**SUSTAINABILITY ANALYSIS OF A 12 GHz ORTHOGONAL MODULE TRANSDUCER PRIMARILY USING R-STRATEGIES.**

Lappeenranta–Lahti University of Technology LUT

Bachelor's Programme in Mechanical Engineering, bachelor's thesis)

2025

KIPLAGAT ANTHONY

Examiner: Associate professor, Docent, D.Sc. Harri Eskelinen

ABSTRACT

Lappeenranta–Lahti University of Technology LUT

Your school: LUT School of Energy Systems

Your degree programme: Mechanical Engineering

KIPLAGAT ANTHONY

**Sustainability Analysis of a 12GHZ Orthogonal Module Transducer Primarily Using the R-9 Principles.**

Bachelor’s thesis

2025

56 pages, 13 figures, 6 tables and 11 appendices

Examiner: Associate professor, Docent, D.Sc. Harri Eskelinen

Keywords: R-9; Sustainability; 12 GHz; OMT; SolidWorks sustainability module.

This thesis focuses on the sustainability analysis of a 12 GHz Orthogonal Module Transducer (OMT) for anti-aircraft fire control radar antennas, that work to separate linearly polarized signals. This work includes aassessments based on R-strategies on how well the product meets the principles of sustainable development and circular economy, expert interview of this MW/RF related device - aimed at understanding its functionality, created solid works model of the device, analysed environmental impact of the modelled device using SolidWorks sustainability model to support the R-9 analysis, conducted literature review of information to support the expert interview and the results from the solid works sustainability module analysis. The key components that make up this device are the body, the square and circular flanges, the long and small tube, the tuning pin, the diode and the BNC connector. The results include a literature review, a source analysis table, a reliability table and a value analysis table. This thesis research belongs to the broader LUT University project on Microwave Technology and RF Engineering.

ACKNOWLEDGEMENTS

To my family, friends and supervisor for all the support without whom none of this would have been possible.

## SYMBOLS AND ABBREVIATIONS

DFMA – Design for Manufacturing and Assembly

EMI – Electromagnetic Interference

ES – Electroplating Sludge

GHG – Green House Gas

GHz – Giga hertz

HAZs – Heat Affected Zones

LCA – Lifecycle Assessment

MW/RF – Microwave and Radio Frequency

OMT – Orthogonal Mode Transducer

RoHS – directive on Restriction of Hazardous Substances in Electrical and Electronic Equipment

SW – SolidWorks

VSAT – Very Small Aperture Terminal

WEEE – Waste from Electrical and Electronic Equipment

3D CAD – 3 Dimension Computer Aided Design

**Table of contents**

# 1 Introduction

This chapter introduce the research project, explaining its background, purpose, and the aim to make it more sustainable. It focuses on designing a 12 GHz OMT for radar systems used in anti-aircraft defence. An OMT is responsible for combining or separating the received and transmitted signals in an antenna.

It is crucial because it helps to improve communication and provide location accuracy for systems such as the anti-aircraft fire control radar systems. This thesis is written to research and provide the findings of how the 12 Ghz OMT can be redesigned to optimize for sustainability.

The advancement in radar technology coupled with their requirements to operate across bandwidth has led to the development of new designs for the OMT which is an essential component in antennas used for communication. These developments, coupled with the increasing sustainability concerns have led to efforts geared at establishing the impact these devices have on the sustainability front.

## 1.1 Goal of the research

The objective of this thesis will be to analyze a 12 Ghz Orthogonal mode transducer primarily using the R-strategies in support with Expert Interviews, and SolidWorks Sustainability module to research and provide the findings of how the current product can be optimized to meet the principles of sustainable development and circular economy.

## 1.2 Background and motivation

OMTs are important parts of radar and communication systems that take a combined signal and split it into two separate signals based on their polarization. They help separate signals with different polarizations allowing the system to be dually polarized. This improves the range and performance of radar systems.

The motivation for this thesis is part of a larger research project going on in the university that studies the design, manufacturing, and sustainability of microwave devices and their parts.

DFMA analysis thesis research was completed at LUT University in the spring 2024 of a similar MW/RF component with a primary focus improving manufacturing accuracy and overall equipment reliability. This thesis, however, will focus on providing insight of how the device can be manufactured in a sustainable way.

## 1.3 Research problems and questions.

The problem that this thesis tackles is how can the parts and manufacturing process of this device be reimagined to ensure sustainability. Therefore, this thesis will investigate to find viable options in terms of material selection and manufacturing process to engineer it from a sustainable standpoint.

The questions are.

- Which aspect in the manufacture of this device will yield the most impact on the environment?
- What are other production methods considerations apart from soldering and why would they be favorable for production?
- What are other materials considerations for the manufacture of the device and why?

## 1.4 Research methods

This thesis will use triangulation as a form of methodology. This will be the triangulation of three methods namely, R-9 Principles, Expert Interview and Literature review and SolidWorks sustainability Module.

The R-9 Principles will provide information on how to sustainably consider the device across its entire life cycle. Secondly, an Expert Interview will provide an understanding of the functionality of the device. Thirdly, the SolidWorks sustainability Module will work to quantify the impact that the material used poses on the environment. Lastly, Literature review will provide supporting evidence for the information given.

## 1.5 Expected contribution.

The R-9 Principles and Solid Works sustainability module will work to support each other, and the Expert Interview will provide current information as it will mostly deal with the functionality of the device. Literature review will provide a base to create a source analysis tool for the quality of references used.

## 1.6 Scope

The extends of this document is the manufacturing process and material selection for the OMT. The environmental impact is limited to carbon, water, air, energy used and the material financial impact.

Figure 1. OMT Device.

The device has three functional interfaces. The tubular waveguide is for a horn which illuminates the parabolic antenna of the radar. The rectangular waveguide is for the receiver and the smaller tubular part is for the BNC connector of the transmitter.

# 2 Methods used in the sustainability analysis for the 12 Ghz OMT

This chapter will explore in more detail the methods to be employed in the implementation of this thesis. Triangulation will be applied as different methods will be used to study the sustainability of the OMT. However, the primary method of use will be the R-9 principles. This section explores the individual methods used giving their descriptions with their respective flow charts of implementation.

## 2.1 Method Triangulation

In this report, the OMT investigated is one used as a part of a fire-control antenna or as part of a space antenna. This thesis will employ different methodologies as shown in Figure 2 below to ensure its fundamental success. These methods will work to support each other and to provide a row of results.

The methods are.

- R – 9 Strategies
- Expert interviews
- Solid works sustainability model and Life cycle analysis

Solid works sustainability module will work to support the R-9 principles, and literature review will provide referential support for the expert interview.

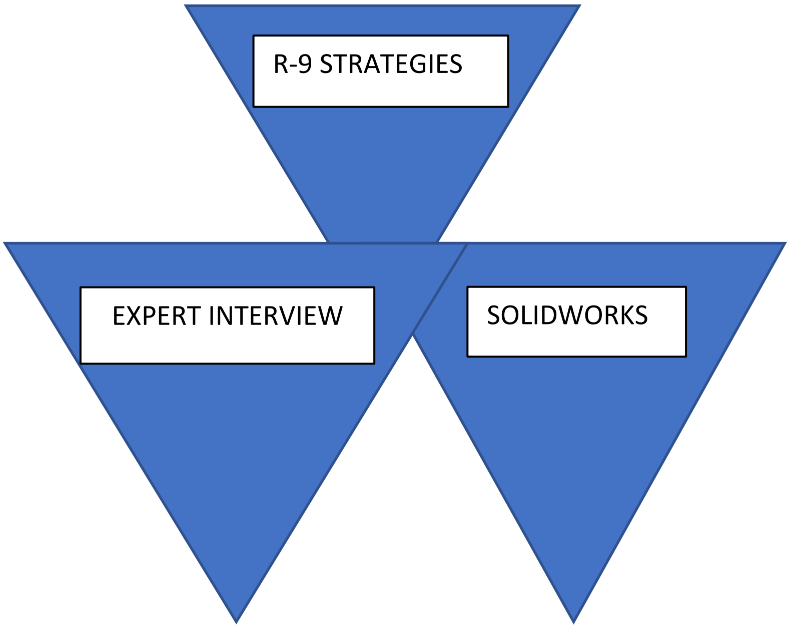



Figure 2. Triangulation Method.

## 2.2 R-9 Principles

These are strategies that explain ways in which the available resources can be used in a more efficient manner to reduce and minimize waste and at the same time, show how a product or material can be used with maximum efficiency in its life cycle.

These strategies are ordered in a hierarchy divided into three categories. The first category is in the production phase. It is concerned with the smart use and manufacture of resources.

Category number two is in the consumption phase. These cover the lifespan of a product and its parts. Finally, the last category is end of life. It views the materials of the product if they can be captured and the waste used as a resource, or the value of the materials used is lost and the product ends up as waste in a landfill.

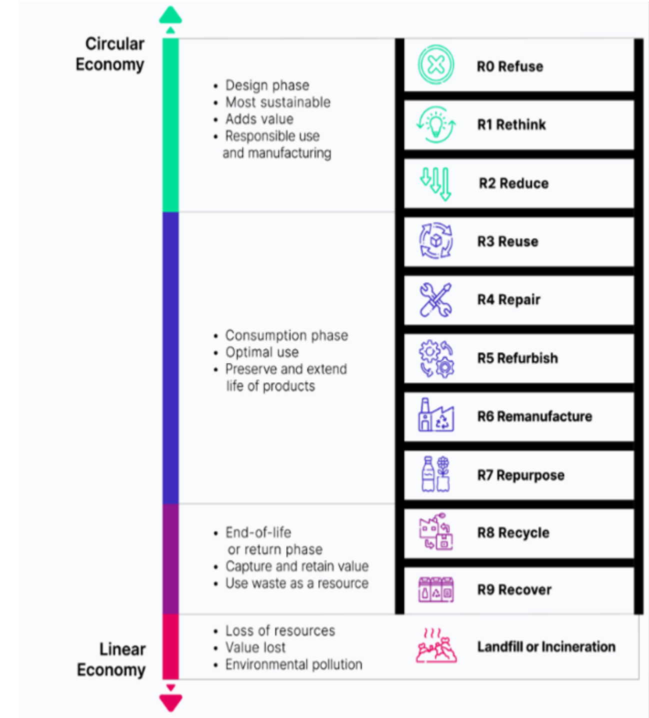



Figure 3. R-9 Strategies.

As seen from Figure 3 above, there are different R-9 strategies, and this thesis will look at the viable options unique to the manufacture and production of the 12 GHz OMT. These strategies are.

### 2.2.1 R-0 Refuse

This strategy advocates for the complete disuse of a material and replacing it with another material that has the same properties and is much greener. From the sustainability standpoint of our product, we can refuse to use brass and find alternatives.

### 2.2.2 R-1 Rethink

As is now the case, one antenna is used for one anti-aircraft fire-control. Rethinking asks that a product is made use-intensive by sharing and multi-functionality. In the case of an OMT, making the parent antenna multi-functional to be used by more than one anti-aircraft fire-control would mean less OMTS used and therefore less of the materials required.

### 2.2.3 R-2 Reduce

Considering this strategy, the aim is to use less resources in production. This plays out by evaluating the impact of the materials used on the environment. Additionally, as in Rethinking the use of one antenna would subsequently reduce the amount of material that is used in manufacturing.

### 2.2.4 R-3 Reuse

As a part of an anti-aircraft fire-control antenna, the OMT has a higher chance of reaching the end of life for the entire system since it is separate from the operating system that is responsible for firing. Once the anti-aircraft fire-control is down the same antenna should be used for another anti-aircraft fire-control system.

### 2.2.5 R-4 Repair

As the name suggests, this strategy is concerned with maintenance and repair of defective OMTS from a used up an anti-aircraft fire-control radar antenna to ensure its extended use. Looking at the OMT repair can be done by resoldering broken joints and replacing defective BNC connectors.

### 2.2.6 R-5 Refurbish

Refurbishing applies to the OMT as a means of taking up old and used OMTS from previous generations of the anti-aircraft fire-control radar antenna and upgrading and updating it to meet the required standards fit for it to be used in newer generations.

### 2.2.7 R-6 Remanufacture

Here, parts of a discarded OMT say the BNC connector are taken and integrated for use in the development of new products performing the same functions - say radio antennas or in nuclear instrumentation. The OMT in its entirety can be remanufactured to be used as a part of a Very Small Aperture Terminal (VSAT) or a part of a terrestrial microwave radio.

### 2.2.8 R-8 Recycle

This proves to be quite nuanced from this product's standpoint. The primary goal that recycling aims to serve is to process the materials to obtain higher or lower quality grades of the primary materials used in a product that is out of service. As a part of an anti-aircraft fire-control radar antenna, the materials can be easily scrapped to obtain the core metals. However, if the OMT is a part of a satellite that is launched into space recycling the materials is utterly impossible.

### 2.2.9 Value Analysis Tool

This is a value engineering tool presented in table form that will be used to provide weighting and a complete analysis of the various R-9 principles that are viable to the device under study. "Value engineering is a management thought and skill that aims at increasing the value of the study through the collaboration of related field and the systematic analysis of the function and cost of the study (International Conference on Information Management, Innovation Management and Industrial Engineering Xi'an Shi, China, (2009)." The value analysis will be presented to support the use of R9 principles. The table 1 shows a sample representation of the tool.

