Technical Report 4:

Hopper and Trailer technical subsystem

&

Business management

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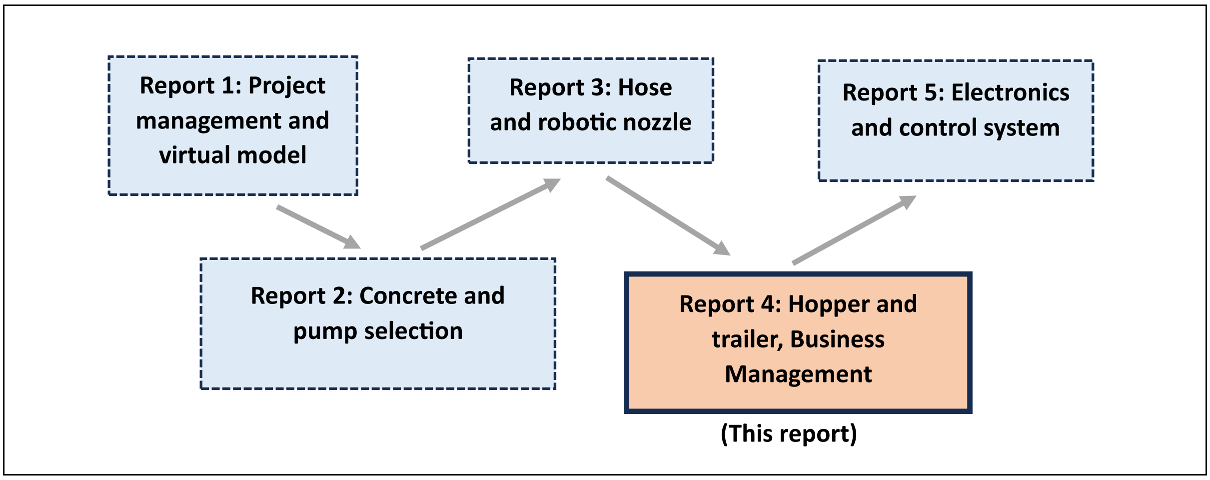
Abstract

As a collective, project Anaconda aims to provide a solution for concrete pumping on small to medium scale worksites.

The final proposed solution, dubbed 'The Anaconduit', is a 3.5 tonne trailer-mounted peristaltic line pump capable of delivering $8m^3$ loads of concrete in 30 minutes. It can be towed with a Category B Driver's License, has a reach of up to 29 metres, and an expected placement depth up to 1.5 metres.

Of the five technical reports documenting the project, this is fourth in the reading order. Contained within this is the documentation relating to the Hopper and Trailer technical subsystem of the Anaconduit, as well as the business management report.



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1. Introduction

1.1. Overview

The fourth report in reading order, this report is split into two distinct sections.

The first, technical aspect covers documentation relating to the hopper and trailer subsystem of the Anaconduit. Broadly, this consists of design specifications, component selection, costing, and verification of the final subsystem design. It then concludes with an evaluation of the current iteration of the subsystem, noting points of furture development.

The second, more colloquial aspect of this report covers content relating to the role of business manager within the Anaconduit team. This includes defining managerial responsibilities, a record of team activities, and documentation and reflection relating to the challenges faced throughout the project. If the reader wishes to begin here, refer to the end of the technical report, after 'Section 9. Conclusion and evaluation of technical subsystem'.

1.2. Description of technical components

1.2.1. Description

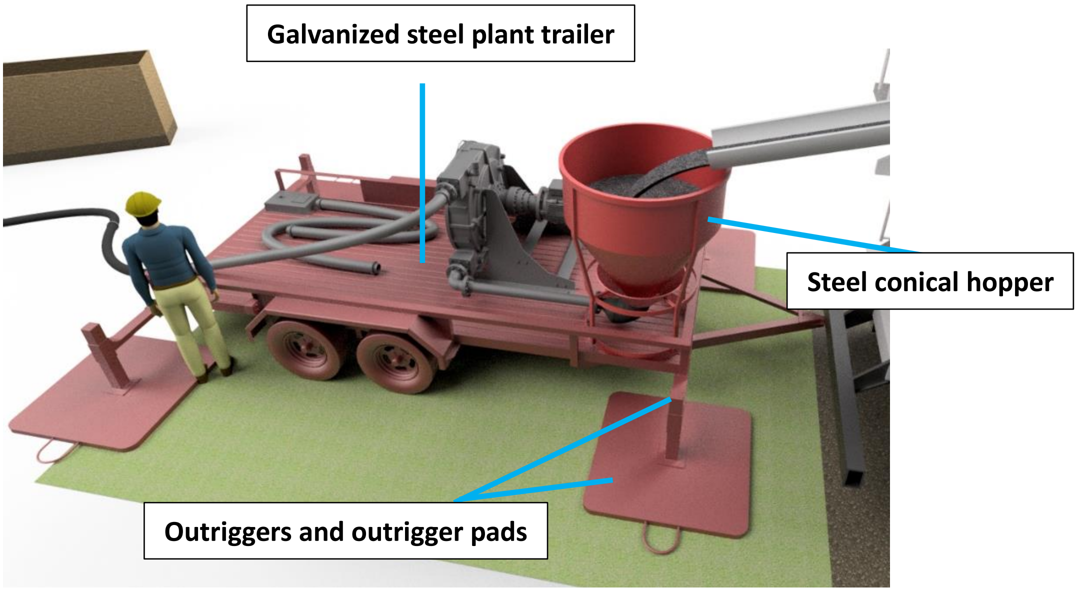

Figure 1: Description of subsystem using CAD render of Anaconduit

Labelled above in Figure 1 are the main physical components associated with the hopper and trailer subsystem.

At a high level, it features a painted steel conical hopper, a specialised plant trailer made of galvanised steel, and a set of four extendible outriggers to be used with pressure-spreading pads.

Specially assembled with the intent of maximising the use of OTS (off-the-shelf) components, this subsystem allows for the Anaconduit to be easily transported by towing as a standard 3.5 tonne trailer within the UK, as well as deployed safely on a worksite with the aid of outriggers.

In addition to the selection of these components, this report details the various joints and interfaces within the subsystem, products and supplies that would be needed to assist in transport, and displays pertaining to health and safety regulations in the construction industry.

In total, the hopper and trailer subsystem is estimated to cost £6316.67, with £5028.26 (80%) attributed to purchasing main subsystem components, £608.72 (10%) attributed to joining and workshop costs, £579.70 (9%) to transportation-related components, and £100 (1%) to signs and displays.

1.2.2. Relationship to other subsystems

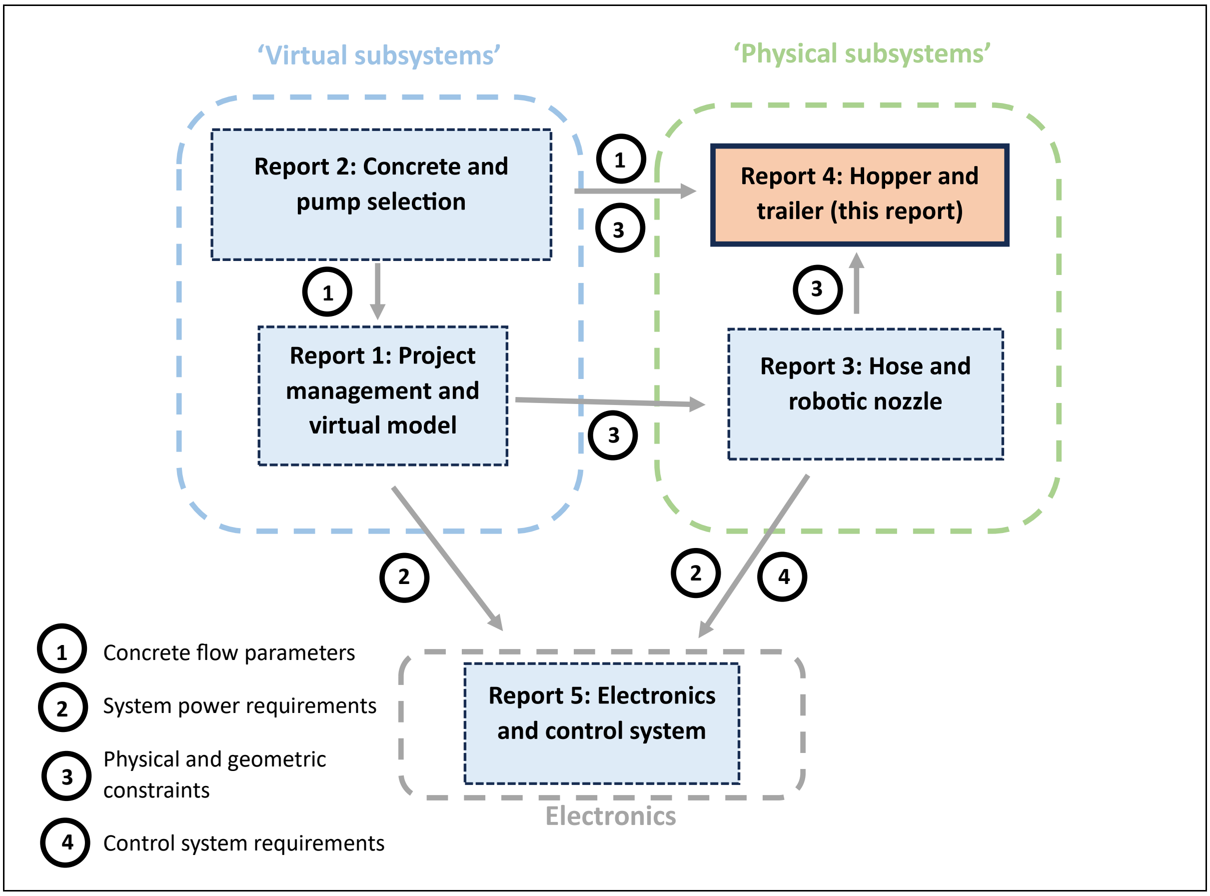

Figure 2: Schematic diagram showing technical relationships between various reports

Illustrated in Figure 2 is a schematic diagram showing how the various technical reports within the project interact with one another, and where this report lies among them.

Notably, the technical content of this report was directly dependent on outputs from Reports 2 and 3, which were in turn dependent on content relating to Report 1.

1.2.3. Dependencies

<u>Report 2: concrete and pump selection subsystem</u>

The first group of dependencies relating to Report 2 concerned concrete properties, where information was needed to aid hopper design as well as material selection. However, given that only a basic information was needed (concrete density, approximate pH values, etc), this did not pose a significant hurdle to this subsystem's design process

However, the second group, relating to pump selection, did. Initially during the design process of the Anaconduit, chassis and hopper design was initially done for an assumedly light (<25 kg), modular pump. Within this context, the scope of the hopper and chassis subsystem was to design a subsystem suitable to be **handled ergonomically, and transported within a large van.**

However, this changed significantly later in the design process, when the eventually selected pump was found to weigh 1200 kg, and a group decision was made to abandon modularity as a concept altogether.

The led to significant design changes of the Anaconduit, now needed to be suitable for **hauling by trailer**, and effectively redefining key constraints to the hopper and chassis subsystem. This is further documented in '1.3. Subsystem design process.'

<u>Report 3: Hose and robotic nozzle</u>

In comparison, dependencies relating to Report 3 were easier to manage. Dependencies were primarily guiding values, rather than constraints, such as pipe length, total subsystem weight, and other geometrical parameters.

In the initial stages of design, these factors were accounted for using formative, generous values during calculations. When they were subsequently solidified in Report 3, verification was done iteratively on already-selected components, and modifications made where relevant.

1.3. Technical subsystem design process

1.3.1. Design process flow chart

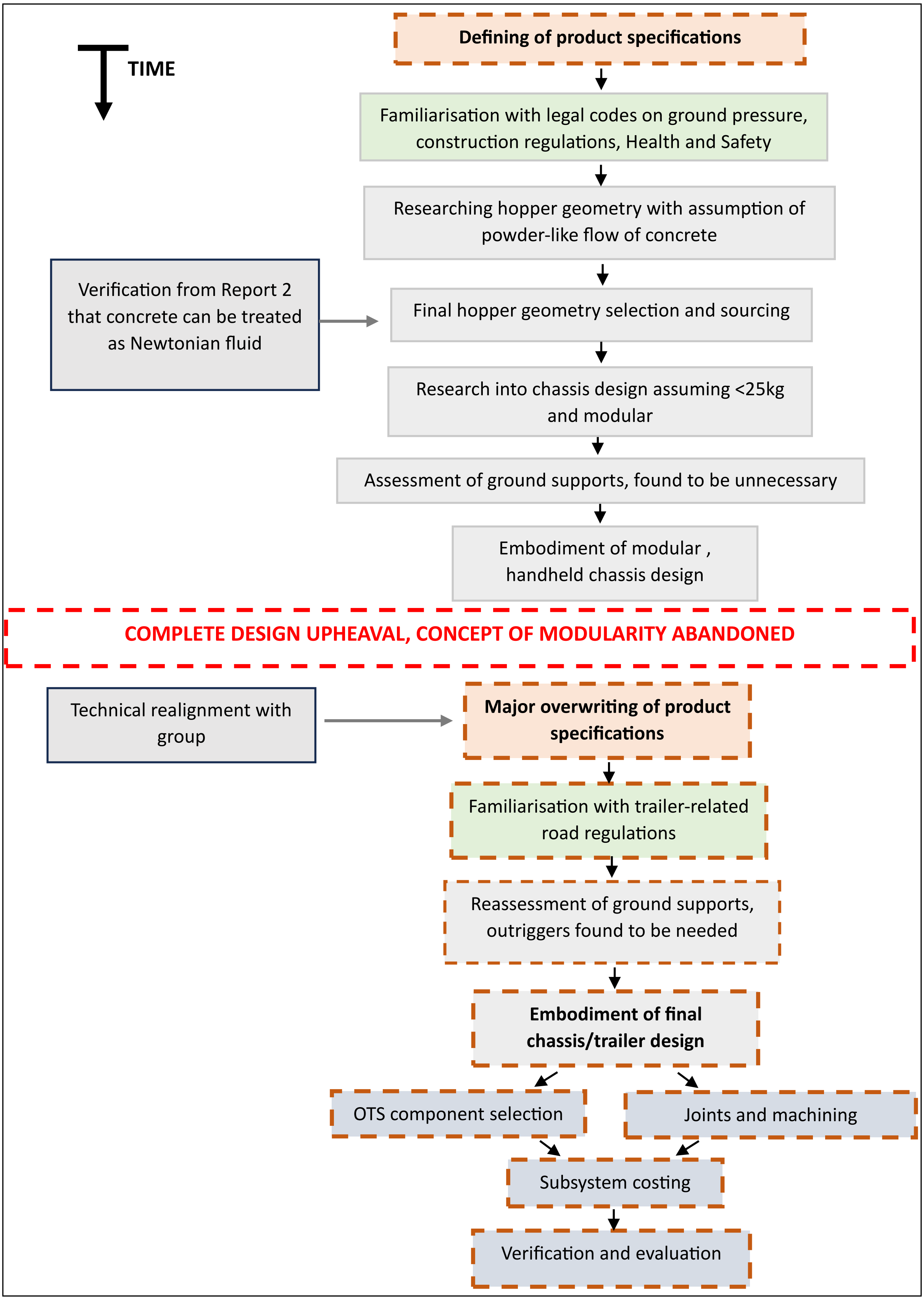

Figure 3: Flow chart detailing subsystem design process

1.3.2. Description of design process

Illustrated in Figure 3 is a detailed flowchart recording the design process of the trailer and hopper subsystem.

First, upon receiving the project brief from the client (Appendix A), a detailed set of design specifications were created, and an initial design proposal for the Anaconduit was produced.

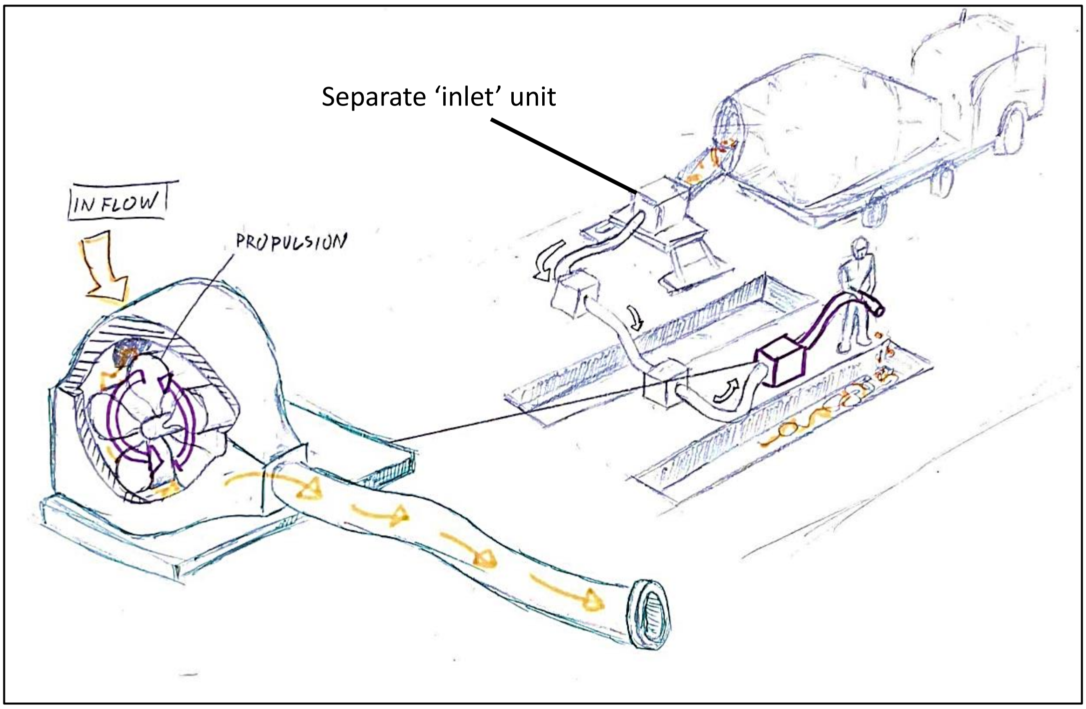

Figure 4: Initial, modular concept design of the Anaconduit

This concept proposal for the Anaconduit consisted of a modular, easily linked pump and pipe unit, with a separate unit acting as an inlet. Designed to be handheld, this concept utilised modularity and ease-of-use as a selling point, with modularity allowing for flexibility in scaling over a wide range of site sizes.

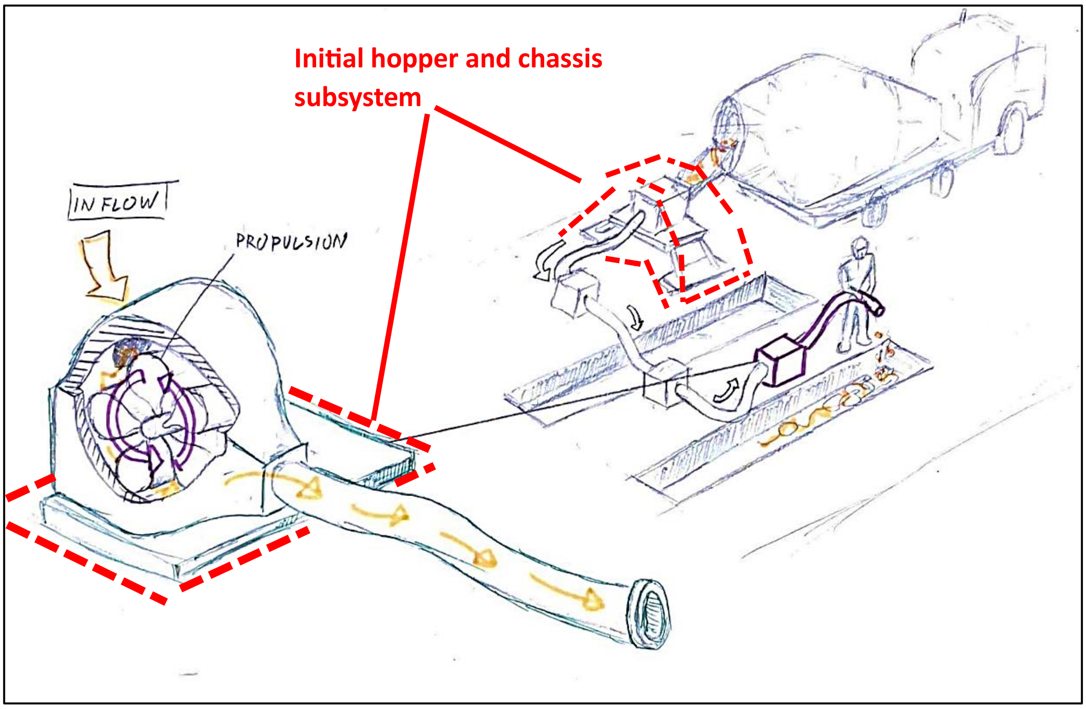

Figure 5: Initial hopper and chassis subsystem

Within this, the hopper and chassis subsection (then called the 'inlet and chassis subsection') consisted of designing the platform for each modular unit to rest against when on the ground, a method for receiving concrete from the truck, and ensuring the system could be transportable by van.

At a high level, this meant researching into how machinery might interact with its environment, and designing methods to account for this.

With this, research was done regarding the geometry, verification and selection of a concrete hopper. This was then followed immediately by research and embodiment pertaining to the design of a chassis for a small, light piece of machinery.

1.3.2. Consideration and subsequent discarding of modularity concept

For most of the project, subsystem research assumed this modular design to be effectively locked, taking hopper and pump chasses design as far as the embodiment stage.

However, as noted in red in Figure 3, there was a major upheaval to this when the group collectively found that modularity would be technically unfeasible. *Whilst this is recorded in more detail in Reports 1 and 2, the primary reason for this was that the peristaltic pump needed for the desired flow* *rate was found to weigh approximately 1200 kg, compared to the 25 kg aim guided by the legal weight limit for free-hand carrying of workers* (HSWA, 1974)*.*

This weight change directly affected the hopper and chassis subsystem, as the Anaconduit would no longer be road-legal for van transport. Upon further research, it was decided to change the Anaconduit's transportability from "transport by van" to "transport by standard trailer."

This is noted in final Design specification **No. 4.3.1.**

> *" Sub-system must be able to be transported in an analogous manner of a standard trailer"*

Subsequently, subsystem research switched from designing bespoke chasses, to selecting an OTS trailer suitable for use with the Anaconduit, and various design specifications had to be overwritten.

Additionally, with discarding the concept of modularity, Anaconduit was no longer aiming to be a product suitable for production at scale. This made it difficult to justify designing and making components in-house, as they could potentially incur large costs for marginal return.

