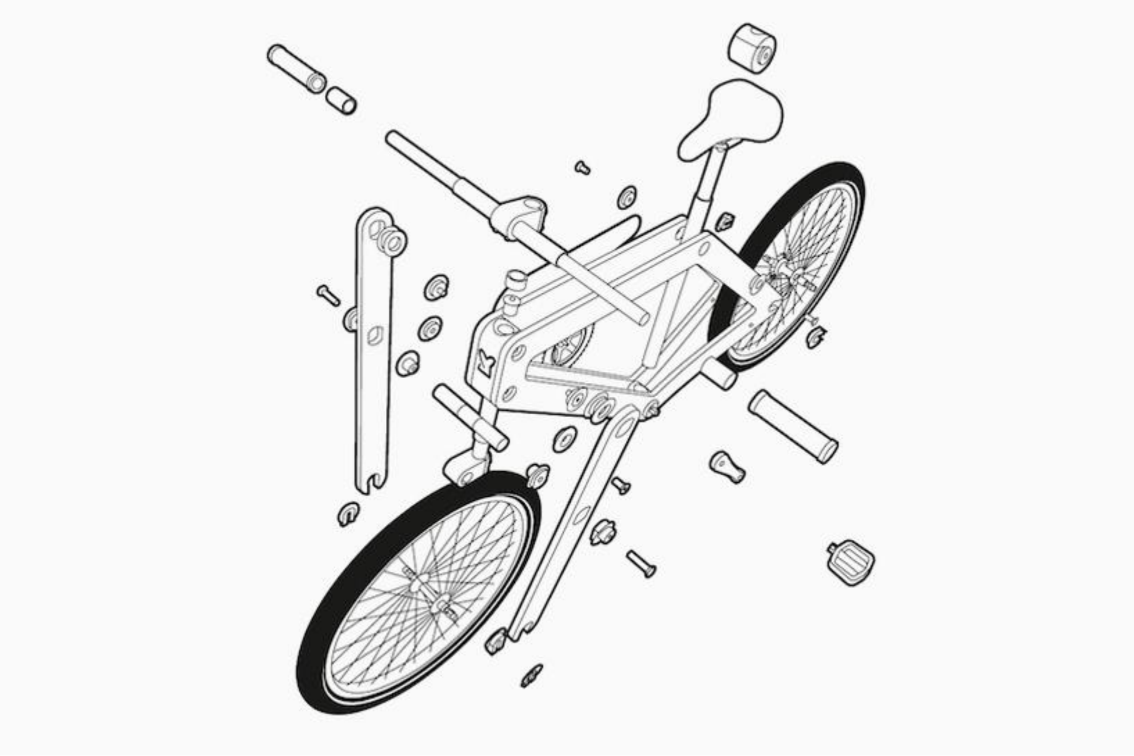

Figure 99. Exploded view of the Sandwichbike DIY flat-pack wooden bicycles by Pedalfactory. Retrieved from http://www.sandwichbikes.com/pages/story-of-the-sandwichbike

All images courtesy Sandwichbikes.

2.1.1.7. Unidentified Wooden Bicycles

Internet searches reveal various hand-built, one-off wooden bicycles made from a variety of wood materials and wood derivatives (Figure 100).

Various approaches are taken regarding the design of the frames from diamond frame versions to more elaborate custom bicycles.

Figure 100. Plywood bicycle. Constructor unknown.

In this case the front forks do not appear to be actually made of wood, and on closer observation are simply used as a decorative addition and would seem to fulfil no other function than aesthetic appearance.

The wooden framed bicycle on the following page (Figure 101) is based on the traditional diamond frame format and the manufactures' blurb states the following:

> *"The Connor Wood Bikes elegantly form and function into a rideable work of art. The design embodies simple, pure fun in the most unique way possible on two wheels. Enjoy the unbelievably smooth ride and*

> *the distinct look that only an individually crafted, hand sculpted wood bicycle provides".*

Figure 101. Contemporary Connor wooden bicycle. Retrieved from http://connorcycles.com/

2.1.1.8. Bough Bikes

Bough Bikes manufacture bicycles from European oak. The frames incorporate wooden forks and have been designed on the "cross-frame" format (Figure 102). There does not seem to be any provision for a front brake on the examples shown here.

Figure 102. Bough Bikes Oak Framed Bicycle 2013. Retrieved from http://www.boughbikes.nl/

The extract below is taken from Bough Bikes Webpage

> *"Bough Bikes" are constructed from oak wood sourced from eco-friendly managed forests in France. They also feature stainless steel hardware components and extra durable Schwalbe tires, a 2-speed SRAM automatic shifter, a coaster break. They include a manual front break have been, too. Made to be extremely durable, they have passed the TÜV Rhineland endurance test. The unique Dutch design has recently arrived in NYC, featuring two models: an open and a solid frame".*

Jan Gunneweg Combines Nature & City With Wooden Bough Bikes.

Figure 103. The standard Bough Bikes bicycle retails for approximately 1,500 euros. http://www.boughbikes.nl/Retrieved from

Figure 104. Figure 1 Wooden bicycle developed by Cyclowood UK. Retrieved from http://www.cyclowood.com/

Figure 105. Cyclowood “Beach Cruiser”. Retrieved from http://www.cyclowood.com/

The Cyclowood “Beach Cruiser” model (Figure 105) shown above uses different types of wood in its construction to enhance the decorative effect. The forks are conventional with V brakes.

Judging from the manufactures description below, the nomenclature used is very generic and worded in such a way as to just list the basic specifications rather than technical specifications.

- *Hidden rear brake operated by pedal*
- *Leather seat*
- *Wood handles*
- *Fenders: Natural wood matching frame*
- *Faro: LED*
- *Front light: LED*
- *The constant evolution and improvement of our frames supposed to make small changes in configuration and design, without implying a change in supply*

> *conditions. Also the elements or complements of our frames and bikes can be modified or replaced, in form or supplier, always to provide a better product.*

A rather more sophisticated and higher quality bicycle manufactured by Grainworks, California is shown below (Figure 106).

Figure 106. Grainworks Custom *Holzfahrrad* AnalogOne. Retrieved from http://www.blessthisstuff.com/stuff/vehicles/cycles/analogone-one-bicycle-by-grainworks/

Featuring laminated veneers of various woods, highly figured hardwoods and carpentry joints as visual features the AnalogOne retailing for about $5000is is the flagship of the Grainworks Company (Figure 107).

Figure 107. Laminated Wood Head Tube Detail – AnalogOne. Retrieved from http://www.blessthisstuff.com/stuff/vehicles/cycles/analogone-one-bicycle-by-grainworks/

Figure 108. Angel MDF Bicycle Made in Portugal. Retrieved from http://greensavers.sapo.pt/2013/11/28/bicicleta-portuguesa-angel-sera-a-primeira-exposta-na-miami-art-river/

Angel Bicycles Portugal founded by ex-footballer Nuno Zamaro produce bicycles made from MDF which retail for about 400 euros. An interesting marketing feature of the bicycles is the diversity of promotional graphic imagery which is applied to the surface of the bikes. On close observation, the decoration would appear to have been applied by self-adhesive vinyl (Figure 108).

The following extract is taken from the Angel Bicycles website.

> *"Fizemos uma primeira experiência, que funcionou muito bem, e depois fomos aperfeiçoando o modelo que tínhamos", explicou Nuno Amaro ao Economia Verde. A Angel é uma bicicleta feita de madeira – com desperdícios da indústria da madeira, aliás – e um verdadeiro objecto de design.*
>
> *A bicicleta pode ser personalizada e decorada ao gosto de cada um. A sua estrutura de madeira também é reutilizável. "Ao fim de uns anos [de utilização], quando a bicicleta ficar deteriorada, podemos desmontá-la e, na compra de uma nova, entregar essa, que depois será reciclada", continua Nuno Amaro. De acordo como Economia Verde, 70% dos materiais da Angel são recicláveis.*
>
> *O primeiro modelo da Angel é feito de madeira, alumínio e ferro, mas estão a ser desenvolvidas novas versões com cortiça. José Nuno Amaro diz mesmo que o produto é 102% português – o 2% representa, graceja o designer, a cortiça.*
>
> *"O projecto é global e pode ser utilizado em qualquer lado. Mas se podemos utilizar um produto que é nosso, como a cortiça, reforça [a sua portugalidade]", explica o responsável.*
>
> *As primeiras Angel serão comercializadas em Janeiro e já têm preço: entre os €350 e os €400. Numa primeira fase, Nuno Amaro colocará*

> *no mercado cerca de 100 bicicletas. O objectivo é chegar às mil por ano, a médio prazo”.*

2.2. Wooden Bicycle Styles

As previously demonstrated wooden bicycles lend themselves to a diversity of styles. The three bicycles featured below all have one thing in common: the absence of the seat tube (Figures 109, 110, & 111). This absence creates a void which is encroached upon or “eclipsed” by the rear wheel. Frames without this member appear to be much lighter than the previous example of the Angel bicycle which is supposedly made from recycled materials.

Figure 109. The Embira Bicycle Thomas Pascoli Scott, Brazil. Retrieved from http://www.thecycler.net/category/concept-bikes/page/2

Figure 110. The Waldmeister Bicycle, Germany. Retrieved from http://www.waldmeister-bikes.de/html/index.html

Although apparently modern in its styling, the Waldmeister owes its appearance to the use of carbon fibre wheels and expensive off-the-shelf modern components fitted to the laminated frame. However, the frame design itself bears a striking similarity to the Whalen and Janssen laminated wood frame bicycle from 70 years ago shown below.

Figure 111. Whalen and Janssen laminated wood frame bicycle. The Smithsonian Collection – Catalog #: 313,040, Accession #: 173,992. Retrieved from http://amhistory.si.edu/onthemove/collection/object_312.html

The absence of the seat tube as a Design “statement” is a theme which has been present in bicycles from for more than half a century and it is interesting that a patent for a similarly shaped frame was taken out by Elgin bicycles in 1939 (Figure 112). However this frame is made in steel but the overall appearance is very similar to the Whalen and Janssen bicycle of the same era.

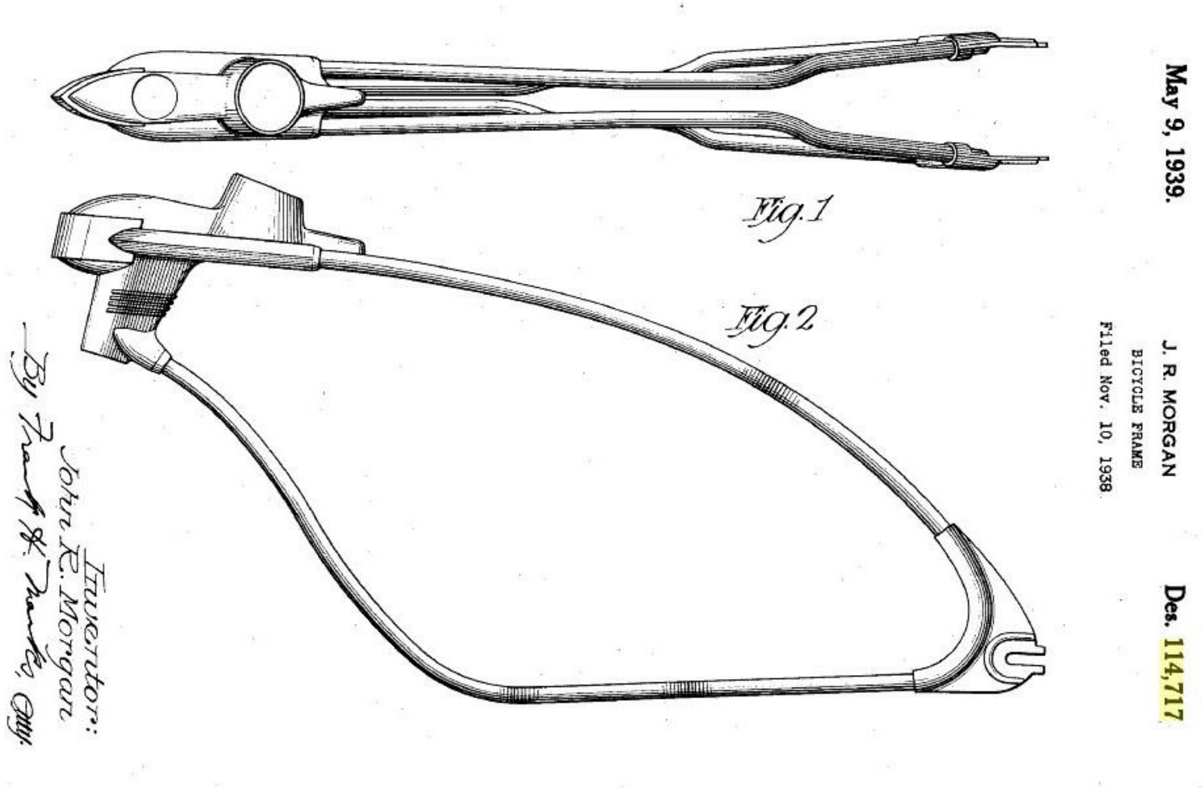

Figure 112. 1939 Patent Application for Steel Elgin Bicycle Frame. Retrieved from http://www.oldbike.eu/museum/1930s/1938-2/1938-elgin-twin-20-model-502/

Another approach to wooden bicycle design and construction has been taken by the Italian furniture designer Tino Sana

Figure 113. Wooden Bicycle produced by Tino Sana. Retrieved from http://www.lignea.it/curiosita_eng.htm

Possibly more cohesive in appearance than other examples, Tino Sana's wooden bicycle from 1990, goes as far as having wooden wheels (Figure 113). The objective of the Tina Sana bike is not to create a light weight machine, but rather to explore the visual, physical, and aesthetic qualities of wood. Possibly due to the void in the frame the appearance of the bicycle does not indicate exceptional heaviness; however, due to the wooden wheels, chain guard, mudguards, and saddle etc. the bike must be a heavyweight. The wooden frame is contoured to make it thicker at highly stressed points, and thinner at points of less structural strain. The walnut wood laminated with beech and ash, has been chosen to feature quite a pronounced grain pattern, thus adding to the "wood for wood's sake" approach to the design. Such items as the seat post, front forks, brakes, crank, gears etc., are all standard bicycle parts. The saddle is a sprung leather Lepper model, which fits into the seat post housing, which along with the steerer tube appear to be simple tubes, whilst the rear dropouts are specially made.

The current value of a pre-owned Tino Sana bicycle on E-bay is approximately 3,500 Euros.

A different approach to using wood as a frame material has been employed by Renovo.

Renovo frames are made from solid wood which is extensively machined to shape and hollowed to reduce weight. Essentially a composite, the frame halves are machined and then bonded together (Figure 114).

Figure 114. Renovo Bicycles Laminated Wood Frame (Left hand side). Retrieved from http://renovobikes.com/

Metal inserts and the bottom bracket shell is epoxy bonded to the shell and the visual result is similar to a convention diamond frame composite.

Figure 115. An Original Bamboo Bicycle circa 1895. Retrieved from http://bamboobicycleclub.org/bamboo-bikes-new-concept/

Testimonial from a user of the bamboo bicycle.

> *“December 1895I consider they possess several advantages over other machines, and certainly the appearance of them, in my mind, is better than that of steel machines. There still, however, appears to be a prejudice against them, but as far as my experience goes, it is an unfounded one. I believe they will stand every bit as much wear and tear, and are as strong as any on the market.*
>
> *Yours faithfully*
>
> *(SIR) R. WILLIAMS BULKELEY”*

The possibility of using wood as a frame building material gave rise to the opportunity of designing a wooden frame bicycle that did not necessarily follow the structural "diamond frame" format.

I.e. although the position of the rider, the handlebars, the saddle, wheels etc. were more or less fixed, the way in which the elements were combined could be varied by an approach which takes into account not only the structural characteristics of the material but its artistic potential and availability.

At first glance, replacing the tubular elements would appear to be a natural extension of the idea to develop a diversity of frame elements. However, as has been noted in the various historical and contemporary examples the points of interface with other bicycle components, namely the rear dropouts, bottom bracket, steerer tube, and seat stem are invariably standard bicycle design solutions closely related to the traditional lugged frame. Therefore it was decided that a departure from the concept of substituting the steel tubes of a "diamond frame" for others, such as had been done previously with bamboo or wood, would constitute a novel approach which would allow the elaboration and development of a series of proposals related directly to characteristics of the materials employed, such as, in this case engineered wood (plywood). This approach had already been tried by Whalen and Janssen with their laminated wood frame bicycle (See page 163)

Particularly noteworthy on the Whalen and Janssen bicycle (Figure 111) is the novel treatment of the rear dropout and the saddle configurations whilst the bottom bracket and steerer tube remain essentially similar to those used on standard bicycles. The solutions applied to the rear dropouts and the saddle set this bicycle apart from others mainly due to the fact that the laminated wood frame is an adaptation of manufacturing methodology applied to items such as furniture.

Due to the increased use of birch being used to produce bent wood furniture by Michael Thonet in the mid-1800s, the viability of the technique was proven by the structural integrity of the chairs (50 million of the most well-known example being sold by1930) the technique was also applied to the building of bicycle frames. In the same way as the idea was applied to furniture, taking advantage of the characteristics of steamed beech, the frame was built as a loop starting from the bottom bracket and curving round to meet the steerer tube resulting in an integral frame component with no joints throughout its length (Figure 116). Other bent wood parts are the handlebars, wheels, and the forks.

Figure 116. Bent wood and Metal Bicycle with Wooden Wheels circa 1900. Retrieved from http://footloosefietser.blogspot.pt/p/velomuseum-bicycle-boneyard.html

CHAPTER 3

3. Wooden bicycle frame design and development

As may be seen in the previous chapter, although not common, a number of functional wooden framed bicycles exist. Mostly they are “one-offs” built by individuals. However, such companies as Renovo[17] for example, produce wooden framed bicycles commercially.

In the majority of cases, wooden framed bicycles are based on the traditional diamond frame configuration where the structural members (tubes) are replaced by wood. The most basic interpretation of this type of construction has been to use lugs to join the frame members. Other methods employ a type of monocoque construction such as the previously mentioned Renovo Bicycles. Nevertheless, the frame format is basically similar to any conventional bicycle whether steel, aluminium, or carbon fibre.

As my initial idea to produce a wooden bicycle frame was to start from the “ground up” i.e. from basic principles - rather than modifying or adapting the diamond frame - a different approach was taken.

Based on the resources and materials available, complex manufacturing methods such as moulding, laminating, and machining were to be avoided. Also, given the structural limitations of wood itself (or rather the unavailability of material of suitable quality) and given the inherent qualities of engineered wood, plywood was the most suitable choice taking into consideration quality control, dimensional stability, predictable structural characteristics, availability, and fabrication techniques.[18]

It should be made clear at this point that no specific type or size of bicycle was envisaged either from the point of view of improvement of existing models or making “just another” wooden bicycle, but rather a deconstruction of the object and through an iterative approach developing a functional human powered vehicle from wood which falls into the generic category of “bicycle”.

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[17] http://renovobikes.com/

[18] http://tinyurl.com/hwr4kcl

The following section is based on direct observation and the compilation of empirical evidence directly retrieved from practical examples, which were tested analysed and if necessary retested to validate the initial hypothesis “Is Wood and its Derivatives a Viable Alternative to Conventional Materials in the Fabrication of Bicycle frames”. To test this hypothesis, information has been taken from a series of experimental projects carried out by myself and wherever possible the results were recorded and later analysed.

NOTE: Much of the data was collected informally and in many cases amendments were made and ad-hoc solutions applied directly. Therefore, in some cases a retrospective analysis was made of the results.

3.1. Initial Design ideas for a wooden framed bicycle.

The initial approach to test the use of wood as a bicycle frame building material began with the design of a wooden bicycle. Initially the approach was somewhat random and intuitive with no specific design methodology other than exploring the qualities of wood as a possible construction material. The notion of a frame structure that owed nothing to previously produced frames gave rise to an idea that would use wood for *everything* structural, i.e. including the forks, handlebars and possibly the wheels and saddle (Figure 117). A further consideration at that point was that, if possible, the frame could be made and assembled from materials available from any hardware store or ironmongers (nuts, bolts, hinges, screws etc.) rather than conventional components other than the transmission which was considered to be too complex, and had over many decades become more and more efficient and practical.[19]

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[19] http://www.cyclingpowerlab.com/DrivetrainEfficiency.aspx

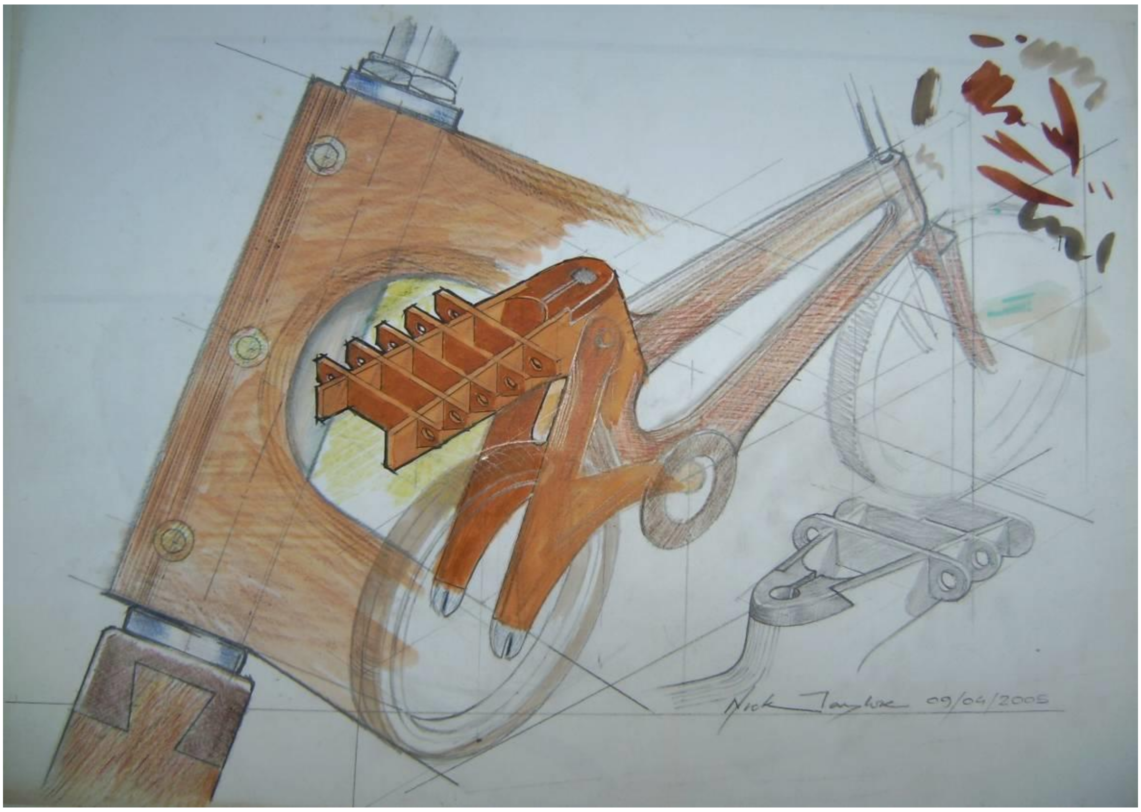

Figure 117. Initial Design Sketches for Wooden Bicycle – Taylor, Nicholas.

One of the main factors which was taken into consideration was that by using engineered wood (Composites, plywood, MDF etc.) which is essentially a homogenous material with predictable properties, a wider range of possibilities could be addressed without the concerns associated with the defects of natural wood such as shakes, cracks, abnormal growth, and knots which could adversely affect the structural integrity of the material (Figure 118). (However, the use of natural wood was not entirely excluded if suitable material was available).

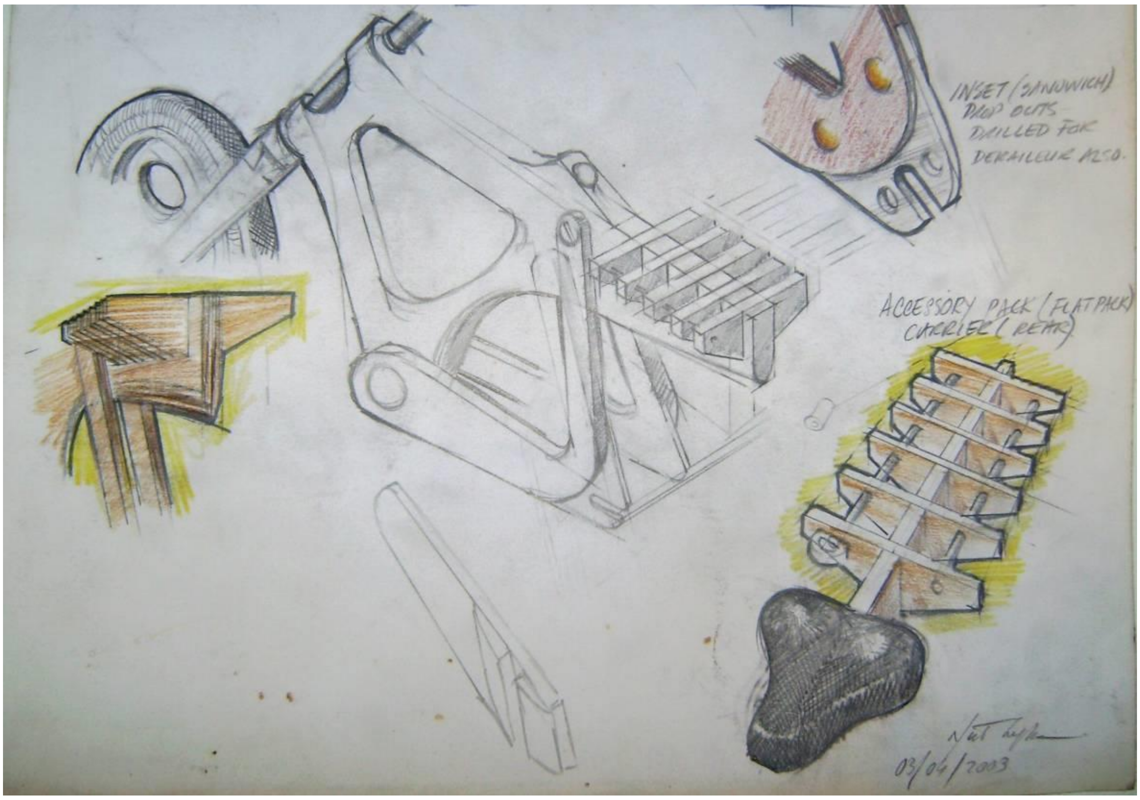

Figure 118. Preliminary Wooden Frame Bicycle Design Sketches – Taylor, Nicholas. 2004

The initial concept for the frame aimed to valorise the visual aesthetic of wood and its derivatives and taking this into consideration the appearance was very loosely based on styling from 1950s Americana with swoopy lines, streamlining, and bulbous forms which flowed into each other. The wheel size (which was never initially defined) was based on the only easily available wheel size which was a 26” MTB wheel, which is similar in size to the American Cruiser bicycle. The following image (Figure 119) is the only existing photograph of the wooden fork prototype which was never tested. The pin is lacking which would have acted as the pivot (A), as are the aluminium or steel dropouts which would have been fitted into the rebates at the ends of the fork (B).

Figure 119. Original Wooden Bicycle Mock-up – Taylor, Nicholas.

As means of creating an articulating front fork, a hinged finger joint was employed as a way of making a robust joint with multiple bearing surfaces which would distribute loading evenly (Figure 120).

As the bearing surfaces of wood against wood are prone to premature wear and excessive friction, a decision was made to leave enough clearance between the bearing surfaces to insert brass washers which could, if necessary be replaced, functioning as a type of shim in the event of wear (A). The size (diameter) of the pivot pin and the method of keeping it place were not tested due to the prototype forks being stolen. Consequently there was no opportunity to test the theory of a wooden fork regarding suitability, durability, longevity, function and practicality. However, considering that most of the critical forces acting on a fork are bending (forwards and backwards) and compression, and given the possibility that the pneumatic tyres would reduce shocks and vibration it seems reasonable to assume that, given the right design and materials, a wooden fork could stand up to the stresses and strains that would be expected for a bicycle not undergoing extreme conditions.

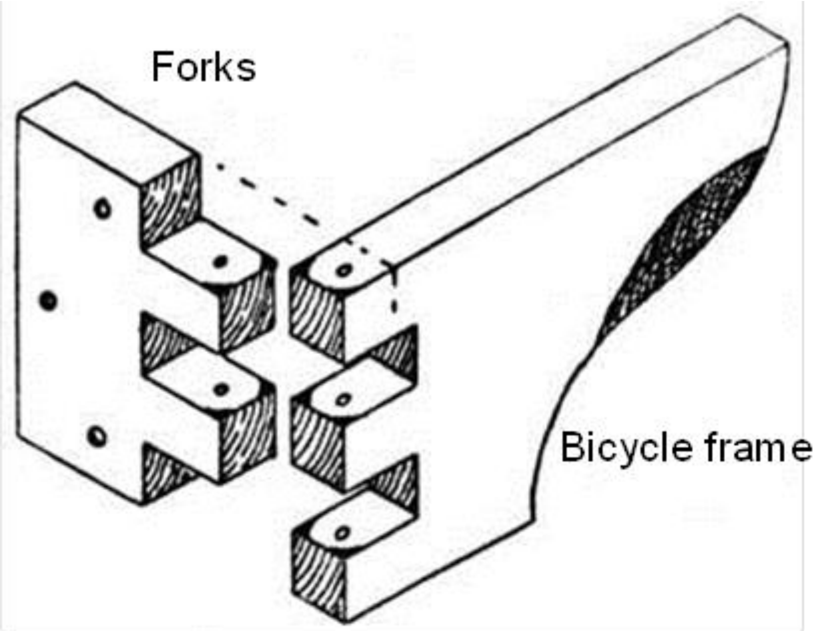

Figure 120. Illustration Showing Wooden Bicycle Steering Idea – Retrieved from http://sawdustmaking.com/woodjoints/hinged.htm

Although the main structure of the front wooden forks was fabricated and provisionally fitted to the frame, they were never finished. However a number of factors were taken into consideration during the design stage regarding their construction and function. E.g.:

The thickness of the dropouts (to be made in metal) would be determined by the material but also by the type front wheel axle fitting employed. I.e. Nuts or quick release skewer. Furthermore, the design of the dropouts was the subject of extensive deliberation, especially regarding the minimum of machining and drilling required to produce them.

After having decided on the use of aluminium it was envisaged that the dropouts would be drilled and tapped to accept two fixing screws per side which would possibly be countersunk; in addition, they would be bonded to the plywood fork blades with an epoxy resin such as Araldite. As a way of maintaining a cleaner appearance to the forks the dropouts were to be mounted flush with the inside surface. Consideration was also given to the possibility of using holes rather than slots to fit the front wheel (as were found on some early bicycles) as, unlike metal fork legs which are relatively rigid, the fork legs are flexible enough to be spread over the axle ends to fit the wheel and tightened later, drawing the fork ends inwards and creating a slight "bowing" effect giving more rigidity. From the point of view of safety this may be a bonus as an untightened wheel axle has less likelihood of falling out. (See note regarding safety dropouts – tabbed washers)

Note: Some American bicycle forks, especially those designed for children, have a small hole above the forks slot for positioning a tabbed washer, which in the event of the wheel nut becoming loose, the wheel is prevented from falling out (Figure 121).

Figure 121. Tabbed Wheel Spindle Safety Washer. Retrieved from http://www.bicyclepartswholesale.com.au/contents/en-us/d65.html,.

3.2. Dropout materials

Metal was considered to be the most appropriate material for the dropout due to its mechanical resistance and resistance to wear. However, no special preference was given to using either steel or aluminium for the fork ends; the rebates in the plywood were routed out to a depth of 3mm, which would be suitable for 3mm thick steel dropouts which would be flush with the surface of the fork ends. 3mm thick steel was chosen for two reasons – 3mm thickness is a standard size for steel plate, and the thickness of the majority of steel dropouts is designed for axle protrusions of nominally 3mm. The construction of the fork is made up of a pine core at the top, formed in a wedge shape which was narrower at the top than at the bottom to allow the fork legs to splay outwards. This method was chosen for two reasons. Primarily as an aesthetic consideration as parallel fork legs at approximately the Width Over Dropouts "WOD" of a typical front wheel, i.e. 100mm, would appear bulky and secondly, if V brakes or fork mounted brakes were fitted, the distance between the fixing pivots i.e. generally 80mm or 85mm, would be too wide for them to function. Therefore it was envisioned that when the front wheel was affixed, the fork legs would take on a bowed format giving increased rigidity.[20] Lateral stability wasn't considered to be a problem as the top of the forks and the wheel axle effectively create a closed triangle formation (note: this triangular format was considered more structurally stable than a rectangular one). The rake of the forks and steering geometry would have been potentially adjustable by the use of cranked dropouts, (angled forwards) or possibly on the prototype, multiple hole dropouts to allow various set-ups of steering geometry to be tested. As can be seen in the photograph, laminated "streamlined" plywood bosses were included further up the fork legs for the fitting of V brake mounting bolts. As previously mentioned, one of the considerations for the format of the forks being wedge shaped was also the fact that the distance between the mounting points for V-brakes cannot be greater than 90mm apart for wheels with typically dimensioned rims, (30mm width). However, following the tests which were made on the V-brakes on later frames (see Xylon #1) the use of V brakes on the wooden forks would probably not have been a viable option due to the forces applied to the rim by the leverage of the brakes distorting the wooden fork legs, i.e. bowing outwards. This could have possibly been overcome by fitting a "horseshoe" type yoke over the brake mounting points, however, as this would have meant that another specialised part would be required involving extra materials and machining it was considered that the type of brakes used on road bicycles (centre pivot calliper brakes) would be a better option as no stresses are transferred to the fork legs, but to the upper portion of the fork yoke where the resultant stresses would be centred on the fixing screw along the longitudinal plane. However, some form of fitment would still be needed to be devised to fit these types of brakes. Given these constraints the most probable and viable solution for a frame with wooden forks would be to dispense with the front brake option and rely on a coaster rear brake only, similar to American style cruiser bicycles.

A further consideration regarding the fork design was the diameter of the wheel with tyre, and the width of the tyre which would be used. In the case of the wooden prototype forks, a 26" mountain bike tyre was used as a model, with a relatively narrow slick type tyre, however the opportunity to test this set up was made impossible due to the theft and subsequent unavailability of the wooden forks prototype. As can be seen

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[20] Linear Analysis of Skeletal Structures David Johnson Nottingham Trent University p 73

in the photograph an attempt was made to create a formal and structural coherence between the frame and the fork where they meet at the pivot point. This was achieved by continuing the curve of the bottom of the frame to meet the verticals of the forks, and then carrying it down in a reverse curve to the bottom of the fork legs. Furthermore the section of the fork legs was sculpted like the surface of an aeroplane wing section to give some semblance of lightness, potential speed, and aerodynamics, and to a certain degree take advantage of exposing the contours of the plywood. Given their appearance and rigidity, it would have seemed that the wooden forks would have stood up to “normal” wear and tear without failing. However, one problem was foreseen regarding their alignment with the vertical axis of the frame. If the alignment of the holes in the fork yolk and the frame were just a millimetre or two out of true it could result in a deviation of 10 to 15mm at the fork ends. One possibility to overcome this potential problem was to consider the use of a steel tube for the pivot of up to 15mm diameter, with the ends finishing flush with the top of the forks, then a 12mm diameter solid steel pin with threaded ends would be used to secure the tube in place. The idea was that the relatively large diameter hole would give more accuracy during drilling with less possibility of lateral run-out (forward/backward run-out are considerably less critical than lateral run-out, as only minor steering geometry changes would result.

3.3. Handlebars

At this stage, a further use of wood could have been for the handlebars and a number of ideas were proposed, ranging from a simple bar pushed through a hole, to sculpted composite bars being inserted into a slot in the forks (Figure 122). However, no models, prototypes or proof of principle handlebars were ever constructed.