Table 1. Model table of value analysis.

| Value analysis matrix for R9 principle | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| | | | | | | | |
| R9 criteria | Weightening of the criterium | Grade for material and design option #1 | Grade for material and design option #2 | Grade for material and design option #3 | Scores for material and design option #1 | Scores for material and design option #2 | Scores for material and design option #3 |
| Refuse | w1 | #1g1 | #2g1 | #3g1 | w1×#1g1 | w1×#2g1 | w1×#3g1 |
| Rethink | w2 | #1g2 | #2g2 | #3g2 | w2×#1g2 | w2×#2g2 | w2×#3g2 |
| Reduce | w3 | #1g3 | #2g3 | #3g3 | w3×#1g3 | w3×#2g3 | w3×#3g3 |
| Reuse | w4 | #1g4 | #2g4 | #3g4 | w4×#1g4 | w4×#2g4 | w4×#3g4 |
| Repair | w5 | #1g5 | #2g5 | #3g5 | w5×#1g5 | w5×#2g5 | w5×#3g5 |
| Refurbish | w6 | #1g6 | #2g6 | #3g6 | w6×#1g6 | w6×#2g6 | w6×#3g6 |
| Remanufacture | w7 | #1g7 | #2g7 | #3g7 | w7×#1g7 | w7×#2g7 | w7×#3g7 |
| Repurpose | w8 | #1g8 | #2g8 | #3g8 | w8×#1g8 | w8×#2g8 | w8×#3g8 |
| Recycle | w9 | #1g9 | #2g9 | #3g9 | w9×#1g9 | w9×#2g9 | w9×#3g9 |
| Recover | w10 | #1g10 | #2g10 | #3g10 | w10×#1g10 | w10×#2g10 | w10×#3g10 |
| Total | WΣ=w1+...w10=1 | | | Total scores (TS) | TS#1=Σ=wi×#1gi | TS#2=Σ=wi×#2gi | T3#1=Σ=wi×#3gi |
| | | | | Total price (PR) € | PR#1 | PR#2 | PR#3 |
| | | | | Costs/score (C) € | C#1=PR#1/TS#1 | C#2=PR#2/TS#2 | C#3=PR#3/TS#3 |

**DATA COLLECTION**

Reference material - academic journals and papers.

Age of refence material - at least 7 years.

Data base – Scopus, Google Scholar.

Key words – Sustainability, Circular economy, OMT, R-9

↓

**DATA ANALYSIS**

The data will be analyzed using a value analysis tool.

↓

**PRESENTING RESULTS**

↓

**RELIABILITY ANLYSIS**

Reliability analysis will be presented in a reliability table covering all the six aspects including the three methods.

## 2.3 Expert Interview and Literature Review

Regarding this specific product, the Expert interview conducted will be based on device performance. The reason being that the expert in this case is a seasoned Electrical Engineer. Literature review will provide supporting evidence for the information used in this thesis and a source analysis table will assess the quality of the references used.

The source analysis table will be provided in the results chapter. The question presented to the expert was if, from the standpoint of material reduction, it was possible to have one antenna working to serve several systems e.g. multiple anti-aircraft fire-control systems?

**DATA COLLECTION**

Reference material - Expert Interview.

Date – 10/2/2025

↓

**DATA ANALYSIS**

The results from the interview be analyzed using triangulation by comparing, combining or contrasting with the results from literature review.

↓

**PRESENTING RESULTS**

The results will be presented in the results chapter supported by literature review.

↓

**RELIABILITY ANALYSIS**

The reliability analysis will be done using a reliability table and the source analysis table.

Table 2. Source analysis Table.

Table 1. Source materials analysis tool

| Questions Q1-Qn, to which the answers are searched for | Reference #1 | Reference #2 | Reference #3 | Reference #4 | Reference #5 | Reference #6 | Reference #7 | Reference #8 | Reference #9... | Reference #N | Summarized observations to integrate the final answers to each question |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Q1 | | | | | | | | | | | |
| Q2 | | | | | | | | | | | |
| Q3 | | | | | | | | | | | |
| Q4... | | | | | | | | | | | |
| | | | | | | | | | | | |
| Qn | | | | | | | | | | | |
| Summarized observations about the relevance of each reference | | | | | | | | | | | |

Reference list:

[1]

[2]

[3]

[4]...

[N]

## 2.4 SolidWorks Sustainability Module

Solid works sustainability module is a built-in model into solid works that evaluates 3D-CAD models and gives feedback on the impact that the materials have on the environment.

**DATA COLLECTION**

Reference material **-** Solid works sustainability environment

Data base – SolidWorks'

Key words – Sustainability, Circular economy, Life cycle Assessment

↓

**DATA ANALYSIS**

The data will be analyzed quantitatively using the software

↓

**PRESENTING RESULTS**

The results will be presented through pie charts and combining with the R-9 principles.

↓

**RELIABILITY ANLYSIS**

The reliability analysis will be done using a reliability table and by applying triangulation.

Using this module, the environmental impacts are assessed in five major categories: carbon, air, water, energy, and material monetary impact as shown in Figure 4 below.

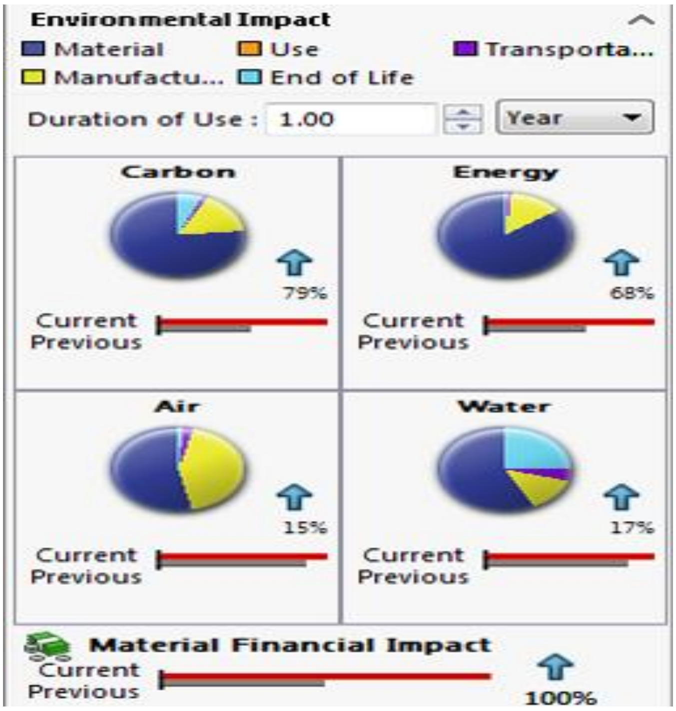



Figure 4. SW module results interface (SW).

The module helps analyse the entire life cycle of materials by using LCA during the design process. It looks at all the stages of a product's life, based on the user's inputs. This helps to show how choices like the type of material, how and where it is made, and where it is used can affect the environment.

To perform this analysis, the thesis used 3D CAD models made by students. These models are shown in the appendix section of the paper.

### 2.5 Reliability Analysis.

The reliability of the analysis performed in this thesis will have to be tested. To do this, this thesis employs the use of a reliability table. The table 3 shows the reliability tool that is used.

Table 3. Reliability Analysis Table.

| | R-9 STRATEGIES | SOLIDWORKS | EXPERT INTERVIEW | TRIANGULATION |
|---|---|---|---|---|
| **VALIDITY** | Scientific Journals, Scopus database. | SolidWorks | The expert is believed to be accurate. | Comparing collected information from all the methods. |
| **RELIABILITY** | In line with R-9 strategies, and reference material age of more than 7 years. | Replication of the procedure a couple of times with the same result. | The expert answers are taken to be replicable. | Reference material used to support the expert interview is of more than 7 years, in line with R-9 strategies, supported by solid works |
| **SENSITIVITY** | R-strategies are only applicable to the product, with at least three supporting references. | Source of material, effect of change of material. | Literature review as supporting information. | The ideal result is supported by all three methods. |
| **ERROR ANALYSIS** | Not Applicable | Not Applicable | Not Applicable | Not Applicable |
| **ACCURACY** | The viable strategies are shown. | Circular Economy, Life cycle assessment | Device Functionality | R-9, OMT, Sustainable, LCA, Circular economy |
| **SATURATION** | Only the applicable strategies are found. | Comparison with the base equivalents. | All the research questions are answered. | All three methods produce the same outcome. |

# 3 Results obtained from the used methods.

This chapter provide the results obtained from the methods used in this thesis. It brings forth the answers to the main questions that this thesis aimed to tackle.

## 3.1 Expert Interview.

This subsection provides the findings about this device functionality from the expert interview conducted on the 10th day of February 2025 backed with references from literature review.

It also presents along with it, general findings about MW technology from different questions asked by my fellow students that are applicable to all the MW technology and RF engineering devices that were presented. The expert as referenced in the reference 1 is a professor from Aalto who is a specialist in Electrical Engineering specialising in MW technologies and RF.

His answer to the expert interview question presented earlier was both yes, and No.

Yes, in that the technology is already being implemented and there are antennas in place that work to serve several systems and no with emphasis to this specific device. The reason being that there are components – the tuning screw and the connector - of the 12GHz OMT that are strongly dependent on the frequency of the device.

In his response to the functionality of other MW devices, he mentioned the commonalities that were applicable across all the MW devices. Firstly, he pointed out that the reason why the devices are gold coated is because gold ensures the best conductivity which in turn ensures proper device functionality. However, in cases where cost is a source of concern, silver coating could also be used.

Secondly, he noted that the devices which were being observed, were fully optimised to the point where they met the standard requirements to function optimally for the ongoing space projects and use in anti- aircraft fire control systems.

Thirdly, he added that the main mode of production for the device is silver soldering because silver can withstand harsh environmental conditions. Other production methods could include electroplating or machining. Soldering posed a challenge if the soldering gets into the device.

## 3.2 Literature Review

Having looked at the functionality of device, this paper then further presents findings from literature to support the choice of material used (mainly brass) and findings on what other materials could be used as alternatives. This was important for the success of this paper because, the 3D CAD models of the device that were used for the sustainability analysis in Solid Works were modelled using the different materials mentioned in this paper and compared to the one made entirely from brass and the Environmental impact they presented.

The paper further goes on to provide strong evidence from literature to show the various production methods that could be used to manufacture the 12 GHz OMT device and the impact they all pose to the environment. These are provided in detail below from sub section 3.2.6 to sub section 3.2.8 below.

It was evident from the literature that each manufacturing method offers distinct advantages: Milling provides high precision and repeatability and is ideal for cylindrical components with concentric features; soldering creates electrical and mechanical connections between components with relatively low thermal input; and electroplating enhances the material surface properties such as conductivity, wear resistance, or corrosion protection.

Finally, the quality and number of the references used to gather the information used in this thesis is presented in the source analysis table at the end of this sub section.

### 3.2.1 Brass

The main material used in the production and manufacture of the OMT is brass. Brass is fundamentally an alloy composed of copper and zinc, in proportions of 66% copper and 34% zinc.

This composition can be adjusted to achieve specific material properties depending on the intended application. The fundamental properties that make brass a widely used engineering material are explained and listed here.

Strength and Ductility**:** Brass exhibits a good combination of strength and ductility, making it suitable for various mechanical applications. According to (Shashank Lingappa, Srinath & Amarendra, 2018) the tensile strength of brass can reach up to 350.88 MPa, and its hardness can be around 153.3 Hv, which are beneficial for structural integrity and durability.

Corrosion and wear Resistance**:** In their works, (Dheeraj et al., 2022) and (Memar, Azadi & abdoos, 2023) show that brass has excellent corrosion resistance, which is crucial for maintaining performance in applications where there is exposure to moisture and atmospheric conditions. It should be noted however, that brass does corrode under certain conditions.

Formability: One of the qualities of brass that allows it to be an excellent pick for use in the manufacture of the 12 GHz OMT is it malleability and formability (Dheeraj et al., 2022; Memar, Azadi & abdoos, 2023). This allows it to be easily shaped into complex geometries required for OMTs design. Compared to steel, brass has a lower melting point that makes it a favourable choice to reduce energy requirements during production.

Conductivity: Brass possesses a high electrical conductivity ((Yilmaz Atay et al., 2020)), which is essential for minimizing signal loss and ensuring efficient transmission of electromagnetic waves. This property is particularly important for high-frequency applications like a 12 GHz OMT.

Material Stability: Brass has an ability to maintain its integrity and performance across a range of operations and temperature. This is crucial for materials used in the 12 GHz OMT because the component can be used as a part of a space satellite and the temperature conditions can go subzero. (Singh et al., 2020) information of how brass maintains it performance in these sub-zero temperatures

Acoustic Ability: Brass has the capacity to produce resonant tones that make it a favourite pick for this device. its internal grain structure allows for efficient sound propagation while minimizing unwanted harmonics.

