System Design for Recyclability

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Hello, good afternoon. My name is Christian and I am going to be talking to you about [title]

Aim and Contents

Aim: To provide overview of completed MSc thesis

Contents

- Personal Profile
- Thesis Introduction
- Methodology
- Example sUAS
- Soft Systems Analysis
- Model Based Analysis
- Systems Thinking
- Findings
- So what?

The aim of this presentation is [aim]. The contents will cover more information about me, a summary of the content of my thesis and the activities undertaken following completion of my thesis.

Personal Profile

- IEng IMechE
- 2020 INCOSE UK ECF Student Liaison
- Employee at Defence Equipment and Support:
  - L3 Air Certification Engineer
  - L2 Protector Engineering Authority (EA)
  - L2 Mini-UAS Deputy EA
  - L2 TALISMAN MLU PM
- P/T MSc in Systems Engineering for Defence Capability, Cranfield University;
- Graduate Scheme in Aerospace consultancy;
- BEng in Aerospace Manufacturing Engineering, UWE;

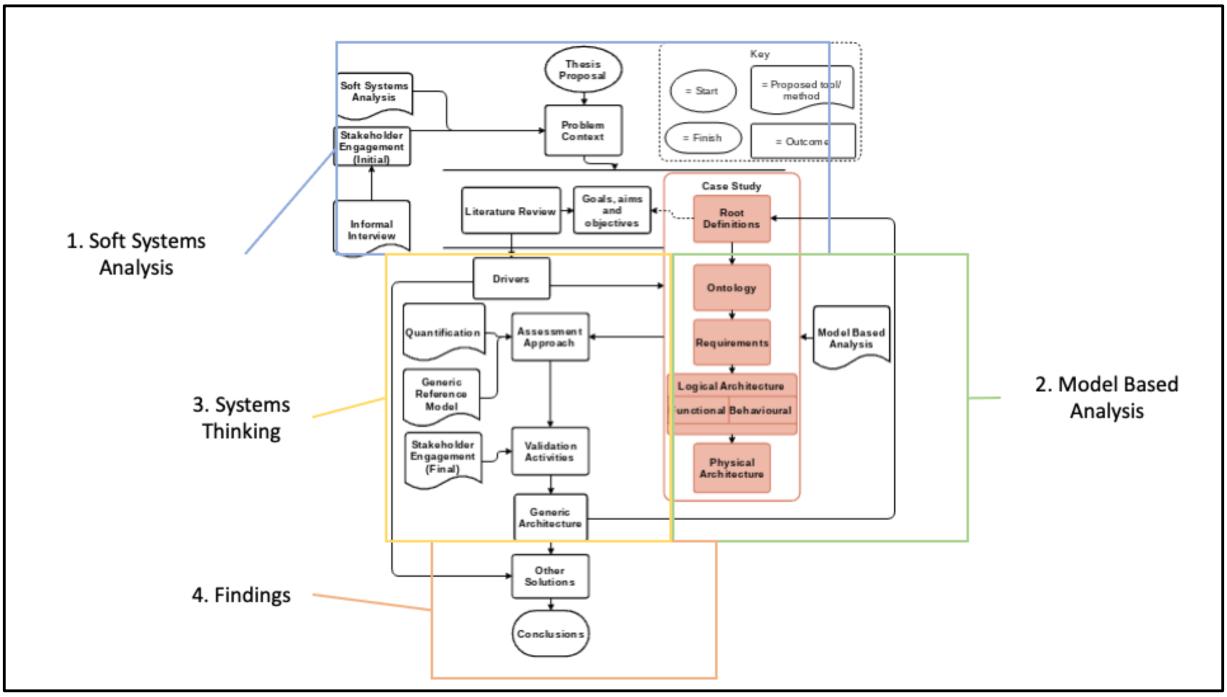
N.B. Content only reflects personal views developed from research

Starting with my personal profile my experience mainly focuses around Aerospace and Defence, covering a range of roles. See [N.B.]

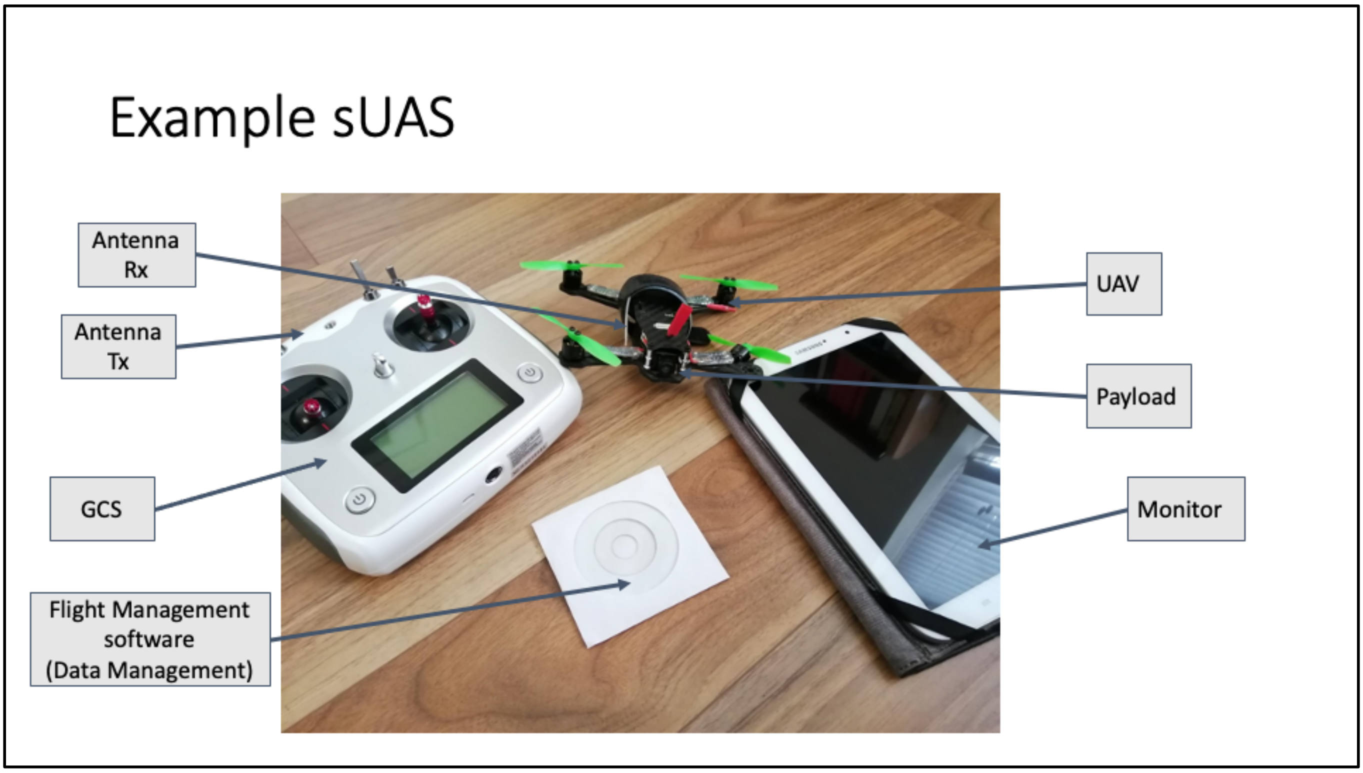
Thesis Introduction

- Thesis title: System Design Considerations for Recyclability
- Applied to case study of a small UAS
- Visual Paradigm used as drawing tool (functionality limited)
- Inspired by:
  - National Geographic June 2018 edition on plastics
  - CE audits on small-UAS manufacturers across Europe and N. America
  - Climate Change crisis

As part of my MSc at Cranfield University, I chose the thesis title [title], using a case study of a sUAS. VP was selected for use due to its free license, although its functionality is limited. Inspiration came from my work a NG edition on plastic waste, my experience in the DE&S mini-UAS team and of course the Climate Change crisis.



