

CDIO DESIGN CHALLENGE

ME519 MEng Group Project

Carlos Lopez Ayesta, Dominic Johnston, David Mann,
Andrew Martin, Aaron Thomson

Supervisor: Prof J. Boyle

Date: 17/03/17

<http://bikecentricstudios.wixsite.com/bikecentricstudios>



Acknowledgments

Bike Centric Studios would like to recognise the contribution of a number of individuals, without whom this project would not have been successfully completed. Firstly, BCS would like to thank Professor James Boyle, who acted as supervisor for the project, for his assistance and input when required. Secondly, Mr Drew Irvine, Mr Chris Cameron and their team of technicians, Mr Steven Black and Mr Dominic Smith. Without their assistance, an operational prototype of the final design would not have been built. Thirdly, to all the staff at The Bike Station, Glasgow for assistance with bicycle parts, their technical knowledge and their support when BCS approached them for sponsorship.

Executive Summary

The aim of this project was to conceive, design, implement and operate a folding bicycle in accordance with the CDIO Initiative. In order to successfully complete this task, key design parameters had to be taken into consideration, primarily the dimensions of the prototype, its weight and compliance with regulation, especially regarding safe usage. The project was divided so as to mirror the key areas of a business, the aim being that each of the five members would have a key role at the principal stages of the project. Three members were assigned a lead role in research and development, design engineering and manufacturing engineering, whilst the remaining two members took on the roles of Chief Executive Officer and Chief Financial Officer/ Communications Director. The group conceived a number of concepts for the prototype, which were then used to successfully develop a final design using engineering techniques learned throughout our degree courses. The final design was then taken to the manufacturing stage and a final prototype assembled, with testing to be completed before the CDIO Design Challenge Competition in May. A three-year business plan was created, demonstrating that BCS would be able to operate as a limited company, producing and selling its exciting new entrant into the folding bicycle market, the Urban Rider. In doing so BCS participated in the CDIO Design Challenge and covered the four pillars of the initiative; conceiving, designing, implementing and operating.

Table of Contents

| | |
|---------------------------------------|-----------|
| Acknowledgments | 1 |
| Executive Summary | 2 |
| Table of Contents | 3 |
| 1.0 Introduction | 6 |
| 2.0 Statement of Work | 7 |
| 3.0 Bike Centric Studios | 11 |
| 3.1 Roles..... | 11 |
| 4.0 Project Plan | 13 |
| 5.0 Risk Management | 15 |
| 5.1 Risk Mitigation Planning..... | 15 |
| 5.2 Major Risks..... | 17 |
| 5.3 Finances..... | 19 |
| 5.4 Sponsorship..... | 19 |
| 6.0 Market Research | 21 |
| 6.1 UK Cycle Economy..... | 21 |
| 6.2 Market Competitors..... | 21 |
| 6.3 Pricing..... | 22 |
| 6.4 Product Testing..... | 22 |
| 6.5 Folding Mechanisms..... | 23 |
| 6.6 Consumer Survey..... | 25 |
| 6.7 Bicycles & Public Transport..... | 25 |
| 6.8 Patents..... | 26 |
| 6.9 Standards..... | 27 |
| 6.10 Geometry..... | 28 |
| 6.11 Materials..... | 30 |
| 7.0 Design Process | 33 |
| 7.1 Specification..... | 34 |
| 7.2 Concept Design..... | 34 |
| 8.0 Detailed Design | 37 |
| 8.1 Rear Triangle..... | 37 |
| 8.2 Top tube assembly..... | 39 |
| 8.3 Materials..... | 39 |
| 8.4 FEA- Frame..... | 40 |
| 8.5 Drivetrain..... | 44 |
| 8.6 Steering System..... | 45 |
| 8.7 Braking System..... | 47 |
| 8.8 Seat Tube..... | 48 |

| | |
|--|-----------|
| 9.0 Final Design | 53 |
| 10.0 Parts Procurement..... | 55 |
| 11.0 Manufacturing Process | 56 |
| 11.1 Construction of the Top Tube Assembly..... | 56 |
| 11.2 Back Triangle | 57 |
| 11.3 Hinges | 59 |
| 11.4 Handlebars | 59 |
| 11.5 Seat post | 60 |
| 11.6 Head Tube | 61 |
| 11.7 Steering column..... | 61 |
| 11.8 Final Assembly..... | 62 |
| 12.0 Testing..... | 64 |
| 13.0 Final Product | 65 |
| 14.0 Business Plan | 67 |
| 15.0 BCS Website | 68 |
| 15.1 Function of the Website..... | 68 |
| 15.2 Structure | 68 |
| 15.3 Building the Website | 69 |
| 16.0 BCS Evaluation- Team | 72 |
| 16.1 Semester 1..... | 72 |
| 16.2 Semester 2..... | 72 |
| 17.0 BCS Evaluation- Risk Management..... | 75 |
| 17.1 Major Risks..... | 75 |
| 17.2 Unidentified Risks..... | 75 |
| 18.0 BCS Evaluation- Finances | 77 |
| 19.0 BCS Evaluation- Manufacturing..... | 79 |
| 19.1 Top Tube | 79 |
| 19.2 Rear Triangle | 79 |
| 19.3 Hinges | 80 |
| 19.4 Handle Bars | 80 |
| 19.5 Head tube..... | 81 |
| 19.6 Steering column..... | 82 |
| 19.7 Final Assembly..... | 83 |
| 19.8 Overall Manufacture Evaluation | 84 |
| 20.0 Adherence to Contract..... | 86 |
| 21.0 Conclusion | 87 |
| 22.0 References..... | 89 |
| <i>Appendix A: Project Plan</i> | 92 |

| | |
|--|------------|
| <i>Appendix B: Contract</i> | 94 |
| <i>Appendix D: Consumer Survey</i> | 98 |
| <i>Appendix E: Product Design Specification</i> | 102 |
| <i>Appendix F: Initial Design Concepts</i> | 104 |
| <i>Appendix G: Concept Convergence Matrices</i> | 108 |
| <i>Appendix H: Final Design Concepts</i> | 110 |
| <i>Appendix I: Hinge Concept Drawings</i> | 115 |
| <i>Appendix J: Handlebar Concepts</i> | 116 |
| <i>Appendix K: Drawings</i> | 117 |
| <i>Appendix L: BCS Business Plan</i> | 133 |

1.0 Introduction

Across the world, cities are becoming increasingly polluted with toxic fumes caused by the excessive numbers of vehicles on their roads. Many commuters are undertaking journeys alone in cars designed for five people. Governments and cities are trying to combat this with congestion charges, policies to encourage the use of public transport, car sharing, and car pool lanes. Recently, the advent of cycling lanes has brought cycling to the public's attention as a method of commuting.

The bicycle is considered to be an effective way of seeking to combat the problem of congestion, whilst also reducing carbon emissions and promoting healthy living. Two of the biggest issues with using bicycles for commuting, are how to store them at work and how to use them in conjunction with public transport. The folding bicycle was introduced to the market to address these issues and this project will focus on the folding bicycle and how to improve it. The goal is to design, build and test a folding bicycle that meets the requirements set by the Conceive Design Implement Operate (CDIO)¹ Design Challenge. These require teams to produce a prototype folding bicycle with a production cost of £500, with a mass of less than 10kg and which when folded can fit into a locker of 58x45x43cm. BCS had twenty weeks to complete the project in its entirety. Having achieved this, the group hope to enter the prototype, the Urban Rider, into the CDIO Design Competition in Belfast, Ireland where it will compete against several other universities from around the UK.

2.0 Statement of Work

| | | | |
|---------------------------|---|-----------------|-------------------|
| PROJECT TITLE | CDIO Design Challenge- Single Person City Transporter | | |
| COMPANY NAME | Bike Centric Studios | CLIENT | Prof. James Boyle |
| PROJECT BEGIN DATE | 14/10/2015 | END DATE | 17/03/2017 |

SUMMARY

Bike Centric Studios took on the CDIO Design Challenge, which addresses the issue of growing urbanisation throughout the world. As cities become overcrowded, journey times lengthen due to increasing congestion. Most urban journeys only involve one person travelling a short distance. This leads to increasing carbon emissions due to the high number of internal combustion engine vehicles polluting cities. As global warming becomes an ever more increasing concern within governments, pressure has been placed on reducing our carbon emissions by setting targets and introducing policies (and sometimes setting penalties), with the overall aim to reduce emissions. The use of human powered single seater transporters such as bicycles, especially folding bicycles, is an ideal solution which can be used in conjunction with public transport to reduce the number of cars on roads within cities. Bike Centric Studios plan to respond to the Challenge by developing concept ideas and designing and manufacturing a bespoke prototype for a new folding bicycle that will promote a more active lifestyle and allow use of public transport. This will help reduce the number of cars on the roads and reduce carbon emissions within cities, allowing emission targets to be met. Particular emphasis will be placed on the size of the bicycle, to ensure that getting on and off public transport is as efficient and easy as possible.

PROJECT GOALS

The main goal of Bike Centric Studios is to design, develop and manufacture a light and space saving folding bicycle prototype which encourages commuters to complete journeys from their homes to their workplaces. The bicycle has to be able to fold easily, because

most commuter journeys in the world's most polluted cities include the use of public transport and so ease of folding is essential.

In the early stages of the project the company conducted market research in order to establish what the customer expects from a folding bicycle and what characteristics the prototype should have. The company then developed viable concepts according to the research previously done and performed the detailed design of its final choice. Concepts were required to satisfy the specifications given by the CDIO Design Challenge and additionally, they had to be capable of being manufactured in a relatively straightforward manner. The specifications set down by the challenge are as follows:

- The mass of the whole prototype should be less than **10 kg**.
- When folded, the bicycle should be able to fit inside a locker of internal dimensions:

Height: 58cm. Width: 45 cm. Depth: 43 cm.

This is further limited as the prototype must be able to enter the locker through a door of dimensions: **Height: 53 cm. Width: 39 cm.**

- The production cost of the prototype must not exceed £500.
- The prototype must *meet BS EN ISO 4210-2:2014 "Cycles — Safety requirements for bicycles. Requirements for city and trekking, young adult, mountain and racing bicycles"*, particularly para 4.6.1 regarding the provision of an adequate brake on each wheel.

Apart from the objective of simply developing and manufacturing the bicycle, another major objective is to enter it into the CDIO Competition, demonstrating the successful completion of the single seater city transporter to the specifications set.

BCS has also created a business plan for the formation of a limited company, committed to the manufacture and sale of its new folding bicycle, with sales promotion from advertising and further support from its website and social media platforms.

DEPENDENCIES

The client is to provide a suitable location to construct the folding bicycle. The help of technicians during the manufacturing stage is likely to be required and the client and technicians should understand and work to the milestones presented in order for the bicycle to be completed.

FINANCE

The group will receive a grant from the University of Strathclyde of £100 per person which totals £500 for the project. Any purchases made must be approved by the client and signed off accordingly. The final cost of the bicycle is likely to exceed the grant, once the finalised design has been produced a better estimation of the costs can be made and any further funding will have to be acquired through sponsorship and donations.

| MILESTONES | DATE DUE |
|---|------------------------|
| Research (Market, Consumers, Patents etc.) | Week 5 (23/10/2016) |
| Design (Pughs Design Process, PDS, Concept Generation etc.) | Week 8 (13/11/2016) |
| Detailed design (CAD drawings for manufacturing, FEA analysis on frame and other major parts) | Week 11 (02/12/2016) |
| Manufacturing | Week 4 - Semester 2 |
| Prototype construction | Week 6/ 7 - Semester 2 |
| Prototype testing | Week 9 - Semester 2 |

| DELIVERABLES & DELIVERY SCHEDULE | |
|----------------------------------|----------------------|
| DELIVERABLE DESCRIPTION | DELIVERABLE DATE DUE |
| Interim report | 18/11/2016 |
| Interim Presentation | 29/11/2017 |
| Final Report | 17/03/2017 |
| Website | 17/03/2017 |
| Final Presentation | 27/03/2017 |
| CDIO Design Competition | 10/05/2017 |

3.0 Bike Centric Studios

Bike Centric Studios (BCS) is made up of five students with a passion for engineering and cycling. The impression we want the name of BCS to emit, is of a design studio which possesses these two key factors at its core: “Bike Centric” effectively describing the passion for cycling the company has and “Studios”, conveying the vision of an effective design and engineering team.

These same principles were then applied to the design of our company logo (**Figure 1**). BCS written in bold, capital letters surrounds an outline of a bicycle, encompassing who and what we are. The phrase “Redefining The Fold” then refers to our specialty which is of course folding bicycles.



Figure 1: Bike Centric Studios Logo

3.1 Roles

To ensure that the group worked effectively and efficiently as a team, and in order to produce the deliverables of the project, specific management roles were created and assigned to each member of BCS.

Management roles were assigned after taking into account each member of the group's previous experience in internships and group projects. Belbin's Self Perception Inventory (SPI) test was also taken by each member of the group to highlight individual strengths and weaknesses.

An open discussion then took place with each member voicing their opinion on their preferred role and a management structure was unanimously agreed upon. The details of the management positions and the group member assigned to each is shown in **Table 1**.

| Management Position | Description of Role | Group Member |
|--|--|---------------------|
| Chief Executive Officer | Manages the overall operations of BCS. Makes key decisions, keeping track of all upcoming deadlines and ensures that they are met. | Aaron Thomson |
| Chief Financial Officer & Communications Director | Manages all the financial operations of BCS, including securing sponsorship for materials and travel expenses. In addition, all communications to/ from the client and sponsors are via this member. | Dominic Johnston |
| Research & Development/ Social Media | Manages all aspects of the initial research phase of the project and the development of BCS social media and website. | Carlos López Ayesta |
| Lead Design Engineer | Manages all aspects of the concept generation and detailed design phases of the project. | David Mann |
| Lead Manufacturing Engineer | Manages all aspects of the manufacturing and testing phases of the project with help from the Lead Design Engineer. | Andrew Martin |

Table 1: Management Structure

4.0 Project Plan

To ensure that the team keep on track with set goals and deadlines, a detailed project plan was created in Microsoft (MS) Project. The project plan milestones include the following:

- Initial project planning (Company Name, Gantt Chart)
- Obtain funding/ sponsorship from university and external sources
- Market research (existing market, patents/ regulations, consumer survey)
- Conceptual design (Pugh's Total Design Process)
- Interim Report (November 2016)
- Generation of CAD models of the final design, including FEA structural analysis
- Manufacture of final design
- Perform testing of prototype
- Company website
- Final report (17th March 2017)
- Presentation (27th March 2017)
- CDIO Competition (10th May 2017)

When this information had been collated, a project plan was generated in MS Project, which self-generates a Gantt chart with tasks and deadlines. A critical path is also highlighted by the software after deciding which tasks require to be completed before another can begin.

The plan was initiated by first inputting the major tasks/ milestones and their deadlines, as noted above. Subtasks were then created below each major task, in order to make the plan more detailed. Once the tasks had been entered, timeframes were decided upon for each individual task to ensure that these were completed within the relevant deadlines for the project. The group decided upon these timeframes together, to ensure that the time allocated to each task was fair, appropriate and deliverable. This also ensured that everyone was aware when each major deadline was, so that work could be completed in a well-structured manner and to ensure that all deadlines would be met without major issues. The final project plan can be seen in **Appendix A** (for clarity, only the major deadlines have been shown). As noted, in

tandem with the Gantt chart, the critical path of the project was generated by the MS Project software. This allowed the group to clearly see which parts of the project could not fall behind because if the delivery of these activities were to be delayed, the final completion of the prototype would fall behind schedule. Due to the high number of activities involved in this project, the critical path allowed the company to observe which tasks were of the most importance, so as to ensure that BCS delivered what it set out to do as outlined in the ***Statement of Work***.

At the start of the second semester the project plan was reviewed and refined to ensure that the manufacturing would be completed. This included reference to the final manufacturing deadline, which was critical to the final report being submitted. Deadlines for the website and business plan were also adjusted, to ensure that the team was not overloaded with work in the immediate weeks running up to the report submission date.

5.0 Risk Management

Risk mitigation planning is the process of developing options and actions to enhance opportunities and reduce threats to project objectives². From the outset of BCS's formation, the team set out to evaluate as many risks to the project as possible and take active steps to mitigate these. Risk assessment, and in particular the management of risks, is one of the most important factors which can cause a project to succeed or fail.

5.1 Risk Mitigation Planning

BCS employed a 9 step process for its risk mitigation planning, as outlined below:

1. Identify possible risks to the project.
2. Perform an assessment on the potential impact each risk could cause to the project.
3. Perform an assessment of the probability that each risk will occur.
4. Rank and prioritise the different risks identified.
5. Outline mitigating steps to reduce the probability of each risk occurring.
6. Update ranking and prioritisation.
7. If the overall risk is still deemed to be too high, the creation of a contingency is devised and to be used in the event of the risk occurring.
8. Ensure that all risks have a group member assigned to them for management and monitoring throughout the project.
9. Monitor all risks on an ongoing basis with regular updates and noting any changes.

The impact and probabilities were each given a risk factor, as described in **Table 2**.

| Factor | Impact | Probability |
|--------|---|---------------|
| 1 | Negligible: low cause of concern and/ or with a simple solution | Unlikely |
| 2 | Moderate: could create a serious issue if not handled correctly | Possible |
| 3 | Severe: high risk of causing project failure | Highly Likely |

Table 2: Risk Factor Definitions

The ranking of risks was achieved by multiplying the two factors of impact and probability together to give an overall risk factor (1-9). **Figure 2** shows a pictorial representation of this process.

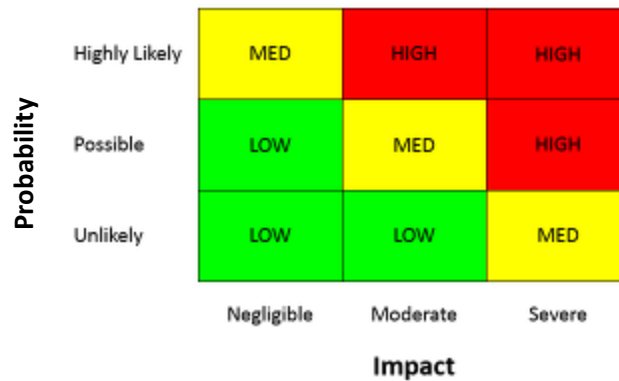


Figure 2: 3x3 Risk Matrix

Once all mitigation steps had been detailed a new probability factor was given for each risk and thus a new ranking was achieved. Risks that remained above a factor of 6 after the mitigation steps were applied, were deemed to remain high risk issues and as such were given contingences in the event of their occurrence. In total, there were 23 different risks identified and mitigation steps outlined for each. Two were deemed to remain high risks and were given contingences. An example of the process is shown in below in **Figure 3**, with the entire risk mitigation planning shown in **Appendix C**.


| Bike Centric Studios | | | | | | | | | | |
|---|--|--|-------------------|-------------|---------|---|-----------------|-------------|-------------|--------------------------|
|  | | | | | | | | | | |
| Risk Mitigation Planning- Project | | | | | | | | | | |
| Section | Risk | Potential Consequence | Impact Assessment | Probability | Ranking | Mitigation Steps | New Probability | New Ranking | Contingency | Group Member Responsible |
| Group | Lack of manufacturing experience | Inexperience leading to an overcomplicated design which proves challenging | 2 | 2 | 4 | N/A | 2 | 4 | | N/A |
| | Not meeting fixed deadlines such as report hand in date etc. | Penalty in grading process | 3 | 2 | 6 | Keep an up to date Gantt chart and make sure each member of the group is aware of upcoming milestones/ deadline dates | 1 | 3 | | Aaron |
| | Inefficient tasking of roles/ responsibilities | The final product is not ideal | 2 | 2 | 4 | Belbin's Self Perception Inventory (SPI) test taken by each group member in order to more accurately divide roles | 1 | 2 | | Aaron |
| | Communication breakdown between members | Tasks/ deadlines are missed due to lack of communication | 2 | 2 | 4 | Facebook group created for easy communication between group members. Along with weekly scheduled meetings for updates | 1 | 2 | | Aaron |
| | Unforeseen group member absences due to illness etc. | Delays in the tasks assigned to that group member(s) | 2 | 1 | 2 | Each group member is prepared to take over the tasks of another in the event it is required. | 1 | 2 | | ALL |

Figure 3: Risk Mitigation Planning Extract

5.2 Major Risks

Given the multitude of potential risks a project of this nature can generate, only the major risks identified by BCS are outlined below, along with their mitigation steps and contingencies if applicable:

- **Overdesign:** Designing a prototype which is outwith the manufacturing capabilities of the group and the technicians of Strathclyde University. To reduce this risk, meetings with university technicians took place to ensure that the final design was feasible and within the facilities, capabilities and tools available to BCS.
- **Delays in Receiving Materials:** This could create a major issue whereby all design and structural analysis is completed, however, the group are unable to progress with the project, potentially leading to deadlines not being met and voiding the contract with the client. In order to mitigate this risk BCS planned to finalise the design process as early as possible and order the required materials as soon as this was complete. In addition to this BCS expected delays and as such built them into the Gantt chart, to give some safeguard against this issue.
- **Lack of Technician Availability:** Unforeseen technician absences, causing delays to the manufacturing of required parts. This was outwith BCS's control, however, submitting parts requiring technician assistance as early as possible would help to minimise this risk. In addition to this a contingency was created whereby BCS sourced external facilities for possible help with manufacturing if required at The Bike Station, BCS's sponsor.
- **Financial:** The budget assigned by the CDIO framework and university might not have been adequate to purchase the required materials for the final design. An estimated budget was created (shown in **Section 5.3**) and BCS was able to secure sponsorship from an external source to be drawn on if required. If sponsorship from an external source had not been secured BCS could have requested further financial assistance from the university if such a situation arose. A financial expenses sheet was also continually updated throughout the project in order to be able to compare the estimated cost of materials to the actual amount BCS were paying, to ensure that BCS would not unknowingly go over budget.

- **Designing the prototype to the limits of the dimensional constraints:** This was deemed a major risk as any discrepancies between the design and manufacturing could potentially cause the bicycle to be too large to fully fit inside the locker. Given the size constraints of the locker BCS deemed this to be an acceptable risk as for the bicycle to be as ergonomic as possible it would have to push the limits of the available space.

BCS are aware of the cost of change, with **Figure 4** showing how cost/ flexibility varies as a project timeline progresses. Correcting an error in the early stages of design is relatively cheap and simple, however, as the project progresses there are fewer simple solutions available and thus the cost of making changes is greatly increased. This highlights the need for a risk management process in order to highlight as many potential matters that can go wrong in the project as early as possible and pre-plan solutions in order to minimise the financial cost of making changes late in the project.

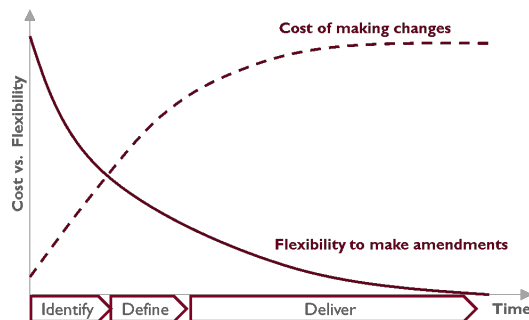


Figure 4: Cost/ Flexibility vs Time

5.3 Finances

In order to determine whether or not completion if the project was financially feasible within the given budget constraints, an estimated budget was created, as shown in **Table 3**.


| Bike Centric Studios Projected Budget | |
|--|-------------|
|  | |
| INCOME | |
| | Estimated |
| Group Project Standard Funding | 500 |
| Total Budget | £500 |
| EXPENSE | |
| | Estimated |
| Bottom Bracket | 20 |
| Brake Levers | 30 |
| Braking calipers | 40 |
| Cables | 10 |
| Chain | 5 |
| Crankset | 20 |
| Grips/ bar tape | 10 |
| Headset | 15 |
| Hinge Pins/ Bolts | 30 |
| Paint | 25 |
| Pedals | 15 |
| Saddle | 20 |
| Seat Clamps x2 | 10 |
| Seat Rail Clamp | 10 |
| Stem | 20 |
| Stickers | 10 |
| Tyres | 14 |
| Wheelset (Rims, Hubs, Spokes, Tubes) | 100 |
| Total Estimated EXPENSES | £504 |
| NET (Income - Expenses) | -£4 |

Table 3: BCS Projected Budget

5.4 Sponsorship

As can be seen from the estimated budget in **Table 3**, the projected financial cost of this project would very close to that of the CDIO Challenge framework target of £500. As such, sponsorship was sought to help ensure the completion of the project and fill any gap between the standard funding and any development costs. Emails were sent to numerous bicycle stores in and around greater Glasgow, outlining the company that is BCS and asking for potential sponsorship to help us complete our task. An agreement was reached with The Bike

Station³, Glasgow, a bicycle store which specialises in refurbishing 2nd hand bicycles and additionally provides the maintenance and redistribution requirements of Glasgow's *NextBike*⁴ bicycle sharing. The Bike Station offered BCS sponsorship in the form of free or discounted parts and technical assistance for certain aspects of the construction phase.



Figure 5: The Bike Station Logo

Upon completion of the prototype, it is the aim of BCS to travel to Belfast, where the bicycle will compete in the CDIO Design Challenge against groups of students from other university students, all studying mechanical engineering. As travel and accommodation would undoubtedly exceed the entire budget allowed for production of the bicycle, sponsorship was requested from Prof. Andrew Heyes, the Head of Mechanical Engineering at University of Strathclyde. It is understood that sponsorship of BCS is likely to be approved, allowing us to participate in the CDIO Design Challenge.

6.0 Market Research

6.1 UK Cycle Economy

The UK cycling market has been growing at a steady rate over the last decade, with cyclists contributing £3bn to the UK economy in 2010. Included in this, approximately 23,000 people were employed directly in bicycle sales, distribution and maintenance of cycling infrastructure, generating £500m in wages and £100m in tax revenue⁴.

Around 3.6 million bicycles are sold in the UK each year and given that there were 3.21 million cars newly registered the UK in 2015, more bicycles were sold than there were new cars registered⁴.

Bicycle crime is still quite prevalent throughout the UK, with 327,000 reported cases of bicycle theft in England and Wales alone from April 2015 to March 2016⁴. Folding bicycles have less chance of being stolen since they can easily be stored inside, instead of being left outside unattended.

6.2 Market Competitors

One of the first tasks of the market research was an evaluation of the competition Bike Centric Studios will face in the market. A meeting was held in which BCS characterised the positives and negatives of current folding bicycles. BCS evaluated these bicycles with reference to the time taken to fold, the ease of fold, weight, size, price and aesthetics.

The results of BCS's evaluation of the 6 main 'competitors', are summarised below:

- **Brompton**⁵: BCS view the Brompton as one of the best folding bicycle currently available on the market. The Brompton is one of the fastest and easiest to fold, due to its folding mechanism which is unique to the market. Its base weight is one of the lowest (but not CDIO compliant), and when folded it is one of the smallest. A negative of the Brompton is that it is one of the most expensive folding bicycles on the market, starting at £800.
- **Dahon EEZZ D3**⁶: This is similar in price to the basic Brompton, however is able to meet the weight requirements of the CDIO Competition at 9.7kg. Its folding mechanism is

unique in that the entire front fork folds under the top tube, taking only an impressive 10 seconds to fully fold. Again however, it does not meet the CDIO size specification.

- **Vello Bike**⁷: The Vello bike is an electric lightweight folding bicycle which was successfully funded in 2016 through crowdfunding. It comes close to the 10 kg weight limit, but it does not meet the folded size dimensions. Its folding mechanism is unique in the sense that once folded, it can be rolled along the ground for easy transportation.
- **Montague Crosstown**⁸: This is a full-size folding bicycle that in terms of comfort and value for money is one of the best on the market, but its size and weight do not come close the constraints set by the CDIO Design Challenge.
- **Viking Easy Street**⁹: This is one of the cheapest folding bicycles on the market, however, as it is made completely of steel, its weight is far above the requirements.
- **CMYK 4.0**¹⁰: The CMYK 4.0 bicycle is very small even when unfolded for operation and relatively light but it does not satisfy the requirements for the CDIO Challenge in terms of its weight and its folded size.

6.3 Pricing

There is a broad range in prices in the folding bicycle market, from the very low-cost versions such as the Integra Safari 6 at £136¹¹ to the most expensive Brompton at £2,500⁵.

With regard to low-cost folding bicycles it was found that none of these come close to meeting the weight and folded dimension requirements of the CDIO Design Challenge. The price of low-cost folding bicycles is between £130 to £530 and the majority of these favour a two-fold design as this is simpler and less expensive.

Turning to the high end folding bicycle market, with prices ranging from £1,000-£2,500, the majority of these are also above the weight and folded dimension requirements of the CDIO Design Challenge. The majority of these favour a three-fold design for increased compactness when folded.

6.4 Product Testing

Through *The Bike Station*, Glasgow and *Uni-Cycle*¹², BCS was given a Brompton folding bicycle for a four-week period free of charge. Brompton is the market leader in high-end folding

bicycles. Being able to use a Brompton bicycle first hand provided a considerable amount of insight into this type of bicycle. Each member of the group was able to get hands on experience of both riding and folding/ unfolding the bicycle, which none previously had. This research helped with the design process considerably as it highlighted the positives and negatives of folding bicycles and guided us as to what would be in fact technically feasible within our concepts, thereby influencing the choice of our final design.

6.5 Folding Mechanisms

There are many different folding mechanisms on the market, which vary with the manufacturer. Most folds use some sort of hinge mechanism, with an example of one currently on the market shown in **Figure 6**.



Figure 6: Hinge Mechanism¹³

Many manufacturers only use two folds, however, BCS quickly realised that it would be very difficult to produce a prototype that fits the CDIO Design Challenge requirements with just two folds. Of the mechanisms using three folds, the Brompton bicycle was deemed to be the most efficient. Its folding mechanism is simple and effective and it helps to make the bicycle more compact once fully folded. It begins by releasing the rear coupling and the rear wheel is then rotated to sit underneath the top tube. The front fork and handlebars are then folded over horizontally using a hinge mechanism, and finally, the handlebars are folded using another similar hinge mechanism, as shown in **Figure 7**.



Figure 7: Brompton Handlebar & Top Tube Hinge Mechanism¹⁴

The folding mechanism of a two-fold bicycle is generally simple. First the top tube's hinge is rotated so that the back wheel meets the front part of the bicycle. Then the handlebar hinge is released and folded downwards. Finally, the seat post is pushed down to complete the folding process. Some examples of hinge mechanisms used in two-fold bicycles can be seen in Bickerton and Dahon folding bicycles (**Figure 8 & 9**, respectively).



Figure 8: Bickerton Hinge Mechanism¹⁵



Figure 9: Dahon Hinge Mechanism¹⁶

Most folding bicycles, no matter if they have two or three folds, have a structure and shape that is simple and effective, composed of a simple frame, a seat post and a handlebar. But some companies are developing prototypes and bringing new products to the market which have complicated structures which give them the opportunity of making a light weight and compact folding bicycle. BCS have had to be aware of these developments in considering the design of its product. **Figure 10** and **Figure 11** show two examples of these:



Figure 10: A-bike Folding Bicycle¹⁷



Figure 11: Carryme Folding Bicycle¹⁸

6.6 Consumer Survey

The team created a consumer survey consisting of eleven questions drafted to gain information about average commuter habits and preferences, specifically regarding commuter bicycling. The survey received over 500 responses and the breakdown of these responses is shown in **Appendix D**. The results show that 54% of commuters work within 10 miles of their home. This is deemed to be an acceptable distance to cycle to and from work each day, yet only 1% actually use their bicycle for their daily commute. This result is even more surprising considering that 59% of people (almost six out of ten) state that they own a bicycle.

76% of the respondents said that they would be willing to spend a maximum of one-minute folding or unfolding a bicycle, with 48% stating that they would be willing to spend up to £200 on a folding bicycle. The survey also showed that 57% of people would rather use a standard pedal bike, as opposed to one with electric (9%) or hybrid power (34%). The most popular method of transporting a folded bicycle was using a rolling luggage type style (39%), closely followed by carrying it over the shoulder (36%), and finally hand carrying (23%).

The main benefit of completing a consumer survey is to gain valuable information as to what potential customers require from a product. By using this information in the design stage, BCS incorporated key design features which the public would wish and expect from a folding bicycle.

