



BRINGING THE CIRCULAR ECONOMY IN WALES

Research proposal

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Introduction

The importance of recycling waste

Understanding the significance of recycling and end-of-life usage is critical in promoting sustainability, resource conservation and environmental sustainability. Recycling allows for the recovery and reuse of valuable materials from products that have reached the end of their lifecycle. Furthermore, recycling conserves natural resources and reduces the need for virgin raw materials, mitigating the environmental impact associated with resource extraction and processing (King, et al., 2006).

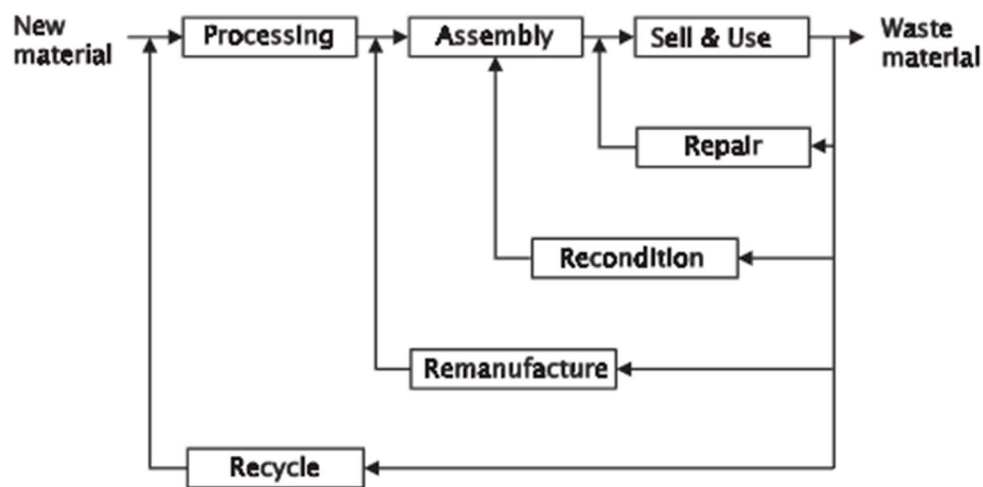


Figure 1. The closed-loop design of repair, manufacturing and recycling (King, Burgess, Ijomah, & McMahon, 2006,p.260)

To enhance sustainability, designers must take a comprehensive approach considering every aspect of a product's life cycle, from obtaining raw materials to manufacturing, use, and eventual disposal. A fundamental framework that emerges as pivotal is the closed-loop design, whereby the waste materials are integrated to serve as new inputs for manufacturing raw material sources.

This principle is illustrated in Figure 1, which illustrates closed-loop design strategies such as repair, remanufacturing, or recycling. Essentially, the fate of waste materials can be categorised into two possibilities: reuse within a closed-loop system or dissipation into an open-loop system, aligning with the principle of the conservation of mass (King, et al., 2006). Furthermore, the growing demand for rare earth elements (REEs), categorised as critical by entities such as the United States and the European Union, has witnessed an increase in global demand since 1995, with a 60% surge in production over the last decade (Hayes & McCullough, 2018). Similarly, metals such as cobalt and lithium are considered vulnerable in the supply chain, as explained in Appendix 1 and Appendix 2 (Fortier, et al., 2018).

Moreover, Figure 2 shows that the growth has exceeded 300% due to the extensive use in automotive, aerospace, defence, and telecommunications. Similarly, indium, a geologically scarce metal crucial for flat panel displays and solar photovoltaics (PVs), has seen its global demand climb to over 750 metric tons annually in recent years—a 125% increase since 2000 (Babbitt, et al., 2021).

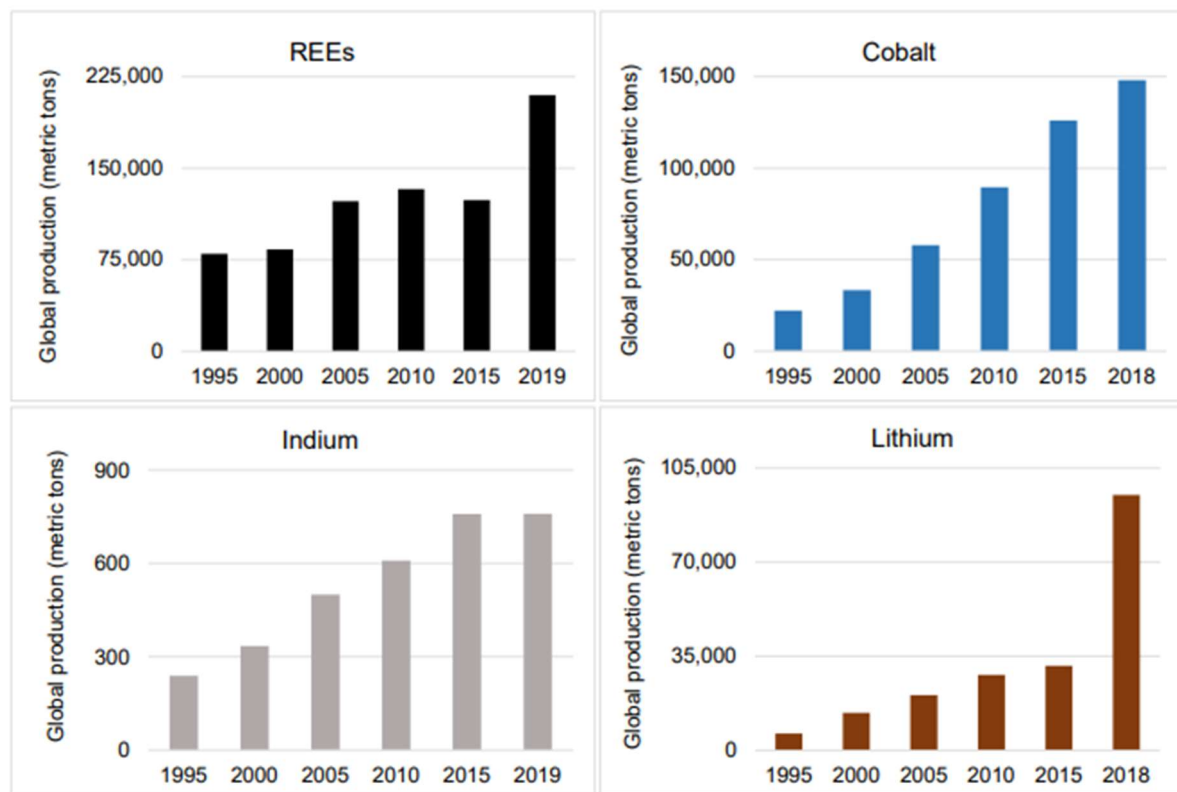


Figure 2. Worldwide productions of critical material: Rare Earth elements, cobalt, indium and lithium (p.356)