The methodology used for my thesis is shown. The black boxes show the flow of activities, which were broadly split into 4 phases as shown [read phases]



As mentioned the case study I based my thesis on is a small UAS. For illustrative purposes the picture shows the scale of what I had in mind and the component sub-systems.

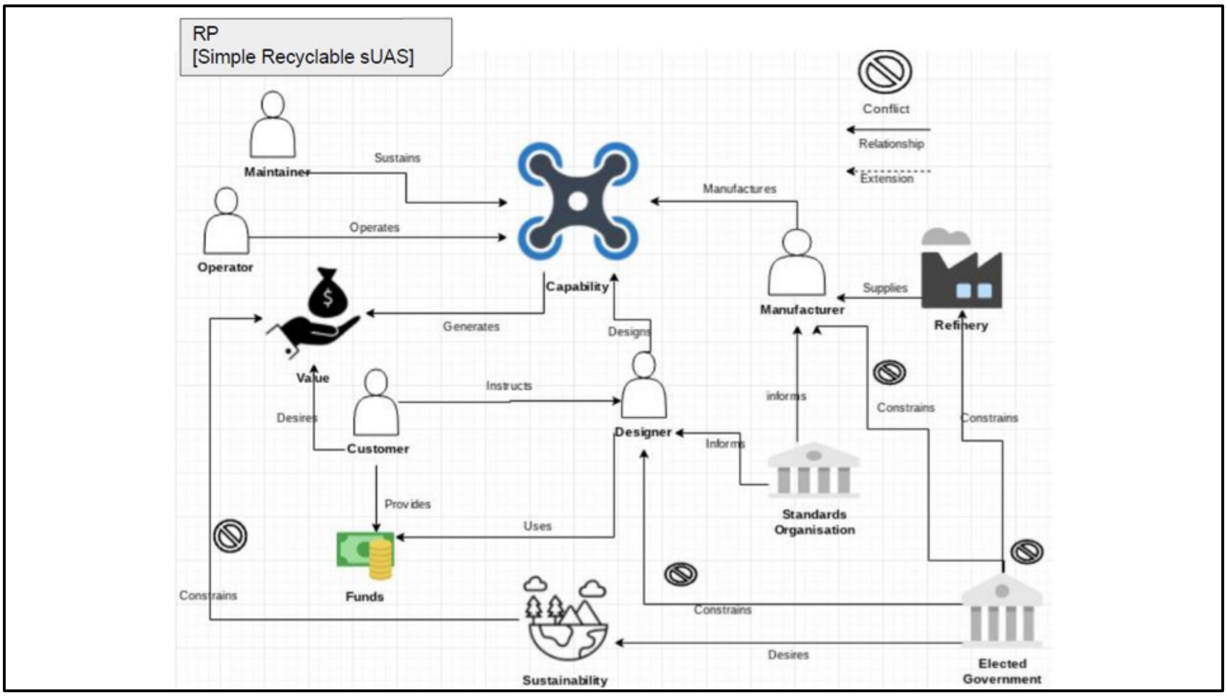
1. Soft Systems Analysis

- sUAS industry surveyed
- Simple Rich Picture (RP)
- Simple Context Diagram (CD)

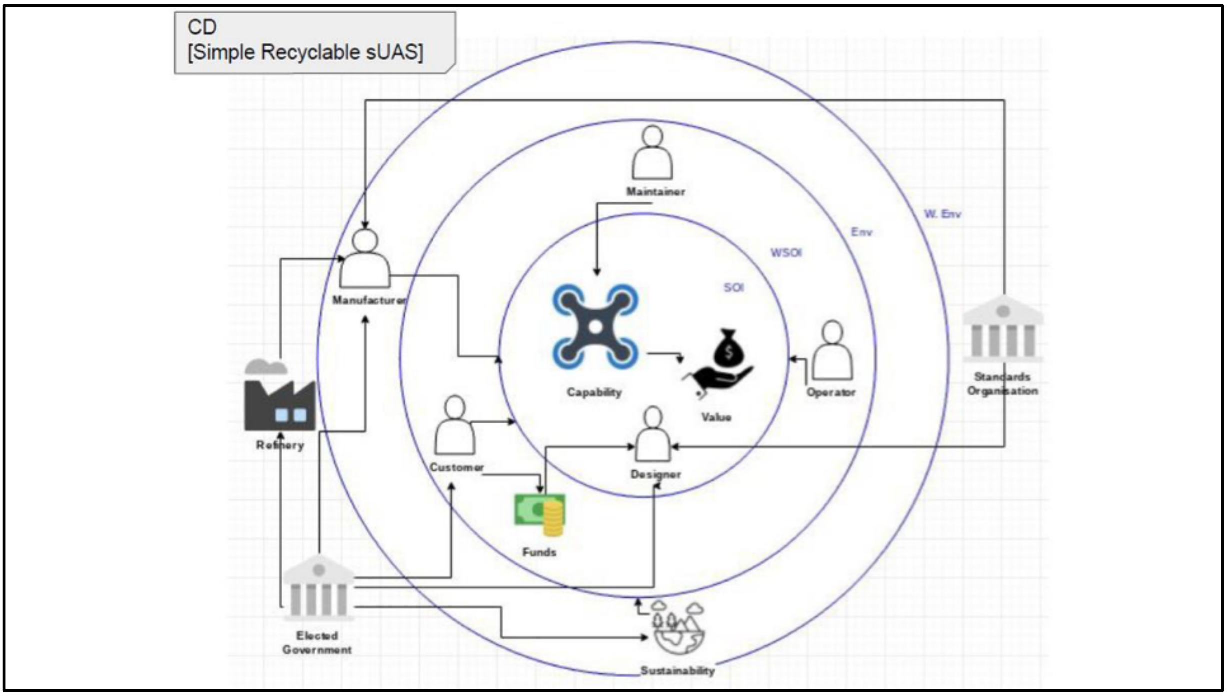
N.B. conflicting priorities identified

- Initial Root Definitions (RD)
- Thesis aim:
  - To improve the consideration of recyclability in SE decision making across a system's life cycle.
- Detailed RP, CD & RD
- Actors Roles

Phase 1 of my thesis covered SSA, which include SS modelling, of various levels of detail and the derivation of a thesis aim [read aim]



Initial survey & modelling resulted in this RP, showing different stakeholders, system elements and their relationships. N.B. the identified conflicts were significant esp. between sustainability and value



Taking the RP I was able to bound the system elements into different categories using a CD. SOI in the middle and wider Env on the outside

Initial Root Definitions

PQR analysis: Do P (what), by Q (how), in order to help achieve R (why).

RD1 = Produce a capable small UAS by designing and manufacturing a suitable system in order to generate value through its operation.

RD2 = Produce a recyclable small UAS by designing and manufacturing a suitable system in order to generate a sustainable small UAS solution.