6.7 Bicycles & Public Transport

As noted, cities are becoming more and more congested with vehicles, leading to greater commuting times for many workers. As a result, many commuters have looked to alternative means of travel to and from work. One of the more popular modes of alternative transport is the bicycle as it is free from pollutants, compact and a form of exercise. The compactness of a bicycle lets the rider slip between traffic and for some commutes can reduce journey times. For some commuters a standard bicycle is not appropriate as many work places do not have sufficient space to store a bicycle and so a folding bicycle is a more attractive solution, as it can be stored easily. Many commuters use both a bicycle and public transport on the same journey and this can prove to be problematic. Public transport is not geared towards allowing

bicycles and transport companies have policies in place regarding what is allowed, as shown in **Table 4** below:

| <i>Transport</i> | <i>Bicycle</i> | <i>Folding Bicycle</i> | <i>Prams</i> | <i>Other</i> |
|------------------|--|------------------------------------|--------------|-----------------------|
| <i>Bus</i> | Depends on service/ time restricted | Yes | Yes | At drivers discretion |
| <i>Train</i> | Yes/ reservation required | Yes/ no reservation required | Yes | Contact rail service |

Table 4: Large Objects Permitted on Public Transport Systems

A standard bicycle is allowed on a bus but is dependent on the company, the route or the driver¹⁹. There can also be a time restriction with bicycles not being permitted during peak times or if the bus is busy. With regard to trains, bicycles are allowed on most services but it is advised that a space is booked for the bicycle²⁰.

Folding bicycles do not fall under the same restrictions which apply to a standard bicycle and can be stored in the luggage areas of either a bus or train. This makes for a desirable solution for many commuters and increased usage could convince other commuters to change their way of commuting to and from work.

6.8 Patents

When any prototype is under development it is important to know whether the product already exists or if features of the design infringe on any active patents. Patents exist to protect exclusive rights for an inventor and prevent any existing design from being copied, as any patent breach can lead to legal action. Patents are not granted by a central body or organisation, rather they are granted by sovereign states. Under the Patent Cooperation Treaty, inventors can seek patents in numerous countries with one application, thereby simplifying the process and granting international protection for a design²¹. It was therefore imperative that research on existing patents be carried out so that BCS did not infringe on any active patents.

There are certain aspects of the bicycle which were researched for existing patents, those being types of hinges or folds, handle bars, frame, and seat post. The conclusions reached

from the research were that there are few patents that are specific to one area of the bicycle and, of those discovered, no part of BCS's design infringed on these patents. As BCS looks to become a leading company in the folding bicycle market, BCS intends to apply for its own patents focusing on the bicycle as a whole and also specific design features.

6.9 Standards

The bicycle must adhere to the British Standard *BS EN ISO 4210* to ensure that it meets British safety standards and in order to be entered into the CDIO Design Challenge. The bicycle must adhere to at least *BS EN ISO 4210-2:2014*. This part of the standards provides a summary of "safety requirement for city and trekking, young adult, mountain and racing bicycles". This section outlines the requirements necessary for the bicycle to pass tests set out in further parts of *BS EN 4210*, which outline the conditions required for these. One key area which the team identified to be addressed is section 4.6.1, which involves the issue of providing adequate brakes on each wheel. This means that both wheels should have brakes which work independently without binding. Furthermore, the braking system must adhere to the braking performance requirements stated this section. The braking performance can be measured either using a test track or a test rig explained in section 4210. Due to rig constraints, the group has decided that the braking system shall be tested using a test track. This means that the bicycle must fulfill the braking distance requirements set out in table 2 of 4.6.8.1.1 for city and trekking bicycles. For the braking to pass these tests it needs to also ensure that it does not have adverse braking characteristics such as excessive juddering, front wheel locking and loss of control occurring during testing. Further characteristics and general requirements are detailed in section 4.6 for the braking system.

Subsections 3-9 of the standard *ISO 4210* outline the standard testing methods. These tests must pass the requirements set out in *BS EN 4210-2*. The standards are based on standard bicycles with no specifics regarding folding bicycles, however, there are standards for city and trekking bicycles which are the most comparable. Therefore, some of the tests specified for the bicycles would need to be modified to be applied to folding bicycles. Furthermore, most of the tests require test rigs which are not available to the group. Efforts are being made to test the bicycle as close to the testing specifications as possible.

Certain parts such as the front fork and wheels were purchased pre-manufactured and as such testing on these parts individually was not required. Although the specifications of the project only state that brakes needed to adhere to the standards, the team felt that it was still important to ensure that other areas adhered to them. It was decided therefore that the frame, seat post and steering mechanism should all be compliant, under the subsections noted below:

- **Subsection 5** highlights the testing methods required for the handlebars and these tests are to be carried out to ensure they are safe.
- **Subsection 6** addresses the frame itself. However, certain rigs are needed to fully test the frame. Adaptations of these tests are planned to ensure that the frame is safe and strong enough to withstand the forces exerted on it.
- **Subsection 9** details two different seat post test methods which need specialist rigs and once again a simplified version is to be conducted to ensure that the seat post design is suitably strong.

6.10 Geometry

The geometry of a bicycle is an important aspect of design, as this is responsible for the ergonomics and comfort. Bicycle frames are typically built from two triangles, with the triangle angles and lengths being altered based on the needs of the consumer. Bicycles such as touring bicycles have been designed with comfort in mind. This is because they are primarily used to travel large distances (**Figure 12**). Examining touring bicycles, one can identify key angles and lengths required to create a comfortable bicycle. Further research of commuter folding bicycle geometries have shown similarities between touring and folding bicycles. As folding bicycles have different needs and tend to be smaller, comparing the two gave us an indication of what the folding bicycle industry saw as the most important lengths and angles.

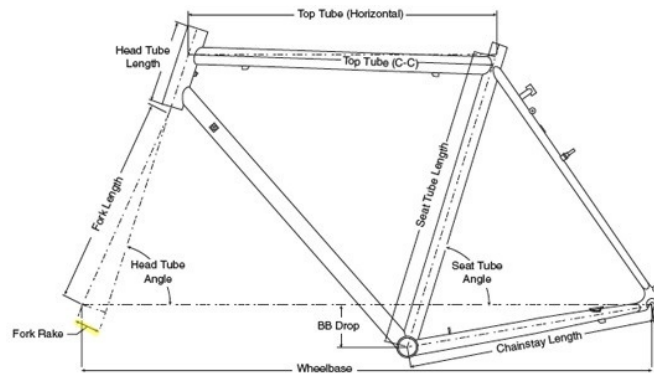


Figure 12: Bicycle Geometry of a Touring Bicycle

Key geometries of touring bicycles are:

- **The head tube angle and the fork rake length:** these affect the ease and speed of steering.
- **The chain stay length:** this increases the wheel base; a longer chain stay is more attractive.
- **The wheel base:** this is a large factor in comfort and stability of the bicycle. A longer wheelbase will also provide a more stable ride.
- **The seat tube angle:** this is an important factor for pedalling, however, the optimal pedal position does not vary that much between bicycles and is generally around 73 degrees.
- **The top tube:** this affects the reach from the saddle to the handlebar. The top tube length tends to vary with frame size.

Table 5 shows a comparison of the general dimensions of touring and two folding bicycle dimensions, the Dahon Curve & Giant Halfway.

| Geometry | General Touring Bike ²² | Dahon Curve i3 ²³ | Giant Halfway ²⁴ |
|--------------------------|------------------------------------|------------------------------|-----------------------------|
| Head Tube Angle | 71 - 72° | 73° | 72° |
| Wheel Base | 1050 - 1070mm | 945mm | 978mm |
| Chain Stay Length | 450 - 470mm | 385mm | 381mm |
| Top Tube Length | 550 - 580mm | 525mm | 559mm |

Table 5: Touring & Folding Bicycle Dimensions

As can be seen from **Table 5**, the head tube angle and top tube length are similar in both folding and touring bicycles. Another important dimension the team identified was the chain stay length as this impacts on the folded length and achievable wheel size. This in turn determines whether the folding bicycle will meet the size specifications set by the CDIO Design Challenge. The team decided that to create an ergonomic bicycle, important angles and lengths required to match as closely as possible to those identified earlier in **Table 5**.

6.11 Materials

One of the main areas of concern when it came to the creation of the prototype was with regard to the materials to be used. Bicycles are made from various materials, the main ones being steel, aluminium alloy, carbon fibre and titanium. As mentioned previously, there are conditions to be met when creating the prototype and so careful consideration had to be taken so as to determine what material would be best suited.

| Property | Mild Steel ²⁵ | Aluminium Alloy (6061 T6) ²⁶ | Titanium Alloy (Ti6Al4V) ²⁷ | Carbon Fibre ²⁸ |
|---------------------------------|--|---|--|----------------------------|
| Yield Strength (MPa) | 370 | 240 | 880 | N/A |
| Ultimate Tensile Strength (MPa) | 440 | 270 | 950 | 600 |
| Young's Modulus (GPa) | 205 | 80 | 113 | 70 |
| Density (kg/m ³) | 7870 | 2700 | 4430 | 1600 |
| Weldability | Easy to weld using traditional methods | Good weldability | Good weldability | Cannot be welded |

Table 6: Material Properties

Table 6 (above) shows the main material properties of the four most common materials used in the construction of bicycles. The properties of mild steel are advantageous in bicycle production. It is a strong metal, meaning that it should be able to cope as the frame of the bicycle and support the weight of a human. Steel is also very easy to weld, as it can be welded using traditional methods such as metal inert gas (MIG) welding. Steel is a relatively cheap metal and easy to source and as a result, many low-cost bicycles are made from it. The main disadvantage of mild steel is its density. It has the highest density of all the materials considered and this would result in a heavier bicycle and would likely make it difficult to meet the 10kg limit set by the CDIO Design Challenge. Steel is also a ferrous metal and is therefore prone to rusting and would require a protective coating to prevent rusting from occurring, adding cost and time to the manufacturing process.

The second material considered is 6061 T6 aluminium. This is a heat treated aluminium alloy, which is used in bicycles as it is stronger than pure aluminium. In terms of strength, it is not quite as strong as steel or titanium but is sufficient for bicycle frames. Aluminium, like steel, can be welded but requires more skill than traditional steel welding due to aluminium being a soft metal with a lower melting point. It is less dense than steel making it an attractive alternative as this would allow for a lighter frame and could allow for the 10kg limit to be met.

Aluminium is abundant and easy to source and is slightly more expensive than steel, but still cheaper than both titanium and carbon fibre. Aluminium frames are typically found in mid-range bicycles.

Titanium alloy has very good strength, which is desirable for a bicycle frame but has a fairly high density. Due to the high strength, less titanium would be required and thus the frame could be built by using smaller tubing than that of aluminium or steel. This factor could mean that the prototype would meet the weight requirements and is comparable to aluminium in this respect. Titanium is expensive and more difficult to source, however, and this would increase expenditure and lead to longer delivery times. This particular type of titanium alloy can be welded using traditional techniques but further precautions are required and care must be taken in order not to introduce contaminants to the weld. In the bicycle market titanium alloy bicycle frames are found in the high price range.

As developments in carbon fibre have progressed significantly in the past couple of decades this has led to the introduction of carbon fibre bicycle frames in recent years. Carbon fibre has comparable strength to that of aluminium but is less dense. This strength to density ratio makes it a very desirable material for bicycle frames. It is however very expensive to purchase and manufacture. Carbon fibre cannot be welded and requires alternative techniques to form a frame. Typically, the frame would be formed in a single piece so that there are no weak joints. Carbon fibre is known to be a brittle material and due to its lack of ductility the prediction of failure is difficult and therefore becomes a safety issue. Quality control is therefore essential and can be costly.

Comparing the materials, it was decided that aluminium would be the best choice, the reason being that it is generally a low density material allowing the bicycle to be within the weight limit and it is strong enough to support the weight of a human when made into a frame. The technicians at the university also have experience with welding aluminium and so manufacturing should not be difficult in this regard. Finally, it is relatively cheap and easy to source.

7.0 Design Process

The design exercise was carried out using Pugh's Total Design Process. This provided a structured process which ensured that the best possible product was designed in a systematic way.

Pugh's Design Process is a total design process which encompasses the "systematic activity necessary, from the identification of the market/user need, to the selling of the successful product to satisfy that need – an activity that encompasses product, process, people and organization"²⁹. The total design process follows a design core. This is a set of activities imperative to design and if used properly and systematically will reduce unnecessary iteration of designs (**Figure 13**). Pugh's Design Process encompasses the first three letters of CDIO, tackling the conceive, design and implement parts of the challenge.

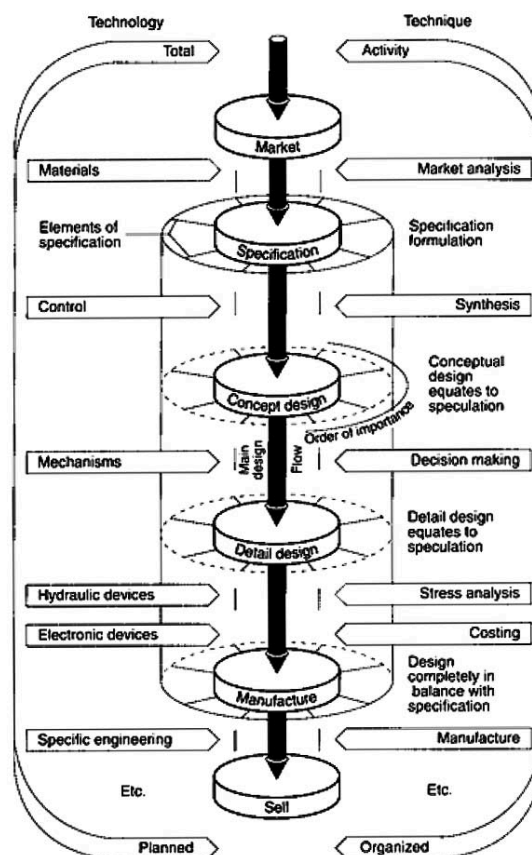


Figure 13: Pugh's Total Design Process

The first design stage is market research, outlined in **Section 6.0** of this report. On completion of market research the next core stage is specification. This stage involves creating a set of specifications based on market research, ultimately creating a Product Design Specification

(PDS) (shown in **Appendix E**). The next stage is conceptual design. This stage is the beginning of concept generation and is based around the PDS. Concepts are generated and then evaluated against a design matrix of specifications. This involves identifying which concepts are better than, worse than, or the same as a datum concept. This process of concept generation and evaluation is iterative, and can be done multiple times to eliminate poor concepts and generate the best possible product. Once a final concept has been decided upon, the next phase in the design core is the detailed design. The detailed design phase is the most important phase where all necessary dimensions required for the bicycle are calculated. These dimensions are then checked using stress analysis programs to validate the structural strength. Detailed design also incorporates the production of orthographic drawings for manufacturing, making the detailed design as thorough as possible, thus ensuring that once the next core stage of Pugh's total design process begins, no additional changes require to be made as this can be costly and delay the project.

7.1 Specification

The PDS shown was created by the team following the market research. The research highlighted specific criteria which would be useful to include in the PDS. A precise PDS ensures that the folding bicycle is competitive in the current market. In addition, specifications such as weight and folded dimensions were predetermined by the CDIO Design Challenge briefing.

7.2 Concept Design

With the aid of the PDS the concept generation stage could begin. The team decided that each member would create at least two concepts. It was important that this exercise was completed individually as this would provide us with the best chance of having a variety of concepts to consider, due to the different backgrounds and knowledge within BCS. Thirteen concepts were created for the initial design meeting giving us a wide variety of choice, **Appendix F**. Using the PDS, a concept convergence matrix (CCM) was created to analyse the concepts compared to a chosen datum design. Each concept was compared to a chosen datum concept and ranked as either 'better than' (+), the 'same as' (s) or 'worse than' (-) for all the specifications chosen for the CCM. This process ensured a fair elimination of weak concepts. This process was conducted twice using two different designs as the datum, to ensure the initial results were accurate. The positives and negatives of each concept

highlighted by the initial CCM were used to further develop the chosen concepts for the next round of iterations. **Table 7** and **Table 10** in **Appendix G: Concept Convergence Matrix** show the first and second CCMs, respectively.

| Specifications | Datum (0) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---------------------|-----------|---|---|---|---|----|----|---|----|----|----|----|----|
| Ease of Folding | | - | - | - | s | - | s | - | s | s | + | + | s |
| Folding Time | | s | - | - | s | s | + | - | s | s | + | + | - |
| Ease of Manufacture | | - | - | - | - | -2 | -2 | - | -2 | -2 | -2 | -2 | - |
| Aesthetics | | - | s | + | + | s | s | + | - | + | + | - | + |
| Ergonomics | | s | + | s | + | - | + | + | - | + | s | - | + |
| Manufactured Price | | - | - | - | - | - | - | - | -2 | - | - | - | - |
| Folding Size | | s | + | s | + | s | + | + | - | + | s | - | + |
| Weight | | - | s | - | - | - | - | - | - | - | - | - | - |
| + | | 0 | 2 | 1 | 3 | 1 | 3 | 3 | 0 | 3 | 3 | 2 | 3 |
| s | | 3 | 2 | 2 | 2 | 2 | 2 | 0 | 2 | 2 | 2 | 0 | 1 |
| - | | 5 | 4 | 5 | 3 | 6 | 4 | 5 | 8 | 4 | 4 | 7 | 4 |

Table 7: First Concept Convergence Matrix

From the initial CCMs the group decided that Concepts 2, 4, 6 & 12 had enough positive attributes to take forward in the design process. A week was assigned for further refinement of these designs before the team used the same CCM to eliminate poor concepts, the results can be seen in Appendix H: Final Design Concepts. A datum concept, concept 4, was chosen to compare the improved concepts to. **Table 11** shows the results of the final CCM, shown in **Appendix G**.

After performing the final CCM it was clear that both concept 2 and 6 performed better than the datum, which was thought to be one of the stronger concepts. The final concept chosen was concept 6 (**Figure 14**). Concept 6 was chosen as the CCM showed that this concept could be a lighter bicycle and was easier to fold than concept 2. The main feature of Concept 6 is its two main folds across the bicycle splitting the bicycle up into three different parts. Other features such as the folding steering tube and simple seat post design ensure a compact fold.

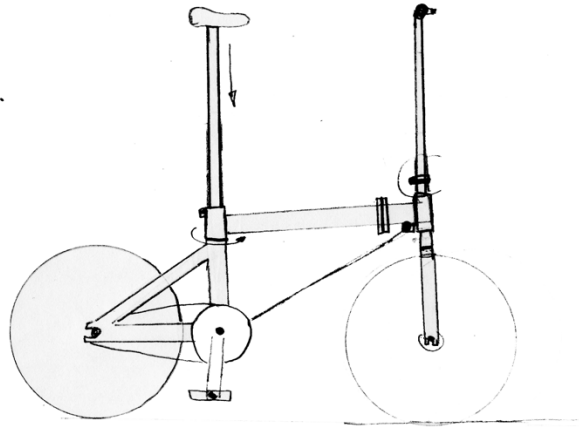


Figure 14: Concept 6

With the final design chosen the next step in Pugh's design process is to produce a detailed design of the concept. Before this began, the team created concepts for different types of hinges and a concept for the rotating tube for the different types of folds within the bicycle.

From the hinge concepts created by the team (shown in **Appendix I**) the simplest hinge design, concept 5, was determined to be the easiest to manufacture as well as being the most practical in terms of ease of use (**Figure 15**). In addition to the hinges a rotating tube design was made for the main folding mechanism of the bicycle. This was considerably more difficult as this part must withstand the greatest forces which will be exerted. The team focused on one main concept using a clamp and bolt system. The bolt would keep the bicycle in the orientation required and the clamp would further secure the top tube to the rear triangle in the same way the seat post is clamped.

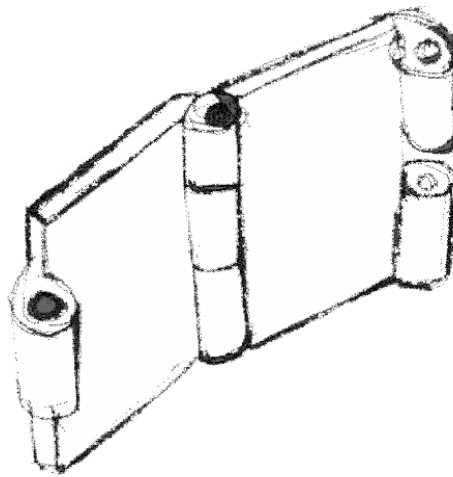


Figure 15: Hinge Concept 5

8.0 Detailed Design

With the final concept chosen the next phase was the detailed design process. This involved determining the specific details required for the bicycle to be manufactured, such as tubing lengths, angles and materials. Using the research conducted in **Section 6** certain dimensions were identified as being critical if the prototype was to be ergonomically sound and therefore comfortable to ride. The design team decided that for the bicycle to ride as comfortably as possible, the wheel size should be as large as possible within the dimension constraints. Furthermore, the top tube length, handle bar reach and seat angle all required to be considered to provide a suitably comfortable ride. Although these dimensions are important, the limitations of the size constraints put in place by the CDIO Design Challenge had also to be considered and compromises made. The team decided that the best use of the space available in the locker would be to fit the bicycle in diagonally as this would allow for a longer, more ergonomic bicycle. Designing the prototype to the maximum specification was identified as a major risk, however, the group felt that if the bicycle were to perform well, it would need to have a large enough wheel base and therefore needed to be as large as allowed by the constraints. In addition, due to the weight specification, careful decisions on materials and size of tubing required to be made to ensure the strongest and lightest possible configuration.

The design team split the concept's frame into two distinct sub-categories: the rear triangle, the top tube assembly.

8.1 Rear Triangle

The group identified from the outset that there were some limiting factors for the rear triangle which directly impacted on the bicycles ability to fit into the locker size specifications. These further impacted on the allowable sizes of wheels the bicycle could have. The distance from the bottom bracket to the end of the rear wheel (**Figure 16**) was a dimension that would need to be carefully thought out if the bicycle was to fit into the locker. This length is a combination of the chain stay length and half the wheel diameter. For the bicycle to ride well this distance would need to be as large as physically possible.



Figure 16: Rear Triangle Showing Limiting Dimension

The chain stay length can only be determined once the wheel size has been confirmed. From market research the typical size of folding bicycle wheels is 16 to 20 inches. These wheel sizes would take up the majority of the available space in the specified locker and therefore, the decision was made to use 14 inch wheels instead. The seat tube and seat post were another issue to be addressed if the prototype were to fit in the locker when folded. The Brompton has a bottom bracket in front of the seat tube and this means that the seat post can go all the way through the seat tube to the ground. As this was not an option for our prototype we decided that the simplest solution was to remove the seat post from the bicycle and store it separately. The seat tube however was more complicated to design due to the rotating tube around it. This meant that the seat post angle would need to increase from the suggested 71° - 75° to 85° . The main reason that the seat tube angle was changed was to ensure that when the top tube rotated around, the height of the bicycle would still fit within the set specifications. Once the chain stay length and seat tube had been determined, the seat stay length could be calculated using simple trigonometric calculations.

8.2 Top tube assembly

The top tube is relatively basic with the base and end of the top tube being connected by a hinge (**Figure 17**).



Figure 17: Top Tube Assembly

The hinge design ultimately chosen was machined from a solid block of aluminium rather than being purchased and this allowed the group to fully customise the hinges to ensure that they were strong enough to handle the expected loads. The hinge was designed so that the two parts comprising the hinge were identical, allowing for a quicker machining process. One side of the hinge is bolted while the other side is held together by a quick release pin to ensure fast opening and closing of the hinges so that the bicycle can be folded quickly and with minimal effort.

Another aspect of the top tube design was the head tube angle on the bicycle. Initially, this was meant to be as close to that of standard folding bicycles. A smaller head tube angle would mean the wheelbase would be greater, but this would mean that when the bicycle was in the folded position, it would be too big for the specification. The head tube angle was therefore set to 82° as this would ensure that the bicycle would have a suitable angle so that the steering would not be too sharp. The total top tube length was based on the length of existing folding and touring bicycles to provide a comfortable reach for the rider when cycling. This also had a direct impact on the size of the wheelbase which is another dimension that is key to rider comfort. The final top tube length was also directly affected by the hinge placement along it. The placement was determined so that, when the bicycle was in the folded position, the wheels would be sitting next to each other.

8.3 Materials

The group discussed many different materials to be used in the prototype, however, realistically there were only two to decide between, which were within the group's budget

and which are relatively easy to weld together. The decision was ultimately between using aluminium or steel. With the weight limit specification, the decision was made to manufacture the prototype out of aluminium, which is not as dense as steel but still has suitable strength properties. Tubing sizes were initially chosen from standard tubing sizes in the cycling industry, with set wall thickness and diameters. To check whether the dimensions on the design were suitable, finite element analysis (FEA) was conducted.

8.4 FEA- Frame

A 3D CAD drawing of the completed frame was produced in Creo Parametric and then transferred into ANSYS Workbench so that appropriate FEA could be conducted. Two static structural load cases were agreed upon and are detailed in **Table 8**. The load cases were based on a typical load which might be seen through the bicycle when ridden. The first load case was based on the rider sitting on the seat and exerting a force through the pedals. The second load case mimicked someone sitting on the saddle with all their weight while the bicycle is stationary. The bicycle was load tested to 1.5 times the max weight set to incorporate a factor of safety within the design. The support locations were identical for both load cases (shown in **Figure 18 & Figure 21**)

Once the geometry had been imported from Creo the material was defined as a standard aluminium alloy 6061 from the engineering material data incorporated in the ANSYS software. The next stage was generating an appropriate mesh which had a suitable number of elements of a high enough quality to ensure that the results were as accurate as possible. The mesh produced had a high uniformity and element quality as seen most clearly in **Figure 20**. This ensured a reasonable level of accuracy when applying the two load conditions. In addition, an effort was made to ensure that the connections between the surfaces would be as accurate as possible, indicating where bonded or free connections exist.

| Load case | Support location | Force location | Force Magnitude |
|-----------|----------------------|-------------------|-----------------|
| 1 | A. Base of head tube | C. Bottom bracket | C. 950N |
| | B. Rear drop outs | D. Seat tube | D.670N |
| 2 | A. Base of head tube | C. Seat tube | C. 1500N |
| | B. Rear drop outs | | |

Table 8: FEA Load Cases

Load Case 1

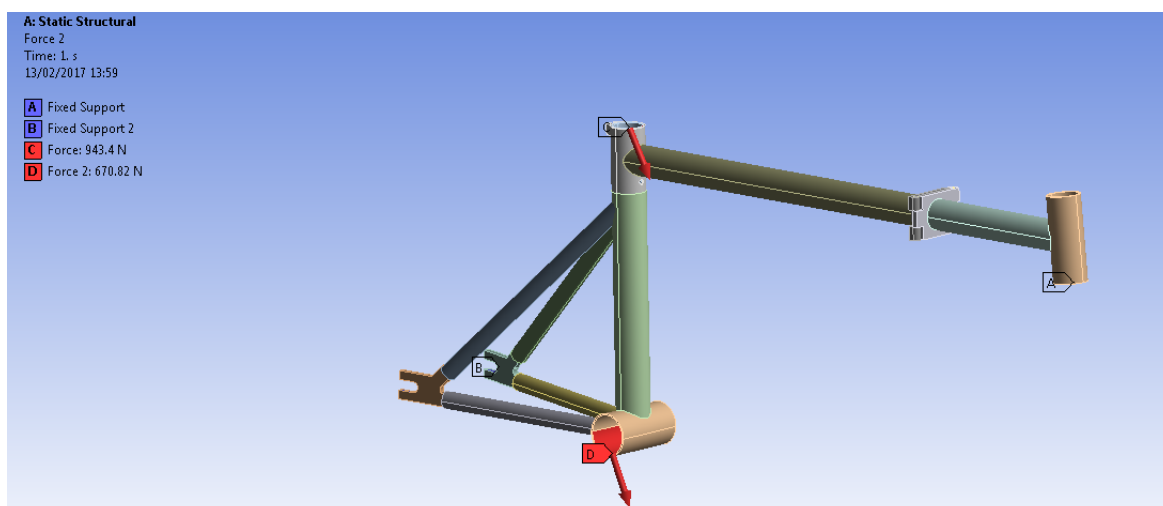


Figure 18: Load & Support Locations for Load Case 1

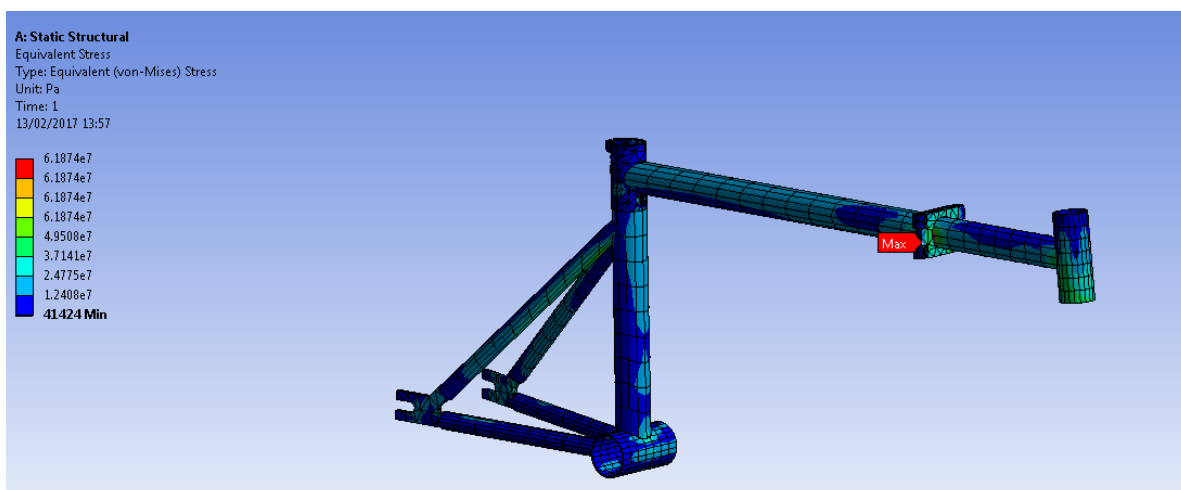


Figure 19 : Equivalent von Misses Stresses of Load Case 1

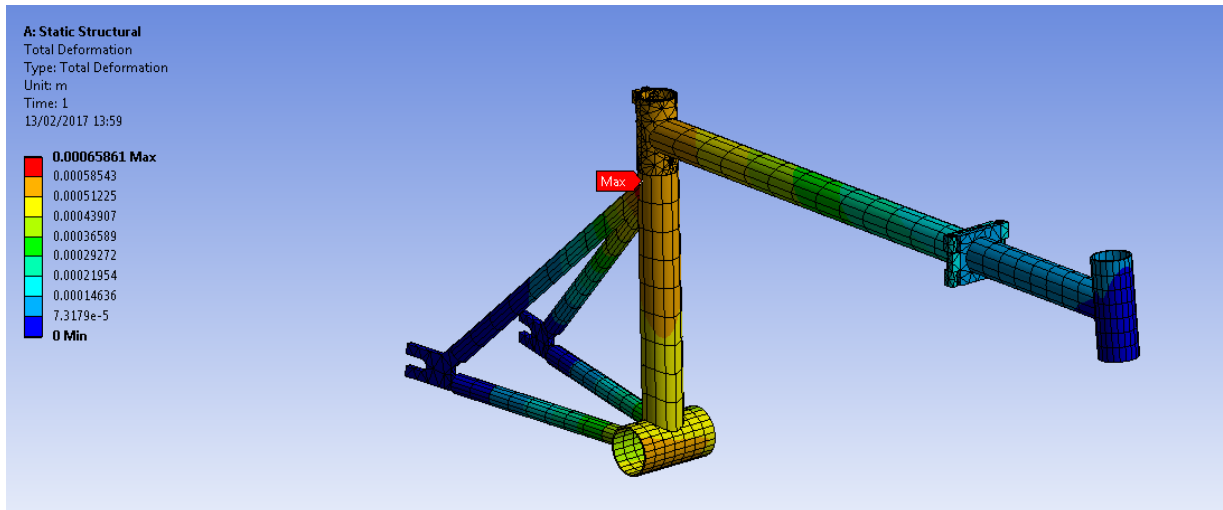


Figure 20: Total Deformation of Load Case 1

In **Figure 19**, the high stress locations are in the areas in which we would expect them to occur, at the joints between the tubes. As the high stress regions tend to occur around the joints, especially around the top tube hinges, the welding must be performed to a high standard to ensure that there is adequate strength at joint areas. This was a location which the team thought may cause problems, however, from the deformation plot (**Figure 20**) it can be seen that this should not be an issue, but was still an area to keep an eye on. Furthermore, the total deformation indicates that there will be a max deformation of 0.66mm, located in the seat tube, this is the area around the rotating tube. As both the seat tube and rotating tube were areas the team had concerns about when designing them, the low deformations indicated that the design was in fact suitable. The team also identified that the first half of the top tube could flex and has some deflection but again nothing significant.