The lasting impact this had on the hopper and chassis subsystem was that ordering components OTS was now of high priority, aiming to minimise needless capital costs.

To conclude, whilst this report aims to record the full development of this final, non-modular design, it is worth noting that much information within this process has been omitted.

1.3. Business report

In addition to technical elements relating to the hopper and trailer subsystem, this report also contains documentation relating to the role of Business Manager. Covering responsibilities, a record of related activities, and challenges faced within the role. This can be found upon finishing 'Section 9. Conclusion and evaluation of technical subsystem'.

2. Design specifications

2.1. Approach to Design Specifications

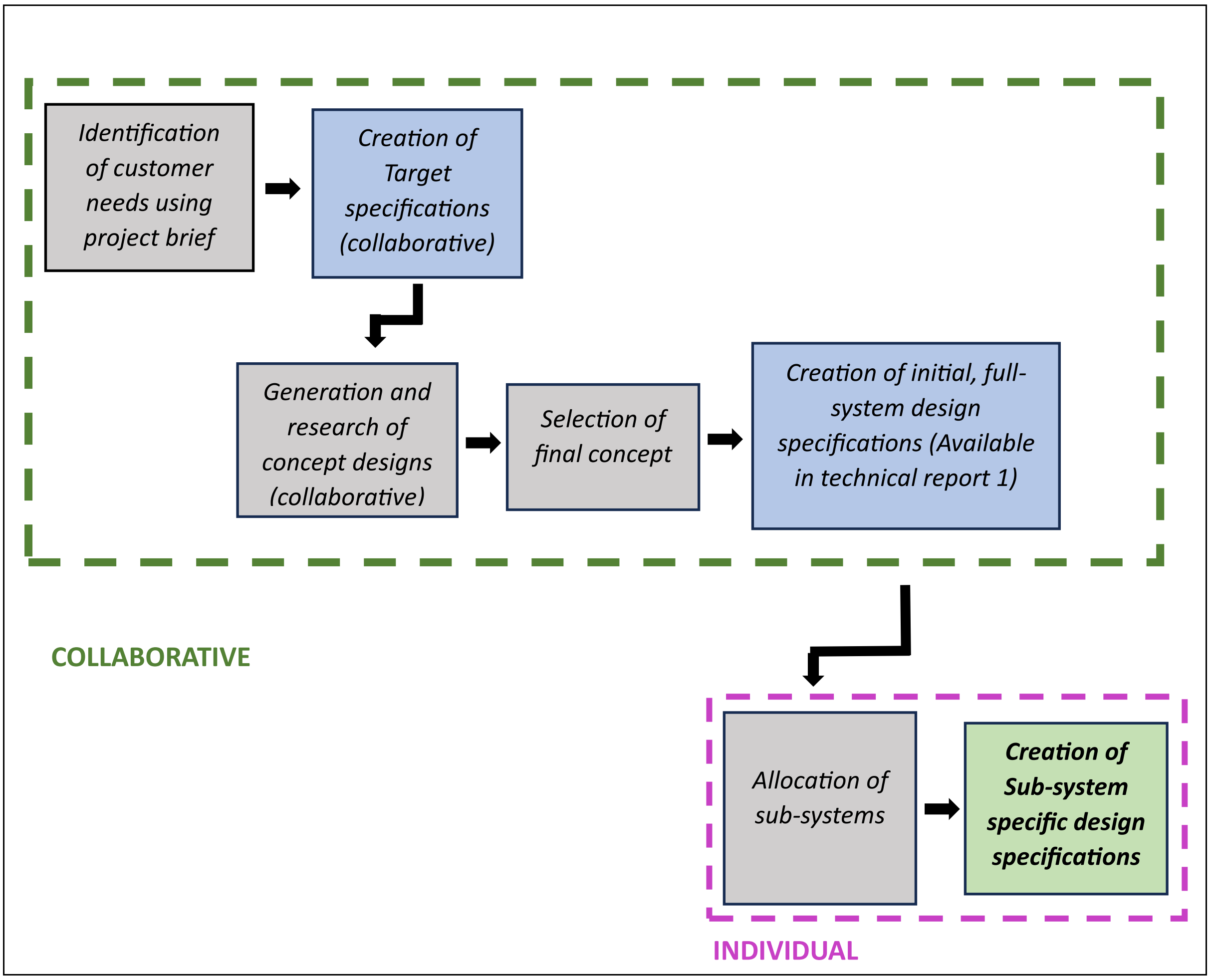

Figure 6: Flow diagram representing journey from project brief to sub-system design specifications

Figure 6 details the process by which subsystem-specific design specifications were created, starting from the initial project brief.

Guided by the methods outlined in Chapter 6 of Ulrich's book 'Product Design and Development' (Ulrich, et al., 2020), key customer needs (Appendix B) were identified qualitatively using the initial project brief (Appendices A) and conversations with the client. These generally took the form of quotes or statements, and were subsequently converted into a set of target specifications (Appendices C).

Then, upon completing initial concept ideation and technical research, a more detailed set of research-informed, full-system design specifications (Available in Report 1) were created. These included factors such as legal codes that would have to be adhered to, as well as key performance benchmarks to be met for our product to be competitive.

This was followed by final concept selection, where the project was split into five distinct subsystems. Upon this, subsystem-specific, detailed sets of design specifications were then produced.

Customer need	**Target specification**	**Full-system design specification**	**Sub-system design specification**
"The product should be of industry-standard quality"	The product shall be compliant with legal codes and/or standards where relevant	The product shall adhere to regulations outlined in '*Eurocode 1 - Actions on structures*'	The product shall not exert a ground-bearing pressure exceeding 150 kPa [1]

Table 1: Example developmental path of a customer need into sub-system design specification

Shown above Table 1 is an example for how an initially vague, qualitative customer need gradually evolves into a specific, quantifiable design specification.

[1] Informed by British Standards EN 1991-1-1:2002 (British Standards Institution, 2002)

2.2. Table of Subsystem Design specifications

Table 2: Detailed design specifications of the trailer and hopper subsystem

Ref No.[2]	D/W[3]	Description	Unit	Value	Verification activity	Reference[4]	Source
4.1.	**Operational requirements and worksite considerations**						
4.1.1.	**D**	System must be designed to be deployed and used on a standard work site	-	-	Incorporated into design development	1.01, 1.02	Project Brief
4.1.2.	**D**	Sub-system must be deployable without aid of external power source	Pass/ Fail	-	Final product specifications	1.08	Report 5
4.1.3.	**D**	While fully filled with concrete during operation, system must not exert a ground pressure of 150 kPa[5] with the assistance of outrigger pads	kPa	≤150	Operation cycle study following methodology outlined in Eurocode 1	1.12	Eurocode 1[6]: Part 1

[2] Where the first digit '4' is in reference to this being the fourth report in reading order
[3] Demands/Wishes
[4] In reference to the Master Design Spec in Report 1
[5] Tested in accordance with (Eurocode, 2004)
[6] Eurocode 1: Actions on Structures (British Standards Institution, 2002)

4.1.4.	**W**	While fully filled with concrete during operation, system must not exert a ground pressure of 75 kPa with the assistance of outrigger pads	kPa	≤75	Operation cycle study following methodology outline d in Eurocode 1	1.12	Eurocode 1: Part 1
4.1.5.	**D**	Whilst Anaconduit is being used, system must not vibrate excessively in accordance with Eurocode 1: Part 3	Characteristic values	Optimise	Operation cycle study using procedure detailed in Eurocode 1: Part 3: Section 3	1.13	Eurocode 1: Part 3
4.1.6.	**D**	Whilst deployed, system must not take up a footprint larger than 4 x 6 m	A x B m	4 x 6	Final product specifications	3.05	Project Brief
4.1.7.	**D**	Sub-system shall be managed, setup, and cleaned by a total of no more than 3 people	No. people	3	Operation cycle study	3.02	Project Brief
4.1.8.	**D**	Concrete must be received at a height not exceeding 188cm	Cm	≤188	Final product specifications	3.05	Standard height of cement truck chute as detailed in Project Brief
4.1.9.	**D**	Subsystem shall, wherever possible, not encourage segregation in the concrete	-	-	Operation cycle study	1.03	Report 2

4.1.10	**D**	Whilst in use, subsystem shall be able to store at least 0.5 m^3 of concrete	m^3	0.5	Final product specifications	1.07	Hand calculations using Report 1
4.2.	**Health and Safety**						
4.2.1.	**D**	Whilst sub-system is being prepared for use, it should not, wherever possible, cause harm to individuals in the area	Pass/Fail	EHSR[7] guidelines	Risk assessment	1.13, 2.06	Section 6 of HSWA 1974[8]
4.2.2.	**D**	Whilst sub-system is in use, it should not, wherever possible, cause harm to individuals in the area	Pass/Fail	EHSR guidelines	Risk assessment	2.07	Section 6 of HSWA 1974
4.2.3.	**D**	Sub-system must clearly display soil-bearing-pressure ratings in concordance with Eurocode 1 and HSWA	Pass/Fail	EHSR guidelines	Incorporate into design	2.07	- Eurocode 1 - Section 7 of LOLER 1998[9] - Section 7 of HSWA
4.2.4.	**D**	Sub-system must clearly display system load bearing limits	Pass/Fail	EHSR guidelines	Incorporate into design	2.07	- Eurocode 1 - section 7 of LOLER 1998

[7] Essential Health and Safety Requirements (EHSR, 2015)
[8] Health and Safety Work Act 1974 (HSWA, 1974)
[9] Lifting Operations and Lifting Equipment Operations 1998 (LOLER, 1998)

4.2.5.	**D**	Sub-system must clearly display 'do not sit', unless specifically designed for that purpose	Pass/Fail	EHSR guidelines	Incorporate into design	2.07	Section 28 of HSWA
4.2.6.	**D**	Sub-system must be clearly marked to contain hazardous substances, and described as heavy machinery	Pass/Fail	EHSR guidelines	Incorporate into design	2.07	Section 12 of HSWA
4.2.7.	**D**	When in use, system must emit no more than 90 dB in noise level	dB	≤90	Operation cycle study using methodology outlined according to ISO 14000[10]	2.07	Section 8 of NWR[11] 1989
4.3.	**Transport**						
4.3.1.	**D**	Sub-system must be able to be transported in an analogous manner of a standard 3.5 tonne trailer	-	-	Final product specifications	1.11	Chosen concept design
4.3.2.	**D**	During transport, total system must not exceed 3500 kg	kg	≤3500	Weighbridge	1.11	Maximum authorised trailer weight for standard

[10] ISO 14000: Environmental Management Standards (Morris, 2004)

[11] Noise at Work Regulations 1989 (NWR, 1989)

							vehicle in accordance with RTA 1988[12]
4.3.3.	**D**	During transport, total system length must not exceed 7m (in the direction of road travel)	m	≤7	Final product specifications	1.11, 3.05	- Section 7 of TRVR 1986[13]
4.3.4.	**D**	During transport, total system must not exceed a width of 2.5m	m	≤2.5	Final product specifications	1.11, 3.05	Section 8 of TRVR 1986
4.3.5.	**D**	During transport, the lowest point of the system must have a minimum ground clearance of 160mm	mm	≥160	Final product specifications	1.11	Section 76 of TRVR 1986
4.3.6.	**D**	During transport, all components must be able to be physically secured	-	-	Operation cycle study	1.11, 2.07	Section 40A of RTA
4.4.	**Cleaning and maintenance**						
4.4.1.	**D**	System must be cleaned after use using either pressurised water or air in under 60 minutes	Minutes	≤60	Operation cycle study	2.04	Benchmark cleaning procedures for a line pump (Putzmeister, n.d.) (Camfaud, n.d.)

[12] Road traffic Act 1988 (RTA, 2021)
[13] The Road Vehicle Regulations (construction and use) 1986 (TRVR, 1986)

4.4.2.	**D**	Sub-system must be designed with the intention of scheduled maintenance every 6 months	Months	≥6	Solution lifecycle calculations	2.01, 2.04	Industry standard recommendation (Medic, n.d.)
4.4.3.	**D**	Sub-system must be easily disassembled for maintenance and repair	-	-	Operation cycle study	2.01, 2.04	Section 9 of HSWA 1974
4.4.4.	**D**	Sub-system must be easily disassembled for periodic maintenance and repair	Months	≥6	Operation cycle study	2.01	Section 9 of HSWA 1974
4.4.5.	**D**	Sub-system must resist damage due to corrosion, exposure to concrete, weathering, and other	Comparative	Qualitative	Materials analysis using Ashby charts and Granta Edupack (ANSYS, 2023)	2.01, 2.03	Report 1
4.4.6.	**D**	System shall not fail due to fatigue within its lifetime of 10,000 hrs	Pass/Fail	Fatigue analysis	Fatigue load analysis	2.01	Report 1
4.4.7.	**D**	The subsystem shall be designed not fail due to yielding	Pass/Fail	FEA analysis	FEA analysis	2.02	
4.5.	**Manufacturing, Cost, Sustainability and Environment**						
4.5.1.	**D**	Sub-system assembly shall use standard parts and components where feasible	-	-	Incorporated into design development	1.03	Chapter 7 of Ulrich's textbook (Ulrich, et al., 2020)

4.5.2.	**W**	Sub-system should not use components or materials that are not easily disposed of safely	Comparative	Qualitative	Materials analysis using Ashby charts and Granta Edupack	1.13	ISO 14000 guidelines
4.5.3.	**W**	Sub-system should be designed with materials that are environmentally friendly	Embodied carbon (kg.CO_2)	Minimise	Embodied carbon calculations	1.13	ISO 14000 guidelines
4.5.4.	**W**	Sub-system shall, wherever possible, minimise manufacturing cost	£	Minimise	Detailed costing	4.01	Report 1

2.3. Categories outlined design specifications

Shown Table 2 are the design specifications relating to the technical components in this report, created using the methodology outlined in Figure 6.[14]

Operations and requirements

A majority of specifications in this category were informed by Eurocode 1, as the subsystem, by nature, will constantly be interacting directly with the ground whilst active on a worksite.

Particularly integral to this report, a value for maximum ground bearing pressure was produced using the soil bearing pressure ratings for stiff clays, 150kPa, whilst a preferable limit of 75kPa corresponded to soft clays and salts. (British Standards Institution, 2002).

Other specifications in this category were guided by constraints set by other subsystems, as well as the project brief.

Health and safety

Specifications in this category were guided predominantly by HSWA and Eurocode guidelines.

Notably to the design embodiment, symbols and stickers need to be clearly displayed indicating potential hazards to the user to avoid health and safety risks.

Transport

Specifications found in this category relate exclusively to transporting the Anaconduit as a road-legal trailer. This pertains to its Master Design Specification reference:

> ***1.11.*** *System shall be able to be transported and stored as a standard trailer (Report 1)*

As such, RTA and TRVR regulations served as key informing documents.

[14] Customer needs, Target specification, and full-system design specifications served as key informing documents, and can be found in Appendix B, Appendix C, and Report 1 respectively.

Cleaning and maintenance

Constraints in this category relating to on-site cleaning were selected using values taken from industry-standard line pumps, and using them as a comparative measure. Whilst they are not hard limits, they pose suitable targets to aim for.

In regards to more periodic, long term maintenance and repair, HSWA guidelines associated with industrial trailer maintenance were used.

Manufacturing, Cost, Sustainability and the Environment

The primary challenge with this set of specifications was selecting metrics to measure them by. For example, specification **4.5.1.** could be described as simply common engineering practice, and even specification **4.5.3.,** measured quantitatively in the units of embodied carbon kg.CO_2, is difficult to approach (embodied carbon values for any material are highly unreliable depending on supply chain (Sergio Alvarez, 2016)).

This posed the difficulty of verifying whether they have been met, as setting benchmarks were at best, formative.

As such, these specifications served not as metrics to compare the final product solution against, but as guiding principles to assist during design development

Final Product Specifications and Solution Cycle Analysis

For certain specifications, 'in-house' verification activities were assigned. A description of these are as follows:

> **Final Product Specifications** – A detailed, technical description associated with the final, fully developed product
>
> **Solution cycle Analysis** – Taking a fully embodied prototype, the sub-system is put through a series of activities emulating its work environment. Measurements are taken from this, and used to inform further development

However, as these activities are dependent on having a physical prototype, they remain at the time of writing incomplete, to be done at a later stage in development

3. Technical Component: Hopper

Figure 7: CAD render of Anaconduit, with hopper highlighted in red

3.1. Justification

The use of hoppers in funnelling and moving concrete is a well-established, familiar industry procedure (Ding, 2004). Valued for their simplicity in both use and manufacture, they are a standard component of high market availability, and would be familiar to industry professionals (Merlin Industrial, n.d.) (Haarup, n.d.).

For these reasons, the use of a hopper was incorporated into funnelling and temporarily storing concrete within the Anaconduit.

3.2. Geometry

3.2.1. Shape

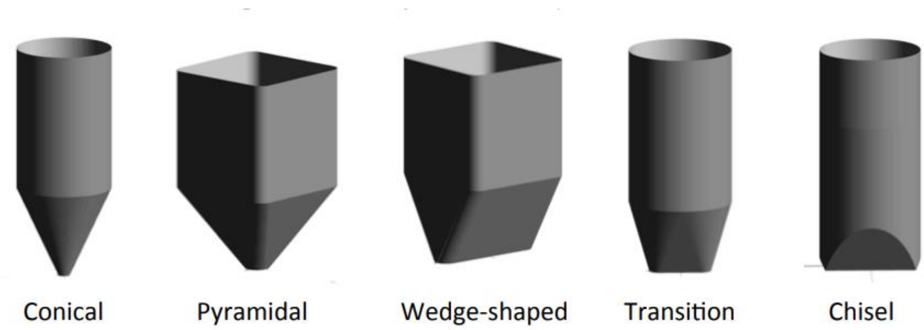

Figure 8: Commonly available hopper geometries (Mehos, n.d.)[15]

[15] Whilst asymmetrical geometries are also occasionally used, they were not considered as they offer no technical advantages in regards to mass-flow, while being more difficult to manufacture and source (Schultz, 2021)

Shown in Figure 8 are a range of common hopper geometries. Wedge-shaped, transition, and chisel geometries were not considered due to geometrical constraints set by the pipe and robotic arm sub-system (Report 3), while a comparative study was done between the remaining two.

Table 3: Geometry comparison of conical and pyramidal geometries

Geometry	Advantages	Disadvantages
Conical	**Less likely to instil turbulent flow**	Less volume per unit height
	Less likely to cause segregation in bulk solids	
Pyramidal	More volume per unit height	Higher tendency to cause segregation in bulk solids
		Difficult to clean, edges encourage material buildup

Illustrated in Table 3 is a qualitative comparison, using 'designing for mass-flow in bulk solids' as well as 'designing for laminar flow in fluids' as a guiding metric (Schultz, 2021), (Pirozzoli, 2018). With this, consultation was done with relevant design specifications (**4.1.8., 4.1.9., 4.4.7.**).

Ultimately, even with its lowered capacity for volume efficiency, the conical hopper was selected due to a better capacity for concrete handling, as well as cleaning.

3.2.2. Key dimensions and specifications

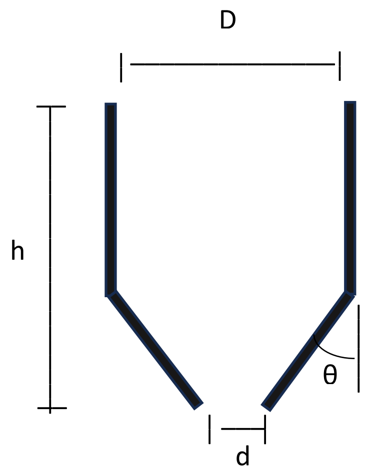

Figure 9: Schematic diagram showing key hopper geometries

Table 4: Key parameters in concrete hopper selection

Symbol	Parameter	Value	Source	Relevant design specifications
D	Major Diameter	≤2500	Maximum legal trailer width	**4.3.4.**
d	Outlet diameter (mm)	≥ 80	Constraint set by Report 2, bulk solid approximation (Amalsi, Jan. 24, 2023)	**4.1.9.**
θ	Hopper half angle (degrees)	60 ± 5	Industry rule of thumb using a bulk solid approximation (Amalsi, Jan. 24, 2023)	**4.1.9.**
h	Height (mm)	≤1500	Hand calculations (Appendix D)	**4.1.8.**
	Weight	Minimise	Design specification	**4.3.2.**
	Product specified holding volume (m^3)	0.5 m^3	Constraints set by Report 2	**4.1.10**
	Cost (£)	Minimise	-	**4.5.1., 4.5.4.**
	Embodied Carbon ($kg.CO_2$)	Minimise	Design specification	**4.5.3.**
	Embodied Energy (MJ)	Minimise	Design specification	**4.5.3.**

Based on this, a list of parameters was created to guide hopper selection.

A note regarding hopper angles:

In deriving maximum hopper angle, two approaches were taken. The first utilised the industry 'rule of thumb' (Amalsi, Jan. 24, 2023), producing a value of 60 ± 5 degrees, whilst the second used the assumption that concrete could be treated as a cohesive bulk solid.

Using the Jenike method (Jenike, 1961) with formative powder properties, this second approach produced a maximum hopper angle of 72 degrees was derived to prevent funnel flow.

Given that the rule of thumb produced a higher constraint, this was used as the final parameter constraint.

Notably, based on the findings of Report 2, concrete was also found to behave as a Newtonian fluid once moving, omitting the need of the Jenike method.

3.2.3. Selection from product market

Table 5: Hopper selection from online market

		Model					
		 [16]		 [17]		 [18]	
Dimension	**Benchmark**	**BCT80**	**BCT99**	**SBB 7**	**SBB-10**	**BB-7**	**BB-10**
Major Diameter (mm)	≤2500	**1250**	1250	1230	1475	1250	1475
Base Diameter (mm)	≤2500	**930**	930	-	-	-	-
Outlet diameter (mm)	≥ 80	**200**	200	405	405	405	405
Hopper half angle (degrees)	60 ± 5	**55**	55	50	50	50	50
Height (mm)	≤1500	**11**	1160	1090	1170	1250	1475
Weight (kg)	Minimise	**180**	195	190	250	115	140
Volume (m^3)	0.5	**0.8**	1.0	0.6	0.8	0.6	0.8
Cost (£)	Minimise	**1115.59**	1153.15	Awaiting quote	Awaiting quote	Awaiting quote	Awaiting quote
Material	-	**Painted steel**	Painted steel	Painted steel	Painted steel	Aluminium	Aluminium
Embodied Carbon (kg.CO_2)[19]	Minimise	**360**	390	380	500	1380	1680
Embodied Energy (MJ)	Minimise	**6120**	6630	6260	8500	24150	29400

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[16] https://www.rollawaycontainer.com/conical-concrete-bucket-central-unloading-rubber-hose-capacity-3900-kg.html
[17] https://mandbmag.ca/index.php/concrete-buckets/steel-buckets/upright-steel-buckets/
[18] https://mandbmag.ca/index.php/concrete-buckets/aluminum-buckets/upright-aluminum-buckets/
[19] Approximated using embodied carbon values from textbook 'Data, Statistics, and Useful Numbers for Environmental Sustainability' (Benoit & Cremonini, 2021)

With this, hopper selection was done by comparing off-the-shelf (OTS) products against the defined parameters.