The frame in the photograph embodies the initial concepts of a wooden framed bicycle which is not based on the traditional diamond frame format. The shape is loosely based on a type of “Z” format, which was intended to give a dynamic visual appearance to the frame. What would equate to the chain-stays and the seat-stays of a traditional format are not in a fixed position on the proof of principle model but loosely connected to allow positioning of wheels and other components such as the bottom bracket and cranks.

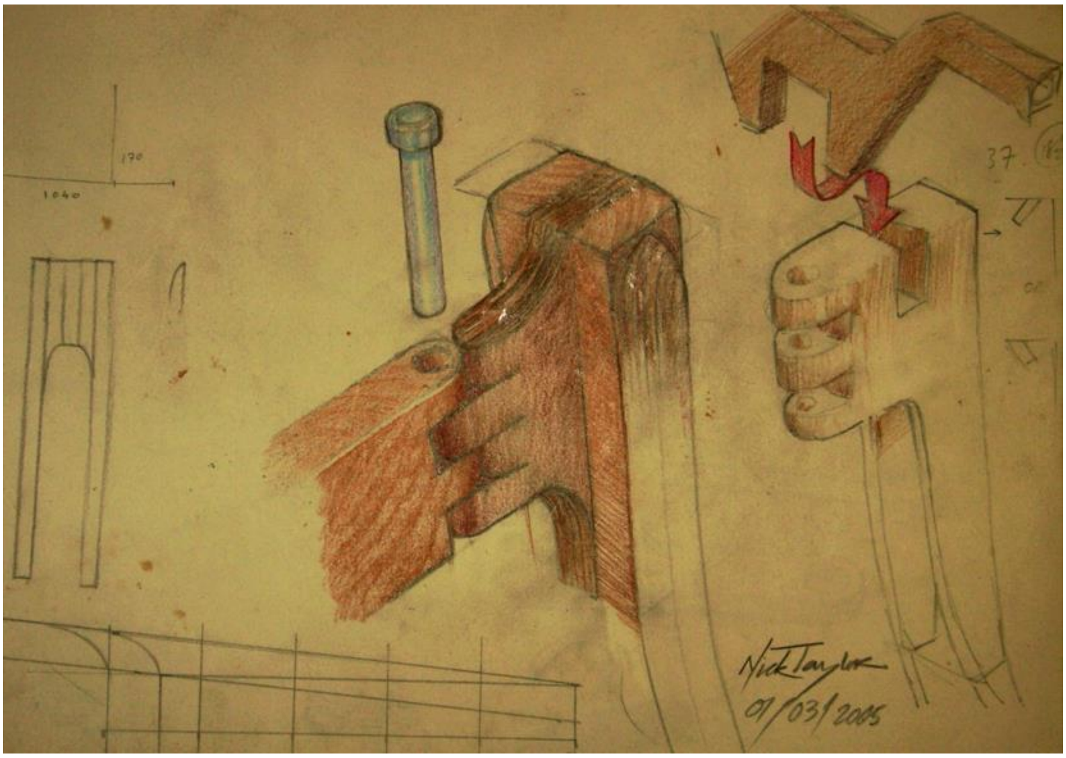

Figure 122. Illustration of Possible Wooden Forks Design and Wooden Handlebars. Taylor, Nicholas. 2005

On the original model, the bottom bracket housing was a cylindrical wooden element 68mm wide, with a hole drilled of a suitable diameter to accept a standard bottom bracket assembly as a non-standard bottom bracket, cranks, and pedal sub assembly were considered to be outside the scope of the project as they are a pivotal part of the bicycle and already at a point in their development which would entail significant research and development to improve or change.

The rear dropouts to accommodate an axle diameter of 10mm in the model were cut out of the “chainstays” in a horizontal direction to coincide with axis the bottom bracket, this orientation was chosen to allow the forwards and backwards movement of the rear wheel in the slots to facilitate chain tensioning. In order to establish the angle of the chainstays in relation to the bottom bracket, a rear wheel was affixed in position with a distance over locknuts of 120mm and tightened with washers and nuts, as the nuts were tightened the two chainstays assumed a parallel format 120mm apart, and pulled away from the bottom bracket housing. When the chainstays were pulled into position on the bottom bracket housing there was a tendency to “bruise” the wood around the dropouts and the chainstays took on a slightly curved shape. However, this curve was very slight due to the compression of the wood around the dropout slots.

Having positioned the rear wheel it immediately became apparent that there was a flaw in the proof of principle model. The shape of the chainstays would not allow the chain to be used without modifying them by making a hole or slot for the chain to pass through, the position of this slot being conditioned by the diameter of the crank and the diameter (number of teeth) on the rear sprocket, and the distance of the rear wheel from the bottom bracket. Furthermore there were doubts as to whether the crank would turn without fouling (rubbing against) the drive side chainstay.

Having assembled a provisional mock-up of the frame it was decided that too many unforeseen factors were evident, and those which had been previously factored in remained unresolved. Therefore a different approach was taken which was based on the rationalisation of the bicycle frame and subsequent development.

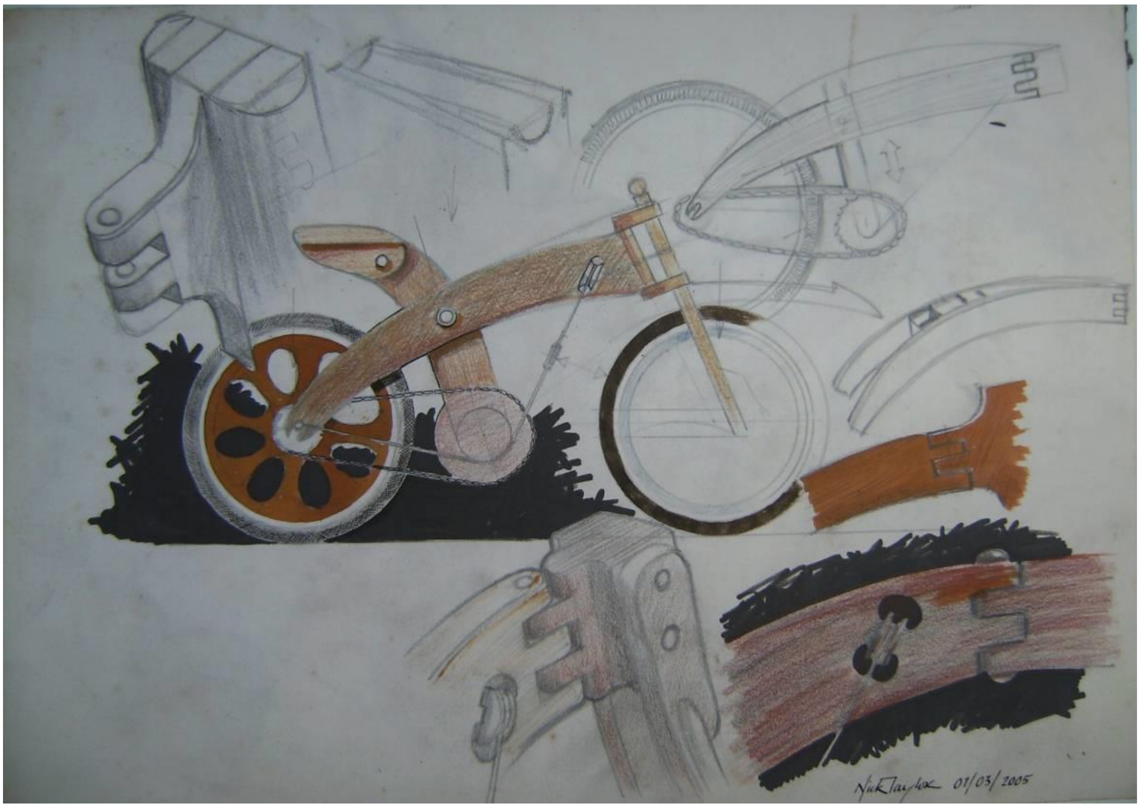

Figure 123. Initial Design Sketches for Wooden Bicycle – Taylor, Nicholas. 2005

Note: It was at this stage that the possibility of using raised chainstays was considered as it would mean that the integrity of the chainstays would not be compromised and possible weakened by removing material from them to allow the chain to pass (Figure 123). It would also mean that chain removal could be effected without requiring a chain breaker tool, thus reducing the quantity of specialised tools. Also on the initial model, no consideration was given to the positioning or fixing of a saddle sub assembly.

Figure 124. Main Body of Wooden Bicycle Frame Mock-up – Taylor, Nicholas. 2005

Following initial ideas regarding the making of a wooden bicycle (no restrictions were imposed regarding the use of wood for all components) a series of design sketches were made taking into consideration the following provisos.

1. The bicycle frame would be made from wood.
2. The wheels could possibly made from wood (except the tyres)
3. The saddle could possibly be made from wood.
4. The forks could possibly be made from wood.
5. The handlebars could possibly be made from wood
6. Wherever possible easily obtainable common hardware such as screws, nuts, bolts etc. could be used instead of standard bicycle components and fittings.

In order to limit and focus the design concept, a decision was made not to “copy” the diamond frame style of bicycle by imitating the structural procedure traditionally employed and simply substituting the frame elements with wooden ones. Therefore the possibly arose of generating and developing a “monocoque” style bicycle frame.

No specific briefing was defined other than that the size of the frame should be suitable for adult users (either male or female) and the possible style, methods of manufacture, appearance etc. would be chosen to project the qualities of wood as a “plastic/sculptural” medium which would allow a form of styling which was in keeping with the properties and qualities of wood and its derivatives. In other words, the material would not be disguised or altered visually by painting or other surface treatments. Furthermore, although a number of conceptual ideas would be developed, the bicycle must function as a practical method of transport such as a proof of principle model and not solely as an “idea” or concept.

3.4. Design Process

A series of sketches were made in order to explore the aesthetic and mechanical possibilities involved in the development of a wooden framed bicycle. At this stage sketches and studies were confined to scaled-down drawings rather than full size drawings being made.

As a starting point, no particular style of bicycle was chosen (such as City, MTB, Road etc.) but a generic form with the only constraints being the rider’s position (sitting, not recumbent), and the approximate wheel base the same as the majority of adult sized bicycles. Wheel size was not defined as a design criteria; this was a result of the proportional considerations of the frame sketches. I.e. the wheel size was not defined by bicycle typology, but rather by the way the wheels integrated into the proposed frame designs.

At the same time, various methods of joining wood with itself and other materials were explored, such as jointing, screwing, gluing, etc.

It became quickly apparent that a holistic approach was required in the Design Process as the design and development of the various components and sub-assemblies are entirely dependent upon each other as there is no established paradigm.

Following on from the “monocoque” concept and the sculptable qualities of wood a number of divergences from typical bicycle design resulted, these decisions are described in the accompanying Development Sketches.

As the traditional bicycle frame format is essentially a triangulated framework there are significant “voids” or spaces which give the visual effect of lightness to the structure, especially the traditional steel tube framed road bicycle where light weight and strength are the principle considerations. Taking this into account it must be stressed that weight saving or reduction of weight were *not* taken into consideration during the initial design stages and sketches of possible configurations. Furthermore the front forks were regarded as a potential extension of the frame design without any specific regard to geometry or frame set-up other than the free rotation of the wheel and movement of the forks to steer the bicycle.

3.5. iterative approach to frame design - “A Wooden Bike in a Week” project

As a way of stimulating creativity, and accelerating the Design Process, I launched the “A Wooden Bike in a Week” project as an extracurricular project. The intention and objective was to design and make a real functioning bicycle made from wood rather than an “idea” or “concept”, the metaphor that was applied to the project was that “You can’t escape from a desert island on a concept…but you can on a raft”.

3.5.1. Frame Design Methodology

Following the intuitive non-analytical approach described prior to this, it became apparent that there were serious inherent flaws in this type of approach. Therefore the exercise served as a way of expressing some fundamental concepts without the constraints of going into depth with regard to mechanics, rideability, structural strength, and detailed solutions. Although the concept stage included a partly finished full size model of some of the ideas, it was primarily carried out as a styling exercise with readily available materials as to how a wooden framed bicycle might look, and at the same time how it might be constructed. Bearing this in mind, the following analytical approach was taken to designing the bicycle frame, starting from a re-evaluation of the basic concepts of the bicycle regardless of the materials used in its construction.

3.5.2. Determination of interface positioning

To access the rider experience in general various experiments were carried out by riding a typical 26” wheel mountain bike and listing a series of observations. It soon became apparent that the experiences and observations would play an important part in the design of a bicycle and full size drawings were made of the mountain bike that was being used and the observations were noted. For example, due to the interconnectivity of components, altering one component would have impacts on others. Hence it was decided to start from a single datum point and develop the bicycle around this. It became apparent that the height of the pedal at the bottom of its stroke (6 o’clock) was an extremely important factor. If the height of the pedal from the ground was too low, there was a danger of grounding it when riding up a curb or turning a corner if it was in this position.

Note. Most cyclists are aware of this phenomenon and tend to raise the inside pedal when cornering, and keep both pedals horizontal when riding up or down a curb.

Figure 125. Rene Herse Crankset showing Crank Arm Length. Retrieved from http://velosniper.blogspot.pt/2008/10/wednesday-price-porn-rene-herse-cranks.html

After having measured the crank lengths of a series of adult bicycles and researched the specifications that were available from various manufactures it was found that the crank arm length on an adult bicycle could vary from 165mm to 175mm (Figure 125). Taking this into consideration the minimum height above ground level was derived from measuring a random sample of bicycles and marking this height above ground level. This was taken as the first datum point. (Datum 1). I.e. Pedal height 10 cm above ground level.

Having established this datum, the height of Datum 2 was vertically projected 175mm above Datum 1, thus the centre height of the bottom bracket was fixed at 27.5 cm. (D2 in Figure 5)

The following datum was arrived at by circumstance and empirically. As the majority of available bicycles were of the typical mountain bike type, each bicycle was fitted with 26” BTT wheels i.e. 54-559 ERTRO (European Tyre and Rim Technical Organisation)[21] See Appendix iii. Commonly referred to as 26 × 2.00 Inch. The only variation to this size was the type of tyre fitted to the rim, some tyres being wider and higher and some tyres being narrower and lower. In order to ensure the desired height above ground of the pedal regardless of tyre size, the lowest or narrowest dimension measured from the hub of the wheel to the outer surface of the tyre was used as Datum 3 (33cm). This line was then projected horizontally above Datum 1 and 2 (Figure 126).

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[21] http://www.etrto.org/page.asp?id=1594

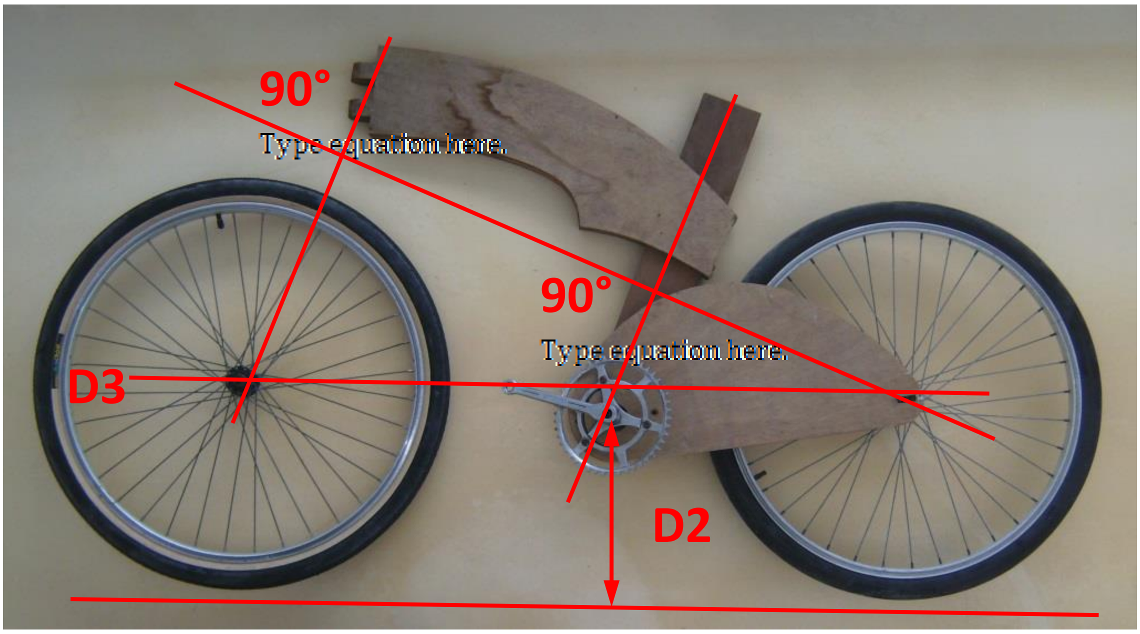

Figure 126. Full Scale Simulation of Wooden Frame Bicycle minus Forks – Taylor, Nicholas 2005

At this point, having established the tree datum points measured from ground level the distance between wheel centres was calculated as follows. Starting with the arc projected by the rotation of the crank with a pedal attached, the “worst-case scenario” was simulated where an average size adult foot (size 41) described an arc with the heel on the pedal. This is considered the worst case scenario as this form of pedalling can lead to the toe of the leading foot interfering with the arc described by the front wheel when the handlebars are turned, possibly resulting in an accident. Having the arc of the movement of the crank as a reference, the front wheel was then drawn making two tangentially external circles with the centre of the larger on datum line 3.

Having established these points, as front and rear wheels are the same size, the position of the rear wheel centre point was determined along the Datum 3 line. The choice of this point was the result of studying available bicycles and measuring the distance from the bottom bracket centre to the rear wheel axle centre (C2 Figure 5). However, it was discovered later that this was not in fact, a critical distance and was determined by a variety of factors such as handling, comfort etc. For example if this distance is shorter it aids hill climbing, if it is longer the bicycle is more stable.

The next component which was introduced to the calculations was the font forks. A front fork without suspension was used from a mountain bicycle. The fork was attached to a front wheel with tyre and aligned with the datum points on the drawing.

NB. At this phase a crucial decision was made which would affect and condition further design and development of the wooden bicycle frame.

Taking into account my experience with working with wood and the joining and boring of wooden parts at angles other than 90º (i.e. perpendicular) such as legs of tables, chairs etc. the front fork was moved through an arc until its top section coincided with a projected line from the rear wheel centre at 90º. Following this, the length of the head-tube of the donor bicycle was measured (120mm) and a parallel line drawn above it. In this way the main structural member of the bicycle frame was created running from the front fork to the rear wheel axle.

Still maintaining the proviso that whenever possible, wooden joints should be made perpendicular to each other, a further line was projected upwards from the bottom bracket centre to intersect this line at 90º. In this way the “cross-frame” structure was established as the simplest solution to frame design. To keep visual coherence, this second “cross member” was given the same dimension as the main frame member, i.e. 120mm.

At this point it became apparent that dimensions taken from traditionally framed bicycles could not be used without some alteration. When the second frame element was drawn, it was found that there was insufficient clearance between the arc of the rear wheel and the second frame member which would equate to the seat tube of a tradition bicycle. Therefore a wheel and tyre was positioned on the drawing and moved backwards to give a clearance of approximately 20mm from the tyre to the frame post. As a result, other adjustments were made to the overall layout and the essential interface points established.

3.5.3. Component and frame dimensioning

A number of essential dimensions were needed to be established so that the components would be suitably fitted to the frame.

3.5.4. Fork to frame interface

The first dimension to be established was the diameter of the hole for the steering stem of the forks. As the steering assembly rotates on two sets of bearings, upper and lower, the set of parts comprises an upper and lower bearing cup as previously described. (See figure 69 – head-set)

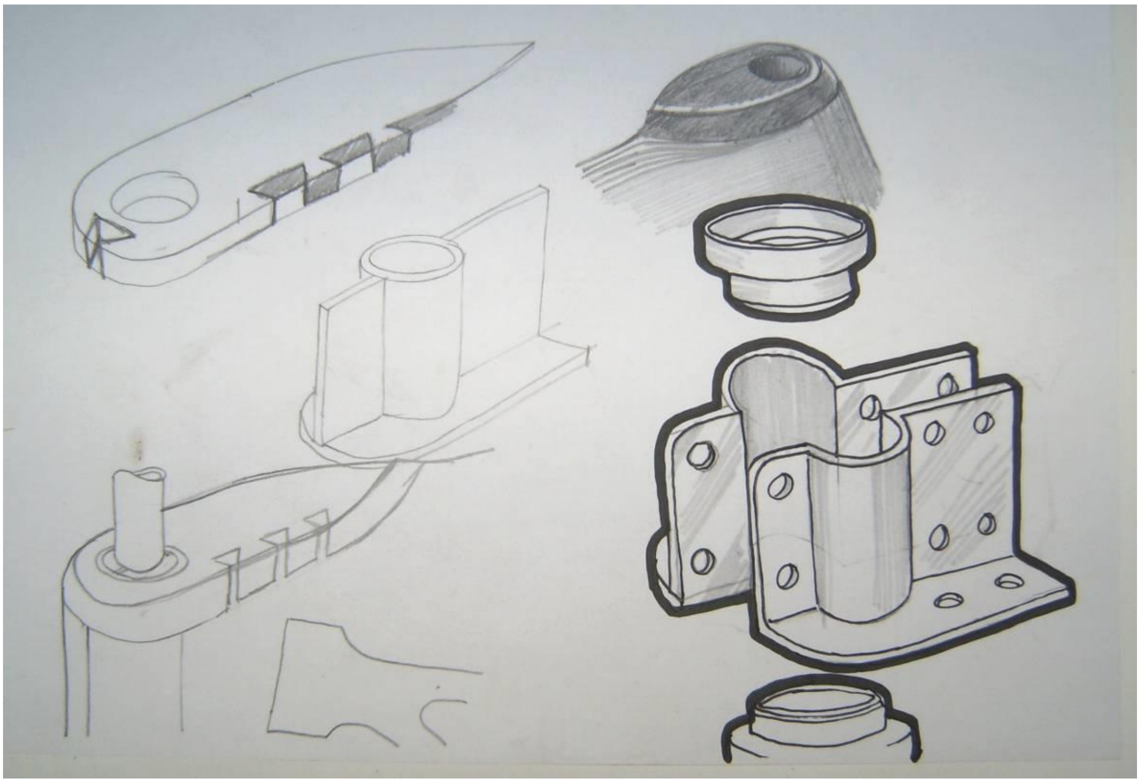

Figure 127. Initial Design Sketches for Head Tube Fitting – Taylor, Nicholas 2005

As the outer diameter of the bearing cups is 30.2mm it was decided to bore the holes to fit them 30mm so that the cups could be a press fit into the frame. A series of test holes were drilled in various types of wood and plywood and the hypothesis was tested with acceptable results, the bearing cups being retained in the samples.

At this point a situation arose where further considerations were necessary. As the forks are a critically important part of the frame assembly structurally, the dimensions of the frame at that interface (width) needed to be ascertained. Referring back to the possible structural methods incorporating both solid wood and plywood, it was decided to opt for a dimension that would allow at least 10mm of material on either side of the hole laterally (Figure 128).

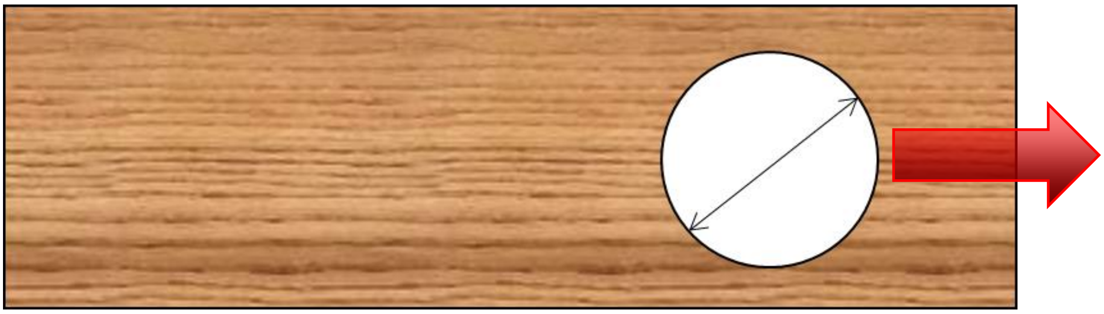

Figure 128. Top View of Wooden Core – Grain Direction and Steerer Tube Position – Taylor, Nicholas.

This would give a nominal frame width at that point of 50mm (30mm + 10mm + 10mm). The acceptable safe distance of the hole from the front of the frame having to be determined later, as the characteristics of the member were different in that the possibility of "pull-out" or rupture were greater as the forces acting on the forks are greater in the linear front/rear plane than the sideways stresses, and the grain of the wood at that point is relatively short. Although a certain amount of material in front of the steerer tube was considered necessary, no specific dimension was decided upon. The amount of material was estimated at approximately 40mm. Any more than this would have given the frame a "nose" which was something that would have a tendency to alter the "feel" whilst riding (i.e. the bicycle would appear to be go straight on when the handlebars were turned).

3.5.5. Bottom bracket to frame interface

Having taken measurements of the bottom bracket with a Vernier calliper from all available bicycles, (twenty one examples) there were two principle dimensions to be taken into consideration (Figure 129).

- The width of the bottom bracket which was found to be 68mm
- The internal (unable to determine) and external diameter of the bottom bracket shell

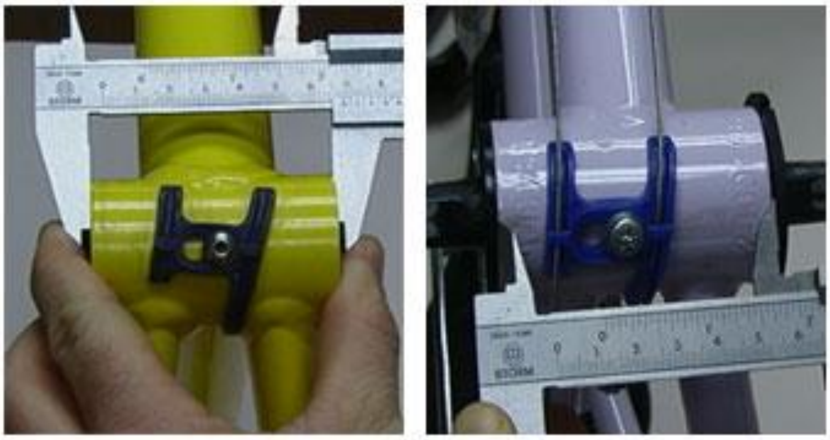

Figure 129. Measuring Standard Bottom Bracket Widths. Retrieved from https://www.nashbar.com/webapp/wcs/stores/servlet/CustomContentView?storeId=10053&catalogId=10052&dynamicSpotName=sizeforbikeSpot_Part1

The internal diameter of the bottom bracket shell is almost uniformly 33mm, however the outer diameter depends on the thickness of the tube and the metal which is used, but in the large majority of cases is found to be 40mm (in the case of steel).

The outer and inner diameters are conditioned by the bottom bracket threading requirements:

1.370" x 24 TPI right hand thread for the adjustable cup, and 1.370" x 24 TPI left hand thread for the fixed cup.

Before tapping, the inner diameter must be bored out to 33mm nominal.

Considering the width of the frame cross member on the wooden prototype was nominally 120mm, there was considered sufficient material to house the bottom bracket shell regardless of structural constraints, especially the torsion created by pedalling or standing on the pedals. However, the width of the bottom bracket shell of 68mm needed to be established with a certain amount of precision. If the width was greater than the nominal 68mm, the standard bottom bracket shaft or cartridge would have insufficient protrusion on either side which not allow free rotation of the cranks and chainwheel. And if the width were less the bottom bracket, cups or cartridge would not be able to be screwed in sufficiently. Although the 68mm dimension is ideal (between flanges) it is possible that the following solutions could be applied.

1. The bottom bracket shell could protrude beyond the frame (if the bottom bracket shell is a single piece.
2. If the frame thickness at the bottom bracket interface is greater than 68mm it could be reduced in the vicinity of the interface.

3.5.6. Bottom bracket and seat post housing.

The simplest method of creating a bottom bracket housing and seat post was to incorporate both elements into one structural component mounted approximately perpendicular to the other frame member, essentially making a type of cross where the two members met. The width of this frame member was defined primarily by the width of a standard bottom bracket housing which in the vast majority of cases is 68mm. Having established this dimension it was necessary to consider most practical dimension for the breadth of the member. As the diameter of the bottom bracket is approximately 40mm it was decided to provide the same dimension on either side, i.e. 40mm and below the bottom bracket to provide structural integrity and symmetry, with the option of reducing this dimension 120mm, if necessary after testing. The length of the vertical member was established by the geometry of the frame taking into consideration seat height and pedal ground clearance. As the width of the horizontal frame member had already been established it was decided to maintain the front portion of the horizontal frame member parallel up to the vertical frame member which meant that the vertical member to horizontal member interface needed to be tapered down to 40mm at the front part. The resulting angle of approximately 6º provided the required width at the rear axle dropouts. The vertical frame member was laminated by gluing plywood to attain the required thickness. At this point it was necessary to address the issue of the bottom bracket housing and the seat post. As the seat post was the simpler of the two, the diameter of the seat post was measured and found to be 1” or 25.4mm diameter which facilitated the use of a standard drill. At this point no proposals were considered regarding the fixing of the seat post in the frame, but merely positioning it. However, the dimensions of the vertical member did permit the drilling of 3 holes for the seat post which gave the possibility of altering the frame geometry by moving the seat post to the forward, central, or rear positions. Due to the requirements of bottom bracket fixing the following were taken into consideration:

- Use of standard bottom bracket,
- precision and alignment,
- Provision for adjustment.

Considering the difference in structural integrity of the plywood and the metal bottom bracket, it was decided to use the bottom bracket from the donor bicycle. This was cut off with a hacksaw and filed to an approximately cylindrical shape. At this point it was necessary to establish as to how the bottom bracket housing was to be fitted to the frame. Considering the stresses and strains imposed, especially the torque when pedalling hard it was decided to mechanically fasten the bottom bracket to the frame. This was carried out as follows.

The bottom bracket housing was sawn into two halves, denominated Left and Right, denoting their orientation when located on the frame in the usual orientation. I.e. R/H and L/H threads. In order to fix each half to the frame a clearance hole – 42mm diameter, was drilled through the vertical frame member perpendicular to the frame orientation. Two circular flanges of equal dimensions were machined in 3mm thick steel with 3 countersunk 6mm clearance holes on a Pitch Circle Diameter of 60mm and a tight clearance hole for the bottom bracket housings. Alter initial fitting to ensure linearity on a surface plate the flanges and housings were brazed together (Figure 130).

Brazing was used in preference to welding so as to reduce the thickness of the fillet which could interfere with the location in the frame and to avoid localised heating which could lead to warping of the components. Finishing time was also reduced due to the economic and judicious use of brass filler rod. The components were then polished on a lathe and initial fitting carried out. Due to the two halves being separate it was essential to ensure that the two halves were aligned without any deviation. In a production situation a mandrill of suitable proportions would be employed for this purpose, however, in order to accomplish this on the prototype, a bottom bracket sealed unit was used as a makeshift mandrill. With the bottom bracket halves in position the hole positions were marked out using the flange as a template (Figure 131).

Figure 130. Handmade Two-piece Bottom Bracket Shell Prototype with Flanges – Xylonbikes 2005. Taylor, Nicholas.

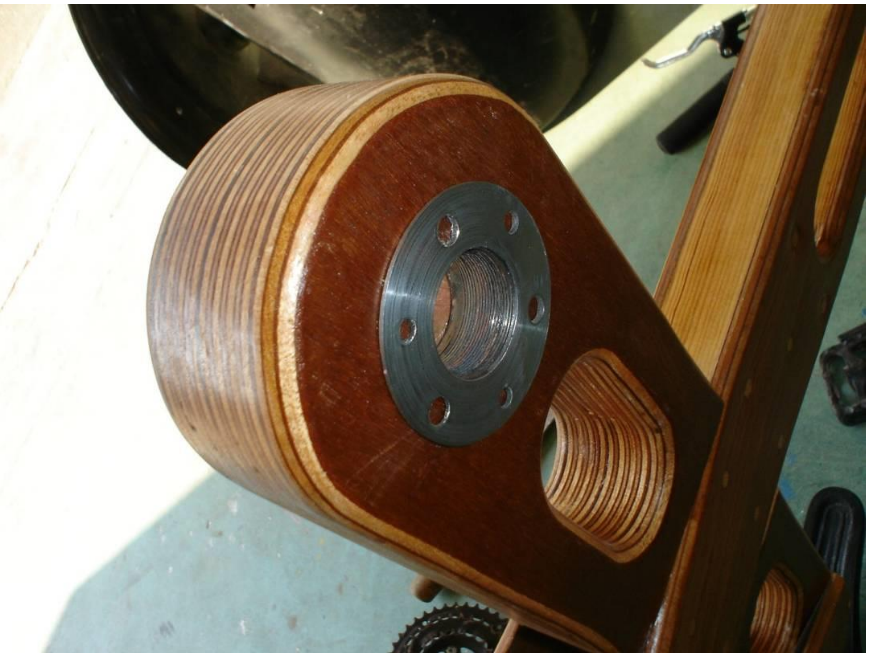

Figure 131. Handmade Two-piece Bottom Bracket Shell with Flanges Trial Fitting to Xylon #1 – Xylonbikes 2005. Taylor, Nicholas.

Initially the two flanges were secured by self-tapping wood screws, however, due to the friable structure of the plywood, the screws stripped out the holes when over tightened (Figure 132). As a more secure alternative, the following method was employed, which would also allow the components to be removed and repositioned more easily and not compromise the structural integrity of the plywood. The fixing holes in the plywood frame were through-drilled to 8mm diameter and three 50mm long, 8mm external diameter steel bars were drilled and tapped to M6. The resulting threaded tubes having been cut to a dimension less than the width of the bottom bracket housing to ensure tightening against the vertical frame member abutment (which was the width gauge of 68mm – 5mm + 5mm = 58mm nominal).

Figure 132. Handmade Two-piece Bottom Bracket Shell with Flanges Trial Fitting to Xylon #1 – Xylonbikes 2005. Taylor, Nicholas.

The threaded tubes were inserted in the frame and the flanges secured by M6 x 20mm countersunk screws to a torque of 4.5Nm to 5Nm. The length of the tubes in relation to the length of the screws was such that in the event of the screws on one side being fully tightened and drawn into contact with the inner face of the flange, the length of the opposing screw was enough to be threaded at least 10mm into the tube. Having secured one flange the other was offered up and it was noted that the holes did not coincide. This could have been due to two possible errors:

(a) Inaccuracies in setting out or drilling the pitch circle diameter on the bottom bracket flanges, or

(b) The holes drilled in the frame were not perpendicular to the surface and were running off

It was noted that a deviation of as little as 2mm was sufficient to impede the tightening of the countersunk screws. The only viable solution in the circumstances was to enlarge the holes in the frame to approximately 10mm diameter to accommodate the screws by providing sufficient clearance. The screws were tightened and the two flanges were drawn inwards. However, in spite of the use of the sealed cartridge being used as a mandrill a very slight deviation out of alignment made it difficult to screw in the R/H threaded (i.e.) the left hand securing ring.

NB. If the bottom bracket housing is to be manufactured in two parts, a very accurate jig and mandrill set-up must be used to ensure correct alignment. A possible solution to this problem was found in a bottom bracket conversion which is available from some manufactures who have responded to the need for an American bottom bracket to Euro bottom bracket adaptor (Figure 133).

Figure 133. Commercially Available American to European Bottom Bracket Adaptor – TruVativ. Retrieved from https://www.sram.com/truvativ

The adaptor has right and left hand threaded bottom bracket halves and the outer diameter corresponds to the inner diameter of American bottom bracket housing. The two halves are drawn together by three screws which draw the flanges tight against the outer surface of the bottom bracket housing, ensuring (if the bottom bracket is accurately faced) parallelism of the two halves. The tolerance is very small and relies on the adaptor and the existing bottom bracket housing being machined to close tolerances, otherwise there will be a tendency for the adaptor to rotate. This sort of adaptor is a viable solution for a wooden framed bicycle; however, a number of factors need to be considered.