Load Case 2

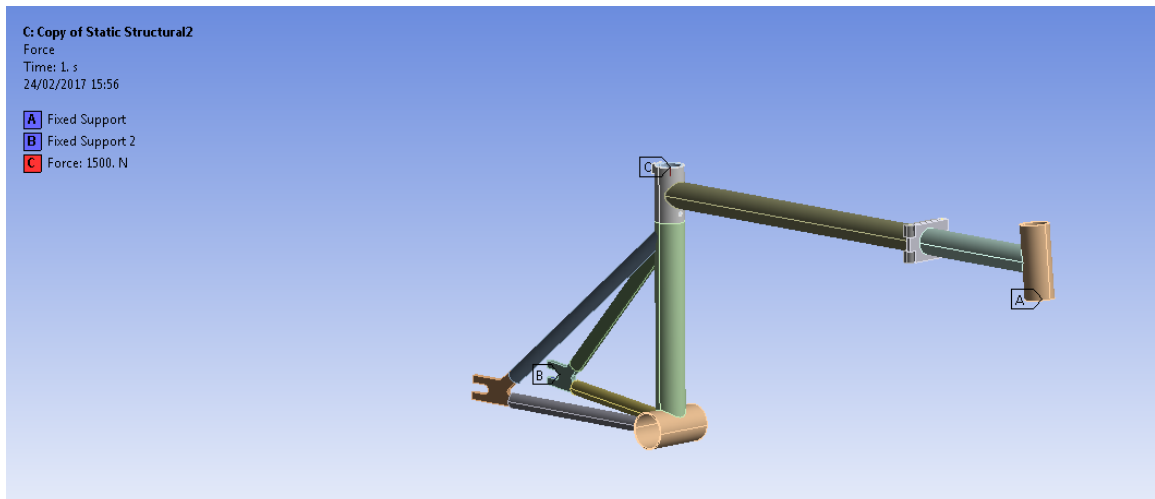


Figure 21: Load & Support Location for Load Case 2

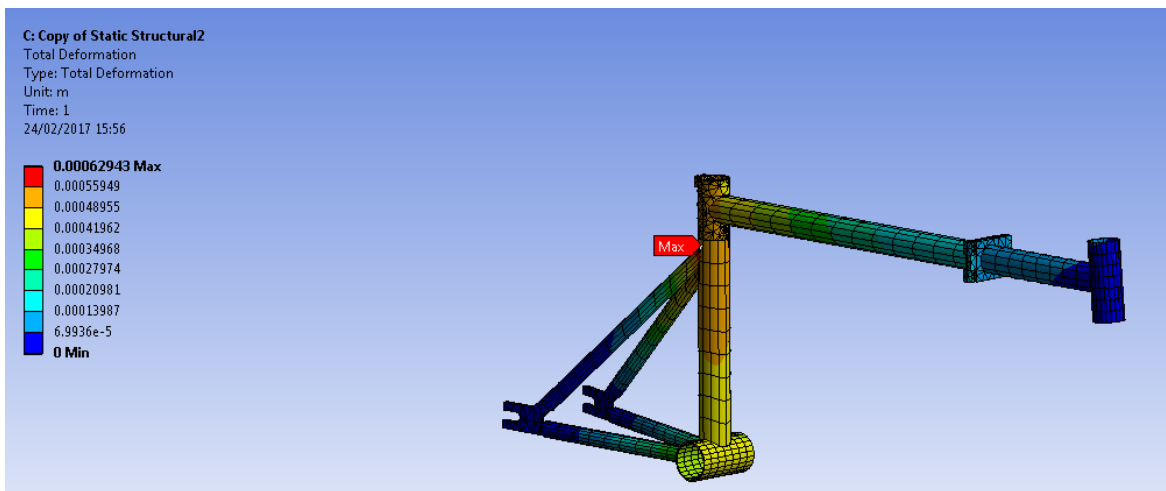


Figure 22: Equivalent von Mises Stresses of Load Case 2

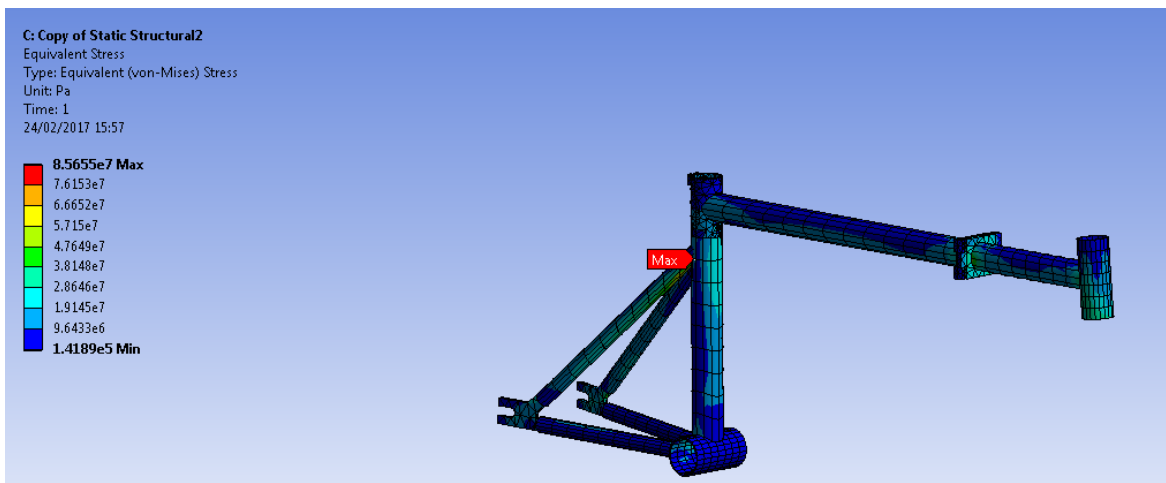


Figure 23: Total Deformation Due to Load Case 2

Looking at **Load Case 2** we can see again that the maximum stress has moved to the top of the rear triangle at the joint between tubes and there remains a high stress region around the hinge (**Figure 22**). The total deformation (**Figure 23**) also occurs in a similar location to **Load Case 1** and is once again very small. However, there is a greater amount of deflection in the first half of the top tube although still minimal.

The results from both load cases confirmed that the areas of stress were where the group thought they would occur. From the analysis, the group had confidence in the design, however, it was identified that areas such as the hinge to top tube joints would need to be welded precisely to ensure that the frame would hold under the weight of a cyclist. The total deformation results gave the team further confidence that the design of the frame would be suitable under the loading conditions that it would be typically subjected to. Therefore, the conclusion was drawn that from the FEA the aluminium tubing chosen for the design would be suitable for the design.

8.5 Drivetrain

Once the detailed design of the frame had been finalised a more detailed investigation into the drivetrain system was conducted. The team had already decided that standard parts such as bottom brackets and cranks would be bought as part of the drivetrain as these would be too complex to design and manufacture. Although the specification of sizes had not been decided until the detailed design had been conducted, the team identified three main factors to consider when deciding on the specifics of the drivetrain: the wheel size, the crank arm length and the gearing ratio. For this prototype, it was decided that a single speed system would be most suitable due to its simplicity and its weight savings. As the wheel size had been determined already, and is relatively small, the single speed system would need a gearing ratio equal to or greater than two. This would provide a suitable gearing ratio to start from a stationary position without the need for overexertion and provide easy pedalling at cruising speeds.

The crank arm length also plays a role in the ease of pedalling, with a longer crank arm giving more leverage. Unfortunately, due to the compromise in wheel size the crank arm length would need to be shortened to ensure acceptable ground clearance while cycling and therefore a crank arm length of 140mm was required.

The team discussed the addition of using gears in the bicycle design for future versions of the prototype. A simple light weight single speed gearing system was decided for the initial prototype as it saved weight and made the design of the bicycle simpler. Additionally, a single speed system does not require as much maintenance from the owner and this can be appealing for people with a limited knowledge of bicycles. However, in future, the addition of gears could make the bicycle more appealing to a greater number of customers. Two main concepts were discussed for the future of the gearing system of the bicycle: using an integrated hub which could house 3 to 6 gears, or by adding a rear derailleur and a small cassette. Adding a rear hub with internal gears would be a relatively simple option, however, this would add considerable weight to the bicycle. Other factors such as the wheel size mean that a custom rear wheel would need to be built on the hub and this would increase the cost of the bicycle considerably. The other option when trying to introduce gears to the design is by using a rear derailleur and cassette. This increases the complexity of the rear triangle design. Mounting the rear derailleur needs to be done accurately to ensure that the cassette gears line up with the moving rear derailleur, to allow smooth transition between gears. Furthermore, a rear derailleur hanger would have to be incorporated into the bicycle design meaning that the rear dropouts would have to be altered. Once again, an increase in weight would be noticed, however, it would not be as large as an integrated hub. The bicycle would take longer to manufacture and assemble, and therefore increasing the labour costs required for each bicycle.

8.6 Steering System

A sub team was created and made responsible for the design of the steering system. Due to the specifications of the locker, the steering system was also required to fold. As with most folding bicycles a hinge is typically placed at the base of the steering column to allow the bars to fold down next to the forks. The team decided that this simple solution was the best way, and keeping the steering tube as a single tube rather than a telescopic system would be best. The handlebars themselves also needed to be folded as they took up too much space as a single piece beside the front fork. Inspiration for the folding design of the handlebars was taken from children's micro scooters which have detachable handlebars. A similar push button system was determined to be the easiest system to secure the removable parts of the handlebars and to allow them to be detached easily.

FEA was conducted on the design to ensure that the detachable handles on the handlebar could withstand the forces that may act on it. A basic load case is shown in **Figure 24**, with the center of the handlebars fixed and opposing forces placed on the ends.

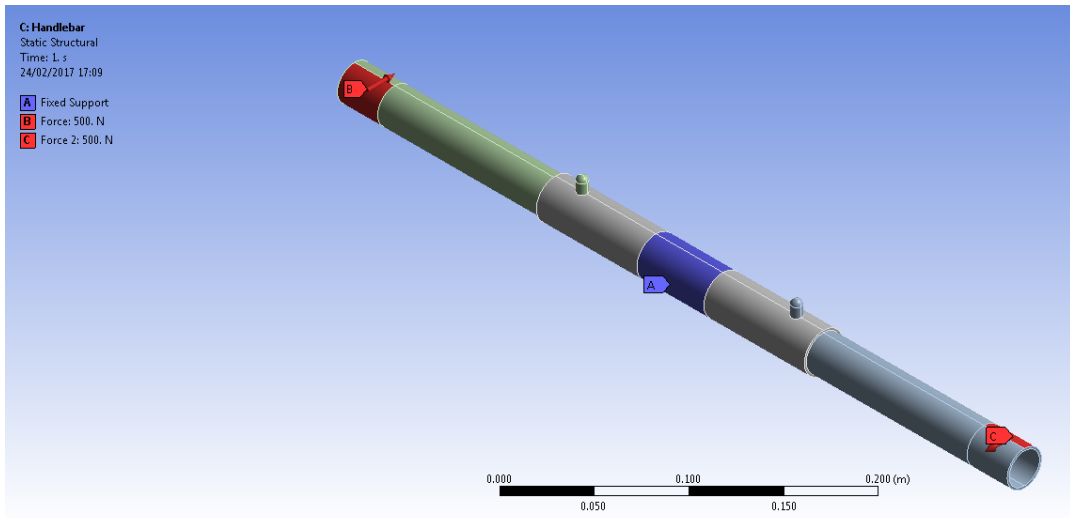


Figure 24: Load & Support Location for Handlebars

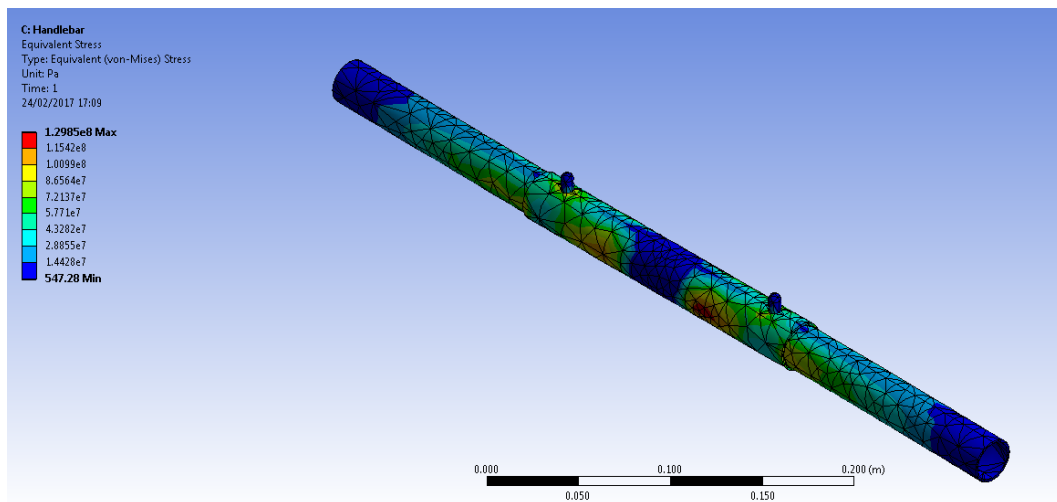


Figure 25: Equivalent von Mises Stresses of Handlebars

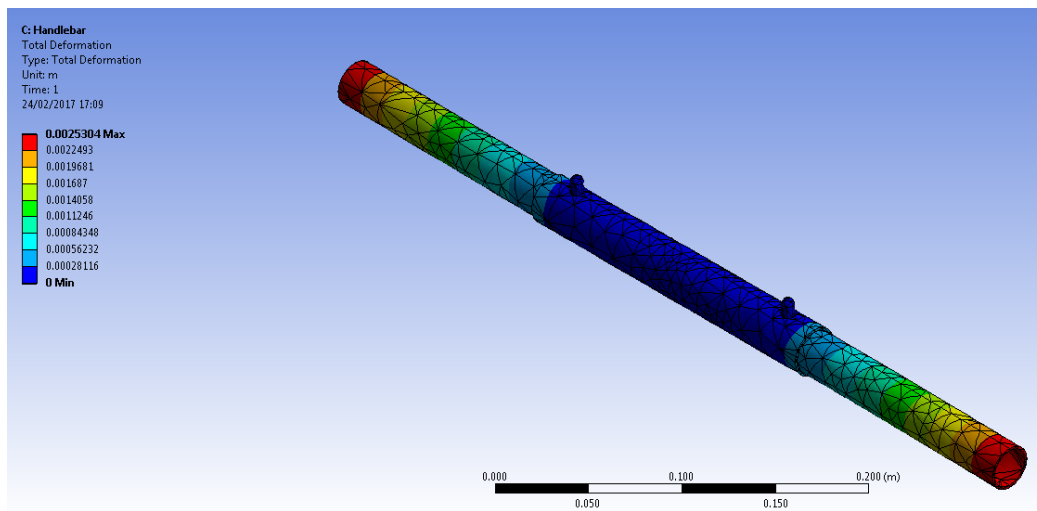


Figure 26: Total Deformation of Handlebars

The FEA shows that the handlebars designed should withstand any large forces acting on them. As expected, the maximum stresses occur in the areas at the junction between the tubes (Figure 25) and the total deflection is minimal at 2.5mm (Figure 26). As there is no excessive deformation, this is reassuring as the handlebars are a key part of the bicycle. To attach the handlebars to the steering column a standard stem was used as it provided a quick and light weight solution. Designing the steering system to a standard stem would also allow customers to alter the length of the stem by buying a longer or shorter one. This would allow the rider to tailor the bicycle accordingly, to ensure the greatest comfort when cycling. The steering column could also be cut to size depending on the height of the rider again to customise the riding experience.

8.7 Braking System

From the CDIO Design Challenge specifications, the bicycle had to adhere to all *BSI EN 4210* codes, with the code for the braking system being the most vital. Although this has not been shown in the detailed design, the front fork purchased for this prototype has a front brake already mounted on to it. The rear brake mount position was hard to determine, therefore, the mounting position of the brake was chosen when the rear triangle of the frame had been completed. A piece of $\frac{3}{4}$ inch pipe was used to create a mounting point for the rear brake, and this was welded in place once the rear triangle had been completed.

8.8 Seat Tube

The seat tube was originally designed to be a straight tube with the saddle placed on top with a clamp. During week 5 of semester 2 the team were waiting for manufacturing and decided to further investigate the seat design, in order to create a better cycling position. The team looked at using a setback on the seat post to compensate for the steep seat tube angle. The wheel base of the bicycle is narrow as a result of the specifications. This meant that the angle of the seat tube was close to 90°, leaving the saddle almost directly above the pedals, therefore making an uncomfortable riding position. The setback would be placed at the end of the seat post allowing for the saddle to be placed further back from the seat post, thus creating a more comfortable riding position for the cyclist. The seat post would then come off and be placed beside the bicycle in the locker. Another suggestion by some members of the team, which had been in previous concepts, was the possibility of using a telescopic seat post. This would allow the seat post to drop low enough so that it could fit in the locker without removing it from the bicycle. Analyses on the setback seat post, as well as the telescopic seat post with setback, were conducted to assess the feasibility of both designs.

Setback seat post Design:

The seat post design consists of an aluminium tube of 25.4mm diameter (a standard tubing diameter used in bicycle components), 1.5mm thick and 500mm in length with a setback piece at the top of the seat post. As part of the analysis the setback length was adjusted to find the best length that could be achieved without excessive deformation. The setback was altered from 70mm to 110mm in length in 10mm increments. A force of 1,500N was applied where the saddle would be situated. The reason for a 1,500N force is to account for a factor of safety in the analysis. The maximum allowable load stated by BCS on the bicycle is 1,000N, therefore if the components can withstand a force of 1,500N then the seat post would be suitable for use. A static constraint was applied to the bottom 100mm of the seat post as this section is located within the seat tube and would be clamped in position.

The initial results showed high deformations and as such a small bar was introduced between the seat post and the set back to stiffen the structure. This improved the results and the deformations for each setback were plotted into a graph as shown in **Figure 27** below. As can be seen in **Figure 27** the deflections of the seat post assembly are relatively high at 8mm being

the smallest deflection, with the deflections increasing in a linear fashion as the length of the setback increases. From this analysis it was determined that the stiffening bar did have a positive effect on the deflection of the beam.

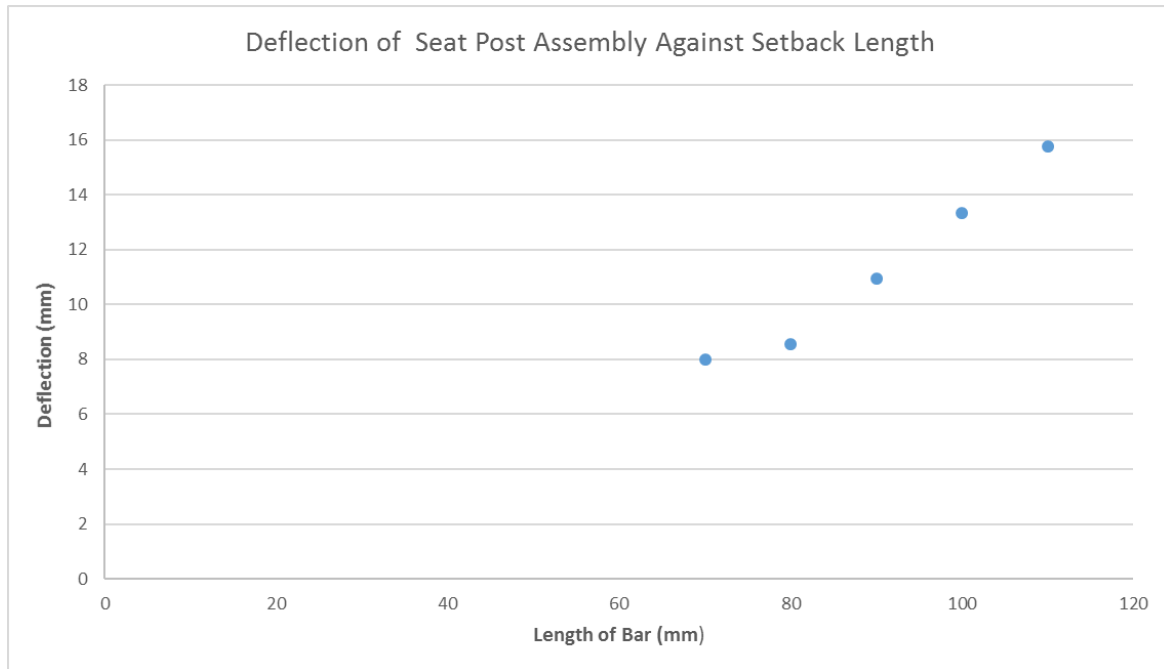


Figure 27: Deflection of the Seat Post Assembly

To try to reduce the deflection further, the seat post was thickened to 3mm and the analysis repeated using the same loading conditions to see how this would affect the deflection. The results of the second analysis are shown in **Figure 28**. Once again, a linear relationship between the setback length and deflection can be seen. From **Figure 28** the results have effectively halved with the lowest deflection at a 70mm setback length being 3.7mm. This is a vast improvement on the previous 1.5mm thick seat post and produces a deflection that would be less noticeable to the user. The deflection nonetheless is still relatively large and would most likely be noticed when the force is applied.

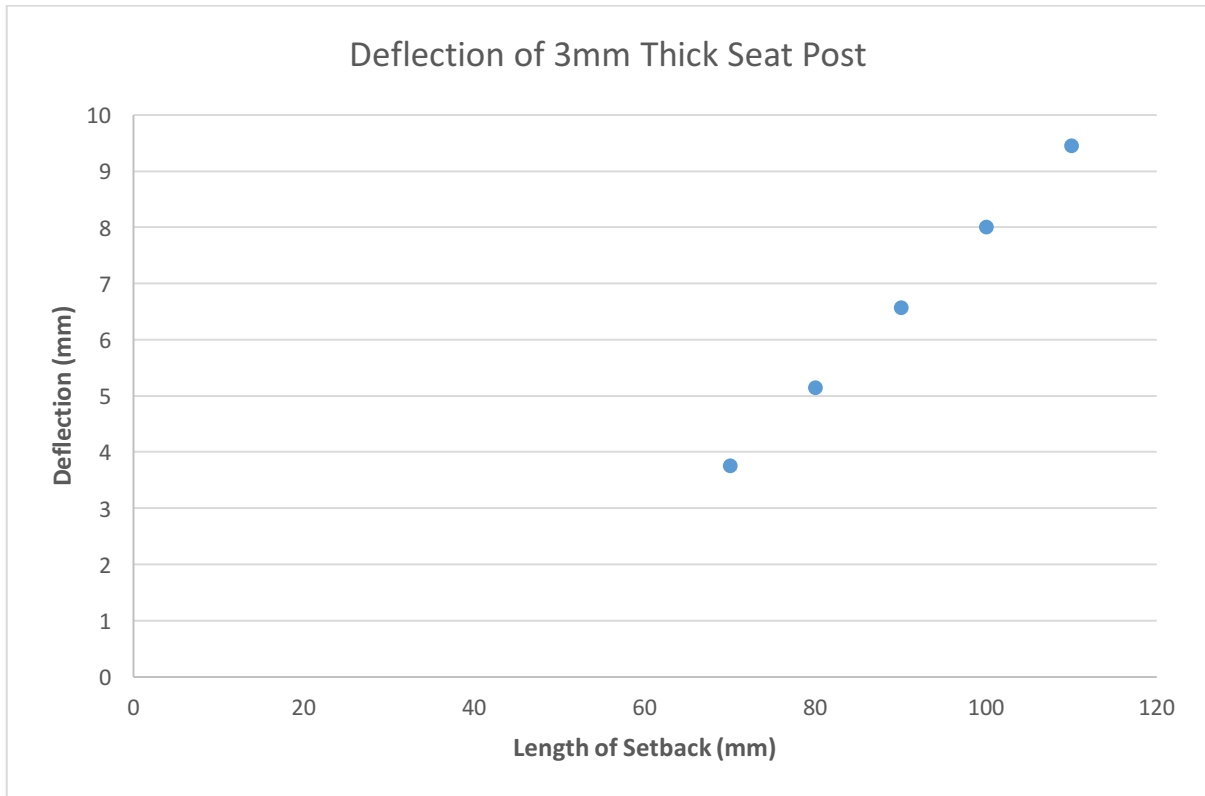


Figure 28: 3mm Thick Seat Post Deflection

The analysis was conducted once more with a 1.5mm thick mild steel tube to compare the deflection plot generated. The results of this analysis are shown in **Figure 29**.

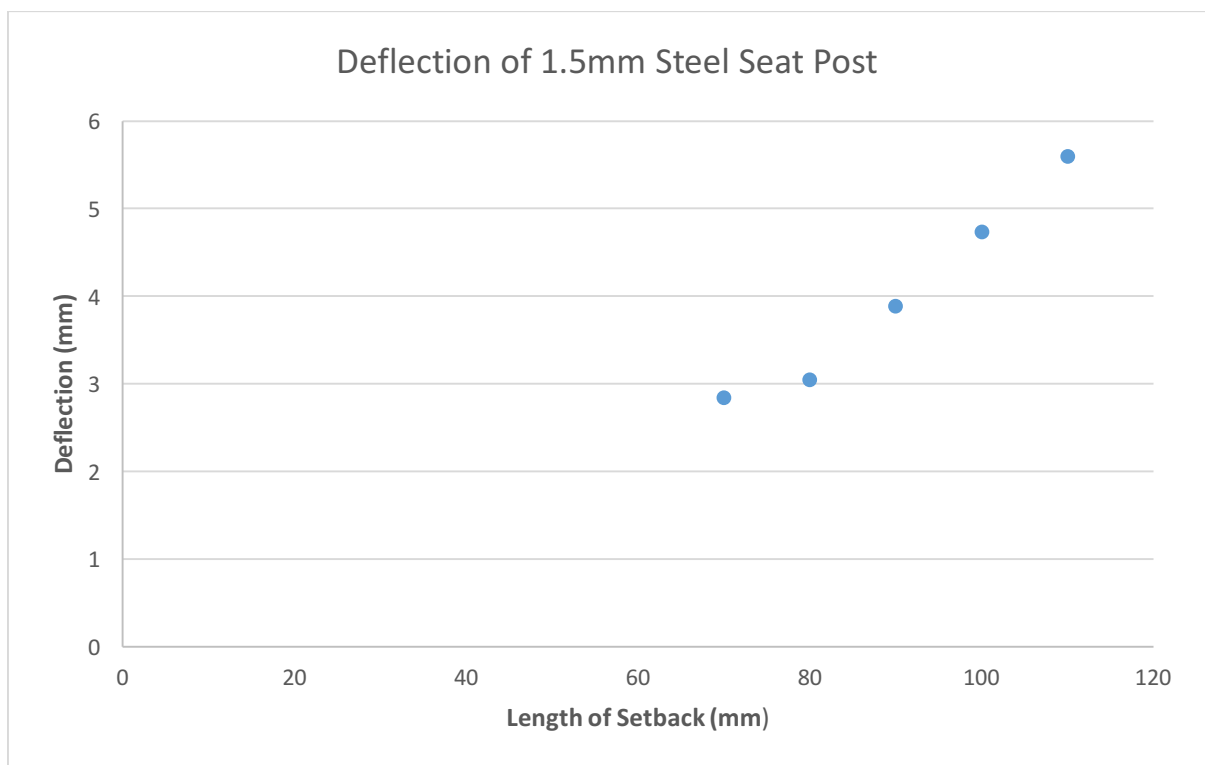


Figure 29: Deflection Generated with a Steel Seat Post

As expected the deflection of a steel seat post is smaller due to its greater strength and greater Young's modulus. The minimum deflection is 2.8mm and this deflection is more desirable. It is desirable to have the lowest deflection possible from a safety point of view and was therefore agreed that the setback bar would be 80mm in length. The reason the 80mm bar was chosen as opposed to the 70mm bar was due to the fact that the 70mm setback would provide very little benefit in terms of riding comfort. Although an 80mm bar is only 10mm in difference it would improve ride comfort and the deformation is still acceptable.

Telescopic Seat Post:

The telescopic seat post consisted of two 1.5mm thick tubes, one of length 250mm and the other 300mm. The external diameter of the longer tube was 25.4mm and the external diameter of the shorter tube was 22.6mm. The overlap of the two tubes was made to be 100mm. The same conditions were used as the previous analyses with a 1,500N force applied to the area where the saddle would be positioned and a fixed support applied at the bottom 100mm. For this analysis, the setback was only analysed at a length of 80mm. The deformation for the aluminium telescopic tube was found to be 9mm and this deformation is comparable to a straight aluminium tube of 1.5mm. The same assembly was then repeated with mild steel and the same setup applied to the model. The deformation of the telescopic steel seat post was found to be 3mm. Finally, the analysis was repeated but instead both tubes were made to be 3mm thick and with the same set up, the deflection was tested and was found to be 1.6mm.

From the analyses, it was concluded that a telescopic seat post could be as good as a straight seat post with some further work. Both the setback with stiffener and the telescopic design were improvements in the ergonomics of the bicycle over the original design. Steel proved to be better than aluminium for a seat post due to the lower deflections. This is attributed to its greater strength properties. However, as stated previously in the market research, steel is a very dense material and would make a heavy seat post. Due to the weight constraint set by the CDIO Design Challenge a steel seat post would take up a lot of the available weight meaning weight savings would be required in other parts of the design. Aluminium is sufficient in terms of strength, the deflections however, are tolerable but the savings made in weight compensate for this fact. On completion of the analyses the team decided that within the available time left before the completion in Belfast, it may be possible to improve

the design by manufacturing the simple setback seat post rather than the more complicated telescopic seat post.

9.0 Final Design

The final design was completed in week 3 of the second semester. All dimensions had been determined and all FEA completed on the necessary components, ensuring that the design was structurally sound. A final 3D CAD drawing of the frame (**Figure 30**) was created so that all the necessary drawings required for the manufacturing process could be made. In addition, renderings of the frame were created to get an impression of what the bicycle would look like, allowing the group to update the website with concept images of BCS's prototype.



Figure 30: Final Frame Design Rendering

With the CAD model completed for the frame, a CAD model was created as a representation of the whole bicycle (**Figure 31**). This provided the group with a good visualisation of how the bicycle would fully fold, allowing further thought to be put into the fine details such as the hinge pins and bolts.



Figure 31: Final Folding Bicycle Design Rendering Unfolded & Folded

With the 3D CAD representation finished, the Lead Design Engineer signed off on this initial part of the design phase so that the drawings for the prototype could be made. The bicycle was split into sections and allocated among the team, with work to be completed within a week, as the design stage had taken slightly longer than originally anticipated, with all drawings being completed within week 4 of the second semester. During the final process of completing the design and creating the drawings, raw materials were being sourced by the Lead Manufacturing Engineer. With the completion of the drawings during week 4 all the tubing had been sourced to allow the frame portion of the manufacturing stage to proceed, with the raw materials for the steering system and seat post being sourced in subsequent weeks. At this stage, the Lead Design Engineer had signed off on the last stages of the detailed design phase and the Lead Manufacturing Engineer then took over the submission of all necessary materials and drawings to the workshop to be cut and welded.

10.0 Parts Procurement

Parts and material procurement was a major step between the detailed design and manufacturing stages. This section was overseen by the Lead Manufacturing Engineer, with input from the Lead Design Engineer and the CFO. The materials necessary to manufacture the bicycle were sourced as quickly as possible and a number of quotes found per part to ensure best value. Where possible, though without compromising on price or quality, local retailers were chosen to reduce delivery times. All materials and parts were sourced and listed by the design and manufacturing teams to be signed off by the client. However, due to delays in some of the design, BCS decided to take a financial risk and ordered parts without final sign off from the client to ensure that the bicycle would be built in time. As both the client and team were busy this was the only way BCS considered that it could be completed on time. Having arranged a meeting with the client after parts had been ordered there were no issues and all parts that had already been bought were approved. All aluminium tubing and plates, apart from the head tube and bottom bracket sleeve, were sourced locally in Glasgow, with the head tube and bottom bracket sleeve being sourced from a specialist frame building company, Ceeway bicycle suppliers. As the team had decided to use a standard bottom bracket sleeve and standard head tube these parts were sourced during the design stage. These parts proved more difficult to find as aluminium versions of head tubes and bottom bracket sleeves are difficult to acquire within the UK.