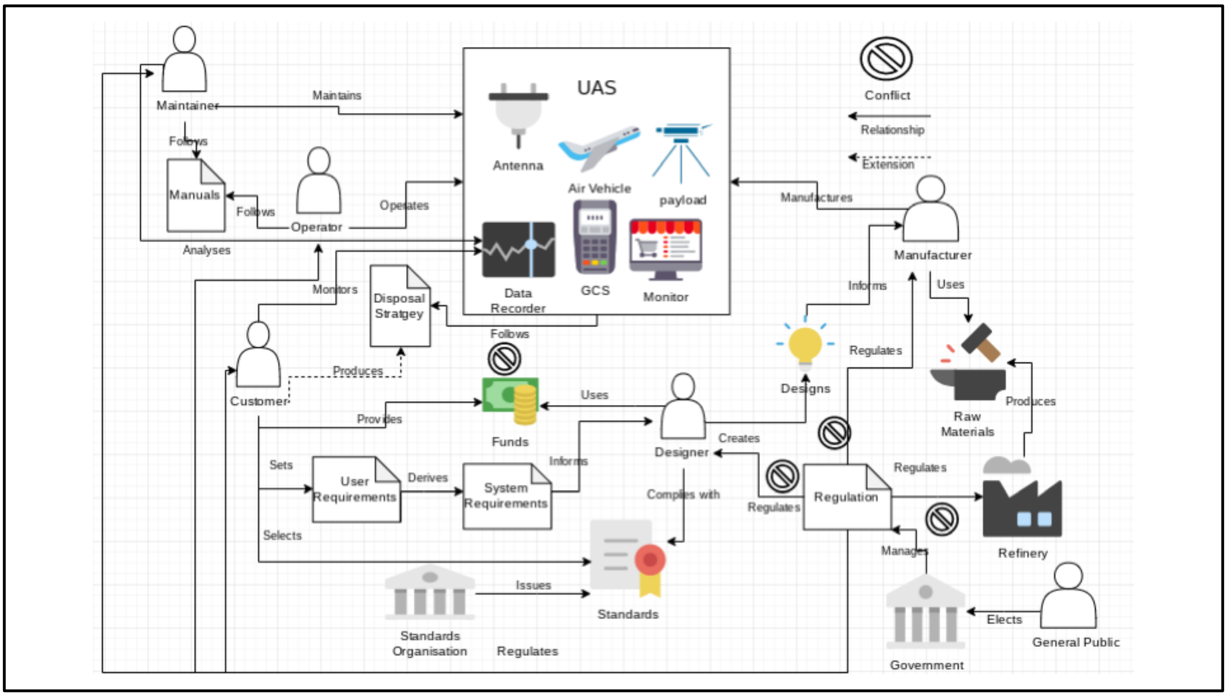
From this initial analysis, I used PQR analysis to produce 2 root definitions. 1 focused on generating value, the other focused on recyclability.

Literature Review

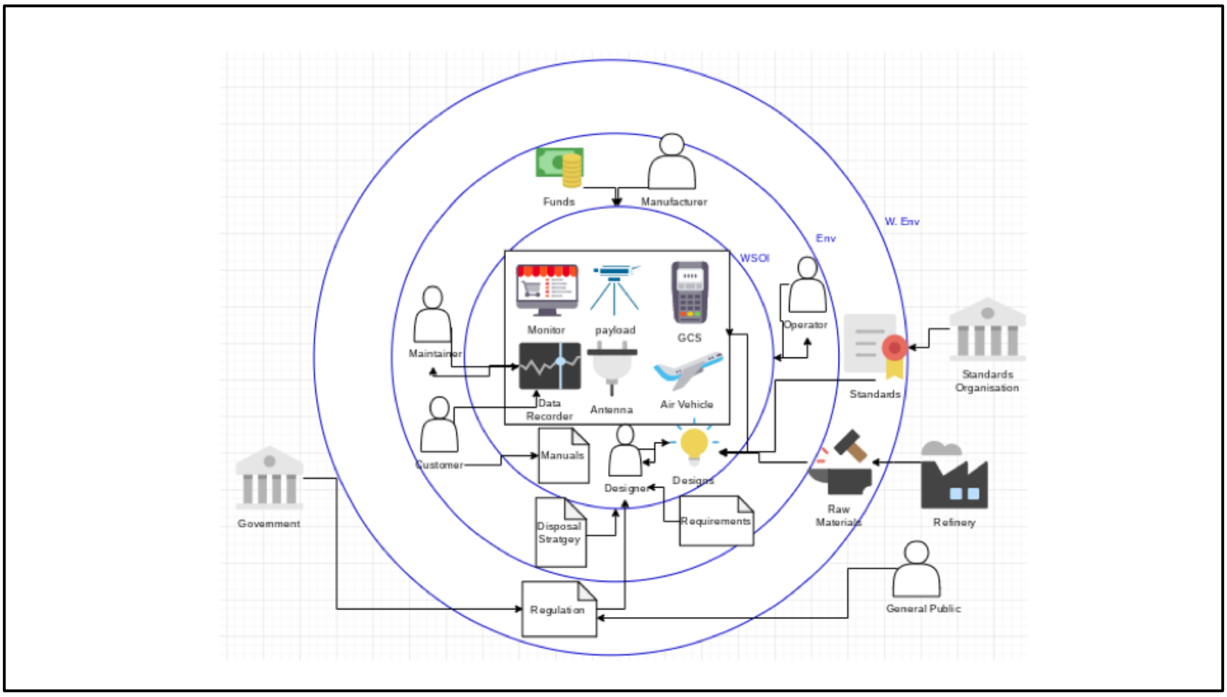
	Circular Economy Lifecycle Phase	System Lifecycle Phase
Recyclability Considerations	Raw Materials	Conceptualisation
	Design	
	Production/ Remanufacturing	Realisation
	Distribution	Utilisation
	Consumption/ Use/ Reuse/ Repair	Evolution
	Collection	Disposal
	Recycling	

- Lifecycle approach taken
- 20 Recyclability drivers identified…

From this initial scoping exercise I could then focus on the LR using a LC approach.
The middle and RH columns map the phases in a CE LC to those of the SE LC.
Although recycling was identified as occurring at the end of a LC, the considerations of Recyclability i.e. the ability to recycle, are significant across all phases, as indicated by the LH column.
From the LR 20 Recyclability drivers were identified, which informed future aspects of the modelling.



Having explored the different recyclability factors across a LC, I was able to add in detail to the earlier analysis. A significant addition is the range of documentation which enable system actors to interface with the other system elements e.g. the customer setting requirements to better inform the designer.



This additional detail was again bound into categories using a CD. This provides a good view on what has the most significant influence on the design and use of a sUAS.