This is achieved by the ability of the material to dampen vibrations. In relation to the work done by ((Hopulele, Axinte & Nejneru, 2014) we witness the notable damping capacity of brass, which is beneficial for the 12 GHz OMT in controlling sound vibrations. Further developments done by (Kausel et al., 2015) show that coupling of axial bell vibrations to the internal air column in influence input impedance and radiated sound.

### 3.2.2 Steel S355

Strength and Toughness: S355 steel exhibits high strength and good fracture toughness, which are essential for structural integrity. The fracture toughness varies across different microstructures, with the base metal showing higher toughness compared to the heat-affected zone and weld metal. This is a critical aspect of the material because the component will exist in harsh conditions and therefore a material exhibiting good fracture toughness will offer a good alternative.

Impact Resistance**:** Referring to (Mehmanparast et al., 2018) the temperature effect on steel (s355) impact resistance is that as temperature rises the impact strength decreases in the heat affected zones (HAZs). As a part of an anti-aircraft fire control system, the nature of the device functionality possesses an increase in temperature potential and this property of steel is what would prove a good manufacturing alternative.

Durability**:** The 12 GHz OMT is produced and manufacture to last an estimate 15 years. This then means that the material used should be a highly durable material. Looking at the works of (WANG et al., 2018) we see that certain elements like ZrO2 are used to enhance the strength and durability of S355.

### 3.2.3 Copper

Copper provides excellent electrical conductivity than brass, making it ideal signal transmission. However, it presents challenges in machinability compared to brass. Brass C360 and C272 are composed of 70% and 75% of copper respectively.

High Electrical Conductivity: (Raab et al., 2016) illustrates the electrical conductivity of copper which is crucial for efficient electromagnetic field generation and transmission.

This is an important property regarding the 12 GHz OMT because it is an electrical device. In its functionality, faster processing of the signals is heavily dependent on the electrical conductivity of the material used. This ensures minimal signal loss and high performance in high-frequency applications.

Electromagnetic Interference (EMI) Shielding: In their exploration, (Maruthi et al., 2021) provide detailed evidence on this property of copper. Copper has a ubiquitous capacity for shielding against electromagnetic interference especially in high-frequency ranges like 12 GHz. This is due to its high surface conductivity and the ability to form effective barriers against stray electromagnetic radiation. This is very crucial for this device because of its functionality either in space projects or when used as part of an anti-aircraft fire control system where any form of interference my prove to be quite fatal and costly.

High-Frequency Suitability: As a result of its good conductivity, copper has frequently been used for high frequency applications with studies by (Feili et al., 2010) showing good performance at frequencies up to 24 GHz. This implies equally good performance at 12 GHz. (Yue et al., 2023) also points out how this is helpful against power losses.

Copper's resistance to corrosion ensures long-term durability, which is important for the performance of the transducer in various environmental conditions. This information by (Baligidad et al., 2021) is in line with the choice of silver soldering as a joining method for the OMT because of its ability to withstand harsh environmental conditions especially for aviation, military and space applications.

### 3.2.4 Aluminum

Aluminum offers significantly lower weight than brass with a density of about one-third that of brass which is advantageous for reducing antenna weight in telecommunication applications that extend to the device under study. Even though Aluminium forms a protective oxide layer, it can easily corrode and will require surface treatment to prevent this degradation. Additionally, it is not as easily machined as brass in many operations.

High Electrical Conductivity: Antena systems require electromagnetic wave propagations that rely on the electrical conductivity of the chosen material.

Non-magnetic Properties: Aluminum is a nonmagnetic metal, and this property plays a big role in reducing interference and ensuring signal integrity in applications that demand high frequencies. This is as articulated by (Scamans, Birbilis & Buchheit, 2010) in their works, "*Corrosion of Aluminum and its Alloys.*"

Wideband Frequency Performance: In their research on the effects of surface roughness on a 3D printed Ka-band made of Aluminium(Rico-Fernández et al., 2023) found out that some Aluminium alloys such as AlSi10Mg can be used as waveguide components and produce results to frequencies as high as 32 GHz without compromising on performance.

### 3.2.5 Gold coating

Results from the expert interview showed that gold was a material of choice for most of the space components. This was because gold offered several good qualities suitable for the functionality of this device.

The first property was its ability to resist corrosion. As a non-oxidizing metal, it meant that gold did not lose its lustre over time. According to (Freialdenhoven et al., 2022), this is vital in maintaining the integrity and performance of the device especially in harsh environment. This stability ensures that the electrical properties of gold-coated components remain consistent throughout the operational lifetime of the device.

The second property was its excellent electrical conductivity, which is essential for efficient signal transmission in RF and MW applications. This high conductivity reduces signal loss and improves the overall performance of the devices. At 12 GHz, the skin depth – the depth at which current flows in a conductor – is extremely shallow, making surface conductivity the dominant factor in performance. Gold's excellent surface conductivity makes it particularly suitable for this frequency range. This surface conductivity in line with the works of (Freialdenhoven et al., 2022) ensures optimal performance at the target frequency.

The last property mentioned was gold's thermal conductivity. According to (Farrar et al., 2007) Gold's high reflectivity in the infrared spectrum helps in effective heat dissipation, preventing excessive heating of sensitive radar components.

This thermal stability is essential for maintaining the precise dimensional tolerances required in waveguide components like OMTs, where thermal expansion could result in signal distortion and maintaining the longevity of the devices.

### 3.2.6 Silver soldering

Silver soldering is the chosen as the main joining methods because of the following properties attributed to its structure as supporting material to the expert interview.

One is that if offers a high thermal and electrical Conductivity making it suitable for high-temperature and frequency applications like OMT. These are clearly elaborated in detail by (Masson et al., 2013).

The second property is its ability to resist corrosion and oxidation, making it ideal for this device. This enhances the longevity and durability of the soldered joints. Moreso, according to the study on silver-based solder alloys, “silver-based solders exhibit high mechanical strength and reliability, which is crucial for maintaining the integrity of solder joints under thermal and mechanical stresses (Sharif & Sharif, 2019).”

Finally, it is the joint quality resulting from silver soldering. In a study conducted by (Kinga Synkiewicz, Skwarek & Witek, 2014) they show that the use of silver in soldering leads to higher quality joints with fewer voids and better structural integrity, especially when combined with techniques like vacuum application during vapor phase soldering.

These however, does not mean that it has no impact on the environment. According (Ekvall & Andrae, 2006), although silver soldering reduces the lead-based emissions, it has its environmental impacts. The number one concern of this joining method is emissions. Silver emissions to the environment are significant, with “tailings and landfills making up almost three-fourths of the total(Eckelman & Graedel, 2007)” global emissions. According to (Fuse & Tsunemi, 2013) the impact of these emissions is felt significantly both on land and water.

Another effect of silver soldering and production is indicated in *Evaluating microwave-synthesized silver nanoparticles from silver nitrate with life cycle assessment techniques*. “Human health particulate air, and human toxicity and non-cancer potentials (Bafana et al., 2018)" are all indicated as possible negative impact of silver soldering and production to the environment and society at large to mention just but a few.

### 3.2.7 Milling

According to (International Conference on Production and Operations Management Society Peradeniya, Sri Lanka) (2018 :) on research that they conducted, it was concluded a great contribute to the environmental footprint associated with milling was mainly due to its high energy consumption. hat milling processes consume substantial amounts of energy, which greatly contributes to their environmental footprint.

GHG Emissions**:** In a study conducted by (Balogun, Edem & Mativenga, 2016), the trio were able to draw a direct connection between the intense energy usage of milling and greenhouse emissions. The intensive energy used during milling coupled with the fact that for most of the milling machines, fossil fuels are used to produce power, and they contribute to GHG emissions e.g. CO2, NOx, and CH4. In their study, (Kurukulasuriya, Gamage & Mangala, 2020) elaborate how these gases have a negative impact not only to the environment but also to the people that are exposed to them.

Milling as a method works by removing material from the work piece to produce final product which leads to material waste. (Faludi et al., 2015) provides an in-depth overview of these waste which includes metal shavings and cutting fluids and how they result in environmental pollution.

By definition," embodied energy is the energy consumed in all activities necessary to support a process in its entire lifecycle(Liu et al., 2017)." This embodied energy in the material, most of it is lost under the consumption of tool and during milling. Higher embodied energy lost in the milling processes leads to greater greenhouse gas emissions and as illustrated by (Balogun, Edem & Mativenga, 2016) these emissions contribute to climate change. This contributes to the overall environmental footprint of milling.

### 3.2.8 Electroplating

Electroplating as a method of production has the major environmental challenge in the form of Electroplating Sludge (ES). In reviewing the works of (Guo et al., 2024) we see that ES contains high concentrations of hazardous substances which pose serious threats to both the environment and human health. Given that the treatment and disposal of this sludge is costly and inefficient it is unattractive to manufacturers.

Air Emissions**:** According to (Schlesinger & Paunovic, 2011) the process also releases harmful chemicals into the air that are a health hazard. These emissions lower the air quality and when dissolved they are reintroduced to the environment as acid rain that harms aquatic life and causes pollution.

Groundwater Pollution**:** In their study, (Rawat & Rai, 2013) showed how the effluents - heavy metals like chromium, nickel, and zinc- of electroplating find their way into groundwater by leaching leading to contamination and reducing it quality making it unsuitable for human consumption. This leaching also harms the local ecosystem surrounding the plant.

High Resource Use: As a method of production, **(**(Song, Bhadbhade & Huang, 2016) in their work show how large amounts of water, energy, and raw materials are consumed in the electroplating process. As a result, it contributes to the overall environmental footprint of the industry. Coupling with resource consumption, they also elaborate how inefficient energy use in the process results in increased waste.

All the references used in this study are provided in the reference section of this thesis. The table 4 shown below is used for illustration purposes of the source analysis tool. This was important not only to verify the information used in this study, but also to show the quality of the references used.

Table 4. Source Analysis Table.

| | Ref #1 | Ref #2 | Ref #3 | Ref #4 | Ref #5 | Ref #6 | Ref #7 | Ref #8 | Ref #9 | Ref #10 | Summarized observations for intergration |
|---|---|---|---|---|---|---|---|---|---|---|---|
| What materials can be used? | ✓ | | | | | ✓ | | | | | ✓ |
| How is sustainability taken into account in the manufacture of the component? | | ✓ | | | | | ✓ | | | | ✓ |
| What production methods are considered? | | | ✓ | | | | | ✓ | | | ✓ |
| What environmental effects are considered when using Solidworks sustainability module? | | | | ✓ | | | | | ✓ | | ✓ |
| What role does material cladding play in sustainability? | | | | | ✓ | | | | | ✓ | ✓ |

| | REFRENCE LIST |
|---|---|
| Ref #1 | Sandeep, M. et al. (2019) 'Evaluation and Optimization of Material Properties of Brass at Subzero Temperature Using Taguchi Robust Design', in Materials today : proceedings. [Online]. 2019 Elsevier Ltd. pp. 4458–4465. |
| Ref #2 | Abbasi, M. H. et al. (2023) A framework to identify and prioritise the key sustainability indicators: Assessment of heating systems in the built environment. Sustainable cities and society. [Online] 95104629-. |
| Ref #3 | Siores, E. & Do Rego, D. (1995) Microwave applications in materials joining. Journal of materials processing technology. [Online] 48 (1–4), 619–625. |
| Ref #4 | Torcătoru, C. & Săvescu, D. (2019) Analyzing the sustainability of an automotive component using SolidWorks CAD software. IOP conference series. Materials Science and Engineering. [Online] 568 (1), 12113-. |
| Ref #5 | Singh, Sunpreet. et al. (eds.) (2020) Advances in Materials Processing : Select Proceedings of ICFMMP 2019. 1st ed. 2020. [Online]. Singapore: Springer Nature Singapore |
| Ref #6 | Yilmaz Atay, H. et al. (2020) Investigations of microstructure and mechanical properties of brass alloys produced by sand casting method at different casting temperatures. IOP conference series. Materials Science and Engineering. [Online] 726 (1), 12018-. |
| | |

| | |
|---|---|
| Ref #7 | Asjad, M. et al. (2023) ‘Synthesis and Analysis of Vital Social Sustainability Indicators Using Pareto Analysis’, in Recent Advances in Mechanical Engineering. [Online]. Singapore: Springer. pp. 333–343. |
| Ref #8 | Singh, S. et al. (2015) Microwave Processing of Materials and Applications in Manufacturing Industries: A Review. Materials and manufacturing processes. [Online] 30 (1), 1–29 |
| Ref #9 | Popa, L. I. & Popa, V. N. (2017) ‘Products eco-sustainability analysis using CAD SolidWorks software’, in MATEC web of conferences. [Online]. 2017 Les Ulis: EDP Sciences. pp. 6002-. |
| Ref #10 | Mehta, A. et al. (2024) Role of sustainable manufacturing approach: microwave processing of materials. International journal on interactive design and manufacturing. [Online] 18 (8), 5283–5299. |

## 3.3 R-9 Principles

This sub chapter provides the results obtained from the R-strategies. It gives an in-depth overview of how the current product meets the R-strategies by weighting them.

The value analysis table that was presented beforehand in the method section, is used here to provide quantitative weightings of only the strategies relevant to this device. The table 5 shows the value analysis tool that is used.