In addition, standard component parts were sourced online as they tend to be cheaper and easier to source. Components such as the bottom bracket, headset, crank set, pedals etc. were all purchased from online bicycle retailers. Other parts such as the wheels, brakes and front fork were kindly donated by our sponsor The Bike Station.

A parts list detailing sources, quantity and related drawings, where applicable, have been included in **Appendix K**.

11.0 Manufacturing Process

With the detailed design and drawings completed, the Lead Design Engineer handed over to the Lead Manufacturing Engineer who oversaw the manufacturing process, including the acquisition of all necessary materials with the CFO. Several manufacturing techniques, including milling, drilling, welding and water-jet cutting, were employed to bring the bicycle into being. This section of the report will look at the manufacturing processes and how the bicycle was eventually assembled.

11.1 Construction of the Top Tube Assembly

The frame was the most complicated part of the design, requiring the tubing to be cut to size and welded together. The welding was conducted by the university technicians as BCS do not have sufficient skill and health and safety training to conduct the work itself. All engineering drawings were given to the technicians and were discussed in detail to confirm that it was possible to fabricate the proposed design or if any changes to the design were required. No major issues were identified and the drawings were submitted to the technicians to create the frame of the bicycle.

Construction of the frame began with connecting the head tube (with the head tube's bearings being pressed in previously) to the top tube of the bicycle. Firstly, the head tube was cut to its correct length of 90mm and the profile of the top tube was cut and filed with the total length of the top tube measuring 518mm. The profile of the top tube would allow the tube to fit around the head tube. To allow for welding, a basic rig was set up to keep both pieces of aluminium in position and the two sections were then welded together.

The next stage in the construction of the frame was to weld the rotating tube to the other end of the top tube. Similar to the head tube, the rotating tube was cut to a length of 60mm and the top tube profiled to fit the seat post. The rotating tube and top tube were then welded together as shown in **Figure 32**.



Figure 32: Rotating Tube (Left) Welded to Top Tube & Hinge (Right)

Now that both ends of the beam had been fixed to the seat tubes and head tubes the fold could be created. The top tube was cut 150mm from the head tube and filed to create a flat edge. Both halves of the hinges were welded to the top tube sections and this completed the manufacture of the top tube assembly.

11.2 Back Triangle

The back triangle is one of the more complicated aspects of the design and also the most difficult part to manufacture. There were several steps required to generate this section. The first step in the manufacturing of the back triangle was the welding of the two concentric tubes which would form the seat tube. The seat tube insert was placed within the seat tube, creating one tube which was welded together. The rotating tube attaches to the top tube allowing it to rotate around the seat tube insert. At the base of the seat tube, the bottom bracket was welded and this completed the vertical section of the back triangle.

The next stage in the manufacture of the rear triangle was the two triangular sections, the connection of the seat stays, chain stays and the rear drop out mounts. This section is required so that a rear wheel can be attached. As shown from the technical drawings (**Appendix K**) two aluminium tubes of diameter 19mm and length 170mm protrude perpendicularly from the bottom bracket to form the chain stays and are situated at an angle of 24° from each other. A rig was essential for this part of the process and both tubes were profiled and welded to the bottom bracket. Similarly, there are two aluminium tubes of diameter 19mm and length 260mm and situated at the same angle from each other as the chain stay tubes, these being the seat stay tubes. The seat stay tubes are angled 47° from the horizontal chain stays. These tubes were profiled to fit with the seat tube and a rig was set up to allow for the tubes to be properly aligned. **Figure 33** provides a visual representation of the completed model of the back triangle, with all the components annotated.

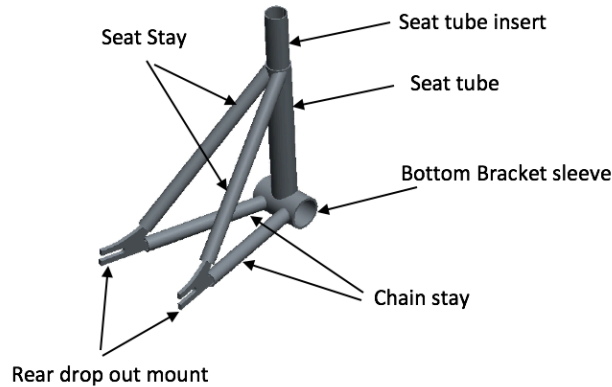


Figure 33: CAD Model of Back Triangle Assembly

The final part of the manufacturing process to complete the back triangle was the creation of the rear drop out mounts (rear wheel mounts). This component was created on Creo and the water-jet cutter was used to cut a plate of aluminium to shape. Two rear dropout mounts of the same dimensions were created and these components were slotted into the protruding pipes. The distance between the rear dropout mounts was dictated by the width of the wheel and this set up was placed on a rig. The distance between the rear dropout mounts also determined the angle of the seat stay and chain stay tubes between the bottom bracket and mounts. The bottom bracket was also placed on the rig and this allowed the technicians to align the seat stay and chain stay tubes in the correct positions to be welded. **Figure 34** shows the rig which was used to weld the chain stays, seat stays and rear drop out mounts into position.



Figure 34: Rig Set-Up for Back Triangle Assembly

11.3 Hinges

Sourcing appropriate hinges proved to be a difficult task. Most hinges are made of steel and would have to be welded to the aluminium tubing and this is difficult due to the use of two different metals. Aluminium hinges were also researched but the majority of hinges available were not of the appropriate size or strength. The group decided that the best approach would be to create bespoke hinges. The hinges were designed to fit the demands of the bicycle and it was decided to make use of the water-jet cutter available at the university. The water-jet cutter cut out the top profile of the hinges. The second step was creating the shape of the hinges and this was achieved using the milling machine. When the profiling and shape of the hinges were finalised the hole that would join both halves of the hinges were drilled using a pedestal drill.

11.4 Handlebars

The handlebars were manufactured from two aluminium tubes. A 28.6mm tube with a 1.5mm wall thickness and a 25.6mm tube with a wall thickness of 1.5mm. The design for the handlebar is deliberately simple but one which BCS feels is the most effective. The smaller tube was cut into 20cm lengths and a 7mm hole drilled 2cm from one end of each tube. Taking inspiration from micro scooters, the same push button system was used. Push buttons were sourced and placed within the smaller tubes. Two holes were then drilled again 2cm from each end of the larger tube. The smaller tubes slot into the larger tube with the push buttons fitting perfectly into the two holes created, **Figure 35**.

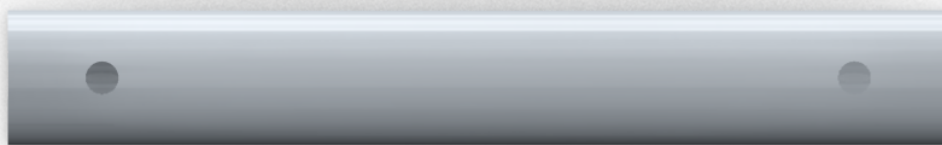


Figure 35: Centre Handlebar Tube

The larger tube was not a standard size for a standard stem. However, if the tubes were any larger the handlebar grip would not be comfortable. Therefore, a shim was made for the larger tube which would allow it to be clamped. In the future, a double butted tube (**Figure 36**) could be used as the centre tube creating a cleaner look.

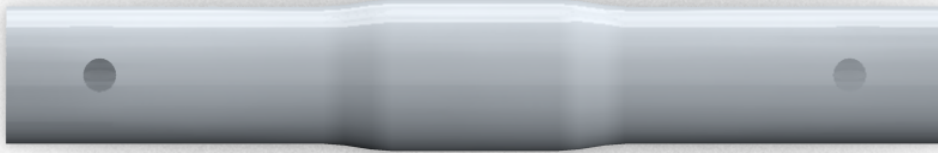


Figure 36: Double butted centre handlebar tube

11.5 Seat post

The seat post consists of an aluminium tube of diameter 25.4mm and 3mm thickness. The seat post slots into the seat tube and is clamped to hold its position. The seat tube was cut to 500mm. The seat setback consists of an aluminium bar 0.5 inches thick (12.77mm) and 1.5mm wide (38.1mm) and was cut to a length of 80mm. The seat set back has the seat post placed through the setback and sitting flush with the top side of the setback. The hole is 25.4mm in diameter and the centre of the hole is situated 22.5mm from the end of the aluminium bar and is cut using the milling machine.

There is another hole of 11mm placed 20mm from the other end of the set back which is again cut from the milling machine. This hole is for the position of the seat clamp. To allow the seat clamp to fit properly on the set back a groove is to be carved out. This groove has radius of 33.33mm and will penetrate the top side of the set back by 5mm creating a shallow curve in the aluminium. The seat post will then be inserted to the set back and welded together. The final part of the seat post is the supporting bar that acts as a stiffener and connects the rear end of the set back to the seat post. The stiffener measures 8mm in both width and depth and is angled 45° between the seat post and setback and is placed centrally to both components. One end of the bar will be profiled to match the curve of the seat post and this can be achieved by filing the aluminium. The stiffener will then be welded into position completing the seat post assembly. At the time of completion of this report the seat post tube has not been completed. The completed setback component is shown in **Figure 37**.

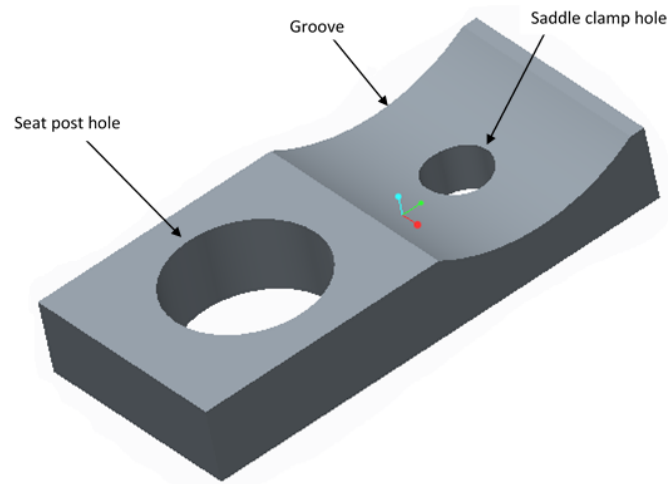


Figure 37: Setback Piece

11.6 Head Tube

The head tube encapsulates the forks, the steering tube and the head cups. The fork was taken from an old bicycle as this would give the correct clearance for a 14-inch wheel. The head cups had to be pressed inside the head tube before being placed over the front fork. The head cups have to be inserted carefully so that they are aligned correctly as this would ultimately affect the steering of the bicycle. The Bike Station helped us in this process, in part due to their experience with bicycles and they also had the correct tools to carry out this procedure properly. This process required the use of a headset press tool: the headset press tool is essentially a big screw that is used to pull the head cups into position inside the head tube. The head tube and the head cups were positioned on the headset press. The bolts on either end of the head set press were tightened and this slowly forced the head cups into the headset press. One of the head cups did not align properly with the head tube and when inserted was slightly out of position. This was resolved by applying modest force to the head cup until it was correctly aligned within the head tube.

11.7 Steering column

The stem connects the fork and handle bars to the bicycle frame. The steering column consists of a tube 28.6mm in diameter, 1.5mm thick and 500mm in length. This tube was welded to one half of the hinge. The other part of the steering column consists of a tube of 22.2mm in diameter, 1.5mm thickness and a length of 80mm. This tube was then welded to the other half of the weld and was inserted inside the fork. The tube on the bottom section of the

steering column was cut at a 45° angle and was bolted into the fork using a wedge shaped nut keeping the steering column in position.

11.8 Final Assembly

The final assembly brought together all parts of the bicycle and this task was carried out by Bike Centric Studios. The team began with the assembly of the top tube. The first step was addressing the top tube hinge. This was bolted together at one end allowing it to rotate, and it was closed at the other end using a removable pin. The rotating tube was placed on the seat tube insert and a clamp was placed over the rotating tube, holding the rotating rear triangle in place. A star knob bolt was cut to size which was then screwed into the rotating tube, so that the top tube could be aligned in the correct position. The seat post was then placed into the seat tube insert and this too was clamped, holding the seat in position.

The rear triangle section required the assembly of the rear wheel, brakes, chain, crank set and folding pedals. The crank set was from an old child's bicycle kindly donated to us from our sponsors The Bike Station. It contained three chain rings on the crank set, however only one was required. The middle chain ring contained 34 teeth and this provided a good gearing ratio with the rear wheel sprocket. The other two rings had to be removed as they were not required and this would also reduce the weight. The chain rings had been riveted together and could not simply be removed. The pillar drill was used to drill through the rivets and break them allowing the redundant chain rings to be removed.

The bottom bracket was then screwed into the bottom bracket sleeve, before the crank arms were placed on either side. The wheel was then bolted on to the rear drop out mounts and positioned to allow the chain to be adjusted. Once the chain had been measured it was attached over the chain ring and rear sprocket and the wheel tightened in place. The braking system was then bolted onto the brake mount and the brake pads aligned with the rim of the wheel. To finish the rear triangle, the folding pedals were attached to their respective crank arm.

The final section in the manufacturing of the bike was the front fork, steering column and handle bars. The fork was placed inside the head tube with the bearings greased and ensuring that they were seated properly before screwing the top nut into position. The bottom section of the steering column was then placed inside the fork and bolted into position. The

handlebars were connected to the top section of the steering column by using a stem that bolted both tubes into position. Both halves of the steering column were joined together at the hinge and bolted together, allowing the steering column to fold. This hinge had to be positioned at roughly 45° so that when folded it would sit flush with the front wheel. The front wheel was then bolted to the front fork and the front brake attached to the mounting point. The brake cabling was one of the last pieces to add. This involved attaching one end of the cable to the brake lever and the other to the brake calliper, before adjusting them to ensure safe and effective braking.

12.0 Testing

Testing was to have been completed by week 9 of semester 2 but was postponed to week 10/11. This was due to the delays with manufacturing, which caused the assembly of the prototype to commence during week 9. The team strove to assemble the bicycle as quickly as possible and to include as much information about the prototype as possible within this report. Painting and testing of the bicycle will take place in the following weeks with the aim of having the bicycle fully completed by the competition deadline in May.

13.0 Final Product

The bicycle was completed and the first prototype of the Urban Rider is below in **Figure 38**. There are some teething issues with the final prototype and these are mentioned in further detail in **Section 19**. Initial testing of the bicycle indicates that it can withstand the weight of a typical cyclist. The addition of a wire down tube was necessary to avoid any excessive flexing in the top tube. The clearance of the pedals currently is too low and smaller cranks have been ordered to address this. The mass of the bicycle was measured to be 8.9 kg therefore meeting the mass limit of the CDIO Design Challenge (**Figure 38**).



Figure 38: Final Assembly of Prototype

The final fold position of the prototype can be seen in **Figure 39**. The bike measures 58cm in height, 48cm in depth, and 40cm in width, occupying 111 litres. At face value, these dimensions would not allow the bicycle to fit inside the locker head on, however, the bicycle was designed to fit inside diagonally. As of submission of this report, size testing has yet to be undertaken.

In order for the bicycle to meet the specifications set by the CDIO Design Challenge several folds were required, thus increasing the required time to fully fold the prototype. Additionally, manufacturing issues such as the improper alignment of the quick release pins added to the length of folding time. This will be greatly reduced with further development and testing.

The rear triangle is held in position with a star knob bolt ensuring that the top tube can be locked into the correct position and so that the bike is aligned correctly. The top tube rotates smoothly around the rear triangle and can easily be clamped into position. The total folding time on average was found to be under one minute. As noted, this will be reduced with further development and testing.



Figure 39: Final Folding Position

14.0 Business Plan

BCS have prepared a three-year business plan which proposes that a limited company should be set up to manufacture the Urban Rider in Glasgow. This business plan outlines the formation of the company, examines funding options and outlines anticipated incoming and outgoing finances, all as detailed in **Appendix L**. A financial overview was created for the first three years to show projected sales, cost of goods sold (COGS), expenses and the operating profit of the BCS trading business.

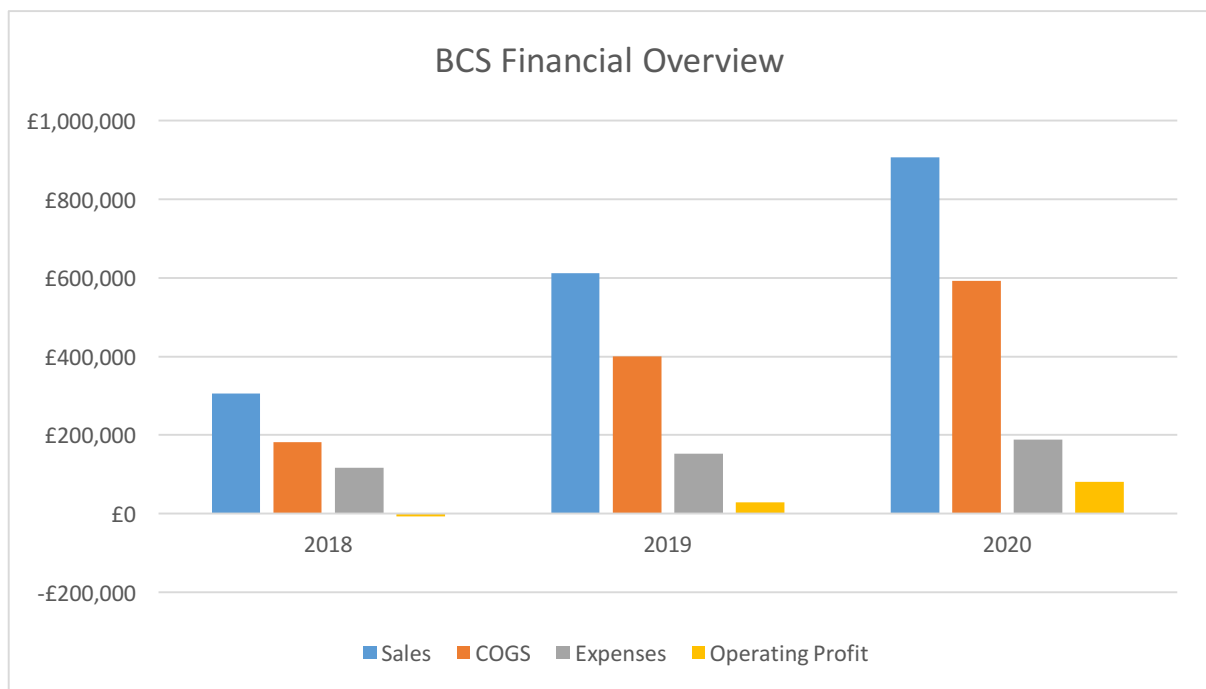


Figure 40: BCS Financial Overview

Figure 40 shows the results of this financial assessment, which excludes set up costs funded which will be funded by a small business bank loan. As expected, for the first year the company does not make an operating profit. This is largely because of the time taken to build up sales. By year 3 however, sales have tripled, and BCS is making a healthy profit. BCS is confident that it will reach its sales target as it will be selling a well-priced, lightweight and compact folding bicycle, which will make it stand out from its main competitors.

BCS is aware that cash flow issues cause many start up businesses to collapse. An indicative cash position has been prepared and this shows that the company can operate comfortably within its bank overdraft limits.

15.0 BCS Website

15.1 Function of the Website

The primary reason for creating a website is to promote BCS and its products to the world in the most cost effective and far reaching way possible. Such a website was one of the project's deliverables outlined in the ***Statement of Work***.

The website has been created using the free website builder Wix³⁰. This allowed the team to create a thorough and professional looking website without having to purchase a domain name, and allowed the entire budget to be spent on manufacturing of the prototype.

15.2 Structure

The first thing to consider when creating a website is the structure of the site and the headings to be included. After some market research, focusing on the layout and headings other bicycle manufacturers include, a meeting was held where the group deliberated on this topic, with the results shown below:

- **Home:** a brief introduction to Bike Centric Studios, our objectives and how to contact us.
- **About Us:** who Bike Centric Studios are and an explanation of the CDIO Design Challenge.
- **Urban Rider:** brief explanation of our bicycle from its design to manufacturing. This section also highlights to the customer how our folding mechanism is unique and details the reasons why they should purchase the Urban Rider.
- **Who We Are:** describes the team members' positions within BCS. A brief explanation of BCS's project management stages, milestones and main deliverables is also included in this section. This allows customers to see BCS's qualifications, so as to generate trust in the design and manufacturing of BCS's products.
- **Design:** explains the design process carried out for each part of the bicycle.
- **Manufacturing:** explains the manufacturing processes carried out to build the bicycle.

- **Sponsors:** a page dedicated to BCS's sponsors, the University of Strathclyde and The Bike Station, as within out them, the bicycle could not be built.
- **Shop:** shows customers all our available products for purchase with a brief description and their respective prices (this will be released publicly when trading commences).

The website has been created in a way that is easy to read and inviting to potential customers so as to give the best possible perception of BCS and its products and thus encourage the purchase of BCS products.

15.3 Building the Website

After all sections of the website were defined, the next step was to build it, following the instructions and guidelines of the website builder used. Each section was designed in a step by step process, taking care to protect the image BCS wants to portray to customers.

The header of the website where the BCS logo is shown, the email address where customers can contact our company and the titles of each sections of the website, all had to be created with customers' best interests in mind. A poorly designed website has the potential to subconsciously provide negative connotations of BCS and its products to potential customers, or simply deter them from making a purchase. Our team set out to create a dynamic website which draws the customer in and promotes BCS's products. A number of screenshots from the finished website are shown below:



Figure 41: Home Page

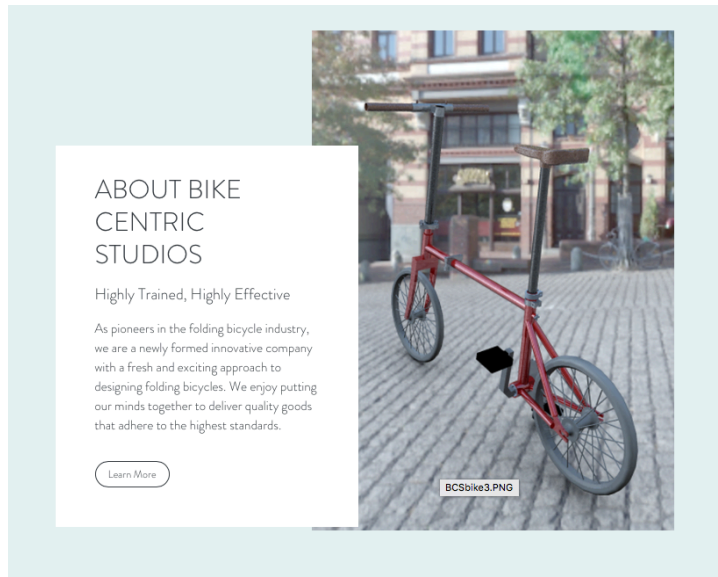


Figure 42: About BCS

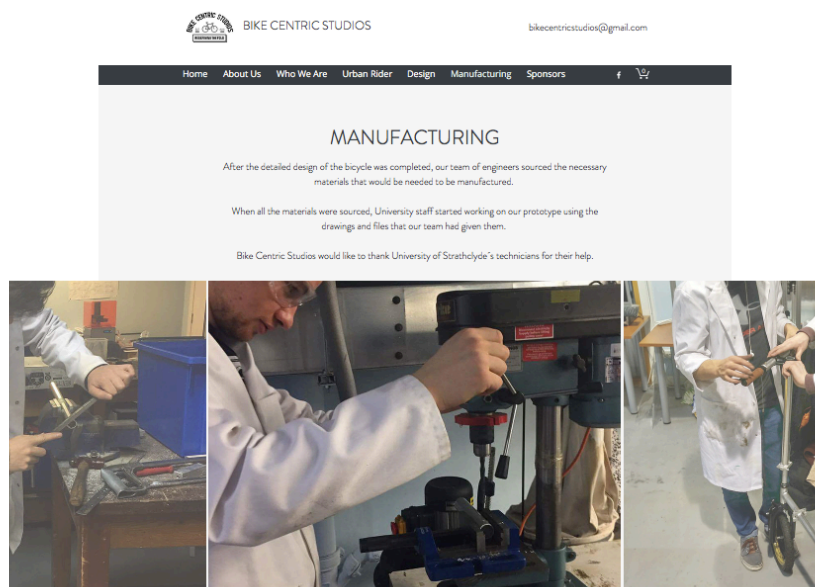


Figure 43: Manufacturing

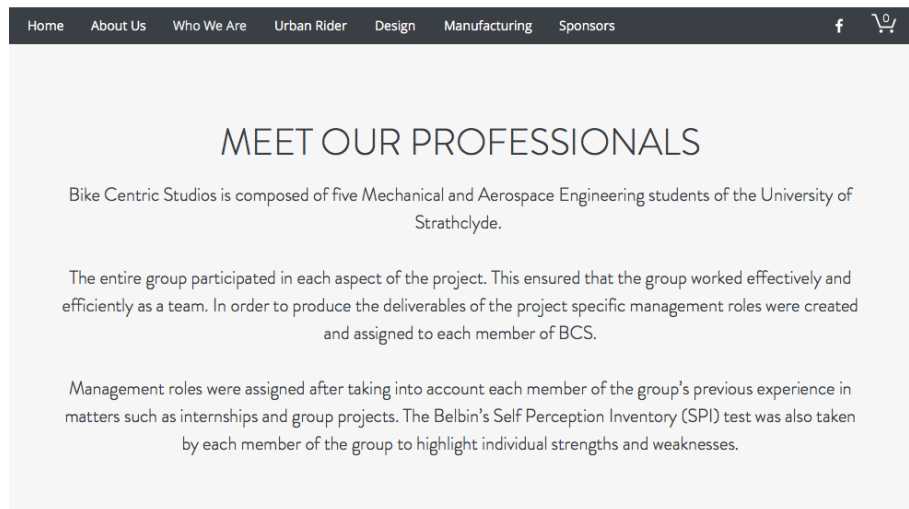


Figure 44: Meet Our Professionals

16.0 BCS Evaluation- Team

16.1 Semester 1

During the initial stages of the project, the planning, research and design phase, the group worked well together, using a combination of efficient planning skills and effective team collaboration. The benefit of creating an effective and appropriate management structure at the beginning of the project ensured that progress through the first semester was in accordance with the project plan. Each member knew that during the project it would be their turn at some point to take the lead role, allowing for the Chief Executive Officer to take a step back and allow them to take the reins, whilst still ensuring that project tasks and deadlines were still being adhered to. However, whilst there was always a group member in charge of each phase, all group members were involved in all the different aspects of the project. By making sure every project member was kept up to date with the current progress, the project ran without anyone falling behind and being out of step with the status of the current work package. This was achieved by having at least one meeting per week with all group members in attendance. Minutes were taken by the CFO in order to keep a record of all key decisions taken. Having weekly meetings allowed the group to give feedback to the project manager, and to discuss key issues which may have arisen during the week. An online group chat was also created, which meant the group could keep in daily communication should it be required. Both the weekly meetings and method of collaboration meant that no member became isolated, and ensured that key deadlines were met and any potential risks or issues were raised immediately as they occurred.

16.2 Semester 2

The successful team work and structure from semester one were carried over into semester two, which began with a meeting to discuss one slot a week when all members of the group were free to meet, with the duration of the meeting being increased in order to deal with the increased volume of work. As with semester one, this ensured that all members of the group knew what stage the project was at, and that any issues the team were encountering could be dealt with together.

At this point in the project, due to the different sub-projects which were commencing, work was divided accordingly. The Lead Design Engineer handed over to the Lead Manufacturing Engineer, as the final design had now been approved. Although the Lead Manufacturing Engineer took the lead, the Lead Design Engineer was involved with the manufacturing to ensure that the design was successfully carried through to the manufacturing stage. The website was also created, which was taken on by the research and development officer, whilst the CFO and CEO took responsibility for the business plan. One of the key strengths of Bike Centric Studios is the ability of all members to move between the different sub-projects if necessary, as for example, when assembling the final product, when all of the team were involved. By dividing up the work load evenly between the five members at the beginning of the semester, no member was overloaded by the sub-project they had been assigned.

One of the major issues the team faced however, was with manufacturing delays from the university's welding department. As students are not permitted to use this machinery, the parts were handed over to the technicians once they had been purchased from local suppliers in order for them to be machined and then welded into position.

During the period of delay, the Lead Design and Manufacturing Engineers explored other options for the seat post design in particular. Two new designs were investigated to see if these options were feasible to implement. After conducting FEA analysis, the team decided that with the time left they would try and manufacture a seat post setback on a straight tube. As the team explored these options, the set back seat post was delayed because of manufacturing constraints within the university. It should however be completed in time for the CDIO Design Competition.

From the project plan, it can be seen that the manufacturing stage was to be completed by 1st of March, in order to give the group time to assemble and test the prototype and address any issues that may occur. Completing the bicycle at this stage would also have allowed the team to complete the report in time for the final submission. To ensure that the team was not overloaded with work in the two weeks running up to the final deadline, emphasis was placed on establishing the main body of the report. Along with this, final parts were ordered so the prototype could be assembled and components such as the handlebars manufactured. The final week before the report submission was used to assemble the final prototype and make alterations to the report. The collective efforts of the group in the final week ensured

that the report was completed and the final prototype assembled in time for the presentation. Development of the prototype and further testing will be undertaken in time for the CDIO Design Competition on 10th of May.

To ensure that this project was a success, having a structured and well organised team was essential from a project management perspective. Dividing the different work areas amongst the team was essential in order to make sure that the workload was dealt with fairly and each member was given the opportunity to lead a section of the project, under supervision from the CEO. However, in order for each of the members to lead their respective work packages, the input from the CEO was kept to a minimum, except from involvement with key decisions and time management.

The meetings throughout the project were useful for all members of the group. Each meeting followed a general structure, whereby the meeting commenced with an update from the lead team member depending on the current stage of the project, a general discussion of any issues that had arisen, and finally the following weeks plan was outlined. This meant that the team had a clear idea of what was expected of them and key deadlines that were approaching. Along with key meetings, a group chat and forum was used for daily communication. These were highly useful when meeting times needed to be altered or a member of the group had an issue or key information to share. Minutes of meetings were published on the forum in the event of any team members being unable to attend.

When reviewing the project as a whole, BCS consider that its successful completion is due to the strong work ethic, variety of skills and effective collaboration by all members of the team. By ensuring that each team member kept up to date with the project and completed the work assigned to them when expected, including additional work during busy periods of the project, the team succeeded in designing and manufacturing a prototype in the form of the Urban Rider. It was unfortunate however, that testing and development of the prototype could not be completed, owing to circumstances outwith the control of BCS.

17.0 BCS Evaluation- Risk Management

Now that the project is complete, BCS has evaluated the effectiveness of its risk mitigation process.

17.1 Major Risks

- **Overdesign:** the design of the Urban Rider was intended to be as simple to use for the consumer as possible, while at the same time being technically advanced. With the help of the university technicians and especially discussions with Drew Irvine, BCS was able to achieve this goal.
- **Delays in Receiving Materials:** with proper time management, planning and the sourcing of local materials which were able to be collected, BCS were effectively able to mitigate this potential risk and delays in receiving materials so that this did not have a detrimental impact on the project.
- **Lack of Technician Availability:** as expected this was the area which caused the most delay to the manufacturing of the prototype. BCS attempted to take account of delays in its Gantt chart, however, this was still a major concern when the group had to wait almost four weeks for certain parts for be completed. This was due to an unfortunate series of events, with an unexpected retirement within the university technician staff and a breakdown in key university machinery at peak operating time for the technicians, further delaying all projects within the university, not just that of BCS.
- **Designing the prototype to the limits of the dimensional constraints:** BCS deemed this to be an acceptable risk as for the bicycle to be as ergonomic as possible it would have to push the limits of the available space. Due to the manufacturing delays a fully tested prototype has not been produced by the date of submission of this report.