Detailed Root Definitions

CATWOE:

- **C**ustomer
- **A**ctor
- **T**ransformation
- **W**eltanchauung
- **O**wner
- **E**nvironment

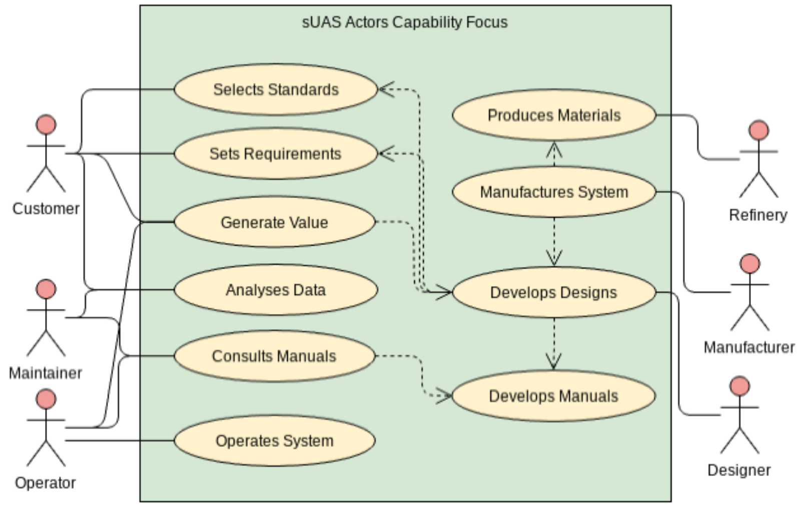
A system owned by O, operated by A to do T, for the benefit of C within the constraints of E

CATWOE RD 1 : A system owned by the Project Sponsor [O], operated by Designers and Manufacturers [A] to turn raw materials into a designed and manufactured sUAS [T], for the benefit of sUAS Operators [C], within the constraints of cost, time and quality and capability requirements [E]."

CATWOE RD 2: A system owned by the Project Sponsor [O], operated by Designers and Manufacturers [A] to turn raw materials into a designed and manufactured recyclable sUAS [T], for the benefit of the general public [C], within the constraints of capability requirements and regulation [E].

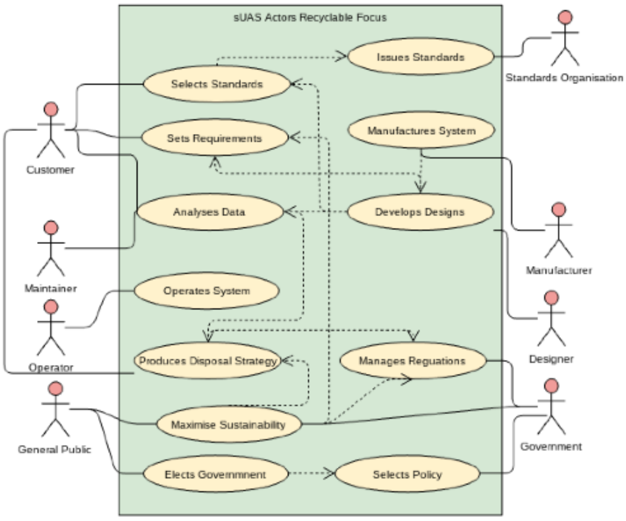
Following was a more detailed set of RDs, again running with 2 themes 1 focused on maximising value, the other focused on recyclability

UCD – Actors Roles for RD1



Having identified the different system actors and their interfaces with other system elements, a set of use cases could be developed for each RD to understand the different actors roles. Shown is the UCD for RD1. Some use cases included or extended to other use cases e.g. developing designs includes selecting standards.

UCD – Actors Roles for RD2

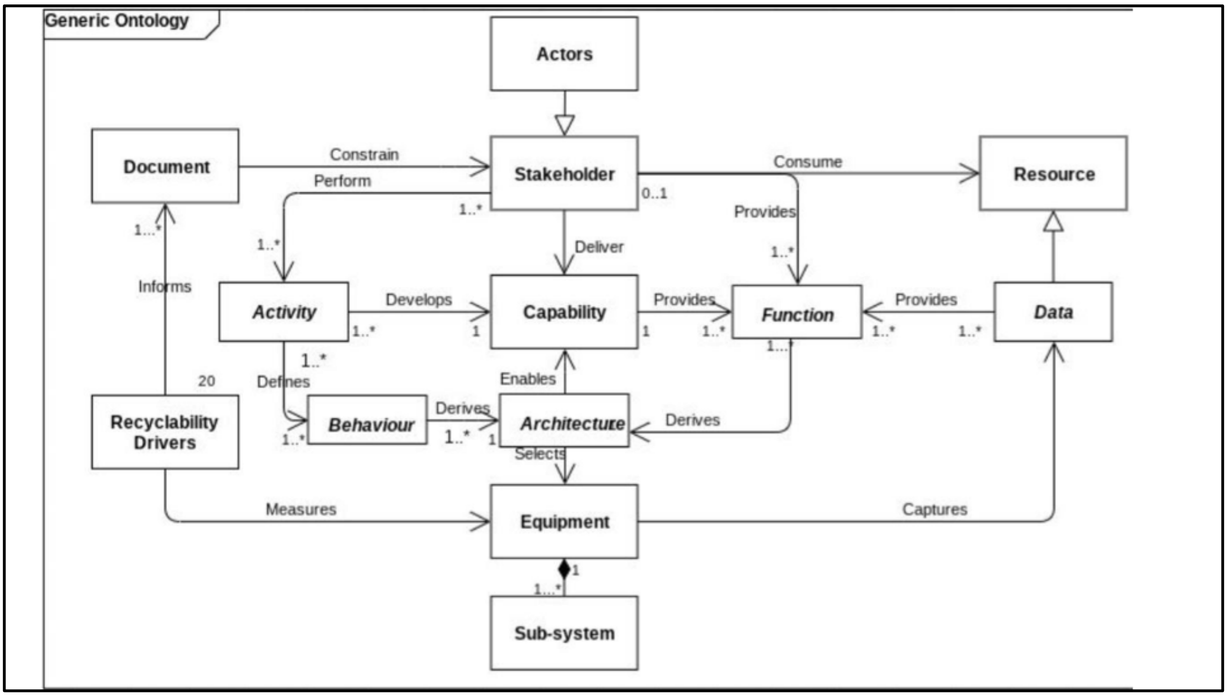


Shown is the UCD for RD2. This view includes 2 more actors: the general public and government, which reflects the demand and use cases to ensure sustainability.

2. Model Based Analysis

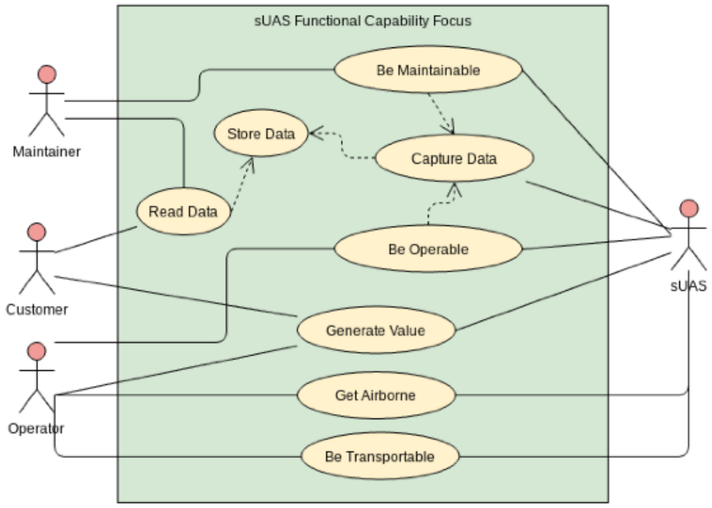
- Ontology
- Requirements Elicitation
- Functional Modelling
- Logical Form
- Recycle Property Expansion
- Dynamic Relationships Between Drivers (hidden slide)
- Physical Architecture

This brings me on to the second phase of my thesis, the MBA aspects. The MBA includes the shown activities.