In total, ten models of concrete hoppers were considered. Whilst a full table can be found in Appendix E, the six models that satisfied the outlined constraints best are shown in Table 4, with green indicating the final selection, and orange indicating those disregarded.

Of these, three were disregarded due to relatively excessive weight, and two due to relatively high embodied energy and carbon. This left the final selection: the *Rollaway Container BCT80* model.

3.3. Selected component

Figure 10: Selected concrete hopper (Rollaway Container, n.d.)

Table 6: Selected Hopper Specifications

Model	BCT80	
Parameter	**Value**	**Constraint**
Major Diameter (mm)	1250	≤2500
Base dimeter (mm)	930	≤2500
Outlet diameter (mm)	200	≥ 80
Hopper half-angle (degrees)	55	60 ± 5
Height (mm)	1120	≤1500
Weight (kg)	180	-
Volume (m^3)	0.8	0.5
Cost (£)	1115.59	-
Material	Painted steel	-
Embodied Carbon (kg.CO_2)	360	Minimise
Embodied Energy (MJ)	6120	Minimise

*Product also complies with the following: UNI EN ISO 12100, UNI EN 349, UNI ISO 8686,UNI EN 10027 and UNI EN 10204 standards

4. Technical component: Trailer

Figure 11: CAD render of Anaconduit, with trailer highlighted in red

4.1. Justification

As detailed before in the Introduction and Design Specification **4.3.1.** , the final design of the Anaconduit features the ability to be transported as a trailer.

Like hoppers, trailers are standard, common pieces of construction equipment, and as such easily available commercially.

Given this, there is little justification to manufacturing a new trailer in-house, as specialised manufacturers exist[20]. Additionally, strict legal regulations in the manufacturing and use of such components would pose high barriers to in-house manufacturing[21], further justifying ordering them OTS.

[20] Of which even make bespoke models to order. Bateson Trailers UK, for example (Bateson Trailers, n.d.)
[21] Guided by the TRVR and RTA

4.2. Key dimensions and specifications

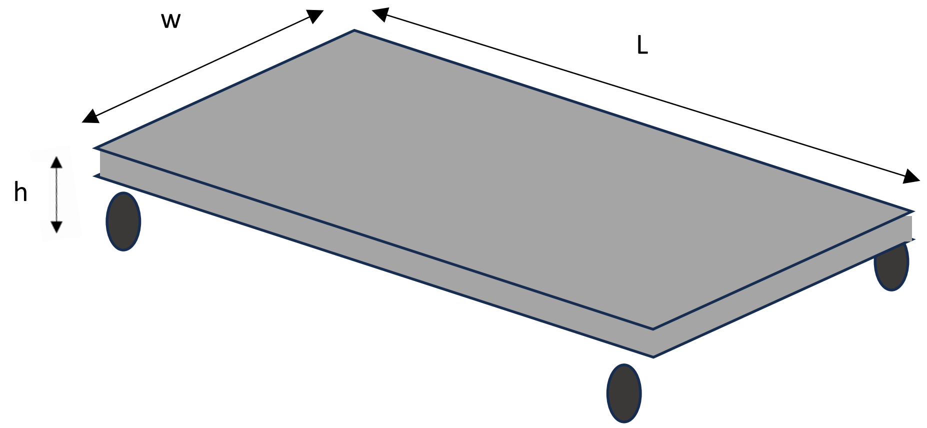

Figure 12: Schematic diagram showing key trailer dimensions

Table 7: Estimated weight of Anticonduit during transport

Component	Pump	Pipe and nozzle	Hopper	Outriggers[22]	Total
Weight (kg)	1200	140	180	200	**1720**
Relevant report	Report 2	Report 3	Covered within this report	Covered within this report	

[22] Conservative limit from preliminary market study

Table 8: Key parameters in Trailer selection

Symbol	Parameter	Value	Source	Relevant design specifications
L	Length (mm)	≤7000	TRVR 1986	**4.3.3.**
w	Width (mm)	≤2500	TRVR 1986	**4.3.4.**
		≥1300	Pump dimensions (Report 2)	**-**
h	Bed height (mm)	≥160	TRVR 1986	**4.3.5.**
		≤760	Hand Calculation (Appendix D)	**4.1.8.**
LW	Maximum laden weight while in transport (kg)	≤3500	RTA 1988	**4.3.2.**
UW	Unladen weight (kg)	Minimise	-	**4.3.2.**
	Minimum load capacity (kg)	≥1720	Table 7	**-**
	Cost (£)	Minimise	-	**4.5.1.**
	Embodied Carbon (kg.CO_2)	Minimise	ISO 14000	**4.5.3.**
	Embodied Energy (MJ)	Minimise	ISO 14000	**4.5.3.**
	Compatibility with outrigger selection	Qualitative	Selection process	**-**

Constraints driving trailer selection were set predominantly by RTA guidelines. These are listed in the subsystem design specifications, and again above.

The other key constraint was the trailer's ability to carry the Anaconduit without damage, and remaining road safe through the use of common securing methods (ropes, tie-downs, etc.). Using conservative values, preliminary estimates produced a minimum loading capacity of 1720 kg, with the breakdown shown in Table 7.

A preliminary note on Outriggers

In addition to transport, the selected trailer also had to support the Anaconduit whilst in use, i.e. filled with up to 0.5 m^3 of concrete, an additional 1300kg.

Preliminary research indicated that the most feasible solution to this would be the addition of aftermarket, extendible outriggers, which would strengthen the supporting capacity of the Anaconduit whilst deployed.

As such, during component selection, ***trailer selection was conducted in parallel with outrigger selection***, iteratively comparing models in each component for compatibility. This effectively produced a difficult-to-quantify selection parameter of *'compatibility with outriggers'* during trailer selection, and an analogous *'compatibility with trailer'* parameter during outrigger selection.

4.3. Trailer selection from product market

Table 9: Trailer selection from online market

		Model			
					
Parameter	**Constraint**	[26 MD Plant Trailer]	[1264 General Purpose Trailer]	[0854 General Purpose Trailer]	[1064 General Purpose Trailer]
Length (mm)	≤7000	4220	5010	2500	4410
Width (mm)	≥1300 ≤2500	1760	2300	1500	2300
Bed height (mm)	≥160	450	420	450	450
Laden weight (kg)	≤3500	2600	2600	2000	2600
Unladen weight (kg)	Minimise	500	545	400	490
Load capacity (kg)	≥1720	2100	2055	1600	2110
Cost (£)	Minimise	3050	3100	2600	3000
Material	-	Galvanised Steel	Steel	Galvanised Steel	Galvanised Steel
Embodied carbon [23]	Minimise (kg.CO_2)	2000	1090	1600	980
Embodied Energy	Minimise (MJ)	16000	17440	12800	15680

In total, ten models of trailer were considered for the Anaconduit. A majority of these were sourced from Bateson Trailers UK (Bateson Trailers, n.d.), with others from other independent manufacturers. Whilst a full table can be found in Appendix F, Table 9 outlines the four best suited for the Anaconduit.

Of the ten initially considered models, six were immediately disregarded due to not meeting required specifications. One other was then disregarded due to being geometrically incompatible with the selected hopper.

[23] Approximated using embodied carbon values from textbook ‘Data, Statistics, and Useful Numbers for Environmental Sustainability’ (Benoit & Cremonini, 2021)

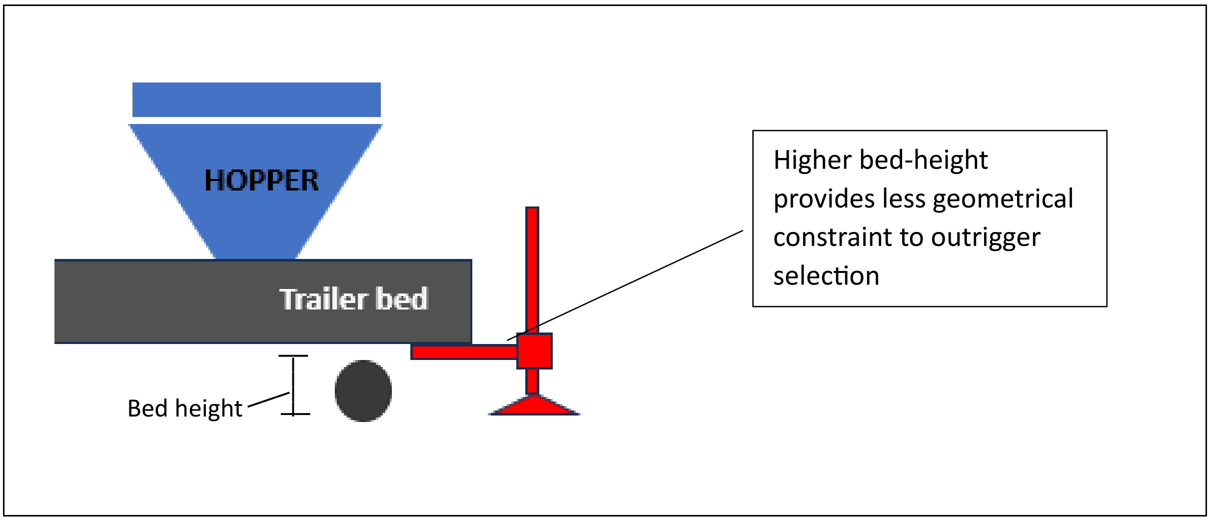

Figure 13 : Schematic diagram describing bed-height consideration

Of the remaining, the chosen model (indicated in green) was selected for two reasons. First, its functionally suitability, given its specificity of design for plant[24] transport, and second, its relatively high bed height, which allowed for more geometrical freedom in outrigger selection. Figure 13 illustrates this schematically

[24] In construction, plant typically refers to heavy machinery and large equipment (Go Construct, 2021)

4.4. Selected component

Figure 14: Final Trailer selection (Bateson Trailers, n.d.)[25]

Table 10: Selected Trailer Specifications

Model	Bateson **26 MD Plant Trailer**	
Parameter	**Value**	**Constraint**
Length (mm)	4220	≤7000
Width (mm)	1760	≥1300
		≤2500
Bed height (mm)	450	≥160
Laden weight (kg)	2600	≤3500
Unladen weight (kg)	500	Minimise
Load capacity (kg)	2100	≥1720
Cost (£)	3050	Minimise
Material	Galvanised Steel	-
Embodied carbon [26]	2000	Minimise (kg.CO_2)
Embodied Energy	16000	Minimise (MJ)

Shown above is the selected plant trailer for the Anaconduit. It features a 2.6 tonne carrying capacity, as well as a collapsible rear wall. Designed for the transport of mini diggers, it can be easily altered for use in the Anaconduit.

[25] https://www.batesontrailers.com/product/26md-mini-digger-plant-excavator-trailer/
[26] Approximated using embodied carbon values from textbook 'Data, Statistics, and Useful Numbers for Environmental Sustainability' (Benoit & Cremonini, 2021)

5. Technical component: Outriggers and outrigger pads

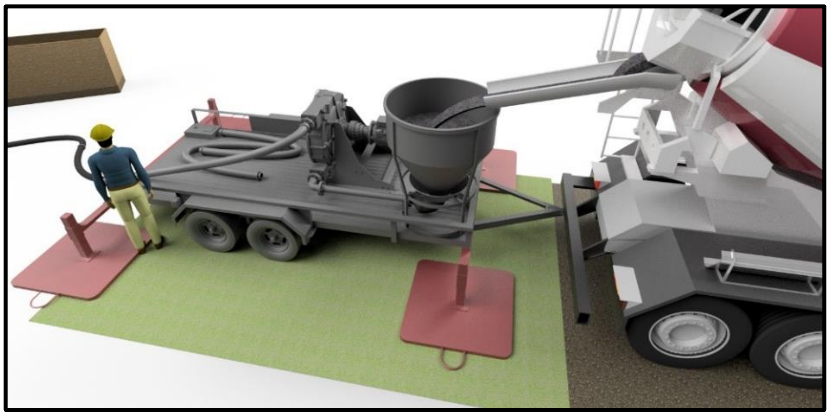

Figure 15: CAD render of Anaconduit, with outriggers and outrigger pads highlighted in red

5.1. Justification

As noted prior, the trailer-hopper subsystem is responsible for ensuring that safety is maintained on the worksite whilst the Anaconduit is in use.

The key concern in this, in contrast to transport, was ensuring that the system could hold an additional 0.5 m^3 of concrete without exceeding acceptable soil bearing pressure.

Table 11: Soil bearing pressure limits[27]

Ultimate soil bearing pressure limit	Desired soil bearing pressure limit
<150 kPa	<75 kPa

To this regard, it was decided that aftermarket outriggers would be added to the OTS trailer, recognised to be a common solution to this problem within the industry. (Interface, 2023) (Power-Packer, n.d.).

The verification for the need and subsequent specification of outriggers was conducted using an FBD and moment's analysis, with conservative assumptions where relevant. This is available in Appendix G.

This section records the selection of OTS aftermarket outriggers, as well as outrigger pads (pressure-spreading pads that held distribute weight across the ground).

[27] Taken directly from design specifications

5.2. Outriggers

5.2.1. Key specifications

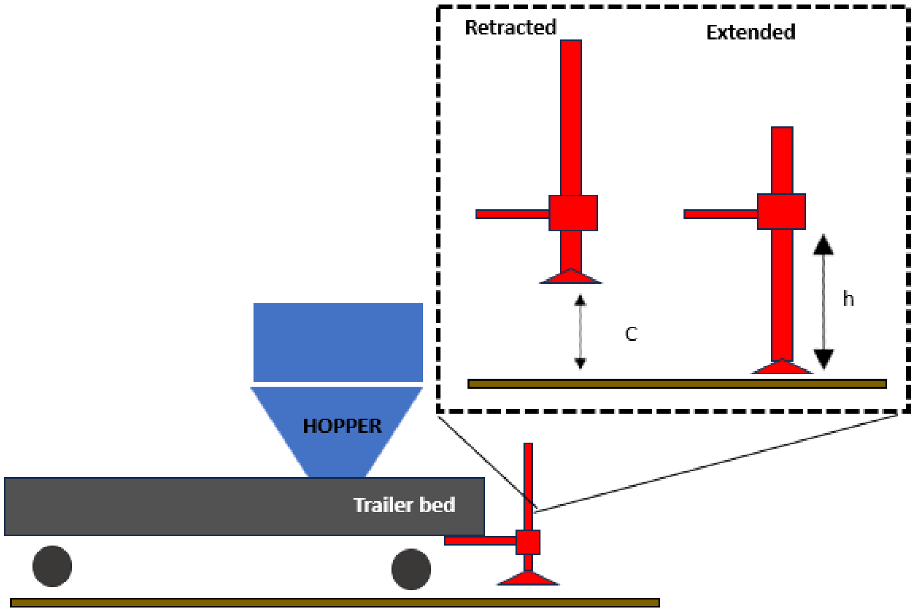

Figure 16: Schematic diagram representing key parameters

Table 12: Key parameters in Outrigger selection

Symbol	Parameter	Value	Source	Relevant design specifications
	Weight (kg)	Minimise	-	**4.1.1**
	Bearing capacity (kN)	≥32	Appendix G	-
C	Clearance height (mm)	≥160	TRVR 1986	**4.3.5.**
h	Height (mm)	-	Compatible with trailer	**4.1.8.**
	Cost (£)	Minimise	-	**4.5.1.**
	Embodied Carbon (kg.CO_2)	Minimise	ISO 14000	**4.5.3.**
	Embodied energy (MJ)	Minimise	ISO 14000	**4.5.3.**
	Compatibility with outrigger selection	Qualitative	Selection process	-

**Note the qualitative 'Compatibility with outrigger selection', that reflects the in-tandem selection process that outriggers and trailers had to be done in*

In selecting aftermarket outriggers, the primary aim was trailer-compatibility. As such, strict geometrical constraints were not produced, other than ensuring a retracted clearance height of ≥160mm.

The reason for this was the difficulty of producing homogenous constraints across different types of outriggers. For example, an outrigger may be either bottom-mounted, or side mounted. These two types would be defined by different geometries, and as such considered independently. A similar thing can be said for swing-out outriggers vs folding, or hydraulic vs manual.

In addition to the in-tandem trailer and outrigger selection process, this meant that key parameters in outrigger selection were relatively lax, as reflected in Table 12.

5.2.2. Outrigger selection from product market

Table 13: Outrigger selection from online market

		Model				
		 [28]		 [29]	 [30]	
		Semi-trailer outrigger		**Standard outrigger**	**Hydraulic outrigger system < 14000 lbs.**	
Parameter	**Constraint**	**2010-18**	**3510000265**	**SQ2819F-G1**	**Round legs**	**Square legs**
Weight		33.11	47.63	100 per leg	75	60
Bearing capacity	**≥32 kN per leg**	71 kN	71 kN	25 tons per leg lifting 50 tons static	62.3 kN	62.3 kN
Height from fixing to retracted base	**≥140 mm**	0	0	0	535	429
Extended length		457	635	840	1173	1334
Span (if relevant)		-	-	-	2081	2081
Cost (£)	**Minimise**	Awaiting quote	Awaiting quote	90 per leg	-	-
Material		Stainless steel	Stainless steel	Stainless steel	Stainless steel	Stainless steel
Embodied carbon [31]	**Minimise ($kg.CO_2$)**	165	235	500	375	300
Embodied Energy (MJ)	**Minimise**	2904	4191	8800	6600	5280
Notes		Side Mounted, ISO 9001 certified		Side mounted ECE[32] certified	Bottom mounted, ISO9000 certified	

In total, nine outrigger models were compared across the online market, specifically selecting options from reputable, certified manufacturers. Whilst a full table of this can be found in Appendix H, the five best models are shown in Table 13. Orange indicates factors that removed products from consideration, while green indicates the selected product.

[28] https://www.powerpackerus.com/hydraulic-cylinders/stabilization-truck-outriggers/standard-hydraulic-stabilization-legs/
[29] https://www.alibaba.com/product-detail/Truck-Trailer-Parts-Heavy-Duty-StLanding_1601122119796.html
[30] https://www.powerpackerus.com/hydraulic-cylinders/stabilization-truck-outriggers/hydraulic-outrigger-stabilizers/
[31] Approximated using embodied carbon values from textbook ‘Data, Statistics, and Useful Numbers for Environmental Sustainability’ (Benoit & Cremonini, 2021)
[32] Economic Commission of Europe (Economic Commission for Europe, n.d.)

During selection, all models were rated well above the needed bearing capacity of 32 kN per leg, with even the lowest-rated model desigend for up to 62 kN per leg. As such, selection was primarily guided by minimising geometric and environmental factors, as well as weight.

Of the five best options, two were disregarded due to mounting height posing a limiting factor to trailer selection. (Being bottom mounted, they need a larger bed clearance compared to side-mounted options)

Of the remaining, selection was done by comparing embodied carbon and energy values. This produced the *PowerPacker 2010-18* (Power-Packer, n.d.) as the best solution.

5.3. Outrigger pads

5.3.1. Key specifications

Table 14: Estimated weight of physical components in the Anaconduit during use

Component	**Pump**	**Pipe and nozzle**	**Hopper**	**Trailer**[33]	**Outriggers**[34]	**Concrete**	**Total**
Weight (kg)	1200	140	180	820	200	**1300**	**3840**
Relevant report	Report 2	Report 3	Covered within this report	Covered within this report	Covered within this report	Design spec **4.1.10.**	

[33] Conservative limit from preliminary market study
[34] Conservative limit from preliminary market study

Table 15: Key parameters in outrigger pad selection

Symbol	Parameter	Value	Source	Relevant design specifications
A	Area (m^2)	≥0.25	75 kPa soil bearing limit assumption, Conservative estimate using Weight of major components (Appendix I)	**4.1.3., 4.1.4.**
	Area (m x m)	0.5 x 0.5		
	Bearing capacity (kg)	≥2000	Conservative estimate using Weight of major components (Appendix I)	**4.1.3., 4.1.4.**
	Cost (£)	Minimise	-	**4.5.1.**
	Embodied Carbon (kg.CO_2)	Minimise		**4.5.3.**
	Embodied Energy (MJ)	Minimise		**4.5.3.**

In addition to outriggers, pads were also selected from the online market. Required specifications were guided with the use of conservative FBD and moment calculations, detailed in Appendix I.

5.3.2. Outrigger Pad selection from product market

Table 16: Outrigger Selection from Online market

		Model		
		 [35]	 [36]	 [37]
Parameter	**Constraint**	**500 x 500: IP-72001**	**500 x 500: IP-72002**	**500 x 500: IP-57096**
Bearing capacity (tonnes)	**≥4**	15	15	15
Area (m^2)	**≥0.25**	0.25	0.25	0.25
i.e. square of length	**≥0.5 m**	0.5	0.5	0.5
Height (m)	**Minimise**	0.04	0.04	0.04
Weight (kg)	**Minimise**	9.90	9.90	10.50
Cost (£)	**Minimise**	65.77	80.26	76.76
Material	**-**	High mol weight polyethylene	High mol weight polyethylene	Heavy duty UHMW polyethylene
Embodied carbon (kg.CO_2) [38]	**Minimise**	29.7	29.7	31.5
Embodied Energy (MJ)	**Minimise**	544.5	544.5	577.5
Notes			**Final selection**	

[35] https://www.outriggerpads.co.uk/product/500x500x40-eco-lift-outrigger-pad/
[36] https://www.outriggerpads.co.uk/product/500x500x40-hi-viz-outrigger-pad/
[37] https://www.outriggerpads.co.uk/product/500x500x40-premium-outrigger-pad/
[38] Approximated using embodied carbon values from textbook 'Data, Statistics, and Useful Numbers for Environmental Sustainability' (Benoit & Cremonini, 2021)

Of the ten outrigger pads considered for use with the Anaconduit (full table in Appendix J), the three best-suited are shown above.

Outrigger pads are an extremely simple, standard piece of equipment. As such, there proved to be little variance in product specifications across the market regarding bearing capacity, size, and price.

Consequently, key determining factors during selection were embodied carbon, embodied energy, and weight. Accounting for a safety factor, products that were well above minimum bearing capacity (that were on balance heavier and more expensive) were disregarded, with the final chosen product being that with the least embodied carbon.