17.2 Unidentified Risks

One risk that BCS did not account for, was slightly illogical standards in the bicycle industry and manufacturing errors. This was found when the group bought a standard size head tube which the headset cups were meant to be pressed into. After an attempt to fit the cups into the tube, the group learned that there are in fact two sizes of one-inch headset cup diameters, a smaller and larger size, which was unknown to the group. Although this was initially thought

to be the issue, it also transpired that the standard head tube had been manufactured slightly too small. This was an unforeseen circumstance as the manufacturing of the tube appeared to be outwith the tolerances. Unfortunately, there was not enough time to get a replacement tube. However, with the expertise of our sponsor, The Bike Station, their technicians were still able to press the cups in, although with some difficulty.

18.0 BCS Evaluation- Finances

Exercising control over the group's finances was a key aspect of the project in order to meet the required constraints of the CDIO Design Challenge. The Lead Design and Manufacturing Engineers and the CFO worked closely together in order to estimate as accurately as possible the total cost of manufacturing the prototype (**Table 3**). After this estimation was deemed to be on the limits of the available funds, sponsorship was sourced in order to try to eliminate the concern that there would not be enough funds to complete the project. Sponsorship was agreed with The Bike Station and BCS was generously offered spare parts and manufacturing assistance with regard to certain complex components.

When sourcing the parts required for the project, a minimum of three quotes were obtained in order to confirm that the price being quoted was fair and to ensure that the group got the part for the best price available. After these quotes were obtained, all expenses were signed off by the CFO who regularly monitored and updated the budget sheet in order to effectively keep track of the group's finances. In addition to this, after each purchase, a comparison was made to the estimated cost of that material/ part in order to gauge the accuracy of the original project cost estimate. This helped to determine whether or not the group would be within the stated budget as the project progressed.

Table 9 shows the breakdown of the estimated material costs at the beginning of the project, the actual cost of the materials for the chosen design, what BCS paid for those materials (often this sum was zero due to the generous sponsorship from The Bike Station) and thus any increases incurred or savings accrued. It can be seen, that through The Bike Station's sponsorship, BCS has managed to save an estimated £160, and the total cost for the prototype was £301. This sponsorship ensured that the project remained within the CDIO Design Challenge budget.


| Bike Centric Studios | |  | | Project Budget | |
|--------------------------------------|------------------|---|----------------|----------------|--|
| INCOME | | | Paid | | |
| Group Project Standard Funding | | | 500 | | |
| Total Budget | | | £500.00 | | |
| EXPENSES | Estimated | Actual | Paid | Savings | |
| Bottom Bracket | 20 | 15.49 | 15.49 | 0.00 | |
| Brake Levers | 30 | 22.99 | 19.91 | 3.08 | |
| Braking calipers | 40 | 40.00 | 0.00 | 40.00 | |
| Cables | 10 | 9.00 | 9.00 | 0.00 | |
| Chain | 5 | 6.99 | 0.00 | 6.99 | |
| Crankset | 20 | 16.00 | 16.00 | 0.00 | |
| Grease | - | 4.99 | 4.90 | 0.09 | |
| Grips/ bar tape | 10 | 6.99 | 6.99 | 0.00 | |
| Handlebar Push Button x2 | - | 3.90 | 0.00 | 3.90 | |
| Headset | 15 | 11.99 | 11.99 | 0.00 | |
| Hinge pins/ bolts | 30 | 16.50 | 48.75 | -32.25 | |
| Paint | 25 | 16.24 | 16.24 | 0.00 | |
| Pedals | 15 | 8.99 | 8.99 | 0.00 | |
| Saddle | 20 | 19.99 | 0.00 | 19.99 | |
| Seat Clamps x2 | 10 | 7.98 | 7.98 | 0.00 | |
| Seat Rail Clamp | 10 | 5.99 | 5.99 | 0.00 | |
| Stem | 20 | 19.99 | 16.20 | 3.79 | |
| Stickers | 10 | 10.00 | 10.00 | 0.00 | |
| Tubing & Plates | 100 | 91.39 | 91.39 | 0.00 | |
| Tyres | 14 | 10.99 | 10.99 | 0.00 | |
| Wheelset (Rims, Hubs, Spokes, Tubes) | 100 | 117.00 | 0.00 | 117.00 | |
| Total EXPENSES | £504.00 | £463.40 | £300.81 | | |
| NET (Income - Expenses) | | | £300.81 | £162.59 | |

Table 9: Expenses Report

19.0 BCS Evaluation- Manufacturing

19.1 Top Tube

The top tube assembly was of a high quality, with both the rotating tube and head tube having strong welds to the top tube. Unfortunately, the weld at the rotating tube went through the metal and created bulges on the inside which needed filing in order for the rotating tube to slot onto the seat tube insert. Using a thicker tube for this part would prevent this from happening in future. Once filed the rotating tube fitted on the seat tube insert and allowed the rear triangle to rotate smoothly. Both halves of the hinges were welded well to each part of the top tube. As discussed previously the hinges were not drilled correctly, which created a small gap between the plates. As a result of this gap between the hinges, when the hinge was closed it created a minor flex in the top tube. This issue was resolved using layers of aluminium plate to fill the gap. Reducing the gap in the hinge prevented the hinge from flexing as previously under the same loading. With the hinge bolts in place the hinge could freely rotate and no further problems were encountered.

19.2 Rear Triangle

The rear triangle assembly was manufactured to a high standard (**Figure 45**). The rear drop-out mounts were slightly too small for the wheel axle and were filed out before welding. The bottom bracket sleeve had been warped very slightly due to the heat from welding. This was however not a serious issue as the bottom bracket was screwed in with no major difficulty. The rear brake mount was welded slightly higher than desired making it difficult for the brakes to reach the rear wheel rim. To compensate for the high brake mount a piece of aluminium was cut and two 6mm holes were drilled. The plate was bolted to the brake mount and the brakes were bolted through the other hole allowing the brakes to be aligned with the wheel rims properly, ensuring that the standards could be met.



Figure 45: Rear Triangle

19.3 Hinges

The hinges were produced to an acceptable quality, with the milling machine providing the correct shape for both halves of the hinge. The water jet cutter produced a clean and straight cut of the top profile. The holes required for the hinge were unfortunately drilled off centre and as a result brought forth some minor complications. This made it imperative that the weld between the main tube and the hinges were aligned properly so that the hinge would function correctly. As the hole is the most pivotal part of the hinge design any misalignment can cause the hinge to become ineffective. The bolts are able to fit in the holes, however, some of the bolts require some encouragement to be inserted. In the prototype when the hinges are fully closed there is a gap between the two halves creating flex in the top tube. This was resolved by placing aluminium sheeting between the hinges to prevent the frame from flexing further.

In hindsight, more emphasis should have been placed on the holes and the importance of correct alignment when drilling so that the hinge would function properly. Delays in the manufacturing meant that any manufacturing errors that became apparent during the assembly phase were not able to be resolved as well as they could have been. If the manufacturing process had been started earlier then some of these issues could have been resolved to a better standard.

19.4 Handle Bars

The handle bars were one of the components that could be manufactured exclusively by the team and is shown in **Figure 46**. The handle bars are a suitable length and taped to provide a

comfortable grip for the rider. A standard aluminium stem was used to hold the handlebars in position creating a light weight steering setup. The handle bars are detachable and the concentric tubes fit well with each other, with little room for movement. The push pin mechanism works well and holds the handlebars in place when attached.



Figure 46: Handlebars

19.5 Head tube

The head tube assembly was manufactured without any major issues, with most parts fitting as planned. The head cups fitted into the head tube, albeit a little tight. This had the repercussion of the head cups beginning to creep out from the head tube after welding, due to the changes in heat and they had to be reinserted into the head tube using a headset press. Once the head tube became part of the fork assembly, the head cups did not cause any further problems. Once assembled however, the team realised that the head tube angle specified was not the actual angle that the head tube was welded at. This meant that there was a steeper head tube angle, making the steering more responsive than intended. The head tube and fork assembly rotates freely allowing the cyclist to steer the bicycle (**Figure 47**).



Figure 47: Head Tube & Fork

19.6 Steering column

The steering column of the bicycle presented a few challenges for BCS following completion of the manufacturing process. It was discovered that after the technicians had welded the hinges to the steering tube, the steering tube was too large and did not fit with the standard stem attachment. This resulted in the steering tube being resubmitted with a smaller size of tubing for re-welding. The new steering column was too small for the handlebar stem as the local metal supplier did not have the tube diameter the team required and ordering from another supplier would not allow the issue to be resolved in time. Using a smaller diameter tube allowed the team to make a shim out of spare tubing of the correct diameter. This was cut to size and sliced down its length allowing the handlebar stem to be attached to the new steering tube. This was the result of an error in conversion from inches to millimetres and should have been avoided by checking all units in the technical drawings before submission. In addition, the weld on the stem insert was out of alignment, as can be seen in **Figure 48**. This was an error on the technician's part and meant that the steering column was slightly off axis, however, it was not a major issue and did not affect the ability to steer the bicycle.



Figure 48: The Stem Connecting the Front Fork & Handlebars

19.7 Final Assembly

The assembly of the bicycle was ultimately a success. Overall the weld quality of the prototype performed by the university technicians was of a high standard. The bottom bracket was screwed into the bottom bracket sleeve, although the threading was tight and so extra care was taken. As a result of the rear triangle being smaller than most standard bicycles the chain rubs against the chain stay. This is undesirable and causes damage to both the chain stay and chain itself. The rear tyre rubs slightly against the chain stay which is undesirable as this increases the pedal resistance. To try to address this issue the group have ordered thinner tyres which will be tested before the CDIO Competition.

The frame appears to hold up well when assembled, however, under loading appears to flex, putting strain on the frame and, in particular, the hinge at the top tube. To address this issue, a wire was looped around the bottom bracket and head tube and then clamped into place. This greatly reduced the flex in the frame as the wire acted like a down tube on a normal bicycle and created a stronger frame.

The bicycle can easily be folded with the hinges and rotating sections swinging smoothly. Some of the bolts and pins that keep the hinges and rotating section in place are tight and this increases the time to fold.

The gear ratio is that of 34/16, which is a rather low ratio, decreasing the rear sprocket to 14 teeth and increasing the teeth in the chain ring would improve this. Generally, a larger gear ratio increases the effort required to pedal bicycle in return for speed, however, due to the already low gear ratio of the prototype, having a larger ratio would likely improve the overall ability to pedal the bicycle.

19.8 Overall Manufacture Evaluation

On reflection of the design and manufacturing process, most of the issues that occurred during this process stemmed from the lack of design experience and limited knowledge of the team. Issues such as sizing of components on the bicycle were sometimes overlooked causing some minor adjustment to be made once the part had been made. Some of these issues could have been avoided particularly with drawing submissions if greater diligence was applied when reviewing drawings before job submission.

Regarding errors that occurred because of the manufacture of components these could not be avoided as these were undertaken by the technicians and not Bike Centric Studios. The main delay in the manufacturing section was the time the parts spent with the technicians. The original quoted time for the parts to be completed was 2 weeks, however this was not achieved. The team had to wait 4 weeks for the frame to be welded which only took the technician 2 days to complete. This caused major delays and constant changing of plans to ensure that the bike could be assembled in time for the report. If the manufacturing stage had been implemented earlier and the manufacturing time had not taken so long many of these issues could have been addressed sooner and would have allowed for more time to improve the bicycle design.

One of the other main issues that was encountered during manufacturing was the low tolerances set on the hinges and this was an area which caused a few problems once the bike was assembled. The issue was that the holes on the plates had been drilled by hand and were not in the correct position for the hinge to work as intended. Placing more emphasis on the importance of the hole position would have saved the hinges from being produced incorrectly. Furthermore, due to the time it took them to machine the hinges the deadline was very close and welding was still required, so there was no opportunity to make new hinges.

Another area which caused some issues during the manufacturing was the welding. This was due to the thin tubes that were specified, which in hindsight, could have been made thicker to avoid any bulging or deforming due to the heat of the welding. Having a greater knowledge of the welding processes and more communication between the team and technicians could have solved these issues. In addition, some of the parts had been welded in the wrong place which was not a major issue but required some problem solving to address the issues.

As the team had very little knowledge of how to design a folding bicycle this presented a few challenges once the manufacturing had occurred. As the specifications set by the CDIO Design Challenge were very small, this increased the complexity of the dimensions of the rear triangle. As the team had limited experience in designing such a component, with so many variables to take into account, it was unfortunate that in the end the chain rubbed against one of the supports. Consulting expert frame builders could have been an option here to avoid such a problem and is an area the team agreed we would have benefited from.

The FEA analysis was another area the team felt could have been improved. With only basic knowledge of the software in the team, only simplified analyses could be accomplished. Having an expert within the team would have ensured that the complex interactions between folding parts could have been modelled more accurately to produce more realistic results. Although the FEA reassured the team that the bike would hold up to simple static conditions. In real life, it was quite a different story due to the issue with the manufacturing creating imperfection and causing increased demands on parts. Small issues have been attempted to be resolved and a new support added to ensure the bike would not flex.

20.0 Adherence to Contract

The entire project was conducted under the terms of the signed contract between Bike Centric Studios (the consultant) and Professor James Boyle (the client) shown in **Appendix B**. Several conditions were laid out in the contract as to the scope of the project. These conditions were complied with, except that full testing was not possible because of delays in the manufacture and assembly of the prototype. Monthly meetings were held with the client to discuss the progress of the project and to discuss any issues arising. The total cost of the prototype came to £301 which is under the allocated fund of £500. User safety is imperative when manufacturing a bicycle for purchase by the public and is required by the conditions set by the CDIO Design Challenge. The requirements are those set out by the British Standards *BS EN ISO 4210-2:2014*, in particular stipulation requiring an adequate braking system on each wheel. Bike Centric Studios have fully complied with this and also, all the conditions set by Dr. Maclaren in regard to the project. This includes the submission of an interim report, 1st oral exam, and this final report.

Where possible Bike Centric Studios undertook the manufacturing of the prototype. The parts of the bicycle manufacturing that were beyond the technical capabilities of Bike Centric Studios were successfully completed by the technicians of Strathclyde University's Mechanical & Aerospace Engineering Department.

21.0 Conclusion

The CDIO Design Challenge is an initiative aimed at helping engineers utilize their knowledge and understanding by applying theoretical engineering to a real-world challenge. The current problem of pollution caused by urbanisation is an issue which needs addressed, and the CDIO Initiative aims to do this. BCS's final product, the Urban Rider, met the weight requirement of the CDIO Design Challenge and as of submission of this report, size testing has yet to be undertaken. The project required all group members to apply the engineering skills and principles learned during their degree courses. Research was undertaken to explore the current bicycle market in order for BCS to decide in which direction to take the design phase. Pugh's Total Design Process was then utilised so that a final design for the prototype could be generated, meeting the criteria set by the CDIO Design Challenge. This design was then modelled using 3D modelling software and tested using structural analysis software to ensure that the structure was strong enough for commuter usage.

Materials were obtained at the beginning of semester two in order for the technical drawings to be submitted to the welding department. Whilst manufacturing of the prototype was taking place, a company website and three-year business plan were generated. The final prototype was assembled and operational in time for the final presentation in March.

With the benefit of hindsight, there are various aspects of the project BCS would have done differently. The main adverse issue the group encountered was delays with the university technicians' department. These welding delays, accounting for two weeks, meant that the team was stretched in the week leading up to the report deadline in March, trying to complete the report, as well as assemble the prototype. Were the project to be carried out again, the manufacturing segment should aim to be started at the end of January, in order to give greater leeway for any delays to the welding of the prototype.

Over the course of the project, the team worked well together and collaborated across all aspects of the CDIO Design Challenge. The excellent communications skills within BCS helped the project to run smoothly, and all members ensured that they were on kept on track with their respective roles. That said, the biggest challenge was the timescale in which to deliver the final prototype, which required that all members had to ensure they kept to the strict project plan. Due to the effective collaboration within the group, this project can be ultimately

viewed as a success, with a final prototype on track to be able to compete at Queen's University in Belfast in May.

22.0 References

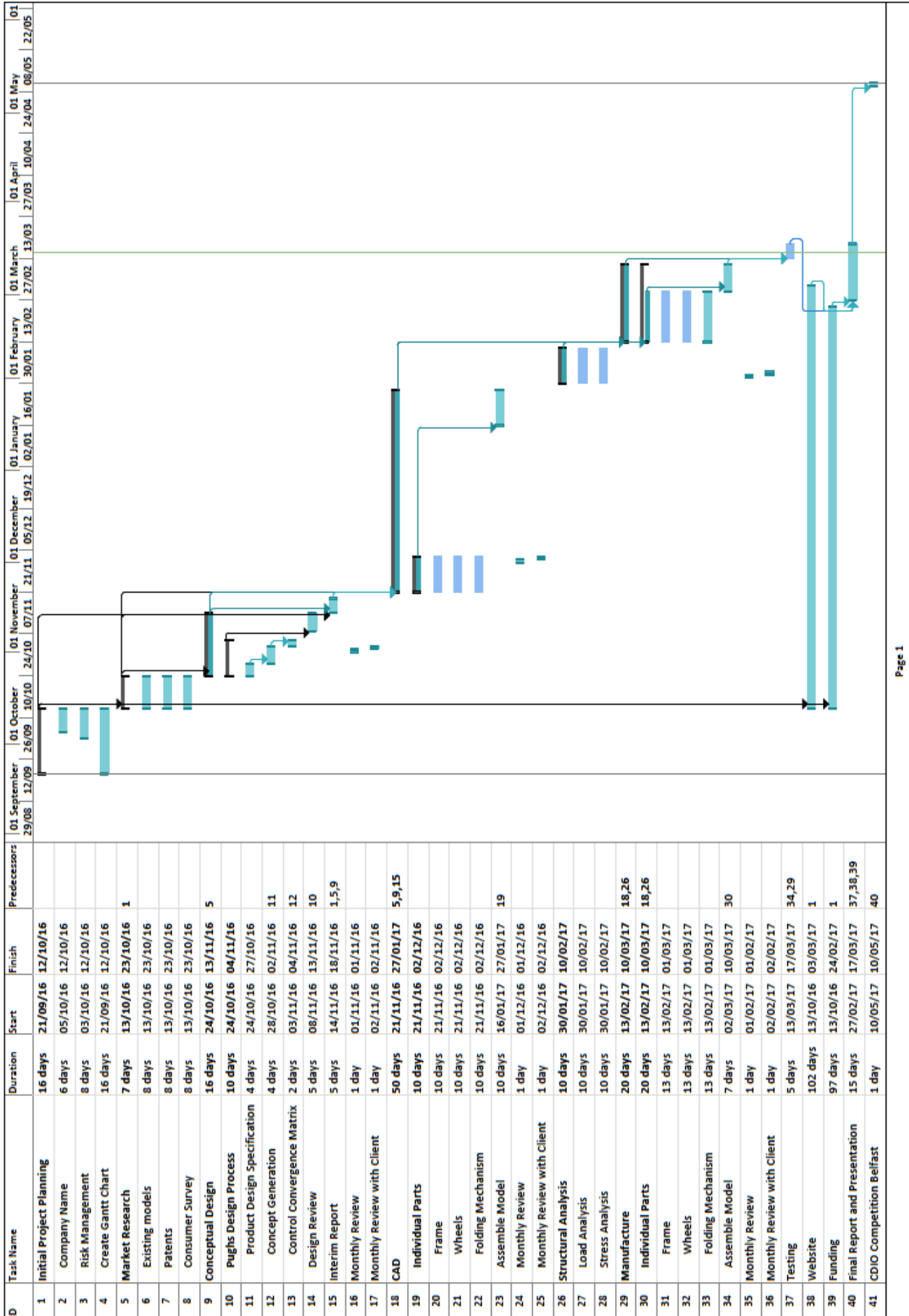
1. CDIO Initiative [Online] Available at: <http://cdio.org/about> [Accessed 10 Oct. 2016]
2. The MITRE Corporation. (2017). *Risk Mitigation Planning, Implementation, and Progress Monitoring*. [online] Available at: <https://www.mitre.org/publications/systems-engineering-guide/acquisition-systems-engineering/risk-management/risk-mitigation-planning-implementation-and-progress-monitoring> [Accessed 15 Jan. 2017].
3. The Bike Station, Glasgow. Website available at:
<http://www.thebikestation.org.uk/glasgow/>
4. Cycling and The Economy. (2016). [online] Available at:
<http://www.cyclinguk.org/campaigning/views-and-briefings/cycling-and-economy>
[Accessed 14 Nov. 2016]
5. Brompton. *Brompton Official Website*. [online] Available at: www.brompton.com
[Accessed 10 Nov 2016]
6. Dahon EEZZ D3. *Evans Cycles Official Website*. [online] Available at:
<https://www.evanscycles.com/dahon-eezz-2017-folding-bike-EV293510> [Accessed 10 Nov 2016]
7. Vello Bike. *Vello Official Website*. [online] Available at: <http://vello.bike/> [Accessed 10 Nov 2016]
8. Montague Crosstown. *Montague Bikes Official Website*. [online] Available at:
<https://www.montaguebikes.com/product/crosstown/> [Accessed 10 Nov 2016]
9. Viking Easy Street. *Ten Best Folding Bikes for Cycling Commuters*. [online] Available at:
<http://www.telegraph.co.uk/men/recreational-cycling/10-best-folding-bikes-for-cycling-commuters/viking/> [Accessed 10 Nov 2016]
10. CMYK 4.0: Smart Electric Folding Bike. *Indiegogo Official Website* [online] Available at:
<https://www.indiegogo.com/projects/cmyk-4-0-smart-folding-electric-bike#/> [Accessed 10 Nov 2016]
11. Integra Safari 6 Speed Folding Bike 13" [Internet]. Halfords.com. 2017 [cited 9 March 2017]. Available from: <http://www.halfords.com/cycling/bikes/folding-bikes/integra-safari-6-speed-folding-bike-13?istCompanyId=b8708c57-7a02-4cf6-b2c0->

[dc36b54a327e&istItemId=xtlamrmqai&istBid=tztx&_ija=tsid:35522%7Ccid:627838503%7Cagid:32471675404%7Ctid:pla-211148733124%7Ccid:112784842204%7Cnw:g%7Crnd:2906574565914918683%7Cdvc:c%7Cadp:1o2&gclid=CJWMI-XTydlCFeUp0wodG-II_w](https://www.ebay.com/itm/dc36b54a327e&istItemId=xtlamrmqai&istBid=tztx&_ija=tsid:35522%7Ccid:627838503%7Cagid:32471675404%7Ctid:pla-211148733124%7Ccid:112784842204%7Cnw:g%7Crnd:2906574565914918683%7Cdvc:c%7Cadp:1o2&gclid=CJWMI-XTydlCFeUp0wodG-II_w)

12. Uni-Cycle. Website available at: <http://www.thebikestation.org.uk/glasgow/whats-going/pro/uni-cycle/>
13. Citizen Hinge Mechanism. *Citizen Folding Bikes Official Website*. [online] Available at: http://www.citizenbike.com/club.asp?support_page_id=50 [Accessed 10 November 2016]
14. *Brompton Bicycles Australia*. [online] Available at: <http://www.bromptonaustralia.com.au/brompton-hinge-clamp-lever-and-bolt-blue-903.html> [Accessed 10 November 2016]
15. Bickerton Hinge Mechanism. *Wiggle Official Website*. [online] Available at: <http://www.wiggle.co.uk/bickerton-junction-1909-country/> [Accessed 10 November 2016]
16. Thomson, P. (2015). Dahon Speed Uno Folding Bike Review. [online] Available at: <http://www.foldingbike365.com/dahon-speed-uno-review/> [Accessed 10 November 2016]
17. A-Bike Folding Bicycle. *A-Bike Official Website*. [online] Available at: <http://a-bike.co.uk/product/electric-a-bike-euro-plug-type-c/> [Accessed 10 November 2016]
18. Carryme Folding Bicycle. *Gearculture Official Website*. [online] Available at: <http://www.gearculture.com/goods/carryme-ds-bicycle/> [Accessed 10 November 2016]
19. "Cycling", Scotrail, (2016). [online] available at: <https://www.scotrail.co.uk/plan-your-journey/travel-connections/cycling>
20. "Can I take my bike on the bus?", Stagecoach (2016). [online] available at: <https://www.stagecoachbus.com/help-and-contact/national/can-i-take-my-bike-on-the-bus>
21. Anon, (2017). [online] Available at: 1. <http://www.wipo.int/pct/en/> [Accessed 17 Oct. 2016].

22. *Understanding Bicycle Frame Geometry* - CyclingAbout [online]. CyclingAbout. 2016 [cited 14 November 2016]. Available from:
<http://www.cyclingabout.com/understanding-bicycle-frame-geometry/>
23. Curve i3 16" - DAHON [online]. DAHON. 2016 [cited 14 November 2016]. Available from:
<http://dahon.com/bikes/curve-i3-16-2/>
24. Bicycles G. *HALFWAY - Giant Bicycles* [online]. Giant-bicycles.com. 2016 [cited 14 November 2016]. Available from: <https://www.giant-bicycles.com/en-ca/bikes/model/halfway/8076/45722/#geometry>
25. AISI 1018 Mild/Low Carbon Steel, Azom, (2012). [online] available at:
<http://www.azom.com/article.aspx?ArticleID=6115> [accessed 9 Nov 2016]
26. Aluminium Alloy 6061 - Composition, Properties, Temper and Applications of 6061 Aluminium, Azom, (2006). [online] available at:
http://www.azom.com/article.aspx?ArticleID=3328#_Mechanical_Properties [accessed 9 Nov 2016]
27. Titanium Ti-6Al-4V (Grade 5), Annealed, ASM Aerospace Specification metals inc., (2007) [online] available at:
<http://asm.matweb.com/search/SpecificMaterial.asp?bassnum=MTP641> [accessed 9 Nov. 2016]
28. Carbon / Epoxy Composite Materials – Properties, Azom, (2003), [online] available at:
<http://www.azom.com/article.aspx?ArticleID=1995> [accessed 9 Nov. 2016]
29. Pugh S. *Total design*. 1st ed. Wokingham, England: Addison-Wesley Pub. Co.; 1991.
30. *Wix*. Available at: <http://www.wix.com> (Accessed: 11 October 2016).

Appendix A: Project Plan



Appendix B: Contract

Bike Centric Studios Contract

14/11/2016

This contract is between the consultant, Bike Centric Studios, a group of students comprising of Carlos López Ayesta (Research & Development), Dominic Johnston (CFO & Communications Director), David Mann (Lead Design Engineer), Andrew Martin (Lead Manufacturing Engineer) and Aaron Thomson (CEO) and the client, Prof J Boyle of Strathclyde University. Communication will be made on behalf of the consultant to the client by the CFO & Communications Director and if he is unavailable, by the Lead Design Engineer.

This contract will come into effect on the **14/11/2016** and both parties agree to the following terms:

1. The consultant will design, manufacture and test a folding bicycle optimised for urban usage.
2. A minimum of 1 meeting per month will be held with the client to ensure both parties are up to date and informed with the progress of the project.
3. Up to £100 per group member, a total of £500, will be provided by the client through the University of Strathclyde towards the cost of completing the project. Any expenses will be submitted to the client for approval, with the client informing the consultant of the decision within 1 week of delivery.
4. The prototype bicycle will adhere to the specifications set by the CDIO Worldwide Challenge and shall meet BS EN ISO 4210-2:2014 "cycles – safety requirements for bicycles. Requirement for city and trekking, young adult, mountain and racing bicycles".
5. The consultant will follow the guidelines established by Dr. Maclaren in the delivery of the project.
6. An Interim Report to be delivered to the client by **18/11/2016**.

Construction of the prototype will be undertaken by the consultant with assistance from the technicians of Strathclyde University's Mechanical & Aerospace Engineering Department when expert skills are required, which are beyond the technical ability of the members of the consultant.

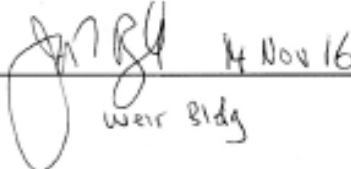
This contract shall last for the period **14/11/2016** to **17/03/2017** or such earlier date on which the client has signed off the consultant, following delivery of the prototype and report.

By signing below both parties are in agreement with the terms and conditions stated in this contract.


Bike Centric Studios

| | |
|---|-----|
|  | CLA |
|  | DJ |
|  | DM |
|  | AM |
|  | AT |

Client

| | |
|--|------------|
|  | Prof Boyle |
| 14 Nov 16 | |
| weir Bldg | |

Appendix C: Risk Mitigation Planning- Project

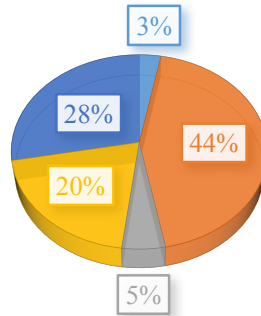
| Bike Centric Studios | |  | | Risk Mitigation Planning- Project | | | | | | |
|----------------------|---|--|-------------------|-----------------------------------|---------|--|-----------------|-------------|--|--------------------------|
| Section | Risk | Potential Consequence | Impact Assessment | Probability | Ranking | Mitigation Steps | New Probability | New Ranking | Contingency | Group Member Responsible |
| Group | Lack of manufacturing experience | Inexperience leading to an overcomplicated design which proves challenging | 2 | 2 | 4 | N/A | 2 | 4 | | N/A |
| | Not meeting fixed deadlines such as report hand in date etc. | Penalty in grading process | 3 | 2 | 6 | Keep an up to date Gantt chart and make sure each member of the group is aware of upcoming milestones/ deadline dates | 1 | 3 | | Aaron |
| | Inefficient tasking of roles/ responsibilities | The final product is not ideal | 2 | 2 | 4 | Belbin's Self Perception Inventory (SPI) test taken by each group member in order to more accurately divide roles | 1 | 2 | | Aaron |
| | Communication breakdown between members | Tasks/ deadlines are missed due to lack of communication | 2 | 2 | 4 | Facebook group created for easy communication between group members. Along with weekly scheduled meetings for updates | 1 | 2 | | Aaron |
| | Unforeseen group member absences due to illness etc. | Delays in the tasks assigned to that group member(s) | 2 | 1 | 2 | Each group member is prepared to take over the tasks of another in the event it is required. | 1 | 2 | | ALL |
| Design Process | Designing the bicycle to the limits of the dimensional constraints in order to have the most ergonomic design | The prototype does not fit inside the locker | 3 | 3 | 9 | Create an accurate 3D model of the proposed design | 2 | 6 | Risk deemed acceptable given the added ergonomics that will be incurred with a larger design | Dave |
| | Mistakes in the final detailed design not realised and brought to manufacturing stage | Possible redesign of the bicycle required leading to project delays and greater incurred costs | 3 | 2 | 6 | Detailed design to be checked over by each member of the group and signed off to reduce the risk of something slipping through | 1 | 3 | | ALL |
| | Not being able to create a detailed design that meets the constraints of the project | Failing the requirements set out by the CDIO | 3 | 2 | 6 | Each member of the group to create minimum of 2 concepts. | 1 | 3 | | Dave |
| | Inadequately performed structural analysis | Leading to the manufacturing of a design that will fail | 3 | 2 | 6 | Perform a detailed structural analysis with appropriate forces applied using FEA and signed off by each member of the group | 1 | 3 | | ALL |
| | Inadvertently infringing existing patents | Potential law suit filed against BCS | 3 | 2 | 6 | Research existing patents relating to folding bicycle design | 1 | 3 | | Andrew |
| | Final design too complicated for the group/ university technicians to execute | A re-design would have to take place, delaying the project considerably | 3 | 2 | 6 | Regular checks with the technicians to confirm that our proposed design will in fact be feasible | 1 | 3 | | Dave |
| | Not meeting health & safety requirements | Bicycle unable to be put forward for sale | 3 | 1 | 3 | Research all health and safety requirements and ensure the design meets them | 1 | 3 | | Carlos |
| | Failure during structural analysis | Redesign of the bicycle leading to project delays | 2 | 2 | 4 | Perform appropriate research on existing bicycle design to reduce the risk of design failure | 1 | 2 | | Dave |
| | Limited amount of concepts generated leading to "tunnel vision" of a single design | The selection of a sub par design and subsequently final product | 1 | 2 | 2 | Each member of the group to create min of 2 concepts. | 1 | 1 | | ALL |

| | | | | | | | | | | |
|----------------------|---|---|---|---|---|--|---|---|---|--------|
| Manufacturing | Lack of technician availability/ unforeseen absences | Leading to delays in the manufacturing press | 3 | 3 | 9 | Speak to the university technicians and get a likely timescale of the jobs required and aim to submit them as soon as possible | 2 | 6 | Source external facilities for possible help with manufacturing if required | Andrew |
| | Prototype testing failures | Manufacturing delays at a critical time with upcoming deadlines. Increased costs to rectify the problem | 3 | 2 | 6 | Detailed design and structural analysis to reduce the chances of a design related failure | 1 | 3 | | Andrew |
| | Securing an appropriate workspace with the necessary tools etc. | Not having a location or the required equipment to build the bicycle | 3 | 1 | 3 | Arrange a suitable location to be used by BCS with the university as early as possible | 1 | 3 | | Andrew |
| | Unforeseen manufacturing issues/ failures | Leading to delays in the manufacturing process | 2 | 2 | 4 | Begin the manufacturing stage as early as possible so that any issues may be addressed in time of deadlines | 1 | 2 | | Andrew |
| Financials | Cannot source external sponsorship | Cannot afford to complete the task | 3 | 2 | 6 | Get in contact with as many sources of potential sponsorship as early as possible in the project | 2 | 6 | Request financial assistance from the university if required | Dom |
| | The budget assigned by the university is not adequate enough to meet the required materials for our design | Cannot afford to complete the task | 3 | 2 | 6 | Create an estimated budget and secure sponsorship from an external source | 1 | 3 | | Dom |
| Miscellaneous | Delays in receiving materials | Cause delays to the manufacturing process | 3 | 2 | 6 | Finalise the detailed design as early as possible and order the required materials as soon as this is complete | 1 | 3 | | ALL |
| | Not identifying appropriate risks and then mitigating them | Project failure | 3 | 2 | 6 | Perform an appropriate risk management process | 1 | 3 | | Dom |
| | Not adhering to the signed contract between BCS & the client | Project failure | 3 | 1 | 3 | Clearly state what is expected from BCS in the contract and make sure each member is aware of this | 1 | 3 | | Dom |
| | Having company IP stolen | Competitors manufacture and sell our prototype before we can bring it to market | 1 | 1 | 1 | Do not publish any detailed design drawings to the public | 1 | 1 | | Carlos |

Appendix D: Consumer Survey

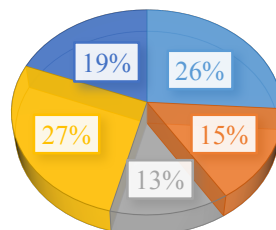
Q1: WHAT AGE BRACKET ARE YOU IN?