1 The hole through the frame needs to be machined to a close tolerance, and possibly be an interference fit. (N.B. as wood has less dimensional stability than metal great care should be taken to stabilise the wood by undertaking such operations in a controlled environment)

2 The two faces in contact with the flanges must be parallel so as to avoid any misalignment of the two halves and subsequent difficulties in fitting the bottom bracket cartridge as previously mentioned.

3. Possible compressibility of the wood should also be considered, although the choice of a compact hardwood and the surface area involved would probably overcome this problem.
4. If the problem in no 3 is not resolvable, a plain tube could be pressed into the wooden frame in order to create a more stable bottom bracket housing
5. Whichever solution is found to be the most appropriate, in order to ensure further stability, the components/adaptor could be affixed with epoxy resin in addition to the screws.

Or as an alternative the bottom bracket housing should be a single unit (Figure 134), thus eliminating the problems encountered with the two part versions such as alignment.

Figure 134. Steel Bottom Bracket Shell – Generic Part. Retrieved from
http://www.henryjames.com/bicyle-parts/bike-bottom-bracket-shells.html

However, it should be born in mind that a “one-piece” bottom bracket housing would require a method of fixing it to the frame. And due to the high torsional forces applied to it the fixing method should be robust, most probably permanent, and possibly recuperable in the event of damage such as crossed or stripped thread. A number of possibilities are shown below.

The advantage of the one piece bottom bracket is that it can be bought-in as a standard part, pre threaded on each side to accept the standard cartridge or bearing cups.

A relatively recent product is the threadless bottom bracket cartridge (Figure 135). The cartridge was originally conceived to be used as an alternative to recuperating a bottom bracket shell with irretrievably damaged threads, which usually implies scrapping the frame if the bottom bracket shell is welded rather than a lug.

Figure 135. Threadless Bottom Bracket Cartridge. Retrieved from http://www.freemanscycles.co.uk/bicycle-parts/acor-threadless-bottom-bracket-unit.html

From the point of view of reducing machining costs associated with bottom bracket shell thread-cutting the threadless bottom bracket is a possible alternative.

Another of the possibilities for the bottom bracket is the eccentric bottom bracket (Figure 136). Although not popular and not necessary with normal bicycles as the movement of the rear wheel within the dropouts allows the chain to be tensioned, the eccentric bottom bracket is employed on tandems where it is necessary to tension the chain between the cranksets without the need for a chain tensioner.

Figure 136. Eccentric Bottom Bracket. Retrieved from http://locksidebikes.co.uk/?p=164

The above photograph clearly shows an eccentric bottom bracket fitted to a metal framed bicycle. As its name implies, due to the eccentricity of the housing, if the unit is rotated in the frame, the distance of the crankset will alter in relation to the rear wheel thereby tensioning or slackening the chain. This system is desirable where there is no possible movement of the rear wheel in the rear dropouts and allows internally geared hubs and coaster brakes to be used. In order to fit an eccentric bottom bracket, an oversize housing or shell is required. The diameter of the housing defines the possible distance moved by the bottom bracket axle. There is also a small but insignificant movement upwards or downwards of the bottom bracket axle. There are various methods of clamping or fixing the eccentric bottom bracket in the frame. There are also various methods used to rotate the eccentric bottom bracket within the housing. The bottom bracket axle or cartridge housing uses standard dimensions as previously mentioned. Due to the eccentric bottom bracket not being a common part, and its relatively specific use, it is more expensive than standard bottom brackets, however, there are clear advantages to its use in non-standard bicycles such as tandems and wooden framed bicycles where other constraints are imposed.

Although the bottom bracket which was initially proposed for use in the wooden bicycle frame was the European Standard bottom bracket. Another type of commonly used bottom bracket is the American or Ashtabula bottom bracket (Figure 137).

Figure 137. Ashtabula Bottom Bracket Housing. Retrieved from http://www.henryjames.com/bicyle-parts/bike-bottom-bracket-shells.html

As can be seen in the preceding photograph the Ashtabula bottom bracket housing is unthreaded. Bearing cups are press fitted into the housing and a one piece crank (Figure 138) with bearing cones is inserted which is then tightened against the ball bearings by a threaded cone on one side. See following illustration:

Figure 138. Ashtabula (American) One Piece Crank. Retrieved from http://www.sheldonbrown.com/opc.html

The Ashtabula one-piece-crank is robust, but as it is forged from steel it is heavy. It has now mostly been superseded, but is still used on children's bicycles and low quality adult cycles.

3.5.7. Rear wheel interface

Up until this point all measurements and calculations were made with the frame in profile. The layout of the various components lying in either the vertical of fixed horizontal plane. A number of other factors were needed to be taken into consideration regarding the rear wheel interface. Unlike the other three interfaces, the rear wheel interface is not restricted to just one part. It is composed of two elements, i.e. the chain stays, which must be aligned horizontally, longitudinally and vertically.

The first dimension to be considered was the Distance over Locknuts of the rear wheel.

Figure 139. Xylon #1 Initial Trials – Rear Dropouts – Taylor, Nicholas.

As available wheels all had gear clusters, the average distance over locknuts was calculated as 130mm nominal (Figure 139). Two slots were cut in the chainstays to insert the rear wheel axle. The rear wheel was then mounted and the nuts tightened. Taking into consideration the perceived structural resistance of a frame made from wood, and the fact that natural wood has a relatively low density and is composed of hollow longitudinal fibres, which due to their approximately cylindrical form gives them inherent stiffness because their tubular shape resists bucking and the load-bearing surfaces are held together by lignin which acts as a sort of glue, these “bundles” increase the resistance to compression and tension. However, the characteristic structural weaknesses inherent in wood such as grain, shakes, knots, could potentially make it an unsuitable material prone to failure for a number of reasons unless suitably modified.

The following photograph (Figure 140) shows the first “rolling chassis” of the wooden framed bicycle. The chainstays are slightly tapered towards the rear to give it a less heavy, boxy appearance. The headset is fitted perpendicular to the frame core. The bearing cups are directly press fitted into the wooden core, and the structure is provisionally assembled by drilling and fixing with 8mm threaded bar and nuts and washers. The rear wheel is fitted into slots.

Figure 140. Xylon #1 Initial Trials – Main Frame Member –Taylor, Nicholas.

The next photograph shows the seat tube fitted to the main structural frame member. Once again the seat tube is fixed using threaded bar and nuts and large diameter washers. The positions of the holes being defined by the equal distribution of stress at the joint, and resistance to turning. The seat tube is mounted at 90º, perpendicular to the main structural frame member (Figure 140). Where the two frame members cross, the upright is slotted and sloped to receive the main structural member, where the two are tightened together the ends are forced apart to the approximate over lock nut dimension of the wheel.

Figure 141. Xylon #1 Initial Trials – Full Size Cross-Frame Construction –Taylor, Nicholas.

After riding the bicycle with this set up it rapidly became apparent that the frame was unstable. The flexing of the frame created an almost uncontrollable wobble/oscillation. Attempts to pedal worsened the effect due to the torsion applied to the frame via the crankset. The conclusion was that the bicycle at this stage was unrideable and some form of correction would be required in order to make the frame stable enough to use.

The photograph below shows the solution to this problem.

Figure 142. Xylon #1 Initial Trials – Fitting of Seatstay Bracing Strut –Taylor, Nicholas.

As oscillation was worse from the upright towards the rear of the frame the following solution was applied. Two more threaded bars were inserted close to the upright member to pull the two halves closer together. And a diagonal triangulation member was added from the top of the upright to the chainstays, being bolted to the upright in two places and in two places on the chainstays also (Figure 142). As the chainstay and the upright are not on the same plane, large diameter steel washers were used to distribute the load and avoid chewing up the wood. This was carried out with the rear wheel in place, but rather than tightening the rear wheel axle nut directly against the chainstays slots, wedge shaped wooden washers were used. As the seat stay nuts were tightened both the seat stay and chainstay distorted until they were brought into full contact with each other (Figure 143).

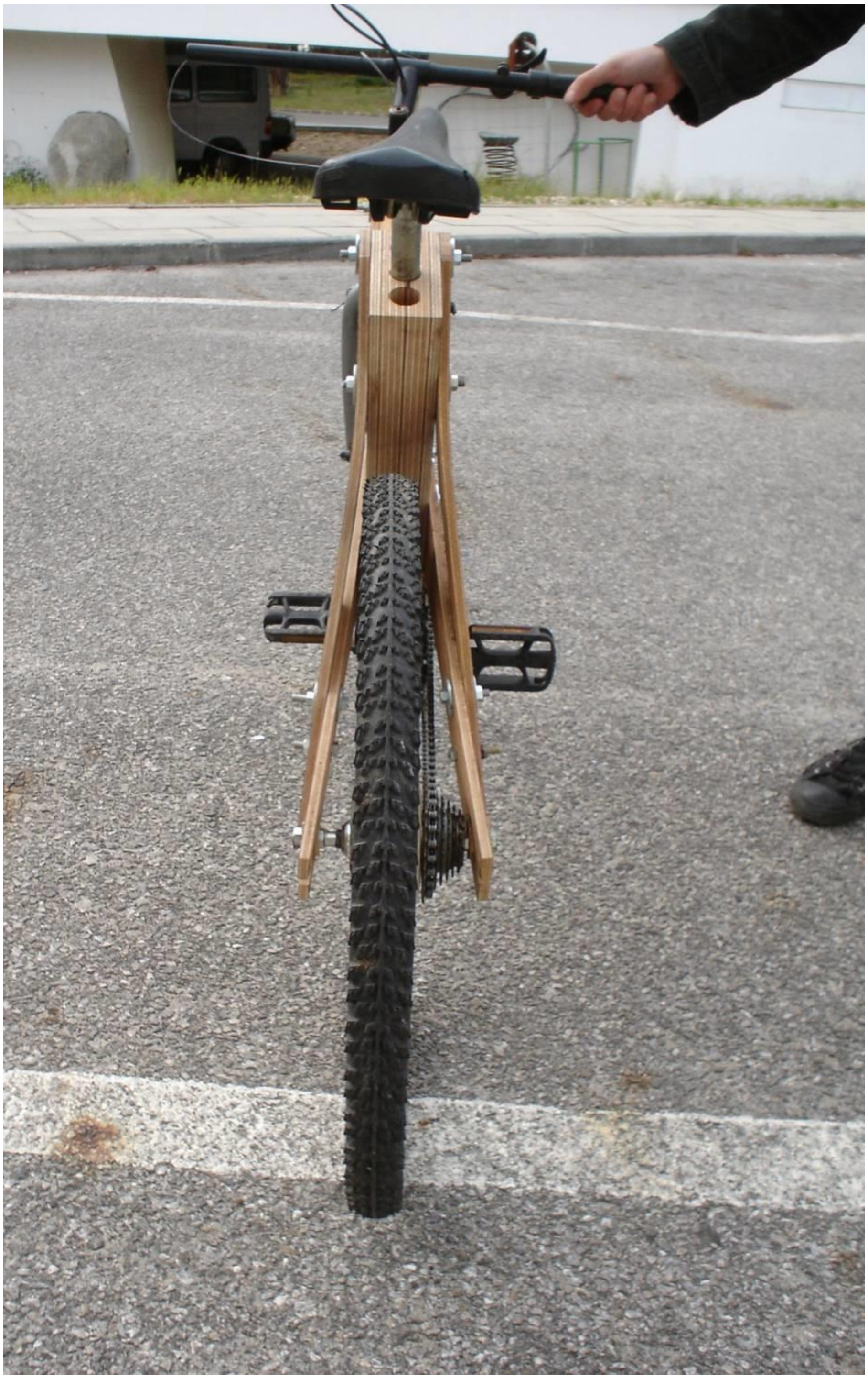

Figure 143. Xylon #1 Initial Trials – Rear View Showing Chain Line –Taylor, Nicholas.

An advantage of this was that a certain pre-tension was introduced to the rear frame and when the bicycle was tested again there was a significant improvement.

So much so that any feeling of insecurity on the part of the rider was completely dispelled. This stiffening of the rear frame could possibly be attributed to the potential flexing of the chainstays being reduced by the forces being resisted by the triangulated frame as in a tradition bicycle. And in addition the triangulation created by the chainstays and the rear axle. The bicycle was tested by various people and all the results were favourable (Figure 144).

Figure 144. Sergio Cordeiro Testing Xylon #1 During Initial Trials –Taylor, Nicholas.

NOTE: As the improvement was significant, other than the test rides, there were no quantitative tests carried out on the frame at this stage such as measuring the forces required to deflect the frame, and the amount the frame deflected. However, the photograph above shows the worst case scenario where the rider's weight is wholly sustained by the frame and none of the weight is distributed through the pedals.

Figure 145. Leonel Mateus Drilling Xylon #1 Frame for Bottom Bracket Fitting –Taylor, Nicholas.

The frame was now considered suitable from the structural point of view but a decision was made to visually and physically lighten the frame by removing material from the main and upright members (Figure 146). This decision was taken as the removal of material from about the central axis of the two members would have very little impact on the overall frame strength.

Figure 146. Xylon #1 Frame Detail –Taylor, Nicholas.

As the frame members were both based on a dimension that was derived from the steerer tube – 120mm, the proportion of material removed was based on the ratio 40mm – 40mm – 40mm. Without compromising the strength of the members at crucial points, a 40mm wide opening was made in the two members. Machining was facilitated by 40mm diameter hole-saw and a router. At the same time the edges of the frame were rounded to reduce the risk of splintering, this was also an aesthetic choice which gave the frame a more finished appearance. The bottom bracket housing was also curved to accompany the radius of the bottom bracket. The frame was then glued together with PVA (white glue) wood glue and cramped with G cramps and also with the 8mm threaded rods and large diameter washers passing through all the frame members (Figure 147).

Figure 147. Xylon #1 Full Size Prototype During Initial Trials –Taylor Nicholas.

The above photograph shows the addition of struts (seatstays) fixed with 8mm threaded rod, large diameter washers and M8 hex nuts.

Figure 148. Testing Xylon #1 Prototype During Initial Trials –Taylor, Nicholas.

The photograph above shows the first rideable wooden prototype bicycle. The derailleur on this model is non-functional as a gear changing mechanism and simply serves as a chain tensioner (Figure 148). The format (proportions) of the frame are almost identical to a standard bicycle frame using 26inch MTB wheels and tyres.

The rear brake is inoperative and it has been decommissioned due to excessive frame flexion which made it ineffectual.

3.6. Testing

Specialised testing equipment for bicycles and bicycle frames has been designed to test various parts of the frame by repeatedly applying precise forces in specific areas. Typically cycles of around 100,000 are applied and the frame parts analysed for fatigue or fracturing. However the frame jigs are designed for conventional bicycle frames and the stress points have been identified over time by hundreds of tests. These dedicated test rigs are operated by companies specialising in the service and are beyond the scope of a project of this dimension.

3.6.1. Structural failure

Although destructive testing of the Xylon #1 frame was never anticipated or planned, and attempts were made to preserve it for as long as possible whilst using it regularly, the frame eventually failed.

Note on testing:

In the absence of standardised testing equipment[22] tests were carried out by users to evaluate the wooden bicycle frames performance, the results were recorded and modifications recommended. Testing is ongoing with any relevant findings analysed and decisions made as to whether significant alterations are needed.

Although the prototype Xylon #1 frame performed well for several months and covered at least 50km, being ridden by a variety of users, both male and female, it eventually failed when ridden hard by a young rider who was more used to riding BMX bicycles. Had this not occurred it is quite possible that Xylon #1 would still be serviceable.

The cause of failure was undoubtedly due to excessive torsion applied to the frame. By analysing the frame the following conclusions were reached.

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[22] Development of a multi-directional rating test method for bicycle frame stiffness - J Vanwalleghem, I De Baere, M Loccufier, W Van Paepegem Journal of Science and Cycling

As the frame had been strengthened to resist the compression of the V brakes with a steel tube with an 8mm threaded rod running through it acting in the same way as the V brake reinforcement yoke on telescopic mountain bike forks, it had been necessary to drill the seat stays at this point (Figure 149).

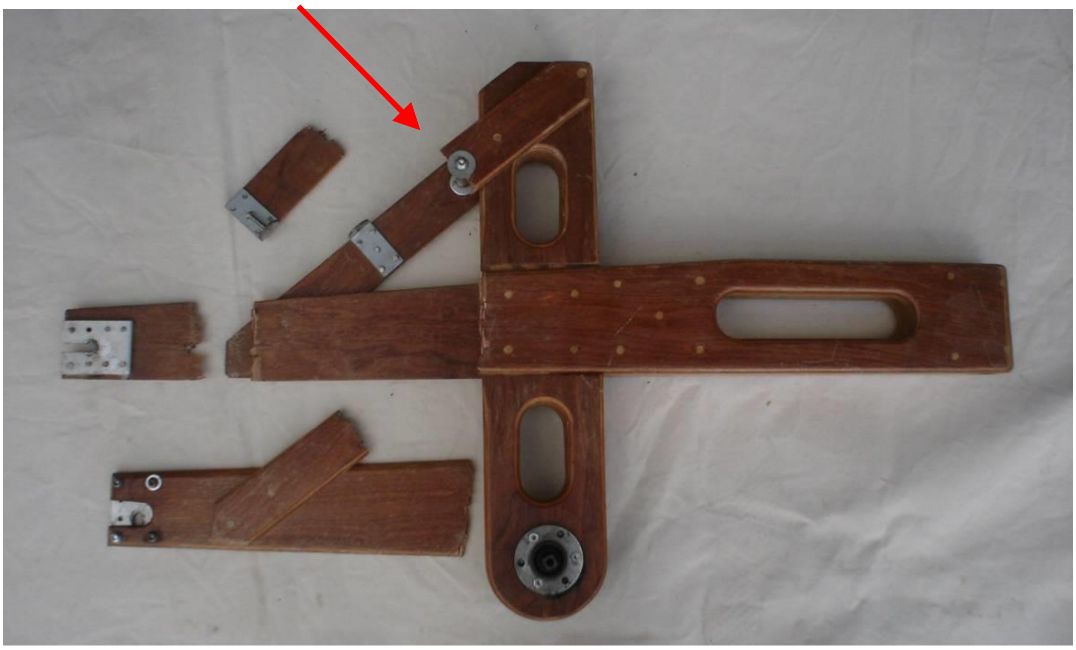

Figure 149. Xylon #1 Prototype after Failure–Taylor, Nicholas.

Also the seat stay had been drilled to attach the V brake mounting. Five 6mm holes had been drilled in each seatstays.

Figure 150. Initial Fitting of V-Brakes on Xylon #1 Prototype –Taylor, Nicholas 2005

The principle hypothesis is that the excess torsion exerted by the rider on the chain (drive) side tended to bend the right-hand chain stay. Consequently, the weakened seat stay failed at the two points indicated in the photograph.

Without the seat-stay to stabilize the twisting forces applied to the frame, the main chain-stay failed where it was attached to the upright frame member, as along its length it was flexible up until this point.

Then, as the rear axle was unsupported on the chain side but the chain was still under tension, the left hand chain stay failed where it had been previously drilled to accept 8mm bolts which were replaced by 8mm wooden dowels when the frame was glued together.

Figure 151. Detail of Failure on Xylon #1 Prototype at V-brake Fixing Holes –Taylor, Nicholas. 2006

Although the previously postulated sequence is the result of speculation, the frame failures, with the exception of the right hand chain stay, all occurred at points where the integrity of the plywood had been compromised by the removal of material by drilling and the removal of material (such as in some cases countersinking).

Note. At this point no consideration was given to the type or quality of the plywood. Nor was any attempt made to orientate the laminations of the plywood in a particular direction.

This led to the conclusion that, in order not to weaken the frame at highly stressed locations, whenever possible subsequent frames made to the same or similar format should not be drilled at these positions, or if drilling is inevitable it should be confined to areas of less stress, or these points should be suitably reinforced, and the perforations should be as small as possible.

The above photograph clearly demonstrates the frame failure around the V brake fixing bracket holes (Figure 151). To some degree, the failure was predictable at this point. No reinforcement or thickening of the seat stay was attempted, and the break is almost coincident with the V brake metal plate.

Figure 152. Detail of Failure on Xylon #1 Prototype at Rear Bracing Tie –Taylor, Nicholas. 2006

This failure (and other factors referred to) led to the decision to abandon the use of V brakes operating on the rear wheel, and alternative methods of braking being evaluated.

Figure 153. Detail of Failure on Xylon #1 Prototype at Rear Chainstay –Taylor, Nicholas. 2006

The failure points can be clearly identified as where the frame had been weakened by drilling and did not resist the high torsional stresses.

Analysis of the glued joint also provides evidence of poor performance of the glue. This may have been due to inferior quality glue (exceed shelf life), insufficient glue, inadequately prepared surfaces, insufficient clamping pressure, or insufficient clamping time, glue not homogeneously applied etc. (Figure 153).

The causes for the failure were not pursued in this case as white PVA wood glue would probably not be the type of adhesive used on future frames, as its water resistant properties are not suitable for outdoor use. However the failure of the glue at these points was an important reminder about the stresses occurring at this type of frame joint.

Note about the plywood used in Xylon #1

NOTE: Although wood is quite strong in the direction that its fibres run, it is weak in tension and compression when subjected to loads across the gain. Plywood overcomes this problem by crisscrossing the wood fibres during lamination. (Usually in odd numbers of laminations). Therefore plywood retains most of the stiffness of solid wood of similar dimensions, but has a tendency to be stiffer in the direction of the grain of the face veneers.

The plywood selected for the frame of Xylon #1, was not selected following any criteria other than availability, and the approximate thickness which appeared to be adequate. No investigation was made into its physical characteristics such as structural strength, density, type of wood, bonding agents etc.

Having subsequently examined the reasons for the structural failure of Xylon #1, the type of plywood which was used was undoubtedly a contributing factor. The face veneers are most probably mahogany and the core laminations sapele, the core laminations are not the same thickness, the mahogany laminates being thinner than the others.

In conclusion, the plywood used was probably furniture grade plywood, and therefore not suitable for structures which would be subjected to the types of stress that a dynamic structure such as a bicycle frame would be subjected to.

As a result of this analysis, other sorts of plywood were studied so as to reduce the possibility of structural failure. Therefore, as future designs would probably be subjected to exposure to rainwater the first type of plywood considered was what is commonly referred to as marine ply. Secondly, due to the dynamic nature of a bicycle frame, the second requirement was that the plywood should be structural grade. Finally after the two previous criteria had been met the decision was made to use 9mm thick material. This decision was made more intuitively rather than scientifically. Samples of thicker material than that which was used in the prototype did not exhibit the capacity to bend where this property was required, and thinner material appeared to be too flexible. Therefore the thickness selected was very similar to the material originally used in the Xylon #1.

3.6.2. Cross Frame Bicycles

The rationale behind the initial idea of applying a constructive approach to the design of the wooden bicycle frame was taken without prior knowledge of similar frame designs. However, although references to this design were not consulted, there are some similarities with the wooden prototype to the German Hercules 2000 cross-frame bicycle (Figure 154) designed by Herman Klaue[23]. It is interesting to note that the frame members are NOT perpendicular to each other in this case.

Figure 154. The Hercules 2000 HK 1958. Retrieved from http://www.loeschenbrand.net/hercules2000.html

The frame was manufactured in aluminium, and was a radical rationalisation and departure from the traditional diamond frame bicycle design. The fundamental parts of the frame are the main frame member and the seat tube. The design of the elevated chain stays allows the removal of the chain without the need of any special tools. Most of the other components such as the seat post and the forks are standard bicycle components.

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[23] http://tinyurl.com/zczzugl

A modern steel bicycle frame designed by ex ESAD student and bicycle designer Miguel Garcia in Portugal in 2010 is also simplified to its most basic components. Unlike the wooden porotype by the author there are no issues with flexing due to the use of box section steel tubes (Figure 155).

Note. The bicycle has no rear V brakes.

Figure 155. Cross Frame Bicycle Designed by Miguel Garcia 2010. Garcia, Miguel. 2010

The designer and builder Miguel Garcia states:

> *“This was a bit of a forced order of a shop owner here in Lisbon. Portuguese who started a bicycle business in Netherlands that, for doing so well there, open another shop in Portugal.*
>
> *I asked him if he wanted something from me, a frame, a bicycle, whatever…and he said that there was a bike that he really love but it*

> *only existed on 20’s wheels and he wanted the same design frame but to fit some 26’s wheels. The essential on this bike it’s the rectangular tube and then the extreme simplicity of the frame, being just a cross with the steering axle and bracket axle inside the rectangular tube.*
>
> *For the rear wheel I cut the back tube in the middle then weld witch part to a side then extended to fit the fat tire that he wanted. It is good but inevitably heavy because of the rectangular tubing”.*

3.7. Towards a commercially viable wooden bicycle

Regarding the use of Xylon, Xylonbikes, and specific Model Nomenclature.

Following the opportunity to exhibit the bicycles so far manufactured in the Festibike International Bicycle Festival, CNEMA, Santarem Portugal in 2004 it was necessary to identify the bicycles.

As a branding exercise the name Xylon was chosen as it was short, contained two relatively unusual juxtaposed letters, i.e. X and Y, was easy to pronounce, had a dynamic initial letter often associated with sporting references, and more importantly means WOOD in Greek and is used in various products related to wood.

3.7.1. Xylonbikes variants

Figure 156. Xylon Klassic #1 with Slotted Dropout Holes. Taylor, Nicholas. 2005

In order to create a more specific brand related to both wood and bicycles Xylon Bikes, and eventually Xylonbikes were included in the product branding, consequently Xylon, Xylon Bikes, and Xylonbikes are interchangeable throughout this study.

Figure 157. Xylon Bikes Logo. Cordeiro, Sergio. 2005

The Xylonbikes logotype (Figure 157) was designed by Sergio Cordeiro to give the visual impression of a contoured plywood initial letter X with a central hole to indicate a relationship with a wheel and mirror the stylised profile of the original Xylon frame. The logotype can be etched on aluminium parts. Laser cut on wood parts. Applied as a decal with a transparent background or branded by pyrography.

3.7.2. Xylonbikes Models

As the bicycles produced during the second Design Phase were the result of individual criteria, but based on the Xylonbikes methodology and theme, it was necessary to identify each model as unique.

- The first experimental prototype was named Xylon #1 i.e. Number 1
- the second completed bicycle by the author was named the Xylon Klassic as it was based on a relatively conservative classic bicycle format but with Classic misspelt as Klassic to differentiate and echo the X of Xylon
- The Xylon Cell by Sergio Cordeiro was named after the cellular structure of wood

- The Xylon OII by Luis Aniceto was named after the appearance of the O shaped aperture in the frame
- And the Xylon Synergy by Leonel Mateus was named due to its organic sinuous structure which freely echoes natural forms.
- The Xylon Eclipse by Nick Taylor and Luis Aniceto owes its name to the visual intersection of the rear frame with the rear wheel which it effectively eclipses.
- Subsequent models of the Xylon Klassic with detail differences are chronologically designated Klassic #2, #3 etc. depending on detail changes.
- The Xylon Quadrado by Luis Aniceto due to its rectilinear angular appearance.
- The Xylon Hybrid, due to its specific nature to suit individual criteria
- And the Xylon Fleet by Nick Taylor which was specifically designed as an economical material saving alternative which is destined for Bike Sharing or Bicycle Rental schemes comprising a Fleet of similar bicycles which can be Corporate Graphics.

The photograph (Figure 156) shows the first prototype Xylonbikes Klassic frame. The core is made up of two laminated hardwoods - mahogany, (dark brown) and Idigbo (yellowish light brown). Idigbo is easy to work and shape and has good overall strength and a natural resistance to moisture. The side panels are Baltic Birch Plywood. The laminations can be seen exposed where the bottom bracket flange housing has been machined away.

3.8. The Xylonbikes Models

After the relative success of the Xylon #1 Prototype, the most appropriate construction techniques that were used were applied to the design and development of four different models. The three students who assisted the building of Xylon #1 each developed their own wooden frame.

3.8.1. Xylon Klassic Frame – Author Nick Taylor

Description

The Klassic frame (Figure 156) is constructed from a multiple laminate hardwood core measuring 40mm wide (58mm total width with side panels). The upright frame member is constructed the same way with the exception that the cross section is trapezoidal measuring 40mm at its narrowest point and 60mm at its widest with a height of 120mm.

Figure 158. Sergio Cordeiro and Luís Aniceto checking dimensions on Xylon Klassic #2. Taylor, Nicholas. 2005

If the Klassic frame is observed in profile, the cross-form basis of the frame (see Figure 147) can be seen. As acute corners or pronounced changes of direction of wooden components profiles tend to create stress points and weaken the structure, the outline of the profile was drawn in smooth curves of the largest radii possible.

Figure 159. Xylon Klassic #3 with Inlaid Hardwood Detailing. Taylor, Nicholas. 2007

The holes for the dropouts were kept to the smallest size possible to allow the type of fastening to be tightened or loosed conveniently. The holes for the fixing screws were spaced as far apart as was practical. The metal dropouts are made from 3mm thick stainless steel held in place by five stainless steel M6 screws and Nyloc® nuts.

Figure 160. Xylon Klassic #3 with Inlaid Hardwood Detailing (Control Model). Taylor, Nicholas. 2007

The 9mm thick Baltic Birch Marine Plywood side panels are glued directly to the core with D4 code mono-component polyurethane adhesive without screws or pegs creating a monocoque construction. The symmetrical “chainstays” are of the raised type which means that the chain can be fitted without special tools and the side panels are not perforated to allow the chain to pass and follow the chain-line.

Areas where the plywood laminations have been shaved away to show the contours was the inspiration for some decorative features, the frame shown above has inlaid hardwood decoration part of which features this technique of removing material to accentuate the visual effect.

Figure 161. Sergio Cordeiro riding the Xylon Klassic #1 in Lisbon. Taylor, Nicholas. 2005

3.8.2. Oll frame: Author Luís Aniceto

Figure 162. The Xylon Oll Frame on display at the ESTGAD Finalists Exhibition Caldas da Rainha. Taylor, Nicholas. 2005

The design concept of the Oll frame was to give the impression of lightness and space whilst maintaining the organic characteristics of wood by incorporating convex and concave curves with straight lines (Figure 162). The Oll frame also incorporated a feature which would be explored on subsequent models: during fabrication cable routing was an integral part of the frame. Entry and exit points were established and semi rigid PVC tubes were inset into the core wood, which in this case was Tola Branca, a relatively soft and easily worked tropical hardwood. Cable entry point were situated either side of the head tube and exit points either side of the seat tube.

Figure 163. Completely Assembled Xylon Oll – Aniceto, Luís. 2005

The simulation on the following page (Figure 164) shows a configuration based on the construction principles that were established as being the most effective. Broken down to the minimum number of parts, the frame comprises two plywood side panels and a wooden core bonded together.

Note the asymmetrical side panels on this model (seatstays/chainstays), the right hand side being profiled to allow the drive chain to pass unimpeded, and chain replacement without the need to use special tools (chain breaker)

Figure 164. Design Simulations Based on the Oll Frame – Aniceto, Luís. 2006

The side panels are only perforated in the areas where seat post clamp, rear dropouts, and bottom bracket are attached, thus maintaining as much integrity as possible. Within these basic parameters the side panels may be designed to follow a number of profiles. In this case the raised chainstay permits the removal of the chain without the need for special tools. Chain tensioning is via the slotted dropouts.

Figure 165. Design Development of the Eclipse Frame – Aniceto, Luís. 2006

Development of Xylonbikes "OII" model by Luís Aniceto: the original design can be seen on the left and the "Eclipse" which was designed and constructed as an entry proposal for the Berado Museum in the Centro Cultural de Belem, Lisbon, can be seen on the right (Figure 165) – Authors: Nick Taylor and Luís Aniceto.

Figure 166. Xylon Quadrado designed by Lúis Aniceto. Taylor, Nicholas. 2008

As a way of diversifying the appearance of the wooden framed bicycles, Luís Aniceto designed the Quadrado (Figure 166). The idea was to economise on material by the use of cutting straight lines which would leave less waste material when cut from a standard sheet. The large diameter holes were made in an attempt to lighten the frame as it was the heaviest of all the Xylonbikes models. To date the Quadrado has never been tested or ridden. The frame remains unvarnished apart from the interior of the rear side panels. The photograph on the following page shows the Xylon Quadrado viewed from the right-hand side. The photograph shows the asymmetrical construction of the chainstay which is cut away to allow the passage of the chain (Figure 167). The distribution of the holes follows a linear format. The bottom bracket is a component taken from a donor bicycle.

Figure 167. Xylon Quadrado designed by Luís Aniceto. Nicholas, Taylor. 2008

Although the Eclipse was not included in the Berardo Museum collection, the bicycle was used as the basis of a concept E-bike shown below (Figure 168). In this version the power is provided by a combined battery pack and motor enclosed in the module which acts directly on the rear tyre similar to the Solex moped.

Figure 168. Mock-up of E-bike Based on the Xylon Eclipse Frame – Taylor, Nicholas. 2013

3.8.3. Synergy frame bicycle: Leonel Mateus

Although employing the same fabrication methodology, the Synergy frame (Figure 170) was a radical departure from the other models in that it was based on small wheels (20” dimeter). This approach led to the design limitations due to constraints inherent in the 26” wheel versions being surpassed – for example the shorter length of the chainstay/seatstay meant that flexion was reduced and a low step-over height could be explored.

The lack of these constraints allowed a diversity of proposals based more on the aesthetic of the engineered wood (plywood) and the hardwoods available.

Figure 169. Leonel Mateus Gluing and Cramping the Synergy frame. Taylor, Nicholas. 2005

The photograph above (Figure 169) - taken during the fabrication of the Synergy bicycle - shows cramping of the frame. To ensure complete contact with the glued surfaces a minimum of 14 G-cramps are used with blocks of softwood or offcuts so as not to bruise or damage the plywood side panels. Although transparent when uncured, seepage of the mono-component urethane adhesive when cured creates a hard white foam. Contact with the visual surfaces leads to staining which is also absorbed by the wood fibres and is difficult to remove. On subsequent models in the series any visual surfaces were masked off using paper masking tape. However, care must be taken with the choice of masking tape as prolonged contact with the visual surfaces, especially if in an area of pressure from the G-cramps causes the tape to adhere strongly to the surface veneer. Consequently a low-tack adhesive tape is recommended for this application in order to avoid lifting the surface grain of the plywood.

Figure 170. Xylon Synergy 20” Wheel Concept Bicycle. Mateus, Leonel. 2005

Although it was never intended initially to produce children’s bicycles, Leonel Mateus’s interest in small wheels sizes i.e. 20” wheels, gave rise to the fabrication of two small wheel bicycles; the “Odobe” a custom built child’s bicycle, and a BMX bicycle (Figures 171 & 172). Unlike other Xylonbikes the Odobe has an Ashtabula American style bottom bracket. However, the construction techniques employed are virtually identical to the other bicycles. No formal evaluation or testing was made on this bicycle.

Figure 171. Odobe Child's Bicycle – Mateus, Leonel. 2009

The BMX is somewhat different as it was produced with 12mm thick Marine grade birch plywood. This decision was made as it was thought that the 9mm thick plywood used on the other models would not be strong enough to withstand typical BMX manoeuvres and freestyle tricks. As the thicker plywood allowed the removal of material without compromising strength, decorative 3mm thick hardwood inlays were applied to the non-stressed part of the frame. As raised chainstays would have weakened the highly stressed rear part of the frame, a slot was cut to allow the chain to pass. There is no information available about performance of the Xylonbikes BMX bicycle.

Figure 172. . Xylonbikes BMX. Mateus, Leonel. 2007

3.8.4. Cell frame bicycle: Sergio Cordeiro

The theme of the Cell design was based on a macro representation of the cellular cross section of wood itself. Given the constraint imposed by availability of equipment, the design of the cells was carried by drilling various diameter holes to simulate the cellular configuration (Figure 173).

The same fabrication techniques were employed in the frame construction as the other models; however, the core material used is pine rather than hardwood. The holes which pass through the core were drilled after gluing and fabrication to ensure concentricity. The large diameter holes (40mm diameter and above) were drilled with hole saws. Due to the thickness of the combined core and side panels it was not possible to drill from one side only. The method of drilling from both sides of the frame was also necessary to avoid “break-out” and splintering of the facing veneers. In order to ensure concentricity a dummy mandrill was used after drilling a 6mm diameter hole through the combined composite frame. This approach was successful but very labour intensive and time consuming.