5.4. Selected Components

Outriggers

Figure 17: final outrigger selection (Power-Packer, n.d.)[39]

Table 17: final outrigger specifications

Model	Power-Packer standard outrigger: 2010-18	
Model	**Value**	**Constraint**
	33.11	Minimise
Bearing capacity	71 kN	≥32 kN per leg
Height from fixing to retracted base	0	≥140 mm
Extended length	457	Compatible with Trailer
Cost (£)	Awaiting quote	Minimise
Material	Stainless steel	-
Embodied carbon [40]	165	Minimise (kg.CO_2)
Embodied Energy (MJ)	2904	Minimise
Notes	Side Mounted, ISO 9001 certified	-

*Product also complies with ISO 9001

[39] https://www.powerpackerus.com/hydraulic-cylinders/stabilization-truck-outriggers/standard-hydraulic-stabilization-legs/

[40] Approximated using embodied carbon values from textbook 'Data, Statistics, and Useful Numbers for Environmental Sustainability' (Benoit & Cremonini, 2021)

Outrigger pads

Figure 18: Selected Outrigger Pad (Outrigger Pads, n.d.) [41]

Table 18: Selected outrigger pad specifications

Model	Bearing Capacity (tonnes)	Area (m^2)	Thickness (m)	Weight (kg)	Material	Embodied carbon ($kg.CO_2$)	Embodied energy (MJ)	Cost (£)
IP-72002	15	0.25	0.04	9.90	High Molecular weight Polyethylene	29.7	544.5	80.26
Constraint	4	≥0.25	-	Minimise	-	Minimise	Minimise	Minimise

*Product also complies with the following: ISO 527, ISO 868, ISO 15527, ASTM D1505, ASTM D3418

[41] https://www.outriggerpads.co.uk/product/500x500x40-hi-viz-outrigger-pad/

6. Joints, transport attachments and Displays

6.1. Joints

Outriggers-to-trailer

Figure 19: Example of nut and bolt joint

To join the outriggers to the trailer, all four legs can be simply bolted to the chassis, as noted in their product specifications (Power-Packer, n.d.).

A simple workshop procedure, at an estimated £38 hourly rate in Bath (hamuch.com, 2024) and one hour per leg, the outrigger-trailer interface is estimated to cost £152.

Hopper-to-trailer

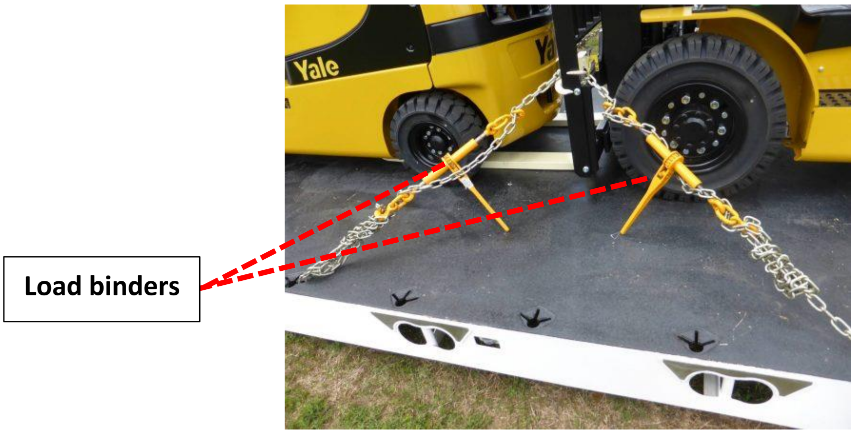

Figure 20: Example of lashing chains in use (Cottinham, n.d.)

To secure the hopper to the trailer, two forms of joining were considered. The first was to join them permanently through workshop processes such as welding or brackets.

However, such a process could potentially hinder efforts to conduct maintenance on the hopper, as it would be difficult to disengage from the trailer.

This led to the selected joining method - the use of lashing chains.

Traditionally used to secure large vehicles to trailers, lashing chains are easily engaged and disengaged by twisting the central load binder. This would allow for the hopper to be both easily secured to the trailer, as well as loosened for maintenance, cleaning, or work-site preference (LES, n.d.).

Assuming that three chains would be needed to restrict movement of the hopper, at £76.24 apiece, the hopper-trailer interface is estimated to cost £228.72 (the Ratchetshop, n.d.).

Pump-to-Trailer

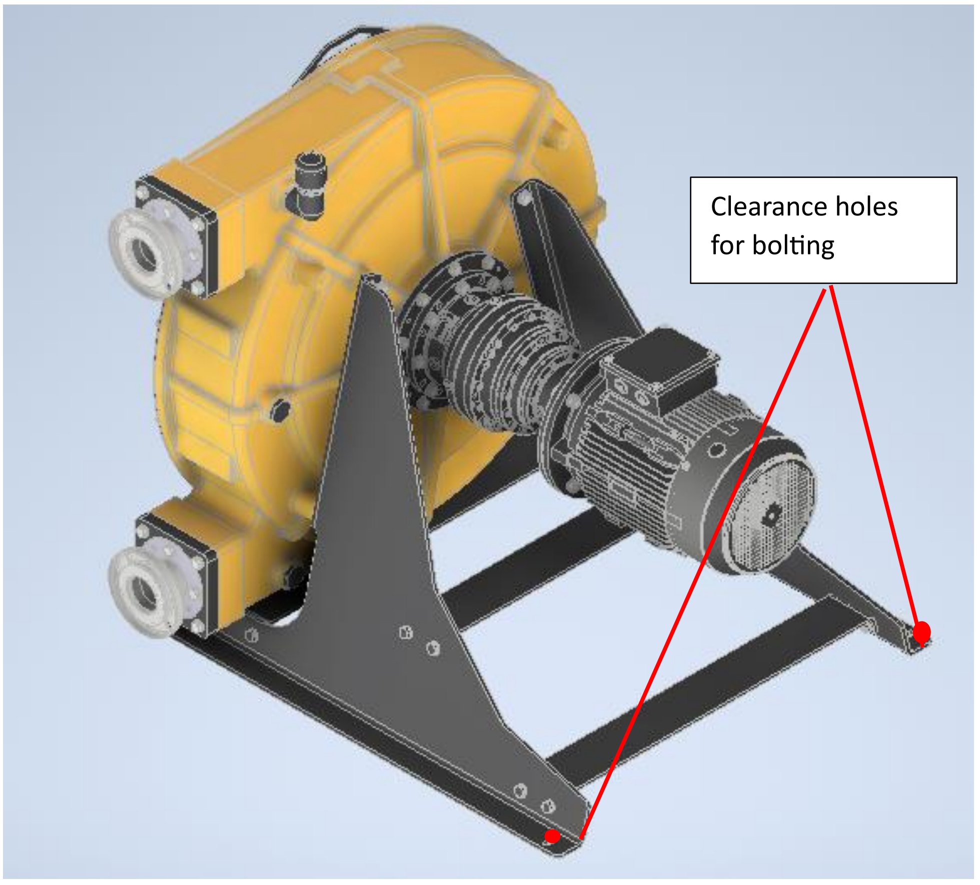

Figure 21: Pump CAD, with holes for bolting/joining annotated

As the selected pump is designed to be bolted to a flat surface (Report 2), this interface would be managed by bolting the pump directly to the trailer bed.

At an estimated [£ 38]() hourly rate in Bath (hamuch.com, 2024) and an assumption of six hours needed for this process (Drilling, cleaning, etc.), this interface is estimated to cost £228.

However, it should be noted that whilst this was the selected joining method, it could potentially compromise the bearing capacity of the trailer, as drilling holes would create stress concentration regions within its structure (Axsom, 2022).

As such, a potential point of future design development would be to design a bespoke pump chassis, which the pump is first bolted onto, before then being mounted onto the trailer. Unfortunately, given the time constraints within this project as well as unforeseen delays in pump selection, this chassis has not been designed, and should be revisited later.

Hopper to pipe

The final major component interface pertaining to the trailer-hopper subsystem is the interface between the hopper outlet, and the hose and robotic arm subsystem. This was done by augmenting the hopper outlet, adapting the diameter to match that of the hose. For more detail, refer to Report 3.

6.2. Transport securing components

For the Anaconduit to be secured during transport, certain items are needed. These are listed here, with the identification of suitable securing methods guided by industry recommendation (Robertson, 2023).

Figure 22: Trailer tarpaulin (Amazon, n.d.)

Figure 23: Heavy-duty ratchet straps (WebEX Supply, n.d.)

Figure 24: Heavy-duty 18mm synthetic rope (Rope Services UK, n.d.)

Table 19: Components associated with Anconduit transport

Component	Est. Number needed	Est. total Cost (£)
Tarp	4 x 3 m	130
Heavy duty ratchet straps	4	28
Rope	40m	100
Total	**-**	**258**

First, physical subsystems of the Anaconduit (pipes, robotics, hopper…) would be secured to the trailer using heavy duty ratchet straps. This would prevent damage from sudden, jerking movements associated with road travel.

Next, a protective, waterproof tarp would be placed on top of the Anaconduit, secured in place with the use of 18mm synthetic rope. This protects the Anaconduit from unfavourable weather, sun damage, and flying debris.

For these components, a detailed market comparison was not conducted as they are cheap, standard, and mass-produced. However, to aid costing, an average cost was found by comparing similar components across the market, with a full list available in Appendix K.

In total, purchases associated with the securing of Anaconduit during transport were estimated at £258.

6.3. Displays

Operating as a piece of construction equipment, various stickers and displays would have to be placed on the Anaconduit to remain concordant with industry health and safety guidelines.

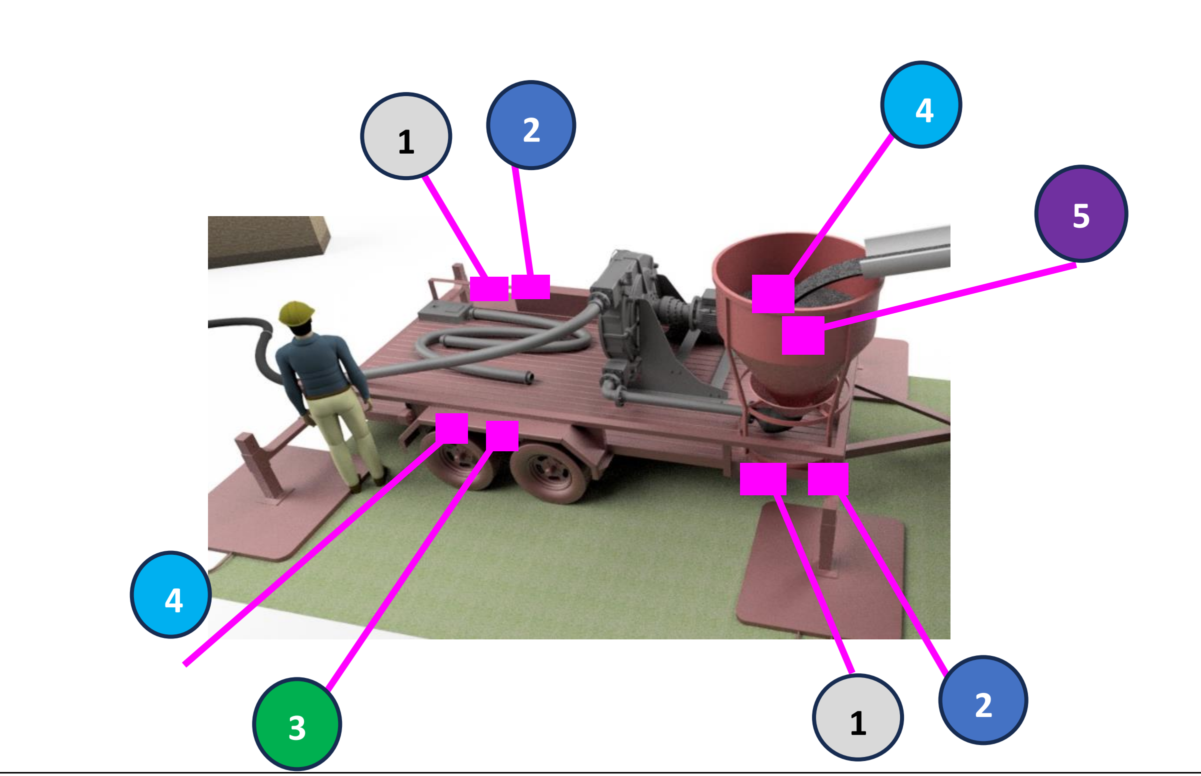

Figure 25 : Trailer and hopper subsystem: label and display orientation

Figure 25 indicates where each display within the trailer-hopper subsystem would be placed, with each number corresponding to a particular sign.

In accordance with HSWA, labels and signs pertaining to safety must be "*Obviously displayed*" (HSWA, 1974). Whilst the suggested placements above attempt to reflect this, they should be reassessed upon physical embodiment of the Anaconduit, e.g., verifying that signs are close to eye-level, easy to see at distance, etc.

Note: For each display, the guidelines that they pertain to have been noted within the figure captions.

1

TYPE OF SOIL	BEARING VALUE		ACTION
	(kPa)	T/sqm	
Dense gravel or dense sand and gravel	>600	>61	SAFE WITH DEPLOY OF OUTRIGGERS
Dense dense gravel or medium dense sand and gravel	200-600	20-61	SAFE WITH DEPLOY OF OUTRIGGERS
Loose gravel or loose sand and gravel	<200	20	SAFE WITH DEPLOY OF OUTRIGGERS AND PADS
Compact sand	>300	>300	SAFE WITH DEPLOY OF OUTRIGGERS AND PADS
Medium dense sane	100-300	10-30	SAFE WITH DEPLOY OF OUTRIGGERS AND PADS
Very stiff boulder clays and hard clays	300-600	30-61	SAFE WITH DEPLOY OF OUTRIGGERS AND PADS
Stiff clays	150-300	15-30	SAFE WITH DEPLOY OF OUTRIGGERS AND PADS
Firm clays	75-150	8-15	NOT SUITABLE FOR PLANT
Soft clays and salts	<75	8	NOT SUITABLE FOR PLANT
Very soft clays and salts	-	-	NOT SUITABLE FOR PLANT

Figure 26: Display of soil bearing pressure ratings: In concordance with EHSR, Eurocode 1 and HSWA guidelines[42]

[42] Made with values taken directly from BS 8004 in accordance with Eurocode 1 (British Standards Institution, 2002)

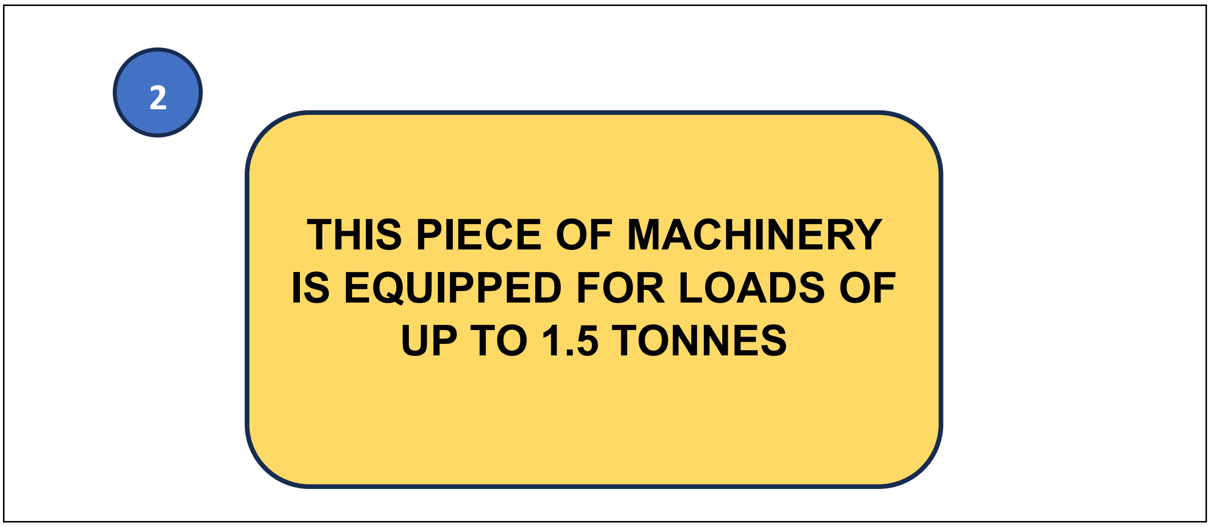

Figure 27: Display of system load bearing limit: In concordance with EHSR, Eurocode 1 and HSWA guidelines

Figure 28: LEFT: "Do not sit" sign (Keysigns, n.d.), in concordance with EHSR guidelines ; RIGHT: "Hazardous substances" sign (hazard signs, n.d.), in concordance with EHSR and HSWA guidelines

5

Figure 29: "Hazardous substances" sign (Seton, n.d.), in concordance with EHSR and HSWA guidelines

Regarding costing, these displays would be made in-house. As such, while costs associated with them would be marginal compared to the total subsystem cost, a formative value of £ 20 per display has been used in the final detailed costing of the subsystem.

7. Subsystem costing

7.1. Detailed costing table

Table 20: Detailed costing of trailer and hopper subsystem

Key
Provided directly by retailer
Accurate value not available, average taken as estimate

Component	Description / model	Quantity	Total cost	£ per unit	Unit	Total Embodied Carbon (kg.CO^2)	Total Embodied Energy (MJ)
	Main components						
Hopper	BCT80	1	1115.59	1115.59	-	360	6120
Trailer	Bateson 26MD Plant Trailer	1	3050.00	3050.00	-	2000	16000
Outriggers	Power-Packer standard outrigger: 2010-18	4	862.67	215.67	-	660	11616
Total			5028.26			3020	33736
	Joints and processes						
Hopper-Trailer	Lashing chains	3	228.72	76.24	-	1	19
Outrigger-Trailer	Nut and bolt	4	152.00	38.00	hour	negligible	negligible
Pump to trailer	Nut and bolt	6	228.00	38.00	hour	negligible	negligible
Total			608.72			1	19
	Transport and work-site related components						
Outrigger Pads	IP-72002	4	321.04	80.26	-	119	2178
Tarp	-	1	129.69	129.69	-	negligible	negligible
Tie down ratchets	-	4	28.17	7.04	-	negligible	negligible
Rope	-	40	100.80	2.52	m	20	710
Total			**579.70**			**20**	**710**

	Signs and displays						
	-	5	100.00	20.00	No. signs	negligible	negligible
Total			**100.00**				

**Note:* *For a detailed breakdown on sources for cost values, refer to Appendix K*

In costing the subsystem, several assumptions were made. For standard items such as rope, tarps and chains, which have little product-to-product variance, averages were calculated using values from the online market.

Costs associated with machining were based the assumption of outsourcing them to workshops, using standard rates around the city of Bath, England. As such, if these processes were to be done in-house, they would be significantly cheaper.

Similarly, costs associated with signs and displays were based on a formative value of £20 per sign, introducing another area of uncertainty.

The largest uncertainty within costing was in aftermarket outriggers. At the time of writing, the retailer had not provided a quote, and as such an estimation had to be made using the cost of other similarly designed products. These values ranged between £200 and £3000 per unit, producing a large variance to provide a reliable estimate. Currently estimated at £862 (13% of total subsystem cost), the true cost of these outriggers could affect the true subsystem cost significantly.

Other assumptions related to embodied carbon and energy. For most components, it was assumed that only one material was used (for example, the trailer was assumed to be made completely of galvanised steel), for ease of calculation. This introduced a level of error, but allowed a useful metric of product comparison.

7.2. Costing summary

Table 21: Subsystem cost summary

TOTAL SUBSYSTEM COST	
Monetary (£)	6316.67
Embodied Carbon (kg.CO^2)	3041.18
Embodied energy (MJ)	34464.94

In total, the trailer and hopper subsystem is estimated to cost a total £6316.67.

Of this cost, £5028.26 (80%) is attributed to purchasing main subsystem components: an OTS hopper, trailer, and four aftermarket outriggers. Of the remaining, £608.72 (10%) is attributed to joining and workshop costs, £579.70 (9%) to transportation-related components, and £100 (1%) to signs and displays.

The subsystem contains approximately 3000 kg.CO^2 of carbon, and 34000 MJ in embodied energy.