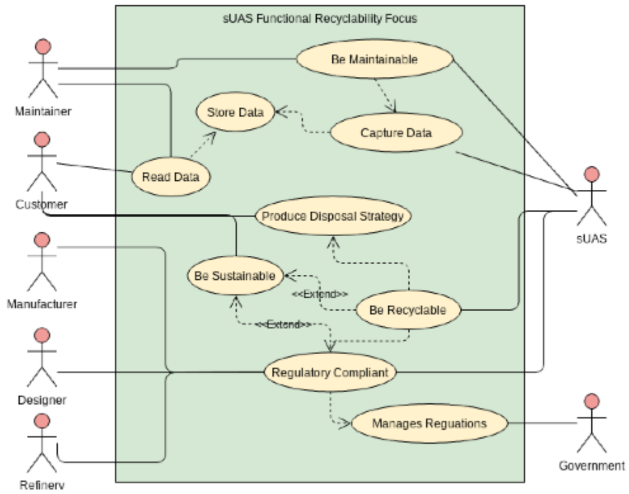
Shown is the ontology used, which details the different terms used in the system and their relationships to each other. There is a more detailed version of the ontology e.g. the actors block has been expanded into the different actors listed in the UCD, however this view was considered sufficient for this presentation.

sUAS Functions for RD1



Next a set of UCD could be developed to show the different functions the system is expected to perform. This view shows the UCD for RD1, note one of the actors is the sUAS itself.

sUAS Functions for RD2



This UCD shows the system functions for RD2, note the additional actors and the functions expected of them.

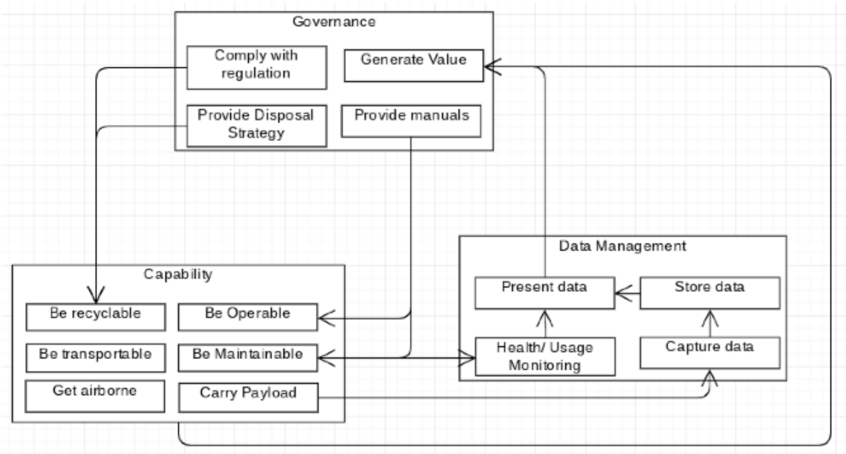
Requirements set

- 12x User Requirements
- 15x System Requirements could be derived

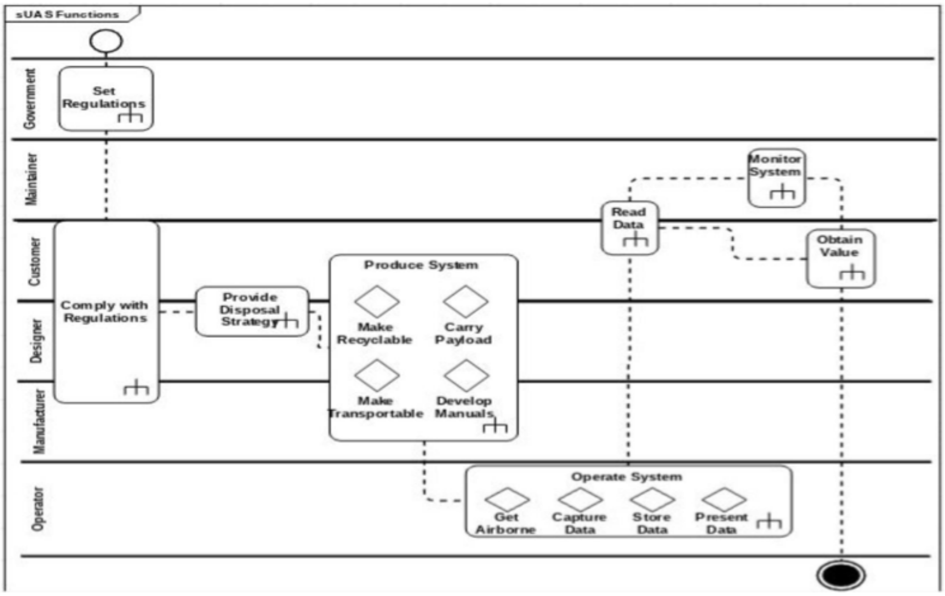
N.B. focus on Recyclability vs Value, not sUAS design

From this understanding of the desired system’s functions, a set of user and system requirements were developed. They were focused on incorporating a balance between Recyclability and Value, rather than the sUAS design e.g. “the system will deliver a useful capability” not what that capability is