■ < 18 ■ 18-25 ■ 26-30 ■ 31-44 ■ 44+



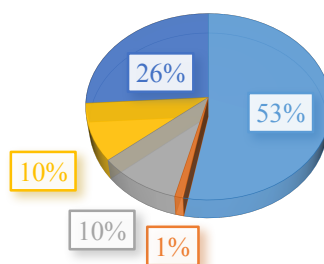
Q2: HOW FAR DO YOU COMMUTE TO WORK?

■ < 1 mile ■ 1-4 miles ■ 5-10 miles ■ 11-24 miles ■ 25+ miles

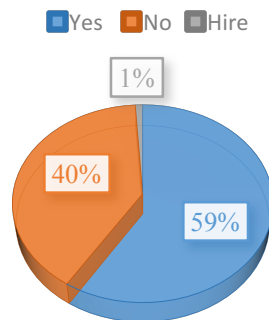


Q3: HOW DO YOU COMMUTE TO WORK CURRENTLY?

■ Car ■ Bike ■ Train/Subway ■ Public Bus ■ Walk

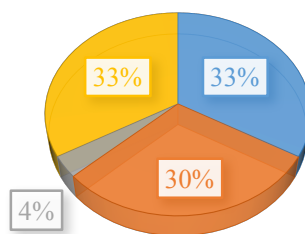


Q4: DO YOU OWN A BICYCLE?



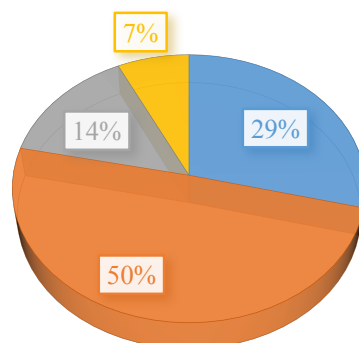
Q5: WHAT DO YOU USE YOUR BIKCYCLE FOR?

Recreation Exercise Transport Sporadically

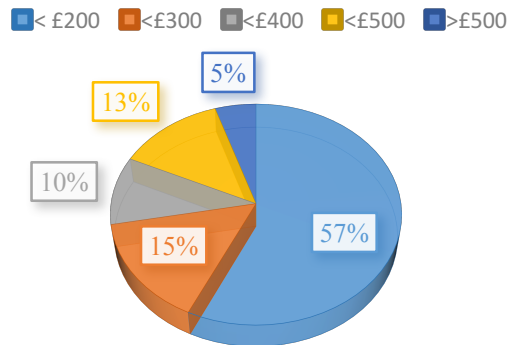


Q6: WHAT IS THE MAXIMUM TIME YOU WOULD BE WILLING TO SPEND FOLDING A BICYCLE?

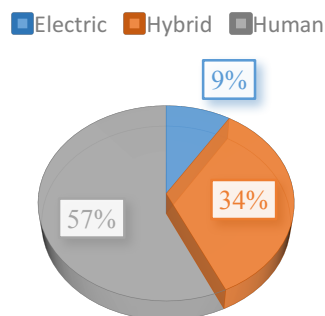
30 seconds 1 minute 2 minutes 2+ minutes



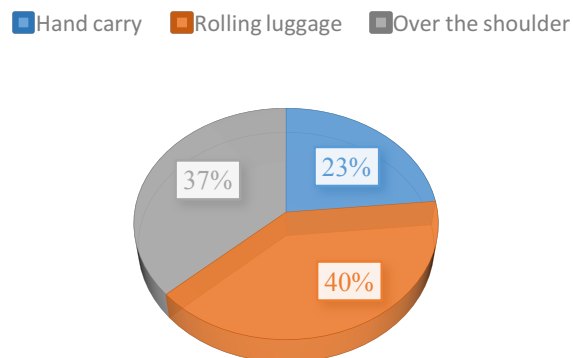
Q7: WHAT IS THE MAXIMUM PRICE YOU WOULD BE WILLING TO PAY FOR BICYCLE?



Q8: WHAT WOULD BE YOUR PREFERRED DRIVETRAIN METHOD?



Q9: WHAT WOULD BE PREFERRED METHOD OF TRANSPORTING A FOLDING BCYCLE?



Appendix E: Product Design Specification

1. Patents

1.1 Must not infringe any current market patents.

2. Quality and Reliability

2.1 The bicycle must be built to a high standard.

3. Weight

3.1 The bicycle's weight must be within a maximum weight of 10kg.

4. Size

4.1 The bicycle must fit into locker of size 58cm x 45cm x 43cm.

4.2 The size of the wheels must not exceed 14" (35.56cm).

5. Customers

5.1 The target market for this folding bicycle is urban commuters.

5.2 The bicycle is designed for those in the age bracket of 25-55 years.

6. Performance

6.1 The bicycle must have a maximum folding time of less than one minute.

6.1.1 Must be easily folded/unfolded by any able bodied adult.

6.2 The bicycle must be able to reach a speed of 25km/h with relative ease.

7. Aesthetics

7.1 The bicycle must be visually pleasing.

8. Ergonomics

8.1 The bicycle must be suitable for users of a height between 5'7 and 6'2.

8.2 The bicycle must be able to hold a person's weight up to 100kg.

9. Materials

9.1 The materials must be lightweight.

9.2 The materials must be cheap to buy and within the allocated budget.

9.2.1 The total sum of all purchased components must not exceed £500.

9.3 The materials must be relatively easy to source and available from reliable retailers.

9.4 The materials used must be strong so that it can support the weight of the rider.

9.5 The material must be relatively easy to weld.

10. Safety

10.1 The bicycle must adhere to safety standards as in *BS EN ISO 4210-2:2014*.

11. Testing

11.1 Testing of the prototype should be carried out by 1/3/17.

12. Timescale

12.1 The final chosen concept must be decided by week 8 (13/11/16).

12.2 The interim report must be submitted by 18/11/16.

12.3 All CAD drawings of the final design must be finalised by 02/12/16.

12.4 Manufacturing of the bicycle must begin on 23/01/17.

12.4.1 Manufacturing of the bicycle must be finished by 01/03/17.

12.5 Testing of the prototype must begin by week 9 in semester 2.

12.6 The final report must be submitted by 17/03/17.

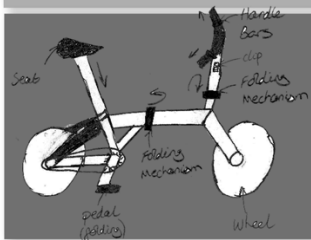
13. Manufacture

13.1 The University of Strathclyde's facilities must be used for manufacturing.

13.2 Standard tooling and machining techniques must be used in the manufacture of the bicycle.

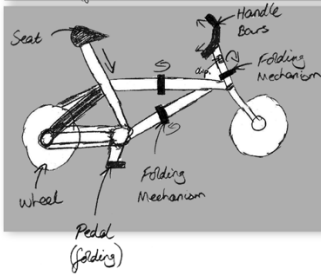
Appendix F: Initial Design Concepts

Concepts



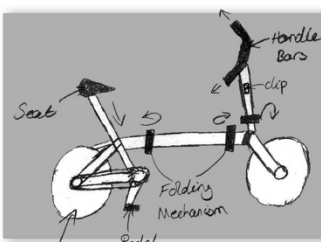
0

- 2 distinct folds
Halfway down top tube ,Bottom of handlebar
- Seat drops in itself
- Pedals Fold in
- Handlebars pull out and clip to steering tube



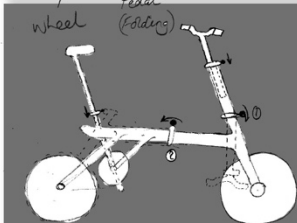
1

- 3 distinct folds
Halfway down top and bottom tube, Bottom of handlebar
- Seat drops in itself
- Pedals Fold in
- Handlebars pull out and clip to steering tube



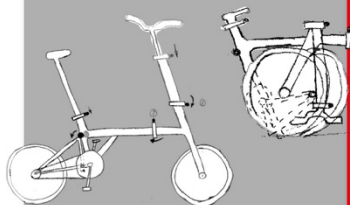
2

- 3 distinct folds
At beginning and end of top tube Bottom of handlebar
- Seat drops in itself
- Pedals Fold in
- Handlebars pull out and clip to steering tube



3

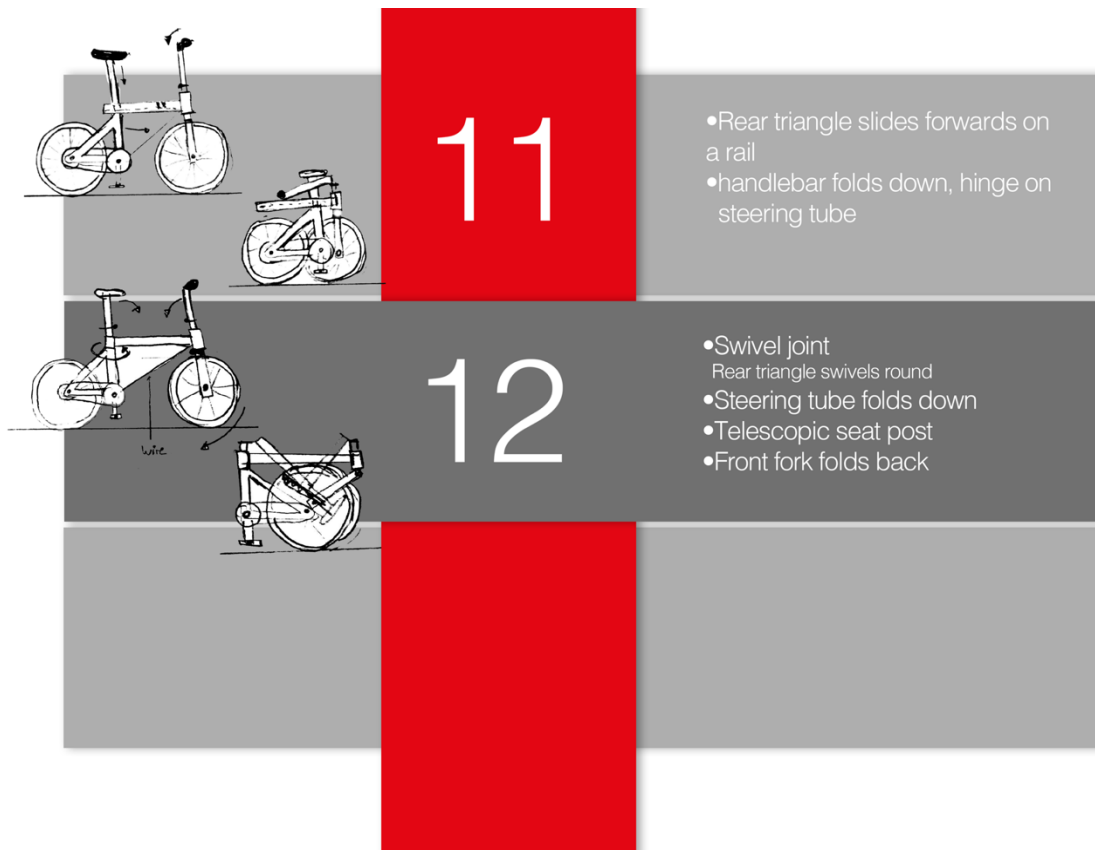
- 1 distinct fold
Hinge middle of frame
- Handlebars fold down at base of steering tube



4

- 2 distinct folds
Back triangle rolls round bottom bracket and sits under top tube Hinge on top tube near head tube
- Handle bar folds down
- Seat tube drops down

| | | |
|--|--|--|
| | <p style="font-size: 48px; text-align: center;">5</p> | <ul style="list-style-type: none"> • Telescopic tube as main tube of bike, so wheels are inline. • Telescopic seat • Handlebars fold down, hinge in steerer tube |
| | <p style="font-size: 48px; text-align: center;">6</p> | <ul style="list-style-type: none"> • 2 distinct folds <ul style="list-style-type: none"> Back triangle swivels round Fold near head tube on the top tube • Handlebars fold down at base of steering tube |
| | <p style="font-size: 48px; text-align: center;">7</p> | <ul style="list-style-type: none"> • 2 distinct folds <ul style="list-style-type: none"> Back triangle split and fold in opposite directions Fold near head tube on the top tube • Steering tube and seat tube are telescopic |
| | <p style="font-size: 48px; text-align: center;">8</p> | <ul style="list-style-type: none"> • Telescopic Top tube • Telescopic seat and steering tube |
| | <p style="font-size: 48px; text-align: center;">9</p> | <ul style="list-style-type: none"> • 2 distinct folds <ul style="list-style-type: none"> Ball and socket joint allows rear triangle to swivel round Seat post tube hinges round on top tube • Handlebars fold down at base of steering tube |
| | <p style="font-size: 48px; text-align: center;">10</p> | <ul style="list-style-type: none"> • 2 swivel joints <ul style="list-style-type: none"> Rear triangle swivels round Front head tube swivels round • Steering tube folds down • Telescopic seat post |



The image displays two technical drawings of bicycle folding mechanisms, labeled 11 and 12. Each drawing shows a bicycle in its unfolded state and its folded state. Drawing 11 shows a bicycle with a rear triangle that slides forward on a rail and handlebars that fold down. Drawing 12 shows a bicycle with a swivel joint rear triangle, a folding steering tube, a telescopic seat post, and a folding front fork. The drawings are set against a background of grey and red blocks.

11

- Rear triangle slides forwards on a rail
- handlebar folds down, hinge on steering tube

12

- Swivel joint
Rear triangle swivels round
- Steering tube folds down
- Telescopic seat post
- Front fork folds back

Appendix G: Concept Convergence Matrices

| Specifications | Datum (4) | 0 | 1 | 2 | 3 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---------------------|-----------|---|---|---|---|----|---|---|---|---|----|----|----|
| Ease of Folding | | + | + | s | + | + | s | - | + | s | + | + | s |
| Folding Time | | + | s | - | + | + | s | - | + | s | + | + | s |
| Ease of Manufacture | | + | - | s | - | -2 | s | - | - | - | - | -2 | - |
| Aesthetics | | - | s | - | - | - | + | + | - | s | + | - | + |
| Ergonomics | | - | - | + | - | - | s | s | - | s | - | - | + |
| Manufactured Price | | + | + | s | - | - | s | - | - | - | - | - | s |
| Folding Size | | - | - | s | - | - | s | s | - | s | - | - | - |
| Weight | | + | + | s | s | - | s | - | - | - | s | s | s |
| + | | 5 | 3 | 1 | 2 | 2 | 1 | 1 | 2 | 0 | 3 | 2 | 2 |
| s | | 0 | 2 | 5 | 5 | 0 | 7 | 2 | 0 | 5 | 1 | 1 | 4 |
| - | | 3 | 3 | 2 | 1 | 7 | 0 | 5 | 6 | 3 | 4 | 6 | 2 |

Table 10: Second Concept Convergence Matrix

| Specifications | Datum (4) | 2 | 6 | 12 |
|---------------------|-----------|---|---|----|
| Ease of Folding | | s | + | s |
| Folding Time | | s | s | s |
| Ease of Manufacture | | + | s | - |
| Aesthetics | | s | + | s |
| Ergonomics | | s | s | s |
| Manufactured Price | | + | s | s |
| Folding Size | | s | s | s |
| Weight | | s | + | s |
| + | | 2 | 3 | 0 |
| s | | 6 | 5 | 7 |
| - | | 0 | 0 | 1 |

Table 11: Final Concept Convergence Matrix

Appendix H: Final Design Concepts

CONCEPT 2

2 distinct folds in the top tube
folding in opposite directions
Seat tube just lowers into the frame

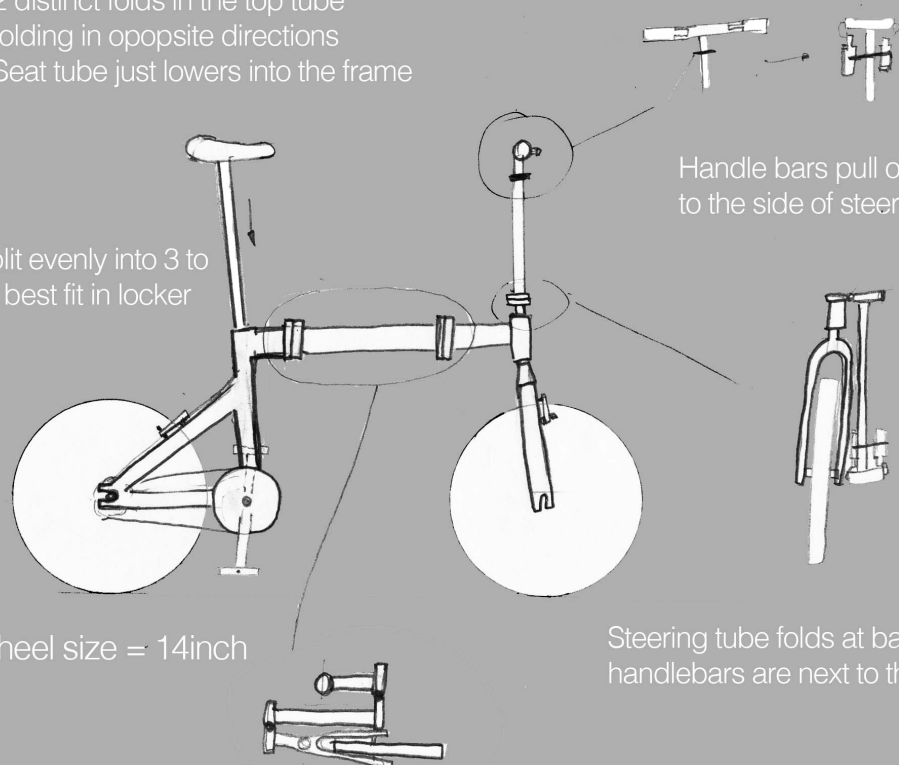
Bike split evenly into 3 to
ensure best fit in locker

Wheel size = 14inch

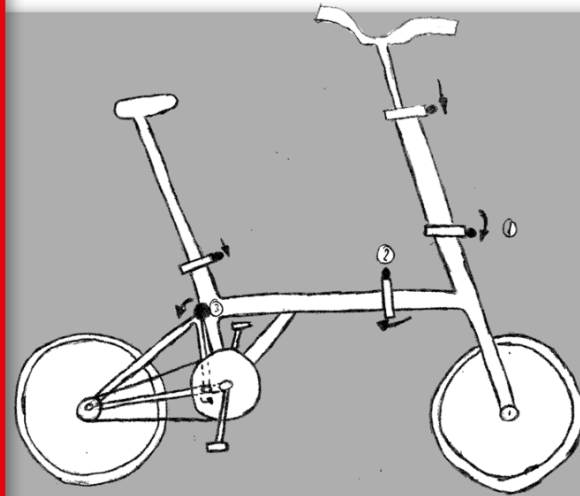
Handle bars pull out and clip
to the side of steering tube.

Steering tube folds at base so that
handlebars are next to the front fork

Folded view of frame from the top



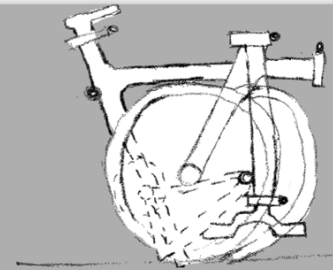
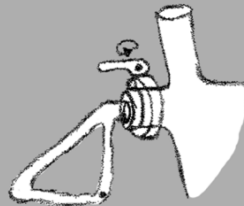
CONCEPT
4



14" wheels = 36cm diameter

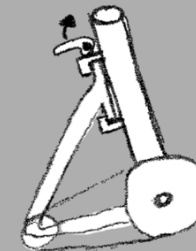
Ideas for coupling:

1. Magnet
2. In order to release the coupling, rotate the key to unwrap the outer tube



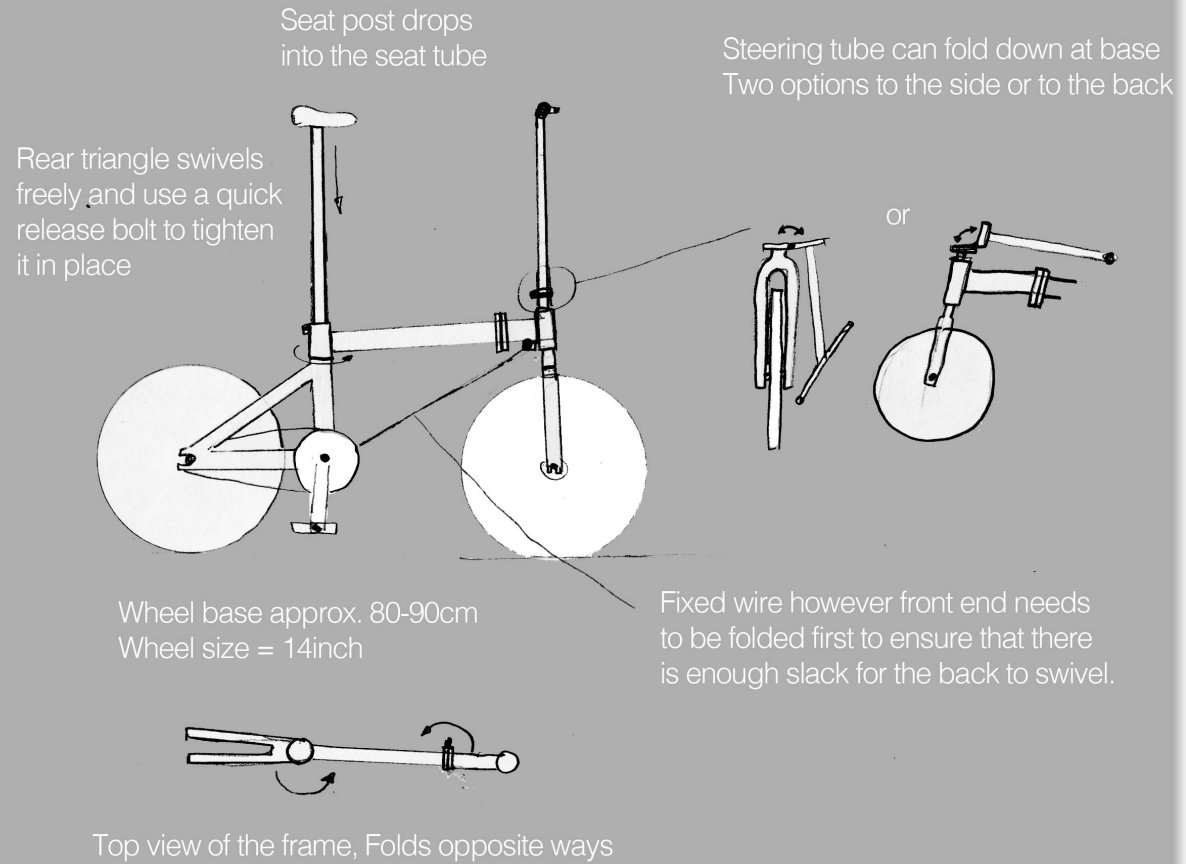
How to fold it

1. Push down telescopic handle bar
2. Pull the rear triangle rotating it 180
3. Push down the telescopic seat
4. Fold the handle bar with the hinge
5. Fold front wheel hinge



3. Avoiding the triangle, just two bars, no vertical bar. Thus saving weight, to fold release the coupling and it will rotate around the bottom bracket.

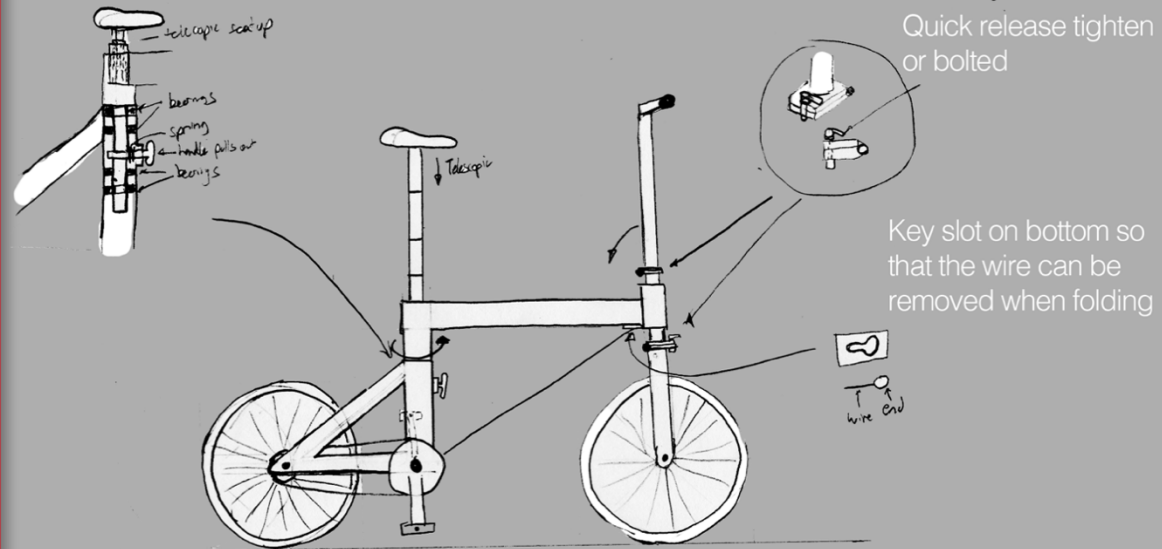
C
O
N
C
E
P
T
6



CONCEPT

12

Bearing setup enabling a smooth rotation of rear triangle.
Sprung handle with a pin to ensure the position of the triangle is straight in line with frame.
telescopic seatpost so that it doesnt interfere with bearing set up.



Wheel size 14/16 inches

Front wheel folds towards top tube with the aim of lining up the wheels next to each other.

Appendix I: Hinge Concept Drawings

| | | |
|--|---|---|
| | 1 | <ul style="list-style-type: none"> • Handle which pulls the two halves together |
| | 2 | <ul style="list-style-type: none"> • Catch on top and possibly bottom of the round hinge • Pin opposite to hinge |
| | 3 | <ul style="list-style-type: none"> • Ratchet and catch style on the end of plate |
| | 4 | <ul style="list-style-type: none"> • Bolted u shape clamp across The two plates. |
| | 5 | <ul style="list-style-type: none"> • Simple square plate hinge with a removable pin • Removable pin - quick release pin Or screw threaded pin |

Appendix J: Handlebar Concepts

1

- Two separate handle bar ends with a pin on the tube which slots into the guide on the central steel tube
- Bungee cord to hold each end when detached from central tube.