Figure 173. Sergio Cordeiro preparing Cell side panel prior to gluing and clamping. Taylor, Nicholas. 2005

The Cell bicycle generated significant interest internationally due to its unusual appearance. The interpretation of the cellular structure worked especially when viewed as a whole on the full size frame. Although the core section of the Cell was robust and did not deflect under load, the chainstays/seatstays flexed considerably. In light of the failure experienced on the Xylon #1 prototype it was decided not to test the Cell under full load. It was ridden with success but was retained as a “concept” bike rather than risk failure. The Cell and other Xylonbikes were featured in numerous magazines and websites. The Chinese lifestyle magazine NB Weekly is shown below (Figure 174).

Figure 174. Xylon Cell featured in Chinese Lifestyle Magazine Southern Metropolis Weekly 2005. Retrieved from http://www.danwei.org/media_guide/magazines/southern_metropolis_weekly.php

During tests whilst the Cell was being ridden, excessive play developed at the head tube. On inspection, the wood where the top and bottom bearing cups had been installed had been compressed allowing them to move.

The reasons for this were found to be twofold:

1. The Cell core had not been fitted with an internal head tube which meant that when the steering stem headset nut was tightened it compressed the wooden core, which with use became more compressed.
2. The wood used for the core of the cell was pine, which is a relatively soft wood and although it resists compression well on the longitudinal axis, the compressive stresses were experienced on the lateral axis which rapidly led to bruising and compaction.

3.8.5. Xylon Hybrid: Nick Taylor

The Xylon Hybrid was designed following requests for a bicycle frame larger than the Klassic. Initially developed for riders over 185cm tall, the frame and the seat tube are approximately 10% longer. Visual lightening was undertaken by large diameter holes drilled in the forepart of the frame only. The Xylon Hybrid is the only Xylon bicycle fitted with telescopic forks and hydraulic front disc brake (Figure 175).

Figure 175. Xylon Hybrid –Taylor, Nicholas. 2015

The patent applied for seat clamping is not used on this bicycle, a standard seat tube and clamp are used instead. A Shimano Nexus 7 internally geared hub is fitted with an integral coaster brake, and a Shimano single crank.

Over the last five years the bicycle has been ridden regularly in all weather conditions and is kept outside all year round in order to act as a test vehicle in comparisons with the Xylon Klassics which are not ridden regularly and kept in a controlled interior environment.

The bicycle has been reliable, has never broken down, and is comfortable and ergonomically designed for the Author who is 182cm tall.

Photographs were taken of the frame on 20th September 2015 to record the effects of prolonged exposure and use on a composite wooden frame.

The photograph below shows flaking, discolouration of the wood, lifting and clouding of the lacquer. However, there is no visible structural damage to the headset or the frame.

Flaking: Flaking occurs predominantly on surfaces where there is a sharp change of direction (edges) and end grain surfaces (Figure 176).

Discolouration: Discolouration and staining occurs especially on unprotected end grain and areas where the lacquer has lifted to expose the bare wood. Staining takes the form of water staining and blackening caused by fungus attack. There is also evidence of sun bleaching and oxidation.

There is no evidence of damage from wood boring insects, however during one winter there was evidence of rodent damage (mice or rats) to the Brooks leather saddle. This was probably due to the use of animal based tallow which was applied as a preservative to the leather.

Figure 176. Lifting: In areas of water ingress lifting of the lacquer has occurred after prolonged exposure (5 years). Taylor, Nicholas. 2015

Compare the above photograph with the following one taken at the same time. There is no evidence of cracking, lifting, flaking or discoloration of the lacquer or the wood. The frame received no special treatment other than being stored or displayed in a controlled environment. There is no splitting or delamination of the glued joints. There are minor scratches and scuffs to the surface in random areas due to general wear and tear. A contributing factor to good condition may also be attributed to the frame contours which are rounded rather than terminating in sharp corners (Figure 177).

Figure 177. Xylon Klassic (Controlled Environment). Taylor, Nicholas. 2015

Figure 178. Xylon Hybrid Flaking and Weather Damage. Taylor, Nicholas. 2015

Figure 179. Xylon Hybrid Flaking, Lifting and Weather Damage. Taylor, Nichols. 2015

In addition to weather damage, minor scrapes and scratches are present caused by chafing, rubbing of cables, and “chain slap” (Figure 180). Chain slap is a common phenomenon on bicycles fitted with derailleurs. Due to the excess chain length required for shifting, a tensioner is fitted to the bottom run of the chain. When the bicycle is motion there is tendency for the top run of the chain to oscillate causing it to “slap” against the chainstays resulting in chipped paint and surface abrasion. This a common occurrence on all bikes and chainstay protectors are often used to protect and preserve the chainstays.

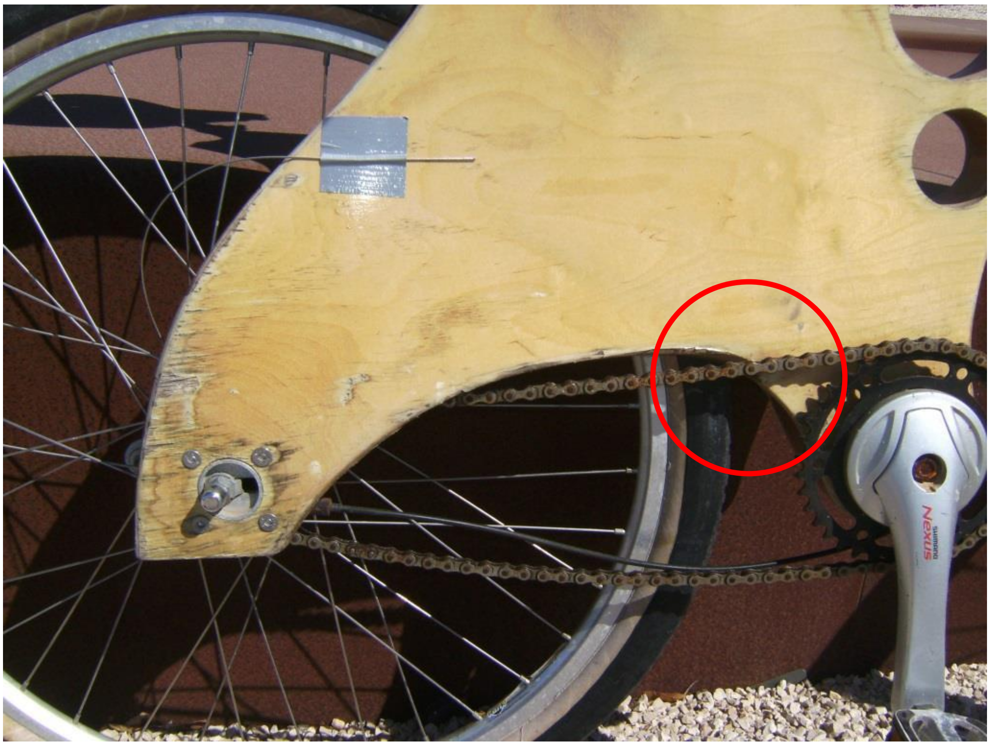

Figure 180. Xylon Hybrid showing Discolouration, Flaking Lacquer, and evidence of Chain Slap –Taylor, Nicholas. 2015

Although none of the bicycles of the Xylon range are fitted with derailleurs there is still a small amount of chain slap. As most models have raised chainstays this not a significant problem. Nevertheless due to the proximity of the chainwheel to the frame (which is required to ensure a good chain line) abrasion occurs when the chain comes into contact with the frame at this point. This is less evident on the Hybrid, and there is only minor abrasion which gives rise to an occasional audible emission. However, on the Klassic which has been used as a control, there is significant damage directly behind the chainwheel due to abrasion. Although this does not adversely affect performance, material was removed from that area and a groove sculpted into the frame in the vicinity of the chain wheel (Figure 181).

This “defect” is directly related to the distance of the chainwheel from the frame, the optimum chain line, and ultimately, the size of the chainwheel. The latter led to the almost exclusive use of the Shimano Nexus FC-NX75 Inter-C Single 170 mm 38 Tooth Chainset, with a chain-line of 44mm.

I.e. the middle of the crankset is 44mm offset from the middle to the bike centre line.

Figure 181. Xylon Klassic exhibits Intact Lacquer but Abrasion to the Frame due to Chain-slap –Taylor, Nicholas. 2015

CHAPTER 4

4. Specialised parts design

Prior to discussing the design development and procurement of specialised parts a mention should be made regarding the sourcing of these parts by other means.

Given the nature of the required parts, initially their procurement was made by the sourcing of “donor” bicycles, i.e. bicycles that for some reason were no longer serviceable and renovation was no longer a viable option due to the cost of replacement parts. Therefore bicycles of this type were sought and relevant parts salvaged and reworked depending on requirements.

Although this not an ideal situation, costs are kept to a minimum and in terms of recycling suitable parts can be adapted and reused with success.

This particularly true with regard to the bottom bracket, head tube, seat tube and forks. However the reuse of the rear dropouts is not a viable option.

In cases where parts were recycled, they were cut from the original frame, filed or cut to size, modified if necessary, grit blasted to remove old paint and corrosion and zinc coated.

Figure 182. Reclaimed Head-tube (left) and Bottom Bracket (right) –Taylor, Nicholas. 2012

By employing this method, parts needing standardised dimensions especially interior diameters calibrated for fitting headsets and seatposts, compatibility is ensured.

The previous photograph shows a reused bottom bracket shell with part of the seat tube still attached to ensure adequate fixing and resist torque, and a head tube which has been grit blasted and zinc coated (Figure 182). The parts in question have been exposed for a period of at least 3 years in the open air and show very little signs of oxidation (rust).

The only foreseeable constraint regarding the use of recycled and reused parts is that their physical condition should be thoroughly checked prior to use. Other than that, as the parts are integrally incorporated in the wooden frame and are not visible there are no special factors which compromise their use.

4.1. Custom made parts for Xylonbikes wooden framed prototype bicycles

As the wooden framed prototypes were not conceived or designed to use standard interface parts it was necessary to design and develop *sui generis* components.

4.1.1. Specialised Part: Rear Dropouts

All parts for the four prototype frames (Klassic, Oll, Cell, and Synergy) were made especially for each frame due to the specific design differences of each proposal.

This was particularly true with regard to the rear dropouts. In each case the dropouts were fabricated to follow the contour of each frame but not use excessive material, and as the contours were not the same, four individual sets of dropouts were designed. The only common factor to each dropout was that it should be made in metal and the slot for the rear wheel spindle should be an elongated opening 10mm wide (to allow a standard rear wheel spindle to pass through and for chain tensioning). The dropouts were all designed so as not to make an opening to the perimeter of the plywood side panels, i.e. holes were made which would allow the use of a socket to tighten or loosen the spindle nuts but not compress the wooden material or weaken it excessively.

As no decision had been reached about the type of metal to be used for the dropouts and at the time, commercial manufacture had not been considered, no constraints were imposed regarding the fabrication techniques other than that the dropouts were hand crafted.

Figure 183. Xylon Synergy showing Slotted Frame and 3mm Steel Plate dropouts. Taylor, Nicholas. 2005

The availability of suitable material and economic constraints were the main factors taken into consideration, however, based on measurements taken from steel and aluminium dropouts on conventional bicycles, the dropouts would not be less than 5mm thick if made from aluminium, and not less than 3mm thick if made from steel. In both of these cases the maximum thickness would be determined by the type of spindle used for the rear wheel e.g. hexagonal nuts or quick release skewers.

The finish of the dropouts was also left to the individual and depended on aesthetic considerations as well as protection against oxidation such as paint etc. if necessary (Figures 183 & 184).

4.1.1.1. Design of production bicycle dropouts

After having assessed the various dropout designs used in the prototype frames, in order to standardise the rear dropouts a number of designs were proposed. One of the main considerations was the decision whether or not to incorporate the dropouts into the frame or add them as an attachment.

Although it is possibly not an issue on a production machines where the parts are CNC machined, the elongated dropout holes undoubtedly require more machining than a regular circular hole.

Figure 184. 3mm Original Steel Plate Dropouts Contoured to fit Frame. Taylor, Nicholas. 2010

The following factors were taken into consideration when designing the rear dropout.

The thickness of the dropout material must be suitable for quick release or normal axle fasteners.

- The dropout must have a slot to enable chain tensioning by moving the wheel forwards or backwards.
- If the dropout is as inset there must be enough space to loosen or tighten the nut (socket spanner) or loosen or tighten the quick release.
- It should be possible to easily alter the orientation of the dropout to change the angle of the slot in relation to the axis between bottom bracket centre and rear wheel axle centre to enable the use of internally geared lock washers to be fitted.
- If designed as an inserted part, the dropout must be easily located.
- The dropout must be attached by bonding **and** mechanical fixtures.
- The dropout should be relatively easy to manufacture at a reasonable cost.
- The dropout material should be rust proof without the need for extra surface treatment.
- The dropout should be a universal fitting for all models.
- Specialised mechanical fixtures should not be needed for fixing.
- The dropout should not be “handed” i.e. the dropout should be a universal part able to be used on both left and right hand sides of the frame.
- Although not a critical criterion as it is a relatively small part, the dropout should be as light as possible without compromising its structural resistance.
- The dropout should be robust and not be considered as a “replaceable” but a permanent integral part of the frame.

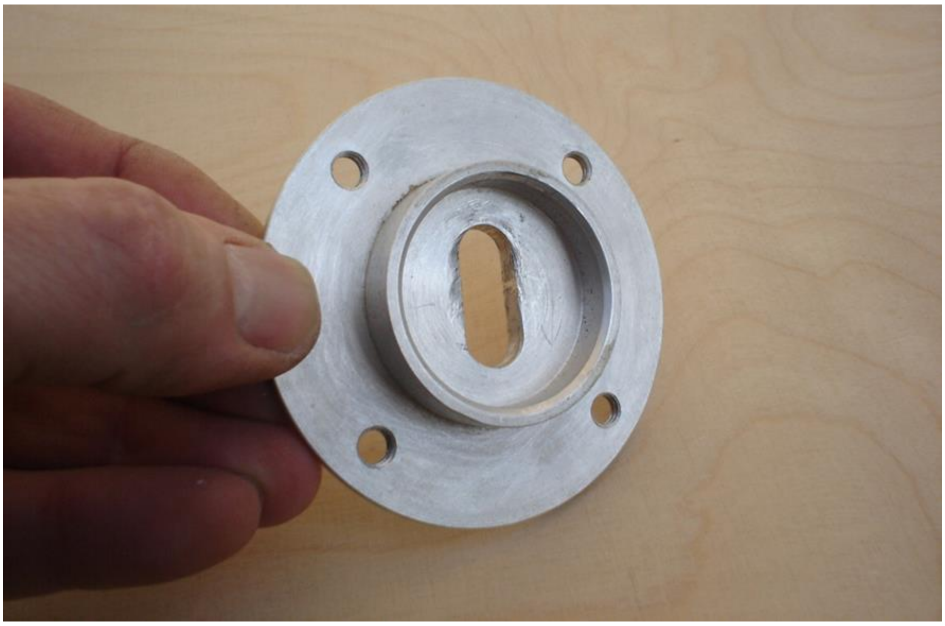

Figure 185. Xylon Turned Aluminium Dropout Prototype #1. Taylor, Nicholas. 2007

The previous and following photographs illustrate the initial production model universal dropout prototype (Figure 185).

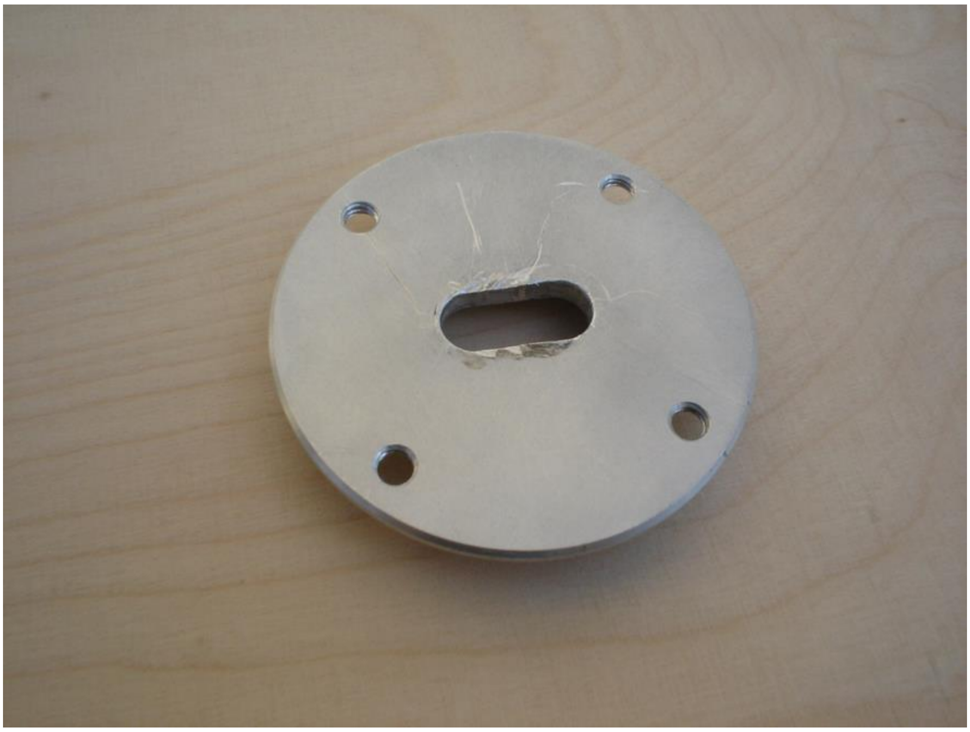

Figure 186. Xylon Turned Aluminium Dropout Prototype #1 (Inside View). Taylor, Nicholas. 2007

Turned aluminium dropout characteristics:

- The slot is 15mm long between centres, and 10mm wide to accept a 10mm diameter rear wheel axle and gives at least 15mm longitudinal movement for chain tensioning.
- The recess allows the insertion of a 14mm socket spanner, or a quick release skewer.
- The dropout was machined from solid aluminium bar. The outer flange is 3mm thick and drilled and tapped to M6 in four radially-spaced positions.
- The centre is thicker than the flange, being 5mm thick to suit both quick release skewers and standard hexagonal nuts.
- The raised boss is 9mm tall, (thickness of plywood) with a wall thickness of 3mm and an outside diameter of 40.5mm. The outside diameter gives a clearance of 0.5mm, as the hole saw used to cut the hole in the plywood chainstay/seatstay is 41mm (1 5/8") nominal diameter. This minimal clearance is called for in order to ensure a homogenous fill of the annular space with epoxy resin.
- The dropout is fitted with epoxy resin such as Araldite, and fixed in position while curing takes place with 15mm long, M6 stainless steel countersunk socket screws.

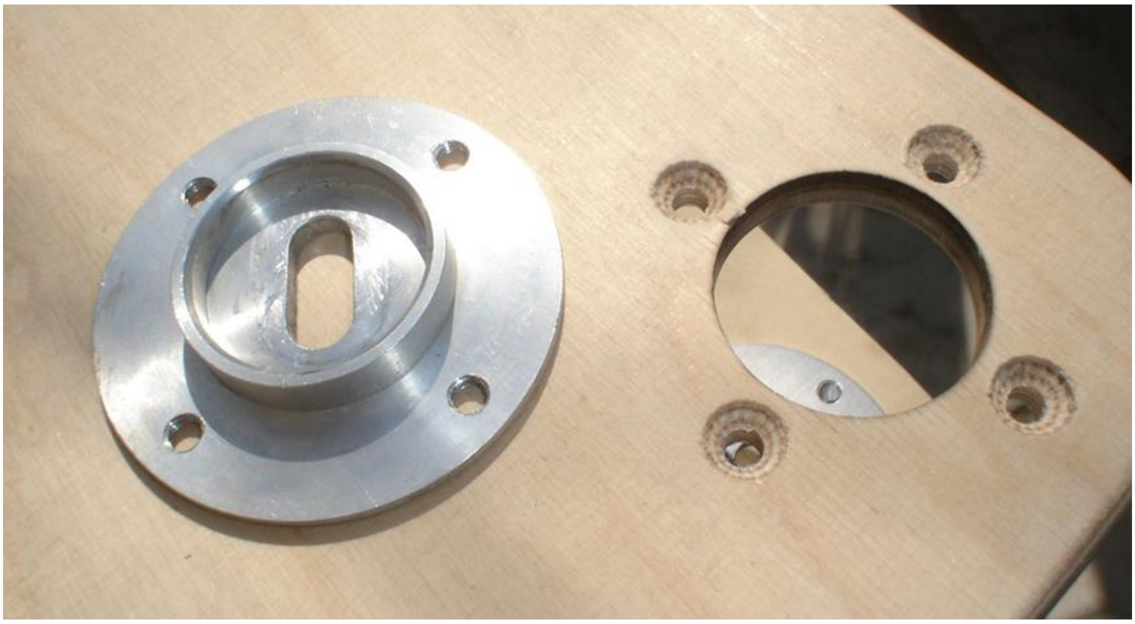

Figure 187. Xylon Turned Aluminium Dropout Prototype #1 Fitting to Frame. Taylor, Nicholas. 2007

The drilling and countersinking can be seen in the photograph above (Figure 187) and the fixed dropout in the following photograph (Figure 188).

Figure 188. Xylon Turned Aluminium Dropout Prototype #1 Fitting Screwed and Bonded to Frame –Taylor, Nicholas. 2007

Due to the short grain of the outer veneer close to one of the fixing holes, some flaking can be observed. Attempts are made to alleviate this by allowing excess epoxy resin to infiltrate the fibres of the veneer.

The quantity of epoxy resin used is carefully calculated by trial and error so that the excess is not greater than the viscosity of the uncured resin's tendency to drip or run. In other words, the excess epoxy resin is not removed but forms a sort of meniscus or fillet about the dropout flange. The same applies to the clearance hole. Therefore the dropout to frame is effectively sealed to prevent the ingress of moisture.

The stainless steel countersunk fasteners are left in position during the curing time and are not intended to be removed as this could compromise the seal.

The whole process is carried out prior to finishing (varnishing) as the bond between the raw untreated plywood and the aluminium dropout is superior due to absorption of the resin by the plywood fibres.

NOTE: During fabrication of the frame it is important that after bonding the dropouts to the frame, the interior of the chainstays/seatstays is definitively **pre-varnished** prior to assembly, gluing, and clamping up to avoid the epoxy running as accessibility is limited after assembly and the application of varnish by spraying is significantly compromised.

Figure 189. Xylon Turned Aluminium Dropout Prototype #2 –Taylor, Nicholas. 2008

The previous photograph (Figure 189) shows the current and potentially definitive rear dropout design. The slot for the rear axle has been extended to the flange wall which allows the rear wheel axle to be inserted more easily (although the position of the axle in the slot is conditioned by the size of the washer or nut used to tighten it).

The number of threaded fixing holes has been increased to eight which means that the dropout can be attached to the frame in the most advantageous position.

4.1.2. Brakes

Although initially not directly related to the design of the dropouts the following should be taken into consideration:

As it was found to be impractical to use V-brakes on the rear wheel due to the excessive deflection under load (See Figures 150 & 151), other forms of braking had to be considered that did not rely on the brakes being mounted on the seatstay equivalents.

One possibility is the use of calliper brakes which are available in three sub-types – single pivot side-pull, dual pivot side-pull, and centre-pull.

Figure 190. Single Pivot Side Pull Calliper Brakes – Taylor, Nicholas. 2015

All of these configurations rely on a central mounting point on the frame and are currently used on road bicycles. As the force is applied to “close” the calliper against the rim there are no external forces to deal with which are responsible for deflection. This type of calliper brake has been used for decades on a wide range of bicycles ranging from roadsters to racing bikes (Figure 190).

The fitting of the calliper brake to wooden frames requires a pre-knowledge of the mounting requirements and although it is possible, significant alterations are required to the frame in the vicinity of the seat post to ensure alignment of the brake pads with the rim and adequate mounting.

Therefore it was decided that another form of rear brake would be used in the wooden frames.

Although not popular in the UK and Western Europe, the “Coaster” brake and the “roller” brake are quite popular in the USA and Eastern Europe. Neither type of brake requires the frame to sustain any forces other than at an anchor point on the frame which resists the rotational forces at the wheel hub (Figure 191).

Figure 191. Shimano Coaster Brake Hub – Taylor, Nicholas. 2015

This anchor point is generally on the left-hand chainstay of conventional bicycles.

After researching the availability of both types of hub brakes they were found to be very difficult to source from local suppliers as the demand for them is very low in the Iberian Peninsula. (Requests from Shimano importers resulted in no stocks being available)

Fortunately a number of Shimano Nexus 7 Internally geared hubs with Coaster Brake were sourced and plans drawn up to fit them to the wooden frames (Figure 192).

Figure 192. Shimano Nexus 7 Internally Geared Hub with Coaster Brake – Taylor, Nicholas 2015

The special dropouts which had machined for the wooden frames were potentially adaptable to the fitting of an anchor point.

Note: As the coaster brake requires an anchor point, this is usually provided by the use of a clamp which wraps around the chainstay. As the wooden framed bicycles have no “chainstay” as such and no method of attaching a clamp, other methods were explored to effect this requirement.

Initially, the most appropriate idea appeared to be to drill a hole in the side panel and attach the torque arm to the frame. However, as the torque arm is perpendicular to the axle, fitting to the sloping side panels presented a problem. In addition, a simple round hole is not suitable as the mounting of the torque arm needs to be adjustable as the rear wheel is moved forwards or backwards to tension or slacken the drive chain. The removal of material at this stress point was considered to be undesirable as it may weaken the frame. Therefore other solutions were studied.

As the mounting of the torque arm is not dependant on directional positioning (it simply serves to prevent rotation of the hub) the fixing point can be positioned at any point on a pitch circle diameter of 90mm to 100mm depending on the model (the length of the torque arm). However, this position is conditioned to some degree by the requirement of a slot, rather than a hole to make adjustments as previously mentioned (Figure 193).

The simplest solution appeared to be the addition of a torque arm mounting bar attached to the dropout mounting screws as this would ensure that the mounting would be positioned in the correct plane.

After several proposals the dimensions of the mounting bar were established and various prototypes constructed.

Figure 193. Torque Arm Mounting Bar – Taylor, Nicholas. 2015

The main criteria applied were that the mounting bar should be affixed with two screws to resist the turning forces, and that the torque arm mounting point should be slotted to allow adjustment. No studies were carried out regarding the maximum or minimum size of the component.

Function of the mounting bar.

In most cases the mounting bar functioned as predicted, however, in one case the Xylon Hybrid was being ridden downhill and the rear brake was applied hard. The mounting bar sheared allowing the torque arm to rotate, consequently the gear change cable wrapped around the hub, pulling the cable attachment at the handlebar, wrenching the handlebars to one side and throwing the rider, who suffered minor scrapes and bruises. The frame remained intact with minimal damage.

On inspection the torque applied to the mounting arm was so great that it yielded under the strain and fractured.

This was due to the mounting bar being fabricated from aluminium which was too thin (approximately 2mm).

Other materials were considered and stainless steel was an option. However, if aluminium was to be used the thickness should be enough to resist the forces applied, therefore a replacement was fabricated which was thicker (3mm). Since this modification there have been no problems with the mounting bar.

4.1.2.1. Specialised part: Bottom bracket shell

Following the experiences with the various bottom bracket types and configurations there was no doubt that the European/British/I.S.O Standard 1.370" diameter X 24 tpi or 1.375" diameter X 24 tpi, right, left, Standard 68 mm width was the most suitable choice.

However, the configuration for a production bicycle is yet to be decided upon as it will depend on availability, financial constraints, and to some extent frame design.

Notwithstanding the above, a number of two part bottom brackets were machined and fitted with success. Due to the quantities made, (4 pairs) the price for material and machining was considered to be high. Greater quantities would reduce the unit price but this was not pursued due to the suspension of the Governor’s Island project.

4.1.2.2. Development of bottom bracket

The illustration below shows the fabricated bottom bracket as previously described in chapter 3. Brazing was used to attach the flanges as the residue is minimal compared to welding which leaves a bead of greater dimensions (Figure 194). (Even so the bottom bracket hole in the wooden frame can be chamfered to accommodate this).

Figure 194. Two part flanged bottom bracket fabricated and brazed. Taylor, Nicholas. 2005

As a way of maintaining a visual and aesthetic cohesion of the interface components a turned aluminium Bottom Bracket was considered to be the most appropriate as it would complement the turned aluminium dropouts. However, considering that the chainwheel side of the bottom bracket is almost totally obscured it is only the left hand side of the bicycle which benefits from this consideration.

A turned aluminium bottom bracket prototype that could potentially be used in production bicycles is shown below (Figure 195).

Figure 195. Turned Aluminium Two Part Bottom Bracket Housing Prototype (Left and Right)
Taylor, Nicholas. 2006

The two sides are identical in format with the exception that they are threaded with left and right hand threads respectively (the letter E indicates *Esquerda*) for left hand thread. In order to avoid confusion as the pieces are visually similar, during or directly after batch machining the bottom bracket halves should be marked with the relevant indicator denoting handedness.

Note: The convention for bottom bracket threading is as follows. Whilst astride the bicycle and facing forwards the crank side (right hand side) bottom bracket is LEFT HAND THREADED, and in the same position the left hand side is RIGHT HAND THREADED.

Consequently the bottom brackets should be labelled or marked in such a way as to avoid interchanging parts such as:

Turned aluminium Bottom Bracket Identification Codes:

- PART Nº BB1 (RH) – CAUTION! FIX TO RIGHT SIDE OF BICYCLE WHEN VIEWED FROM REAR
- PART Nº BB2 (LH) – CAUTION! FIX TO LEFT SIDE OF BICYCLE WHEN VIEWED FROM REAR

This information could be used as a technological tag and may be engraved radially on the outer visible surface of the insert.

Figure 196. Xylon Two Part Bottom Bracket with Sealed Cartridge Unit in Position –Taylor, Nicholas. 2015

The Bottom Bracket inserts can be seen above with a sealed bottom bracket axle in position (Figure 196).

Due to the relatively high cost of machining the bottom bracket inserts only three pairs were made. Subsequent bicycles were fabricated with *ad-hoc* bottom brackets of a variety of types but mainly sourced from conventional donor bicycles.

4.1.2.3. Specialised part: Seat post clamp

Since the fabrication of Xylon #1, the method of fixing the seat post into the frame was an issue which needed to be resolved.

In the initial prototype no great thought was given this as it was purely a test bicycle and the main concern was with the running gear. Nevertheless as already stated three holes were provided in the upright of the original frame as a “gratuitous” option for saddle positioning towards the front or rear.

On the prototype the seat tube was an interference fit in the frame and the centre hole was used.

On subsequent models a single seat post position was established.

As a way of avoiding the insertion of a seat tube with a seat post clamp used to secure the saddle, a new solution was developed.

The fact that the area where the seat post meets the frame is large in terms of volume and material gave rise to an approach which could not be taken with a traditional frame.

After studying seatposts, as previously stated, the diameter of the vast majority is 27.2mm nominal, but rather than start from an existing solution a different approach was considered.

The typical seat tube is round and has been for over a 100 years. This makes sense when frames are made from round tube and a simple telescopic system is easy to manufacture within reasonable tolerances.

However, by re-thinking the seat tube design it is first necessary to determine the function of the seat tube analytically.

Seat tube function:

1. To attach the saddle to the bicycle frame.
2. To resist the weight of the rider and not move downwards while it is being used
3. To resist twisting (rotation) while the bicycle is being ridden
4. To be adjustable for the height of the rider
5. Be removable (e.g replaceable)

The above functions are based on user experience and observation, and in most cases are the results of a seat tube not performing correctly.

If the above points are considered singly a number of wide ranging potential solutions are possible:

For example, in point two, taking a tube within a tube, a possible solution would be to drill the seat post and insert a pin to prevent downward movement.

Figure 197. Axle Stands with Drilled Tube and Pin. Retrieved from http://www.clarketooling.co.uk/tools/info_750.html

The axle stands above illustrate this method (Figure 197).

But this would not necessarily resolve problem 3 (resist twisting), therefore the outer tube could be slotted and the pin would fit inside the slot. Another solution might be to drill through both the outer and inner tube to insert the pin, thereby resolving points 2 & 3. This solution would need to be modified to incorporate point 4 and could be accomplished by drilling a series of holes in the seat tube like in the axle stand shown below (Figure 198).

Figure 198. Axle Stands with Drilled Tube, Drilled Support, and Pin. Retrieved from http://www.clarketooling.co.uk/tools/info_750.html

The solutions proposed above are valid solutions and apart from possible weakening of the frame and seat tube (which could be overcome by using thicker material) and a slight movement due to the tolerances required could be employed as an alternative seat tube solution.

In fact, by changing the format of the tube to square instead of round, potentially the tube would be more stable. See example below (Figure 199):

Figure 199. Axle Stand with Drilled Square Tube, Drilled Support and Double Pin. Retrieved from http://www.clarketooling.co.uk/tools/info_750.html

The above examples serve to illustrate that there are multiple solutions to the same problem and that over time the “best” solution has been arrived at. However if some of the parameters are fundamentally changed, such as the frame material and design in this case the possible solutions are multiplied with the result that are more opportunities to develop viable solutions.

Taking this opportunity, the way in which the seat post could be incorporated into the wooden bicycle frame design was studied.

From experience gained in making Xylon #1, what became apparent was that wood, as opposed to metal, dilates and expands depending on humidity. This was so noticeable that on dry days the seat post would rotate in the frame, and on damp days it would be virtually unmoveable. Consequently this led to an important decision being reached; whatever method of clamping the seat post was employed a metal, or possibly even plastic sleeve should be an integral part of the frame. This would stabilise the dimensions of the hole and allow finer tolerances to be attained.

However, after reaching this conclusion, the significance of such an intervention quickly brought into cause the need for a different solution. If a tube is used to stabilise the seat tube orifice, the most logical solution is to slot and extend the seat tube a sufficient distance to enable a seat tube clamp to be used.

This method has, in fact, been used successfully on some models. However, as a means of creating a coherent visual detail, it is necessary to incorporate a collar, or trim at the tube/frame interface. This trim is not solely decorative or aesthetic, it also serves to protect the tube/frame interface from the ingress of moisture, but from the aesthetic point of view it does provide the opportunity of differentiating the frame in one more way such as by the profile of the trim or by the addition of a logotype, or frame numbering.

The simplest and possibly the most effective trim would be a turned aluminium ring which would be chamfered or have the edges rounded, and would fit over the seat-tube and be bonded with an epoxy adhesive such as araldite. A more sophisticated version of this could possibly be the addition of a type of boss which would be seated in a slightly oversized recess around the seat post, and bonded with araldite in the same way. It is not clear whether such a part would be fitted prior to or after final finishing. (E.g. varnishing or lacquering)

Numerous types of clamping mechanisms were studied and various types were proposed.

4.1.3. Innovative XYLON seat clamp design

The type of clamp which was finally developed had nothing in common with the existing versions of conventional seat clamps.

Taking the previously mentioned basic requirements of a seat clamp the following part was developed.

The solution arose due in part to a visual and aesthetic evaluation of the wooden frame. The photograph (Figure 159) shows a frame with a traditional type seat tube with a wooden trim integrating it with the frame.

As can be seen, in profile there is a large plain expanse of plywood which has very grain patterning (this is a characteristic of the Finnish birch plywood). As a result the surface is unbroken by any detail except for the circular format of the rear axle dropouts (see custom dropouts) and the bottom bracket which is similar in shape and size.

The appearance of the frame in profile is visually heavy, especially due to the chainstay/seatstay side panels.

As a way of breaking this visual monotony another element was proposed working as the third point of a triangle with the other two metallic components.

The diameter of the part was established as follows:

As a clamping part for the seat stem a wooden (Oak) cylinder of approximately 40mm diameter X 60mm was turned on the lathe.

A hole of approximately the same dimension was cut with a hole-saw in the frame to intersect the hollow shaft of the seat tube on exactly the same axis.

A hole approximately the same diameter as the seat tube was then drilled perpendicular the axis if the cylinder at the half way point.