8. Verification against design specifications

Table 22: Verification of subsystem against design specifications

Ref No.[43]	D/W[44]	Description	Unit	Value	Verification activity	Status	Source / Notes
4.1.	**Operational requirements and worksite considerations**						
4.1.1.	**D**	System must be designed to be deployed and used on a standard work site	-	-	Incorporated into design development	Met	Incorporated into design embodiment
4.1.2.	**D**	Sub-system must be deployable without aid of external power source	Pass/ Fail	-	Final product specifications	Met	
4.1.3.	**D**	While fully filled with concrete during operation, system must not exert a ground pressure of 150 kPa[45] with the assistance of outrigger pads	kPa	≤150	Operation cycle study following methodology outlined in Eurocode 1	Met	Use of outriggers and outrigger pads
4.1.4.	**W**	While fully filled with concrete during operation, system must not exert a	kPa	≤75	Operation cycle study following methodology outlined in Eurocode 1	Met	Use of outriggers and outrigger pads

[43] Where the first digit '4' is in reference to this being the fourth report in reading order
[44] Demands/Wishes
[45] Tested in accordance with (Eurocode, 2004)

		ground pressure of 75 kPa with the assistance of outrigger pads					
4.1.5.	**D**	Whilst Anaconduit is being used, system must not vibrate excessively in accordance with Eurocode 1: Part 3	Characteristic values	Optimise	Operation cycle study using procedure detailed in Eurocode 1: Part 3: Section 3	Blocked	Blocked by operation cycle study
4.1.6.	**D**	Whilst deployed, system must not take up a footprint larger than 4 x 6 m	A x B m	4 x 6	Final product specifications	Met	Incorporated into constraints during component selection
4.1.7.	**D**	Sub-system shall be managed, setup, and cleaned by a total of no more than 3 people	No. people	3	Operation cycle study	Blocked	Blocked by operation cycle study
4.1.8.	**D**	Concrete must be received at a height not exceeding 188cm	Cm	≤188	Final product specifications	Met	Incorporated into constraints during component selection
4.1.9.	**D**	Subsystem shall, wherever possible, not encourage segregation in the concrete	-	-	Operation cycle study	Blocked	Blocked by operation cycle study
4.1.10	**D**	Whilst in use, subsystem shall be able to store at least 0.5 m^3 of concrete	m^3	0.5	Final product specifications	Met	Hopper selection within report
4.2.	**Health and Safety**						

4.2.1.	**D**	Whilst sub-system is being prepared for use, it should not, wherever possible, cause harm to individuals in the area	Pass/Fail	EHSR[46] guidelines	Risk assessment	Blocked	Blocked by creation of risk assessment
4.2.2.	**D**	Whilst sub-system is in use, it should not, wherever possible, cause harm to individuals in the area	Pass/Fail	EHSR guidelines	Risk assessment	Blocked	Blocked by creation of risk assessment
4.2.3.	**D**	Sub-system must clearly display soil-bearing-pressure ratings in concordance with Eurocode 1 and HSWA	Pass/Fail	EHSR guidelines	Incorporate into design	Met	'Displays' section within report
4.2.4.	**D**	Sub-system must clearly display system load bearing limits	Pass/Fail	EHSR guidelines	Incorporate into design	Met	'Displays' section within report
4.2.5.	**D**	Sub-system must clearly display 'do not sit', unless specifically designed for that purpose	Pass/Fail	EHSR guidelines	Incorporate into design	Met	'Displays' section within report
4.2.6.	**D**	Sub-system must be clearly marked to contain hazardous substances, and described as heavy machinery	Pass/Fail	EHSR guidelines	Incorporate into design	Met	'Displays' section within report
4.2.7.	**D**	When in use, system must emit no more than 90 dB in noise level	dB	≤90	Operation cycle study using methodology	Blocked	Blocked by operation cycle study

[46] Essential Health and Safety Requirements (EHSR, 2015)

					outlined according to ISO 14000[47]		
4.3.	**Transport**						
4.3.1.	**D**	Sub-system must be able to be transported in an analogous manner of a standard 3.5 tonne trailer	-	-	Final product specifications	Met	Trailer selection within report
4.3.2.	**D**	During transport, total system must not exceed 3500 kg	kg	≤3500	Weighbridge	Blocked	Whilst theoretically met, verification activity incomplete
4.3.3.	**D**	During transport, total system length must not exceed 7m (in the direction of road travel)	m	≤7	Final product specifications	Met	Trailer selection within report
4.3.4.	**D**	During transport, total system must not exceed a width of 2.5m	m	≤2.5	Final product specifications	Met	Trailer selection within report
4.3.5.	**D**	During transport, the lowest point of the system must have a minimum ground clearance of 160mm	mm	≥160	Final product specifications	Met	Trailer and outrigger selection within report
4.3.6.	**D**	During transport, all components must be able to be physically secured	-	-	Operation cycle study	Met	‘Transport securing components’ section within report

[47] ISO 14000: Environmental Management Standards (Morris, 2004)

4.4.	Cleaning and maintenance						
4.4.1.	**D**	System must be cleaned after use using either pressurised water or air in under 60 minutes	Minutes	≤60	Operation cycle study	Blocked	Blocked by operation cycle study
4.4.2.	**D**	Sub-system must be designed with the intention of scheduled maintenance every 6 months	Months	≥6	Solution lifecycle calculations	Blocked	Solution lifecycle not yet considered at time of writing
4.4.3.	**D**	Sub-system must be easily disassembled for maintenance and repair	-	-	Operation cycle study	Blocked	Blocked by operation cycle study
4.4.4.	**D**	Sub-system must be easily disassembled for periodic maintenance and repair	Months	≥6	Operation cycle study	Blocked	Blocked by operation cycle study
4.4.5.	**D**	Sub-system must resist damage due to corrosion, exposure to concrete, weathering, and other	Comparative	Qualitative	Materials analysis using Ashby charts and Granta Edupack (ANSYS, 2023)	Met	All selected components are designed to relevant standards
4.4.6.	**D**	System shall not fail due to fatigue within its lifetime of 10,000 hrs	Pass/Fail	Fatigue analysis	Fatigue load analysis	Blocked	Fatigue load analysis not conducted at time of writing
4.4.7.	**D**	The subsystem shall be designed not fail due to yielding	Pass/Fail	FEA analysis	FEA analysis	Blocked	FEA not conducted at time of writing

4.5.	**Manufacturing, Cost, Sustainability and Environment**						
4.5.1.	**D**	Sub-system assembly shall use standard parts and components where feasible	-	-	Incorporated into design development	Met	-
4.5.2.	**W**	Sub-system should not use components or materials that are not easily disposed of safely	Comparative	Qualitative	Materials analysis using Ashby charts and Granta Edupack	Blocked	Not yet considered at time of writing
4.5.3.	**W**	Sub-system should be designed with materials that are environmentally friendly	Embodied carbon (kg.CO_2)	Minimise	Embodied carbon calculations	Met	Component selection throughout design
4.5.4.	**W**	Sub-system shall, wherever possible, minimise manufacturing cost	£	Minimise	Detailed costing	Met	Component selection throughout design

With the use of the initial subsystem product specifications, this section records the verification of the trailer and hopper subsystem at present.

Where relevant, notes have been made regarding how particular specifications have been met, unmet, or blocked.

Notably, most blocked specifications are as such due to being dependent on conducting an operation cycle study of a physical, fully embodied prototype. These have been indicated in orange.

Regarding this, actions to be visited at later date would be to create a detailed methodology for the operation cycle study, and to conduct a risk assessment. Using these two documents in tandem with the design specifications would allow for a more quantitative mode of verification.

Aside from this, specifications that **could have** been verified but have not currently due to time constraints are indicated in yellow. These relate to verification activities that such as FEA, fatigue load analysis, and solution lifecycle analysis, and represent immediately actionable steps.

9. Conclusion and evaluation of technical subsystem

9.1. Evaluation and reflection

Overall, the current technical solution of the trailer and hopper subsystem satisfactorily meets the functional, legal, and technical needs of the Anaconduit.

Comprised in majority of OTS components and utilising simple joining processes, the subsystem solution takes advantage of existing industry solutions, integrating them into a functioning, intuitive whole.

Whilst it is noted that several challenges and inefficiencies were faced during the design of this subsystem, they were considered and accounted for when possible, and where not, noted for future reference.

A reflection on the topic of in-house manufacturing

With the current design of the Anaconduit, the use of bespoke, custom-made components within the subsystem was difficult to justify.

With a combination of stringent industry standards, as well as an already active, wide market of suitable industry components, it would have been economically inefficient to create parts in-house as opposed to simply ordering them from established retailers.

The decision to use an OTS hopper, trailer, and outriggers within the subsystem reflect this. With strict legal codes surrounding both construction and road transport, to design these components in-house with adequate specifications would have incurred significant financial and logistical costs for marginal efficiency gains.

In addition to this, based on the team's market research, building a business around the manufacture and sale of the Anaconduit was assessed to be non-viable. The final business proposal reflects this, modelled around renting out a small number of Anaconduits on a hire-to-hire basis. [48]

With only a small number needed to fulfil this proposal (with just eight units needed two years downstream), in-house design and manufacture was further disincentivised, as to do so would incur high set-up costs (tooling, moulds, etc.), without the benefits of economical scaling.

[48] Refer to Commercial viability report for more information.

Limitations to the design process

Noting the aforementioned points, it should also be acknowledged that even with the benefits of using OTS components and solutions, certain limitations are imposed by this.

Firstly, in the use of OTS parts, certain constraints were imposed on design, as embodiment was limited by product availability. For example, the hopper was not fully optimised for angle, height, or weight efficiency, as selection was limited by retailers. In a similar manner, trailer geometry was not optimised for storage, holding volume, or weight, and outrigger mounting for structural integrity. These all posed potential sources of inefficiency that could be revisited at a later date.

Secondly, by embodying a subsystem around the use of already available components, there is a possibility that creativity was restricted during the design process, and that more novel, unique design concepts were never considered. As such, there is a chance that the opportunity for more commercially viable designs were missed.

Sub-system related challenges

Finally, regarding the 'functional' position this subsystem holds in relation to the Anaconduit as a whole, heavy, unforeseen time constraints were imposed during the design process, as certain activities were blocked by actions relating to other subsystems. Compared to others, this subsystem was particularly affected as it was heavily dependent on not only the pump subsystem, but also the hose and robotics.

Most notably, for much of the project, chassis design was researched and explored for a presumedly light (<25 kg) and handheld modular pump. It was not until very late that this was deemed unfeasible, and as a result design concepts had to change significantly in a short time to account for a much larger, non-modular, 1200 kg ton pump.

Retrospectively, whilst this posed a significant hurdle, this could not have been avoided given the interlinked nature of the subsystems, as modularity had to be fully explored before being deemed unfeasible. As such, whilst depth of analysis was limited due to this timeframe, they pose key points for future work.

9.2. Future work

With all this noted, there are several key points to take away for future reference.

Firstly, the current approach to the Anaconduit trailer and hopper subsystem was guided heavily by the Anaconduit being designed for one-off/small batch manufacture. As a result, OTS components were used wherever possible in the interest of economic efficiency.

As a result, if the Anaconduit were to be mass-produced in the future, this subsystem would benefit from being revisited, as in-house, bespoke component manufacturing could become economically viable. Particularly, the design of a custom trailer stands to be considered, as at present, it takes up £3050: nearly 50% of total subsystem cost.

Secondly, should the design proposal of this subsystem be taken further, a structural analysis of relevant components within the subsystem is highly recommended. This could take the form/combination of a Finite Element Analysis (FEA), fatigue cycle analysis, or workshop testing. Particularly, a structural analysis of the aftermarket outriggers whilst deployed, and of their mountings, are highly recommended.

Finally, in the future, a risk assessment should be conducted relating to this subsystem during its process cycle (e.g. 'failure mode, effects, and criticality analysis'). This could then be used in tandem with the verification methods outlined in the subsystem design specifications to help assess the safety of the subsystem whilst both in use, and in transport.

Figure 30: CAD render of Anaconduit, with relevant subsystem coloured red

(end of technical section of report)

NOTE TO READER: Writing will subsequently switch to first person for the business section of this report.

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Business report

Overview

Briefly, this section of the report covers content relating to my role as the business manager of the group.

The first, relatively brief subsection identifies and defines the responsibilities associated with my role, providing context to the rest of the report.

The second subsection serves as a record of general, high level tasks associated with research and report-writing, such as allocation of tasks, deadline management, and proofreading.

The third, most significant subsection records the challenges faced during my role as business manager, as well as how I accounted for them throughout the project.

And finally, the business report concludes ‘Summary and key takeaways’, noting important points of reflection for future projects, as well as personal recommendation for how I would approach this role if I were to reprise it.

Key responsibilities

1.Deadline management

Acting as business manager, a key responsibility was ensuring that adequate time was allocated to business-related activities at every stage of the group project.

This consisted primarily of identifying dates by which certain actions would need to be completed, using external deadlines (report hand-in, Mid-term review, etc.) to create a backwards schedule.

In addition to this, I was also responsible for managing internal business deadlines, ensuring that items were completed at a suitable pace whilst accounting for potential hurdles along the way.

2.Formatting of document, granularization, and allocation of tasks

In the initial stages of the project, I took charge of formatting and planning the structure of the group business report. Splitting its contents into distinct research packages, this allowed for key areas of market research to be identified, and for the granularization[49] of tasks to distribute within the group.

[49] i.e. breaking down large work packages into smaller ones

Once I had created a proposed structure for the document, I presented it to the group, who then provided feedback to improve it iteratively over time.

3.Spearheading research

During the initial market researching phase of the project, I was responsible for identifying key areas of information to be investigated. Working closely with the Project manager at this stage, we created a strategy for how we would identify the potential market for our project, size it, and quantify key customer needs.

Split into a top-down secondary research and a primary research phase, this was crucial to not only addressing commercial viability, but also in guiding technical design, as it served a key source for our final product specifications.

4.Proofreading

The final major responsibility I held throughout this project was the proofreading of written work.

Upon receiving work done by members of the team, this involved weaving a narrative thread throughout the sections, maintaining consistency in grammar, and communicating with members when inconsistencies or issues came up.

Coupled with task allocation, this served an efficient 'sandwich-like' package structure throughout the project, where I could allocate tasks to members, and whilst they acted on them, proofread previously written sections.

Record of business-related activities

High-level business task breakdown

Table 23: Summary of 'Before product' and 'After product' tasks

"Before Product"	"After product"
- Identification of potential markets - Identification of potential clients, end-users, and stakeholders - Top-down sizing using secondary data - Primary research via calling industry professionals	- Detailed costing of product - Research of potential business models and legal variables - Breakeven prices - Business setup costs - Cashflow forecast and business model proposal

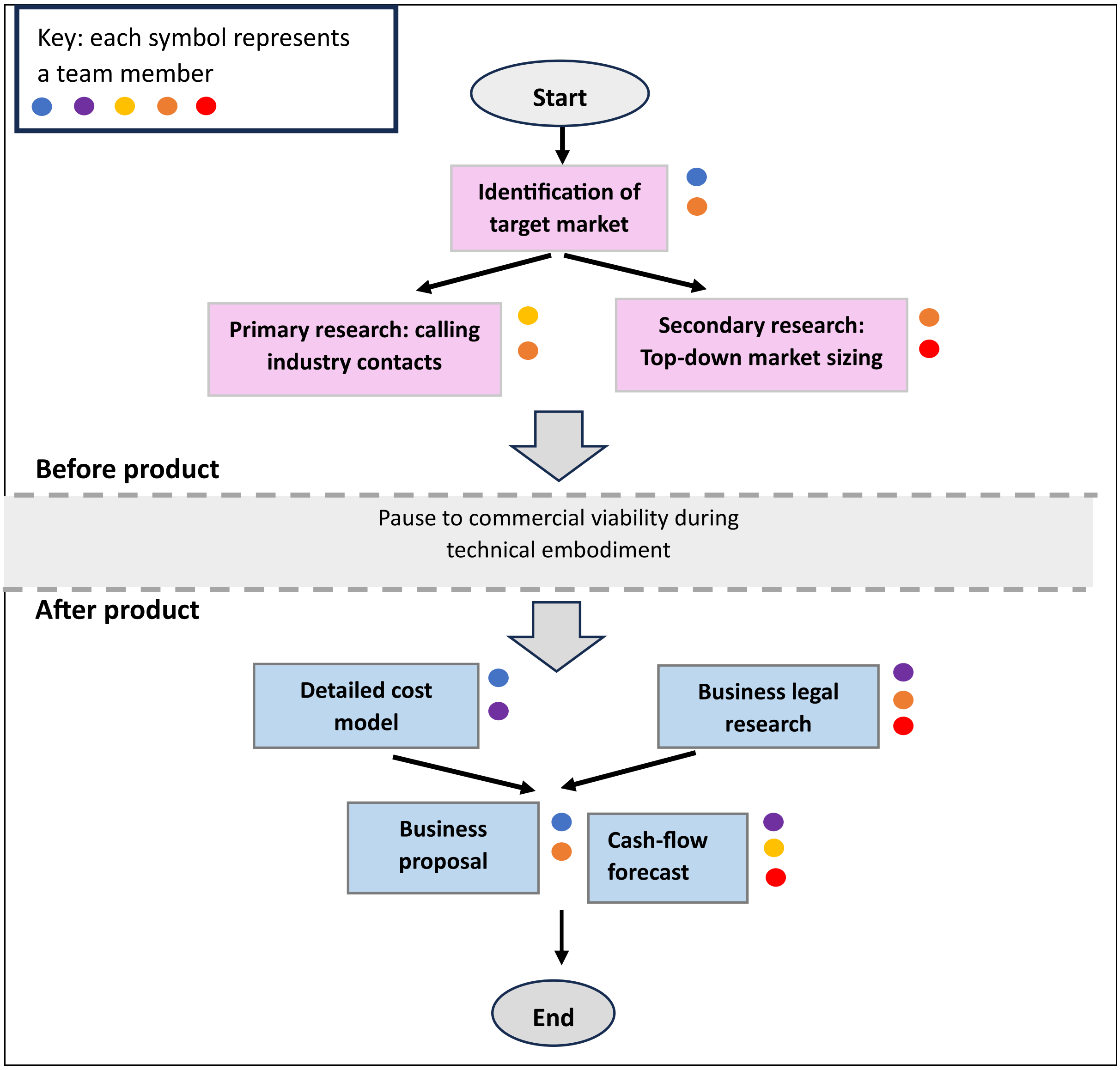


Figure 31: Initial high-level breakdown of business tasks

Broadly, business-related tasks were split into two categories: “Before product” and “After product”. ‘Before product’ tasks focused on identifying and sizing potential target markets, identifying potential stakeholders, and noting performance benchmarks of current industry solutions. Using our initial project brief for guidance, these tasks had to be done either prior to or in parallel with technical design, as their findings directly guided the design process.

Conversely, “After product” tasks focused on commercial verification of our final design, and were as such blocked until a final design was fully embodied.

Splitting the tasks into these categories allowed for business-related work to be done in parallel with technical work, helping streamline the time management of the project.

Proposed timeline and distribution of tasks

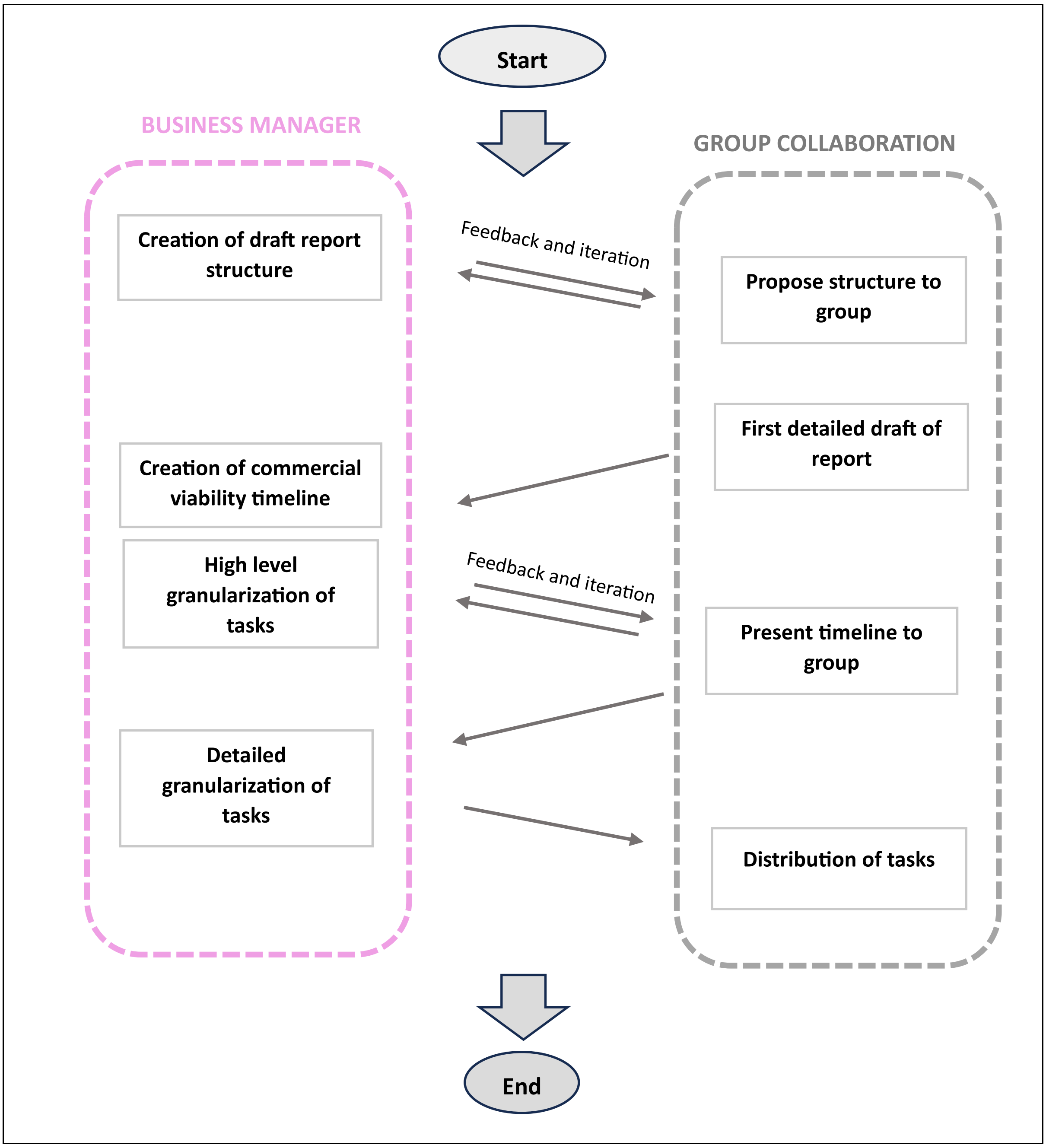
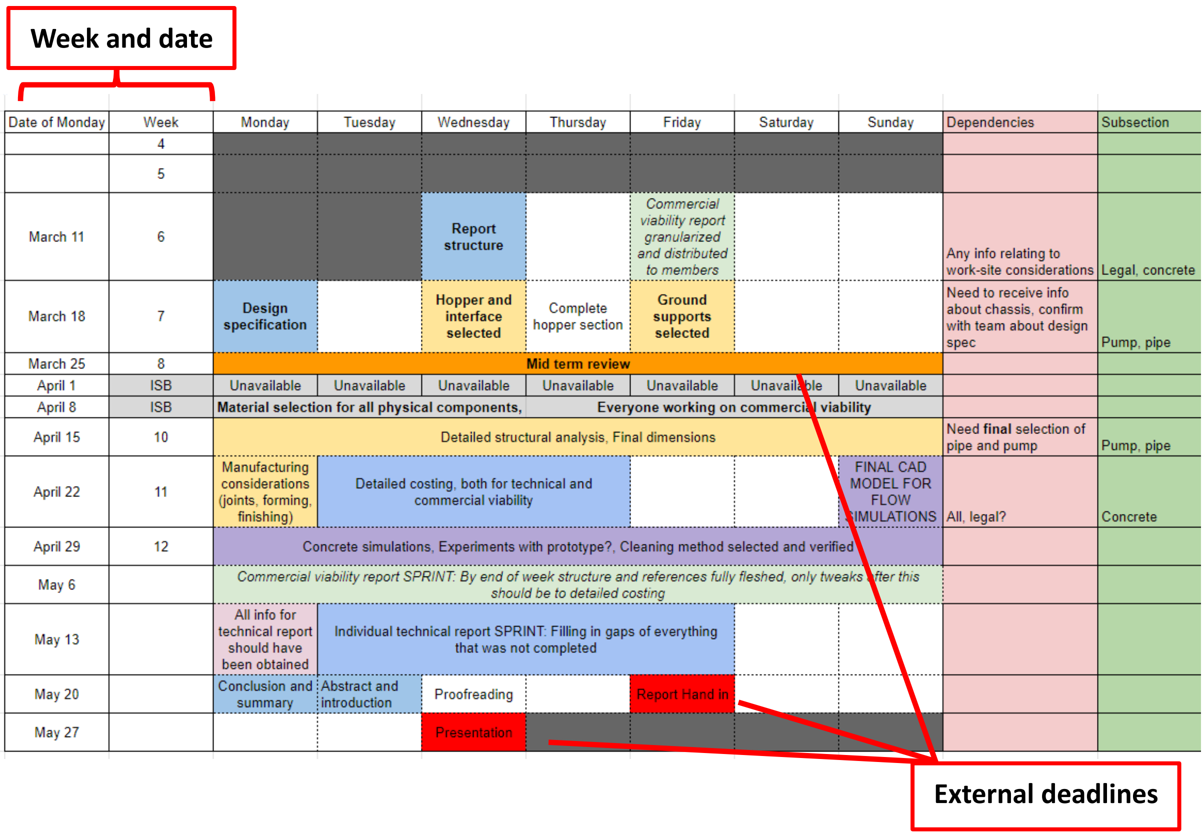