Understanding the Circular Economy

The essence of the circular economy (CE) lies in advocating for a departure from linear economic models towards circular principles, where waste and recycled materials are viewed as valuable resources (Khalifa, et al., 2022). This fundamental approach is motivated by a significant goal: to address environmental challenges and secure long-term sustainability for humanity. The circular economy concept is complex, drawing inspiration from a range of related concepts such as sustainable development, green economy, functional economy, life cycle thinking, industrial ecology, shared value, extended producer responsibility, and eco-design (Reuter, et al., 2019). However, the transition from linear to circular models presents several challenges, according to Korhonen et al. cited in Sehnem, Vazquez-Brust, Pereira, and LM Campos (2019), including technological barriers, regulatory constraints, economic incentives, and cultural shifts (Sehnem, et al., 2019). Additionally, integrating

the circular economy concept into broader policy frameworks and business strategies is crucial to ensure widespread adoption and implementation (Korhonen, et al., 2018).

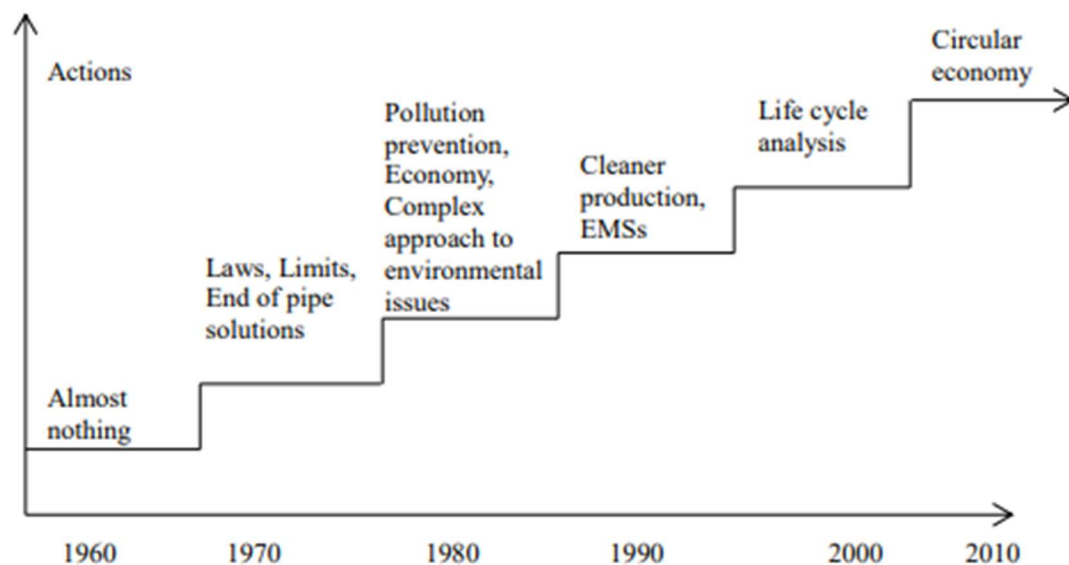


Figure 3. Graph of the Circular Economy (Tambovceva & Titko, 2017,p.34)

Figure 3 illustrates the evolution of the circular economy (CE) concept, highlighting its significance over the past 60 years. Originating from the principles of environmental protection and sustainable development, the idea has gradually evolved into the circular economy framework, marking significant advancements from its inception to the present era (Tambovceva & Titko, 2017).

Aim of the Research

Project Objectives

This project aims to offer essential technical and academic assistance to businesses in Wales. A panel will be established from which an investigated team will assist Welsh companies in pursuing sustainable production methods. In collaboration with MADE Cymru and their team of experts, the author will conduct a comprehensive Circular Economy Assessment in Welsh businesses (MADE_Cymru, 2024).

Approach

A comprehensive Circular Economy Assessment will be performed to evaluate and enhance every stage of the product lifecycle. This includes assessing the sustainability of raw materials and improving the efficiency of end-of-life recycling processes. The primary focus will be assisting Aston Martin Lagonda, particularly in recycling PLA used in 3D printing without depleting natural resources.

Educate and Awareness

Another primary goal will be to educate consumers about the importance of proper disposal and recycling options available for products at the end of their lifecycle. This includes promoting awareness about recycling opportunities when returning products at their end of life.

Research questions

1. How effectively can the circular economy principles be implemented in Wales?
2. How can adopting circular economy principles be optimised within manufacturing processes, specifically regarding PLA production and testing?
3. How can collaborative initiatives between industry, academia, and government agencies foster innovation and facilitate knowledge exchange in the field of material sustainability and manufacturing?

Importance of bringing the Circular economy to Wales

Introducing the Circular Economy to Wales carries significant importance, as highlighted by the Welsh Government's emphasis on prioritising sustainability alongside fostering economic growth. In recent years, Wales has made intensive efforts to position itself as a global pioneer in waste reduction, emphasising the promotion of reuse and repair initiatives alongside traditional economic growth strategies. Figure 4 shows evidence of the importance of circular economy in Wales; David Cheshire, cited in AECOM's Building Revolutions division, has conducted a comparative analysis of circular economy buildings and conventional buildings. This visual representation draws upon concepts introduced by Coert Zachariasse and research conducted at Loughborough University (Constructing_Excellence_in_Wales, 2017).