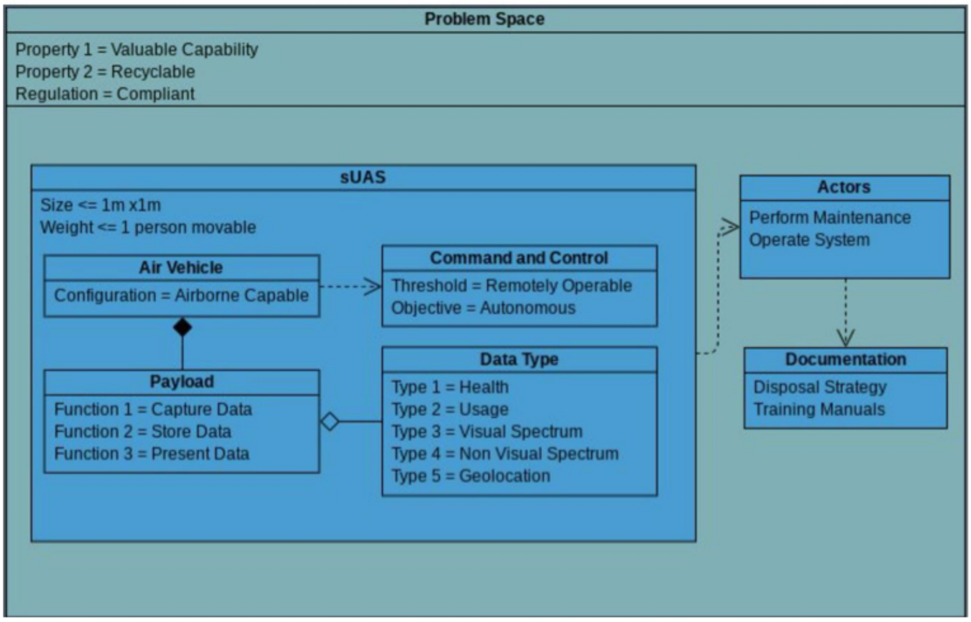
sUAS Functional Architecture



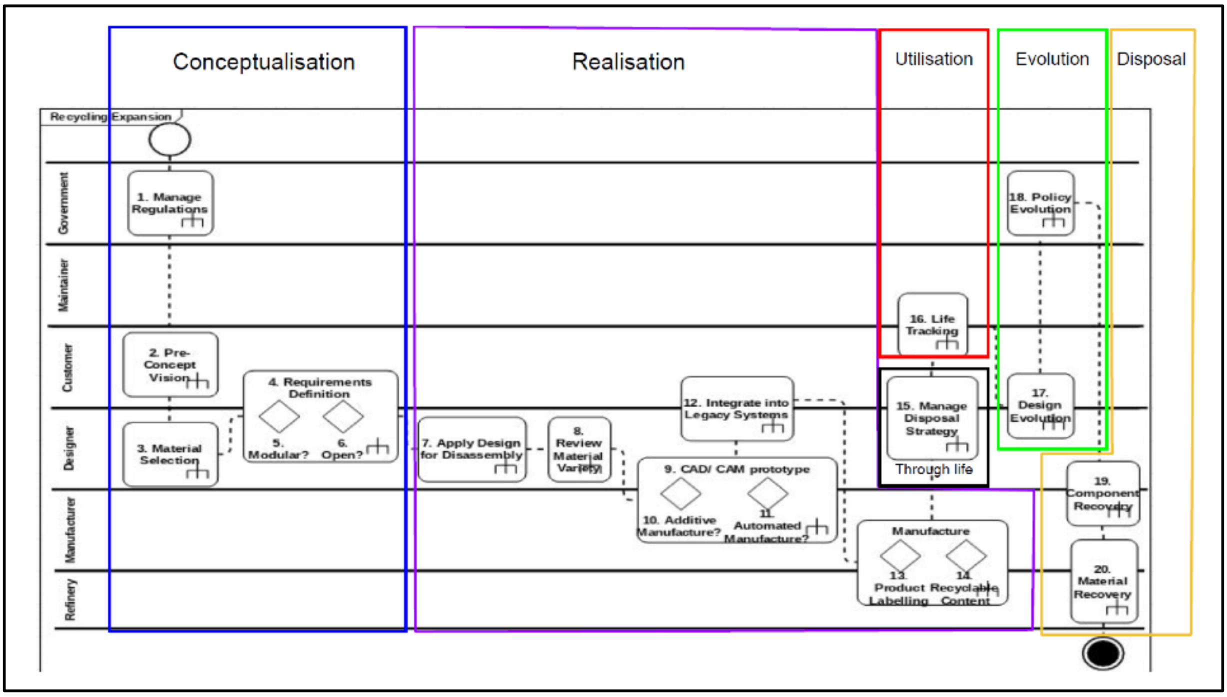
To aide the transition from User Requirements to System Requirements, the functions derived in the previous UCDs were mapped onto a functional architecture. All the functions were grouped together into 3 categories as shown, and their interrelationships added.



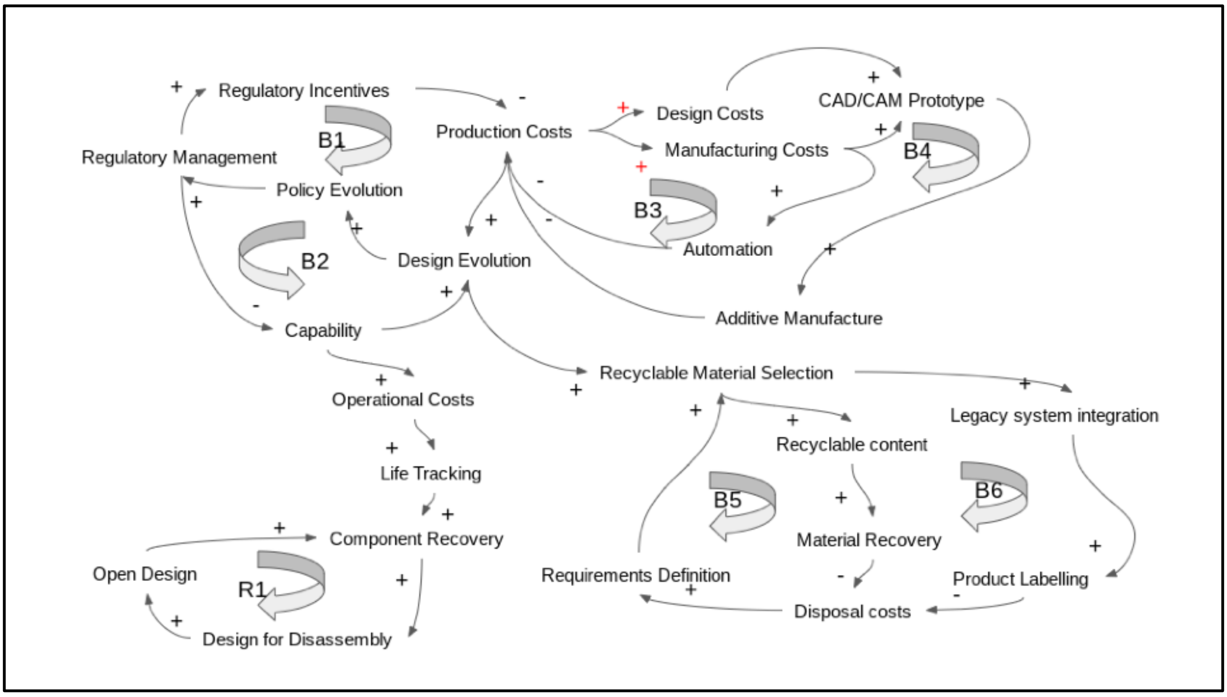
The different functions were mapped onto a activity diagram. Each horizontal swim lane enables the mapping of each function to their respective actors, and the main benefits of this view is to understand the temporal nature and order (from left to right) of the different functions. It was also possible to group some activities into categories e.g. “produce system”.



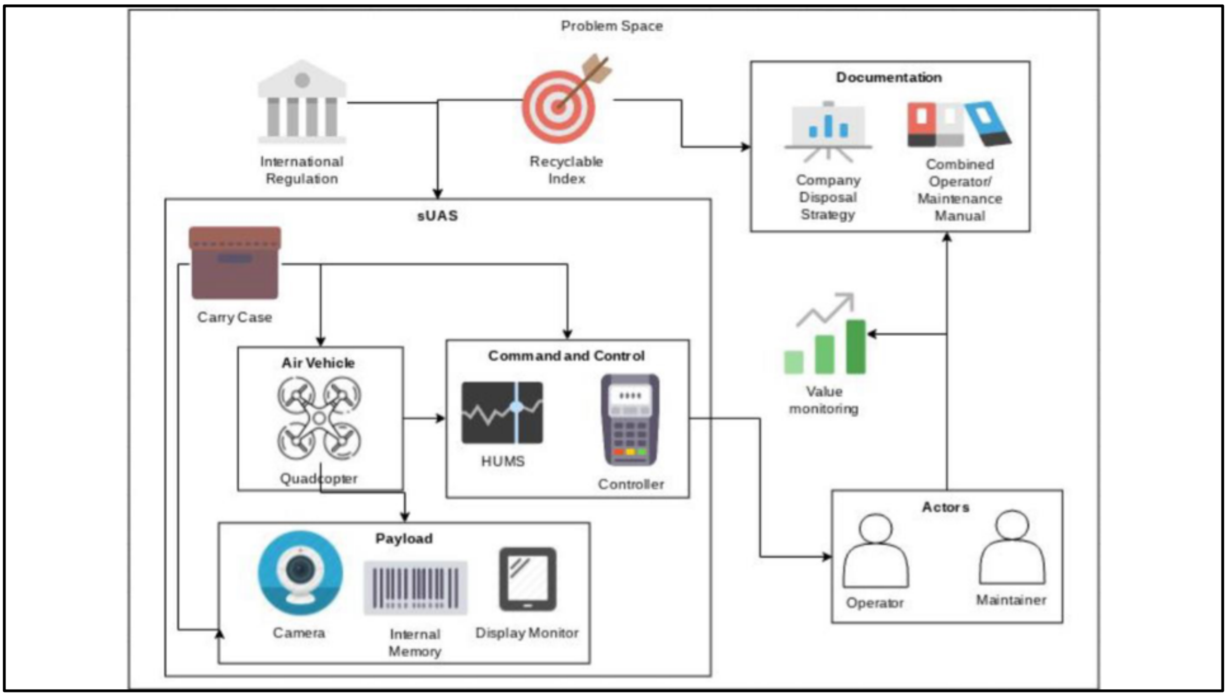
After developing an understanding of the different functions and subsequent system requirements, a logical form of the system solution could be constructed using a BDD. This view bounds different elements of the system and defines their properties e.g. the payload is identified as sitting within the sUAS boundary and has 3 functions attributed to it.