Two holes 8mm dia. were then drilled on one of the ends to a depth of approximately 5mm (the diameter and height of a cylindrical Allen headed screw). A 6mm clearance hole was then drilled longitudinally to a depth of approximately 30mm.

At this point the cylinder was carefully cut in half on a band saw exactly in the centre of the large hole creating two identical halves.

Where the 6mm drill left its mark on the 2nd half. The holes were drilled out to 5mm, taking care to ensure the holes were perpendicular to the end of the cylinder.

These holes were then tapped to M6.

The two halves were then joined by two 50mm M6 cylinder head Allen bolts and the parts offered up to the seat stem.

On tightening the screws, the two halves were drawn together, and due to the material which was lost during the cutting in half process, the effect was to clamp the seat stem.

On the first attempt, the clamping action did not take place as not enough material had been removed by the kerf of the saw.

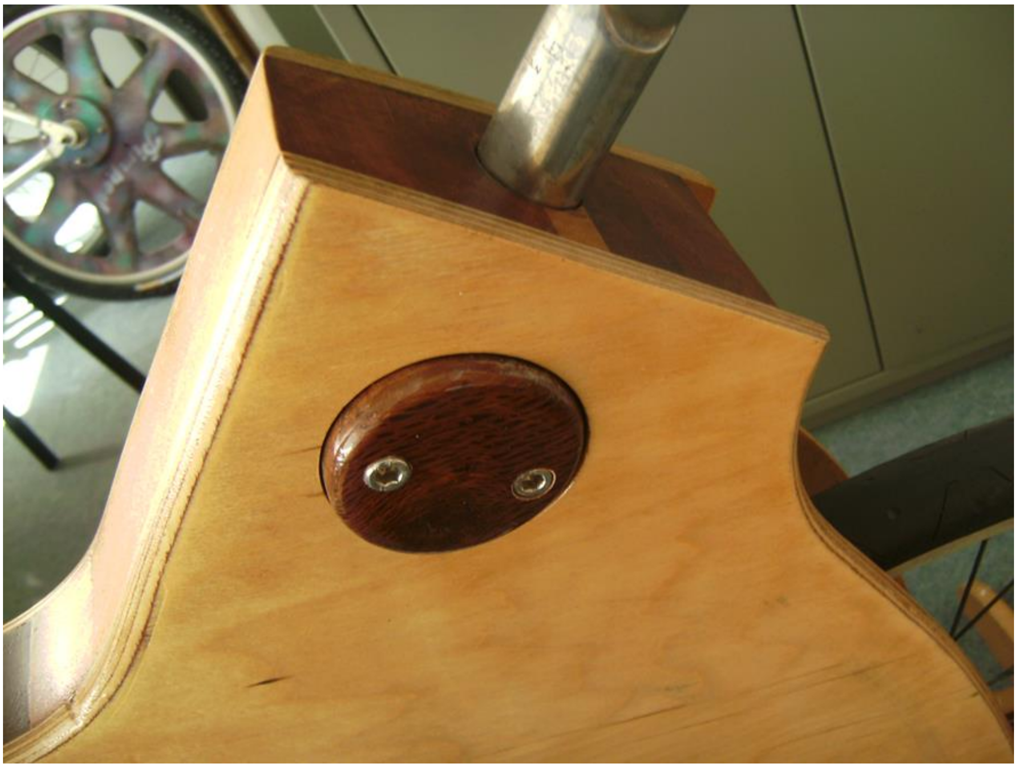

Figure 200. Xylon Wooden Seat post Clamp Prototype #1 – Taylor, Nicholas. 2005

This was remedied by removing approximately 1mm from the inside surface of each half on the belt sander (Figure 200).

The parts were reassembled and tested again. This time the two halves effectively clamped the seat stem tightly with enough clearance to compensate for eventual wear.

The parts were then removed from the seat stem without completely undoing the screws and the whole assembly was inserted into the hole which had been drilled in the frame.

NOTE: At this stage, if the concept of the clamp was non-functional, the frame would have been drilled out to 50mm for nothing. As a contingency plan, the resulting hole was to be used to mount an inlaid emblem on each side with the XYLON logotype engraved into it.

After lining up the hole, the seat stem was inserted into the frame, passing through the new clamp (Figure 203).

Slight inaccuracies in alignment worked to our favour as the seat stem was a snug fit in the clamp even prior to tightening.

The two Allen screws were then tightened with care and the bicycle was ridden.

Figure 201. Xylon Wooden Seat post Clamp Prototype #2. Taylor, Nicholas. 2006

When the bicycle was ridden with no great effort the saddle remained in position, however, when more effort was applied the saddle tended to twist.

The seat clamp was tightened further, but due to the screw thread in the wood being too fragile, the two screws would not tighten anymore and eventually stripped the thread in the 2nd half rendering it unserviceable.

At this point, there was no turning back and a solution had to be found, consequently various proposals were considered:

The chart below shows the pros and cons for a number of possible solutions.

It can be seen from the following chart that there were two viable solutions to the problem.

1. Drill the 2nd half to accept a threaded metal insert.

2. Substitute the wooden seat post clamp with a metal clamp (aluminium for ease of machining and weight)

Table 1. Pros and cons of possible solutions to improve the seat post clamp functionality.

Action	**Advantage**	**Disadvantage**	**Acceptable/Not acceptable**
Drill the clamp all the way through and use hexagonal nuts on the outside of the 2nd half	Cheap Uncomplicated Effective Easily accessible	Visually unattractive	Not acceptable for production bicycle
Drill the clamp all the way through and use hollow screws on the 2nd half	Simple Effective Quite visually attractive	Difficult to find parts of the correct size	Acceptable if parts can be sourced
Drill the 2nd half to accept a threaded nylon insert	Possibly effective Visually unobtrusive	Complicated	Acceptable if nylon material is resilient enough
Drill the 2nd half to accept a threaded metal insert	Possibly effective Visually unobtrusive	Complicated	**Acceptable**
Substitute wood seat post clamp with plastic (nylon)	Expensive Possibly effective	Visually unattractive Incoherent with wood	Not acceptable for production bicycle
Substitute wooden seat post clamp with metal (aluminium)	Expensive Highly effective Visually attractive	Expensive Costly machining	**Acceptable** for production bicycle

As the economic factors made the production of a part in metal not-viable at that time it was decided to pursue option 1.

Initially, drilling and tapping 8mm bar was considered, in a similar way to the bottom bracket solution, however, on researching possible existing solutions, some expanding brass inserts were found to be suitable (Figure 202).

Figure 202. Expanding M5 Threaded Brass Inserts. Retrieved from http://www.theinsertcompany.com/brass_threaded_inserts.php

The knurled exterior grips the interior of the hole, and when the screw is tightened, the fitting expands, and is firmly anchored to the wooden part.

The seat post clamp 2nd half drilled out to 8mm to a depth of 30mm, and was repositioned in the frame. The first part was offered up and the screws tightened.

The clamp was found to be secure during and after a test ride, and the idea was considered to be a viable solution in resolving the seat post clamping problem.

Figure 203. Xylon Wooden Seat post Clamp Prototype #2 Shown in Position on Seat-post. Taylor, Nicholas. 2010

Although relatively labour intensive to make, the raw material is virtually costless, and the screws and inserts are readily available and not considered to be specialist parts.

NOTE: There are no tightening torque figures available for this part, and future studies should carry out tests to establish maximum torque figures as it not only depends on the tightness of the clamp but the pull-out limits of the inserts.

The pull-out limits of the inserts are directly related to the density and hardness of the wood used to turn the seat post clamp. If the pull-out force was considered to be too low, the use of epoxy resin was considered to increase resistance to pull-out.

Figure 204. Turned Aluminium Seatpost Clamp – Taylor, Nicholas.

4.1.4. Metal seat post clamp

At a later date, when limited funding was available, it was decided to have a metal version of the wooden seat post clamp ordered and machined from solid aluminium round bar stock.

The metal version was virtually the same as the wooden original, but slightly shorter, so that it sat a few millimetres inset, inside the frame aperture rather than protruding from the surface of the frame (Figure 204).

As this was the case, the ends of the clamp were not bevelled or rounded but left flat so as to make a tidy interface with the frame which was slightly ramped which due to the shadow gave an interesting visual aspect.

The metal seat post clamp functioned perfectly “out of the box”, and it was decided that if financial and economic constraints would allow, future models of the wooden bicycle frame would employ the innovative seat post clamping device as this was considered to be a viable and innovative alternative and was not so dependent on seat post diameter.

The photograph above illustrates the metal seat post clamp fitted to the XYLON Eclipse model.

If this type of metal seat post clamp is used on production frames, as a way of identifying the product, the possibility of CNC machining, or electro chemical erosion of the logotype on the visible metal halves could be an option.

As the diameter of the bar stock used for the clamp is nominally 40mm, the most economical manufacturing method is by machining. Also being made from aluminium there is also the opportunity of using a coloured anodised surface treatment.

4.2. Finishes

The surface of untreated wood in ideal conditions (controlled humidity and temperature) is still susceptible to oxidation and consequent discolouration due to ultraviolet rays (sunlight). Consequently some form of surface treatment or finish is required, especially if the wooden bicycle will be used in hostile environments or climatic conditions.

4.2.1. Applied finishes

Although Xylon #1 was varnished with two coats of cellulose sanding sealer for purely aesthetic reasons, the choice of finishes for the bicycle frames was an important factor which needed to be addressed. Unlike furniture or other wooden structures which are basically static, the bicycle is in motion for a significant part of its life, this motion can bring it into contact with abrasive surfaces, it can be dropped, scratched, left out in the rain, be exposed to direct sunlight, undergo extremes of temperature, remain in humid or damp environments, or be involved in minor accidents.

Initially, in keeping with the natural material philosophy of the wooden framed bicycle a number of “natural” finishes were tried out.

4.2.2. Oiled finish

One finish which was tried was a type of teak oil which is applied to outdoor garden furniture and firearms, without any prior surface treatment, the teak oil was absorbed by the various woods and remained “damp” to the touch, the finish attracted dirt and dust and the frames became soiled very quickly. The oiled finish was not considered suitable.

4.2.3. Waxes

Another example of a non-solvent based finish was the use of waxes. A mixture which was applied to guitar bodies was made up by a luthier. The exact contents of the solution were not disclosed as it was a trade secret, but the main component was carnauba wax. I personally have had good success with carnauba wax on turned pieces where a glossy sheen can be achieved by high speed burnishing. The mixture was applied over a coat of sanded down cellulose sanding sealer and burnished with a rotary mop. The result was a pleasant, low gloss, satin type sheen. The finish was subjected to a fine mist water spray and left for in the open air overnight in a damp environment. The following day the wax surface was water stained. Attempts were made to buff out the stains with a rotary mop but they remained, and could not be polished out. The control sample which remained in the workshop remained unchanged.

4.2.4. Shellac and boiled linseed oil

Shellac is a commonly applied finish to furniture in the form of French polish, i.e. shellac dissolved in alcohol. As the typically applied French polish finish is known to suffer from staining and discolouration from prolonged exposure to water, and especially hot liquids, the recipe for furniture French polish was modified by the addition of boiled linseed oil. Application is similar r to traditional French polish with a dolly, but a thin film of linseed oil is left on the surface. In spite of the addition of the linseed oil the finish is till prone to staining and discolouration so this method was not pursued.

4.2.5. Varnishes

One of the most commonly applied surface coatings or finishes applied to wood is varnish. Varnish can be clear (transparent), but may be tinted to impart a different colour to the wood. Varnishes are available in many different formulas and bases and with different characteristics. A number of different types of varnishes were tested on the Xylonbikes wooden frames.

4.2.5.1. Yacht varnish

As none of the “natural” methods were considered adequate, proprietary products were resorted to. Samples were sanded, treated with cellulose sanding sealer, sanded again and varnished with single component “Yacht Varnish” (Spar varnish) which is used for marine applications such as woodwork on boats etc. The varnish was brushed on, and applied in two coats. The finish was high gloss and waterproof. The brushed surface showed evidence of dust and particles and was quite easy to scratch; the high gloss finish was not a very suitable aesthetic solution for the frame.

4.2.5.2. Satin finish furniture varnish

As the visual effect of the yacht varnish was not suitable due to the over glossy appearance, a satin finish varnish was used. Samples were sanded, given a coat of cellulose sanding sealer applied by spraying, sanded again and sprayed with single component satin finish cellulose varnish which is used for wooden doors and window frames etc. The varnish was applied by, and applied in two coats. The finish was smooth, slightly glossy and waterproof and although quite easy to scratch the effect was not so noticeable as on the gloss varnish finish.

The four prototype bicycles were all finished in cellulose base satin varnish applied by spray.

4.2.5.3. Clear Synthetic varnish aerosol

Over a period of time after exposure, being moved, suffering minor scratches and scrapes the satin varnish began to show signs of wear. As the finish is easily sanded remedial action was taken and the surfaces were lightly sanded and the "touch up" spray aerosol varnish was applied. Although noticeable due to uneven spry patterns the effect was acceptable as a touch up and was water proof. After a relatively short time the varnish began to separate from the substrate and in the worst cases peeled off like a skin. This was due to the varnish being of a synthetic base and not bonding to the substrate as a cellulose solvent based varnish would do.

Consequently any of the finishes that showed signs of wear and tear were touched up with satin finish cellulose varnish.

NOTE: Due to the nature of the birch plywood outer veneer, the variable porosity of the surface caused successive coats of sanding sealer to present a non-homogenous finish which was difficult to sand consistently as a base for the finishing coats, however, built up coats of satin finish cellulose varnish went some way towards a consistent finish.

4.2.6. Two component automotive lacquer

After analysing all the former alternatives regarding the most suitable finish for wooden frames and finding no solution that was 100% ideal, a different approach was taken. Finishes that were applied to vehicles were considered. This approach was based on the following.

- Vehicles such as automobiles are left out in all sorts of weather in all sorts of climates and there is rarely any problem them
- Repairs to dented or scratched bodywork panels are common
- In the majority of cases the base colour or metallic finish of the bodywork of a car is applied and then lacquered to achieve the desired protection and sheen

A two part acrylic lacquer was applied by spray over a sanded cellulose sealer base. After the first coat, a second coat was applied within the stipulated time for bonding to occur between the two coats. For automotive applications, large areas of body panels are usual sprayed and then cured in an oven. Some difficulty was experienced getting an even coverage of the bicycle frames as there are many small areas which either suffered from an excess of lack of lacquer. The overall finish was acceptable to certain degree, and any unevenness can be sanded down and buffed with cutting paste after fully curing. Repairs are relatively easy to carry out and the surface is 100% waterproof.

Over an extended period of time (years) there has been a breakdown of the lacquer at the end grain of the plywood where it meets the wooden core, with significant blackish discoloration. This can be attributed to the difficulty in sealing the end grain fibres of the plywood. One possible way of countering this effect could be by prolonged soaking of the end fibres in a diluted solution of cellulose sealer so that they absorb sufficient sealant to completely close the pores.

4.2.7. Anti-fungal and anti-insect treatment

Before any of the above finishes were applied the entire frames were treated with Xylophene anti-insect and anti-fungus fluid and allowed to dry at room temperature for 24 hours.

4.3. Finishes - Conclusion

Although a number of finishes (which were by no means exhaustive due to the financial circumstances and time available) were tested, there was no type of finish which was the clear winner when all factors were taken into consideration. All finishes were and either found to be partially acceptable or totally unacceptable, consequently there is no conclusive recommendation for a specific type of finish.

Bearing this in mind, the definitive type of finish should be easily repaired, or touched up, by the user/owner with readily available materials. In addition and possibly more important, the bicycle should be treated with care, wiped down with a dry cloth to remove excessive water or mud after a ride, avoid being used in salt water, and whenever possible stored or parked in a covered, well ventilated dry place.

CHAPTER 5

5. Commercial acceptance of wooden framed bicycles

Although the design, development, and production of the Xylonbikes wooden framed bicycles was not initially intended as a potential business proposal, various initiatives were undertaken such as creating a website and an email address to promote the bicycles.

Although a number of enquiries were received and the bikes were featured on numerous sites, no production facilities or financing were available to respond to the requests.

Consequently the project was put on standby until 2007.

5.1. Case Study - The Governor's Island Project

In 2007 an opportunity arose to test the viability of wooden bike frames in a real time environment. Governors Island which lies in New York Bay was scheduled to be refurbished by making it into a public park. As part of the scheme a bike sharing programme was envisioned for visitors to the island. The winners of the tender, West 8, a firm of Dutch architects, proposed a bicycle sharing scheme with the novel idea of providing wooden bicycles for Governors Island NY.

The following excerpt is from the Governor's Island site[24]:

> *"Not only will Governors Island be getting a makeover, it will also get the city's first bike sharing program. Am New York reported that Dutch firm West 8, hired to handle the Governors Island makeover, "**will also build 3,000 wooden bicycles for free use by visitors to the island**."*

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[24] http://www.west8.nl/projects/all/governors_island/ (Consulted 2007)

Figure 205. Governor's Island Prototype Wooden Bicycle – (West 8). Retrieved from http://www.west8.nl/

The unique prototype wooden bicycle shown above (no others were made) was produced by West 8 to demonstrate the type of bicycle which would be provided for use by visitors Figure 205). The frame comprises laminated plywood sculpted to approximate an animalistic format with a "tail" serving as the rear mudguard and a protruding "head" and carrier basket. The two lugs at the front are designed to be used with a special bicycle parking rack. Various simulations were shown in West 8's proposal (Figure 206)

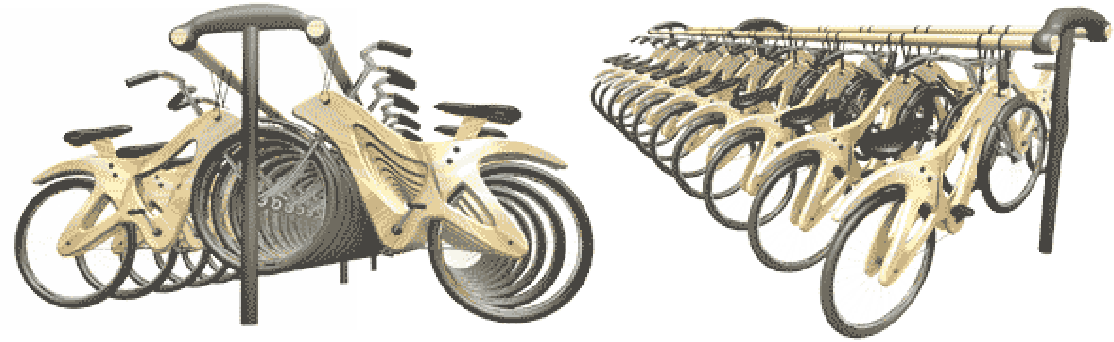


Figure 206. Custom made bicycle hanger racks for West 8's proposed wooden bike share bicycles - (West 8). Retrieved from http://www.west8.nl/

Contact was made with the company and the philosophy behind Xylonbikes' approach to wooden bicycle design was outlined. Consequently a meeting was arranged with a West 8 representative to demonstrate the wooden bicycles thus far produced in Portugal and discuss the possibility of having the opportunity of supplying them to be included in the Governor's Island project.

Up until that time the Xylonbikes bicycles had been produced to order as handmade "one-offs", therefore, in order to provide an indication of cost and production capability a small furniture company in Santarem Portugal was contacted. Following discussions with the company, production methods and materials were discussed as well as the quantities involved. The project was outlined based on supplying 3000 units in accordance with the technical specification laid out as follows.

Table 2. Xylon Bikes wooden bicycle specifications for West 8 Governor's Island Bike Share Project.

Component description (Part Number)	**Material**	**Specification**
SPK1 - Side panel (Left hand)	Birch marine plywood	WISA birch plywood. Phenolic adhesive EN 314-2/Class 3. Surface quality B according to SFS 2413. Thickness 9mm nominal. Number of laminations – 7. Standard panel size 1250 x 2500
SPK2 Side panel (Right hand)	Birch marine plywood	As above
CVM1 - Core – vertical member	Mahogany/Maple/Oak	Naturally seasoned timber without splits knots or defects
CHM2 - Core – horizontal member	Mahogany/Maple/Oak	Naturally seasoned timber without splits knots or defects
Steerer tube	Stainless steel	Stainless steel tube: Internal diameter External diameter Length – 120mm
Seat tube	Stainless steel	Stainless steel tube: Internal diameter 27.2mm External diameter 30mm Length – 120mm
Bottom Bracket	Stainless steel	Stainless steel tube: Internal diameter External diameter Length – 120mm
Rear dropouts	Aluminium	Universal rear dropout. Machined aluminium. Anodised or natural/polished finish.

Preceding page: West 8 – Xylon Wooden bicycle specifications for West 8 Governors Island Project.

Bearing in mind such factors as sustainability and the use of certified harvested wood, and the opportunity to create new business for small enterprises, the company that was chosen was relatively small (six employees) and was considered to have the expertise and flexibility required for the project, but at the same the capacity to deliver the number of frames required within the timescale stipulated.

At the time of the proposal the orientation of the laminations of the plywood and the relative position of the side frames in relation to this was not considered to be critical, therefore it was proposed that the side frames were cut as economically as possible from the stock size certified birch marine plywood sheets. (Consequently the cost per unit was based on these criteria).

Quotations were also based on differing types of both national and imported hardwoods to be used for the core of the frames, such as mahogany, maple, oak, chestnut and possibly olive wood etc.

The proposed production processes relied on patterns and existing spindle moulding machines to initially shape the components rather than employing CNC technology, and then sanding to the required finish. To keep in line with the current environmental regulations regarding solvents, water based varnishes were considered to be the most suitable and eco-friendly.

The vising architect was given a guided tour of the furniture factory installations and agreed that the type of company was ideally suited to the production of the frames as it had both capacity and flexibility.

Although the prototype bicycle made by the West 8 company was a functional machine, in that it was rideable, the production methods employed were highly labour intensive. No plans had been made regarding the mass production of the wooden framed bicycle and no cost estimates were available. The overall weight of the West 8 bicycle was in excess of 25 kilogrammes which under most circumstances can be considered to be excessive for a bicycle as a typical bicycle weighs-in at around 15 kilos. Also the wheels were size 700 and the front basket was quite large which gave the bicycle an unstable appearance which could lead to the possibility of reducing rider confidence (Figure 207).

Note: Most Bike Share schemes are non-selective regarding potential rider experience, competence, and notions of recommended bicycle practice. It is possible that in some cases users have limited experience of riding a bicycle.

Figure 207. West 8's proposed wooden bicycle with basket incorporated simulation – (West 8). Retrieved from http://www.west8.nl/

One of the factors regarding the wooden bicycles proposed for the Island was their useful life. Considering the potential useful life of a typical bicycle which could be years or decades, West 8's estimate of six months appeared to be relatively short, considering that the bicycles were to be on loan on an island which could be only reached by ferry, and damage/vandalism/theft would, theoretically be relatively easily controlled. Considering the useful life of the Xylonbikes wooden bicycles was conservatively estimated at 10 years (now verified by empirical testing), there appeared to be an incompatibility regarding this factor. However, following further discussion, West 8 outlined their innovative strategy regarding renewal of the bicycles. As the bicycle frames were to be made of wood, vandalism *was* to be expected or even encouraged. The type of vandalism that was envisaged (other than operational damage such as wear and tear, breakage, slashing tyres etc.) was that the users would, in some way, in addition to riding the bicycles, be "interactive" and carve the wood with their initials, or other graphisms similar to carving the bark of a tree, scratched graffiti, burnt graffiti, and typical graffiti such as tagging. In this way each bicycle would bear ongoing references of its use and users, eventually becoming customised objects in the urban environment. Then, as a way of amortising the investment, and generating more funds for the replacement of the “damaged/vandalised” bicycles the bicycles were to be auctioned in New York as a type of “urban art” statement. Literally the wooden frames were to function as a “canvas” for sanctioned intervention by individuals who used/abused them; in contrast to typical metal framed bicycles the surface area of the wooden framed was considerably more suitable for this type of treatment.

The Caldas da Rainha Athletics Track was rented for an afternoon and the West 8 representative was invited to ride an example of the Xylonbikes Klassic and the Eclipse. (A second example of the Klassic should have been available for testing but was damaged in an accident the previous day). Having ridden the wooden framed bikes around the oval athletics track, the Klassic was declared “a good bike” by the West 8 representative, and a favourable observation was made regarding the small furniture manufacturers installations which were considered “ideal” as they were a balance between mass production and one-offs.

After having assessed the production requirements the furniture company quoted a cost of approximately 200 euros for the completed frames (no components were included in the quotation other than the aluminium bottom bracket housing, seat post, drop outs, and steerer tube which are integral parts of the fame. The rate of production was set initially at 100 units per week, which would mean the order of 3000 units could be met in 30 weeks with an initial quantity to be agreed upon.

Given the reduced time scale it was not possible to obtain another guide quotation from another company for this service.

Having established that the frames could be manufactured within an acceptable timescale further considerations were necessary with regard to the method of transport, quantities per batch, and sourcing and assembly of components such as wheels, cranks, handlebars etc.

Following studies of sourcing components and assembling the bicycles in Europe it was found to be more viable to send the frames only to the United States and source the components and assemble the bicycles there.

The reasons for this decision rested mainly on the fact that import duties and taxes would be less for “parts” than complete products, i.e. frames rather than assembled bicycles. In addition shipping costs would be less for frames alone due to reduced space and weight. Another consideration was that sourcing and the cost of components would be easier in the United States than in Europe, especially the rear wheel fitted with coaster brake.

Having come to the conclusion that the frames alone would be exported, rather than the complete bicycle it would be necessary to contract labour at the destination and provide supervision and training regarding the specific requirements for assembling wooden framed bicycles.

One of the factors which was identified was that it was difficult to assemble the rear wheel inside the dropouts. This was due to the need to spread the dropouts sufficiently to give enough clearance to insert the axle, then upon tightening the axle nuts the dropouts would be pulled inwards to keep them parallel and fix the coaster brake anchor. On the trials this was a two person operation - One person spreading the rear “stays” and a second locating the rear wheel. Of particular concern was that untrained personnel may spread the rear stays excessively and compromise the glued joint between the core and the plywood side panels (although this never happened in practice, no tests were carried out to ascertain the degree to which the stays could be spread without damage). Therefore in order to circumvent this possibility, the fact that the frames only were being shipped allowed the following solution to be proposed.

It had been noted that the rear stays took on a recurved “set” after a bicycle had been assembled and ridden for some time (approximately one month). This “set” facilitated rear wheel removal and replacement and maintained the dropouts more or less parallel. Therefore an opportunity arose to pre-stress the rear stays during the shipping and storage period prior to assembly.

After manufacture the rear stays take on a simple “V” format. The dimensions of this “V” are based on the following.

- Size of the wheel complete with tyre.
- Width of the rear tyre.
- The dimension of the apex of the “V” is governed by the width of the bottom bracket.

- The angle of the “V” is governed by the diameter and offset of the chain wheel (clearance from stay)

In order to simulate the condition where the “V” comprises two recurved arms it was necessary to develop a method which would be practical, economical, and efficient. In essence it was necessary to design a spacer which could be positioned between the rear stays at a suitable predefined position, and a method of compressing the dropouts to the fixed "O.L.D." (*Over-Lock-nut Distance*).

5.2. Viable solution

Following various proposals a solution was attained based on the following.

Due to the shape, size, and profile of the side members and the standard size of marine plywood there is a relatively large quantity of waste. As this waste plywood is retained in the production installations, storage is required until it can be suitably disposed of (either usefully, as it is a high value premium material, or for firewood).

As the original bicycles proposed by West 8 had a front basket, some form of carrier would be needed for the Xylon framed bicycles. Following evaluation, the front basket as portrayed in the West 8 bicycle has a number of shortcomings.

1. Due to its size it could be used to carry loads, which either due to bulk or weight could compromise the safety or handling of the bicycle.
2. The centre of gravity is too far forward.
3. There is a danger that babies or small children could be carried in the basket.
4. Aesthetically it gives the bicycle “top heavy” appearance.
5. It is expensive to manufacture and it is specific to the West 8 bicycle.
6. Storage requirements (racks) have to accommodate the basket.

Subsequently these potential problems were addressed and the following suggestions proposed.

Reduce the size of the basket to limit its use to lighter, smaller loads.

Place the basket over the rear wheel to distribute the centre of gravity more efficiently

Make the basket strong enough to withstand potential abuse by non-intended use (e.g. children hitching a ride)

Free the front of the bicycle from clutter to make it visibly lighter and steering as intuitive as possible.

Produce the basket/carrier from scrap material resulting from the production process, and develop it in parallel as an accessory in its own right for conventional bicycles.

The front of the bicycle is simplified and racks and storage are non-specific.

Having taken these factors into consideration a part was produced Stay Spacer/Rear carrier.

As there was sufficient scrap material to produce the part a rectangle was cut to the dimensions required and two 12mm wide longitudinal slots routed into it.

Note: The slots are 12mm wide to provide clearance to pass over the 3mm thick dropout flanges on the rear stays.

Due to the length of the slots the rectangle could be pushed over the stays to a fixed position, spreading them outwards in a slight curve, thus widening the O.L.D. Then, an as yet undefined part is use to maintain the dropouts compressed to less than the O.L.D. The objective of this method is to give the stays the required “pre-set” during storage and shipping time (approximately 1 month at the least).

The formers would be removed just prior to assembly of the other components and used as the base for a rear carrier.

5.3. Assembly Procedure

In the event of the frames being exported as parts rather than complete bicycles an assembly schedule was drawn up. Although no specialised labour is required to assemble the bicycles, a working knowledge of bicycles is desirable to ensure safe assembly.

As part of the “package”, the assembly procedure envisioned for completed bicycles can be seen below.

Xylonbikes Wooden Framed Bicycle Assembly Procedure:

Model: Xylon Klassic.

Type: Single Speed Cruiser

Note: Wheels supplied with fitted inner-tubes and tyres

1. Remove dropout clamping bar and discard
2. Carefully slide off “pre-set” spacer/carrier
3. Check frames for damage and put aside for touch up with suitable varnish or other remedial action.
4. Install bottom bracket (standard component)
5. Install cranks
6. Install pedals
7. Install top and bottom head races and seat with headset press
8. Install fork crown race (if not already fitted)
9. Install fork crown race bearing
10. Insert fork stem
11. Install upper race bearing
12. Screw down threaded head race until resistance is felt then turn back ¼ turn
13. Install spacer washer
14. Install locknut and tighten against threaded head race.
15. Insert quill and tighten lock screw (Note safety mark)
16. Attach handlebars (Tighten to 4.5Nm – 5.0Nm)
17. Install front wheel and check alignment
18. Size chain (In production series the chain will be pre-sized and supplied complete)
19. Fit chain to rear sprocket and install rear wheel with loosely tightened bolts
20. Fit chain to front chainwheel
21. Tension chain by pulling rear wheel backwards, check alignment and tighten nuts
22. Fit coaster brake anchor bolt.
23. Check movement of chainwheel and apply coaster brake several times
24. Fit front brake lever (L/H – USA, R/H Europe)
25. Fit handlebar grips
26. Fit front V-brakes (Adjust contact as required)
27. Fit front brake cable (adjust and check)

28. Insert seat post and clamp in position (Note do not exceed maximum extension mark)
29. Fit saddle (Tighten to 4.5Nm – 5.0Nm)
30. Test ride bicycle (Apply front brake, rear coaster brake, figure of 8 R/H, figure of 8 L/H)

CHAPTER 6

6. Analysis of Wooden Framed Bicycles

In order to assess the viability of a wooden bicycle frame a number of factors must be considered. This analysis is broken down as follows.

6.1. Disadvantages of a wooden framed bicycle

The disadvantages of a wooden frame for a bicycle can be categorised as follows.

1. Disadvantages in the production of the bicycle frame.
2. Disadvantages in the use of the bicycle frame
3. Disadvantages over time (long term disadvantages)
4. Disadvantages in marketing

In order to objectively characterise the disadvantages, a number of comparisons have to be made with regard to more traditional manufacturing techniques.

6.2. Disadvantages in the production of a wooden bicycle frame.

Given that the manufacturing techniques used for the production of a wooden bicycle frame are similar to current production methods for furniture, boatbuilding and even aeronautical construction, there are no foreseeable problems related to the construction of a wooden bicycle frame as construction techniques employed are already established, however a number of factors need to be born in mind regarding certain specifics:

Quality and sourcing of raw materials:

The quality of raw materials has to be carefully monitored to ensure consistency, suitability, and wherever necessary certification regarding harvesting and the environment.

Storage of raw materials:

As the materials used are fundamentally untreated natural materials, correct and adequate storage is of prime importance to ensure the quality of the materials is maintained. This is also a factor which needs to be considered with regard to the transport of the materials. In addition, prior to manufacture the materials must be “conditioned” or stabilised in a controlled environment so as to avoid dimensional and physical changes due to large temperature differentials and humidity.

Waste materials:

Due to the manufacturing techniques identified as being the most suitable, and taking into consideration existing production techniques regarding wooden structures it is possible that a large quantity of potentially contaminated waste material will be a by-product of manufacture (phenolic and urethane resins). As this material is not recyclable or reusable, its correct disposal must be taken into consideration. Compared with frame production techniques using materials such as steel and aluminium (but not carbon or graphite fibre) where waste material can be recycled relatively simply, useful treatment of waste is a disadvantage. The most probable solution would be for emission controlled combustion of the materials to heat the facilities or create a stable environment. NB see Appendix iii - Engineered Wood

Knowhow:

Although the industries associated to the construction of conventional wooden products are well versed in production techniques, cost effectiveness and material selection there are some specifics regarding the production of wooden bicycle frames that need to be addressed. Although the aeronautical industry uses wood for airframe construction it is on a relatively small scale which makes monitoring and checking the processes relatively simple (requirements for the FAA and quality assurance). However the production of wooden bicycle frames (within the remit of this hypothesis) would be more akin to mass production given the potential numbers of the product compared to light aircraft. Regarding the dynamic nature of the product and the safety issues it would be necessary to closely monitor and check production to ensure the quality was maintained, especially with regard to bonding and gluing, which unlike furniture, for example, will be subjected to significantly different strains and stresses when in use.

Cost:

Initially the production techniques employed in the fabrication of wooden frames would be highly labour intensive and time consuming, requiring a specific logistics approach to assembly gluing, cramping, and curing etc. In the face of traditional techniques this can be considered to be a disadvantage until such time as different techniques (possibly related to frame design alterations) could be perfected and put into practice.

Storage of completed product (frame):

Considering that the finished frame is well manufactured, stable, protected against the elements by suitable packaging if necessary, storage would be in a suitably conditioned under cover area. With regard to the specific storage requirements such as stacking, palletising, and possible controlled humidity, these factors would have to be addressed through modelling or empirical iteration.

6.3. Disadvantages in the use of the bicycle frame

Taking into consideration the use of the bicycle in everyday activities, a large spectrum of conditions and circumstances must be taken to consideration. In order to more easily categorise these factors a chart was dawn up as follows.

Table 3. General usage comparisons of wood, steel, aluminium or carbon bicycle frames.

	Wood	**Steel**	**Aluminium**	**Composite (Carbon/Graphite)**
Cycling on paved surfaces	Shock absorbing	Springy/responsive	Stiff/hard ride	Springy/responsive

Security	Vandalism	Safe	Safe	Vandalism
Safety	Safe	Safe	Possible metal fatigue	Unexpected failure
Parking (exterior)	Preferably under cover	Rust of unprotected areas	Oxidation of unprotected areas	Safe
Storage	Preferably indoors	Indoor, outdoor	Indoor, outdoor	Indoor outdoor

Cycling:

Having tested the Xylon wooden bicycle by riding it, over 100 users (Males and females) claimed that there was no difference to riding a “normal” i.e. conventional bicycle. However (and possibly due to the greater “visual density” of the frame) many users asked if the bicycle was heavy, i.e. heavier than a traditionally framed bicycle. Future tests may be undertaken where the frame is “hidden” to avoid user preconceptions.

Parking:

No disadvantages were encountered when parking the wooden framed bicycle compared to conventional bicycles other than possibly more care being required to avoid scuffing or scratching of the varnished finish.