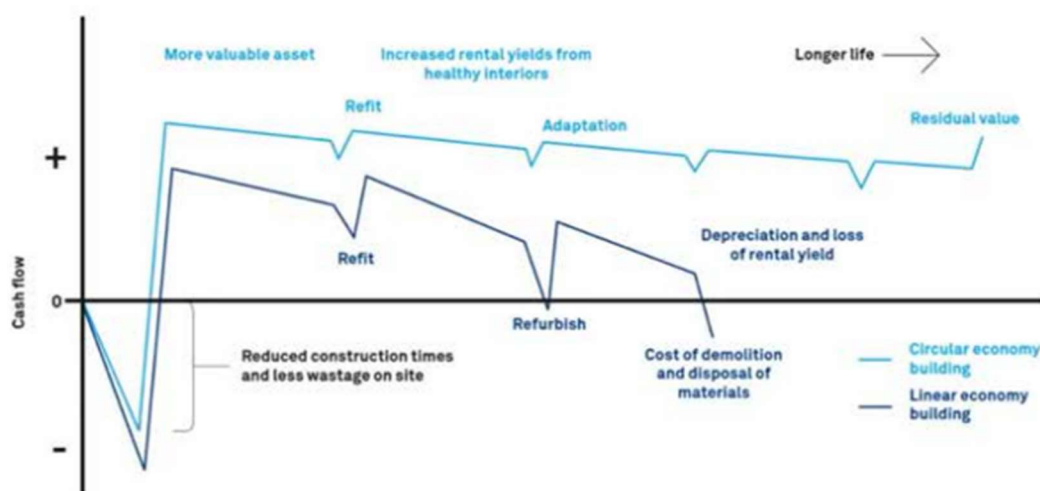


Figure 4. Beneficial of Circular Economy in Wales (Constructing_Excellence_in_Wales, 2017,p.13)

Research Boundaries for Circular Economy Implementation in Wales

Figure 5 outlines the primary boundaries of this proposal, highlighting essential tasks and the project objectives quickly.

Research Topic: Bring the Circular Economy in Wales

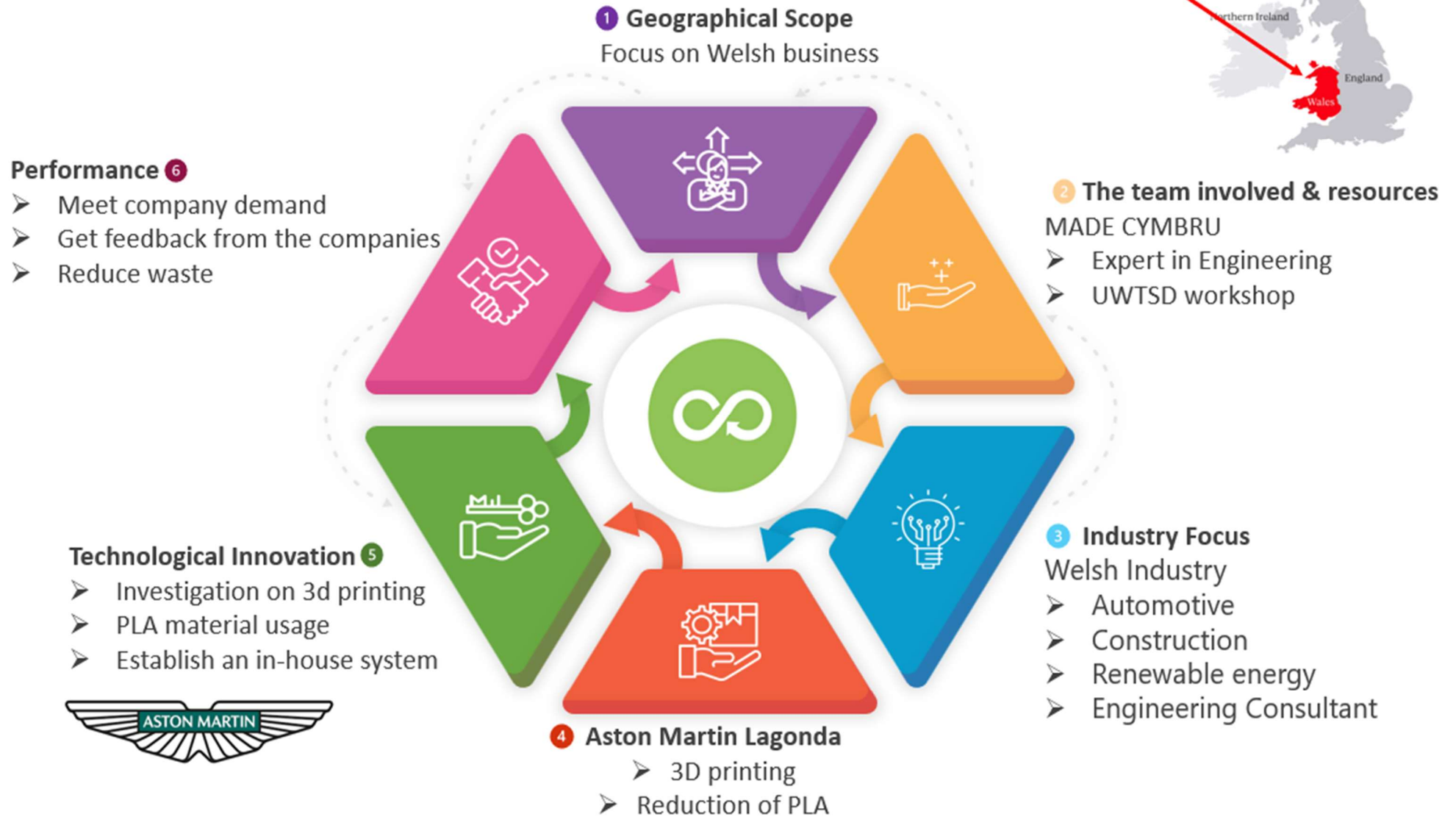


Figure 5. The leading brainstorm of the Circular Economy in Wales

Literature review

Exploring the Growth and Impact of the Circular Economy

The aim of the CE is (Viceda, 2024):

QT1 *“The Circular Economy is an economic system that eliminates pollution and waste by retaining resources and manufactured goods within the system through innovation, **reuse and repair, redistribution, recondition, and recycling processes**, all of which are powered by **renewable energy**.”* (Viceda, 2024, p. 1).

Figure 6 illustrates the moderate growth of the Circular Economy (CE) from 2005 to 2020. Initially, there was a gradual increase in the number of published documents, with a notable rise observed from 2008 onwards. However, starting from 2008, there has been a noteworthy increase in research activity, with the number of publications steadily rising to 112 records by 2020. This represents an average growth rate of 18.5% over the analysed period. Since the establishment of the Ellen MacArthur Foundation (EMF) in 2010, interest and research in the CE have intensified drastically.