Next an expansion of the property "Recyclability" was constructed by mapping the 20 drivers identified in the LR onto an AD. The horizontal swim lanes indicate which set of actors are responsible for each driver and the coloured boxes illustrate which phase of the system LC they can be attributed to.



Shown is a Causal Loop Diagram showing the dynamic relationships between different system drivers. The value generated from creating this view was the identification of additional drivers, but not necessarily those that directly relate to Recyclability. Additionally, an understanding of either balancing or reinforcing relationships were identified, but this would mainly provide value if a stocks and flows simulation was being created, which was out of scope of this thesis.



Based on the previous modelling, a physical architecture of a solution emerged. This attributes physical solutions to the elements identified in the logical architecture. It shows the elements required to develop a solution that is balanced between generating value and is recyclable.

3. Systems Thinking

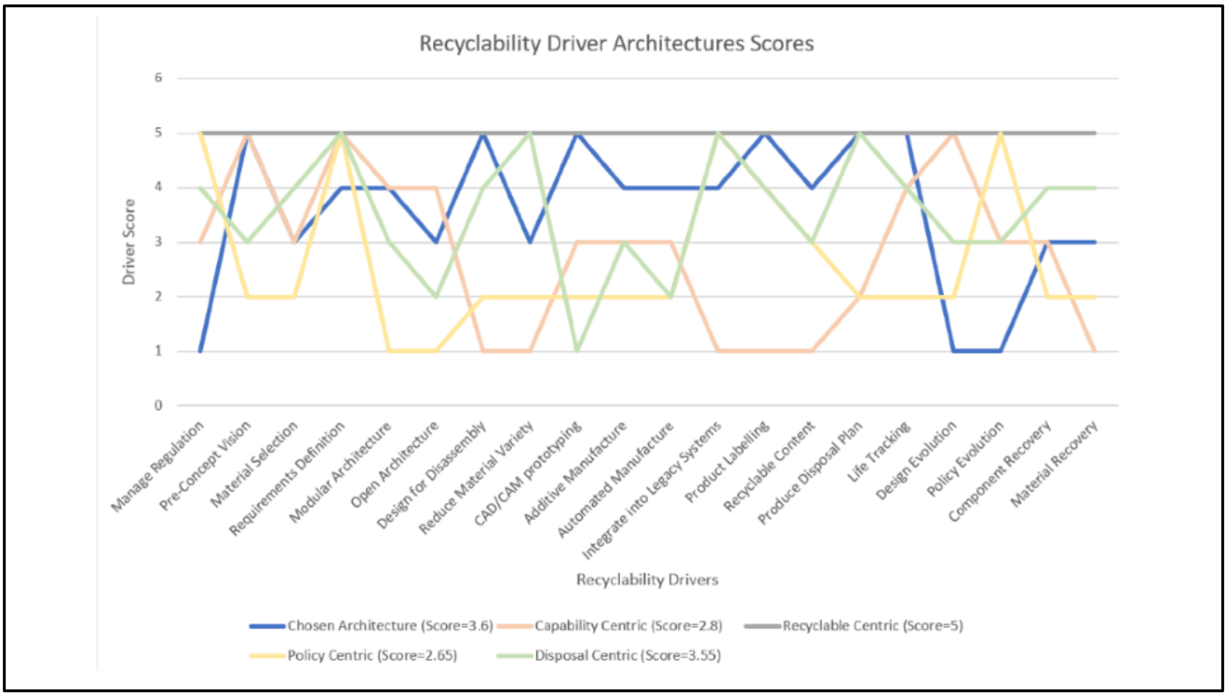
- Quality Function Deployment
- Stakeholder engagement
- Generic Reference Model

The 3rd phase of the thesis involved applying systems thinking to the problem. The modelling outputs were assessed using QFD, my ideas were validated through additional stakeholder engagement and a system completion activity undertaken using a GRM.

Quality Function Deployment Process

- Customer Requirements
  - Weighted 20 recyclability drivers
- Competitive Analysis
  - Scored 5 architectures
- House of Quality
  - Customer requirements vs functional requirements (PA elements e.g. weight)
- House of Quality Roof
  - Correlation between different functional requirements

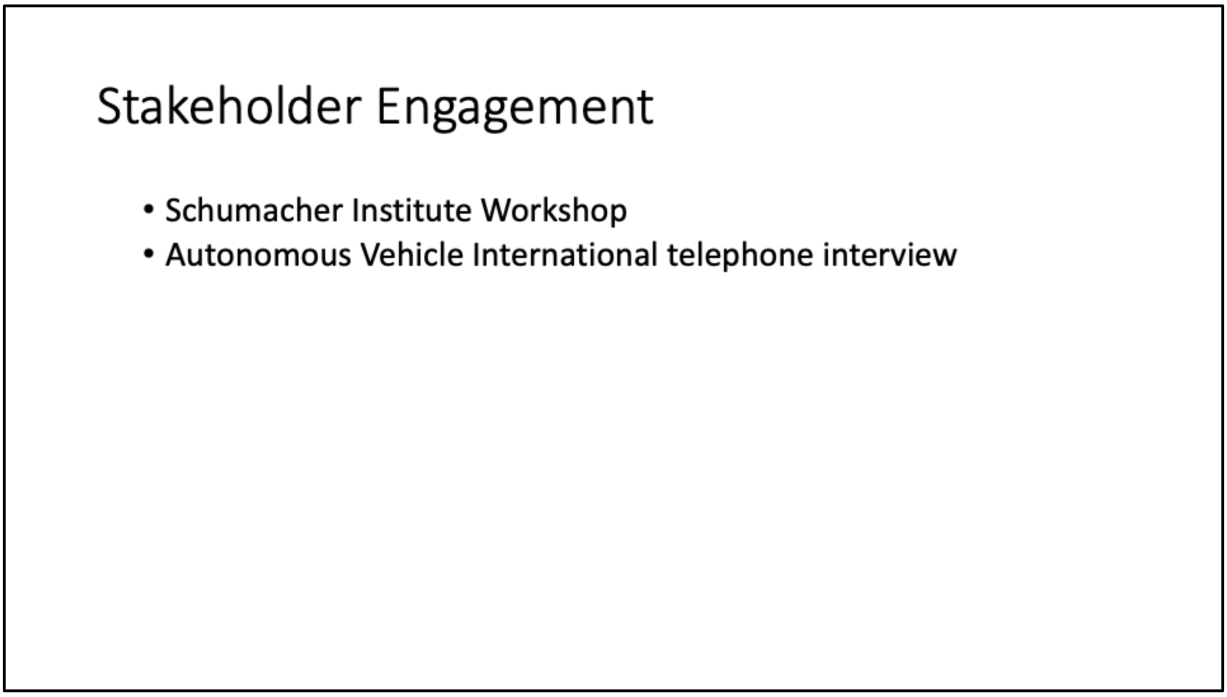
QFD entailed using a predetermined template which went through the processes described. The 20 drivers were weighted according to importance, 5 possible architectures scored, a comparison between initial requirements and possible solutions conducted and an understanding of correlations between requirements was developed.