Table 5. Value Analysis Table

| **R-9 Strategies** | **Weighting** | **Brass** | **Aluminum** | **Steel** | **Score#1** | **Score#2** | **Score#3** |
|---|---|---|---|---|---|---|---|
| **Reduce** | 0.4 | 5 | 5 | 5 | 2 | 2 | 2 |
| **Reuse** | 0.2 | 5 | 3 | 5 | 1 | 0.8 | 1 |
| **Repair** | 0.1 | 3 | 3 | 2 | 0.3 | 0.3 | 0.2 |
| **Repurpose** | 0.1 | 4 | 2 | 4 | 0.4 | 0.2 | 0.3 |
| **Recycle** | 0.2 | 5 | 5 | 5 | 2 | 2 | 2 |
| **Total** | 1 | | | | | | |
| **Score** | | | | | 5.7 | 5.3 | 5.5 |

## 3.4 Solid Works Sustainability Module.

During the modelling and analysis of the device, this paper found out that different components require materials tailored to their specific functions for optimization.

The technical drawings used and provided in the Appendix section of this paper, were modelled with the following materials:

- Tubes: Brass c272
- Flanges: Brass c360
- Body: Aluminum 1060
- Diodes: Stainless steel
- BNC Connectors: Combination of steel and brass with plastic components

The selection of brass for tubes and flanges leverages its excellent formability and machinability for creating precise fluid-carrying or structural components.

Aluminum bodies reduce overall weight while providing adequate structural integrity for enclosure applications. Steel diodes offer the durability and heat resistance needed for electronic components, while BNC connectors utilize a combination of materials to balance conductivity, strength, and insulation requirements.

Connection tolerance refers to the precision with which components must fit together. This is important to note because all the drawings used in this paper are fitted with tolerances. Although tolerancing is mostly a DFMA requirement it was as equally important in the developing of this paper because tolerances influence material selection based on dimensional stability during manufacturing and operation which in turn influences the material quantity which from the environmental sustainability is a key factor to consider. This can further be extrapolated on the sustainability front in terms of energy consumption in that more material consume more energy as compared to less material. Hence why this was an important part of this documentation.

## 3.5 Triangulation

“Triangulation refers to the use of multiple methods or data sources in qualitative research to develop a comprehensive understanding of phenomena (Patton, 2015).” In this subsection, this paper will elaborate the main findings and purpose of conducting this research.

This will be done in three parts that is: combining the results from the expert interview and literature review, comparing the results from R-9 analysis and solid works sustainability module and finally by contrasting the expert interview results and the solid works sustainability module analysis on material selection.

Combining: - According to the expert interview, the main material used for the device is brass and rightfully so. This was fully backed by the literature review results showing why brass was the main material of choice for the manufacture of the 12 GHz OMT. Brass was a perfect fit not only because of its ability to withstand harsh environmental conditions but also because it can be easily formed, has good conductivity, it exhibits good strength properties, can easily resist corrosion and it possesses excellent acoustic properties which cement it position as a material of choice for MW/RF technologies.

Comparing: - By looking at the device and showing how it successfully met the R-9 principles, the results were compared to the results from the solid works sustainability module analysis. With reference to the table 5 above, the principles successfully met in the manufacture of the device included reduce, reuse, refurbish, repurpose and recycle. A figure representation of the tubular waveguide (Long tube) from the analysis has been used for the comparison and the other figures are provided in the Appendix. This contrasted with the initially stated principles in the methodology.

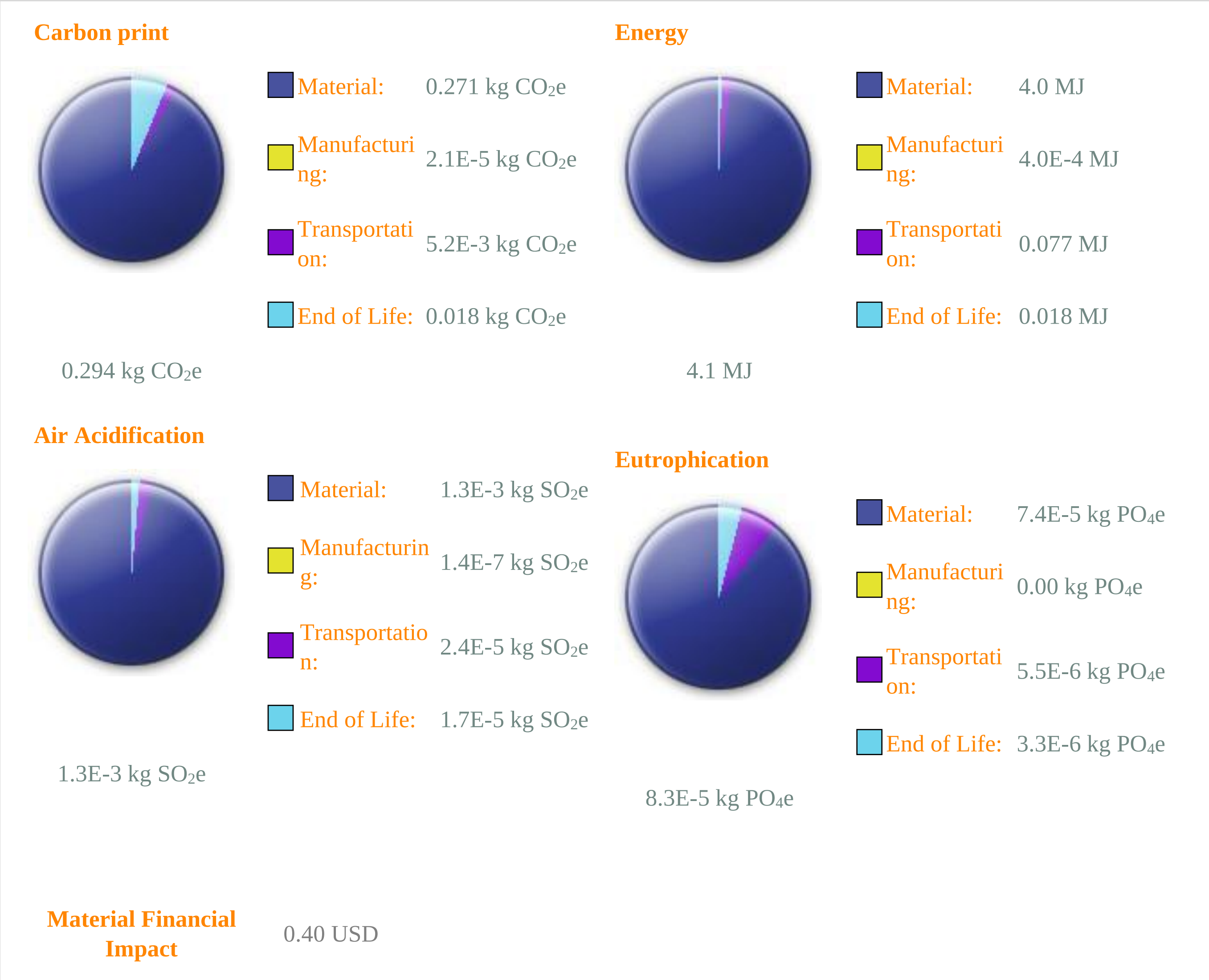



Figure 5. SW report of the long tube using Brass (SW).

Here it is noted that the major contributor of emission is from the material. This information is then used to infer that like the value analysis table, the main strategy to be implemented is reducing the amount of material used answering the first research question.

At the products end of life, it causes least emissions hence recycling should not be over emphasised as it was in the value analysis.

# 4 Discussion

This chapter provides the assessment of the device reflecting on the key findings and conclusions while also providing suggestions of topics on which further research can be carried on in times to come.

## 4.1 Key findings and conclusions

The key findings from this research were that the device designed for optimal performance. However, there is room for improvement. There are materials that possess the same properties as brass and offer a much better environmental impact. The best option for manufacturing is silver soldering because apart from being resistant to harsh weather conditions, the functional interfaces of the device, which is the tubular waveguide, the body, the rectangular flange and the smaller tubular part that houses the BNC connector can all be manufactured separately. In addition to that, this paper found that regarding the use of this device, i.e., in military or space projects, the RoHS directive did not apply to the manufacture of the device.

In conclusion, the main aspect in the manufacture of this device that has the biggest environmental impact deals with the material. Therefore, in a bid to reduce the impact of the device on the environment, material use and acquisition would be where to look at. Tying this to the R-9 strategies, this thesis notes that R-2 (Reduce) is the most important strategy for maximum net positive environmental impact of this device. Moreover, silver soldering is the best method of production. Although the functionality of the device limits the extent to which it accounts for its environmental impact, that is in no means a reason not to consider these impacts.

## 4.2 Comparison and connections with former research

This thesis connects to DFMA analysis thesis research that was completed at LUT University in the spring 2024 of a similar MW/RF component.

The primary focus was on improving the manufacturing accuracy and overall equipment reliability. However, in comparison to that, this thesis focused on conducting research on the device from the circular economy perspectives and lifecycle thinking with a focus on the mechanical engineering aspects of the product.

## 4.3 Reliability assessment of the results

This sub-chapter provides the six foundational basis that ensured that the results generated from this research met the triangulation approach and provides a pathway for this research to be replicated with the same results. The relaibility table is as shown in table 6 below.

## 4.4 Topics for future research

During this research, this paper found two information gaps that might be worth exploring in the future.

The first one concerned the functionality of the device with one antenna serving multiple systems. We now know that the technology is in place but a constraint regarding this device was the tuning pin and connector. A topic for future research would be to explore ways in which to make these two components not frequency dependent.

A second suggestion would be concerning the Aluminum Bronze and Manganese Bronze as alternative materials for the manufacture of the device. The reason for this is that during the solid works sustainability module analysis, these materials exhibited the same properties as brass but with lower specific heat capacities and production cost. This implies that they will in turn require less heat per unit mass of production compared to contemporary materials. As an example, some of the sustainability reports included in the appendix of this paper explore the impact of Aluminum Bronze on the environment.

Table 6. Reliability Analysis Table.

| | R-9 STRATEGIES | SOLIDWORKS | EXPERT INTERVIEW | TRIANGULATION |
|---|---|---|---|---|
| **VALIDITY** | Scientific Journals, Scopus database. | The repeated simulation provided the same answers. | The expert answers are accurate. | The three methods were compared, combined, and contrasted. |
| **RELIABILITY** | The R-9 principles are not subject to change | The analysis was repeated at least three times with the same result. | The expert answers are replicable. | Reference material used was more than 7 years, in line with R-9 Principles, common grounds from all methods. |
| **SENSITIVITY** | R-strategies are only applicable to the product, with at least three supporting references. | Change in material resulted in lower energy used. | Literature review provided supporting information. | The ideal result combined all three methods. |
| **ERROR ANALYSIS** | Not Applicable | Not Applicable | Not Applicable | Not Applicable |
| **ACCURACY** | Only the R-strategies, viable to the device were used for value analysis. | Circular Economy, Life cycle assessment | The expert's answers were backed up by information from literature. | Results from all three methods were combined, compared, and contrasted. |
| **SATURATION** | All the R-9 strategies viable for the device were accounted for. | There was no change in results after the third simulation. | The expert interview question was answered and supported by literature. | The research questions were answered by the three methods used. |

# 5 Summary

The 12 GHz OMT as used in this research is a part of an anti-aircraft fire-control radar antenna and/or part of an antenna used in space projects. The device has three functional interfaces. The tubular waveguide which is used for a horn which illuminates the parabolic antenna of the radar, the rectangular waveguide for the receiver and the smaller tubular part for the BNC connector of the transmitter.

Due to its functionality, this paper unearthed that the WEEE directive that dictates EU rules on treating electrical waste in a circular manner and RoHS that restricts using harmful elements in electronic equipment did not hold.

Although the different parts of the 12 GHz OMT are manufactured using different materials for optimal functionality, brass is mainly used as material of choice because apart from its conductivity, strength, and durability, it has good acoustic properties. This is a major advantage serving the purpose of the device is to separate the transmitted and received signal from each other. The main production method is by silver soldering because it can withstand the harsh environmental conditions to which it is exposed to. The device is gold coated to improve its functionality as gold improves the conductivity of the device.

Triangulation of three methods – R-9 strategies which was the primary method of analysis, expert interview and SolidWorks sustainability module – was used in the analysis of this research. After applying triangulation, in line with the objective of the research this paper concluded that for maximum positive impact on the environment the amount of material used had to be reduced.

# References


Bafana A, Kumar SV, Temizel-Sekeryan S, Dahoumane SA, Haselbach L & Jeffryes CS (2018) Evaluating microwave-synthesized silver nanoparticles from silver nitrate with life cycle assessment techniques. *The Science of the Total Environment.* 636: 936–943.

Baligidad SM, Kumar GC, Maharudresh AC & Elangovan K (2021) Experimental investigations on metallization in laser-sintered PA12 part using RF sputtering. *Applied Physics.* 127(7).

Balogun VA, Edem IF & Mativenga PT (2016) E-smart toolpath machining strategy for process planning. *The International Journal of Advanced Manufacturing Technology.* 86(5-8): 1499–1508.