The number of citations follows a similar growth pattern to the publications, generally increasing with a growth rate of 11%. Also, the total number of citations peaked at 8036 in 2017 before gradually decreasing due to the time needed for a new publication to have an impact. These trends are robust indicators of the scientific productivity, influence, and sustained interest in the Circular Economy throughout the analysed period. They highlight the evolving discourse surrounding CE and underscore its increasing relevance in addressing contemporary environmental and economic challenges (Norouzi, et al., 2021).

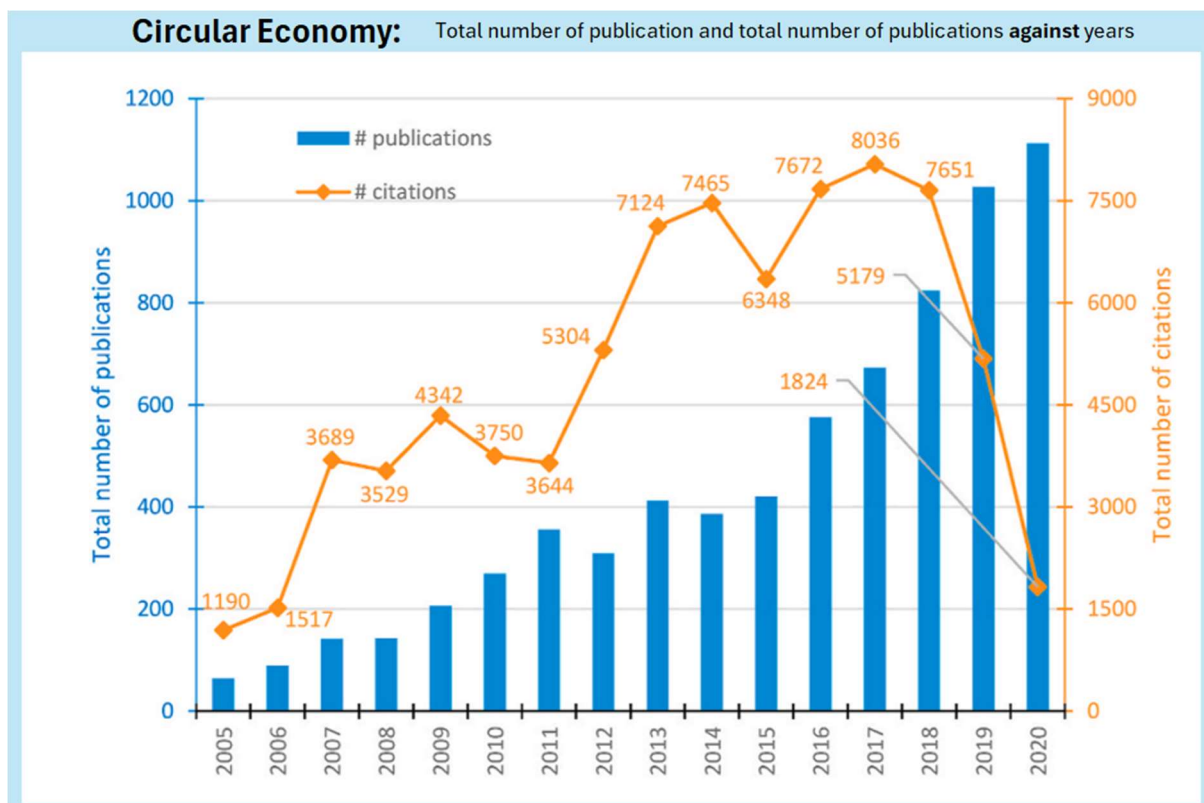


Figure 6. The number of publications over the years in the CE (Norouzi, Chàfer, Cabeza, Jiménez, & Boer, 2021, p.5).

On the other hand, Figure 7 illustrates the progression of publication numbers for the top 10 productive countries. Notably, China emerged as the most prolific country during this period, experiencing two distinct phases of intense growth, beginning in 2008 and continuing into 2015. This highlights China's significant role in advancing CE research and innovation.

Additionally, there was a notable increase in CE-related publications from European Union (EU) countries in 2015, likely influenced by the European Commission's strategy on CE introduced in 2014 and the revised CE package in 2015 (Norouzi, et al., 2021).

The Circular Economy (CE) has emerged as a pivotal concept in addressing contemporary environmental and economic challenges. The author emphasises that analysing publications from the top 10 countries provides valuable insights into the global landscape of Circular Economy (CE) research.

This approach helps highlight diverse regional dynamics, the influence of policies worldwide, and the promotion of sustainable practices on a global scale.

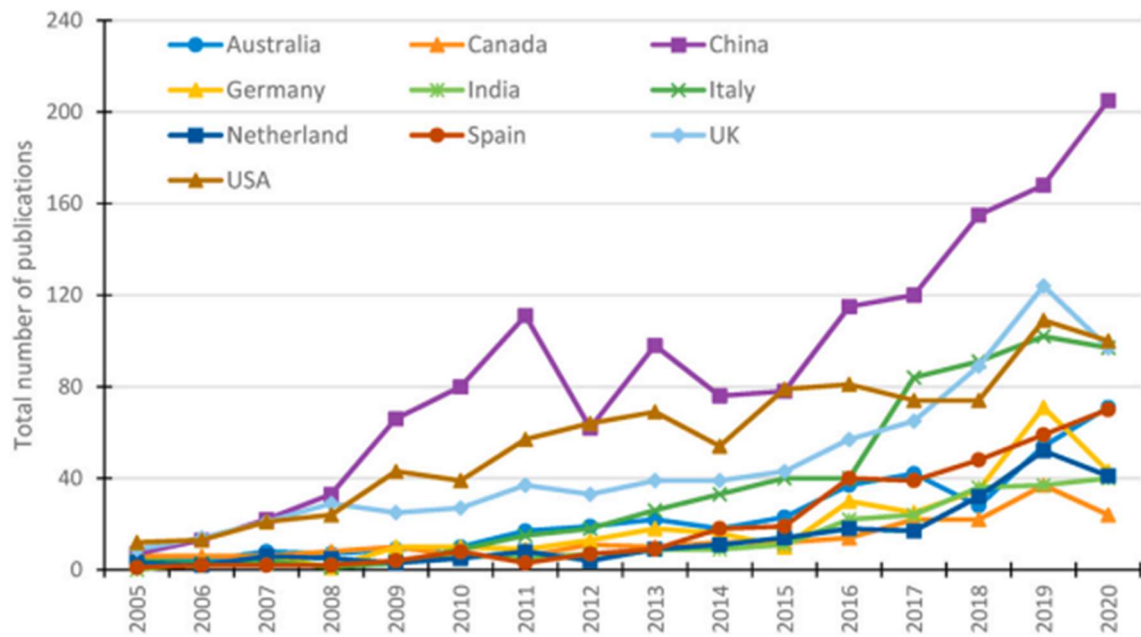


Figure 7. The main ten productive countries trend in the Circular Economy (Norouzi, Chàfer, Cabeza, Jiménez, & Boer, 2021,p.6)

Design considerations for the Circular Economy: Key principles and significance in Lifecycle-Management

The design plays a crucial role in ensuring that the product follows the circular principles right from the start of its lifecycle. Design decisions extensively influence the potential for reusing, recycling, or repurposing materials, thus contributing to the product's overall sustainability. These regulations encompass factors such as spare parts availability, ease of repair, and end-of-life treatment (Commission, 2019).