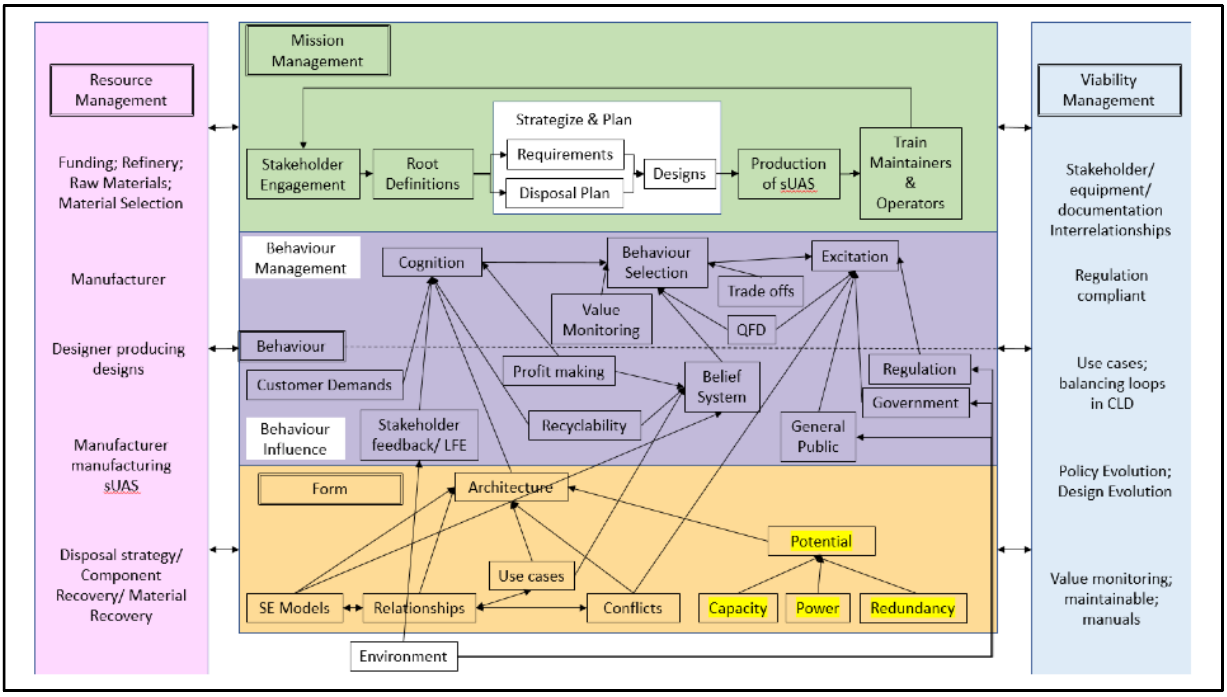
The 5 possible solutions included the chosen architecture, a capability centric solution, a recyclable centric solution i.e. perfect world, a policy centric solution i.e. prioritising legal compliance and a disposal centric solution i.e. focused on end of life disposal. The possible solutions were scored and the results are shown on the graph. The key indicates the overall recyclability score for each solution (0-5).

Functional Requirement	Weight Ranking	No. of trade offs
% recycled	1	2
UAV	2	6
Disposal Strategy	3	0
Recyclable infrastructure	4	0
Data Storage	5	0
Maintenance Resources	6	0
Regulatory Compliance	7	2
Data Capture	8	0
Range	9	3
Weight	10	1
Time for Return on Investment (ROI)	11	6
Data Analysis Capability	12	0
Operator Resources	13	0
Size	14	3

The different physical solutions were compared against each other to understand if there are trade offs. The trade offs are shown in this table with the solutions with the highest trade offs highlighted in yellow.



The additional stakeholder engagement was completed via a think tank workshop and a telephone interview with AVI an international sUAS trade organisation. The results and analysis were in written format and the key points were highlighted in the discussion piece.



The final stage of the systems thinking was to conduct a completion check using this GRM arrangement. In general it was considered that each element of the GRM was satisfied in some way by the modelling, except for the items highlighted in yellow. To incorporate these elements, a full iteration of the modelling would be required to ensure they flow through the analysis correctly. Due to time limits, this was recommended as further work.

4. Findings

- **Discussion**
- **Conclusions**

The final phase of the thesis methodology was to discuss and conclude the findings.

Discussion

- Improvements to methodology implemented
- Data collection
  - Industry specific
  - Survey results non-repeatable due to stakeholder churn
  - Individual feedback repeatable
- Case study
  - A balance between priorities possible
  - Iterations would add accuracy
- Validation
  - Low appetite in sUAS industry for recyclability
  - Critical mass required to realise benefits; collaborations would work
  - Legacy concepts often used
- Ellen Macarthur Foundation’s Circulytics shows utility of using scoring mechanism

The main discussion points focused on how the analysis could be improved, the repeatability of the data collection method, how the analysis worked for the case study, blockers for sUAS manufacturers to incorporate recyclability into their design and other initiatives that took a similar approach.

Conclusions

- SE is useful for analysing sustainability
- Stakeholder engagement was essential
- Methodology enables *production* but not *definition* of architectures
- Lifecycle thinking effective for literature review
- Originality in using SE and sUAS case study for Recyclability
- Recyclability score can be used for other case studies
- No consideration of capability undermines use of resource
- Stakeholder leadership required to improve recyclability

The conclusions highlighted: the effectiveness of SE for sustainability, the requirement for good stakeholder engagement, the utility of the methodology for producing a solution, the advantage of using LC thinking for the LR, the originality of the thesis content, the read across of recyclability scoring to other case studies, the need for a solution to be balanced with creating value and the need for all stakeholders to engage to bring the concept to fruition.

Thesis aim:

"To improve the consideration of recyclability in SE decision making across a system's life cycle."

Considered achieved.

Upon reviewing the thesis aim, it was concluded that the aim had been satisfied.

So What?

- Government transition to net zero emissions by 2050 leads the way for UK industry;
- Defence Strategic direction (Lt Gen Nugee) has prioritised sustainability;
- Engineering council requires “contribute to sustainable development”;
- DE&S World Environment Day presentation produced;
- DE&S have reviewed PQQ and ITT framework to align to sustainability;
- DE&S GEAR Eng. policy alignment to MOD sustainable procurement reviewed;
- BC submitted to Team Defence Info to implement sustainability scoring into future procurement;
- MOD Sanctuary Award feedback “innovative” & “solid proposition”.

How does this work translate to the real world?
The idea upholds and leads the UK NZ2050 ambition
Senior MOD stakeholders are championing sustainability in Defence
The UK Eng council includes sustainable development as a prof registration competence
I promoted my work at the 2020 DE&S WED
I was able to contribute to the development of MOD commercial and engineering policy
I submitted a BC idea to incorporate a Defence system scoring mechanism to TDI, whom are leading the MOD sustainability road map
Feedback from an unsuccessful Sanctuary award nomination was it was “innovative” and a “solid proposition”

Thank you for listening

Any Questions?

Thank you for listening