Security:

The design of the frame permits the typical use of a chain and padlock, or a cable lock without any special characteristics. Some users stated that the bicycle could be stolen by sawing through the frame. The twisted logic of this observation is easily discredited by the fact that any bicycle frame can be sawn through with a hacksaw.

Safety:

In spite of concerns regarding the perceived strength, (in other words preconceptions and therefore the safety of the wooden framed bicycle due to there being no metal structure within the frame the bicycle was considered to be as safe as traditionally framed bicycles.

Figure 208. Xylon Klassic after head on collision with a “conventional” steel framed bicycle. Taylor, Nicholas. 2008

The previous photograph was taken after the bicycle was recovered from the Caldas da Rainha Police Station after the two bicycles involved in the head-on crash were impounded. On inspection, the front wheel was so damaged that it was beyond repair and was subsequently scrapped (Figure 208). The front forks were also damaged and bent backwards and twisted as can be seen by their position and the flaked paint (the blue area around the fork crown). The forks were also damaged so severely that they too were scrapped. On stripping down the bicycle to check if any further structural damage had occurred, the only other areas to show damage were parts of the varnish which was scuffed and scratched. An area of potential concern was the steel steerer tube insert which could have sustained damage, however this was found to be in good order and suffered from no deformity such as ovality, nor did the surrounding wood suffer any damage such as compaction or distortion.

The bicycle in question was rebuilt using a chromium plated steel threaded type headset forks with approximately the same forward rake as the originals, and an aluminium quill and raised handlebars. The original Shimano front hub was re-laced with a radial fork pattern to a 26” BTT rim as was originally fitted. V-brakes were fitted with the lever mounted on the right hand side to give a more direct cable route. A higher quality crank and pedals were fitted as the original was basically used to test the bicycle, and a Brooks’ leather saddle fitted to the original seat post. The original semi-slick tyres were retained as were the remaining components. The resulting bicycle can be seen below. Subsequently it was exported to Germany to appear in the Frankfurt Eurobike bicycle show (Figure 209).

Figure 209. Xylon Klassic in the Frankfurt Eurobike Show – Bleckwedel, Thora. 2008

6.4. Advantages of a wooden framed bicycle

The advantages of a wooden framed bicycle are difficult to define objectively especially as there are preconceptions to overcome; however, the main advantage is that of differentiation. Although when this study was initially undertaken, there were very few contemporary wooden framed bicycles available on the market, and there were few wooden framed bicycles found on the internet and by other search methods.

6.4.1. Definitive specifications (Frame)

Description:

An adult bicycle frame made from wood and engineered wood.

Materials:

Fully seasoned hard or soft woods selected for homogenous structure and aesthetic appearance. Marine grade plywood. D4 mono-component polyurethane adhesive. Sundry bicycle products.

Finish:

The frame is sanded and finished in two coats of clear cellulose base sanding sealer lightly rubbed down between coats. The final finish is a two part high gloss, transparent acrylic lacquer applied in two coats over the sanding sealer.

6.5. Conclusion

As to whether wood and its derivatives are viable alternatives to other more traditional materials as a bicycle frame building material, the answer is unequivocally yes.

However having established that there were a number of essential criteria which had to be met there are undoubtedly several caveats which need to be factored into the pothesis.

6.5.1. Function

As a way of ensuring viability, a wooden framed bicycle should comply with the requirements of a traditional bicycle in that it uses standardised components; however, due to the specific characteristics of wood it may be necessary to introduce frame/component interface element at points A, B, C, and D (see figure 1).

6.5.2. Materials

Further investigation into the suitability of wood as a frame building material requires an in-depth study of the following factors, which include a number of technological parameters which need to be established, namely:

- The use of different wood types and wood derivatives as a frame material
- The application of existing fixing methods and adhesives
- The use of existing unmodified standard bicycle components
- The development of wooden frame/standard component interface solutions
- The mechanical and structural properties of a wooden framed bicycle compared with frames constructed from traditional materials

However, the above listed criteria may not be exclusive factors. Further variables which could conceivably influence the outcome of such a study are strongly related to the perception of the material and its use in a non- conventional manner such as:

6.5.3. Acceptance

Possibly one of the least viable factors associated to a wooden framed bicycle has to do with the way in which it is accepted by the public. Having identified this criterion, the "public" can be differentiated depending on their individual and collective needs. For example the acceptance by an individual athlete whose prime consideration is directly linked to performance, functionality, and reliability are quite different to the criteria established for a bicycle sharing scheme or a Community Bicycle Programme

The factors outlined below are some of the considerations which need to be addressed regarding acceptance of a bicycle made from non-conventional materials:

- Preconceptions regarding the use of an unconventional frame material
- Lack of recognized and renowned manufacturers
- The long term durability of wood as a dynamic structural material
- The absence of studies and information related to wooden bicycle frames

6.6. Further development

Having analysed the shortcomings of the bicycles which were produced and tested, a number of factors can be addressed in order to assess the broader issue of viability of a wooden framed bicycle. Having been asked on numerous occasions "what are the advantages of a wooden bicycle" and there being no valid or objective answer other than "it looks good" or "does there have to be?" an analytical approach is needed to address this question and provide an acceptable answer.

However, it must be born in mind that when the question is asked "what are the advantages of a wooden bicycle" the asker is in some way pre-empting or conditioning the response. This may be perceived as generally looking for the reason or reasons to change something. It should also be remembered that however knowledgeable or otherwise, questions such as this are (if not vocally) to some extent already answered by the asker due to certain possible preconceptions such as – is it cheaper than a conventional bicycle – is it "better" than a conventional bicycle – rather than – is there something I should know about this bicycle?

Consequently it is necessary to establish some parameters regarding the question, “what are the advantages….”when a product is altered or takes on a radically different appearance to the norm

6.6.1. Appearance

The diamond frame has been around for a long time and it is not surprising that any deviation from that format begs the question referred to previously. Nevertheless the steel bicycle fame has undergone periodic shifts and changes in its basic design with the lowering or raising of structural members, introducing a bend here or a bend there, or making any number of alterations to advertise supposed “innovation”, “improvement” or simply “fashion”. Consequently when a product which is so different to the norm is marketed there are a number of factors which need to be addressed.

Unless aimed at a specific market where the existing pattern of frame is well accepted, in order to broaden the acceptance and scope of the product, the appearance of the frame may have to be altered.

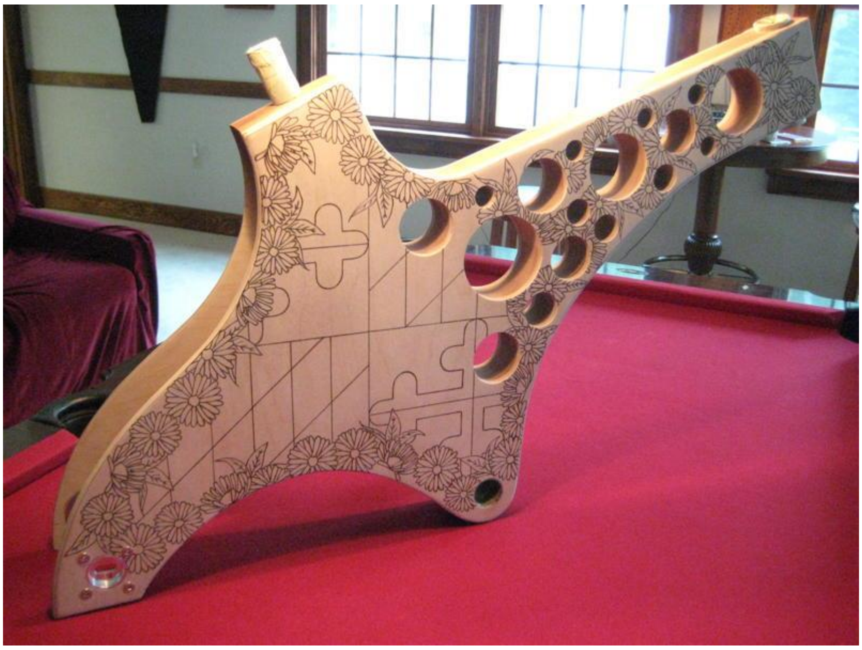


Figure 210. Unvarnished Xylon Frame with Pyrography Designs – Dayton, Kenneth.

The previous photograph (Figure 210) illustrates a wooden frame which was supplied unfinished unvarnished on request.

The objective of the client was to create a Maryland themed decoration whilst retaining some of the characteristics of the wooden frame.

The sort of decorative techniques employed were closely associated with traditional decorative wood methods.

In this case the sanded, but untreated frame was first outlined in pyrography to create distinct fields.

These fields were then filled with wood dye to create the Maryland coat of arms, and the regional flower (Figure 211).

Figure 211. Unvarnished Xylon Frame with Pyrography Design Fields Coloured – Dayton, Kenneth.

The bicycle was then varnished, and customised parts such as wooden mudguards and colour matched wheels were fitted (Figure 212).

Figure 212. Decorated Frame Complete Bicycle –Dayton, Kenneth.

A number of other ways that the appearance may be achieved are listed below:

1. Change design – shape, outline, details, but not manufacturing methodology
2. Use the frame as a “canvas” or background by painting, publicity, vinyl, solar panels, textures, vandalism, patterns, lettering,
3. Colouring, natural, bright, camouflage, animal pattern, flowers, landscape.

6.6.2. Change the design

On a custom built level, changing the design does not actually present any unsurmountable difficulties. Having established the frame building *modus operandi* as comprising a wooden core and shaped side panels, a wide variety of alternatives are completely viable.

In fact, a review of the existing models is testament to this.

6.6.3. Use of the frame as a “canvas”

Contrary to traditional frames which are made up of tubes, the surface area of the wooden frames which have been developed by Xylonbikes serves as an ideal “canvas” for a graphic intervention such as advertising, personalisation, and artwork (Figure 214). The following photograph illustrates a promotional bicycle manufactured by Xylonbikes for Pampero Rum (Figure 213).

Figure 213. Pampero Rum Promotional Bicycle – Mateus, Leonel.

Possibly a more radical and innovative approach has been referred to in the Governor’s Island section where “vandalism” such as carving and graffiti on the bicycles was seen as a deliberate gratuitous design opportunity.

6.6.4. Colouring

In a similar way that the frame can be used as a canvas, there is also the opportunity to “theme” the frame by simply colouring or dying the wood and varnishing it in order to retain the visual characteristics of the wood but coloured in a different way with stains.

Figure 214. . Xylon Klassic with simulated Romantic Artwork. Taylor, Nicholas.

6.6.5. Marketing

Up to the present moment, no serious marketing strategies have been undertaken.

However, a business plan was drawn up but is not considered relevant to this study.

The Xylon bicycles have appeared on various websites but have not been advertised. A number of ways that the product could be promoted in order to reach a wider audience are listed below:

1. Advertising campaign blogs, website, television, placement (appearing in films – futuristic)
2. Media coverage , newspaper, television, magazines, books
3. Green initiative
4. Trade shows
5. Events

Advertising campaign and blogs can be expensive and need constant maintenance.

Media coverage is free and relies on interested parties. Xylonbikes had particular national and international success in this sector.

The Green initiative is undoubtedly a strong component in acceptability at the moment

Trade shows (not just bike shows) are a source of dissemination but are expensive

Events are a potential for wide exposure where the bicycles are seen, tried, and feedback is given.

6.6.6. Materials

Cork is a natural material and a potential material to use in wooden bike frames.

Palm, although less common is also a potential material for future experiments.

Pine is readily available and if well-seasoned a very adequate material.

6.6.7. Sponsorship

During the whole development process of the wooden framed bicycles that are the subject of this work, no sponsorship has been offered other than the opportunity to show the bicycles at the Festibike Bike Show in Santarem free of charge. Possible sponsorship initiatives may be possible through the following:

1. Hotels, energy companies, green companies, camping sites, wood suppliers, cork producers, varnish suppliers, glue suppliers, sustainable energy companies.
2. Famous people, men or women riding wooden bikes
3. Famous events – races, endurance, ride round the world charity ride etc.
4. Bike sharing
5. Community Bicycle Programmes

Figure 215. . The Xylonbikes Fleet. Taylor, Nicholas. 2009

The Xylonbikes “Fleet” (Figure 125) was designed to economise on materials and machining without compromising function. Basically it is a “cut-down” version of the Klassic whilst retaining the overall functional dimensions and the omission of the opening running from the head tube backwards. The totally flat surface enables surface decoration to be applied such as vinyl, pyrography or printing. Tests are ongoing on this model regarding weathering and structural integrity.

6.7. Weight reduction

One of the concerns regarding the wooden framed bicycle in its present form is that of weight.

Not only is the physical weight of the bicycle frequently questioned, but also the *perceived* weight due to its visual density compared with traditional bicycles which generally have relatively narrow structural elements.

This section is dedicated to dealing with the aspect of physical weight (mass). Factors related to “visual density” are dealt with elsewhere.

6.7.1. Removal of material

Removal of material from a structure without compromising its load-bearing characteristics or strength is a process which has been employed in engineering and construction for reasons such as weight saving, reducing material costs, and aesthetics. Analysing the physical strength of the bicycle frame and removing material without compromising its strength (including flexion etc.) may potentially lead to the following modifications being made.

- Simple removal of material
- Removal of material and redistribution of material
- Substitution of material

6.7.1.1. Simple removal of material

Lightening holes

Removal of material from structures has been a common way to reduce weight and has been used in the automotive, aeronautical and bicycle industries for over a century.

The technique of drilling or creating lightening holes is one of the simplest ways to reduce weight.

This technique is used irrespective of material. For example, cast iron, aluminium, or wood structures can be drilled to reduce weight without significantly compromising strength.

Naturally the amount of material removed will depend on the purpose of the object, what stresses it will be subjected to, and to a certain extent, what will be the resulting appearance of the object (Figure 216).

Figure 216. Lightened Chainwheel. Retrieved from http://www.classiclightweights.co.uk/extras/drillium-extras.html

The stock chain wheel above has been drilled both to lighten it and also to create a geometrical pattern. In principle the function of the chain wheel is not compromised

Figure 217. Lightened Plywood Aircraft Bulkheads. Retrieved from http://www.brucespitfire.com/fuselage-page-6.html

The previous photograph shows plywood aircraft fuselage formers drilled to reduce weight without compromising the structural integrity of the fuselage (Figure 217). The lightening holes can be applied to the unseen interior of the structure or can be visible in the case of the Xylon "Cell" shown below.

Figure 218. Xylon Cell on Display at the ESTGAD Finalists exhibition – Caldas da Rainha. Taylor, Nicholas.

Although the aesthetic characteristics of the "Cell" frame are arguably improved, as are the weight characteristics, unfortunately the removal of material for both aesthetic and lightening purposes compromised the structural integrity of the Cell frame. However, the undesirable lack of strength is not homogeneous or the same for the structure as a whole. The series of holes directly behind the "seat tube" or more correctly, the combined seat-stays and chain-stays gave rise to potential failure along the line which runs from top to bottom. Ideally any holes should be of a size, type, and distribution which do not create structural weaknesses (Figure 218). The circular format of the holes themselves, which are easily made with conventional drilling equipment, is a good example of efficient lightening without structural compromise as the stresses are equally distributed around the round holes with no foci of stress. Due to the width of the frame forward of the "seat-tube" (nominally 58mm, as opposed to 9mm for the chain/seat-stays) the strength was not compromised and serves an example of how much material can be removed from that part of the frame.

Routed out material

Another way to reduce weight would be to remove material by routing it out. Material removed in this way could be removed from the exterior of the structure and be incorporated in the visual effect (such as the curved aperture in the Xylon Klassic). Or material could be removed from the interior of the frame without altering the exterior visual appearance. This method could be used in the core of the frame or the thickness of the side panels could be reduced where they meet the core. Removal of material from the chain/seat-stays by routing has been found to seriously compromise their rigidity and strength *sic* – The Oll frame suffered serious deflection whilst being ridden due to the design of the chain/seat-stays. The deflection was so great under load that the chain line altered to such an extent that the chain derailed.

NOTE: Any material which is removed from the core should not compromise the strength of the frame as a whole or by reducing the efficacy of the glued bond between the side panels and the core which is directly related to the surface area in contact.

6.7.1.2. Removal of material and redistribution of material

If the removal of material from one place does not compromise the structural integrity of the frame, other parts of the frame could be reinforced with extra material. This method is a trade off, and the outcome would be a frame which is:

- the same weight, but the structural characteristics are improved, or
- the frame weighs less and the structural characteristics are the same, or
- ideally, the frame weighs less but the structural characteristics are improved.

6.7.2. Different material

One other way to reduce weight would be to use different materials in the frame construction. For example, if areas which suffer low stresses such as torsion or bending are currently fabricated from dense materials, these materials could be substituted with less dense materials as long as the structural integrity is not compromised. Such materials as the following could be used in conjunction with others to maintain structural integrity whilst reducing weight:

1. Cork composite core
2. Cardboard composite core
3. Palm fibre core
4. Balsa wood core
5. Other low density wood core (e.g. poplar or willow)
6. Polymer foam core

Any one of the above or combination of them could be used to reduce weight.

1. **Cork composite**

   Either virgin cork or reconstituted cork composite material could be used in conjunction with higher density natural wood or plywood to create a cork composite core. The advantages would be a lighter core, good shock absorbing qualities, and the use of a natural sustainable material.

2. **Cardboard composite**

   A cardboard honeycomb matrix could be used for the core in conjunction selected hardwoods or engineered wood in a similar way to which household doors are manufactured. The advantages would be lighter weight, and the use of sustainable or recycled material. The disadvantage could be an increased resonance with the frame voids acting as a sound box.

3. **Palm fibre**

   I have carried out studies for the use of palm fibre composites for the Fibrenamics Competition. When dried in a controlled environment and bonded to plywood with a D4 category mono-component urethane adhesive, the result is a stable, light weight composite. A possible disadvantage may be that over the long term there may some degradation of the palm fibre core, therefore it requires further investigation and tests.

4. **Balsa wood**

Balsa wood is a well tried and tested material in the aviation industry; and well-seasoned material in conjunction with denser hardwoods is potentially an excellent material. Although quite expensive related to other woods, the quantities required would not be so large therefore it is a feasible proposal.

5. **Other low density wood**

There are many species of woods with a relatively low density (540 kg/m³ and less) which could be used to create a composite material for the core of the frame. Some examples of woods less than 540 kg/m³ are:

Western Red Cedar, Hemlock, Douglas Fir, Poplar, Obece, Redwood, Aspen, Basswood, etc.

6. Polymer foam core

Although non-sustainable, another possibility might be the use of polymers to create composites with hardwoods or engineered woods. A typical application could be the fabrication of a box structure fame, which would be injected with polyurethane foam to create a composite sandwich. The advantages would be structural integrity, resistance to humidity, fungal and insect attack, and shock absorbing qualities. As previously stated, non-sustainability is an issue with this material.

7. Others

Other organic materials not mentioned here such as bamboo, cut into short cylinders and used to fill the core, reeds, and other types of fibrous materials could be combined with any or all of the above to create composite core materials with the desired attributes of light weight, low density, resistance to vibration, deterioration from humidity or insect attack, and vibration damping and shock absorbing.

CHAPTER 7

7. Diversification

Although the wooden framed bicycle may itself be considered as a diversification of the conventional bicycle, this differentiation may be further explored by applying a strategy that has been applied to existing bicycles.

For example, in recent years alternative bicycles have appeared on the market fitted with electric motors.

7.1. E-bike – Electrically Assisted Bicycle

Considering the wide variety of types of bicycle which exist, there is still the potential to diversify and create specific types/styles.

One type of bicycle which is gaining popularity is the Electric Bicycle, or more correctly the “Electrically Assisted Bicycle”.

Electrically assisted bicycles are not a new idea, and patents have been around almost since the adoption of the safety bicycle. However, for various reasons, particularly regarding the power source, i.e. the battery pack, and autonomy, it was not until relatively recently that the Electric Bicycle or E-bike has been considered as a serious and reliable form of transport.

The “Electrically Assisted Bicycle”, uses an electric motor to power the bicycle, and reduce the effort needed to pedal it.

This electric motor and its battery pack can be positioned in various parts of the bicycle.

The three main locations for the motor are in the front wheel hub, the rear wheel hub, and the bottom bracket.

The battery pack can be located in the frame, integrated with the frame, or mounted on a carrier.

There are advantages and disadvantages of the systems but the electrically powered front hub is probably the least intrusive as the electrically powered wheel and the wiring loom and controls simply replace the normal front wheel, and the battery pack is mounted on a rear carrier which means the frame does not need to be altered.

Many E-bike kits of this type are available for converting standard bicycles.

7.2. Wooden E-bike development

Aware of the potential for developing a wooden E-bike, in 2013 a joint venture was proposed between ESAD CR and a local sustainable energy store to develop a wooden framed E-bike. The bicycle and the business model were to be presented to the *Concurso de Empreendedorismo Oeste Portugal* for sponsorship and start-up.

Taking into account my experience with wooden framed bicycles I was invited to participate in the venture by providing a wooden framed bicycle which could be electrically assisted.

Following discussions regarding the methodology, the design brief was drawn up as follows:

Objective: Design and make a wooden framed bicycle prototype incorporating an electrically powered front wheel with the battery pack integrated in the frame of the bicycle rather than on a separate carrier.

NOTE: This decision was made to avoid the idea that the bicycle had been “adapted” to electricity in a similar way to the one in the photograph below which has the battery pack as an obvious add-on (Figure 219).

Figure 219. Bough Wooden Bicycle with Battery pack – Bough Bikes. Retrieved from http://www.boughbikes.nl/

Design criteria:

1. The bicycle should use standard bicycle parts such as cranks, forks, saddle etc. wherever possible.
2. The battery should be easily removed and replaced, but should incorporate a key type anti-theft device.
3. The brake levers (when fitted) should disable the electric motor when braking.
4. The rear coaster brake (if fitted) should disable the electric motor when applied.
5. The bicycle should be fitted with an internally geared rear hub.
6. Wherever possible, the wiring, cables, and wiring loom should be hidden within the frame.
7. The bicycle should be of the “comfort” type, with upright riding position and comfortable saddle.
8. The battery pack and fittings could not be altered in any way. I.e the parts of the electrically assisted kit should not be changed so as to retain the product warranty in the vent of failure or breakage.

9. All electrical fittings and components (electrical assist kit) to be supplied by the sustainable energy company.
10. 9mm Baltic birch marine grade plywood to be supplied by a local timber merchant.
11. D4 mono-component to be supplied by the same company.
12. The bicycle should be fitted with a “pedelec” sensor on the bottom bracket. (Figure 220).

Figure 220. Pedelec Sensor Components. Retrieved from https://endless-sphere.com/forums/viewtopic.php?f=8&t=41356

On completion of the prototype, two more bicycles were to be fabricated. One for the timber supplier one for the Electrical components supplier, and one for ESAD CR to be used by ESAD students to test the prototype and undertake user surveys.

In addition, a branding exercise was to be carried by the Graphic Design students with a competition being launched in ESAD Caldas da Rainha to give the wooden E-bike a name, design promotional literature, and create a logotype.

Work to be carried out by Nick Taylor, and free access to ESAD workshops.

7.2.1. Wooden E-bike Design Process

From the design perspective, the placement and positioning of the battery pack was a fundamental constraint.

Ideally, given that the battery pack comprises multiple 18650 cells (cylindrical cells that measure 18mm diameter and 65mm long) it should be possible to configure them into any shape to fit the available space. However, as the cost of creating one-off battery pack prototypes was beyond the scope of the project, so work started on the E-bicycle by defining the battery pack characteristics (Figure 221).

Figure 221. Battery Pack comprising Sixty 18650 Cells. Retrieved from http://www.aliexpress.com/popular/60-volt-battery.html

The type of battery selected was a 36V10AH LiFePO4 rack battery for e-bikes, measuring 407mm long x 150mm deep x 67mm wide, which was part of an Electric assist package, and work commenced by experimenting with different orientations and positions of the battery pack within a XYLON frame template.

Figure 222. Commercial Battery Pack. Taylor, Nicholas. 2013

The width of the battery coincided almost exactly with the width of the existing frames which measured nominally 58mm, i.e. 40mm core, and two 9mm ply side panels (78mm at the widest part of the core towards the rear) (Figure 222).

Therefore the battery orientation was established as can be seen in Wooden E-bike Sketch 1 – Battery position (Figure 223)

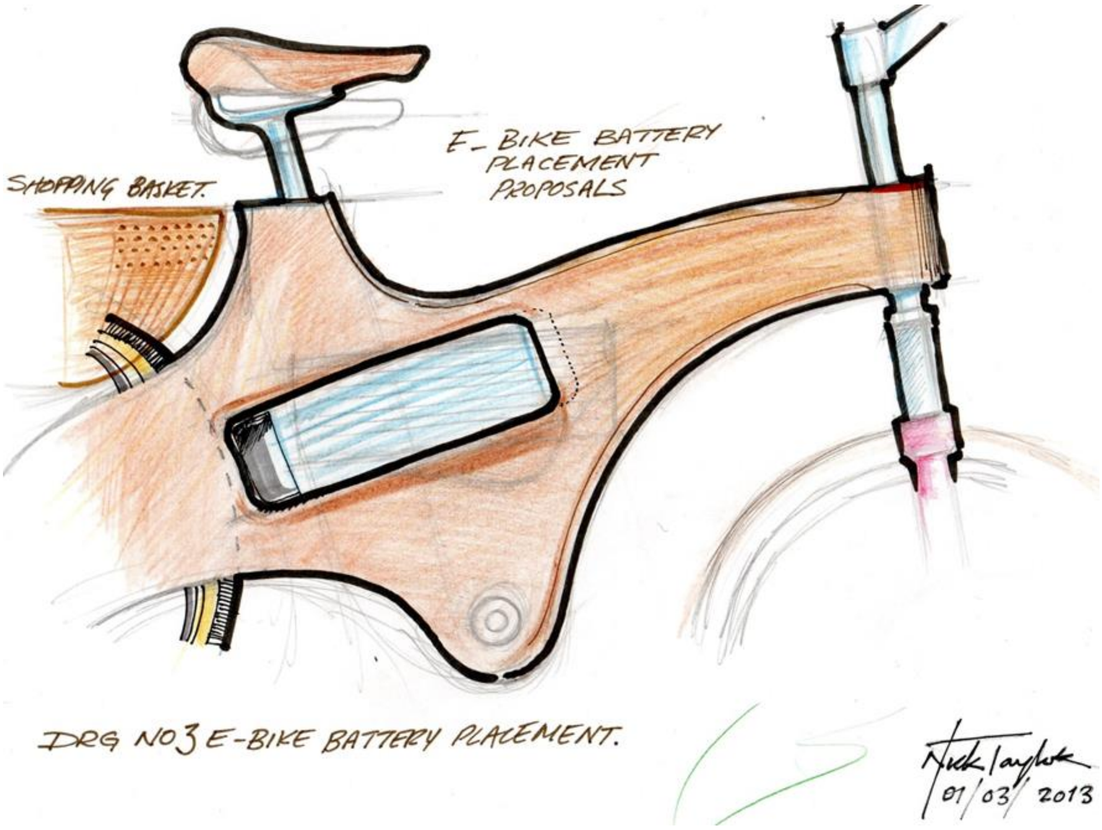


Figure 223. Initial Wooden E-bike Design sketch –Taylor, Nicholas. 2013

However, it soon became apparent that, due to the size of the battery pack, significant modifications to the frame would be required in order to incorporate it within the frame.

7.2.2. Battery charging

Although the battery can be charged *in-situ,* there are cases where the battery pack may be required to be removed from the frame to be charged, for security purposes or maintained in a warm environment.

The battery supplied in the kit has a “docking” unit which houses the connector, an on/off switch (with key) and a locking bolt, as prevention against theft.

The docking unit is considerably wider than the battery itself therefore it is positioned towards the rear of the wooden frame in order to take advantage of the wider part of the frame.

7.2.3. Battery removal and replacement

As the battery and docking unit had been designed to be used with an open type rear carrier, all of these parts were easily accessible in the intended use position. However, incorporating the functionality of these features in the wooden frame proved to be a very complex exercise.

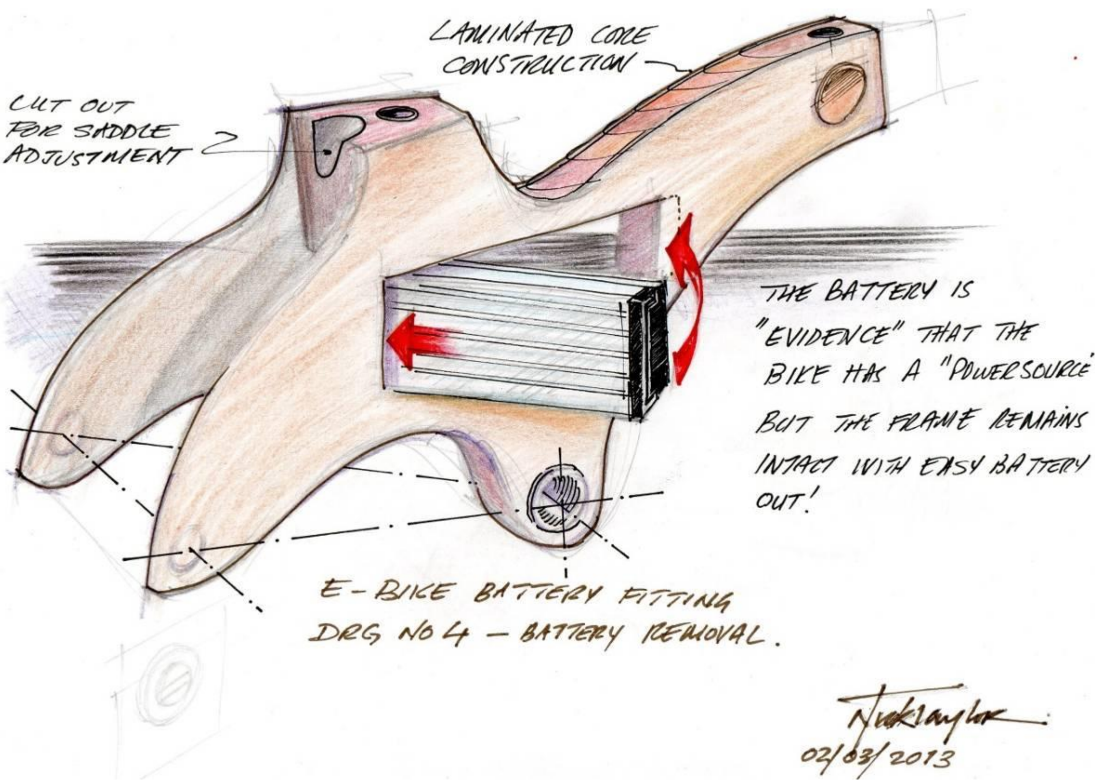


Figure 224. Initial Wooden E-bike Design Sketch (Battery Pack Removal) –Taylor, Nicholas. 2013

After attempting to position the battery pack in an existing frame, it was found that the amount of material which needed to be removed would seriously compromise the structural characteristics of the frame if the same frame design parameters were maintained; therefore the initial modification was to lengthen the frame to accommodate the battery pack and retain sufficient structural strength (Figure 224).

Therefore it was proposed that a new model frame was designed from first principles, but using the battery pack to work around. As there were so many variables involved in the design process, it was decided to develop a sort of E-bike “rolling chassis” test rig.

Using the techniques similar to those employed to develop and build Xylon #1, the E-bike prototype was designed to be taken apart and reassembled whenever modifications were required.

Naturally, such solutions to problems that had been resolved in the Xylon prototypes were applied to the E-bike prototype, such as the steerer tube, bottom bracket, rear dropouts etc.

However, it became apparent that by removing enough material to accommodate the battery and still retain a frame design with approximately the same proportions as a "normal" bicycle, problems were encountered with the structural strength of the "chainstays".

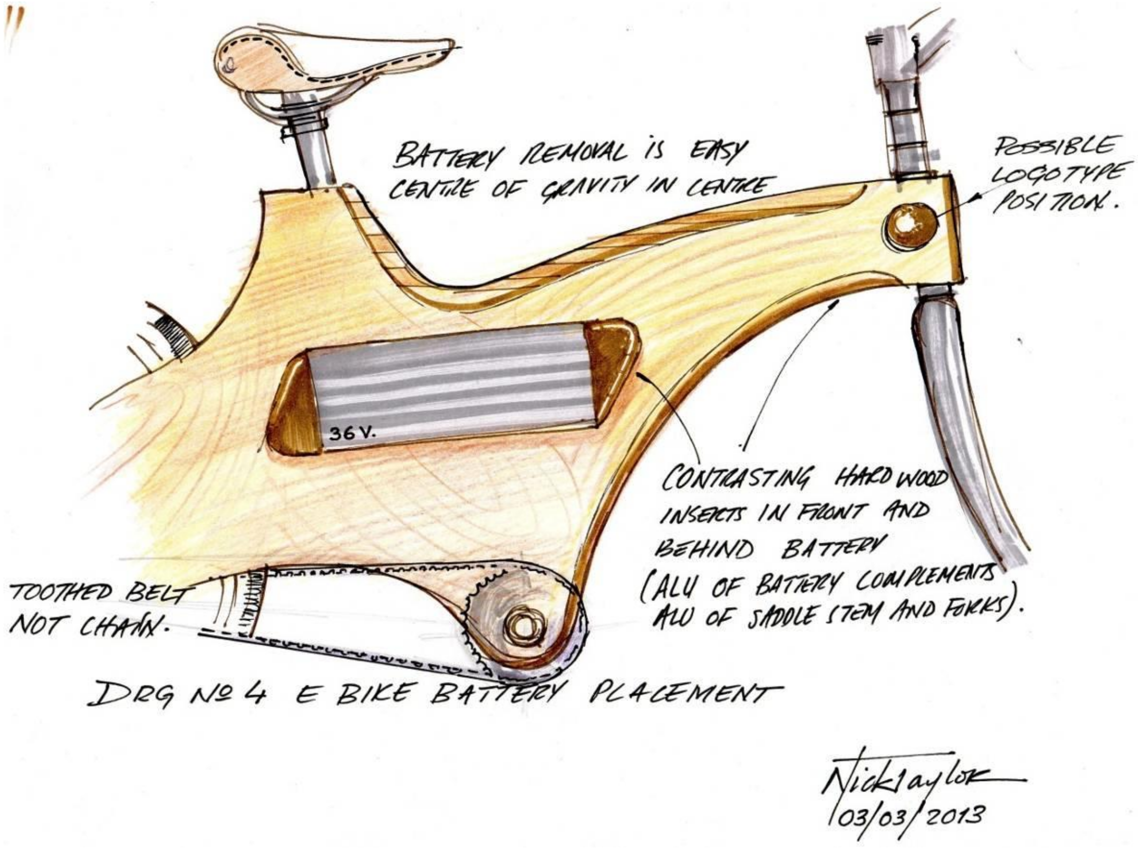


Figure 225. Initial Wooden E-bike Design Sketch (Detailing) –Taylor, Nicholas. 2013

This resulting flexion, which had been an issue since the first the building of Xylon #1, and some subsequent prototypes, required remedial action in order to maintain the viability of the bicycle.

As no other way was possible with that particular set up, a departure was made from the previously employed strategy of not modifying (reinforcing) the plywood rear frame members by the addition of material (Figure 226).

The frame was broken down and the following modification carried out.

1. As the lower part of the rear frame or "chainstays" were subject to excessive flexion and possible failure, two plywood strips were cut to follow the contour of the bottom line of the chainstays.
2. As gluing the reinforcement at that point (i.e. along the chainstay) may have increased the possibility of failure where it met the frame upright, a further modification was carried out at the same time; the reinforcement was extended beyond the front of the chainstays by about 50mm and a physical joint was cut into the frame core upright.
3. The resulting reinforcing strips were then shaped, sanded, and glued into place, effectively doubling the thickness of the plywood to 18mm at that point.

NOTE: It must be mentioned that the chainstays must retain a certain flexibility as the rear wheel is fitted or removed by springing the chainstays apart sufficiently to allow the rear axle to enter the slots in the patented drop-outs.