To accelerate the adoption of circular practices across global supply chains, five main principles outlined by the Commission (2019) and discussed by Tambovceva and Titko (2017) need to be considered (Commission, 2019) (Tambovceva & Titko, 2017):

- **Design out waste:** by eliminating waste through a correct design that is easy to disassemble.
- **Build resilience through diversity:** A diverse system, characterised by features such as modularity, versatility, and adaptability, enhances resilience against external shocks.
- **Rely on renewable energy:** Given the substantial energy consumption in production processes, transitioning to renewable energy sources is essential for sustainable manufacturing systems.
- **Think in systems:** Drawing inspiration from living systems, the circular economy optimises entire systems rather than individual components. Understanding the interconnectedness of different system parts is critical.

- **Waste is food:** In a circular economy, products and materials should circulate through various technological and biological applications.

By considering these five vital steps, the author argues that designers can play a crucial role in advancing the circular economy agenda and ensuring product longevity. This includes incorporating high-quality materials and robust design principles.

Importance of recycling Polylactic Acid (PLA)

It is important to remember that (Muñoz, et al., 2020):

QT2: “Circular economy is based on the regeneration of the components and materials. It uses the waste as a participant in the manufacturing process so decreases the use of virgin materials.” (p.2).

Aston Martin encounters challenges in recycling and reusing materials, particularly in creating innovative tools using 3D printing technology, often involving materials like polylactic acid (PLA) and Hyper-speed (PLA). Therefore, recycling PLA aligns well with the main principle of the circular economy, which aims to keep materials and resources in use for as long as possible through recycling, reusing and remanufacturing (Sivasankaran & Radjaram, 2020).

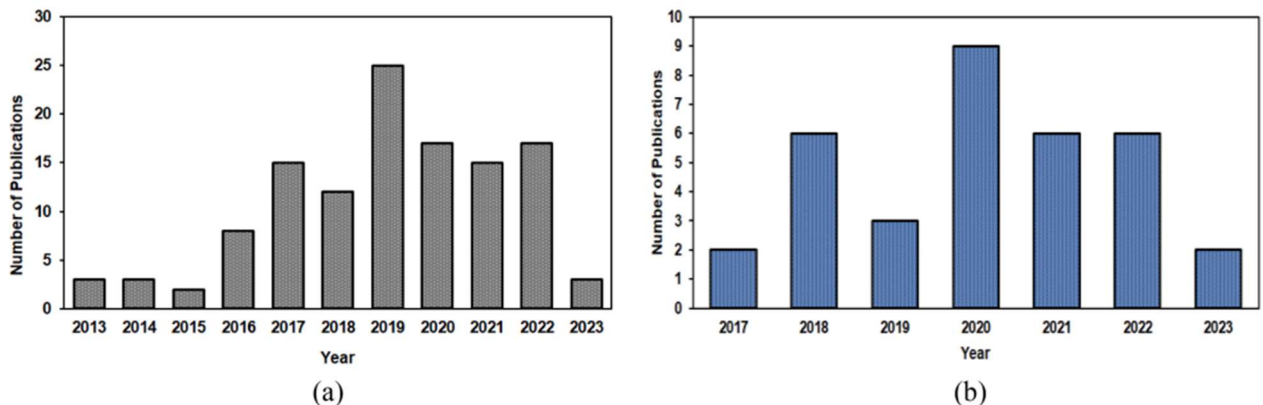


Figure 8. Number of publications each year against LCA of PLA and b) PLA used in the 3D printer (Hasan, Davies, Pramanik, John, & Biswas, Potential of Recycled PLA in 3D Printing: A Review., 2024, p.4)

Figure 8 illustrates a notable increase in Life Cycle Assessment (LCA) studies and the use of recycled plastic in Additive Manufacturing (AM) from 2017 to 2019, following a previous decline in this trend. On the other hand, Figure 8b demonstrates an increasing number of studies focusing on LCA of additive manufacturing processes, particularly those involving 3D printed components, with a significant peak observed in 2020 (Hasan, et al., 2024).

PLA is typically derived from renewable resources such as cornstarch or sugarcane. By recycling PLA, we can conserve these valuable natural resources and reduce the reliance on finite fossil fuels used to

produce traditional plastics (Kreiger & Pearce, 2013). Another important aspect that will need to be considered is that 3D printing enhances sustainability, and personalised products are less likely to be discarded (Woodson, 2015).

Framework to enhance Sustainability: Closed-Loop approach for (PLA) recycling

The main framework that has been used for recycling PLA is the creation of a closed-loop system. Creating an effective closed loop, as evidenced in Figure 9, ensures that waste is collected, processed, and reintroduced into the production cycle. This circular approach minimises waste generation, maximises resource utilisation, and reduces the need for new raw materials (Zhao, et al., 2018).