Figure 32: Flow chart showing route to commercial viability timeline



Date of Monday	Week	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Dependencies	Subsection
	4									
	5									
March 11	6			**Report structure**		*Commercial viability report granularized and distributed to members*			Any info relating to work-site considerations	Legal, concrete
March 18	7	**Design specification**		**Hopper and interface selected**	Complete hopper section	**Ground supports selected**			Need to receive info about chassis, confirm with team about design spec	Pump, pipe
March 25	8	**Mid term review**								
April 1	ISB	Unavailable	Unavailable	Unavailable	Unavailable	Unavailable	Unavailable	Unavailable		
April 8	ISB	**Material selection for all physical components,**				**Everyone working on commercial viability**				
April 15	10	Detailed structural analysis, Final dimensions							Need **final** selection of pipe and pump	Pump, pipe
April 22	11	Manufacturing considerations (joints, forming, finishing)	Detailed costing, both for technical and commercial viability					FINAL CAD MODEL FOR FLOW SIMULATIONS	All, legal?	Concrete
April 29	12	Concrete simulations, Experiments with prototype?, Cleaning method selected and verified								
May 6		*Commercial viability report SPRINT: By end of week structure and references fully fleshed, only tweaks after this should be to detailed costing*								
May 13		All info for technical report should have been obtained	Individual technical report SPRINT: Filling in gaps of everything that was not completed							
May 20		Conclusion and summary	Abstract and introduction	Proofreading		Report Hand in				
May 27				Presentation						

Figure 33: Proposed commercial viability timetable (available in Appendix L)

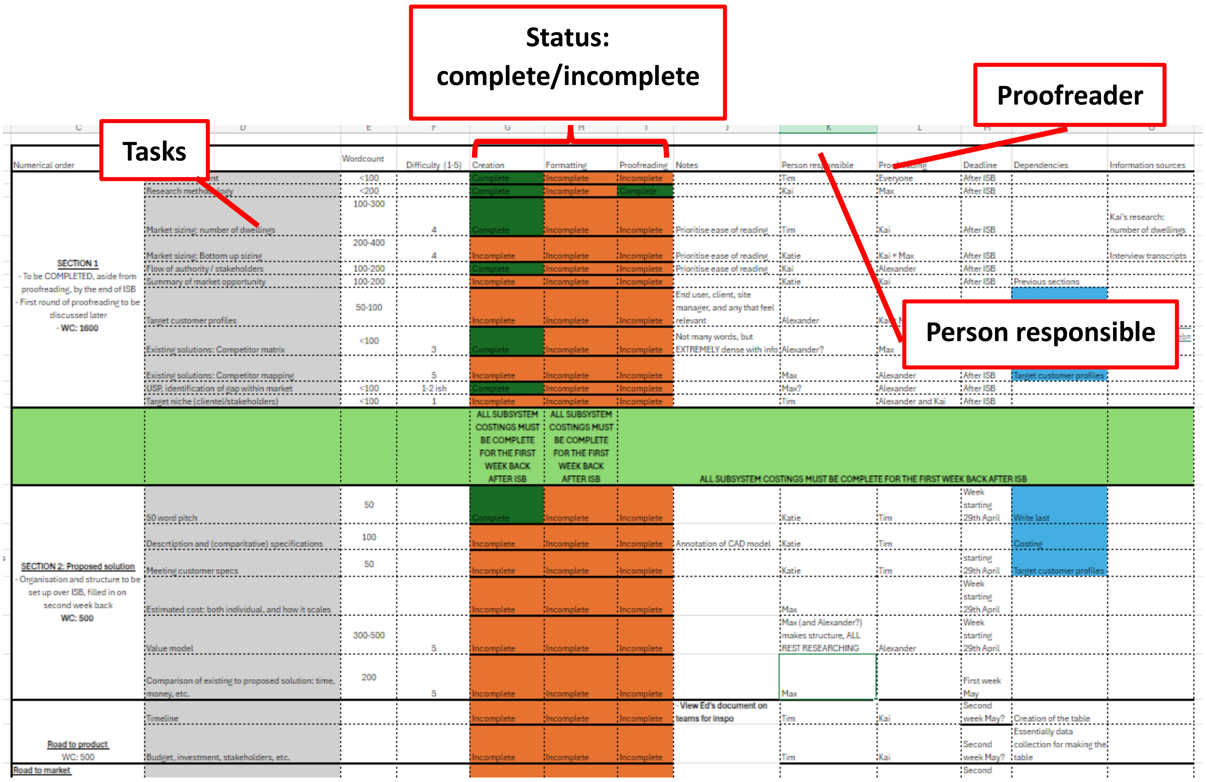


Figure 34: Fully granularized business-related deliverables (available in Appendix M)

In managing the progress and distribution of business-related tasks, a master timeline was first made. Figure 32 represents this process schematically, where accounting for each member's individual technical reports, key dates were identified.

Upon finalising this timeline with the group, a highly detailed, granular list of deliverables was created. Notably, each deliverable was assigned a writer and proofreader, such that upon myself proofreading it, it would have had two proofreading 'passes'.

By updating this document regularly, I was able to keep track of which tasks were on schedule, ahead, or falling behind, and redistribute tasks accordingly.

Formatting and proofreading Gantt chart

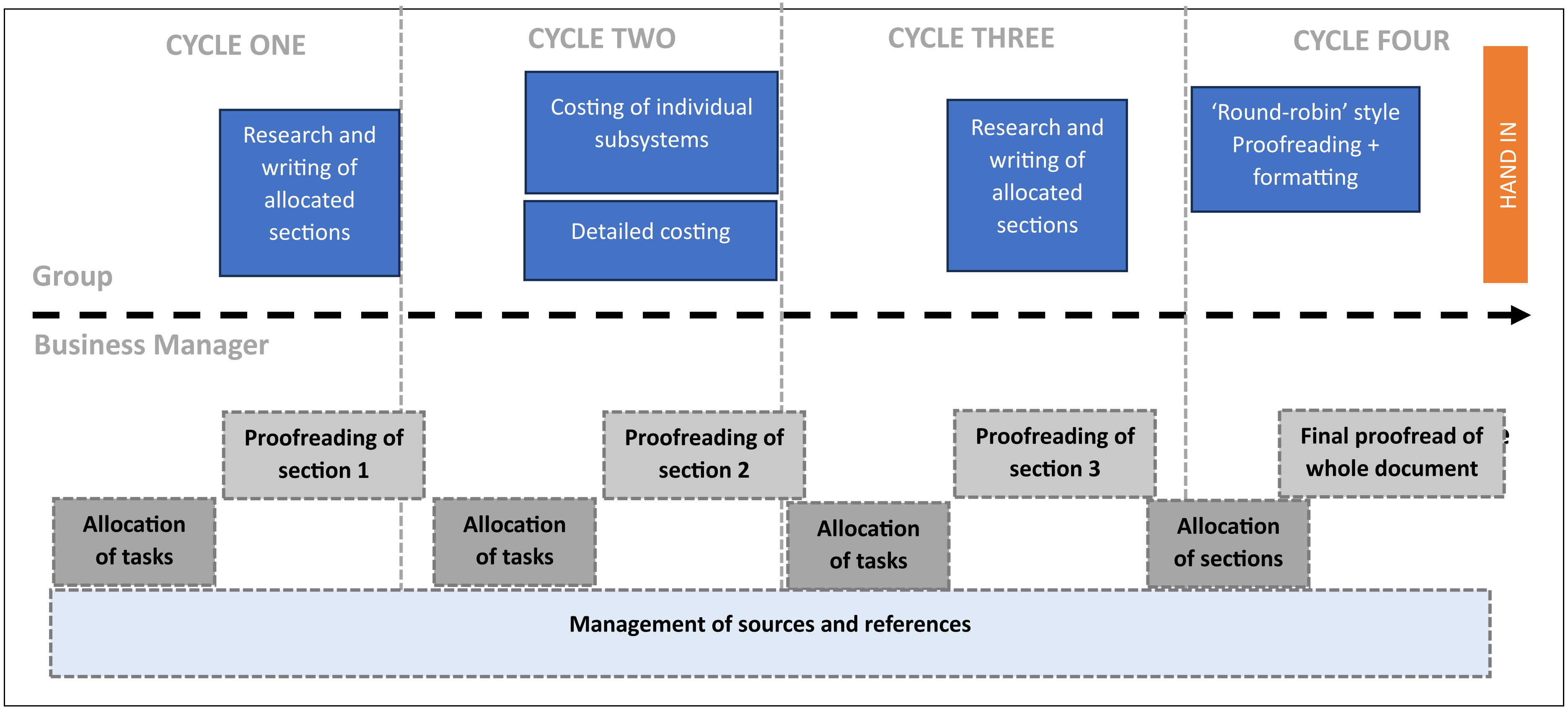


Figure 35: Gantt chart of proofreading and task allocation process

On a high level, contents pertaining to the commercial viability report were split into three distinct sections. This allowed for task allocation, content creation, and proofreading to happen in a cyclical manner, in that order. This is illustrated in the Gantt chart Figure 35. Each 'cycle' represents the start-to-finish process of writing these sections, with cycle four representing proofreading all sections as a whole.

Challenges

Time management and prioritisation of responsibilities

Acting as business manager, I was at times more emotionally invested in the progress of the commercial viability report when compared to other members.

This posed two direct consequences. Firstly, when tasks were allocated to members for completion within a timeframe, they were either not ready for proofreading, or not written at all. This posed a significant hurdle to my managerial responsibility of proofreading, causing delays to my group-related tasks.

The second consequence was conflict of interest. Due to the project unit structure, members understandably prioritised individual technical reports over the group business report for most of the project. Conversely, I heavily prioritised actions relating to the group work over individual, as being business manager I felt a distinct responsibility.

This posed a personal challenge, as it meant that when tasks allocated to other members remained incomplete, I felt personally responsible for taking them on myself. This meant that on average, I wrote and invested disproportionately more time into the group report than other members, leaving little time for my own individual work.

Upon reflection, perhaps a way to account for these issues would be to have a more active role in assessing the progress between task allocation and proofreading, checking in at intermediary points rather than just on the agreed delivery date. This could provide more time to account for unforeseen challenges, and help streamline the process.

Approach to task allocation

Initially, task allocation was approached in a 'first-come, first-serve' manner, where I would granularize actions, and then let members choose their sections in a business meeting.

This approach was used for the first set of allocations, but upon feedback from the project manager, replaced with a more active approach, where I would personally allocate responsibilities *prior* to hosting a business meeting, and let individuals opt out if they wished to.

This proved to be a significant timesaver, and was followed for the rest of the project.

Communication of responsibilities

At the start of the project, communicating with other team members regarding their allocated tasks proved to be a challenge.

Communication was initially approached passively, assuming that members would understand their responsibilities through my written descriptions, and seek clarification when unsure. I would consequently invest much time into writing detailed, thorough descriptions to assist them.

However, upon receiving first drafts of members' sections, this approach was quickly discarded, as it became very clear that I was not a very good writer.

Subsequent task allocation was then approached in a more active manner, arranging individual meetings with members after task allocation to ensure responsibilities were understood. This proved to a huge time-saver, and was followed for the rest of the project.

Conflict with group members

Towards the end of the project, stress levels within the group gradually increased, occasionally presenting a challenge to allocating tasks as people were less enthusiastic to take them on.

On the whole, this was not a significant issue, apart from one incident where a member refused to complete their section and to communicate their decision.

Upon speaking to them and offering support, they returned with the section complete, but of poor quality. We then had two more rounds of feedback with similar result.

Given the little time left, I eventually decided to subsequently take responsibility for this member's section, as I was at this point most familiar with it, and redistributed my other responsibilities among the group.

Retrospectively, it would have been difficult to avoid or manage this conflict differently even with current knowledge. However, one action for future projects could be to account for potential conflicts by creating a team charter to instil a stronger sense of responsibility within members.

Proofreading

Throughout the project, proofreading proved to be an interesting albeit challenging task.

Firstly, integrating different member's writing styles together without altering grammar significantly proved difficult. Certain members preferred to use an active voice, whilst others passive, and as such integrating them together comprised a significant chunk of time.

Secondly, given that different report sections were attributed to different members, it was common for the same information to be repeated by different members independently. Once this was noticed when proofreading the first section of the report, it was accounted for in future sections by writing the 'first' and 'last' sentences of each section before allocating them to members, effectively storyboarding the document.

The final challenge appeared towards the end of the project, where a significant number of words had to be cut for word count. For this, a 'round-robin' proofreading approach was used, allocating members to different sections to cut words, iteratively rotating until word count was met. I then did one more thorough pass through the document before submitting.

Whilst these challenges didn't pose much disturbance to the progress of the group report, this would likely change if the document were larger in size.

As such, one way to mitigate these issues in the future could be to approach task allocations differently: appointing members as either 'designated writers' or 'designated researchers' according to individual skill, rather than have each member do both for their section. Whilst this may restrict each member's ability to work independently initially, it would help streamline the proofreading process thereafter.

Summary and takeaways

Overall, acting as the business manager was a pleasant, fulfilling role.

Throughout the project, certain challenges presented themselves, such as miscommunication between members, poor personal time management, and inefficiencies in my approach to task allocation.

However, as the project progressed, these were gradually accounted for, with no major lasting issues faced. If one were to take on the role of business manager in the future for this group, I would recommend the following.

Firstly, I would suggest being proactive regarding conflict management. This could take the form of having a designated team charter for such situations, or investing in activities that encourage team building.

Similarly, I would also suggest taking a direct approach to communication, arranging individual meetings to discuss task-related details, rather than relying on written description.

Finally, regarding writing a shared document, I would recommend (where possible) splitting the team into designated writers and researchers based on individual strengths *for the whole document*, rather than have members do both for each section. This would be especially recommended for larger documents, where proofreading would take up proportionally more time.

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Appendices

Appendices A: Group Business and Design Project (GBDP) Brief – Project Anaconda

Group Business Design Project 2024

Unit code: ME30068/40228

Group 3 – MEng

Academic supervisor: Andrew Avent aa2235@bath.ac.uk

Company sponsor: N/A

Business mentor: Dr Ali Hadavizadeh ah870@bath.ac.uk

Project title: Anaconda: Concrete placement system for construction sites with restricted access.

Project description

The options available to small and medium sized construction sites to precisely deliver controlled amounts of concrete into (sometimes) complex formwork and reinforcement are limited. The option of hiring in huge (expensive) mobile concrete pumps and accommodating large volumes of pre-mixed concrete on site is often difficult to justify, especially on a multi-phase pour which may happen over several days or even weeks. Conveyors are often too short, not suitable (no camber) and are difficult to hire (hire companies are reluctant to have their equipment used for concrete). The client is looking for an easily deployed, small to medium scale transport system which comes apart for cleaning and can be used to accurately place concrete over distances up to 12m (16m preferable) straight from a standard ready-mix lorry of 8m3 capacity. The chute (3m max) on these lorries is approximately 1.8m from grade and so offers little opportunity to use gravity over 16m distances.

Technical elements of the proposed project

Structural analysis, material analysis, drive/power systems, control systems, overall design integration, business opportunity, etc.

Commercial elements of the proposed project

Aiming to commercialise the output from this project, so a sound design, strong business case and marketing plan needed.

Appendices B: Customer Needs

Customer Needs Analysis		
Reference No.	**Demand/Wish (D/W)**	**Description**

1	**D**	Develops a minimum average flow rate of $8m^3$/ 45mins, including stoppage for manoeuvring system (i.e. with 22.5mins of of stoppage, instantaneous flow rate is up to 16m^3/45mins)
2	**D**	Capable of handling intermittent input flows, from concrete lorries
3	**D**	Deploy fresh concrete with a maximum drop of 500mm
4	**D**	Raise concrete over inclines and declines of up to 1 in 7 (~8.15deg)
5	**D**	Accurately target concrete at a point in 3D space with a minimum precision of 500mm in each axis
6	**W**	Capable of delivering concrete without stoppage in potentially muddy, wet, windy weather, in dry or humid, cold or warm climates
7	**D**	Capable of traversing/spanning Complex Formworks with irregularly spaced and dimensioned trenches
8	**D**	Able to deliver a precise amount of concrete
9	**W**	Able to receive concrete between 0-3m (preferably 0-1.8m) above grade, directly from a mixer truck
10	**D**	Fits into a footprint of 6x4m, with the long axis along the line of the mixer truck
11	**W**	In the worst case, could be able to use outrigger trucks across the site, outside of 12/16m-key-dimension workspace)
12	**D**	Capable of pouring at least C20 concrete with negligible segregation
13	**D**	Capable of delivering concrete to a depth of 2m below grade
14	**D**	Capable of pouring up to 30m^3 of concrete in 1 day
15	**D**	Capable of pouring concrete for footings and Slab on Grade (SoG) projects
16	**D**	Ideally has versatile power options, with a maximum electrical power of 8kW

17	**W**	Ideally targets low slump and reduced-retarder concretes
18	**D**	Capable of supporting itself on subsoil without destabilising soil or nearby formwork
19	**D**	Able to access sites that a concrete mixer can
20	**D**	Capable of delivering concrete up to 12 (preferably 16) metres from the rear of the mixer truck – where 16m is diagonal
21	**D**	Economically attractive compared to worker(s) with shovel and wheelbarrow, and excavator which is probably already on site
22	**W**	Ergonomically attractive to use in most, the same or more situations than a wheelbarrow and worker (Consider terrain, weather, etc.)
23	**W**	Easy to return to storage/vendor cleaned of concrete
24	**D**	Safe for humans and environment in Normal Operations, transport, and Failsafe for humans at LEAST
25	**D**	Deployable, operable, cleanable and stowable by 4 people - 1 ingest operator, 1 manouevring operator, 1 delivery operator, and 1 manager/foreman
26	**D**	Can be transported and deployed anywhere a concrete truck can be
27	**D**	Cleanable on site of construction, within the same day as the concrete pour
28	**D**	Must be compatible with existing standards(power, equipment, communication)
29	**D**	Should be able to be repaired with standard equipment and parts
30	**W**	Rental price is attractive to vendor and recipient for less than £1,000 to hire for a day

31	**W**	Must sell for less than £60,000. Most small towable pumps in the UK go for £30k+ (used) and £70k+ (new) with no tubing but truck mounted pumps go for £150k+ (used) or £300k+ (new).
32		Aesthetics must be oriented towards Customer (owner of anaconda) and operator (renter/owner's operator)
33		Usability must be oriented towards operator and user (construction worker)
34		Must be compliant with existing legal standards where relevant

Appendix C: Target specifications

(A note to the reader)

While viewing this document, it is worth keeping the following points in mind.

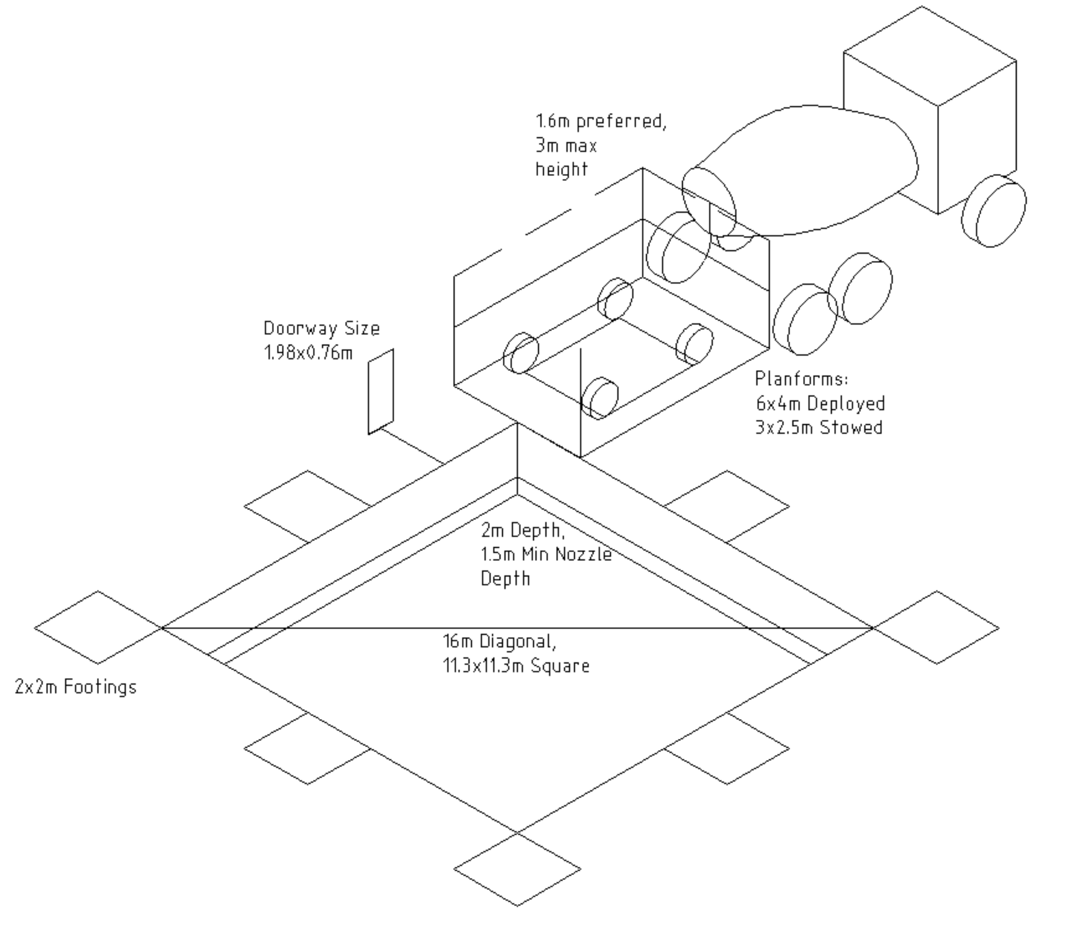
Firstly, the target specifications shown in this appendix were made using the methodology outlined by Ulrich (Ulrich, et al., 2020) as a guide. Certain features, such as referencing the Customer Needs document directly, were omitted, as the target specifications were iterated upon. The reason for this is that as the document evolved, this feature gradually became vestigial, and was consequently removed. If the reader is interested in viewing these, contact any member of the team, starting with the email skw43@bath.ac.uk.