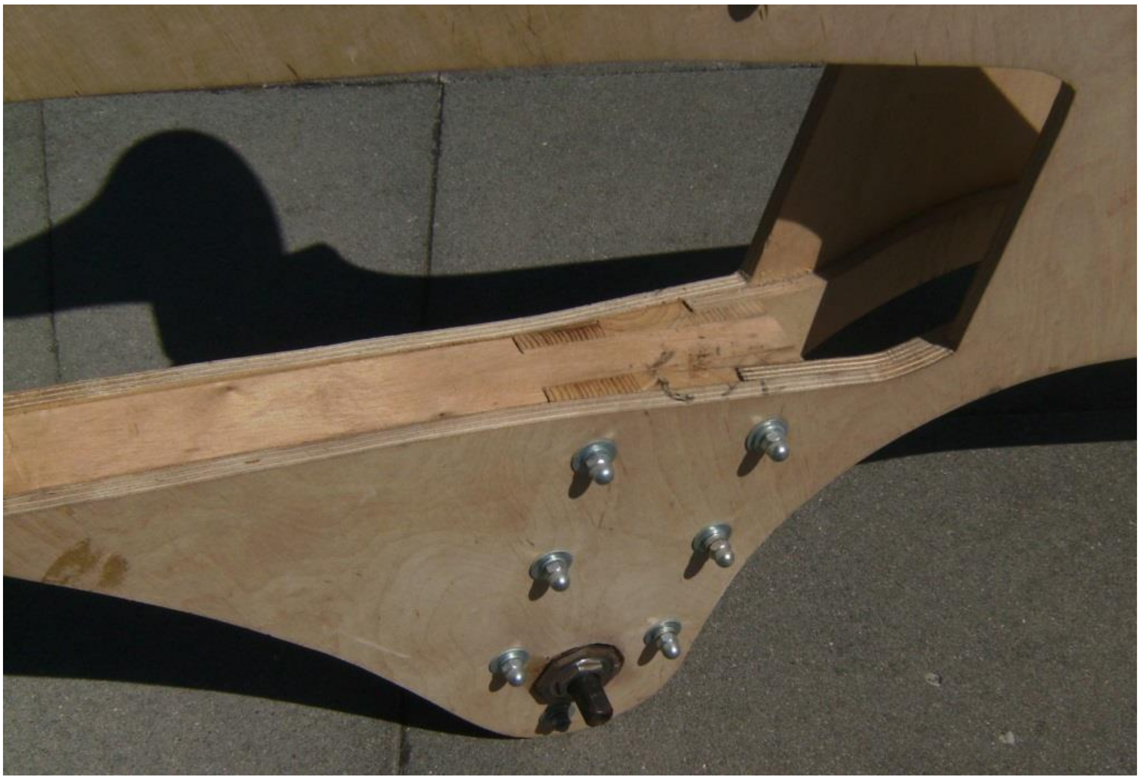


Figure 226. Prototype Xylon E-Bike Detail. Taylor, Nicholas. 2013

4. The frame was reassembled and the bicycle ridden.

5. The rigidity of the frame was considered to be adequate following the modification.

NB: The frame flexion was considered to be "adequate" rather than 100% "acceptable" due to the fact that there was still a certain amount of flexion of the chainstays. This was because they were only bolted to the frame at several points by M6 threaded bar and nuts and washers. Had they been glued, based on previous experience, this flexion would be expected to be considerably lessened when the frame was glued up definitively. The gluing of the frame effectively creates a sort of "monocoque" structure which is designed to function as a whole rather than a series of parts.

Figure 227. Xylon E-Bike Test Frame. Taylor, Nicholas. 2013

Although a rideable prototype (Figure 227) of the Xylon E-bike (albeit without electrical assistance) *was* produced on the limited resources and restricted facilities available, the project did not progress beyond the concept model stage due to the following circumstances:

1. Despite repeated requests, the promised supply of electrical components, bicycle parts and material and technical support was not forthcoming from the renewable energy supplier.
2. The restricted access to the workshop facilities in ESAD proved to be an insurmountable obstacle and most of the work was carried out in conditions that were not entirely suitable for such work.

However, from a “what if” point of view, if the requested material had been supplied, and the bicycle had been set up to be ridden with the electrical assist functioning, the battery-in-frame concept would not have been a practical option due to the following reasons:

1. Difficulty in integrating the battery into the frame without compromising the structural integrity, especially of the chainstays.
2. Difficulty in creating a secure fixing system which would allow easy removal and replacement of the battery
3. Potential problems that could occur if the battery pack configuration were modified (to substitute the original battery for example) and would not be compatible with the frame.

NOTE: Possible changes which would not affect the positioning of the battery in normal bike frames.

7.3. Design compromise

Throughout the iterative design process, as various issues were encountered and found to be difficult to resolve, a contingency plan was formulated regarding the position of the battery.

If none of the proposals to incorporate the battery in the frame were viable, the battery would have been transferred to a proprietary rear carrier designed to accept the battery pack as on conventional E-bikes (Figure 228).

Figure 228. Welded Aluminium Rear Carrier with Battery Pack. Taylor, Nicholas. 2013

A rear battery rack was supplied by the sustainable energy company and attempts were made to fit it to the rear of the wooden frame. However, due to the fixing method used to attach the frame to a standard metal bicycle frame it was not compatible with the wooden frame without considerable modification, consequently due to this and other difficulties, the project was shelved definitively.

However, the main reason for the project’s discontinuity was that the only electronic part to have been supplied by the energy company was a defunct battery pack with a broken docking port, therefore it was decided that it would not be worthwhile to continue with the project.

NOTE: The battery pack that was supplied was completely unserviceable and irreparable and showed severe structural damage due to the rupturing of the cells. In fact the damage to the battery was so severe that it would not slide into the housing on the battery carrier as the aluminium casing was deformed (bowed) by approximately 10mm on each side.

Having evidenced this damage, a note was made that if the battery had in fact been installed in the wooden frame, subsequent deformation of the battery pack could have severely compromised the removal and placement of the battery with possible resulting damage to the surrounding wooden frame members.

In spite of the various set-backs, such as unavailability of materials and limited access to workshop facilities, valuable experience was gained developing the wooden E-bike prototype especially regarding the different constraints which had to be overcome. Of particular interest was the modification made to the rear chainstays which significantly increased rigidity and structural strength of a highly stressed frame member.

7.4. Future frame modifications

As a policy of continual improvement is applied to the design and development of the wooden framed bicycle, (the E-bike reinforced chainstays for example), there may be a modification to the frame design in the future if the rear part of the frame is altered to appear less “solid” (visual density), either by making it smaller, or by the removal of material inside the profile of the side panels (see Xylonbikes “Oll” and “Cell”)

7.5. Other related factors regarding the viability of wooden framed bicycles

Although the objective of this study was to analyse the Viability of Wood and its Derivatives as a Bicycle Frame Building Material from a practical and technological view point within established parameters, there are other factors which could positively or negatively influence these finding.

7.5.1. Financing

With a project such as this, there are financial constraints which need to be taken into consideration. Although the concept stage is not entirely dependent on these constraints, such requirements as proof of purpose modelling and prototypes building carry with them inherent expenses. Other than the supply of the 9mm Baltic Marine plywood boards for the Wooden E-bike prototypes, none of the wooden bicycle development projects received any financial support from any sources other than the author.

7.5.2. Sponsorship

Although sponsorship was not actively sought, there is a potential for financial sponsorship given the nature of the product in the current situation of awareness regarding ecological alternatives.

Potential sponsors such as Electricity Companies or Local Town Councils through Bike-Sharing Schemes could be canvassed in order to finance future projects.

7.6. Plywood fibre orientation

Although not entirely unexpectedly, after having been assembled and used for weeks or possibly months, the chainstay/seatstays of the wooden bicycle prototypes took on an asymmetrical form. This phenomenon was manifested in the curvature of the chainstays/seatstays.

The most probable reason for this asymmetric deformation was almost certainly due to the two side panels not being mirror cut, i.e. cut from the large sheet so that the fibres of the laminations are orientated in exactly the same way on both sides.

Although this difference in deformation is able to be clearly observed from the rear, it does not appear to negatively affect the functioning of the bicycles. This is probably due to the fact that the bicycles produced so far do not have rim brakes but hub operated coaster brakes, and therefore the curvature is not exacerbated by lateral forces.

If the bicycles had been fitted with V brakes, for instance, the problem would have been considerably more noticeable and potentially unviable.

Therefore, as has been mentioned previously, any future side frames should be mirror cut, or at least cut with the laminations of the plywood running in the same direction.

After the initial deformation however, there appears to be no further deviation. Nevertheless the deformation is permanent, and to a certain extent beneficial as the dropouts are brought into a more parallel configuration with each other which allows the rear wheel axle nuts and washers to make better surface contact and thus distribute loading more evenly.

7.7. Aging

An important factor regarding the performance and longevity of any structure made from wood is aging. Unlike steel or aluminium, which over time, are prone to rust and oxidation when exposed to moisture and the air with a potential for altered physical characteristics, wood and engineered wood have a different problem.

Unlike domestic furniture which is kept in a relatively controlled climate with regard to temperature and humidity, a bicycle is used in a wide variety of climatic conditions which can vary from below freezing point, to temperatures of 40 Celsius, and relative humidity of 100% to bone dry. Furthermore the physical characteristics of wood as a construction material are dependent on such things as moisture content, bonding, and surface coating.

Regarding aging it is assumed that the moisture content of the wood used to construct bicycle frames is within the optimum range of moisture content and in good condition. This is also a factor taken into consideration when producing wooden furniture, improperly seasoned or treated wood can warp, bend or split during the post production phase irrespective of the climatic conditions.

There are a number of parallels that than be drawn with furniture and wooden bicycle frames, e.g. the natural aesthetic of the wood has always been and to a certain extent still exists such as the natural colour and grain, also the “warm” nature of the material rather than paint or metal is a factor which can be taken into consideration.

However, unlike furniture which is often loadbearing but bearing loads of a predominantly static nature, (except in some cases such as rocking chairs for example) the bicycle frame is a dynamically loaded structure and thus more susceptible to aging, fatigue, inappropriate use, and climatic changes affecting its performance.

Fortunately it has been possible to test various wooden frames in differing climatic conditions empirically.

On one hand, a number of bicycles have been kept in a relatively controlled closed environment similar to typical conditions where furniture is used. On the other hand, built bicycles have been used like normal bicycles in conditions ranging from heavy rain, intense sunlight, changes in temperature and humidity etc.

Below is a chart comparing visual aging of bicycle frames stored in the dry and used only in good weather with bicycle frames used in a wide range of climatic conditions.

Table 4. Effects of aging: control models compared with test models

CRITERIA	CONTROL Stored inside, used infrequently.	VARIABLE Stored outside, used daily in all weather conditions
Overall appearance.	Predominantly unblemished appearance.	Showing high degree of wear and tear.
Finish (Varnish)	Significantly intact, shows small areas of chipping, and rubbing where components have come into contact.	Chips, scratches and flaking of varnish especially in areas where materials are joined or with exposed end grain (including plywood laminations) Absence of varnish and lifting in some areas.
Colouration	Slight yellowing of varnish and darkening of colour of plywood and hardwood.	Wide variety of discolouration ranging from fading, dirt, oxidation, superficial almost black fungal discoloration and water stains.
General condition of wood	Minor abrasions, scratches, no significant change. Joints good when tested with fingernail test.	Major abrasions, partial separation of plywood laminations (especially on end grain). Splitting and lifting od surface veneers. Glued joints negative to fingernail test. Swelling of unvarnished areas. Highly oxidised and darkened. Cracking and fissures throughout the frame.
Functional operation of the bicycle	Good, 100% functional, no noticeable defects.	Good, 100% functional with no noticeable defects
General	New with slight imperfections (NOS)	Used, mechanically and

description		structurally sound but in need of renovation.

It can be seen from the above chart and the accompanying photographs that a wooden framed bicycle is susceptible to significant wear and tear if used on a regular daily basis. However, the functional operation and structural integrity compare well with a traditional bicycle with only the appearance being a cause for concern. Nevertheless the appearance of a wooden bicycle is possibly a more important issue than the appearance of a conventional bicycle.

7.8. Renovation

Conventional bicycle frames are often renovated by repainting, but generally only after a number of decades. Typically the frame is stripped of its components and any rust removed; the frame is sanded or shot blasted and lacquered or sprayed to the desired colour.

The renovation of the wooden framed bicycle is basically similar but there are some minor differences. Renovation requires no special technique other the techniques used to refurbish wooden furniture for example.

To prepare the frame, the old varnish is stripped off in any one of the usual ways, sanded down, any dents steamed out, the grain lifted with a damp cloth, allowed to dry and lightly sanded smooth again.

This process should be followed by applying a coat of diluted cellulose sanding sealer which is lightly sanded and possibly reapplied if necessary and sanded again. Re-varnishing with a suitable varnish is then carried out in the manner recommended by the manufactures.

There are however, a number of subtle changes that can be made to the appearance of the wooden frame. Tinted varnished can be applied to give a coloured hue or darker appearance. The frame can be the basis for graphic intervention by pyrography for example, or the frame can be painted in a primer and the frame can be painted with an opaque coloured paint for example.

7.9. Special care

Probably the closest approximation that can be made regarding the care of a wooden bicycle is either wooden boat maintenance or the upkeep of garden furniture.

If the bicycle is used in unfavourable conditions it should be cleaned with a damp cloth and any metal parts treated with a water displacing spray such as WD 40.

The frame can be polished with a proprietary brand of furniture polish containing beeswax and carnauba wax.

Scrapes and scratches can be “touched up” with clear varnish or lacquer applied by aerosol, or brush.

NOTE: As the finish of the frame is clear lacquer or varnish there are no problems associated with colour matching.

7.10. Waste of material

Especially with regard to the choice of plywood with the same orientation of laminations for the side panels a great deal of planning is required in order to minimise unnecessary waste of material.

Although important, the generation of waste non-engineered wood does not have so many economic and environmental implications as the waste of plywood which is a high value added product which has undergone extensive fabrication processes and quality control.

From experience gained so far, no significant defects have been found in the Finnish marine plywood used as it is graded B/BB as per the description below:

> *“Single piece face and back veneer. Face veneers are considered clear and free of defects with a light-uniform colour. Back allows 3-6 colour matched patches, which are oval in shape and egg sized. Inner cores are solid birch single piece veneers”.*

Therefore, due to the manufacturing process and the techniques employed to ensure consistent quality and homogeneity are naturally more labour intensive and more expensive than treating timber.

In addition to this there is the use of formaldehyde adhesives which contribute towards pollution if not disposed of adequately.

Taking these factors into consideration there are various methods which can be employed to reduce waste.

1. The design of the side panels can be modified in such a way as to use the maximum surface of the standard size plywood panel (2440mm x 1220mm) in the most economical way thus reducing waste. However there is an important caveat which is elaborated in point 2
2. To provide visual integrity, the same side of the plywood panel is always orientated to the outside of the bicycle frame. This is not only done to ensure a visual cohesion but also to maintain the structural properties of the side panels (if there are slight variations in the thicknesses of laminations for example). This method implies that the panels are “mirror-paired” as, although the side panels are in most cases symmetrical, the same lamination is on the outer surface. Using this method 8 (eight) side panels can be cut from a single standard sized sheet.
   NOTE: Although attempts are made to keep the surface pattern on both sides of the frame, this is not essential as both sides will never be seen simultaneously.
3. Although the method explained in item 2 ensures visual cohesion, it may not ensure structural homogeneity. The reason for this being that there is no control over the orientation of the fibre direction of the laminations, which has been shown, can lead to different behaviours of the right and left side panels when under load or stress. If the side panels are “mirror-paired” with the same orientation 6 (six) panels can be cut from one standard sheet.
4. The fourth side panel cutting technique employs a different methodology. The technique relies on the cutting being based on **two** standard sized sheets. By using the method described in point 2, only left hand or right hand panels are cut from a single sheet of material. This ensures that from one sheet of left hand side panels there is a “batch” consistency to the outer visual surface. The same applies to the other sheet from which are cut right hand panels. Although the methodology is not complex, care must be taken to ensure structural compatibility between the two sheets regarding the orientation of the fibres. This

is not a significant problem if the sheets are cut together face-to-face and marked on the inner surfaces to ensure matching pairs. By applying this technique 8 (eight) panels can be cut from a single sheet, bearing in mind that 16 (sixteen) panels need to cut for each batch.

In fact, irrespective of which method is used, the process is relatively wasteful with the existing side panel design; therefore a contingency plan to deal with the waste material is desirable.

This plan takes into consideration the following possibilities with regard to the plywood offcuts:

1. Cut plywood into strips and laminate to form the core material (without voids) rather than using hardwoods.
2. Cut plywood into strips and assemble half jointed matrix to create lattice type core box sections (with voids).
3. Create shipping protective elements (dropout spacers, inserts etc.).
4. Create accessories such as carriers, handlebars, accessories etc.

An experimental frame was built using laminated plywood. The laminated material can be used for the majority of the core and is a stable, strong material.

As of yet, no prototypes have been made using voids in the core.

A plan was drawn up to use plywood off-cuts to “pre-set” the frames which were to be shipped. The shipping could take up to 3 weeks and the time was considered sufficient to “pre-set” the frames.

The “pre-set” formers could possibly be designed with a secondary function such as a stand, or a luggage carrier to be fitted on assembly.

Plywood handlebars already exist and are a feasible option for using offcuts, however, taking the potential stresses into consideration it is recommended that such handlebars should have a steel core as a precaution.

There are undoubtedly other uses that the plywood offcuts could be put, but that is beyond the scope of this work at present, as the frames are not yet in a phase of mass production.

7.11. Disposal of plywood waste and offcuts

Regarding the disposal of plywood offcuts which are deemed unusable due their dimensions, there are no specific hazards associated with the process, and the combustion of the offcuts as fuel is an acceptable method of disposal as long as combustion is in a closed environment and over 700 degrees Celsius.

NOTE: See handbook of Finnish plywood reference in Appendices.

7.12. Conclusion: Important factors to be taken into consideration when assessing the viability of a wooden framed bicycle.

Taking into account the quantity of wooden framed bicycles that are encountered nowadays compared a decade ago there can be no doubt that a wooden framed bicycle is a viable alternative to other more traditional forms of frame manufacture using other materials.

However there are a number of factors which need to be taken into consideration:

More specifically it is necessary clearly establish the defining criteria which are applied to the question of viability or feasibility of a bicycle frame which falls outside the conventional criteria.

For example, in order to come to a valid conclusion regarding viability, the bicycles which are the central theme of this research – i.e. the bicycles generically entitled “Xylonbikes” constructed and tested by the author and other contributors the question of feasibility needs to be refined.

Undoubtedly the bicycles fabricated based on the original tenets of a slab-sided frame which is essentially a monocoque made from marine plywood permanently bonded to a solid wooden core are feasible in terms of functionality, purpose for use, structural resistance, mechanically, reliability, and finally albeit the most questionable and subjective factor; aesthetics.

By observing and analysing Xylonbikes, both independently and in comparison with other commercially available and craft built wooden frames, the Xylonbikes bicycle frames appear to be over-engineered to the point that some other characteristics were secondary, such as the overall weight of the bicycle for example.

However, this caution to err on the side of mechanical strength has been found to be vindicated from the engineering point of view as is evidenced in the cases which have been cited in the empirical research regarding structural strength and durability whilst taking into account the factor of time. (I.e. the tests have been carried out on “natural aged frames” rather than through simulations or extrapolations)

During the whole period in which the bicycles have been used, stored, maintained and functioned as “regular” bicycles no defects were encountered that would have compromised the structural or mechanical integrity of the frames, and thus their function.

In fact, the frames in question show no predictable signs of fatigue for possibly the next decade, however, the appearance and finish (varnish) in some cases shows degradation and refurbishment is required where the bicycles have been exposed to unfavourable climatic conditions.

See relevant photographs of localised flaking varnish and discoloured wood.

Having established that the frames were potentially over-engineered, the next logical step would be to undertake a follow-up study in which the frames are value-engineered to the point where the factors of function and longevity coincide with the factors of production methods, structural design, and cost. However, due to the scope of this research it beyond the remit of the current study but may be undertaken in the future when conditions allow.

However, by analysing the performance of the frames and some of the modifications which were made during the course of their development it is possible to predict relatively accurately which areas could be modified without the recourse to complex interventions.

In order to validate some of the proposed alterations, references may be made to other wooden framed bicycles which are currently commercialised and which appear to function satisfactorily. (Note: there is no specific data available in this area other than fabricator’s websites)

NB: the bicycles cited are assumed to be in production commercially and perform and function within the established parameters of a “normal” bicycle.

So as to analyse the possible value-engineering of the frame initially, specific areas of the frame can be broken down for individual analysis in a similar way to what has been done previously as follows:

Bottom Bracket

Taking the bottom bracket first and comparing it with the Renovo diamond frame wooden bicycle, the bottom bracket is fixed to the frame with epoxy resin as shown in the photograph (Figure 229).

Figure 229. Bicycle Bottom Bracket – Renovo Bicycles. Retrieved from http://renovobikes.com/

Compared with the Xylon frame the Renovo features considerably less material around the bottom bracket housing. This therefore could be potentially an area where material may be reduced without compromising the structural strength or performance. In addition there is also the advantage of weight reduction. Taking into consideration the size of the flange on the Xylonbikes bottom bracket halves there would appear to be no reason why the frame in that area should not be reduced to coincide with the outer diameter of the flange.

In order to reduce weight even further, the flange itself could be reduced in thickness, or the technique of drilling lightening holes, which is a well-established procedure, could be applied to the component. However, further tests would need to be carried out to determine the minimum thickness of the flange without casing distortion.

Rear dropouts

As the rear dropouts were conceived and developed for the specific function of being integrated into the plywood chain stays it is unlikely that any modification could be carried out without degrading the structural integrity of the part. However, minimum lightening could be employed by perforations. The manufacturing process designated for the rear dropouts was also chosen due to the simplicity and cost of turning the parts on a centre lathe and also the availability of stock material, i.e. 75mm (3”nominal) round bar.

Head Tube

If the Renovo head tube (Figure 230) is compared to the Xylon version, similarly to the bottom bracket, the Renovo model appears to be significantly less robust, and had the Renovo bicycle been involved in a collision of the magnitude that the Xylon bicycle had been involved in, the resultant damage would have been considerable. However, in the Xylon model there head tube is metal and encased in the frame so it is conceivable that some material may be removed from around the tube without compromising structural strength or performance. The Xylon bicycle which was involved in the accident as quoted previously suffered no significant damage to the head tube or the wooden frame surrounding it.

Figure 230. Renovo Bicycle Head-tube Detail. Retrieved from http://renovobikes.com/

Seat Tube

The standard seat tube solution used in the Xylon frames (not the patented clamp system) is inherently strong as it is basically a typical seat tube design found in any standard diamond frame bicycle.

The variable factor regarding the seat tube is the way in which it is incorporated in the wooden frame, currently on Xylonbikes frames there is a large amount of potentially removable material surrounding the seat tube. However, without empirical data, the amount which could be removed is difficult to predict.

Materials

A great deal of research was undertaken in the selection of materials for the frame and accessories, although there may possibly be opportunities to substitute these materials, this is an area which would require further in-depth study.

Frame design and construction

In conclusion, with regard to frame design, it may be possible to remove material or contour significant areas of the frame in order to reduce weight without adversely affecting strength, however, the benefits derived from less weight must be compared against the increased labour costs involved in the removal of the material or any other associated material preparation such as creating voids in the monocoque frame assembly. However, as has been pointed out elsewhere, the basic concept of the frame design would remain unaltered, and rather than investigating, researching, and proposing radical departures from this formula, any modifications or alterations would not fundamentally alter the original concept.

CONCLUSIONS, RECOMMENDATIONS AND FUTURE INVESTIGATION.

Conclusions (EN)

The objective of assessing the viability of a wooden framed bicycle based on empirical research and testing resulted in the fabrication of bicycles which are robust, reliable, and functional. The parameters and criteria that were established in the study are able to be repeated without significant deviation and may be employed in subsequent fabrication of similar wooden framed bicycles. Existing bicycles fabricated to these criteria are the subject of ongoing long term tests and trials, the results of which will be monitored and further conclusions published when available. However, based on the extrapolation of the findings to date there would appear to be no reason why the bicycles constructed in this manner should not continue to provide useful service for the foreseeable future. The wooden framed bicycle is not intended to replace the conventional bicycle but as an alternative to it.

Within the remit of this study, manufacturing techniques such as pre-forming and lamination have not been covered as these techniques require equipment and expertise which is beyond the scope of most small businesses producing wood and wood derivative based products. In addition the visual aspect of the frames is intended to reflect the techniques employed in its construction and embodies simple fabrication.

The interface components were conceived and designed to be easily produced on basic metal workshop machinery rather than expensive, complicated equipment which would imply investment which would require a level of work, production, and sales to sustain it.

All the proposed techniques and methods used in the construction of the wooden frames developed by Xylonbikes use equipment which is easily encountered in small factories working with wood.

E.g. Spindle moulder (*Tupia*), Pantograph Router (*Tupia Copiadora*), Pillar drill (*Engenho de furar de coluna*) Band saw (*Serra de fita*) Table saw (*Máquina de* *carpintaria universal*) Belt sander (*Lixadeira de cinta*) Lathe (*Torno mecânica*) Spray booth (*Cabine de pintura*)

No specialised skills or training are required other than those already present in small companies making furniture.

Production costs could be reduced by using “off-cuts” and surplus material from other processes in factories already involved in manufacturing wood products.

Frame core material could be of “inferior” quality and visual parts made from high quality material (Soft wood for core and hardwoods for visual parts – not veneers)

The basic frame design is the same for all models and qualities, the difference being in detail (branding) or customising.

Running gear can vary the most with basic/middle/high quality components – exactly the same as conventional bicycles.

Development drawings of frames and components are too numerous to include and only the most relevant have been shown.

Two Xylonbikes bicycles will form part off a bike-share scheme in Marvão scheduled for March 2016.

Note: The following table refers to Xylonbikes only

Table 5: Objectives and results obtained from empirical testing of Xylonbikes wooden framed bicycles.

OBJECTIVES	FULLY ATTAINED	PARTIALLY ATTAINED	NOT ATTAINED
The resultant bicycle frame performs comparably with existing bicycles made from the same or other materials.	The Xylonbikes tested perform equally well as a conventional bicycle.		
The useful life of the bicycle compares favourably or exceed that of existing bicycles.	**Empirical** result – at least 10 years, however see next column.	NOTE: As the useful life of a bicycle can vary depending on its use and maintenance, it is not possible to define these parameters.	
The bicycle can be produced with existing woodworking equipment in small workshops/factories already dedicated to producing traditional wood based products, e.g. furniture etc.	The bicycle frames can be fabricated with the most basic of hand tools and equipment.		
The material used is easily and readily available and does not incur excessive costs such as transport or preparation.		Due to the specific requirements of water resistant engineered wood, sourcing from specialised importers is required.	
The material is be sourced from certified suppliers which are preferably local.		Depends on locality.	
The need for special components is kept to a minimum and if required should be able to be produced locally with basic equipment e.g. metal working lathes etc.	Special components are designed taking into account non specialised basic metalworking facilities.		

The aesthetics of the bicycle are appealing to potential users and should embody the visual and tactile qualities of the materials used in its construction e.g. grain pattern, natural wood colour and “feel”.		The visual and tactile aesthetics of the wooden bicycle frame are unable to be ascertained objectively.	
The bicycle uses easily sourced standard components and does not require specialised techniques for fitting them.	All bicycle parts are standard “off the shelf” items available from cycle parts suppliers.		
The bicycle should **not** be considered as a competitor to traditional bicycles but rather as an eco-conscious **alternative**.	Wooden bicycles are more eco-friendly than metal ones.		
The intended use of the bicycle should not be specific such as Road, MTB, and Randonneur etc. but should be general purpose.	In the case of Xylonbikes, the bicycles are general purpose leisure bicycles with no special characteristics.		
The size of the bicycle frame should cater for adult users not taking into consideration users with specific disabilities.	Not applicable. (Same as conventional bicycles)		
The bicycle should be easy to use.	The bicycle is as easy to use as a conventional bicycle		
The bicycle should be safe to use.	All wooden bicycles tested so far are considered to be as safe as conventional		

	bicycles.		
The bicycle should not require special care.		Wooden frames require more care than metal ones in the short term.	

As would be expected from such an unconventional product as a wooden bicycle the market is limited and data is hard to come by regarding specifications, performance, volume of sales, longevity, and customer feedback. In fact many wooden bicycles fall into the category of “one-off” novelties such as the Cermenati wooden bicycle which was given to Pope Benedict, and Designer “concept” bicycles of little or no regard to extended use or practicality such as the Thonet bent wood bike by Andy Martin. Nevertheless the use of plywood for children’s bicycles is more widespread, the most notable examples being the Likeabike and its “clones”.

However, some wooden bicycle manufactures such as Connor Wood Bicycles, and Renovo produce wooden framed bicycles commercially, but they are based on the diamond frame format so consumer acceptance is probably higher than other types of wooden frames which are a radical departure from this pattern. Furthermore, the bicycles produced by these companies retail from 3,500 euros to 7,000 euros which puts them into an economic category which is outside the reach of the general public.

CONCLUSÕES (PT)

O objectivo de avaliar a viabilidade de uma bicicleta com um quadro de madeira baseado em pesquisa e ensaios empíricos resultou na realização de bicicletas que são robustas, confiáveis e funcionais e se comparam favoravelmente com bicicletas convencionais. Os parâmetros e os critérios estabelecidos no estudo podem ser repetidos sem desvio significativo e podem ser empregues no fabrico de bicicletas semelhantes construídas em madeira. As bicicletas existentes, fabricadas pelo autor com esses critérios, são ainda objecto de provas e ensaios de longa duração, cujos resultados serão monitorados e novas conclusões publicadas quando disponíveis. No entanto, com base na extrapolação dos resultados até à data, não parece existir nenhuma razão para que as bicicletas construídas dessa maneira não devam continuar a prestar um serviço útil para o futuro previsível. É importante realçar que uma bicicleta com um quadro feito em madeira não pretende ser considerada como um substituto para uma bicicleta convencional mas sim, como uma alternativa.

No âmbito deste estudo, as técnicas de fabricação, tais como pré-moldagem e laminação não foram abordadas, já que estas técnicas exigem equipamentos e conhecimentos que estão além do alcance da maioria das pequenas e médias empresas que produzem produtos à base de derivados de madeira e madeira. Além disso, o aspecto visual dos quadros destina-se a reflectir as técnicas utilizadas para a sua construção e incorpora fabricação simples.

Os componentes de “interface” foram concebidos e desenhados para serem facilmente reproduzidos nas máquinas vulgares de metalurgia em vez de equipamento complexo que implicaria investimentos que exigiriam um volume de produção e vendas para sustentá-lo.

Todos os métodos e técnicas utilizados na construção dos quadros de madeira desenvolvidos por Xylonbikes utilizam equipamento que pode ser facilmente encontrado em pequenas fábricas ou oficinas que trabalham com madeira como “*core business*”, por exemplo:

Tupia, Tupia Copiadora, Engenho de furar de Coluna, Serra de Fita, Máquina de Carpintaria Universal, Lixadeira de cinta, Torno (Torno mecânica), Cabine de Pintura.

Nenhumas habilitações específicas ou treino especializado são necessários, além dos já existentes em pequenas empresas que produzem móveis de madeira.

Os custos de produção poderiam ser reduzidos pelo uso de "retalhos" e de matérias excedentes de outros processos em fábricas já envolvidas na fabrico de produtos de madeira.

A madeira do núcleo do quadro poderia ser dum qualidade "inferior" e as partes visuais feitas a partir de material de alta qualidade (e.g. madeira macia para o núcleo e madeiras exóticas para as peças visuais - não folheados)

O Design básico do quadro é o mesmo para todos os modelos e qualidades, sendo a diferença em detalhes (marca/*branding*) ou personalização.

Equipamentos como transmissão, rodas, travões etc. podem variar com a escolha de componentes de alta /média/básica qualidade – tal e qual como nas bicicletas convencionais.

Os desenhos técnicos e esboços de desenvolvimento dos quadros e componentes são demasiado numerosos para incluir neste estudo e somente os mais relevantes foram incluídos.

Como seria de esperar de tal produto não convencional como uma bicicleta de madeira, o mercado é limitado e restrito, e os dados relativos às especificações, desempenho, volume de vendas, longevidade e feedback dos clientes são difíceis de encontrar. Na verdade, muitas bicicletas de madeira enquadram-se na categoria de "*one-offs*" (peças únicas) e novidades, como a bicicleta de madeira feita por Cermenati que foi dada ao Papa Bento XVI, e bicicletas de Designer tipo "conceito" que são pouco práticas com quase nenhuma consideração pelo uso para além das "tendências" tais como a bicicleta de madeira "Thonet" por Andy Martin. No entanto, o uso de contraplacado para bicicletas de crianças é muito mais difundido, os exemplos mais notáveis sendo a LIKEaBIKE e seus "clones".

Mesmo assim, alguns fabricantes de bicicletas de madeira como Connor Wood Bicycles, e Renovo produzem bicicletas em madeira comercialmente, mas estas são baseados nos quadros "*diamond frame*" (tipo rombo), e assim a aceitação do consumidor é provavelmente maior do que com outros tipos dos quadros de madeira que são mais afastados desse padrão e de formatos mais radicais. No entanto, as bicicletas produzidas por essas empresas são vendidas a partir de 3.500 euros até 7.000 euros o que as coloca numa categoria que está fora do alcance da maioria do público em geral.

RECOMMENDATIONS

Regardless of the functional viability of wood and its derivative in the fabrication of bicycle frames a number of factors remained unresolved.

Although the fabrication of prototypes based on the findings of the investigation and research and development led to the fabrication of a functional, reliable, and in terms of performance, successful bicycle which is compatible with conventional bicycles, the scope of the project was limited due to financial constraints.

Although labour and man-hours were unremunerated, a considerable amount of time amounting to thousands of hours was spent in modelling and iterative design methodology to reach a viable conclusion. In addition, financial constraints regarding the procurement of materials and parts led to the adoption of significant compromises in the choice of materials, components, available resources and technical assistance.

The absence of funding, facilities, and sponsorship led to choices having to be made which were not ideal regarding components and materials. This was especially due to the topographical location of Portugal and the Bicycle Market which is relatively restricted when compared with other European countries, especially France, Denmark and Holland where supply and demand is much greater.

Specialised parts which were not available on the market and had to be fabricated required sourcing from engineering suppliers in very small quantities and "one-offs" which implied elevated costs regarding tooling and time.

Nevertheless there are a number of crucial factors which must be adhered to if the bicycle constructed from plywood side panels and a wooden core (viz Xylonbikes) are to be viable alternatives to conventional frames.

The plywood side panels should ideally be cut from the same sheet of material in such a way as they are symmetrical – i.e. "mirror cut". In this way their behaviour due to bending and the resultant stresses and deformation will be predictable and the same for both side panels. This measure is applied, not taking into consideration the economic implications and the subsequent waste of material.

As no reliable trials have been undertaken using a derailleur shifting system, the Xylonbikes pattern of construction should use only single speed hubs, or internally geared hubs. In addition, due to the problems arising from using V brakes on the rear wheel, braking should be by hub brake or coaster brake with adequate anchoring to the frame.

NOTE: No other form of rear wheel braking is recommended by Xylonbikes.

The use of internally geared hubs with coaster brakes excludes the use of chain tensioners and consequently the chainwheel must be of the single type (i.e. not multiple chain rings)

In order to overcome these obstacles a working partnership with interested sponsors and/or or joint projects undertaken with appropriate Universities, Polytechnics or even Government Institutions would be beneficial and reduce financial outlay without compromising results.

RECOMENDAÇÕES (PT)

Existe um número de factores fulcrais que devem ser respeitados para que uma bicicleta construída a partir de painéis laterais de contraplacado marítimo com um núcleo de madeira maciça (Sic - Xylonbikes) podia ser uma alternativa viável aos quadros convencionais.