Dheeraj K, Deepak raj M, Rakesh singh S, Vijay Kishore T & Bandhavi C (2022) Experimental determination of forming limit diagram for α + β brass at hot forming conditions. *Materials Today: Proceedings* 62: 4108–4116.

Eckelman MJ & Graedel TE (2007) Silver Emissions and their Environmental Impacts: A Multilevel Assessment. *Environmental Science & Technology* 41(17): 6283–6289.

Ekvall T & Andrae A (2006) Attributional and Consequential Environmental Assessment of the Shift to Lead-Free Solders (10 pp). *The International Journal of Life Cycle Assessment.* 11(5): 344–353.

Faludi J, Bayley C, Bhogal S & Iribarne M (2015) Comparing environmental impacts of additive manufacturing vs traditional machining via life-cycle assessment. *Rapid Prototyping Journal.* 21(1): 14–33.

Farrar D, Douglas DM, Swanson T, Collins C, Darrin A, Osiander R, (2007) *MEMS Shutters for Thermal control—Flight Validation and Lessons Learned.* AIP Conference Proceedings: American Institute of Physics 73–80.

Feili D, Pagel N, Ngo VL, Schwarz P & Seidel H (2010) Cu based patch antenna on polymer substrate for flexible wireless sensor systems applications. *Procedia Engineering* 5: 890–893.

Freialdenhoven T, Witte P, Kob S, Schleifenbaum JH, Dallmann T, (2022) *Different Metallization Techniques using a 3D Printed E-Band Orthomode Transducer.* : European Microwave Association 342–345.

Fuse M & Tsunemi K (2013) Cross-Border Impacts of the Restriction of Hazardous Substances: A Perspective Based on Japanese Solders. *Environmental Science & Technology /* 47(16): 9028–9034.

Guo S, Wang H, Liu X, Zhang Z & Liu Y (2024) Approaches for the Treatment and Resource Utilization of Electroplating Sludge. *Materials.* 17(7): 1707.

Hopulele I, Axinte M & Nejneru C (2014) Alloys with Acoustic Properties. *Applied Mechanics and Materials : AMM.* 657: 417–421.

International Conference on Information Management, Innovation Management and Industrial Engineering Xi'an Shi, China) (2009 : (2009) The New Tools of Enterprise's Innovation Management: Value Engineering. *2009 International Conference on Information Management, Innovation Management and Industrial Engineering :* 4: 507–510.

International Conference on Production and Operations Management Society Peradeniya, Sri Lanka) (2018 : (2018) A review on the impact of process energy on the environmental performance of milling. *2018 International Conference on Production and Operations Management Society :* 255–6.

Kausel W, Chatziioannou V, Moore TR, Gorman BR & Rokni M (2015) Axial vibrations of brass wind instrument bells and their acoustical influence: Theory and simulations. *The Journal of the Acoustical Society of America.* 137(6): 3149–3162.

Kinga Synkiewicz B, Skwarek A & Witek K (2014) Voids investigation in solder joints performed with vapour phase soldering (VPS). *Soldering & Surface Mount Technology* 26(1): 8–11.

Kurukulasuriya M, Gamage J & Mangala J (2020) Sustainable machining: Assessment of environmental performance of milling. *Procedia Manufacturing* 43: 455–462.

Liu ZY, Guo YB, Cao HJ, Zhao GY & Liu ZQ (2017) Embodied Energy in Dry Cutting under Consumption of Tool and Materials. *Procedia CIRP* 61: 535–540.

Maruthi N, Faisal M, Raghavendra N, Prasanna BP, Manohara SR & Revanasiddappa M (2021) Anticorrosive polyaniline-coated copper oxide (PANI/CuO) nanocomposites with tunable electrical properties for broadband electromagnetic interference shielding. *Colloids and Surfaces.* 621: 126611.

Masson A, Sabbah W, Riva R, Buttay C, Azzopradi S, Morel H, Planson D & Meuret R (2013) Die attach using silver sintering. Practical implementation and analysis. *European Journal of Electrical Engineering.* 16(3-4): 293–305.

Mehmanparast A, Taylor J, Brennan F & Tavares I (2018) Experimental investigation of mechanical and fracture properties of offshore wind monopile weldments: SLIC interlaboratory test results. *Fatigue & Fracture of Engineering Materials & Structures.* 41(12): 2485–2501.

Memar S, Azadi M & abdoos H (2023) An evaluation on microstructure, wear, and compression behavior of Al2O3 /brass matrix nanocomposites fabricated by stir casting method. *Materials Today Communications* 34: 105130.

Patton MQ. (2015) *Qualitative Research & Evaluation Methods : Integrating Theory and Practice.* Thousand Oaks, CA: SAGE.

Raab SJ, Guschlbauer R, Lodes MA & Körner C (2016) Thermal and Electrical Conductivity of 99.9% Pure Copper Processed via Selective Electron Beam Melting. *Advanced Engineering Materials.* 18(9): 1661–1666.

Rawat M & Rai JN (2013) Monitoring of Microbiological Attributes of Soil and Groundwater Exposed to Metal Industrial Effluents. *Clean : Soil, Air, Water.* 41(11): 1108–1115.

Rico-Fernández J, Vidarsson FV, Arrebola M, Fonseca NJG & Quevedo-Teruel O (2023) Compact and Lightweight Additive Manufactured Parallel-Plate Waveguide Half-Luneburg Geodesic Lens Multiple-Beam Antenna in the K$_{\mathrm{a}}$-Band. *Antennas and Wireless Propagation Letters.* 22(4): 684–688.

Scamans GM, Birbilis N & Buchheit RG, (2010) *Corrosion of Aluminum and its Alloys.*

Schlesinger M & Paunovic M, (2011) *Modern Electroplating: Fifth Edition.* Hoboken, NJ : Wiley.

Sharif A & Sharif A, (2019) *Recent Advancement of Research in Silver-Based Solder Alloys.* Weinheim, Germany : Wiley-VCH Verlag GmbH & Co.

Shashank Lingappa M, Srinath MS & Amarendra HJ (2018) On characterization of Microwave and Conventional Cast Bulk Brass. *Transactions of the Indian Institute of Metals.* 71(7): 1759–1769.

Singh SK, Kosaraju S, Lade J, Varma VD & Sandeep M, (2020) *Evaluation and Characterization of Rolling of Brass at Cryogenic Conditions.* Duxford, England ; Cambridge, Massachusetts ; Kidlington, England : Woodhead Publishing.

Song H, Bhadbhade N & Huang Y, (2016) *Sustainability Assessment and Performance Improvement of Electroplating Process Systems.*

WANG B, WANG N, YANG Y, ZHONG H, MA M, ZHANG X & LIU R (2018) Fabrication, microstructures and mechanical properties of ZrO 2 dispersion-strengthened Q345 steel. *Transactions of Nonferrous Metals Society of China = 中国有色金属学报（英文版）*. 28(6): 1132–1140.

Yilmaz Atay H, Uslu G, Kahmaz Y & Atay Ö (2020) Investigations of microstructure and mechanical properties of brass alloys produced by sand casting method at different casting temperatures. *IOP Conference Series.Materials Science and Engineering* 726(1): 12018.

Yue S, Tian S, Wang N, Xin T, Wang J & Xu G (2023) Measurements on the conductivity of copper coating with resonant cavity. *Radiation Detection Technology and Methods* 7(2): 248–254

# Appendix 1

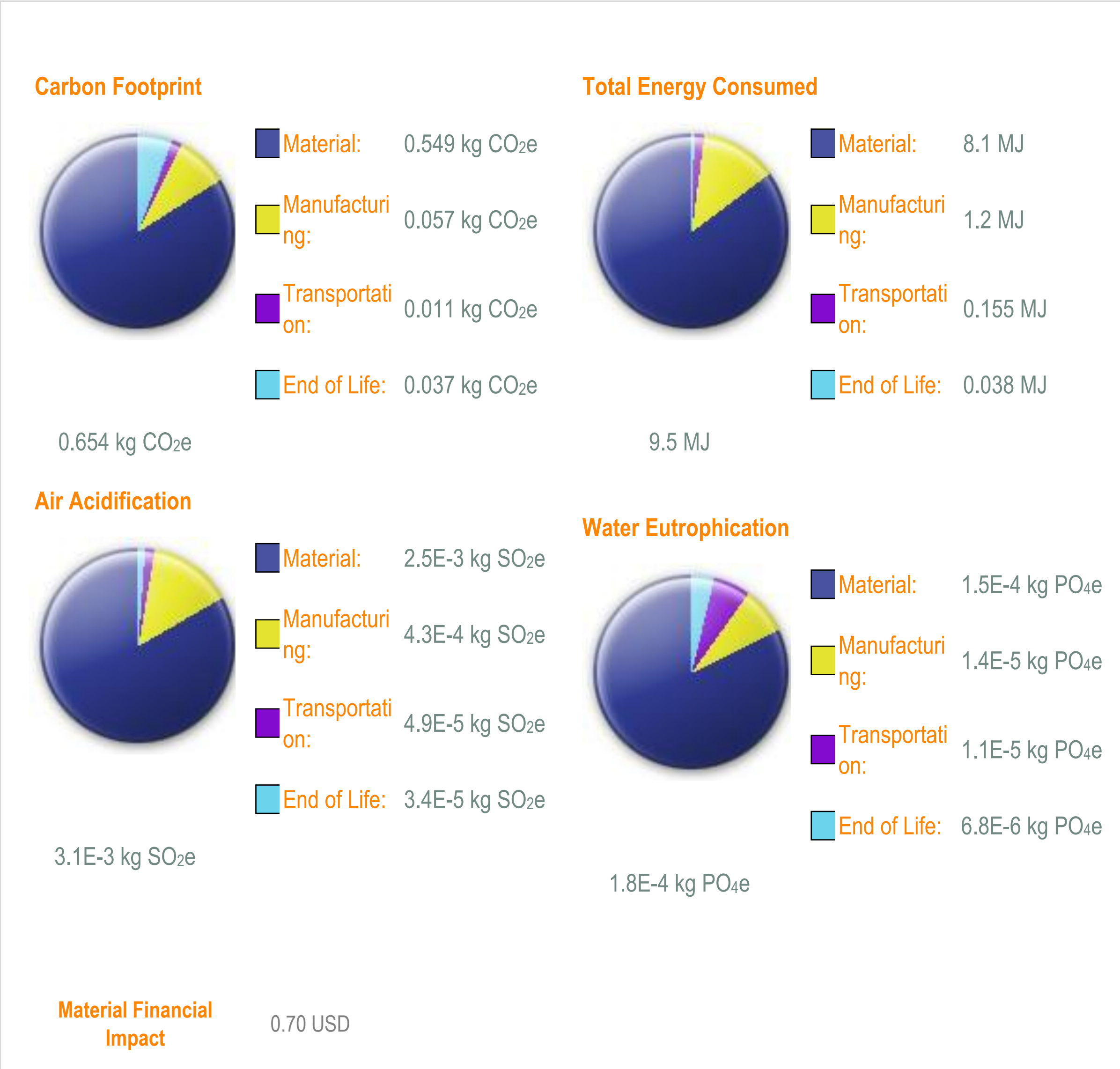



Figure 6: SW report of body using brass (SW).

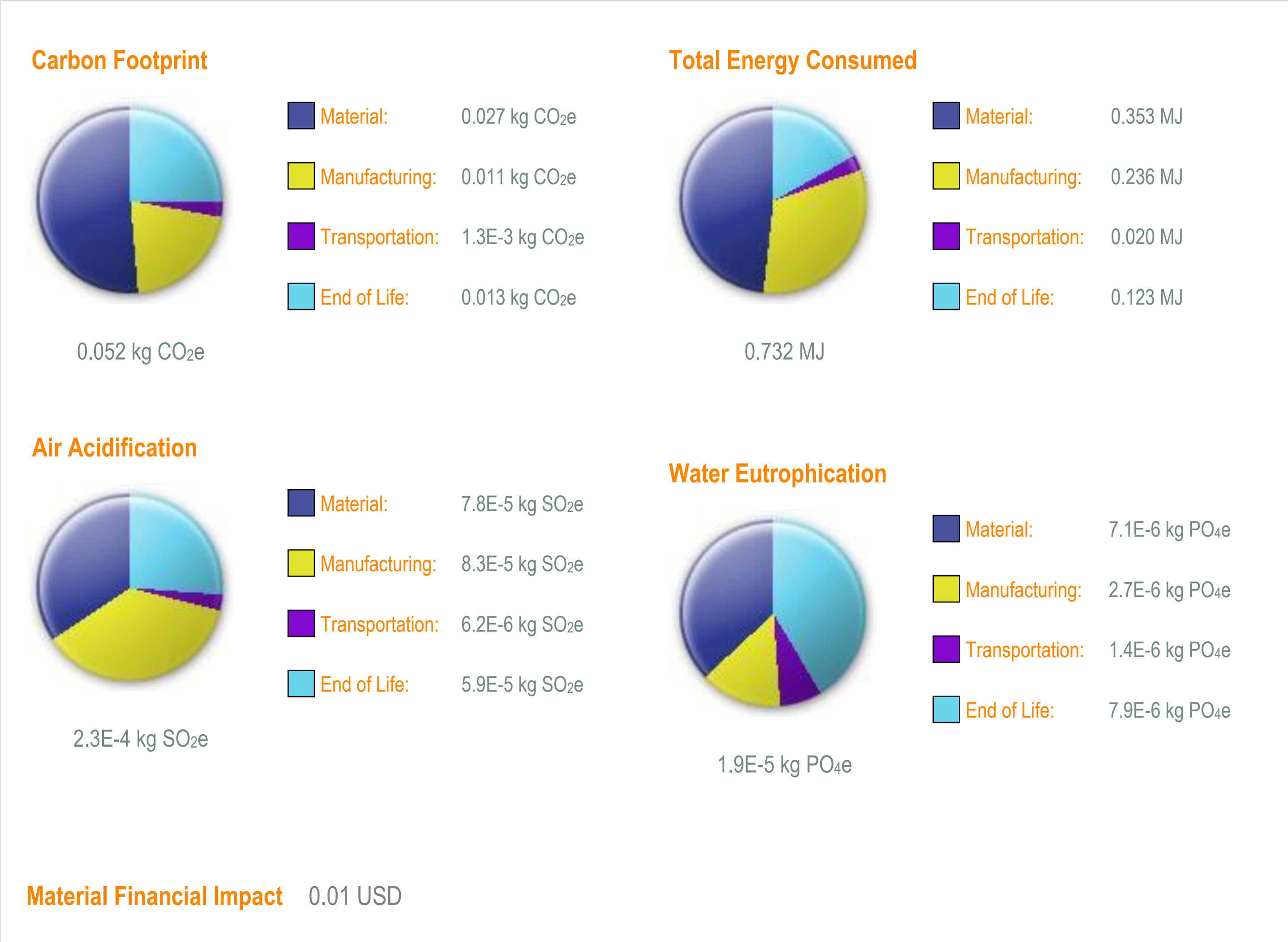



Figure 7. SW report of circular flange using AISI 1020 (SW).