2

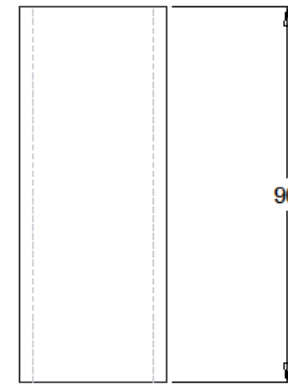
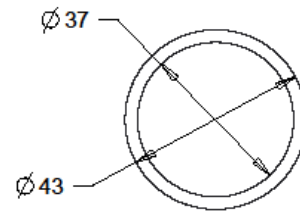
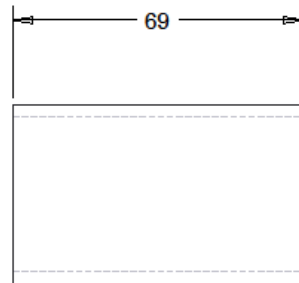
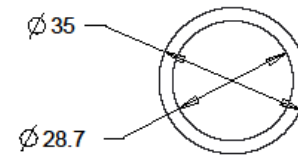
- Push button pins to release grips
- Bungee cord again holding both grips together both grips when unsecure
- grips secured by clamps

Appendix K: Drawings

| QUANTITY | PART NO | DRAWING | DESCRIPTION | SOURCE |
|----------|---------|---------|-----------------------------------|----------------------------|
| 1 | 01 | - | Bottom bracket & Crank Bolts | Chain Reaction Cycles |
| 1 | 02 | A | Bottom Bracket Sleeve & Head Tube | Ceeway Supplies |
| 2 | 03 | - | Brake Cables | Chain Reaction Cycles |
| 2 | 04 | - | Brake Callipers | The Bike Station |
| 2 | 05 | - | Brake Lever | Wiggle |
| 1 | 06 | B | Chain Stay Left | Metal Supermarkets |
| 1 | 07 | B | Chain Stay Right | Metal Supermarkets |
| 1 | 08 | - | Crank Arm (left) | The Bike Station |
| 1 | 09 | - | Crank Arm (Right with Chain Ring) | The Bike Station |
| 2 | 10 | - | Folding Pedals | Ultimate Hardware (Amazon) |
| 1 | 11 | - | Front Fork | The Bike Station |
| 1 | 12 | - | Front Wheel | The Bike Station |
| 1 | 13 | E | Handlebar Centre | Metal Supermarkets |
| 2 | 14 | E | Handlebar Removable End | Metal Supermarkets |
| 1 | 15 | - | Handlebar Tape | Chain Reaction Cycles |
| 1 | 16 | A | Head Tube | Ceeway Supplies |
| 4 | 17 | - | Hinge Pins | B&Q |
| 3 | 18 | I | Hinge Plate | Metal Supermarkets |
| 1 | 19 | G | Hinge Plate Stem | Metal Supermarkets |
| 2 | 20 | H | Rear Drop Out Mount | Metal Supermarkets |
| 1 | 21 | - | Rear Wheel | The Bike Station |
| 1 | 22 | F | Rotating Tube | Metal Supermarkets |
| 2 | 23 | - | Rotating Tube Clamp | Metal Supermarkets |
| 1 | 24 | - | Saddle | The Bike Station |
| 1 | 25 | - | Saddle Rail Clamps | The Bike Station |
| 1 | 26 | J | Seat Post Base Tube | Metal Supermarkets |
| 1 | 27 | J | Bar | Metal Supermarkets |
| 1 | 28 | B | Seat Stay Left | Metal Supermarkets |
| 1 | 29 | B | Seat Stay Right | Metal Supermarkets |
| 1 | 30 | C | Seat Tube | Metal Supermarkets |
| 1 | 31 | C | Seat Tube Insert | Metal Supermarkets |
| 1 | 32 | - | Star Knob Bolt | Sourcingmap (Amazon) |
| 1 | 33 | - | Steering Tube | Metal Supermarkets |
| 1 | 34 | - | Stem | Wiggle |
| 1 | 35 | - | Stem Bolt & Wedge Nut | The Bike Station |
| 1 | 36 | G | Stem Tube | Metal Supermarkets |
| 1 | 37 | D | Top Tube 1 | Metal Supermarkets |
| 1 | 38 | D | Top Tube 2 | Metal Supermarkets |
| 1 | 39 | N | Seat Setback | Metals4U |
| 1 | - | O | Bike Assembly | - |



| Part | Number | Quantity |
|----------------|--------|----------|
| Bottom Bracket | 02 | 1 |
| Head tube | 16 | 1 |



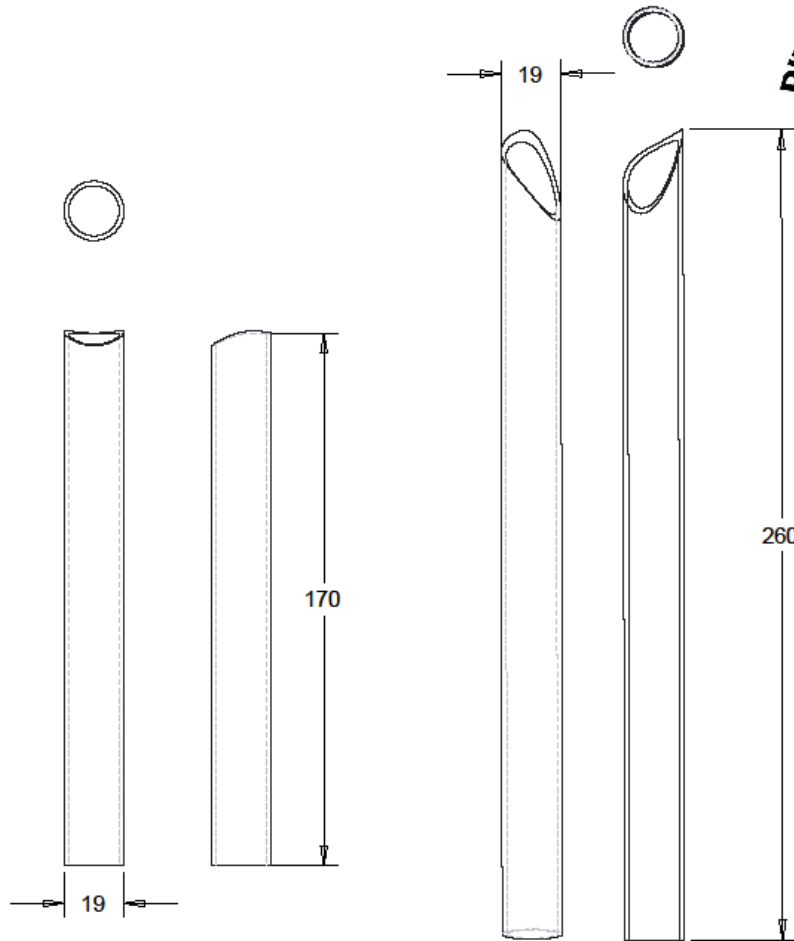
Bottom Bracket

Head tube

| | | | | |
|------------------------------|-------|-------|------|------------|
| Bike Centric Studios | Scale | 1.000 | Date | 03/02/2017 |
| Bottom Bracket and Head tube | DWG | A | | |



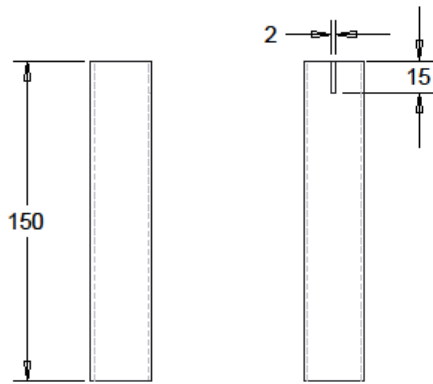
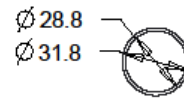
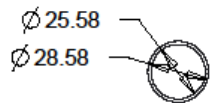
| Part | Number | Quantity |
|------------|--------|----------|
| Chain stay | 6,7 | 2 (L,R) |
| Seat stay | 28,29 | 2 (L,R) |



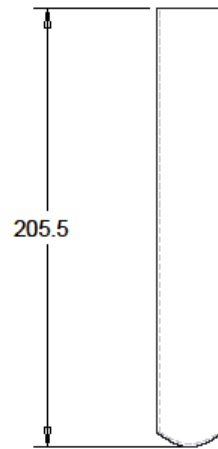
| | | | | |
|-----------------------------|-------|-------|------|------------|
| Bike Centric Studios | Scale | 0.333 | Date | 03/02/2017 |
| Seat stay and Chain Stay | DWG | B | | |



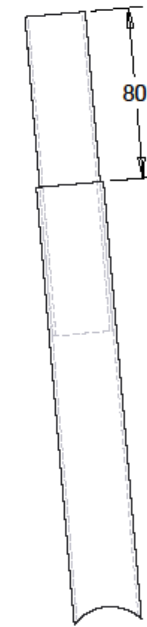
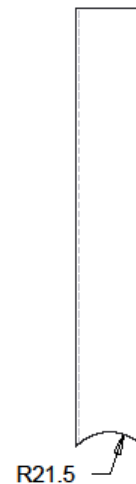
| Part | Number | Quantity |
|------------------|--------|----------|
| Seat tube | 30 | 1 |
| Seat tube insert | 31 | 1 |



Seat tube insert



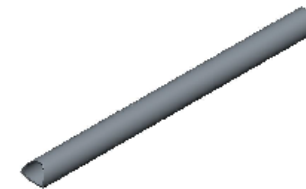
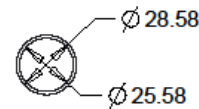
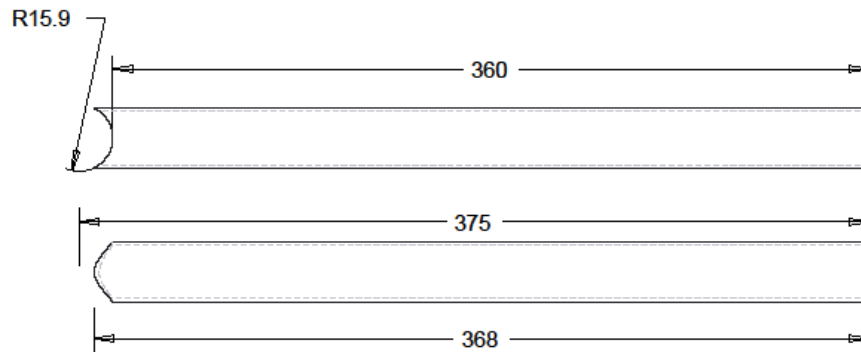
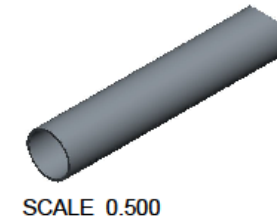
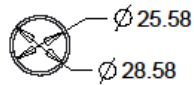
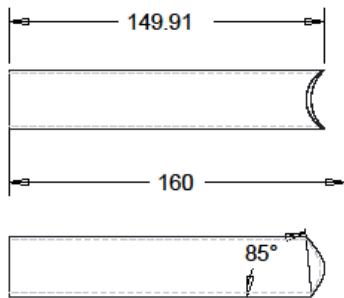
Seat tube



| | | | | |
|----------------------|-----------|-------|------|------------|
| Bike Centric Studios | Scale | 0.333 | Date | 25/01/2017 |
| | Seat Tube | DWG | C | |



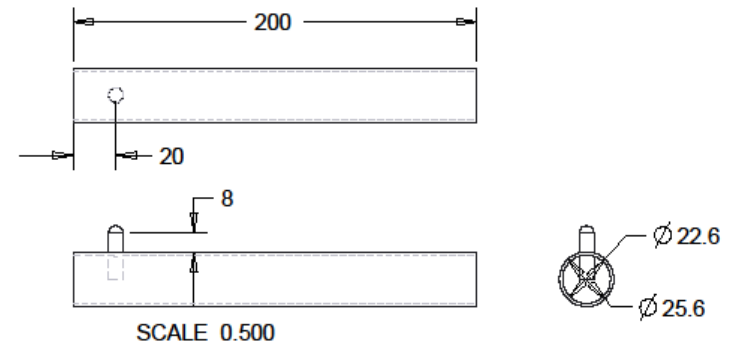
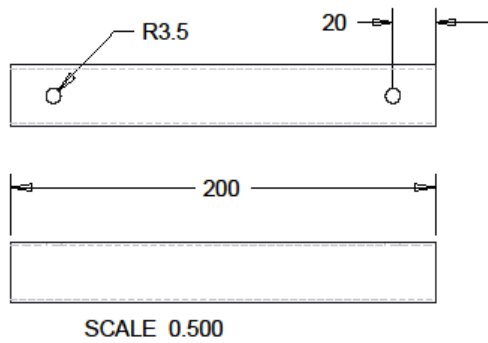
| Part | Number | Quantity |
|------------|--------|----------|
| Top tube 1 | 37 | 1 |
| Top tube 2 | 38 | 1 |



| | | | | |
|----------------------|----------|-------|------|------------|
| Bike Centric Studios | Scale | 0.250 | Date | 29/01/2017 |
| | Top tube | DWG | D | |



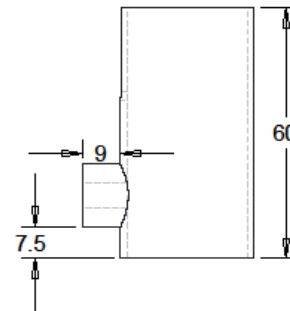
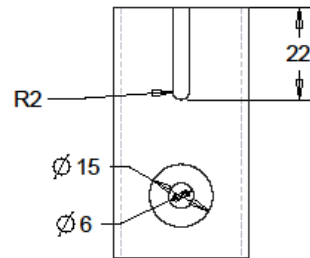
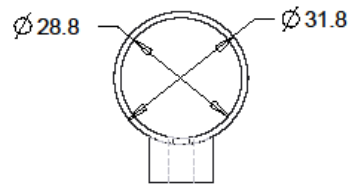
| Part | Number | Quantity |
|-------------------------|--------|----------|
| Handlebar center | 13 | 1 |
| Handlebar removable end | 14 | 2 |



| | | | | |
|----------------------|-----------|-------|------|------------|
| Bike Centric Studios | Scale | 1.000 | Date | 03/02/2017 |
| | Handlebar | DWG | E | |



| Part | Number | Quantity |
|---------------|--------|----------|
| Rotating tube | 22 | 1 |

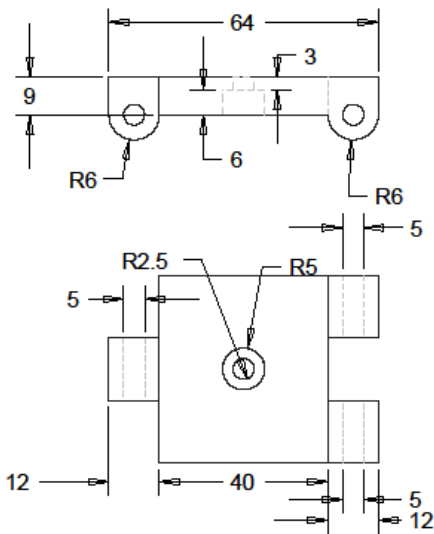


SCALE 2.000

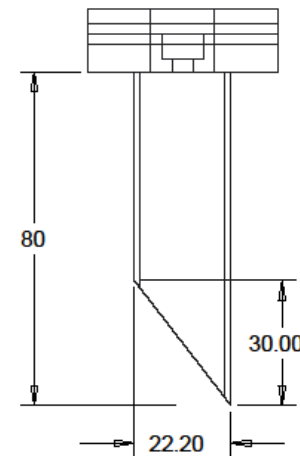
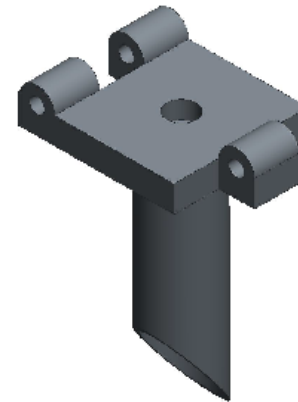
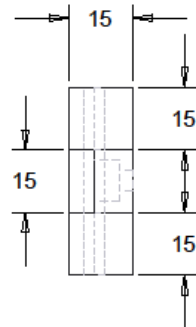
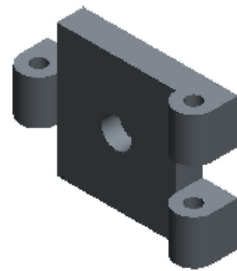
| | | | | |
|-----------------------------|-------|-------|------|------------|
| Bike Centric Studios | Scale | 1.000 | Date | 25/01/2017 |
| Rotating tube | DWG | F | | |



| Part | Number | Quantity |
|------------------|--------|----------|
| Hinge plate stem | 19 | 1 |
| Stem tube | 36 | 1 |



Hinge plate stem

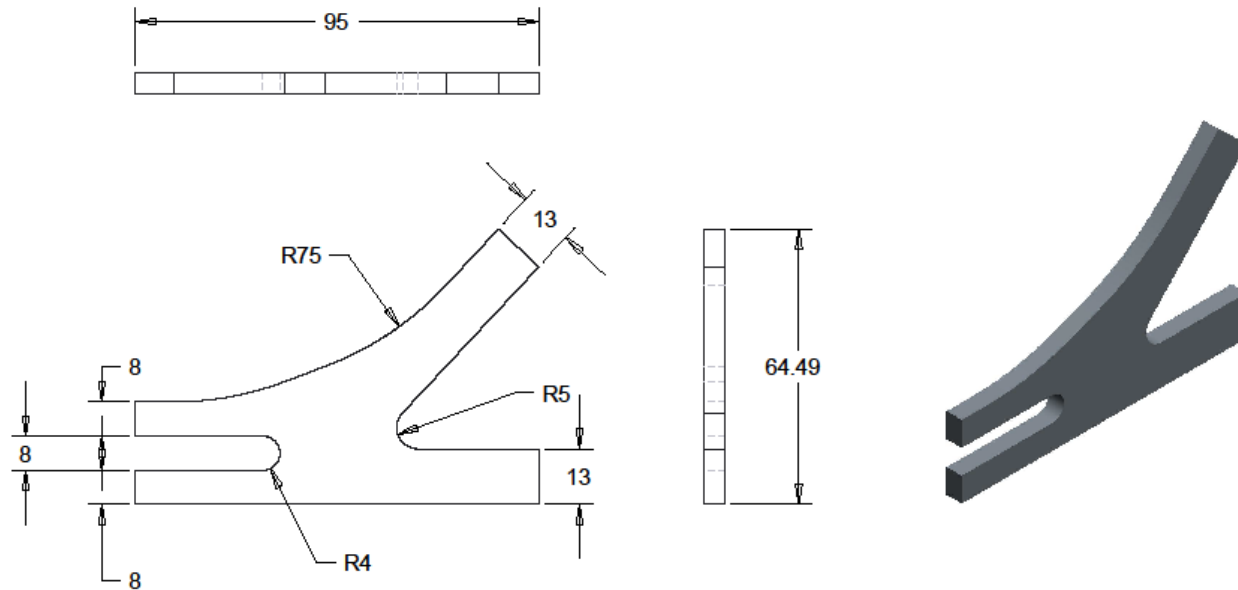


Stem tube

| | | | | |
|-----------------------------|-------|-------|------|------------|
| Bike Centric Studios | Scale | 1.000 | Date | 03/02/2017 |
| Stem hinge base | DWG | G | | |



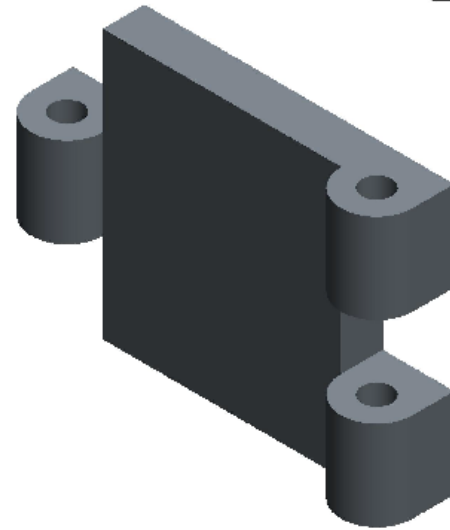
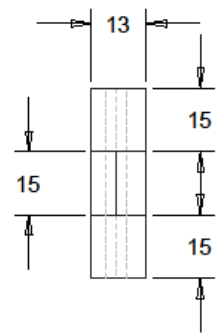
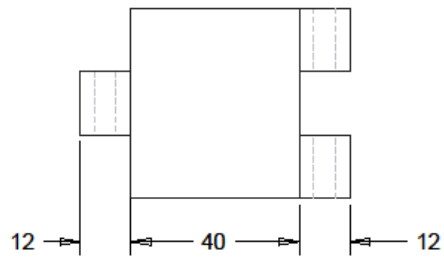
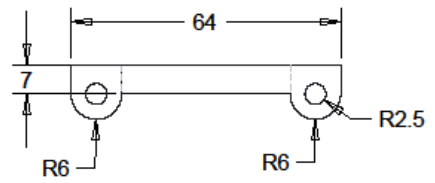
| Part | Number | Quantity |
|---------------------|--------|----------|
| Rear drop out mount | 20 | 2 |



| | | | | |
|-----------------------------|-------|-------|------|------------|
| Bike Centric Studios | Scale | 1.000 | Date | 03/02/2017 |
| Rear drop out mount | DWG | H | | |



| Part | Number | Quantity |
|-------|--------|----------|
| Hinge | 18 | 3 |

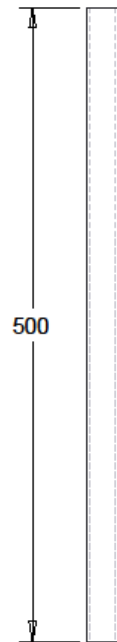
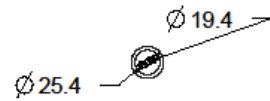


SCALE 2.000

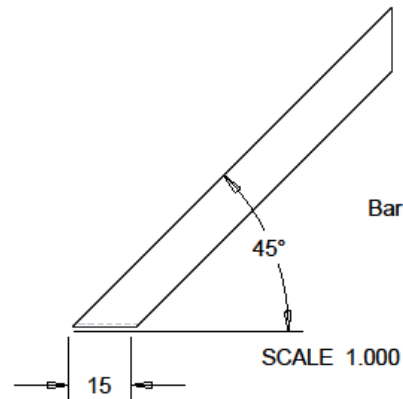
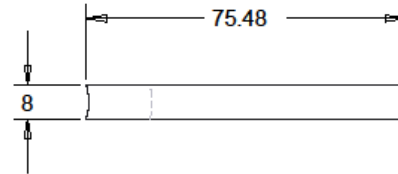
| | | | | |
|-----------------------------|-------|-------|------|------------|
| Bike Centric Studios | Scale | 1.000 | Date | 25/01/2017 |
| | Hinge | DWG | I | |



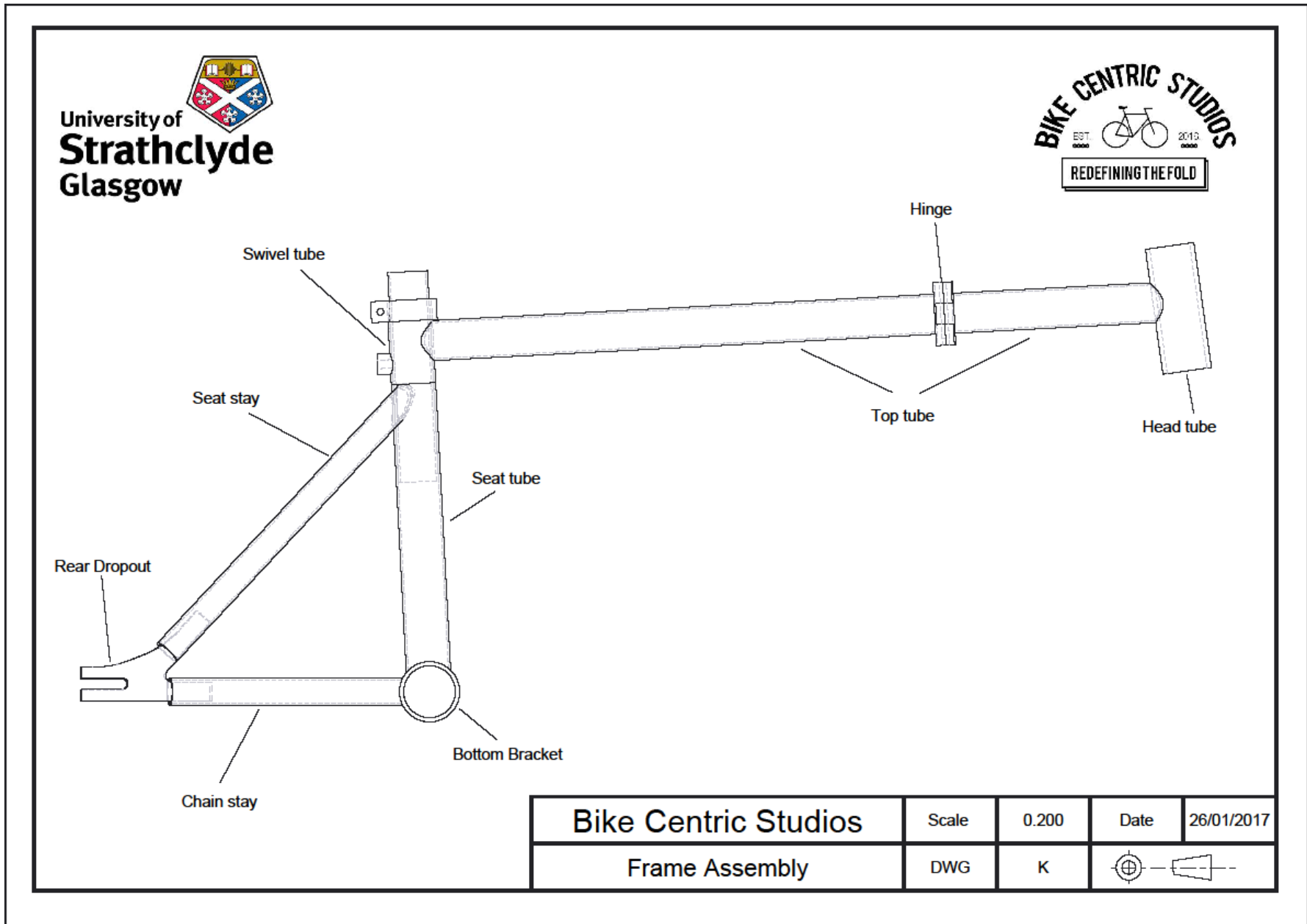
| Part | Number | Quantity |
|-----------|--------|----------|
| Seat tube | 26 | 01 |
| Bar | 27 | 01 |



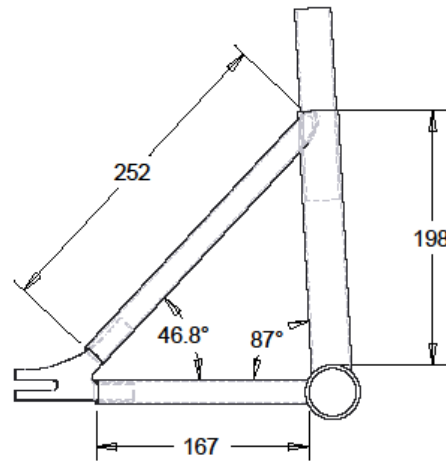
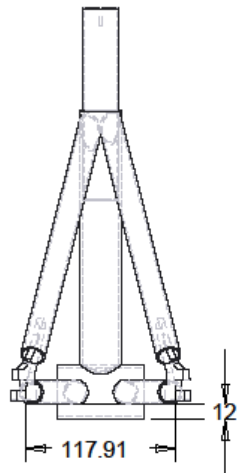
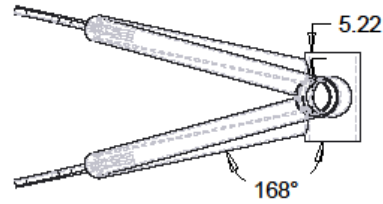
Seat post



| | | | | | |
|-----------------------------|--|---------|-------|------|------------|
| Bike Centric Studios | | Scale | 0.300 | Date | 03/02/2017 |
| Seat post | | DWG NO. | J | | |

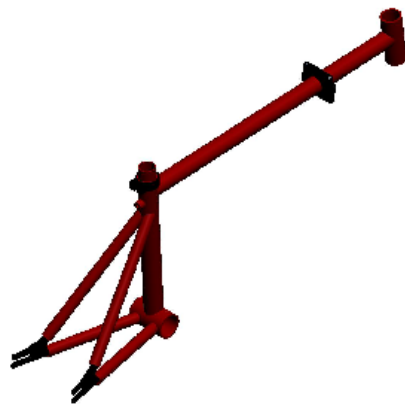


| | | | | | |
|-----------------------------|--|-------|-------|------|------------|
| Bike Centric Studios | | Scale | 0.200 | Date | 26/01/2017 |
| Frame Assembly | | DWG | K | | |

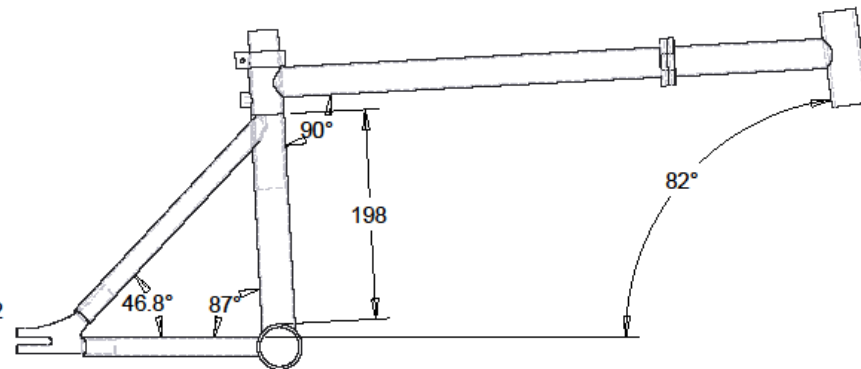
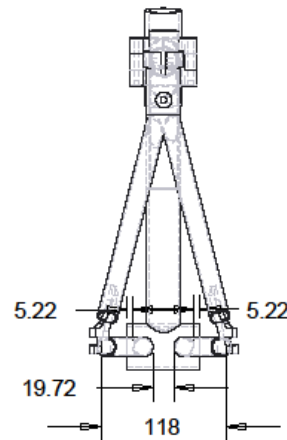
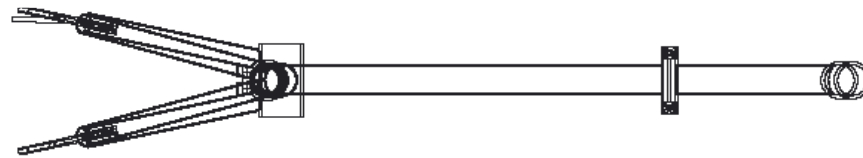


SCALE 0.400

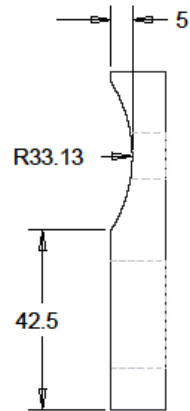
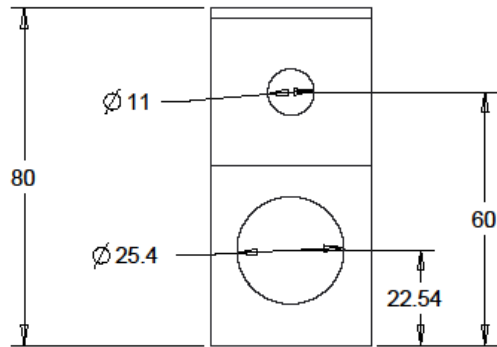
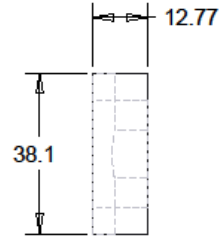
| | | | | |
|----------------------|------------------------|-------|------|------------|
| Bike Centric Studios | Scale | 0.200 | Date | 03/02/2017 |
| | Rear Triangle Assembly | DWG | L | |



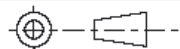
SCALE 0.150

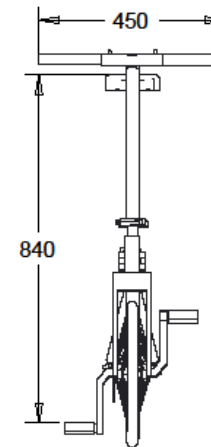
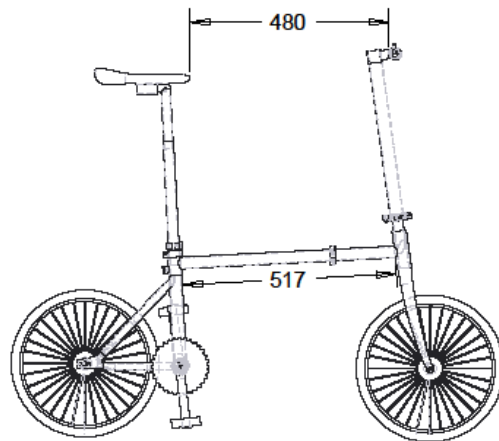
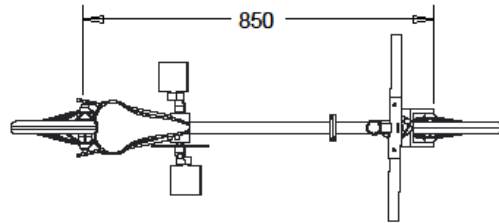


| | | | | |
|-----------------------------|-------|-------|------|------------|
| Bike Centric Studios | Scale | 0.200 | Date | 26/01/2017 |
| Frame | DWG | M | | |



| Part | Number | Quantity |
|--------------|--------|----------|
| Seat Setback | 39 | 01 |

| | | | | |
|---------|-------|---|----------|-----------------------------|
| Scale | 0.167 | Date | 02/03/17 | Bike Centric Studios |
| DWG NO. | N |  | | |



| | | | | |
|-----------------------------|----------|-------|------|------------|
| Bike Centric Studios | Scale | 0.100 | Date | 03/02/2016 |
| | Assembly | DWG | O | |

Appendix L: BCS Business Plan

DEPARTMENT OF MECHANICAL & AEROSPACE ENGINEERING



BIKE CENTRIC STUDIOS

Business Plan



Carlos Lopez Ayesta, Dominic Johnston,
David Mann, Andrew Martin, Aaron
Thompson



Table of Contents

| | |
|--|-----------|
| 1.0 Business Structure | 2 |
| 2.0 Management | 2 |
| 3.0 Location..... | 2 |
| 4.0 Market Assessment | 3 |
| 5.0 Market Competition Assessment | 4 |
| 6.0 Differentiation..... | 5 |
| 7.0 Patents | 6 |
| 9.0 Risks | 6 |
| 10.0 Start-Up Capital | 7 |
| 10.1 Personal investment | 7 |
| 10.2 Crowdfunding..... | 8 |
| 10.3 Venture Capitalists | 9 |
| 10.4 Small Business Bank Loan | 9 |
| 11.0 Pricing | 9 |
| 12.0 Advertising | 10 |
| 13.0 Pre-Launch..... | 10 |
| 14.0 Year 1 | 11 |
| 15.0 Year 2 | 12 |
| 16.0 Year 3 | 12 |
| 17.0 Production & Sales Projection..... | 12 |
| 18.0 Projected Profit & Loss Summary | 13 |
| 19.0 Employees | 13 |
| 20.0 Summary | 14 |
| 21.0 References..... | 16 |
| <i>Appendix A: Risk Mitigation Planning- Business Plan.....</i> | 18 |
| <i>Appendix B: Projected Profit & Loss Statement.....</i> | 21 |

1.0 Business Structure

The most efficient business vehicle for Bike Centric Studios will be a limited company carrying out all business transactions of the proposed venture – employing the staff, buying, selling, entering into contracts and borrowing. Limited company status protects the shareholders and is tax efficient and appropriate for raising capital. The company name will be protected by registering it with the Registrar of Companies. BCS Limited will trade and operate, meeting all the necessary reporting requirements.