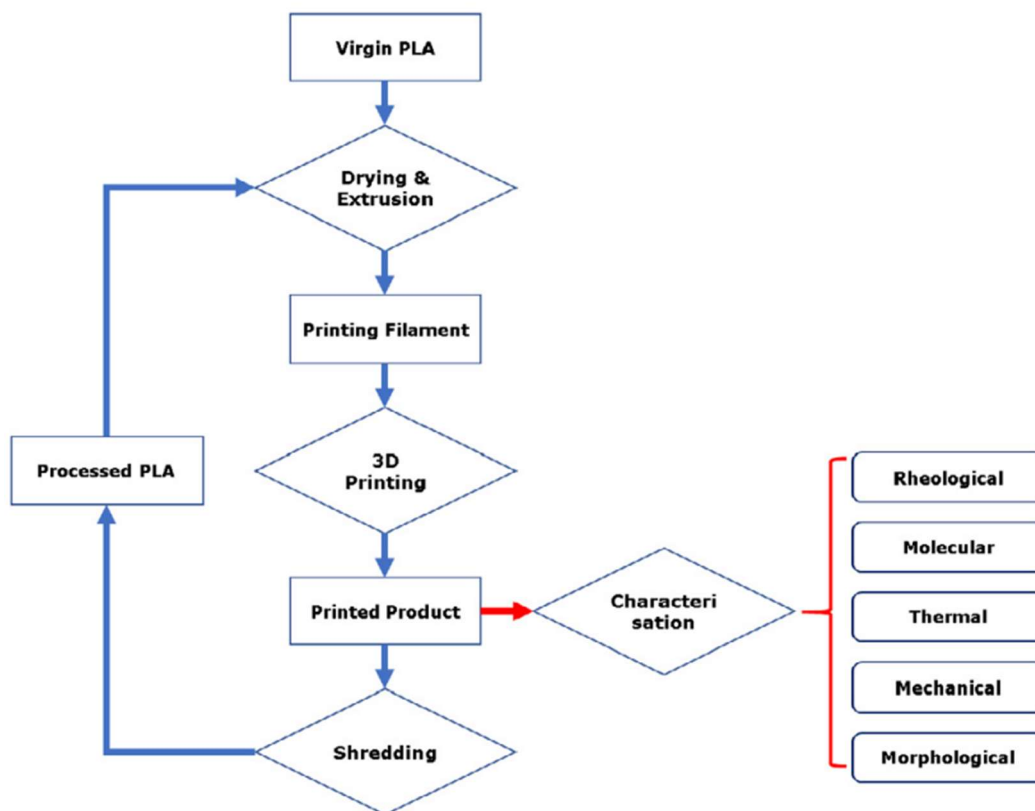


Figure 9. Close-looped recycling of Polylactic Acid that can be utilised in the 3D printing (Zhao, Rao, Gu, Sharmin, & Fu, 2018, p.1048)

Although the PLA is viewed as a more friendly option, it may not be economically viable; indeed, the emission generated from the mechanical recycling process could dismiss its environmental performance in some indicators (Zhao, et al., 2018). Nevertheless, Hahladakis et al. and Zhao explain that when considering the single-score value, it is evident that closed-looped recycling emerges as the most suitable option up of the three alternatives, as illustrated in Figure 10 (Hahladakis, et al., 2018) (Zhao, et al., 2018).

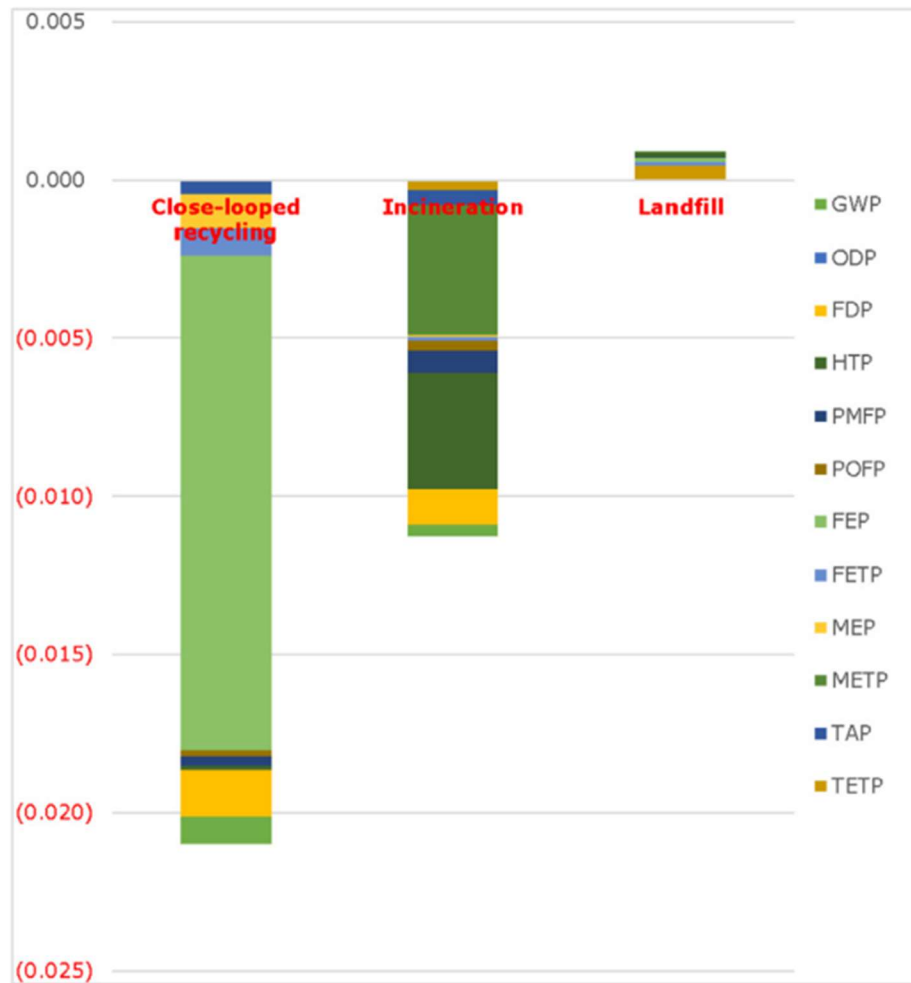


Figure 10. The disposal of 1kg PLA into three different types of end-of-life (p.1053)

Bringing CE in Wales

An effective CE in Wales will have two vital points (Liu, et al., 2023) (Constructing_Excellence_in_Wales, 2017):