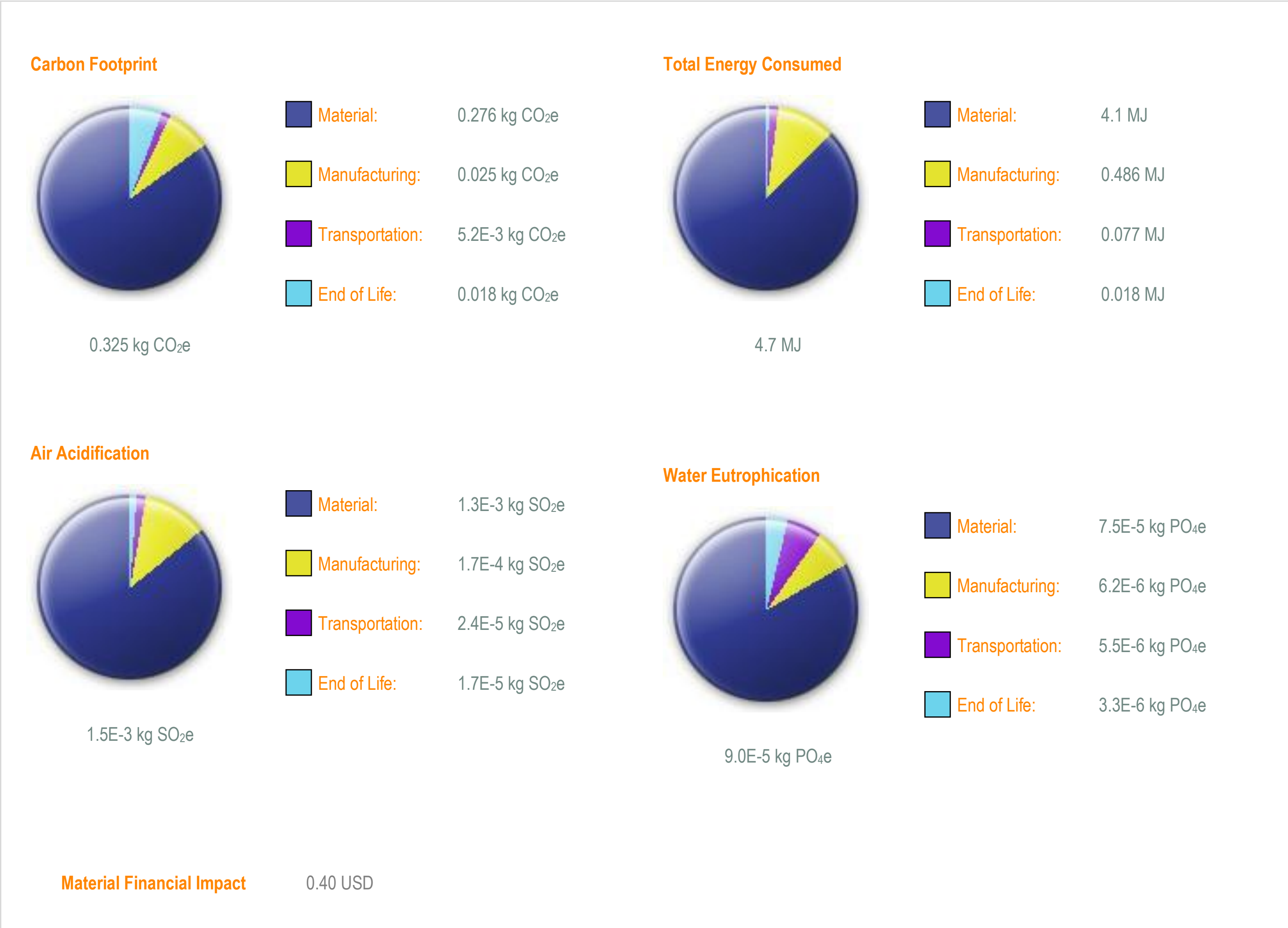



Figure 8. SW report of long tube using Brass (SW).

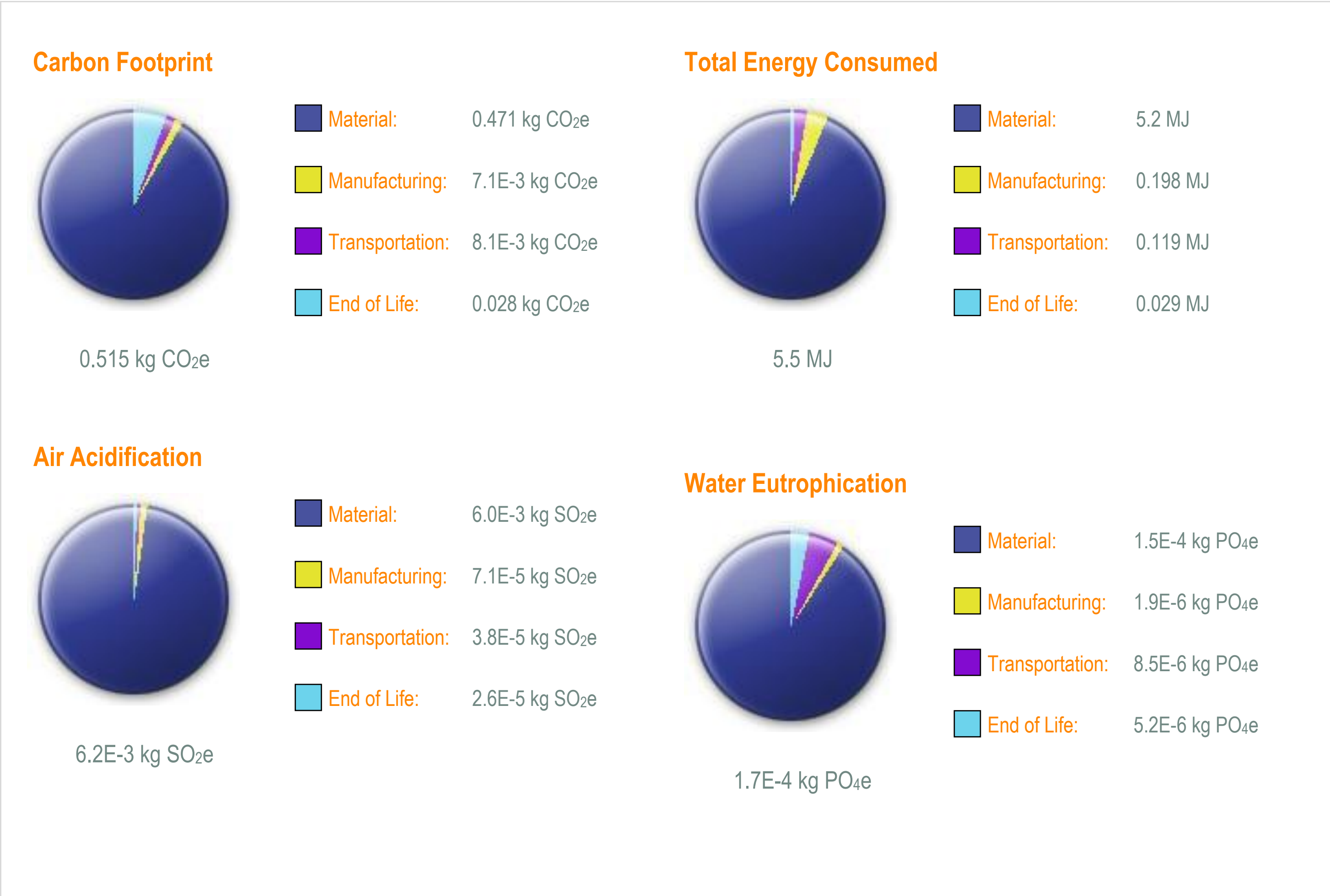



Figure 9. SW report of rectangular flange using Aluminum 1060 (SW).