Os painéis laterais de contraplacado marítimo devem, idealmente, ser cortados a partir do mesmo painel de material, de tal maneira que sejam simétricos - isto é, "corte do espelho". Desta forma, o seu comportamento, resultante da flexão e da deformação, será previsível e o mesmo para ambos os painéis laterais. Contudo, esta medida é aplicada não levando em consideração as implicações económicas e o subsequente desperdício de material.

FUTURE INVESTIGATION

To some extent, and regardless of the results, a project of this type is limited due to the factors previously described. However, based on the research, investigation, and iterate design methodology employed there are significant areas that would benefit from further investigation and research.

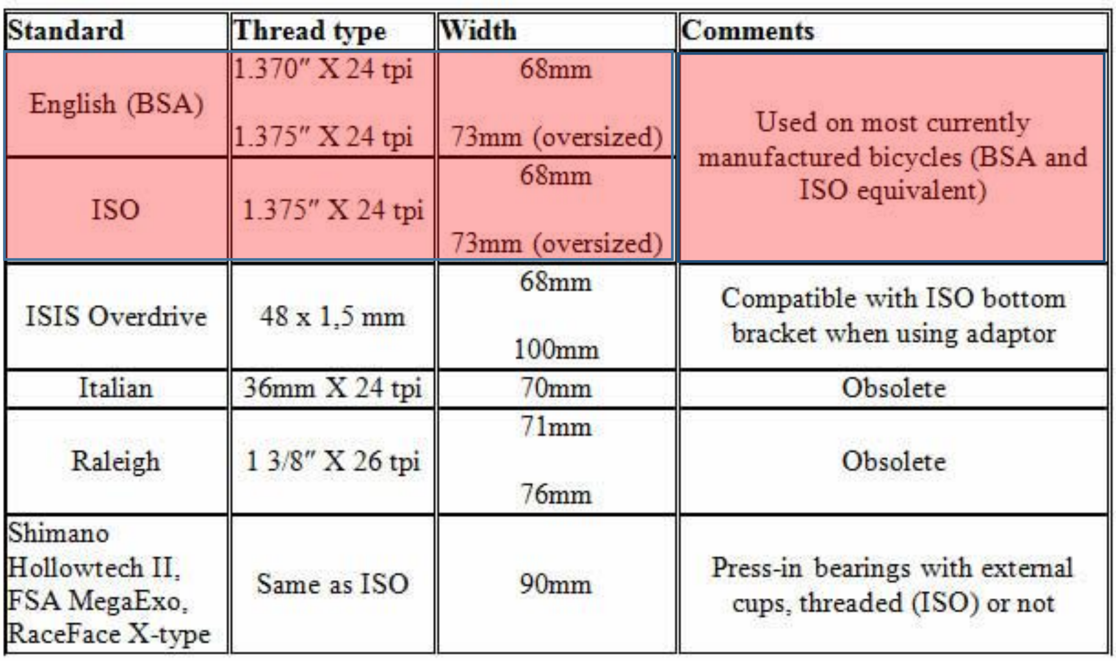
Principally, and in order to investigate fully, the bicycle frames which were fabricated and tested fell into a relatively narrow and restricted sub-type regarding structure, fabrication, and design (i.e. general purpose bicycle constructed with the objective of longevity and reliability and minimum number of specialised parts)

The use of wood as a fabrication material has its constraints and limitations, on the other hand, due to the potential for experimentation and artistic interpretation it is an ideal material for future studies in this particular field.

Appendix i - Bottom bracket dimensions

Note: The English and ISO Bottom Bracket dimensions are virtually interchangeable and due to their widespread use throughout Europe these were the Bottom bracket dimensions that were used for the design and development of the of the prototype wooden bicycle frames.

Table 5. Most commonly used bottom bracket thread specifications



Standard	Thread type	Width	Comments
English (BSA)	1.370″ X 24 tpi 1.375″ X 24 tpi	68mm 73mm (oversized)	Used on most currently manufactured bicycles (BSA and ISO equivalent)
ISO	1.375″ X 24 tpi	68mm 73mm (oversized)	
ISIS Overdrive	48 x 1,5 mm	68mm 100mm	Compatible with ISO bottom bracket when using adaptor
Italian	36mm X 24 tpi	70mm	Obsolete
Raleigh	1 3/8″ X 26 tpi	71mm 76mm	Obsolete
Shimano Hollowtech II, FSA MegaExo, RaceFace X-type	Same as ISO	90mm	Press-in bearings with external cups, threaded (ISO) or not

Appendix ii - Park Tool Bottom Bracket Data

Most bottom bracket shells have an internal thread to accept bottom bracket bearing units from numerous manufacturers. If these threads are not in acceptable condition, they may need preparation. Threads may need realignment, or may have weld splatter from manufacturing that prevents the threading of the bearings. Shells may be out of round due to welding during manufacturing. Additionally, some bearing system benefit from having the faces of the shell square to improve bearing adjustment and bearing longevity. If the shell faces are deformed, and are not parallel to one another, the left and right bearing may not be concentric to one another. Machining the shell face improves concentricity.

The Park Tool Bottom Bracket Tapping and Facing Set BTS-1 will prepare thread and also allow facing of the shell. It consists of two handles, two taps, and a facer. The taps are installed and are left in place as guides for the facer, if facing is desired. Facing is done with hand pressure, which is typically adequate for most bikes.

The Park Tool Facing Set BFS-1 consists of one handle with spring pressure system, two threaded bushings, and one facing cutter. It is intended for facing only. Threaded bushings require a properly threaded bottom bracket. If the threaded bushings do not thread into the shell, the shell must be tapped. The spring pressure system on the BFS-1 allows much greater load to be applied during facing, and will remove material in a shorter time as compared to the hand pressure of the BTS-1 system.

The common thread norm for the bottom bracket-bearing unit is 1.37? x 24 TPI. In some countries outside the USA, this is referred to as 35mm x 24 TPI. This is because the number 1.37" has little meaning, and the term 35mm is common terminology. It has been the habit to name the thread standard by the country of origin, even if the thread is no longer used there. France for example now uses the ISO 1.37" x 24 TPI, but the 35mm x 1mm is called "French" threading. The following is a table of threading used in bicycle bottom brackets:

Table 6. Bottom bracket specification nomenclature

Bottom Bracket Thread Name	Nominal Thread Description	Cup Outside Diameter	Shell Inside Diameter
ISO/English	1.37” x 24 TPI Park Tool tap part number #691-RH (for non-drive) #692-LH (for drive)	34.6-34.9mm Left-hand thread on drive side	33.6-33.9mm
Italian	36mm x 24 TPI Park Tool tap #693 (two required)	35.6-35.9mm Right-hand thread both sides	34.6-34.9mm
French obsolete, rarely seen	35mm x 1mm	34.6-34.9mm Right-hand thread both sides	33.6-33.9mm
Swiss	35mm x 1mm	34.6-34.9mm Left-hand thread drive side	33.6-33.9mm
Whitworth (Obsolete found on older English 3 speeds)	1-3/8" x 26 TPI	34.6-34.9mm Left-hand thread drive side	33.6-33.9mm

Appendix iii - Types of Engineered Wood considered for the construction of a wooden bicycle frame:

Plywood, considered by many to be the original engineered wood, is fabricated from sheets of cross-oriented veneer of determined thicknesses bonded together with suitable adhesives. Alternating the grain direction of the veneers increases or homogenises its strength and stiffness in all directions.

Types of Plywood

There are various types of plywood categorised principally by their applications and uses. Physically, plywood can be categorised by type of wood/woods used, thickness of laminations, number of laminations, and type and quality of veneers. Depending on the applications, the type of glue/bonding agent is also an important factor.

Below is a chart of the relevant standards and projects under the direct responsibility of ISO/TC 89/SC 3 Secretariat

Table 7. Plywood - Relevant standards and projects under the direct responsibility of ISO/TC 89/SC 3 Secretariat

ISO Standard and/or project	
ISO 1096:2014	Plywood -- Classification
ISO 1954:2013	Plywood -- Tolerances on dimensions
ISO 2074:2007	Plywood -- Vocabulary
ISO 2426-1:2000	Plywood -- Classification by surface appearance -- Part 1: General
ISO 2426-2:2000	Plywood -- Classification by surface appearance -- Part 2: Hardwood
ISO 2426-3:2000	Plywood -- Classification by surface appearance -- Part 3: Softwood
ISO 10033-2:2011	Laminated Veneer Lumber (LVL) -- Bonding quality -- Part 1: Test methods
ISO 10033-2:2011	Laminated Veneer Lumber (LVL) -- Bonding quality -- Part 2: Requirements
ISO 12465:2007	Plywood -- Specifications
ISO 12466-1:2007	Plywood -- Bonding quality -- Part 1: Test methods
ISO 12466-1:2007 Amended 1:2013	
ISO 12466-2:2007	Plywood -- Bonding quality -- Part 2: Requirements
ISO 13608:2014	Plywood -- Decorative veneered plywood
ISO 13609:2014	Wood-based panels -- Plywood -- Blockboards and

	battenboards
ISO 18775:2008	Veneers -- Terms and definitions, determination of physical characteristics and tolerances
ISO 18776:2008	Laminated veneer lumber (LVL) -- Specifications
ISO 18776:2008 Amended 1:2013	
ISO 27567:2009	Laminated veneer lumber -- Measurement of dimensions and shape -- Method of test
ISO 18775:2008	Veneers -- Terms and definitions, determination of physical characteristics and tolerances
ISO 18776:2008	Laminated veneer lumber (LVL) – Specifications
ISO 18776:2008/Amd 1:2013	
ISO 27567:2009	Laminated veneer lumber -- Measurement of dimensions and shape -- Method of test

Abstract from BS 1088 – Marine Plywood

BS 1088 is the British Standard specification for marine plywood that applies to plywood produced with untreated tropical hardwood veneers that have a set level of resistance to fungal attack. The plies are bonded with Weather Boil Proof (WBP) glue.

WBP Glue Line: BS 1088 plywood must use an adhesive which has been proven to be highly resistant to weather, micro-organisms, cold and boiling water, steam and dry heat.

Face Veneers: Face veneers must present a solid surface that is free from open defects. Face veneers must be free of knots other than "sound pin" knots, of which there shall be no more than six (6) in any area of one (1) square foot, and there can be no more than an average of two (2) such knots per square foot area over the entire surface of the plywood sheet. The veneers must be “reasonably” free from irregular grain. The use of edge joints is limited, and end joints are not allowed.

Core Veneers: Core veneers have the same basic requirements as face veneers, except that small splits are allowed and there is no limit on the number of pin knots or edge joints. However, end joints are not permitted.

Limits of Manufacturing Defects: Defective bonds, pleats and overlaps, and gaps in faces are not permitted. Occasional gaps may be repaired using veneer inserts bonded with the correct adhesive.

Moisture Content: BS 1088 plywood must have a moisture content of between 6% and 14% when it leaves the factory.

Finishing: Boards will be sanded on both sides equally.

Length & Width: The length or width of a board produced as a standard size shall not be less than the specified size nor more than 6.3 mm (0.25") greater than the specified size.

Squareness: The lengths of the diagonals of a board shall not differ by more than 0.25% of the length of the diagonal.

Thickness Tolerances: Tolerances vary as follows:

4 mm +.02/-0.6 ; 6 mm +.04/-0.65 ; 9 mm +.06/-0.75 ; 12 mm +.09/-0.82; 15 mm +.1/-0.9 ; 18 mm +.12/-0.98 ; 22 mm +.16/-1.08 ; 25 mm +1.8/-1.16

(From the above it may be assumed that nominal 6 mm thick material may vary from between thicknesses of 5.35 mm to 6.04 mm.

Face Veneer thickness: For any three-ply construction which applies to 3 and 4 mm thick material, each face veneer shall be not thinner than 1/8 (one eighth) of the total thickness of veneers assembled dry. Since the dry thicknesses of the boards are 3.6mm and 4.6mm respectively, it may be assumed that for these thicknesses only, the face veneers will be as follows:

3.6 mm dry x 12.5% (1/8) = 0.45 mm 4.6 mm dry x 12.5% (1/8) = 0.575 mm

Multi-Ply Construction: This applies to boards thicker than 4.8 mm (3/16") Three sixteenths of an inch.

Each face veneer shall be a minimum of 1.3 mm and not thicker than 3.8 mm.

Each core veneer shall be no thicker than 4.8 mm

Thicknesses and weights (Material used in project shown highlighted)

Thicknesses and tolerances fulfil the requirements of EN 315 (Plywood - Tolerances for dimensions) and are in part stricter.

Table 8. Plywood – Nominal dimensions of plywood (9mm thick material used for Xylonbikes highlighted in yellow)

Nominal thickness (mm)	Number of plies	Min. thickness (mm)	Max. thickness (mm)	Weight (kg/m^2) abt
6.5	5	6.1	6.9	4.4
9	7	8.8	9.5	6.1
12	9	11.5	12.5	8.2
15	11	14.3	15.3	10.2
18	13	17.1	18.1	12.2
21	15	20.0	20.9	14.3
24	17	22.9	23.7	16.3
27	19	25.2	26.8	18.4

Abstracts from Finnish Plywood Handbook

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HANDBOOK OF FINNISH PLYWOOD
FINNISH PLYWOOD**

1.1 Wood, the most important raw material

The most important raw material for plywood is a renewable natural resource - wood. Finnish birch (Betula pendula, hardwood) and spruce (Picea abies, softwood) are the most important raw materials in the plywood process. Trees grow slowly in Finland’s climate and thus the wood it produces is close-grained and of consistent high quality. Birch is of uniform consistency and it has excellent strength, peeling and gluing properties. Spruce is a less dense and more economical wood species for spruce throughout plywood and in special constructions of mixed birch and spruce veneers.

1.2 Glue

The vast majority of Finnish plywood is of cross-banded construction bonded with phenol resin adhesive. Normal gluing quality is suitable for use in exterior (service class 3) situations when properly protected. A small part of Finnish cross-banded plywood production is bonded with urea formaldehyde glue. These boards are suitable for use in dry (service class 1) or humid (service class 2) conditions. The phenol formaldehyde gluing fulfils the requirements of EN 314-2 class 3 exterior. The gluing quality may still be referred to earlier national classification such as DIN 68705:

BFU 100 or BS 6566: WBP. Finnish phenol formaldehyde glued plywood products exhibit very low levels of formaldehyde emissions. Urea formaldehyde glued products have slightly higher values but they still fulfil the requirements of the most demanding European standards relating to formaldehyde emission and content.

HANDBOOK OF FINNISH PLYWOOD

5.5 Disposal of plywood

The service life of plywood is generally long, and there are several methods of disposal.

It should be noted, however, that the instructions for disposal of panels may vary in different countries depending on current legislation.

Recycling is the preferred way to dispose of most products. Used plywood could be utilised in some other application. This recycling must not burden the environment more than any other method of disposal, nor should it be more expensive than using a new product.

If the fuel value of plywood can be utilised, the burning of plywood is equivalent to recycling. At a combustion temperature of at least +700°C, plywoods uncoated, coated with phenol or melamine resin films or with commonly used paints, do not produce any more hazardous combustion residues than those produced by wood. It is not recommended to burn plywood in an open fire, because burning at a lower temperature releases more harmful combustion residues. When plywood is burnt, its higher density compared with unprocessed wood means a higher fuel value is achieved.

Almost all plywood can be composted. Panels have to be chipped and the long duration of the composting process has to be taken into consideration.

Nearly all plywood products can be taken to the refuse dump. It must be checked if other substances contained in or on the plywood can be taken to the dump. Plywood products rot very slowly.

Standard Finnish plywoods contain nothing classified as hazardous waste.

Appendix iv - Steering bearing cup nomenclature and dimensions.

Note: Although most of the measurements were taken empirically, the Park Tools data sheet was consulted to confirm the findings.

Table 9. Steering bearing cup nomenclature and dimensions. Park Tools. Source: Park Tools

Frame Headtube ID	Bearing or Press OD	Interference of Slip Fit	Description	SHIS term
29.8mm to 29.9mm	30.0mm	Interference fit	Conventional JIS standard for 1-inch steering column, threaded and threadless	EC29
30.0mm to 30.1mm	30.2mm	Interference fit	Conventional "Euro" standard for 1-inch steering column, conventional threaded and threadless Interference fit	EC30
33.8mm to 33.9mm	34.0mm	Interference fit	Conventional 1-1/8 inch for threadless and threaded Interference fit	EC34
36.8mm to 36.9mm	37mm	Interference fit	Conventional 1-1/4 inch for threaded and threadless	EC37
38.15mm to 38.14	38mm	Slip fit	Integrated-angular contact 1-inch steering column 36 x 36 degree contact	IS38
41.05 to 41.1mm	41mm	Slip fit	Integrated-angular contact 1-1/8 inch steering column 36 x 45 degree contact "IS" or "Cane Creek® types	IS41
41.3mm	41.4mm	Interference fit	Low Profile 1-1/8" steering column, with headtube outside diameter nominally 47mm Frame has no angular contact.	ZS41
41.55 to 41.6mm	41.5mm	Slip fit	Integrated-angular contact 36 x36 degree contact TH Industries® ED-36 type	Obsolete
41.85 to 41.9mm	41.8mm	Slip fit	Integrated-angular contact 45 x 45 degree contact Campagnolo® Hiddenset standard	IS42
41.9 to 42mm	42mm	Interference fit	Microtech® Integrated- non-angular contact Frame has no angular contact.	Obsolete

43.9mm	44mm	Interference fit	Low Profile for 1-1/8 inch steering column Cartridge bearing types use slip fit into pressed cup.	ZS44
44.05mm to 44.1mm	44mm	Slip fit	Integrated-angular contact 1-1/8" steering column 36 x 36 degree contact	Obsolete
47.05-47.1	47	Slip fit	Integrated lower only	IS47
49.6mm	49.7mm	Interference fit	Onepointfive® Standard Oversized threadless type	EC49 & ZS49
52.1-52.15	52mm	Slip fit	Integrated lower	IS52
55.90-55.95	56mm	Press fit	Internal and conventional headset	ZS56 & EC56

Appendix v - Tyre and Wheel Sizing

Note: In order to maintain quality and standardise the wheel types used in the fabrication of wooden bicycle frames the ETRTO nomenclature was used to confirm compatibility of common sizes.

Table 10. ETRTO Tyre and wheel sizes – Tyre and wheel sizes used in the project shown highlighted

Large Tire Sizes 28-inch to 26-inch:				**Rim Sizes:**		**Typical Bike Type:**
ISO/ETRTO Metric	French Metric	Decimal Inches	Fractional Inches	Bead Seat Circumference	Country Orig. Rim specs:	
32-647	700	-	28x1-1/4	2032	Britain EA2 Holland	roadster
44-642 37-642	700A	-	28x1-3/4 28x1-3/8	2016	Britain F5, EA4, E4	roadster
40-635 28-635	700B	-	28x1-5/8 28x1-1/2	1994	Britain F10, F25.0, EA4	rod-brake roadster
32-631	-	-	27x1-1/4	1982	Sweden	road
32-630 28-630 20-630	-	-	27x1-3/8 27x1-1/4 27x1	1978	Britain K2, K25.0, EA25.0	touring, road
44-623	-	-	28x1-5/8	1958	Sweden	roadster
42-622 38-622 35-622 32-622 30-622	700C	-	28x1-3/4	1955	-	mountain hybrid Russian roadster tandem
28-622 25-622 23-622 20-622 18-622	700C	-	28x1-3/8 28x1	1955	-	touring road time trial track
40-609	650-32	-	27x1-1/2	1913	Germany	roadster
40-607	-	-	26x1-1/2	1906	America	roadster
35-599 32-599	-	26x1.375 26x1.25	-	1880	America	vintage lightweight

37-597 32-597	650	-	26x1-1/4x1-3/8 26x1-1/4	1876	America Schwinn S-5, S-6	roadster, touring Schwinn lightweight
40-590 37-590	650A	-	26x1-1/2 26x1-3/8	1854	Britain F.4, E.3, EA.3, E23.0, EA23.0, R23.0	roadster, road
40-583	700D	26x1.50	-	1845	-	touring rare GT mtb
47-585 40-585	-	-	26x1-3/4 26x1-1/2	1837	Sweden	roadster
47-584 40-584 32-584	650B	-	26x1-5/8 26x1-1/2 26x1-3/8	1835	France Schwinn S-4 Britain F9	touring, tandem rare Raleigh, Schwinn mtb
47-571	650C	-	26x1-5/8 26x1-3/4	1794	America Schwinn S-7 Britain F9	cruiser, Schwinn middleweight
23-571 20-571	650C	-	26x1 26x3/4	1794	-	time trial, triathlon, small road
62-561	-	-	26x2.25 25x1-3/8	1764	Sweden	roadster
57-559 54-559 50-559 47-559 40-559 38-559 32-559 28-559 25-599	650x45	26x2.125 26x2.0 26x1.90 26x1.75 26x1.60 26x1.50 26x1.40 26x1.25 26x1	-	1755	-	balloon cruiser, mountain middleweight cruiser, mountain bike touring, tandem road

Small Tire Sizes 25-inch to 7-inch:				**Rim Sizes:**		**Bike Types:**
ISO-ETRTO metric	French metric	Decimal inches	Fractional inches	Bead Seat Circumf.	Country Orig. Rim specs:	
37-547	-	-	24x1-3/8	1715	Schwinn	juvenile

32-547			24x1-1/4		S-5, S-6 Britain K.1, E1, EA1	lightweight, Schwinn
37-541 32-541	600A	-	24x1-3/8 24x1	1700	Britain E.5 Holland	juvenile, small road, wheelchair
40-540 32-540	600x35A	-	24x1-3/8 24x1-1/2	1695	Britain E.5, F.3, EA21.0, F21.0, R21.0	juvenile roadster, small road, Raleigh
40-534 38-534	600B	-	24x1-1/2	1676	Britain F8 Holland France	transport
37-533	-	-	26x1-1/2	-	Russia	small road, folding
40-531	-	-	24x1-1/2	1667	Sweden	small roadster
47-521	-	-	24x1-3/4	1635	America Schwinn S-7 Britain	small cruiser
47-520	-	-	24x1-3/4	1633	America	juvenile roadster
20-520 25-520	-	-	24x1-1/8 24x1	1633	-	time trial, triathlon, small road, Terry front
32-508	550x32	-	22x1-1/4	1595	Dutch	juvenile roadster
57-507 50-507 47-507 40-507	600x45	24x2.125 24x1.90 24x1.75 24x1.50	24x2x1-3/4	1592	Schwinn S-2	juvenile mtb, cruiser
50-503	-	-	24x2	1579	Sweden	transport
37-501 32-501	-	-	22x1-3/8 22x1-1/4	1575	Britain F.2, E.6, EA19.5 Italy 550x32A	juvenile roadster
37-498	-	-	22x1-3/8x1-1/4	1563	Germany	folding
37-490	550A	-	22x1-3/8A	1539	France	juvenile road, folding
37-489	-	-	22x1-3/8	1535	Italy 550A Holland 550A	small-wheel roadster
44-484	550B	-	22x1-5/8x1-1/2	1520	France	transport
40-482	-	-	22x1-1/2	1515	Holland 550B	small-wheel roadster
47-470	550C	-	22x1-3/4	1475	France	juvenile roadster
57-457 44-457	-	22x2.125 22x1.75	-	1435	America	juvenile
37-451	-	-	20x1-3/8	1416	Schwinn S-5,	juvenile

32-451 28-451			20x1-1/4 20x1-1/8		S-6 Italy 500x35A Britain E.5J, EA18.0, R18.0, EB18.0	lightweight, bmx racing, recumbent
32-445	-	-	20x1-1/4	-	-	juvenile
-	-	20x1.375 20x1.25	-	-	America	juvenile middleweight
37-440	500A	-	20x1-3/8x1-1/4	1382	France	juvenile, folding
37-438	-	-	20x1-1/2 20x1-3/8	1375	Italy Holland 500x35A	-
40-432	-	-	20x1-1/2	1356	Holland 500x38B	-
54-428 40-428	- 428x40	-	20x2 20x1-5/8x1-1/2	1345	Sweden France	small-wheel roadster
47-419	-	-	20x1-3/4	1314	Schwinn S-7	juvenile, Schwinn
57-406 52-406 47-406 44-406	500x50	20x2.125 20x1.95 20x1.75 20x1.50	20x1-3/4	1274	France Holland America	bmx, juvenile, folding, Moulton APB, recumbent, trailer
54-400 40-400	-	-	20x2 18x1-3/8 Italy 18x1-1/4	1257	Britain E.4J, F.4J Italy 450x32A	small-wheel roadster, folding
40-390 37-390	450A	-	18x1-3/8 18x1-1/4	1225	France	juvenile
32-369	-	-	17x1-1/4 16x1-1/4	1169	Britain	Moulton AM, recumbent
54-355 47-355 44-355	450x45	18x2.125 18x1.75 18x1.50	-	1115	Germany America France	folding juvenile
35-349	-	-	16x1-3/8 16x1-1/4	1097	Britain E.3J, EA14.0, EB14.0 Italy 400x32A	juvenile, folding, early Moulton
37-340 32-340	400A	-	16x1-1/2 16x1-3/8	1069	France	juvenile
37-337	-	-	16x1-3/8A	1058	-	folding Birdy
37-335	-	-	16x1-3/8	738	Poland	juvenile
44-317	-	-	16x1-3/4	996	Schwinn S-7	juvenile, Schwinn
54-305 44-305	-	16x2.125 16x1.75	-	957	America	juvenile, small bmx, folder,

						recumbent, trailer
37-298 32-298	-	-	14x1-3/8 14x1-1/4	937	Britain E2J, F2J, EA11.7 Italy 350x32A	folding, juvenile
37-288	350A	-	-	-	French 350A	folding, juvenile
62-203 57-203	-	-	12-1/2x2 12-1/2x1.75	638	Italy France	juvenile, scooters
44-194 32-194	-	-	10x1-5/8 10x1-1/4	609	- Italy	juvenile
54-152	-	-	10x2	-	America	wheelchair
32-137	-	-	8x1-1/4	-	America	wheelchair
54-110	-	-	8x1-3/4 8x1-1/2	346	-	-
47-94	200x47	-	7x1-3/4	292	Germany	juvenile

Appendix vi - E-bike battery specifications

The E-Bike project required the use of a standard battery pack. The specifications are shown below.

E-bike lithium battery with alloy shell case for rack and controller box for controller

1. Voltage: 36V
2. Capacity: 10AH
3. Charging voltage: 43.8V
4. Discharge protection voltage: 24.0V
5. Overcharge protection voltage: 46.8V
6. Continuous discharge current: 15A
7. Max discharge current: 30A
8. Short circuit protection
9. Lifecycle: 2000 times
10. Dimensions: 407x150x67mm
11. Attached controller box dimension: 145x78x45mm
12. Sliding board and fixing parts will be sent together with the battery

Alloy Charger information

1. Charging voltage: 43.8V
2. Charging current: 2.5A
3. AC input: 220~240V or 90~110V depending on your demand

Packing list:

1. An alloy shell battery 36V10AH with alloy case including PCM-12S-15/30A
2. Sliding board and fixing parts for the case
3. An alloy shell charger, 43.8V2.5A.

Appendix vii - Rattan Cane

From the research regarding the early use of bent wood and bamboo as alternative frame building materials, the potential of Rattan Cane presented itself as a possible alternative. Technical and quality specifications are shown below.

Cane - Rattan – Wicker

Cane - Rattan – Wicker - A Primer to understanding this unique Timber Cane (Rattan):

The use of Cane in home furnishings is not new. It dates back to the 1700s in Asia and the Philippines where cane was used to craft many household articles.

The Victorian era saw an increase popularity of Wicker and Rattan in the 1800s, then in America in the 1920’s and South Africa in the 1950’s. South Africans popularised cane furniture as it was cheaply made and used outdoors on verandas. Nowadays, innovative designs and combinations of wood, wrought iron and leather with Cane make it an attractive option in dining rooms, bedrooms, lounges etc.

Characteristics

Cane is a vine that grows in the mountain regions of the Mallaca Straights and Philippines where the rainfall normally exceeds 1000 mm annually. It grows horizontally in tangles, similar to ivy, but is solid, and not hollow like bamboo. Cane is pliable and easily bent and curved (with the aid of steam ovens) to form many shapes for frames and armatures. Although highly flexible, it is also resilient and although Cane is as strong as wood for furniture making, it is much lighter in weight and will withstand daily use and abuse.

Although the terms “wicker” and cane (rattan) are used interchangeably, they are not the same. Wicker, which means woven, is a by-product of Cane (rattan); hence all Wicker is Cane, but all Cane is not Wicker. Wicker is a term for the smaller stems from the cane plant and is obtained during the harvesting and production period.

Harvesting

Cane cutters are experienced workers and control the cutting of cane for harvesting which takes place when the vine is six to fifteen years old. Cane has become scarce due to deforestation and fines applied for cutting immature cane have resulted in the cutters moving deeper into the jungle. When knots on the cane are far apart this indicates good rain, whereas close knots are as a result of a dry season. If the vines are immature, creasing will take place. At this point, stems can be several metres long with a growth path through every part of the jungle terrain that will not permit use of vehicles and other machinery. As the vines are removed, they are cut into 7m lengths, tied into bundles of usually 50 poles and carried on the backs of the workers, sometimes several miles to local furniture factories or Export Agents.

Natural Manau: Sizing 20/22mm – 32/34mm diameters

Natural Manau cane is the most popular of all the natural canes as it is the easiest to bend.

Natural Batang: Sizing 20/22mm – 32/34mm diameters.

Natural Batang is exactly the same as Natural Manau but not as easy to bend and therefore preferred in straight work.

Natural Tohiti: Sizing 14/16mm – 18/20mm diameters.

Natural Tohiti is the same as all the above natural canes except that it comes in smaller diameters.

Weaving Cane: Sizing 2mm – 15mm diameters. Centre Cane is as the name indicates, the centre of the cane. The raw cane is forced through a stationary cutter and the solid centre of the cane is cut into round pieces of varying millimetre sizes depending on the size of the cutter used.

White Poeleot: Sizing 2/3mm, 2/4mm, 3/6mm diameter White Poeleot is a natural raw material with its skin on. White Poeleot is very popular as a weaving cane through the weaving industry, and is therefore very strong.

Kooboo Basket: Sizing 3/6mm. 4/8mm. 8/11mm. 10/15mm diameter. Kooboo is used mainly in the manufacture of dog baskets, it is extremely strong and very supple.

Rattan Peel: Sizing 5/6mm. 6/7mm diameter. Rattan Peel is referred to as Wrapping and is cut from the skin of the Kooboo Basket. Rattan Peel is used for the wrapping of the joints in cane furniture.

Flat Flat: Sizing 5/6mm. 8mm. 10mm. 16mm (width) x 1mm thick. Flat Flat has all the characteristics of centre canes except its profile is “flat flat” and as the name suggests it is a flat strip of centre cane. This is ideally used for filling in a basket because the weaving goes quickly and it is very light.

Seagrass Cord: Sizing 3/4mm diameter. Seagrass cord is very popular in the manufacturing of lampshades and basketware. Seagrass has a lovely natural appearance and also has a delightful natural grass odour.

Webbing: Sizes ½ inch x 18 inch (45.72cm), ½ inch x 24 inch (60.96cm) x 15-metre roll. Octagonal mesh webbing (because there are 8 sides to each hole). This is the standard traditional webbing used in the seats of antique chairs and for the paneling of the sides of furniture. It is actually made from chair cane 2.5mm. This webbing has its skin on.

Processing

the poles are stripped of bark, boiled in large vessels with a mixture of Palm and Crude oil to eliminate the jungle green colour, fumigated with methol bromide to kill insects as well as to remove moisture and then stood on end in teepee style to dry naturally. The tough outer skin is then carefully peeled away. This skin becomes peel cane, known as Wrapping, which is used to bind the joints of the furniture frame. Wrapping, which is an extremely tough material is also woven to make cane seats and backs (known as Webbing). Next, the cured and stripped poles are sanded, and cut into required lengths for export.

Canes used for furniture and basketware:

Polished Pole Cane: Sizing 10/12mm – 32/34mm diameters. Polished Pole Cane is the description given to all canes that have had their outer skin removed and the cane has then gone through a sanding process to produce a smooth finish. As the skin has been removed from the cane, the cane will now absorb a stain and this cane is therefore ideal for using in furniture that is going to be stained a darker colour. There are three different species of cane in this category, namely Batang, Manau and Tohiti. There is very little difference between the three canes and all types are interchangeable.

Bending

The cut Cane pieces are put into a steam oven that makes them temporarily flexible. Then the poles are shaped into a required furniture part around a handmade jig

Assembly

The formed Cane pieces are then assembled into a frame using screws and glue. When cool, the poles retain their shape. The advantage is that it is accurate and economical for huge quantities of poles. The disadvantage is that it is very labour intensive.

Wrapping, stopping and filling

The frame is then wrapped with Wrapping covering the joints for aesthetic appeal as well as further strengthening the frame. After wrapping, the frame goes to the Stopping division, where screws and or nails are covered for an all over smooth effect. Once the frame has been stopped, it goes to the Filling section where the frame is further Filled with supports making the frame steadfast for support and durability.

Weaving

The frame then goes to the Weaving division where specialist craftsmen weave the structure. The craftsmen achieve this level after a minimum of 10 years' experience.

Finishing

Natural Finish: This finish is a clear lacquer used on Cane that still has its bark.

Refined Finish: Centrecore Canes have had the bark removed. Centrecore is then sanded, lacquer applied and sanded again for a more refined finish.

Stained Finish: Like wood furniture, Cane is most often given a finish using stain. 15 different spirit dye colour stains are used. This means that they will not obscure the grain of Cane but will enhance it.

Appendix viii - Supermarket bicycles and Value Engineering.

Most major supermarkets sell bicycles. In the majority, the bicycles are produced in the Far East and shipped to Europe and the United States in containers. In some cases the supermarket chain or retailer will have their own brand name. “Team” is such a brand name for the “Continent” supermarket chain in Portugal. Other names such as “Treek” are used as they are similar to well-known brands such as Trek.

Generally the “supermarket” or “Walmart” bicycle is of a very low quality. This has led to them often being referred to as “Bike Shaped Objects” or “BSO” i.e. it looks like a bicycle but does not perform within the established paradigm, by people with some bicycle knowledge.

A number of factors contribute to this phenomenon, mainly the manufacture of parts which have been “Value Engineered” to the point where their function is compromised.

Some examples are discussed below:

- V-Brakes
- Front forks
- Pedals
- Derailleur
- Brake levers

V-Brakes: Initially V-Brake arms were made from die cast aluminium, then to economise on material they were made from plastic with steel inserts, another way of economising on material was to make them in stamped steel. Both of these alternatives can lead to deflection when pressure is applied during hard braking resulting in diminished pressure at the wheel rim.

Front forks: Initially made from tapered tubes with brazed or welded dropouts, value engineered examples are made from parallel tube with the dropouts formed by stamping and deformation of the tubes and slotting with the result that the fastening nuts do not seat correctly leading to distorted front wheel axle.

Pedals: Initially fabricated with cones and steel ball bearings, pedals have been produced more cheaply by fabricating from plastic with no bearings other than the contact with the plastic and the steel shaft. In addition the quality control of tread tolerances is poor leading to damaged crank arms threads.

Derailleur: Derailleurs have been the subject of ongoing value engineering, where due to poor tolerances and steel stampings and plastic being used instead of steel or aluminium gear changing is compromised.

> *Simplex more or less single-handedly created the mass market for derailleurs, and in the mid 1950's was as dominant as Shimano is today. Then a single decision, to shift from metal to plastic, set them on the road from triumph to disaster.*
>
> http://www.disraeligears.co.uk/Site/Introduction_to_gears.html

Brake levers: designed to withstand the required pressure applied, brake levers were first made from steel, and then as a lighter alternative, from die cast aluminium. With the adoption of plastics for some components the brake lever was redesigned and moulded in plastic with the result that it is pliable, prone to fatigue, and stress failures.

Add to the above, poor quality control, inferior materials, and poor build quality, supermarket bicycles have a very short lifespan usually due to their impeded function which often leaves them to be abandoned or discarded soon after purchse.

Even if the defects are rectified by the fitting of aftermarket parts the overall cost of the bicycle will most probably be doubled.

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