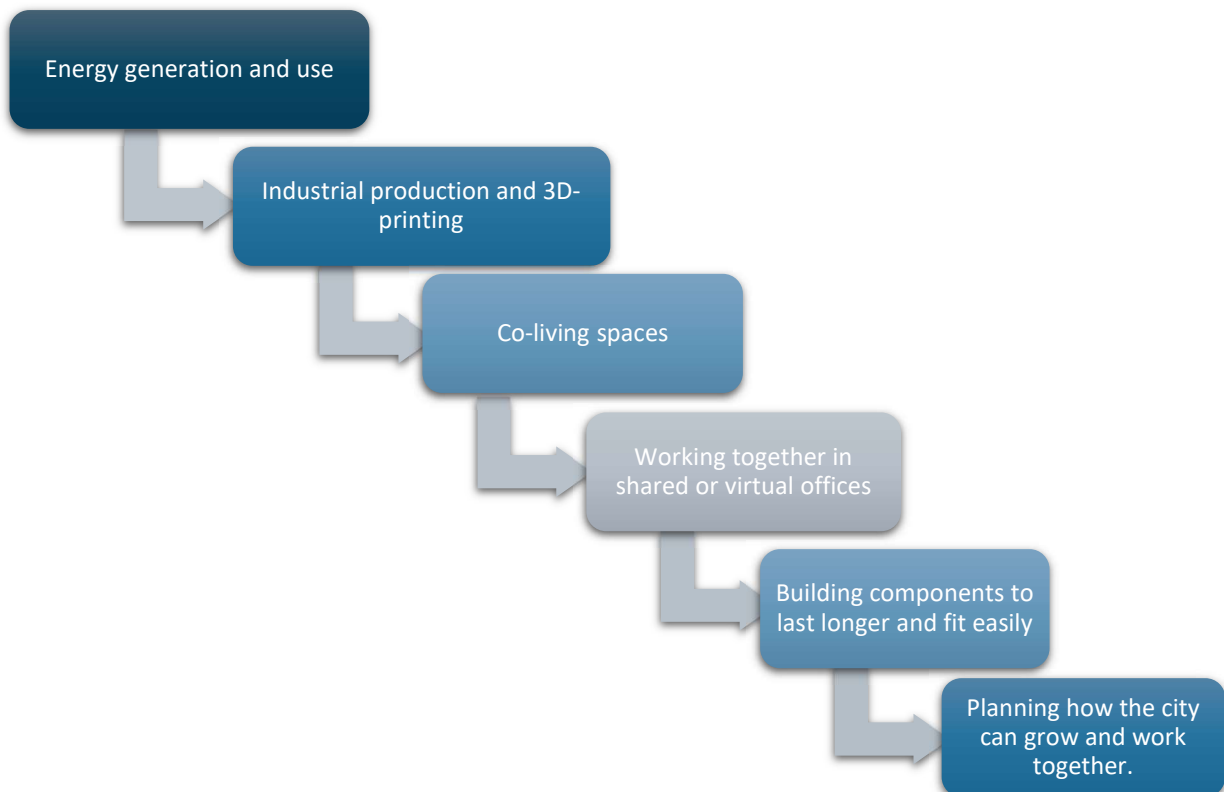
Table 1. Effective CE in Wales

Environmental	By minimising resource extraction, reducing pollution, and lowering energy consumption, the Circular Economy contributes significantly to environmental preservation and climate change mitigation. Supporting circular principles facilitates a more sustainable use of resources, leading to a reduction in waste generation and ecological degradation
Cost Save	Adopting Circular Economy practices presents economic benefits for businesses and consumers alike. By minimising waste disposal costs, optimising resource utilisation, and enhancing product durability through

	repair, refurbishment, and remanufacturing, both businesses and consumers stand to save money.
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Also, implementing the six main steps in the CE in the built environment by 2030 could save approximately £360 billion on additional gross domestic product (GDP).

These six steps are (Constructing_Excellence_in_Wales, 2017):



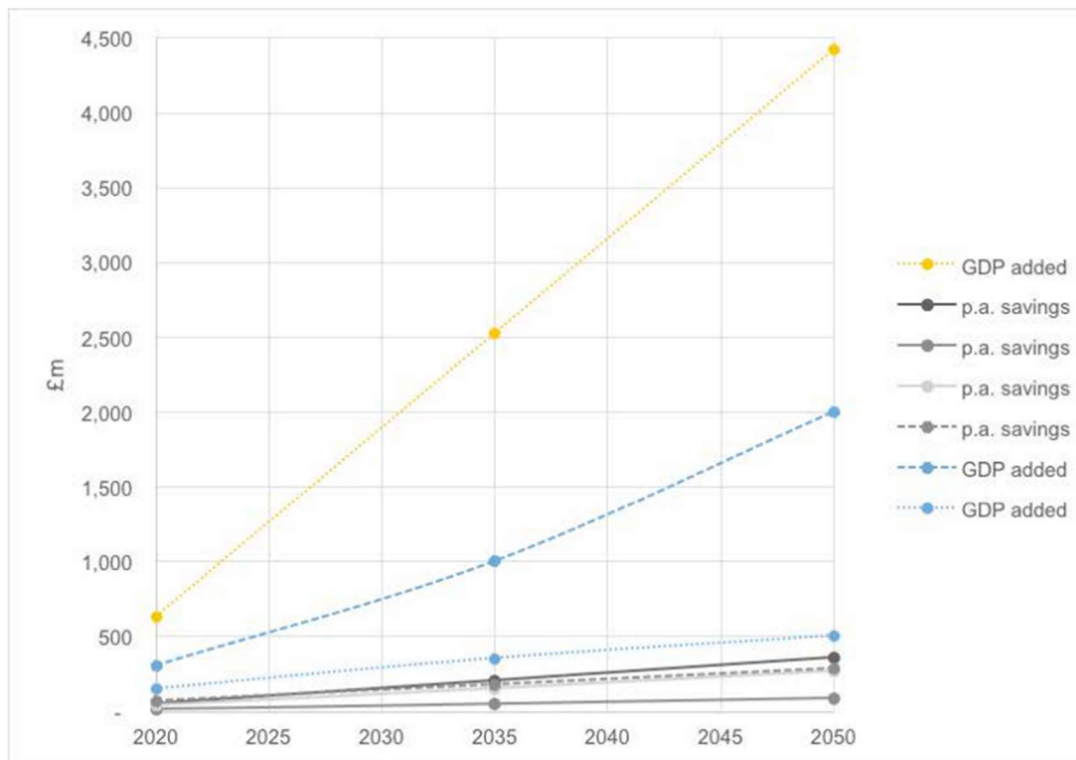


Figure 11. The predicted benefit estimates on the total impact (£) (Constructing_Excellence_in_Wales, 2017,p.37)

Alongside a geographic extrapolation from the study across the Wales area and following the six main rules, it can be seen from Figure 11 that the yellow GDP will have an exponential growth rate from 2020 to 2050. This is based on the assumption that the percentage of GDP contributed or saved through Circular Economy initiatives at a constant average annual rate (Constructing_Excellence_in_Wales, 2017).