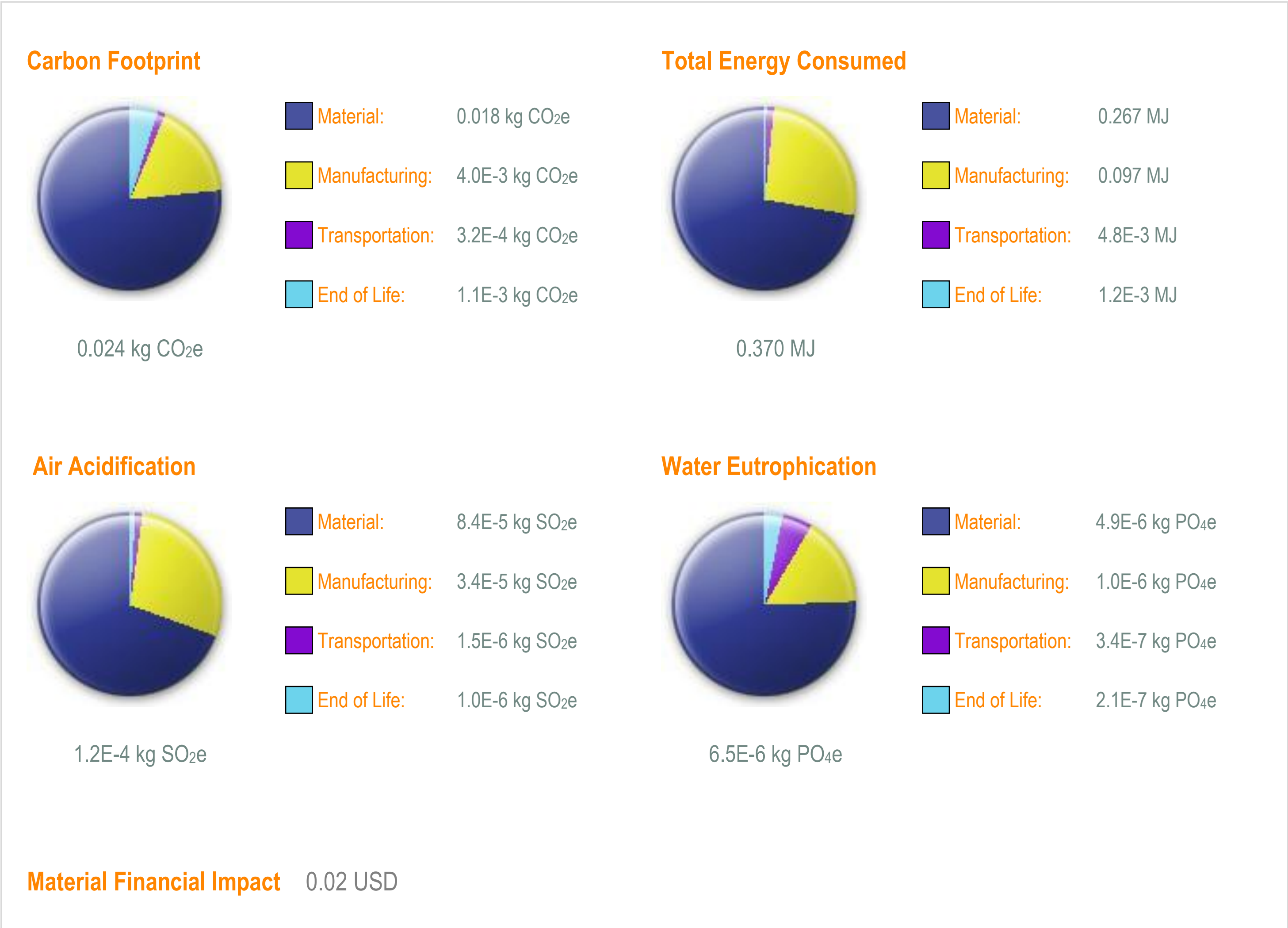
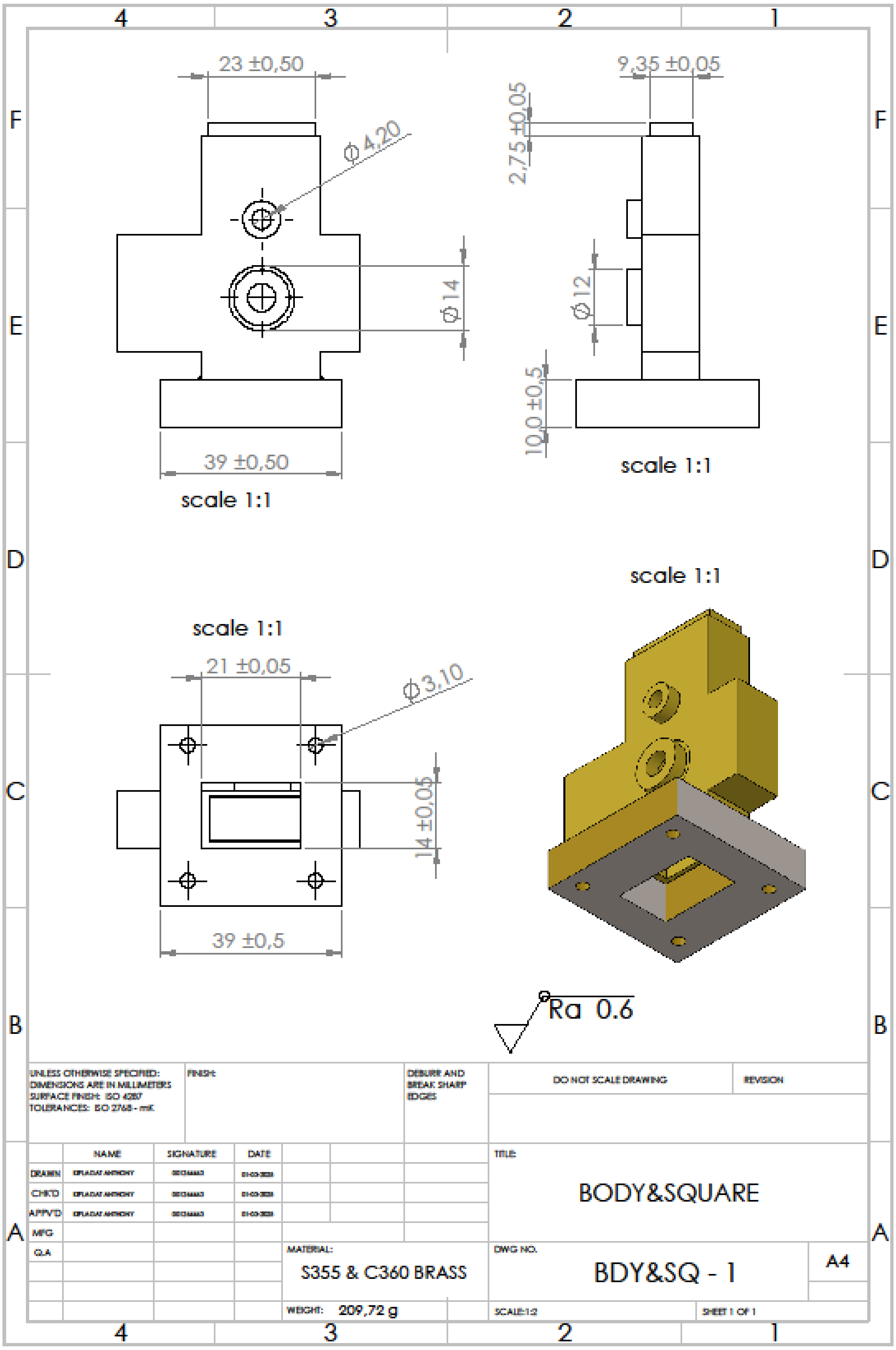
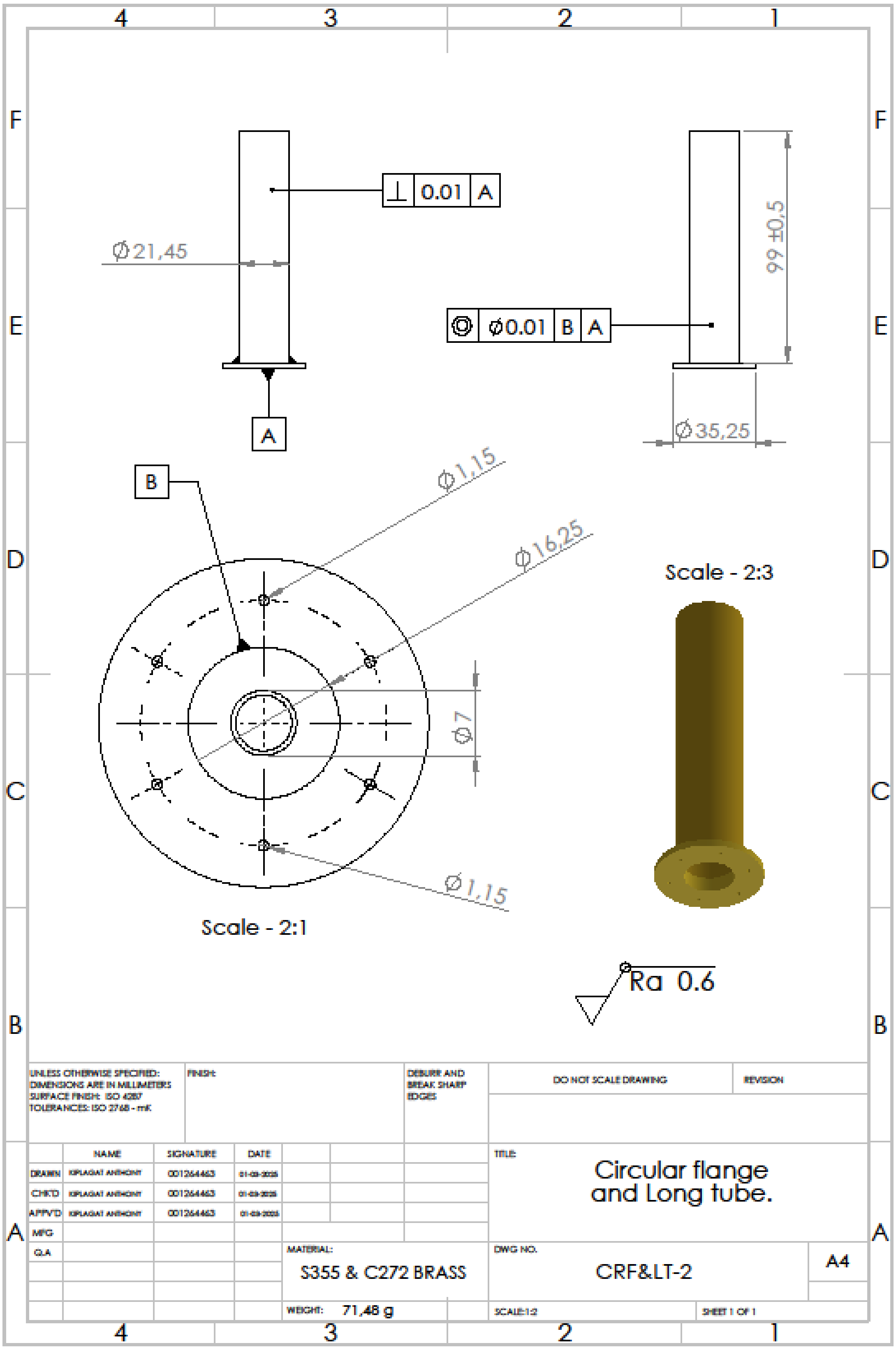
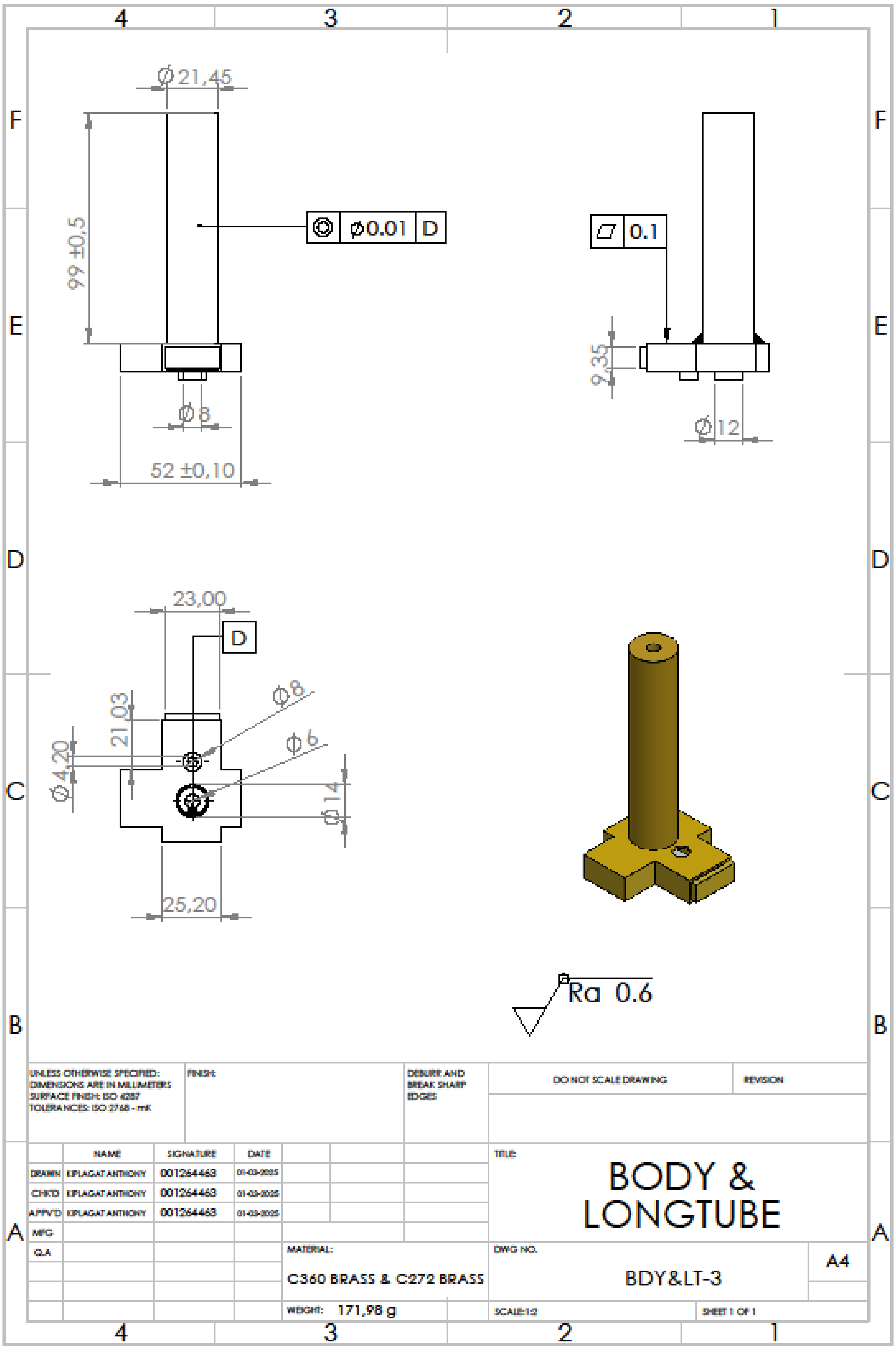



Figure 10. SW report of small tube using Brass (SW).