2.0 Management

Each of the five founding members will hold 20% of the equity in Bike Centric Studios Limited. The management structure will follow the same pattern as detailed in **Section 6** of the CDIO Design Challenge report, with each member having the following defined roles:

- CEO – Aaron Thomson
- CFO – Dominic Johnston
- Research and Development - Carlos López Ayesta
- Lead Design Engineer – David Mann
- Lead Manufacturing Engineer – Andrew Martin

In this structure, the five founding members will be able to control all aspects of the company's operations each using their professional knowledge and skills, each significantly motivated to ensure the operation is a success.

3.0 Location

BCS was founded in Glasgow and it was decided that Glasgow should be the centre of operations at the beginning of its commercial life. Glasgow is major city in the heart of Scotland with a population of around 600,000¹ and an estimated 10,000 people currently using their bicycles as a method of commuting over 307 km of cycle lanes of varying types². This presents a great opportunity for BCS to enter into the local cycling market.

BCS has identified a suitable warehouse in Glasgow's Trade Park³ located in G69. This is a good location for manufacturing, as well as being a convenient base for all business operations. The premises, covering 6,000 ft², give ample room for production expansion during the first few years and the location at Junction 9, just off the M8, makes it ideal for the transport links throughout Scotland and further afield.

In order to reduce early start-up costs, BCS does not intend to have its own retail presence. Instead, it will sell its bikes exclusively online, for delivery or collection at its manufacturing warehouse.

After three years of trading, BCS intends to use the profits generated to branch out in the UK. Several cities were considered, with BCS ultimately deciding to open next a manufacturing presence in Bristol, England. Bristol is the logical location for BCS to expand into as it is known as the UK's "first cycling city", with over 18 million bicycling trips made each year, just under 9 million of which are for work purposes⁴.

4.0 Market Assessment

The market research performed at the start of the project has given Bike Centric Studios very useful information to formulate its business plan and substantial data to evaluate the needs of our customers. One of the most important results obtained from the survey was how few commuters use their bicycle in their daily commute to work, shown in **Figure 1**. One of the primary reasons for this is using a bicycle in conjunction with public transport. With traditional (non-folding) bicycles, this method of commuting is a challenge for most riders when trying to get on busy public transport at rush hour. However, with a bicycle that is easy to fold and unfold, the problem is greatly reduced. This is one of the reasons why BCS believes it will be able to convert more of the commuting urban population into cycling to work and doing so using the Urban Rider.

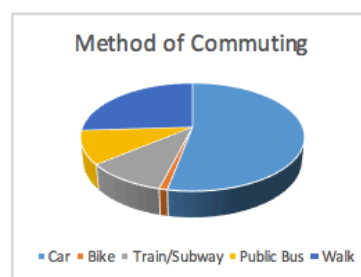


Figure 1: Method of Commuting

BCS will create a marketing strategy which will highlight the Urban Rider's benefits on public transport, to show commuters that with the light, compact, Urban Rider their daily commute will be faster and easier.

5.0 Market Competition Assessment

There are currently many types of folding bikes on the market with a wide range of prices and styles. BCS have evaluated the best and worst aspects of the folding bicycles currently on sale and have used its findings to inform the design of its product, the Urban Rider. BCS deemed that one of the best folding bicycles currently on the market is the British made Brompton. Like BCS's Urban Rider, it has an innovative folding mechanism which allows the bicycle to be quickly and easily folded. The Brompton is by default made of steel, although there is an option for the bike to have the rear triangle made of titanium which saves around 1 kg of weight. Although this bicycle has been deemed to be one of the best on the market, BCS immediately realised that it does not fit the requirements set by the CDIO Design Challenge since its dimensions are too large when folded. Additionally, for it to meet the weight requirements at 9.9kg, the steel/ titanium material option must be selected at an additional cost of £580⁵ to be added to the base of cost of £800. The Brompton bicycle is shown in **Figure 2**.



Figure 2: Brompton Folding Bicycle⁶

The Brompton bicycle has a large range available for purchase which vary with material and personalisation. However, their folding mechanism remains constant throughout. Brompton's price range is between £800 and £2,500.

Another strong market competitor is Tern (**Figure 3**) This company provides a range of folding bicycles from electric to pedal powered and, as with the Brompton, the folding mechanism does not change between models. The folding time is an impressive 10 seconds to fully fold. However,

none of the models meets the CDIO folded dimension requirements. One of the premium Tern models does meet the weight requirements, but is sold at over £1,500.



Figure 3: Tern Folding Bike⁷

Another leading brand in the folding bicycle market is Dahon. Its models cover the same price range as the Brompton bicycle but its folding mechanisms are simpler and vary between models. It was found that the Dahon EEZZ D3 (**Figure 4**) bicycle is the only model able to satisfy the weight requirement of the CDIO competition. The price of this bicycle is £800, which is a reasonable price considering the advantage this bike has against others in the market. It is one of the lightest and least expensive models, however, it does not meet the dimension requirements.



Figure 4: Dahon EEZZ D3 Folding Bike⁸

6.0 Differentiation

The stand out selling points of the Urban Rider are its weight and folding dimensions when compared with its main competitors, and its very competitive price. It weighs less than ten kilograms and its dimensions are at least 10% less than than similar products which cost at least 30% more than the forecast selling price of the Urban Rider - £600. This lightweight, compact, relatively inexpensive package makes the Urban Rider stand out from competitors, as currently a

buyer would have to pay in the region of £1,000 to have a bicycle as light as ten kilograms, as compact as the Urban Rider.

BCS will also produce handmade folding bicycles, tailored to suit the needs of the customer. This will include a range of colours to choose from and choices of the type of gear system. Many companies produce “one product fits all”, whereas BCS will be able to make a variety of products to give the customer a choice.

For those customers who are interested in buying British, the Urban Rider is entirely manufactured in Britain.

7.0 Patents

Bike Centric Studios intends to patent the Urban Rider and key design aspects such as its swivel design. By patenting the swivel design, BCS will be able to secure its intellectual property which one of its key selling points. Although patenting the design will incur costs early in the business, in the long-term it will greatly benefit the company.

8.0 Warranties & Maintenance

Throughout the first three years from start up, BCS will offer a sales and support service for its new products, in a small area set aside for this in its manufacturing plant. There will also be offices to provide for sales and advice on products, together with the website being used for product sales and general enquiries.

BCS will offer a 24-month warranty with the product. This extended warranty, more than the market norm, is a measure of the confidence the company has with the Urban Rider, and is another strong selling point for the product, which will likely bring in new business.

9.0 Risks

Sixty percent of new businesses cease operations within five years⁹. For a new, unproven start up therefore, thorough risk assessment and management is a key factor which can determine the success or failure of a business. BCS is employing the same 9 step process for its risk mitigation planning as described in **Section 5** of the CDIO Design Challenge report, tailored towards the

creation and operation of a business start up. **Appendix A** shows the full set of risks and mitigation steps considered for BCS to become a successful business and enhance confidence in the investment. The major risks identified by BCS are shown below:

- **Getting the price of the bicycle wrong:** pricing the Urban Rider at too high a price to compete effectively and yet generate enough sales to achieve reasonable profit margins. Extensive market research has taken place and the cost of goods sold per bicycle has been estimated as accurately as possible to try and mitigate this risk.
- **Under estimating the number of returns:** leading to an unexpected increase in costs and a reduction in estimated revenue. This is difficult to accurately predict. A conservative percentage of sales has been set to quantity returns and this has been built into the predicted profit and loss statement.
- **Poor follow up service:** BCS intend to offer a 24-month warranty which is more than the industry standard, and outwith that period, will direct customers to BCS officially approved repair shops.
- **Predicted sales increase is overstated:** creating implications for cash flow and level of bank borrowing. BCS has undertaken extensive market research, has underestimated the predicted number of sales, and allowed for potential production increases or decreases if required.
- **Patent infringement:** opening BCS up to a law suit and significant cost and delay consequences if found to be in infringement of any active patents. BCS has and will research active patents to ensure BCS's designs are not in violation.

10.0 Start-Up Capital

There are several ways to generate the capital required in order to launch a new business. Four routes were considered for BCS to explore, as outlined below:

10.1 Personal investment

This would entail an equal personal investment from each founder of BCS in order to meet the required capital to begin manufacturing and business operations, each founding member receiving a return on their investment dependent on the success of BCS. This method has the

advantage that the management team would share any risk evenly and have a greater incentive for BCS to succeed. Additionally, no interest would have to be repaid to a lender and the founding members of BCS would retain full control of the company. However, the capital required for a new business start-up is considerable, and the founding members would only be able to subscribe a small proportion of this.

10.2 Crowdfunding

Crowdfunding is a relatively recent, new form of raising capital, where a group/ business has developed a working prototype but lacks the necessary investment capital to get it off the ground. One of the best examples of a successful crowd funding campaign is of the Pebble Watch. The goal for the Pebble was to raise \$100,000 for production of a smart watch, and after 30 days it raised \$10 million¹⁰. Two major crowdfunding websites are Kickstarter¹¹ and Indiegogo¹². Over 120,000 projects have been backed on Kickstarter to date, and the total amount of money pledged to projects is over \$2.8 billion¹³. The process works by detailing the business idea, from concept drawings to prototypes, and asking the public to pledge money to turn the idea into a working business. A total goal amount is set and different levels of pledge are characterised by how the project will pay the 'investor' back. In relation to BCS's project, a low amount could be simply characterised as a straightforward donation for somebody who wants to help out the project in a small way. A medium sized donation could give the pledger branded merchandise with the BCS logo and the Urban Rider written on them or high quality prints of the finished Urban Rider. Pledges in the form of advance sales, paid for 6 months before start up, could receive a £50 discount on the price. Pledges above £5,000 could be in the form of dividend earnings share capital or a repayable bond, both with some preferential status.

Advantages of crowdfunding are that it can give an early impression of likely sales, provide feedback on the product from a large pool of people, and can generate pre-sales.

Disadvantages of crowdfunding are that there are no guarantees that the project will be funded. Additionally, certain crowdfunding platforms will only allow the money that has been pledged to transfer to the business if the total amount asked for has been successfully pledged. This can prove a challenge as there is a balance between setting an amount that would be required for the business to effectively begin operations with some security and an amount that is likely to fully meet its goal.

10.3 Venture Capitalists

A third option considered to finance the business is by using venture capitalists. BCS would pitch the Urban Rider and business plan to a number of wealthy individuals and/or groups in the hope that they would invest in the company for a percentage share of BCS.

Advantages of this method are that the company would be backed by investors with considerable business acumen, who could advise the company on strategy and decision making, increasing the likelihood of BCS's success. There is also the potential for additional resources and funding should it be required and venture capitalists have connections that BCS would otherwise not have access to as a new start-up company, operating on its own accord.

Disadvantages of venture capitalists are that the founders would likely have to relinquish a large minority share in the company to the investors. This ultimately gives BCS less control in the decision making process and in order to meet the capital required, it may reach the point that the founders relinquish the controlling interest in the company, something that they are reluctant to do.

10.4 Small Business Bank Loan

This would involve borrowing a fixed amount from a bank or building society, whereby BCS would pay back an annual interest fee at a fixed rate. This is an attractive option as there are multiple types of loans available, the rate of interest tends to be lower in the current financial climate and the founders of BCS would retain 100% of the company.

Disadvantages are that the application process can be long and cumbersome. There is the risk the founding members may have to give some personal collateral against the loan.

Because the founders believe strongly in the success of the project, the preference would be not to give up equity, but to go for the small business bank loan and negotiate hard to get a good deal here.

11.0 Pricing

The Urban Rider will be handmade, use British materials and a British workforce and will be marketed at a competitive price of around £600 for a quality product. Comparatively, the market leader with a similar style of folding bicycle, The Brompton, starts at around £800, but doesn't have

the weight and folding dimension advantages of the Urban Rider. These advantages, along with the lower price, provide the key differentiation.

12.0 Advertising

As a new company BCS needs to invest wisely to target the correct audience when advertising. Successful advertising can make a big difference in sales and exposure for BCS's product and heavily influence the success of the company. BCS aim to have a presence on several different social media platforms to promote the company and its products, such as Facebook and Instagram. In addition to this, BCS intends to spend money on adverts through Google AdWords which will allow the company to budget wisely and selectively target our customer base. Through the Google AdWords scheme we will be able to display our adverts on Google search results that relate to the bicycle industry and display adverts on relevant websites. The advantage of using Google AdWords is that the company would only pay for the adverts that are clicked on and a limit per day or per week can be set. Platforms such as Facebook and Instagram also have similar advertising opportunities. Again, BCS would be able to select our target customers by location, age range, and interests and as 1.8 billion people interact with Facebook every month, this is huge resource which BCS can exploit.

For successful advertising, constant analysis and tracking needs to be carried out to identify what works and what does not, to ensure that valuable resources are not wasted on useless advertising. Both Facebook advert and Google AdWords provide the advertiser with critical analysis of how often interactions have occurred and who has interacted with the advertising.

As a bicycle company, BCS have identified from the market research that consumers are more likely to invest in cycling products during the 2nd and 3rd quarters of the year in Europe when the weather is more suited to cycling, therefore, a greater proportion of the advertising budget has been focused on these periods of the year.

13.0 Pre-Launch

BCS intends to launch the Urban Rider commercially at the start of 2018, with three months of planning, development and production to take place beforehand. By 1st October 2017, BCS intend to secure premises and the necessary patents to protect BCS's intellectual property. Equipment costs will be spread over the period, as will legal fees. A staggered production two months prior to launch

will take place for manufacturing testing and training of staff and so that sales of the Urban Rider can begin immediately at launch. The BCS management team have opted to not take their salary for the first two months of pre-launch, in order to reduce overall costs and after this, the BCS management team are to receive salaries of £15,000 each per annum. The labour required for the pre-launch will include the hiring of two dedicated welders, paid at an hourly rate. David and Andrew will become the assembly team, with Andrew remaining as Head of Manufacturing. In order to promote the Urban Rider an initially high amount of advertising will be instructed at a cost of £5,000 per annum.

The estimated pre-launch cash requirement is around £46,000 (**Table 1**) and as such, BCS intend securing a £75,000 overdraft facility at 3% APR interest rate to allow for cash flow issues and unforeseen contingencies. We appreciate we will require to do a detailed short and long term cash flow requirement exercise but believe the working capital can be kept to a minimum with the anticipated sales in years 1 - 3.


| Bike Centric Studios Pre-Launch Cash Requirements | |  | | |
|--|----------------|---|----------------|-------------------|
| Cash Requierment | Oct-17 | Nov-17 | Dec-17 | |
| Labour | - | 250 | 250 | |
| Salary | - | - | 8,333 | |
| Raw Materials | - | 3,450 | 6,900 | |
| Equipment | 5,000 | 5,000 | 5,000 | |
| Insurance | 83 | 83 | 83 | |
| Rent | 1,312 | 1,312 | 1,312 | |
| Utilities | 67 | 67 | 67 | |
| Telephone | 23 | 23 | 23 | |
| Patent | 2,000 | - | - | |
| Legal & Accountancy Fees | 3,000 | 1,000 | 1,000 | |
| Packaging | - | 50 | 100 | |
| Advertisement | 417 | 417 | 417 | |
| Total Cash Requierment | £11,902 | £11,652 | £23,485 | |
| Total Pre-Launch Cash Requierment | | | | £47,038.99 |

Table 1: Pre-Launch Cash Requirements

14.0 Year 1

The manufacturing team will continue to consist of two dedicated welders who, along with David and Andrew, will form the assembly team. Production will be gradually increased quarter upon quarter, at a rate below the projected sales, using the pre-production as a buffer in order to

minimise strain of the production team (**Table 2**). The BCS management team will take salaries of £15,000 per annum. Advertising expenses are to be £5,000 for the year, focused over the seasonal cycling period that is Q2 & Q3. From **Table 4** it can be seen that a trading loss of around £7,000 will be incurred for year 1.

15.0 Year 2

At the beginning of year 2 David and Andrew will move back into fulltime management roles and two more workers will be hired to make up the assembly team. Production for the year will be increased by 53% to match the projected increase in sales (**Tables 2 & 3**). Advertising expenditure will remain constant at £5,000 for the year and is divided in the same manner. David, in his Lead Design role will begin the development of the Urban Rider 2.0, for release at end of Year 2/ start of Year 3. From **Table 4** it can be seen that a profit of around £25,000 will be earned for the entire year.

16.0 Year 3

Given the release of the upcoming Urban Rider 2.0, production has increased by 33% in order to meet the projected increase in sales (**Tables 2 & 3**) and an additional two workers are to be hired to add to the assembly team. From **Table 4**, it can be seen that a profit of around £80,000 will be generated by the end of year 3.

17.0 Production & Sales Projection

Tables 2 & 3 show the projected production and sales schedule for the Urban Rider. It is predicted that BCS will sell a total of just over 3,000 bicycles during its first three years of operations.


| Bike Centric Studios Production Schedule | |  | | | |
|--|-----|--|-----|-----|-------|
| Year | - | Oct | Nov | Dec | TOTAL |
| 2017 | - | 0 | 10 | 20 | 30 |
| Year | Q1 | Q2 | Q3 | Q4 | TOTAL |
| 2018 | 40 | 80 | 160 | 200 | 480 |
| 2019 | 220 | 240 | 260 | 300 | 1,020 |
| 2020 | 330 | 350 | 400 | 430 | 1,510 |

Table 2: Production Schedule


| Bike Centric Studios Projected Sales | |  | | | |
|---|-----|--|-----|-----|-------|
| Year | | Oct | Nov | Dec | TOTAL |
| 2017 | - | 0 | 0 | 0 | 0 |
| Year | Q1 | Q2 | Q3 | Q4 | TOTAL |
| 2018 | 50 | 100 | 160 | 200 | 510 |
| 2019 | 220 | 240 | 260 | 300 | 1,020 |
| 2020 | 330 | 350 | 400 | 430 | 1,510 |
| Total Sales over the 3 years: | | | | | 3,040 |

Table 3: Projected Sales

18.0 Projected Profit & Loss Summary

A detailed profit and loss table with supporting calculations can be seen in Appendix B: Profit & Loss Statement, with **Table 5** showing a breakdown of the main headings for the first three years of BCS's operation.


| Bike Centric Studios Projected P&L Summary | |  | | | |
|---|----------|---|----------|-----------|--|
| | 2018 | 2019 | 2020 | TOTAL | |
| Net Sales | 290,700 | 581,400 | 860,700 | 1,732,800 | |
| COGS | 181,458 | 399,636 | 591,618 | 1,172,712 | |
| Gross Profit | £109,242 | £181,764 | £269,082 | £560,088 | |
| Expenses | 116,724 | 152,914 | 188,574 | 458,212 | |
| Tax | 0 | 0 | 12,481 | 12,481 | |
| Operating Profit | -£7,482 | £28,850 | £80,508 | £101,876 | |

Table 4: Projected P&L Summary

Professionally prepared cash flows will require to be produced, taking account of the ongoing working capital requirements. An indicative cash position as been added to the predicted profit and loss statement shown **Appendix B**.

19.0 Employees

In addition to the five founding members of BCS, a number of manufacturing workers are to be hired in the first three years. **Table 5** shows the breakdown of additional employees during this time.



| Bike Centric Studios Employees | |
|--------------------------------|-------|
| Year | TOTAL |
| 2017 | 2 |
| 2018 | 2 |
| 2019 | 4 |
| 2020 | 6 |

Table 5: BCS Employees

20.0 Summary

BCS, a limited company, intend to trade over the next three years under the management of the five shareholders, using a bank overdraft on agreed terms and conditions. The company will initially operate out of Glasgow, where local knowledge will help assist the company in securing premises and to begin manufacturing. After three years of trading, the company intends to expand across the United Kingdom, and open a second manufacturing base in Bristol, England. This will be achieved by reaching target sales over the course of the three years, with the profits generated from sales being used to fund the new premises.

From the market research conducted, BCS aims to stand out from the competition by showcasing the advantages of owning a lightweight, folding bicycle that can easily be taken on and off public transport, aimed at the typical city commuter. Comparing the Urban Rider to current products in the folding bicycle market, BCS believes that the size and weight of the Urban Rider, together with the lower price, will make it the stand out purchase, and become an immediate success in the market place.

As with any small start-up business, there are many risks to consider, particularly careful control of cash flow. By following a well thought out risk management structure, BCS feels that many possible outcomes have been considered and methods of combating potential issues have been developed and implemented. In order to obtain start-up capital for the company, BCS intends to secure a bank loan to cover the start-up costs, and will control costs carefully including starting salaries for the shareholders of £15,000 a year for the first year.

The company has set a final price for the Urban Rider of £600. This does not only come in at less than its competitors, but also ensures that the company will still be making a reasonable profit margin from each product sold. To make sure that the launch of the company is a success, BCS and

the Urban Rider will be heavily advertised on social media, given that the profile of the company is primarily online. This will ensure exposure to potential customers in the lead up to the release of the Urban Rider at the beginning of 2018.


From the projected profit and loss statements for the first three years of trading, BCS expects to incur an overall loss for the first year of trading, mainly due to high start-up costs, securing premises and advertising costs. However, by the end of the year three, profits and cash are positive, BCS aims to have increased the number of additional employees from two to six and have sold just over three thousand units of its flagship product, the Urban Rider.

21.0 References

1. *Population Of Glasgow In 2016*. Ukpopulation2016.com. 2017 [Online] [Accessed 8 March 2017]. Available from: <http://ukpopulation2016.com/population-of-glasgow-in-2016.html>
2. Glasgow cycling commuter's data. *Cycling Weekly Official Website* [Online] Available at: <http://www.cyclingweekly.co.uk/news/latest-news/glasgow-records-huge-spike-commuter-cycling-141697> (Accessed 3 March 2017)
3. *Light Industrial to rent*. [Internet]. Rightmove.co.uk. 2017 [Accessed 8 March 2017]. Available from: <http://www.rightmove.co.uk/commercial-property-to-let/property-40694817.html>
4. *Bike Life Bristol 2015* [Accessed 11 March 2017]. [Online] Available from: http://www.sustrans.org.uk/sites/default/files/bike_life_bristol_2015.pdf
5. *Bike Builder Brompton*. 2017 [cited 8 March 2017]. [Online] Available from: <http://www.brompton.com/Buy/Build-your-Brompton>
6. Brompton Folding Bike. *Brompton Official Website* [Online] Available at: <http://www.brompton.com/> [Accessed 10 Nov. 2016]
7. Tern Verge Folding Bike. *Tern Bicycles Official Website* [Online] Available at: <http://www.ternbicycles.com/uk/bikes/467> (Accessed 2 March 2017).
8. Dahon EEZZ D3 Folding Bike. *Dahon Official Website* [Online] Available at: <http://www.dahon.eu/bikes/eezz-d3-16/> (Accessed 3 March 2017).
9. Lobel, B. (2016) *Four in ten small businesses die within five years*. [Online] Available at: <http://smallbusiness.co.uk/business-failure-four-ten-small-companies-dont-make-five-years-2533988/> (Accessed: 2 March 2017).
10. Price, M. (2014) *Here's how the pebble Smartwatch became the most funded project in Kickstarter history*. [Online] Available at: http://www.huffingtonpost.com/michaelprice/heres-how-the-pebble-smar_b_5798406.html (Accessed: 2 March 2017).

11. *Kickstarter*. [Online] Available at: <https://www.kickstarter.com> (Accessed: 1 March 2017).
12. *Indiegogo*. [Online] Available at: https://www.indiegogo.com/#/picks_for_you (Accessed: 1 March 2017).
13. *Kickstarter Stats*. [Online] Available at: https://www.kickstarter.com/help/stats?ref=about_subnav (Accessed: 5 March 2017).

Appendix A: Risk Mitigation Planning- Business Plan

| Bike Centric Studios | |  | | Risk Mitigation Planning- Business Plan | | | | | | |
|----------------------|--|---|-------------------|---|---------|--|-----------------|-------------|-------------|--------------------------|
| Section | Risk | Potential Consequence | Impact Assessment | Probability | Ranking | Mitigation Steps | New Probability | New Ranking | Contingency | Group Member Responsible |
| Planning | Underestimating number of returns | Increased costs, reduction in estimated revenue | 2 | 2 | 4 | Expect and account for in profit and loss | 2 | 4 | | Carlos |
| | Bike priced too high | Reduced no of sales leading | 3 | 2 | 6 | Extensive market research and cost of goods sold evaluated | 1 | 3 | | Carlos |
| | Overestimation of sales | Implications for cash flow and level of bank borrowing | 3 | 2 | 6 | Extensive market research, while also underestimating the predicted number of sales and allowing for potential production increases if required. | 1 | 3 | | Carlos |
| | Not advertising adequately enough to promote the product and therefore sales | Product does not sell as well as expected | 3 | 2 | 6 | Initially focus on high levels of advertisement to get our product and company know and gradually reduce this cost | 1 | 3 | | Carlos |
| | Inefficient tasking of roles/responsibilities | Business failure | 3 | 2 | 6 | Belbin's Self Perception Inventory (SPI) test taken by each group member in order to more accurately divide roles | 1 | 3 | | ALL |
| | Poor choice of city to have a base of operations | Low sales and no room for expansion | 3 | 2 | 6 | Extensive market research regarding cyclists per capita etc. | 1 | 3 | | Carlos |
| | Not providing enough additional services | Poor brand image & unhappy customers | 3 | 1 | 3 | Offer 24-month warranty and recommend BCS officially approved repair shops | 1 | 3 | | Andrew |
| | Bike priced too low | Profit margins too low to be financially stable | 2 | 2 | 4 | Extensive market research and cost of goods sold evaluated | 1 | 2 | | Carlos |
| | Underestimating distribution costs | Exponential increase in assumed costs | 2 | 2 | 4 | Get quotes from delivery companies early | 1 | 2 | | Andrew |
| | Underestimation of sales | More sales than manufacturing can handle, leading to delays in consumer orders | 2 | 1 | 2 | Ensure production increases are feasible if required | 1 | 2 | | Carlos |
| | Underestimating packaging costs | Exponential increase in assumed costs | 1 | 2 | 2 | Get quotes from packaging companies early and perform testing | 1 | 1 | | Andrew |
| | Not having a dedicated storefront- reducing sales potential | Lower sales rate | 2 | 2 | 4 | Pitch product to existing major retailers | | 0 | | Dom |
| Health & Safety | Minor Worker incident | Harm to one of BCS's employees | 2 | 3 | 6 | Regular H&S training and a dedicated H&S Officer employees | 2 | 4 | | Dave |
| | Major customer incident | Harm to a customer as a result of BCS, leading to a lawsuit | 3 | 2 | 6 | Ensure throughout testing of products before release to the public | 1 | 3 | | Dave |
| | Major Worker incident | Major Harm to one of BCS's employees, leading to Lawsuit | 3 | 1 | 3 | Regular H&S training and a dedicated H&S Officer employees | 1 | 3 | | Dave |
| | Having to order recalls due to manufacturing error | Major financial losses | 3 | 1 | 3 | Ensure proper inspection of all products before being shipped to the customer | 1 | 3 | | Dave |
| Manufacturing | Manufacturing capabilities not able to meet sales | Having to cancel orders leading to decreases in potential revenue and unhappy customers | 3 | 2 | 6 | Ensure production increases are feasible if required | 1 | 3 | | Andrew |
| | Unforeseen labour absences | Manufacturing delays | 3 | 2 | 6 | Hire temporary workers to take up the slack | 1 | 3 | | Andrew |
| | Unforeseen manufacturing issues/ failures | Leading to delays in the manufacturing process | 2 | 2 | 4 | Start production before general release of the product in order to have time to address any problems | 1 | 2 | | Andrew |
| | Securing a workspace | Not having a location to set up manufacturing facilities | 2 | 1 | 2 | Search for suitable warehouses at the beginning of BCS's commercial life | 1 | 2 | | Andrew |

| | | | | | | | | | | |
|---------------|--|---|---|---|---|---|---|---|---|--------|
| Financials | Cannot source enough start-up capital | Business starts and fails | 3 | 3 | 9 | Explore multiple options for investment | 2 | 6 | Personal investment from each member of BCS | Dom |
| | Cannot source any start-up capital | Business cannot begin | 3 | 2 | 6 | Explore multiple options for investment | 2 | 6 | Save money and eventually commit to a personal investment from each member of BCS | Dom |
| | Required labour costs underestimated | Increased costs, reduction in estimated revenue | 2 | 2 | 4 | Estimate labour time per bike to get a reasonable approximation of labour costs | 2 | 4 | | Dom |
| | Required equipment costs underestimated | Increased costs, reduction in estimated revenue | 2 | 2 | 4 | Research required equipment costs. | 2 | 4 | Buy second hand equipment | Dom |
| | Not able to pay off debts | Lose business/ any collateral | 3 | 2 | 6 | Thorough financial planning | 1 | 3 | | Dom |
| | Requesting too much start up capital leading to unnecessary debt | Decreased profits | 3 | 2 | 6 | Thorough financial planning | 1 | 3 | | Dom |
| Miscellaneous | Not being able to compete effectively | Business failure | 3 | 3 | 9 | Extensive market research and cost of goods sold correctly evaluated | 2 | 6 | N/A | Aaron |
| | Delays in receiving materials | Cause delays to the manufacturing process | 3 | 2 | 6 | Start production before launch date in order to have products ready to go | 1 | 3 | | Andrew |
| | Not identifying appropriate risks and then mitigating them | Business failure | 3 | 2 | 6 | Preform an appropriate risk management process | 1 | 3 | | Dom |
| | Infringing existing patents | Lawsuit | 3 | 2 | 6 | Research of active patents to ensure BCS's designs are not in violation of any. | 1 | 3 | | Aaron |
| | Not fulfilling customer orders | Poor brand image & unhappy customers | 3 | 2 | 6 | Thorough planning of production schedules and delivery lengths | 1 | 3 | | Aaron |
| | Raw materials/ finishes bikes stolen | Lose of capital/ revenue source | 3 | 1 | 3 | Ensure adequate secure on manufacturing premises with security cameras | 1 | 3 | | Aaron |
| | Lack of leadership/ the ability to make tough, strategic decisions | Business failure | 3 | 1 | 3 | Appoint a strong CEO | 1 | 3 | | Aaron |
| | Hostile takeover | Lose control of business | 3 | 1 | 3 | Hire legal experts in order to reduce the chances of a hostile takeover | 1 | 3 | | Aaron |
| | Having company IP stolen | Competitors manufacture and sell any BCS's prototypes before they are can brought to market | 3 | 1 | 3 | Do not publish any detailed design drawings to the public | 1 | 3 | | ALL |
| | Communication breakdown between departments | Tasks/ deadlines are missed due to lack of communication | 2 | 2 | 4 | Weekly scheduled meetings for updates between divisions | 1 | 2 | | Aaron |

Appendix B: Projected Profit & Loss Statement

Supporting Calculations & Assumptions:

- Bicycle sale price = £600
- Sales = Number of predicted sales x bicycle sale price
- Returns = 5% of sales
- Labour Pay (LP) = £7.20 per hour
- Material Costs / Bike = £345
- Man Hours / Bike:
 - Welding = 1 – 1.5 hours
 - Painting = 0.5 – 0.75 hours
 - Assembly = 2 hours
 - Inspection/ Finishing = 1.5 – 2 hours
 - Total \approx 6.25 hours
 - Assumed Total = 6.5 hours
- Cost of Goods Sold (COGS):
 - $Y1 = LP \times \text{welding hrs.} \times \text{no. of bikes produced}$
 - $Y2 = LP \times 6.5\text{hrs} \times \text{no. of bikes produced}$
 - $Y3 = LP \times 6.5\text{hrs} \times \text{no. of bikes produced}$
- Salaries:
 - $Y1 = \text{£}15,000$ per management role
 - $Y2 = \text{£}20,000$ per management role
 - $Y3 = \text{£}25,000$ per management role
- Rent of warehouse = £1,312 pcm
- Depreciation = £15,000 worth of equipment over three years
- Interest on loan: 3% APR of £75,000 = £563 per quarter

- Distribution costs = £15 per sale
- Packaging costs = £5 per sale
- Corporation Tax is assumed to be 19% throughout the three years of the start-up period.
- The remainder of the expenses are a best approximation of likely values.
- The indicative cash position is a worst case scenario and makes no positive allowance for depreciation not actually affecting cash flow. Additionally, it assumes bills will have to be paid when presented or in advance, when it should be possible to negotiate a modest period for payment.