Secondly, the Target specifications served as an active, working document throughout the design process. As such, detailed in this appendix is the **latest version of said document.** As the value of target specifications lies predominantly in communicating within the product design team, certain colloquial comments and notes remain, such as to inform the team if the project were revisited at a later date.

With that, the rest of this appendix contains the most recent iteration of target specifications.

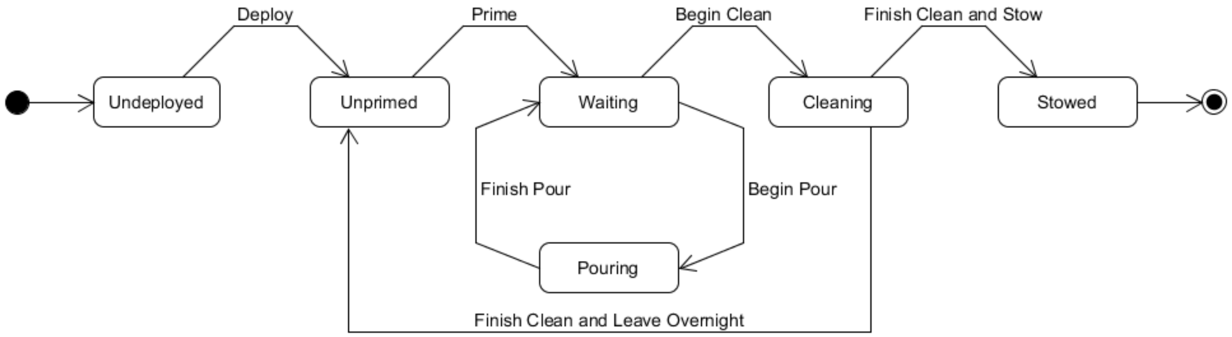
A.C.1. Nomenclature and Diagrams

A.C.1.1. Workspace



A.C.1.2. Operation Cycle

Typically one day's work. Consists of (an optional) deployment from stowed configuration, loading the first concrete load, potentially including a priming, deploying between 4 and 30m^3 of concrete intermittently, cleaning, and re-stowing. If the system is left on site overnight, and is capable of overnighting whilst deployed, then the deployment and/or stowage stages of the cycle can be omitted, but they must bookend a series of operational cycles on a single job site.



A.C.1.3. Concrete

Slump – The distance whilst concrete falls from its initial height when placed into a slump cup, inverted and the cup is removed from above it.

A.C.2. Target Specifications

No.	Demand/Wish	Requirement	Responsible	Source Document	Changes
1.	**Concrete Handling**				
1.1	D	Anaconda shall load concrete directly from mixer trucks	AA 02/02/24	Brief	

1.2	D	Anaconda shall be capable of loading concrete intermittently with at maximum one priming per cleaning during an operation cycle	AA 02/02/24	Implicit from Brief	
1.3	D	Anaconda shall not allow the concrete to cure whilst it is transporting it	AA 02/02/24	Implicit from Brief and common understanding of “place concrete” referring to fresh concrete	
1.4	W	Anaconda shall not allow concrete to cure whilst it is containing it during extended periods of non-operation (not manoeuvring system or pouring)	AEM 06/02/24		
1.5	D	Anaconda shall not segregate the concrete it transports	AA 08/02/24	All Meeting Notes: Meeting Minutes 08/02/2024	
1.6	W	Anaconda shall be capable of accommodating concretes made with Supplementary Cementitious Materials (SCM)	MH 14/02/24		
1.7	D	Anaconda shall deliver concrete at an average rate of 8m^3 per 45 minutes, including stoppages	KJ 09/02/24	Ideal implication from All Meeting Notes: Meeting Minutes 08/02/2024	

1.8	D	Whilst properly maintained, Anaconda shall not fail from wear and tear (for example, but not limited to cracking or corrosion) within its design life from concrete exposure	KJ 09/02/24		
1.9	D	Anaconda shall not change the composition of the concrete (for example, but not limited to crushing of large aggregate)	KJ 09/02/24		
1.10	D	Anaconda shall be capable of accommodating C20 concrete	AA 08/02/24	All Meeting Notes: Meeting Minutes 08/02/2024	
1.11	W	Anaconda shall be capable of accommodating low slump concretes	KJ, AA 09/02/24	All Meeting Notes: Meeting Minutes 08/02/2024	
1.12	W	Anaconda shall be capable of accommodating fibre concretes	MH 12/02/24	Requirements and Spec	
1.13	W	Anaconda shall be capable of switching concrete type mid-operation cycle	KJ 06/02/24		
2.	**Dimensions, Precisions and Tolerances**				

2.1	D	Anaconda shall be able to load concrete at an elevation below 3000mm	AA 04/02/24	Brief	
2.2	W	Anaconda shall be able to load concrete at an elevation below 1800mm	AA 04/02/24	Brief	
2.3	D	Anaconda shall pour concrete from a maximum Z+ displacement of 500mm from the 3D Target	AA 08/02/24	All Meeting Notes: Meeting Minutes 08/02/2024	
2.4	D	Anaconda shall have a spatial resolution of 500mm in X and Y	AA 08/02/24	All Meeting Notes: Meeting Minutes 08/02/2024	
2.5	W	Anaconda shall have a spatial resolution of 250mm in X and Y and Z	KJ, TD 12/02/24	Implication of All Meeting Notes: Meeting Minutes 08/02/2024 and goal of preventing pouring up against formwork	100 to 250mm (less precision is truly required)
2.6	D	Anaconda shall have a volumetric resolution of 1 cubic foot (28.3L, 0.283m^3)	AA 12/02/24	All Meeting Notes: Meeting Minutes 12/02/2024	
2.7	D	Anaconda shall deliver concrete up to 12000mm from the boundary of the workspace	AA 04/02/24	Brief	

2.8	W	Anaconda shall deliver concrete up to 16000mm from the boundary of the workspace	AA 04/02/24	Brief	
2.9	W	Inlet of Anaconduit shall not have to be moved whilst pours are being made within the target site	AA 08/02/24	All Meeting Notes: Meeting Minutes 12/02/2024	
2.10	D	Anaconda shall be able to pour at least 30m^3 of concrete per day	AA 08/02/24	All Meeting Notes: Meeting Minutes 12/02/2024	No upper bound
2.11	D	Anaconda shall fit into a space 4000mm by 6000mm, with the large axis parallel to the axis of the concrete mixer truck.	AA 08/02/24	All Meeting Notes: Meeting Minutes 12/02/2024	
2.12	D	Anaconda shall be able to deliver concrete to a point 2000mm below the local grade.	AA 08/02/24	All Meeting Notes: Meeting Minutes 08/02/2024	
2.13	W	Anaconda shall be able to deliver concrete to a point 15000mm below the local grade.	AEM 13/02/24	All Meeting Notes: As a recommendation of Civil Engineering undergraduate	
2.14	W	Anaconda shall be able to deliver concrete over an increasing or decreasing grade of 14.2% (equivalent to 1 in 7, 8.14°)	AA 08/02/24	All Meeting Notes: Meeting Minutes 08/02/2024	Grade can be up or down

2.15	D	Whilst deployed, any outriggers used by the system shall only contact the ground outside of the workspace			
2.16	D	Any outriggers used shall have a maximum contact patch of 2000mm by 2000mm	AA 12/02/24	All Meeting Notes: Meeting Minutes 12/02/2024	
2.17	W	Anaconda shall be able to transport concrete through a standard sized doorway (1981mm x 762mm)	AEM 14/02/24	https://rapidreadymix.co.uk/2020/11/23/how-much-does-concrete-pump-hire-cost/	
2.18	D	Anaconda shall not slide concrete down a grade of greater than 1 in 40 without appropriate segregation-reduction measures	AA 12/02/24	Should be in meeting notes, but this was not written – 1 in 40 is sewer grade to prevent solid-liquid segregation	
3.	**Legal/Safety**				
3.1	D	Anaconda shall comply with environmental regulations	KJ 13/02/24		
3.2	D	Anaconda shall comply with worker safety regulations	KJ 13/02/24		

3.3	D	Anaconda shall conform to relevant standards for the handling of concrete	KJ 13/02/24		
3.4	D	When practicable, Anaconda shall integrate standard components to interface with other machines, devices and to promote user repair	KJ 13/02/24		
3.5	D	Anaconda's design shall not infringe upon intellectual property rights	KJ 13/02/24		
3.6	D	Anaconda shall comply with transportation regulations	TD 14/02/24		
3.7	D	During Anaconda's operating cycle, the loads, temperatures and noise levels that users are exposed to shall be below limits set in legislation.	KJ 14/02/24		
4.	**Human Ergonomics**				
4.1	D	If anaconda jams it shall be safe and quick to repair.	KJ,TD 15/02/24		Better phrasing

4.2	D	While in operation, Anaconda shall be easy to stop safely and quickly by any on-site personnel.	KJ 12/02/24		
4.3	D	Anaconda shall be able to be operated by a crew of 4 people NB: One person handling the output, one person handling input, one person handling position control, and one person overseeing the entire process	AA 08/02/24	All Meeting Notes: Meeting Minutes 08/02/2024	
4.4	W	Anaconda shall be able to be operated by a crew of 3 people	TD 15/02/24		
4.5	W	Anaconda shall not need special training to operate	KJ/AA 08/02/24, AH 12/02/24		
4.6	D	While operating, it shall be audio-visually obvious that Anaconda is operating.	KJ 12/02/24		
4.7	D	When traversing the workspace, Anaconda shall prevent itself	KJ 12/02/24		

		from making physical contact humans			
4.8	W	Anaconda shall be divisible into modular sections which can combine to extend Anaconda's capabilities.	KJ,MH,AEM, AH 08/02/24		
4.9	D	Anaconda shall be controllable by human operators	KJ 13/02/24		
4.10	D	Anaconda shall have simple, intuitive control systems	KJ 13/02/24		TD 15/02/24 – W->D
4.11	W	Anaconda's deployment and stowage actions within its operating cycle shall take no more than 30 minutes each	KJ 14/02/24	Formative statement	
4.12	D	Anaconda's deployment and stowage actions within its operating cycle shall be tolerant of user error	KJ 14/02/24		TD 15/02/24 – W->D
4.13	W	Whilst operating under the worst expected operating conditions, Anaconda's cycle of operation	KJ 14/02/24	Pulled number from thin air	

		shall be slowed by no more than 20%.			
4.14	D	Anaconda shall reduce the physical load on workers compared to similar or lower priced competitors	KJ 14/02/24		
5.	**Powertrain**				
5.1	W	The powertrain shall be swappable on request to leverage different common power systems on a construction site	KJ 12/02/24		
5.1.1	W	The powertrain shall optionally run on auxiliary hydraulics on a 4 ton or smaller excavator e.g. 22kW Primary Auxiliary Hydraulics	KJ 12/02/24, AA 08/02/24	All Meeting Notes: Meeting Minutes 08/02/2024 Example https://www.takeuchi-mfg.co.uk/compact-excavators/tb240-compact-excavator/	
5.1.2	W	The powertrain shall optionally run via mechanical linkage from one or more powerplants	KJ 12/02/24		
5.1.3	W	The powertrain shall optionally run off a distributed electrical	AA 08/02/24	All Meeting Notes: Meeting Minutes 08/02/2024	

		power system, with a maximum power of 8kW			
5.2	D	The powertrain shall be sufficient to transport concrete under all stated loading conditions (for example, but not limited to: high grade, high flow rate, high winds)	KJ 12/02/24	Brief (effectively)	
6.	**Life Cycle and Operating Conditions**				
6.1	D	Whilst properly maintained, Anaconda shall not fail from wear and tear (for example, but not limited to cracking or corrosion) within its design life of 10,000 hrs from its operating environment (Temperature, weather).	TD 19/02/24		Added lifetime estimate
6.2	D	Anaconda shall have an expected duty cycle of 8 hours of operation per day			
6.3	D	Anaconda shall be expected to be traversing the workspace on a duty cycle of 2 hours per day			

6.4	D	Anaconda shall be able to be cleaned on-site within 2hrs of the final pouring stage	(AA [08 AND 12]/02/24)	All Meeting Notes: Meeting Minutes 08/02/2024, All Meeting Notes: Meeting Minutes 12/02/2024	
6.5	W	Anaconda shall have easy disassembly for cleaning.			
6.6	D	Anaconda shall be capable of operating across complex spaces and formworks.	TD		
6.7	D	Anaconda shall be able to support itself on subsoil without destabilising soil or nearby formworks.			
6.8	D	Anaconda's core functions and reliability shall not be significantly altered due to its operating environment, for example but not limited to muddy, wet, windy weather, or dry, humid, cold or warm climates	KJ 15/02/24		Took responsibility, TD,KJ reworded
6.9	W	Anaconda shall be able to adapt to environment to maintain a consistent operating condition			

		(e.g., flow rate change due to temperature changes impacting concrete).			
6.10	W	Capable of delivering concrete at an assured, high level of reliability			
6.11	D	Anaconda must be capable of being kept overnight on-site, in between cycles while not in use, without affecting performance on the consequent days	SKW 15/02/24		
7.	**Environmental Factors and Maintainability**				
7.1	W	Anaconda shall be constructed so that its constituent parts are commonly recyclable	TD		
7.2	W	Anaconda shall have high mechanical and electrical efficiency	TD		
7.3	W	Anaconda shall save more concrete CO_2 emissions via efficient placement than it emits during operation	TD 15/02/24		Reworded by KJ and TD

7.4	W	Anaconda shall be readily usable on a typical building site, without prior preparation for its arrival	SKW 15/02/24		Reworded KJ, TD
7.5	W	Anaconda shall be constructed out of materials which are sustainable, and easily recyclable	SKW,KJ 15/02/24		
8	**Pricing, Business, and Logistics**				
8.1	W	If any parts of Anaconda is made to be road legal, such parts shall fit into the wheelbase of the Land Rover Defender 130 Wheelbase (2,587 to 3,022 mm).	AA 08/02/24	https://www.landrover.co.uk/defender/defender/specifications.html	
8.2	W	Anaconda shall be sufficiently versatile to be minorly redesigned for other industries, for example but not limited to moving other bulk materials.	KJ 12/02/24		Reworded by KJ,TD
8.3	W	Anaconda will not require the hiring of specialised personnel that charge £150-£250 a day	AEM	https://www.singhconcrete.com/concrete-pump-cost/	
8.4	D	Anaconda's projected rental price shall be less than £1,000 /	AEM	Source: Andrew and https://www.singhconcrete.com/concrete-pump-cost/ Big pumps cost £1k per 8m^3 concrete truck.	

		expected time required to deliver 8 cubic meters of concrete. i.e. Which is £90 to £120 / cubic metre. For reference: MINIMUM (cheap boom pump, 4 cubic metres) would be £360, MAXIMUM (expensive boom pump, 30 cubic metres) would be £3,600.			
8.5	W	Anaconda's expected rental price shall be less than £500/day (4-30 cubic metres).	AEM	Local American DIY projects that use mini concrete pumps cost £400-£628 to rent a day. https://expressconcreteltd.com/how-much-does-concrete-pump-hire-cost/	
8.6	D	Anaconda's unit production cost shall be less than £70,000.	AEM 14/02/24	(Most small towable line pumps in the UK go for £30k+ (used) and £70k+ (new) with no tubing but truck mounted boom pumps go for £150k+ (used) or £300k+ (new).)	
8.7	W	Anaconda's unity production cost shall be less than £20,000	TD 15/02/24	Formative value	

8.8	D	Anaconda will be easily available for hire via web search	AEM		
8.9	W	Anaconda will be accessible to people in remote areas	AEM		
8.10	W	Anaconda shall be able to be brought from storage to a remote site within a working day	SKW 15/02/24		
8.11	D	Anaconda shall be able to service difficult to reach foundations	AEM		
8.12	D	Anaconda will reach a flow rate of 0.3m^3/minute, competing with the smallest, cheapest line pumps.	AEM	https://www.aliexpress.com/item/1005006077605823.htm	
8.13	W	Anaconda will reach a flow rate of 2.67m^3/minute, able to directly compete with the largest boom pumps and expand into the pile driver market.	AEM	https://www.heidelbergmaterials.co.uk/en/ready-mixed-concrete/technical-information/concrete-pump-faqs	
8.14	D	Anaconda will be discoverable by concrete companies which would want to purchase Anaconda for their own private hiring business.	AEM	Book: The Personal MBA, Josh Kaufman	

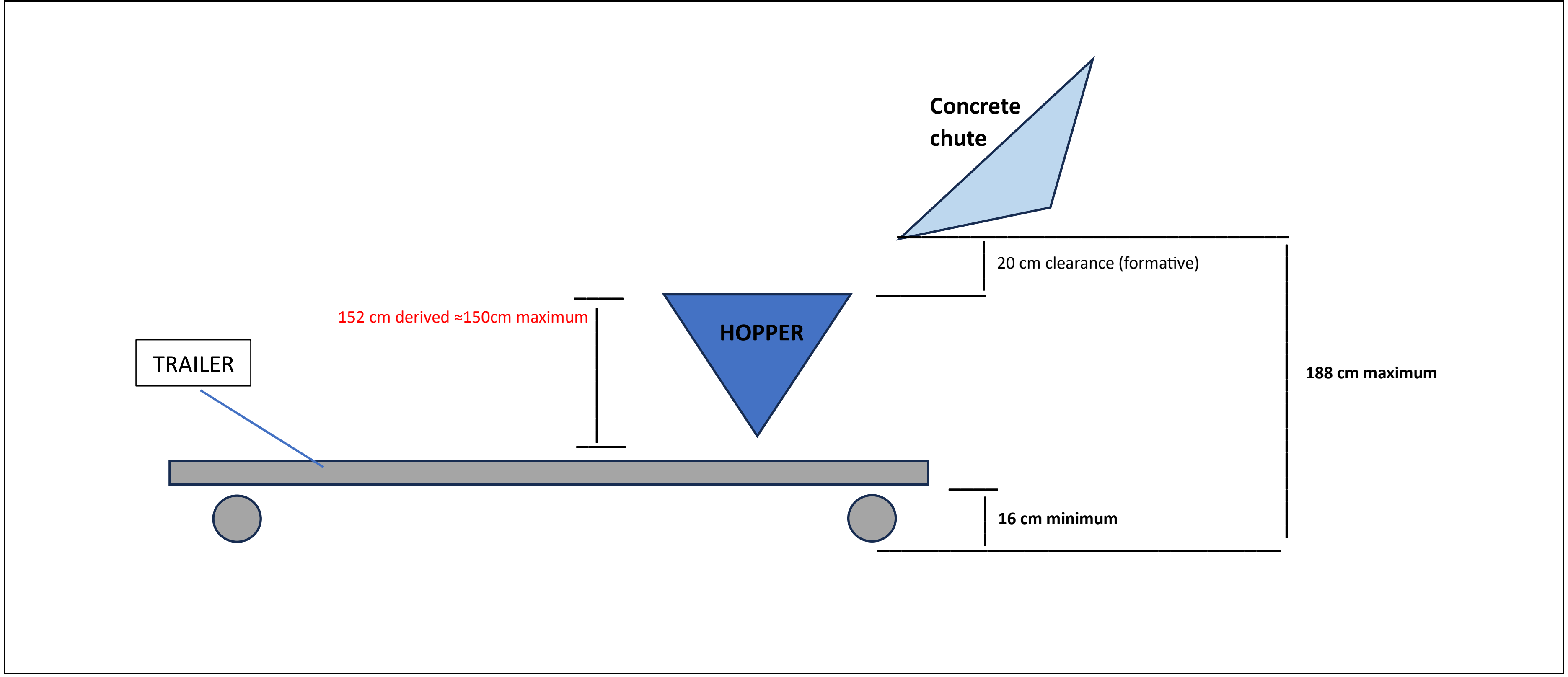
8.15	W	Anaconda shall look powerful and versatile	AEM	The Personal MBA	
8.16	W	Anaconda shall be available for pre-order by large concrete businesses	AEM	The Personal MBA	
8.17	W	Anaconda shall be available for free/cheap test-runs by large concrete businesses (lifetime customers) to encourage purchases	AEM	The Personal MBA	
8.18	D	Any form of market research is conducted before Anaconda manufacture to determine that a demand exists	AEM	The Personal MBA	
8.19	W	Professional market research is conducted to determine exact level of demand and yearly earnings	AEM	The Personal MBA	
8.20	D	A 1-year business plan is created with basic monthly costs and estimated monthly income.	AEM	The Personal MBA	

8.21	W	A detailed business 5-year business plan must be created, accounting for all accumulated costs, estimated investments, estimated debt, estimated income (and income timeline) along with other variables.	AEM	The Personal MBA	
8.21	W	The business plan provided with Anaconda could have contingencies included to account for a recession/weakening economy	SKW 14/02/24		
8.22	D	Anaconda must be able to be used in parallel with other standard equipment, such as diggers, cement trucks, etc.	SKW 14/02/24		
8.23	D	Anaconda must be provided with a pamphlet/booklet with investment costs/fees attached	SKW 14/02/24		
8.24	W	Anaconda shall be able to be adapted for the abide by	SKW 14/02/24		

		regulations in countries other than the United Kingdom			
8.25	W	Anaconda shall be able to accommodate construction practises common in countries other than the United Kingdom	KJ, SKW 15/02/24		TD , KJ Split into legal and technical 8.24, 8.25
8.26	D	Anaconda must be able to be stored within reasonable storage conditions i.e. no need for a specialised storage space	SKW 14/02/24		
8.27	W	Anaconda could be able to be maintained with standard cleaning/repair equipment	SKW 14/02/24		
8.28	D	Anaconda must be made of standard parts where possible, such as to reduce cost of production, and reduce new manufacturing processes	SKW 14/02/24		
8.29	D	Anaconda should have a lifetime of 10,000 hours of working time if properly maintained.	TD 19/02/24	https://thompsontractor.com/blog/average-lifespan-of-common-construction-equipment/	Added 19/02/24

8.30	W	Anaconda will have a lifetime of 15,000 hours of working time if properly maintained	TD 19/02/24	https://www.reactpower.com/blog/the-life-expectancy-of-your-diesel-generator/	Added 19/02/24