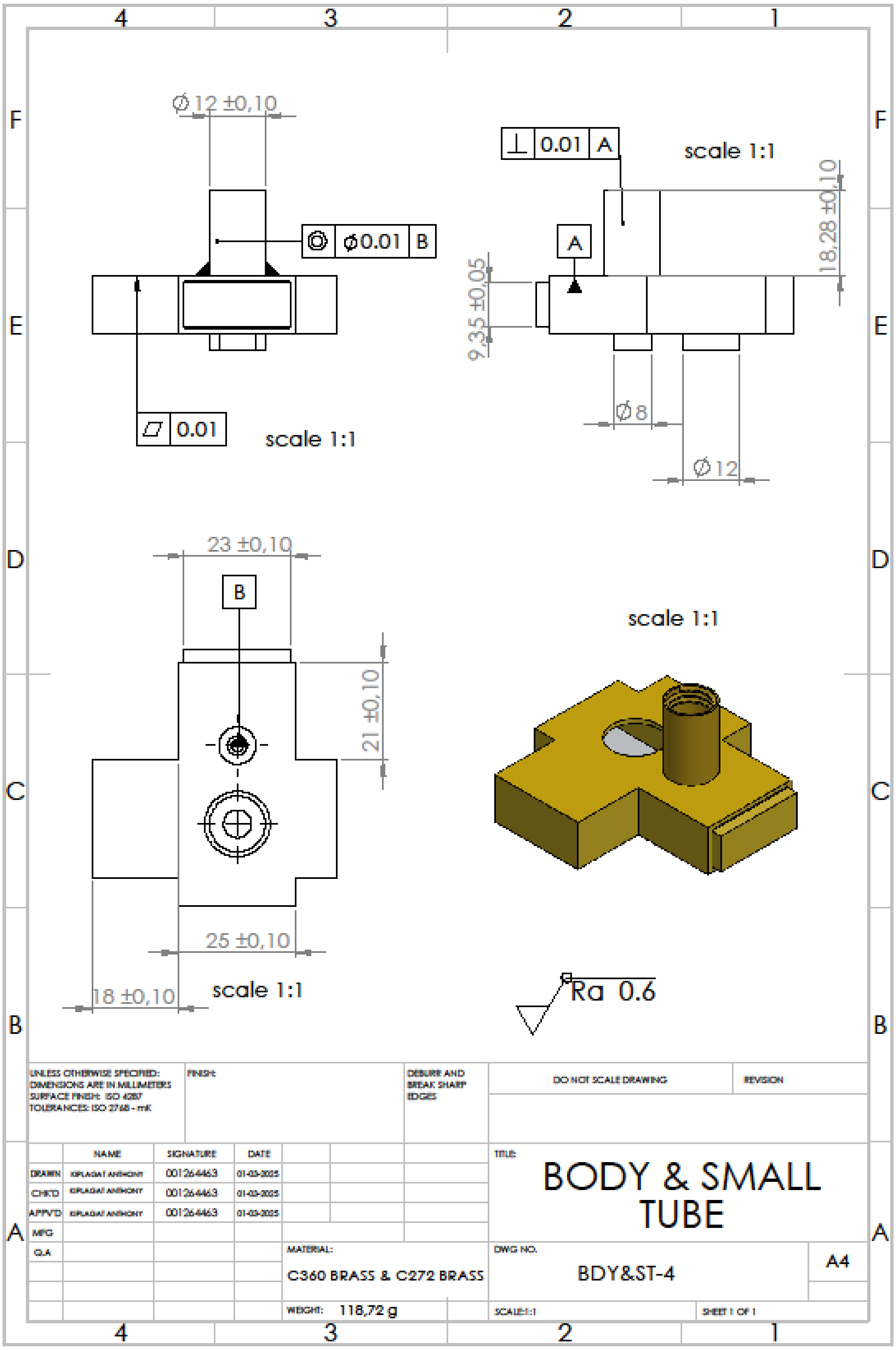

23 ±0,50
ϕ 4,20
ϕ 14
39 ±0,50
scale 1:1
9,35 ±0,05
2,75 ±0,05
ϕ 12
10,0 ±0,5
scale 1:1
scale 1:1
21 ±0,05
ϕ 3,10
14 ±0,05
39 ±0,5
scale 1:1
Ra 0.6
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH: ISO 4287
TOLERANCES: ISO 2768 - mK
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
BODY&SQUARE
MATERIAL:
S355 & C360 BRASS
DWG NO.
BDY&SQ - 1
A4
WEIGHT: 209,72 g
SCALE:1:2
SHEET 1 OF 1



⊥ 0.01 A
Ø21,45
Ø0.01 B A
99 ±0,5
A
Ø35,25
B
Ø1,15
Ø16,25
Ø7
Ø1,15
Scale - 2:1
Scale - 2:3
Ra 0.6
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH: ISO 4287
TOLERANCES: ISO 2768 - mK
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
KIPLAGAT ANTHONY
001264463
CHK'D
KIPLAGAT ANTHONY
001264463
APPV'D
KIPLAGAT ANTHONY
001264463
MFG
Q.A
TITLE:
Circular flange and Long tube.
MATERIAL:
S355 & C272 BRASS
DWG NO.
CRF&LT-2
A4
WEIGHT: 71,48 g
SCALE:1:2
SHEET 1 OF 1

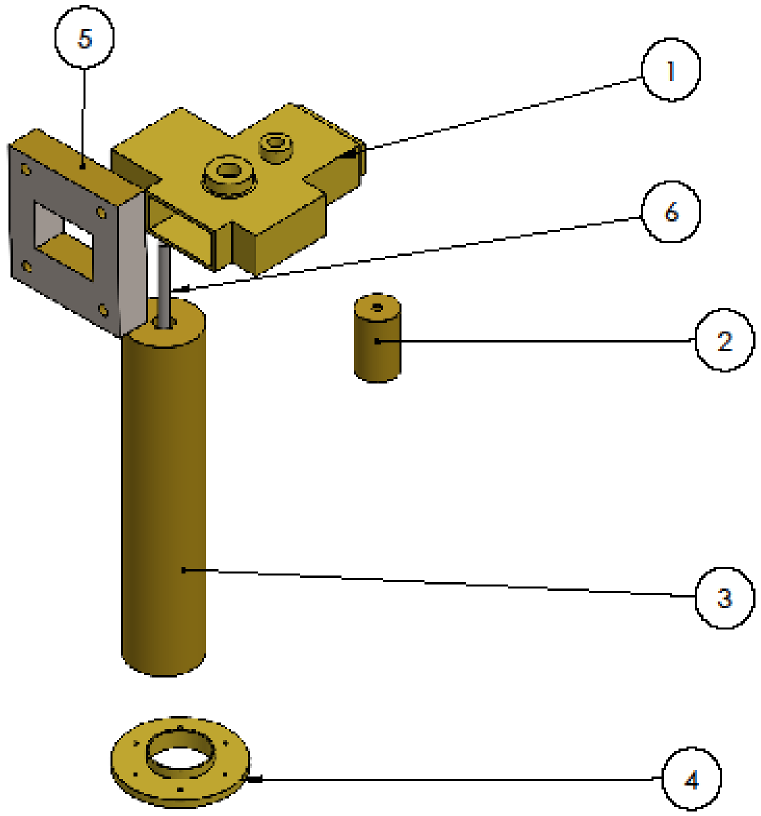


Ø21,45
99 ±0,5
Ø0.01 D
Ø8
52 ±0,10
0.1
9,35
Ø12
23,00
D
Ø8
21,03
Ø6
Ø4,20
Ø14
25,20
Ra 0.6
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH: ISO 4287
TOLERANCES: ISO 2768 - mK
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN KIPLAGAT ANTHONY 001264463 01-03-2025
CHK'D KIPLAGAT ANTHONY 001264463 01-03-2025
APPV'D KIPLAGAT ANTHONY 001264463 01-03-2025
MFG
Q.A
MATERIAL:
C360 BRASS & C272 BRASS
WEIGHT: 171,98 g
TITLE:
BODY & LONGTUBE
DWG NO.
BDY&LT-3
A4
SCALE:1:2
SHEET 1 OF 1



Ø12 ±0,10
Ø0.01 B
0.01
scale 1:1
0.01 A
A
scale 1:1
18,28 ±0,10
9,35 ±0,05
Ø8
Ø12
23 ±0,10
B
21 ±0,10
scale 1:1
25 ±0,10
18 ±0,10
scale 1:1
Ra 0.6
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH: ISO 4287
TOLERANCES: ISO 2768 - mK
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN KIPLAGAT ANTHONY 001264463 01-03-2025
CHK'D KIPLAGAT ANTHONY 001264463 01-03-2025
APPV'D KIPLAGAT ANTHONY 001264463 01-03-2025
MFG
Q.A
TITLE:
BODY & SMALL TUBE
MATERIAL:
C360 BRASS & C272 BRASS
DWG NO.
BDY&ST-4
A4
WEIGHT: 118,72 g
SCALE:1:1
SHEET 1 OF 1

| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | BODY | C360 BRASS | 1 |
| 2 | SMALL TUBE | C272 BRASS | 1 |
| 3 | LONG TUBE | C272 BRASS | 1 |
| 4 | CIRCULAR FLANGE | STEEL (S355) | 1 |
| 5 | RECTANGLE FLANGE | ALLUMINIUM 1060 | 1 |
| 6 | DIODE | STAINLESS STEEL | 1 |




UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH: ISO 4287
TOLERANCES: ISO 2768 - mK

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

| | NAME | SIGNATURE | DATE |
|---|---|---|---|
| DRAWN | KIPLAGAT ANTHONY | 001264463 | [illegible] |
| CHK'D | KIPLAGAT ANTHONY | 001264463 | [illegible] |
| APPV'D | KIPLAGAT ANTHONY | 001264463 | [illegible] |
| MFG | | | |
| Q.A | | | |

MATERIAL:

WEIGHT: 286,15 g

TITLE:

# ASSEMBLY

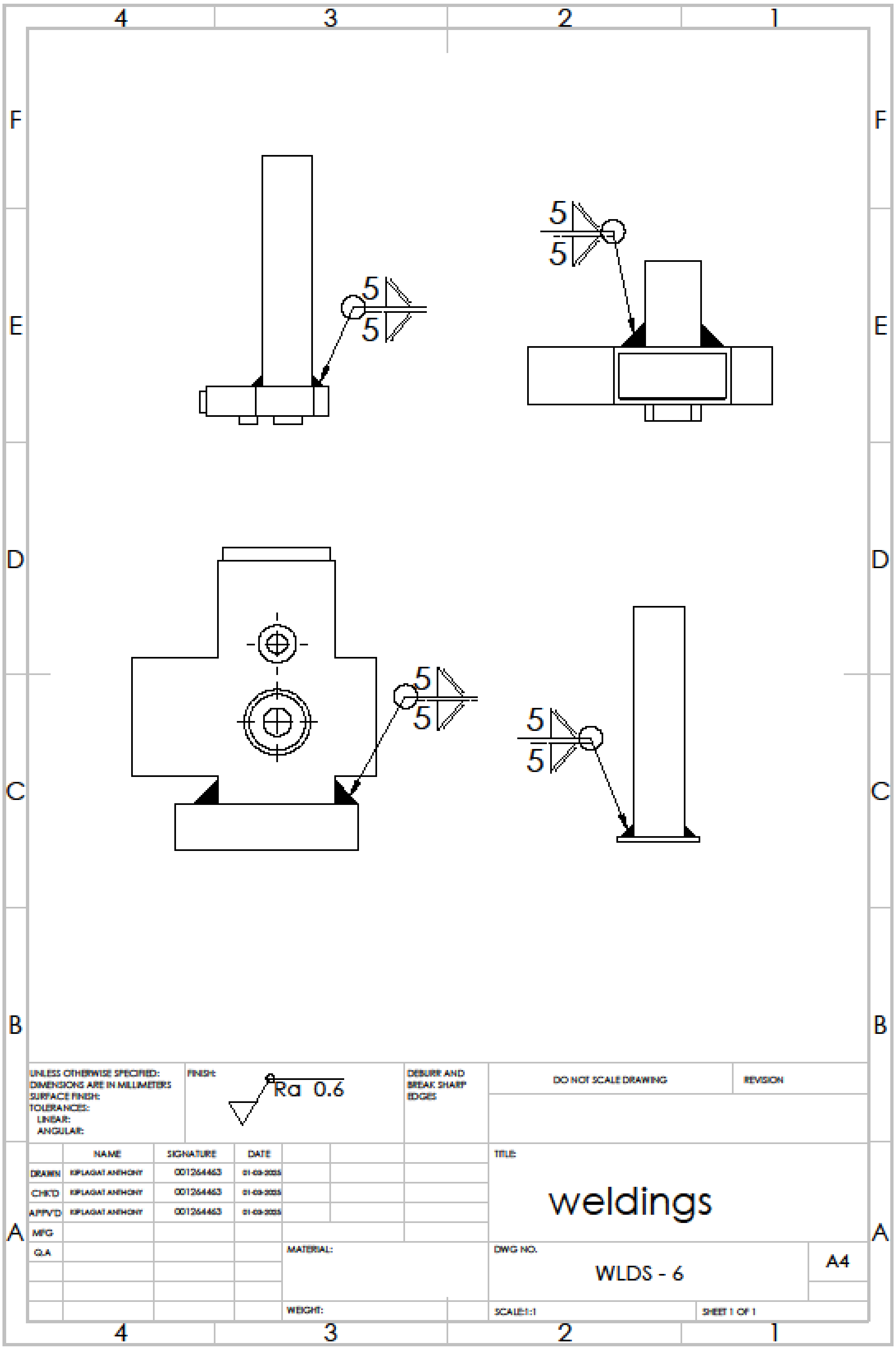
DWG NO.

## ASS-5

A4

SCALE:1:2

SHEET 1 OF 1


5
5
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
Ra 0.6
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN KIPLAGAT ANTHONY 001264463 01-03-2025
CHK'D KIPLAGAT ANTHONY 001264463 01-03-2025
APPV'D KIPLAGAT ANTHONY 001264463 01-03-2025
MFG
Q.A
TITLE:
weldings
MATERIAL:
DWG NO.
WLDS - 6
A4
WEIGHT:
SCALE:1:1
SHEET 1 OF 1