Appendix D: Hand calculations of hopper height



Appendix E: Detailed hopper selection

		Model									
		 [50]		 [51]		 [52]			 [53]		
Parameter	**Benchmark**	**BC80N**	**BC99N**	**BCT80**	**BCT99**	**SBB 7**	**SBB-10**	**SBB-12**	**BB-7**	**BB-10**	**BB-12**
Outlet diameter	**≥ 80mm**	308	321	200	200	405	405	405	405	405	405
Hopper half angle	**60 ± 5 degrees**	62	62	55	55	50	50	50	50	50	50
Height	**≤1.5 m**	1.14	1.26	1.12	1.16	1090	1170	1295	1250	1475	1475
Weight	**Minimise (kg)**	165	225	180	195	190	250	270	115	140	145
Product specified holding volume (m^3)	**0.5 m^3**	0.8	1.0	0.8	1.0	0.6	0.8	1.0	0.6	0.8	1.0
Cost (£)	**Minimise**	1102.79	1153.44	1115.59	1153.15	Awaiting quote	Awaiting quote	Awaiting quote	Awaiting quote	Awaiting quote	Awaiting quote
Material	**-**	Painted steel	Painted steel	Painted steel	Painted steel	Painted steel	Painted steel	Painted steel	Aluminium	Aluminium	Aluminium
Embodied carbon [54]	**Minimise (kg.CO_2)**	330	450	360	390	380	500	540	1380	1680	1740
Embodied Energy (MJ)	**Minimise**	5610	7650	6120	6630	6460	8500	9180	24150	29400	30450
Notes		Outlet diameter	Weight		Weight	Weight		Weight	Environment	Environment	Environment

[50] https://www.rollawaycontainer.com/conical-concrete-bucket-central-unloading-capacity-7800-kg.html
[51] https://www.rollawaycontainer.com/conical-concrete-bucket-central-unloading-rubber-hose-capacity-3900-kg.html
[52] https://mandbmag.ca/index.php/concrete-buckets/steel-buckets/upright-steel-buckets/
[53] https://mandbmag.ca/index.php/concrete-buckets/aluminum-buckets/upright-aluminum-buckets/
[54] Approximated using embodied carbon values from textbook 'Data, Statistics, and Useful Numbers for Environmental Sustainability' (Benoit & Cremonini, 2021)

Appendix F: Detailed Trailer Selection

		Model					
							
Parameter	**Constraint**	**35 PC Plant Trailer**[55]	**35BB platform tipping trailer**[56]	**35 TP hydraulic plant trailer**[57]	**Heavy duty rub trailer**[58]	**HT6010UST-030**[59]	**35MD Plant trailer**[60]
Length	**≤7000 mm**	-	5000	4650	2500	4318	4650
Width	**≥1300 mm** **≤2500 mm**	-	2100	2160	1250	1422	2160
Bed height	**≥160 mm**		600	450	720	1270	380
Maximum laden weight while in transport	**≤3500 kg**	3500	3500	3500	-	-	3500
Unladen weight	**Minimise (kg)**	600	820	795	500	570	725
Load capacity	**≥1720 kg**	2800	2680	2750	3000	930	2750
Cost	**Minimise (£)**	3925 ext. VAT	4250 ext. VAT	4725 ext. VAT	2682	Unavailable	3950

[55] **https://www.batesontrailers.com/shop/plant-trailers/35pc-plant-chassis/**
[56] https://www.batesontrailers.com/shop/transporter-trailers/355b-platform-tipping-trailers/
[57] https://www.batesontrailers.com/shop/hydraulic-tilt-trailers/35tp-general-purpose/
[58] https://trolleysandtrailers.co.uk/i.aspx?i=103732&c=5701&pos=0,1900
[59] https://trailermantrailers.net/product/tube-top-utility/
[60] https://www.batesontrailers.com/shop/plant-trailers/35md-general-purpose-digger-plant/

Material	**Minimise ($kg.CO_2$)**	Galvanised steel	Galvanised steel	Galvanised steel	Timber and steel	Lumber and Steel	Galvanised steel
Notes		Not open-top			Not suitable for road	Bearing capacity too low	

(Detailed Trailer Selection: continued)

		Model			
		 [61]	 [62]	 [63]	 [64]
Parameter	**Constraint**	**26 MD Plant Trailer**	**1264 General Purpose Trailer**	**0854 General Purpose Trailer**	**1064 General Purpose Trailer**
Length (mm)	≤7000	4220	5010	2500	4410
Width (mm)	≥1300	1760	2300	1500	2300
	≤2500				
Bed height (mm)	≥160	450	420	450	450
Maximum laden weight while in transport (kg)	≤3500	2600	2600	2000	2600
Unladen weight (kg)	Minimise	500	545	400	490
Load capacity (kg)	≥1720	2100	2055	1600	2110
Cost (£)	Minimise	3050	3100	2600	3000
Material	-	Galvanised Steel	Steel	Galvanised Steel	Galvanised Steel

[61] https://www.batesontrailers.com/shop/plant-trailers/26md-general-purpose-digger-plan/
[62] https://www.batesontrailers.com/shop/general-purpose-builders-trailer-mower/1264-general-purpose-trailer-12-x-6/
[63] https://www.batesontrailers.com/shop/general-purpose-builders-trailer-mower/0854-general-purpose/
[64] https://www.batesontrailers.com/shop/general-purpose-builders-trailer-mower/1064-general-purpose/

Embodied carbon [65]	Minimise ($kg.CO_2$)	2000	1090	1600	980
Embodied Energy	Minimise (MJ)	16000	17440	12800	15680
Notes				Load capacity	

[65] Approximated using embodied carbon values from textbook 'Data, Statistics, and Useful Numbers for Environmental Sustainability' (Benoit & Cremonini, 2021)

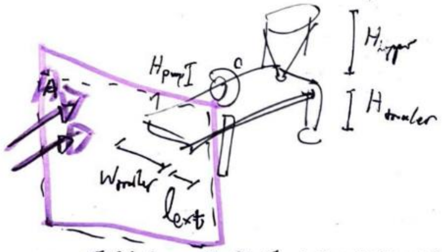
Appendix G: Hand calculations for outrigger selection

WED NIGHT:

- OUTRIGGER TABLE

THURS

10→1300 : ~~[illegible]~~ OUTRIGGER + PAD SELECTION



ASSUMPTION FOR MOMENT CALCULATIONS:

① COM of hopper at center, top

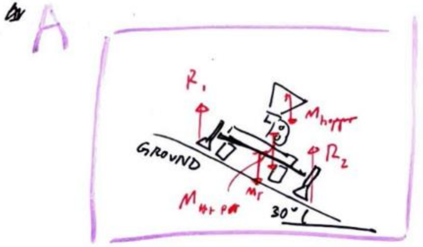
② COM of pump & pipes at top of pump (conservative)

③ 30° tilt on ground.

④ GROUND PRESSURE LIMIT OF 75 kPa (want) and 150 kPa (Need)

⑤ COM of trailer at trailer length/2

⑥ CONCRETE IS 0.5 m^3, COM @ $\frac{2}{3}$ HEIGHT OF HOPPER



WORST CASE ASSUMPTION

EQ FOR COM:

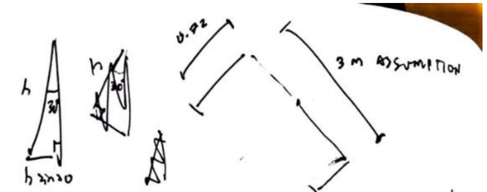
$$x_{cm} = \sum_{i=1}^{N} \frac{m_i x_i}{M}$$

TABLE OF CONSERVATIVE VALUES

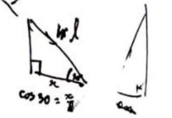
COMPONENT	WEIGHT	HEIGHT
HOPPER	180	1.12 + 0.72 = 1.84
TRAILER	820	0.72 = 0.72
PUMP & PIPE & HOSE	140 + 1200 = 1340	1.215 + 0.72 = 1.935
CONCRETE	1300	0.72 + $\frac{2}{3}$(1.12) = 1.47
OUTRIGGERS	400	0.72

$$x_m = \frac{180(1.84) + 820(0.72) + 1340(1.935) + 1300(1.47) + 400(0.72)}{180 + 820 + 1340 + 1300 + 400}$$

$$= \frac{5713.5}{4040} = 1.414\,m$$ (TOTAL of 4040 kg)



TAKE MOMENTS ABOUT R_1:



$$0 = \sum M_{R_1}$$

$$R_2 = \underbrace{4040}_{\text{mass}}\left[(1.414)\sin 30 + 0.72 \sin 30 + 1.5 \cos 30\right]$$

$$= 4040(2.366)$$

$$= 9558 \text{ kg·m}$$

ASSUME 3m AWAY

BURN LOAD PER OUTRIGGER =

$$\frac{9558 \text{ N.m}}{3} \times \frac{1}{2} = 1593 \text{ kg}$$

= 1593 kg

= 1.593 tons

⇒ WHEN LOOKING, ASSUME MINIMUM BEARING LOAD OF 1.6 tons

SAFETY FACTOR of 2

↳ 3.2 tonnes

Appendix H: Detailed outrigger selection

		Model								
		 [66]		 [67]	 [68]					
Parameter	**Constraint**	HYDRAULIC OUTRIGGER SYSTEMS FOR WORK TRUCKS – round legs < 14000 lbs.	HYDRAULIC OUTRIGGER SYSTEMS FOR WORK TRUCKS – square legs < 14000 lbs.	Semi-trailer outrigger SQ2819F-G1	2010-18	2012-25	2014-18	2027-18	3510000108	3510000265
Weight		75	60	100 per leg	33.11	41.73	24.49	34.02	38.56	47.63
Bearing capacity	**≥32 kN per leg**	62.3 kN	62.3 kN	25 tons per leg lifting 50 tons static	71 kN	71 kN	71 kN	71 kN	71 kN	71 kN
Height from fixing to retracted base	**≥140 mm**	535	429	430	0	0	0	0	0	0
Extended length		1173	1334	840	457	635	457	457	457	635
Span (if relevant)		2081	2081	-	-	-	-	-	-	-
Cost (£)	**Minimise**			90 per leg	Asked for quote, no reply					
Material				Steel						

[66] https://www.powerpackerus.com/hydraulic-cylinders/stabilization-truck-outriggers/hydraulic-outrigger-stabilizers/
[67] https://www.alibaba.com/product-detail/Truck-Trailer-Parts-Heavy-Duty-StLanding_1601122119796.html
[68] https://www.powerpackerus.com/hydraulic-cylinders/stabilization-truck-outriggers/standard-hydraulic-stabilization-legs/

Embodied carbon [69]	**Minimise ($kg.CO_2$)**	375	300	500	165	210	125	170	195	235
Embodied Energy (MJ)	**Minimise**	6600	5280	8800	2904	3696	2200	2992	3393	4191
Notes		Bottom mounted, ISO9000 certified	Bottom mounted, ISO9000 certified	Side mounted ECE[70] certified	Side Mounted, ISO 9001 certified					

[69] Approximated using embodied carbon values from textbook 'Data, Statistics, and Useful Numbers for Environmental Sustainability' (Benoit & Cremonini, 2021)
[70] Economic Commission of Europe (Economic Commission for Europe, n.d.)

Appendix I: Calculation for outrigger pad selection using 75 kPa limit

Assume total weight born by pads is 4000 kg

Assume ground pressure limit of 75 kPa

A_{min} = (Weight x 9.81)/(75 x 10^3)

For four outriggers:

A_{min} = ((4000kg/4) x 9.81)/(75 x 10^3) = 0.1308

Let us include a safety factor of 2

A_{min} = 0.26 m^2

Similiarly, for a ground pressure limit of 150 kPa

A_{min} = 0.13 m^2

However, as 75 kPa is more stringent, that will be the constraint used in outrigger selection

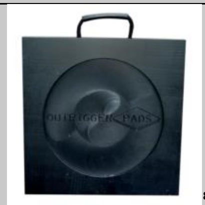
Appendix J: Detailed outrigger Pad selection

		Model						
		 [71]	 [72]	 [73]	 [74]	 [75]	 [76]	 [77]
Parameter	**Constraint**	**500 x 500: IP-72001**	**500 x 500: IP-72002**	**500 x 500: IP-57096**	**1000 x 1000: IP-59001**	**800 x 800: IP-57668**	**Recessed 750 x 750: IP-72037**	**300 x 300:**
Bearing capacity (tonnes)	**≥4**	15	15	15	42	42	28	5
Area (m²)	**≥0.25**	0.25	0.25	0.25	1.00	0.64	0.57	0.09
i.e. square of length	**≥0.5 m**	0.5	0.5	0.5	1.00	0.8	0.75	0.3
Height (m)	**Minimise**	0.04	0.04	0.04	0.04	0.05	0.08	0.03
Weight (kg)	**Minimise**	9.90	9.90	10.50	38.40	31.50	21.00	2.8
Cost (£)	**Minimise**	65.77	80.26	76.76	185.00	194.50	202.95	20.97
Material	**-**	High mol weight polyethylene	High mol weight polyethylene	Heavy duty UHMW polyethylene	heavy duty UHMW polyethylene	heavy duty UHMW polyethylene	high density polyethylene (HDPE)	HMW polyethylene

[71] https://www.outriggerpads.co.uk/product/500x500x40-eco-lift-outrigger-pad/
[72] https://www.outriggerpads.co.uk/product/500x500x40-hi-viz-outrigger-pad/
[73] https://www.outriggerpads.co.uk/product/500x500x40-premium-outrigger-pad/
[74] https://www.outriggerpads.co.uk/product/1000x1000x40-premium-outrigger-pad/
[75] https://www.outriggerpads.co.uk/product/800x800x50-premium-outrigger-pad/
[76] https://www.outriggerpads.co.uk/product/750x750x40-hi-pro-recessed-outrigger-pad/
[77] https://www.multimatts.co.uk/temporary-access-mats/outrigger-pads/eco-lift-outrigger-pad-300mm-x-300-mm-x-30mm-2.8kg

Embodied carbon ($kg.CO_2$) [78]	**Minimise**	29.7	29.7	31.5	115.2	94.5	24	8.4
Embodied Energy (MJ)	**Minimise**	544.5	544.5	577.5	2117.5	1732.5	1155	154
Notes					Overspec'ed, expensive, too much embodied carbon	Overspec'ed, expensive, too much embodied carbon	Weight, embodied energy	Underspec'd

Detailed Outrigger Pad Selection: continued)

		Model		
		 [79]	 [80]	 [81]
Parameter	**Constraint**	**High Viz 300 x 300**	**Recessed 400 x 400**	**Standard 400 x 400**
Bearing capacity (tonnes)	**≥4**	5	12	12
Area (m^2)	**≥0.25**	0.09	0.16	0.16
i.e. square of length	**≥0.5 m**	0.3	0.4	0.4

[78] Approximated using embodied carbon values from textbook 'Data, Statistics, and Useful Numbers for Environmental Sustainability' (Benoit & Cremonini, 2021)
[79] https://www.multimatts.co.uk/temporary-access-mats/outrigger-pads/hi-viz-outrigger-pad-300mm-x-300mm-x-30mm-2.8kg
[80] https://www.multimatts.co.uk/temporary-access-mats/outrigger-pads/recessed-eco-lift-outrigger-pad-400mm-x-400mm-x-40mm-6kg
[81] https://www.multimatts.co.uk/temporary-access-mats/outrigger-pads/eco-lift-outrigger-pad-400mm-x-400mm-x-40mm-6.3kg

Height (m)	**Minimise**	0.03	0.04	0.04
Weight (kg)	**Minimise**	2.8	6	6.3
Cost (£)	**Minimise**	25.75	53.25	48.97
Material	-	HMW polyethylene	HMW polyethylene	HMW polyethylene
Embodied carbon (kg.CO_2)[82]	**Minimise**	8.4	18	18.9
Embodied Energy (MJ)	**Minimise**	154	330	346.5
Notes		Underspec'd	Underspec'd	Underspec'd

[82] Approximated using embodied carbon values from textbook 'Data, Statistics, and Useful Numbers for Environmental Sustainability' (Benoit & Cremonini, 2021)

Appendix K: Detailed costing spreadsheet

NOTE: to view this table in full form including notes, refer to this link. Notes include details such as: assumptions used for embodied carbon and embodied energy.

In regards to the ‘source of cost’ section in this table, this highlights where estimated cost values have been obtained. Some values are based on common rates found through internet search, whilst others have been directly obtained from the retailer of the selected component. Where the retailer has not provided cost, an average was made using similar products on the market, which was then used as the final estimate.

TOTAL SUBSYSTEM COST	
Monetary (£)	6316.67
Embodied Carbon (kg.CO2)	3041.18
Embodied energy (MJ)	34464.94

Key
Provided directly by retailer
Accurate value not available, average calculated and taken as estimate

									Cost Estimation

Component	Description / model	Quantity	Total cost	£ per unit	Unit	Total Embodied Carbon (kg.CO2)	Total Embodied Energy (MJ)	BREAK	Exact value available	formative	Average	Values from market			
	Main components														
Hopper	BCT80	1	1115.59	1115.59	-	360	6120		1115.59						
Trailer	Bateson 26MD Plant Trailer	1	3050.00	3050.00	-	2000	16000		3050.00						
Outriggers	Power-Packer standard outrigger: 2010-18	4	862.67	215.67	-	660	11616				215.67	98.00	157.00	392.00	
Total			**5028.26**			**3020**	**33736**								
	Joints and processes														
Hopper-Trailer	Lashing chains	3	228.72	76.24	-	1	19		76.24						
Outrigger-Trailer	Nut and bolt	4	152.00	38.00	hour	negligible	negligible			38.00					
Pump to trailer	Nut and bolt	6	228.00	38.00	hour	negligible	negligible			38.00					
Total			**608.72**			**1**	**19**								

	Transport and work-site components														
Outrigger Pads	IP-72002	4	321.04	80.26	-	119	2178		80.26						
Tarp	-	1	129.69	129.69	-	negligible	negligible				129.69	87.96	121.78	165.00	144.00
Tie down ratchets	-	4	28.17	7.04	-	negligible	negligible				7.04	5.22	6.17	5.56	11.22
Rope	-	40	100.80	2.52	m	20.00	710.00				2.52	2.17	2.99	2.40	
Total			**579.70**			**20.00**	**710.00**								
	Signs and displays														
	-	5	100.00	20.00	No. signs	negligible	negligible								
Total			**100.00**												

Appendix L: Commercial viability timeline

Date of Monday	Week	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
11-Mar	6			**Report structure**		*Commercial viability report granularized and distributed to members*		
18-Mar	7	Design specification		Hopper and interface selected	Complete hopper section	Ground supports selected		
			Conversation template completed, list of contacts made	Calls to clients			Pause to Commercial viability research	
25-Mar	8	**Mid term review**						
					Split writing up of commercial viability to individuals for the summer, clarify how to insert costing. Be clear at a high level for what they will have to do for report			**Inform of what info we will need to do section 2 and 3, and <u>when</u> we wil need it by, so can work on it for ISB**

01-Apr	ISB	Unavailable	Unavailable	Unavailable	Unavailable	Unavailable	Unavailable	Unavailable
08-Apr	ISB	Material selection for all physical components, **Everyone working on commercial viability**						
15-Apr	10	Detailed structural analysis, Final dimensions						
		Section 1 of commercial viability COMPLETE						
22-Apr	11	Manufacturing considerations (joints, forming, finishing)	Detailed costing, both for technical and commercial viability					FINAL CAD MODEL FOR FLOW SIMULATIONS
						All information needed for section 2 in commercial should be available		
29-Apr	12	Concrete simulations, Experiments with prototype?, Cleaning method selected and verified						

		Research into business strategies, section 2 should be being written up at this point		CAD model images **created and inserted into commercial viability**		Cost of our design should be done, and placed in reference and appendix	Section 2 COMPLETE	
06-May		*Commercial viability report SPRINT: By end of week structure and references fully fleshed, only tweaks after this should be to detailed costing*						
		Focusing primarily on creating section 3 in report						
13-May		All info for technical report should have been obtained	Individual technical report SPRINT: Filling in gaps of everything that was not completed					
			Proofreading, references, tweaking					
20-May		Conclusion and summary	Abstract and introduction	Proofreading				
						Report hand in		

27-May				Presentation				

Appendix M: Detailed granularization of business related tasks

Numerical order	Section	Wordcount	Difficulty (1-5)	Status	Notes	Person responsible	Proofreading	Deadline	Dependencies
SECTION 1 - To be COMPLETED, aside from proofreading, by the end of ISB - First round of proofreading to be discussed later - **WC: 1600**	Problem statement	<100		Incomplete		Tim	Everyone	After ISB	
	Research methodology	<200		Incomplete	Types of research that we did, order	Kai	Max	After ISB	
	Market sizing: number of dwellings	100-300	4	Incomplete	Prioritise ease of reading	Tim	Kai	After ISB	
	Market sizing: Bottom up sizing	200-400	4	Incomplete	Prioritise ease of reading	Katie	Kai + Max	After ISB	
	Flow of authority / stakeholders	100-200		Incomplete	Prioritise ease of reading	Kai	Alexander	After ISB	
	Summary of market opportunity	100-200		Incomplete		Katie	Kai	After ISB	Previous sections
	Target customer profiles	50-100		Incomplete	End user, client, site	Alexander	Kai + Max	After ISB	Mild dependency

					manager, and any that feel relevant				on flow of authority
	Existing solutions: Competitor matrix	<100	3	Incomplete	Not many words, but EXTREMELY dense with info	Alexander?	Max	After ISB	
	Existing solutions: Competitor mapping		5	Incomplete		Max	Alexander	After ISB	Target customer profiles
	USP, identification of gap within market	<100	1-2 ish	Incomplete		Max?	Alexander	After ISB	
	Target niche (clientel/stakeholders)	<100	1	Incomplete		Tim	Alexander and Kai	After ISB	
				ALL SUBSYSTEM COSTINGS MUST BE COMPLETE FOR THE FIRST WEEK BACK AFTER ISB					
SECTION 2: Proposed solution - Organisation	50 word pitch	50		Incomplete		Katie	Tim	Week starting 29th April	Write last

and structure to be set up over ISB, filled in on second week back **WC: 500**	Descrtiption and (comparitative) specifications	100		Incomplete	Annotation of CAD model	Katie	Tim		Costing
	Meeting customer specs	50		Incomplete		Katie	Tim	Week starting 29th April	Target customer profiles
	Estimated cost: both individual, and how it scales			Incomplete		Everyone costs		Week starting 29th April	
	Value model	300-500	5	Incomplete		Max (and Alexander?) makes structure, ALL REST RESEARCHING	Alexander	Week starting 29th April	
<u>Road to product</u> WC: 500	Timeline			Incomplete	Split up into groups, while Max				
	Budget, investment, stakeholders, etc.			Incomplete					

<u>Road to market</u> WC: 500, to be cut down later	Explored strategy			Incomplete	and others complete value model, others research this				
	Proposed strategy			Incomplete					
<u>Conclusion</u> WC: 200	Written at end	100-200		Incomplete					
References	Everyone keep track of what they used in their own document, will merge all of them later			Incomplete					