In this section, the author of the research proposal underscores the significance of implementing the Circular Economy (CE) in Wales. Not only could this initiative benefit the environment, but it also has the potential to boost the country's economy.

Addressing the literature gap

Sustainability concerns, sustainable development, energy, and energy efficiency have become significant research areas within the building industry. Between 2013 and 2018, the researchers shifted their attention towards addressing challenges associated with CE-enabled design, particularly emphasising early-stage interventions like design for disassembly and deconstruction using tools such as Building Information Modelling (BIM). Since 2016, there has been a notable increase in research exploring methodologies for evaluating Circular Economy (CE), including utilising frameworks such as Life Cycle Assessment (LCA) to assess quantifiable environmental benefits and associated costs, as well as Materials Flow Analysis (MFA) to evaluate material flows throughout the entire lifecycle. However,

there remains a lack of appropriate methodologies and a comprehensive range of metrics for implementing CE principles in many sectors. In recent years, from 2017 to 2020, researchers have primarily directed towards three main areas (Norouzi, et al., 2021):

- **Material selection:** The main focus is selecting or substituting similar materials with alternatives that align more closely with circular principles.
- **Development of circular Business Model:** Efforts are made to diversify business models that embrace circularity, aiming to minimise waste and maximise resource efficiency in any business.
- **Relationship between CE and New Technologies:** This area explores the intersection between Circular Economy practices and emerging technologies, investigating how technological advancements can facilitate and enhance the implementation of circular principles in the industry.

Product design plays a crucial role in the Circular economy by shaping products' environmental impact throughout their lifecycle. Demirel and Danisma (2019), cited in Suchek et al. (2021), highlighted that small and medium-sized enterprises (SMEs) often struggle to justify the economic investment required to incorporate circular economy practices. (Suchek, et al., 2021). SMEs constitute 99% of all European businesses and are responsible for getting two-thirds of the jobs in Europe (OECD, 2010). However, their participation in the CE remains limited, often influenced by the activities of larger firms they serve in supply chains. Existing literature highlights the various barriers to SME engagement initiatives (EI), including limited access to finance, inappropriate technological capabilities for adopting EI, low prioritisation in environmental concerns and a lack of perceived benefits (Demirel & Danisman, 2019).

While there is extensive discussion on the importance of the Circular Economy, there remains a deficiency in utilising appropriate technology (Cappelletti, et al., 2022). In addition, some circular technologies may still be in the early stages of development or may not be widely proven or tested in a real-world environment. Also, Velis & Vrancken (2015) and Velis & Vrancken (2019) argue that not only professional/advantageous business framework is needed, but at the same time, implementing new technology is required for a closing loop material system (Velis & Vrancken, 2015) (Kinnunen & Kaksonen, 2019).

Consequently, the technology is considered lacking, and the fragmentation of coordination among the stakeholders can impede the adoption of technology-enabling circular solutions, as each party may prioritise its interests over collective circular objectives. Whereas Ali (2017) recommended investment and support and increase in the development of technology for sustainable raw material production (Ali, et al., 2017) (Kinnunen & Kaksonen, 2019). The evolution of renewable energy sources and other

high-tech applications will necessitate new infrastructure requiring a different assortment of materials compared to current applications (Ali, et al., 2017).

Methods

The author visited Aston Martin Lagonda, a company interested in adopting Circular Economy (CE) principles to enhance sustainability and waste. Aston Martin has been a prestigious automotive company since 1913, notorious for creating some of the world's most desirable luxury British vehicles.

Aston Martin Lagonda recognises the significant potential of 3D printing in automotive manufacturing. By exploring the phenomenal importance of 3D printing in their operations, Aston Martin seeks to reduce production waste, tailor parts to specific requirements, and optimise supply chain efficiency (Aston_Martin, 2024).



Figure 12. The main manufacturing facility in Barry of the Aston Martin Lagonda (Aston_Martin, 2024,p.1)

Aston Martin has recognised 3D printing as a fundamental tool for creating small parts, but daily usage has led to excessive material consumption. The project primarily focuses on utilising two primary materials: Standard PLA and Hyper Speed PLA. However, due to the extensive use of 3D printing for critical models, excessive waste is generated, incurring substantial costs for external recycling. Consequently, MADE CYMBRU's strategic plan aims to mitigate waste generation by providing comprehensive knowledge and training. Additionally, the scope includes providing information to consumers on how to use the product efficiently and maintain it properly to extend its lifespan. Therefore, the main goal of the author's initiative will be to solve this problem and demonstrate a proactive and responsible approach to addressing sustainability challenges in the project in a team that also involves continuous monitoring and evaluation of implemented solutions to ensure their effectiveness and adaptability to changing circumstances. This may involve researching alternative

materials or production methods, redesigning processes to minimise waste generation, or implementing recycling and waste management strategies (Jimmerson, et al., 2005). Also, Figure 13 explains the possible expenses of the project made by the author and the expected £60,000 funding available by the Welsh Government.

As the project leader, the author will work in a team to plan the overall project and ensure that certain activities and milestones are completed.

The author will work closely with the project team to brainstorm ideas, conduct research on alternative materials or production methods, and develop strategies to minimise waste generation throughout the manufacturing process.

Moreover, Figure 14 presents a sequential flowchart detailing the main activities to be carried out after the visit to Aston Martin Lagonda.

MADE CYMRU



Ariennir gan
Lywodraeth Cymru
Funded by
Welsh Government

£60,000

	Project funded "£"	In-kind contribution "£"	Hours spent on a project per week
Personel			
Senior reseacher 30%	8,500	3,000	6
Student researcher "Royal Accademy of Engineering	3,000	5,000	15
Researcher assistant	500	2,000	on call
Engineer Project Manager	4,000	1,000	
Over-time Engineer in Aston Martin	5,000		
Equipment			
New 3D Printer	3,000		
Grinder	500		
Pla	100		
Material for machines	100		
Filament Extruder Machine	3,000		
Tests in UWTSD			
Maintanance of equipments	500		
Travel & Conference			
Hire a vehicle (8 weeks)	900	100	
Fuel	500	200	
Conference with IMECHE	600	400	1
Online events CE	500		2
Project Total	30,700	11,700	
£ 42,400			



ASTON MARTIN

Figure 13. Badget cost prediction to assist the Aston Martin made by the author

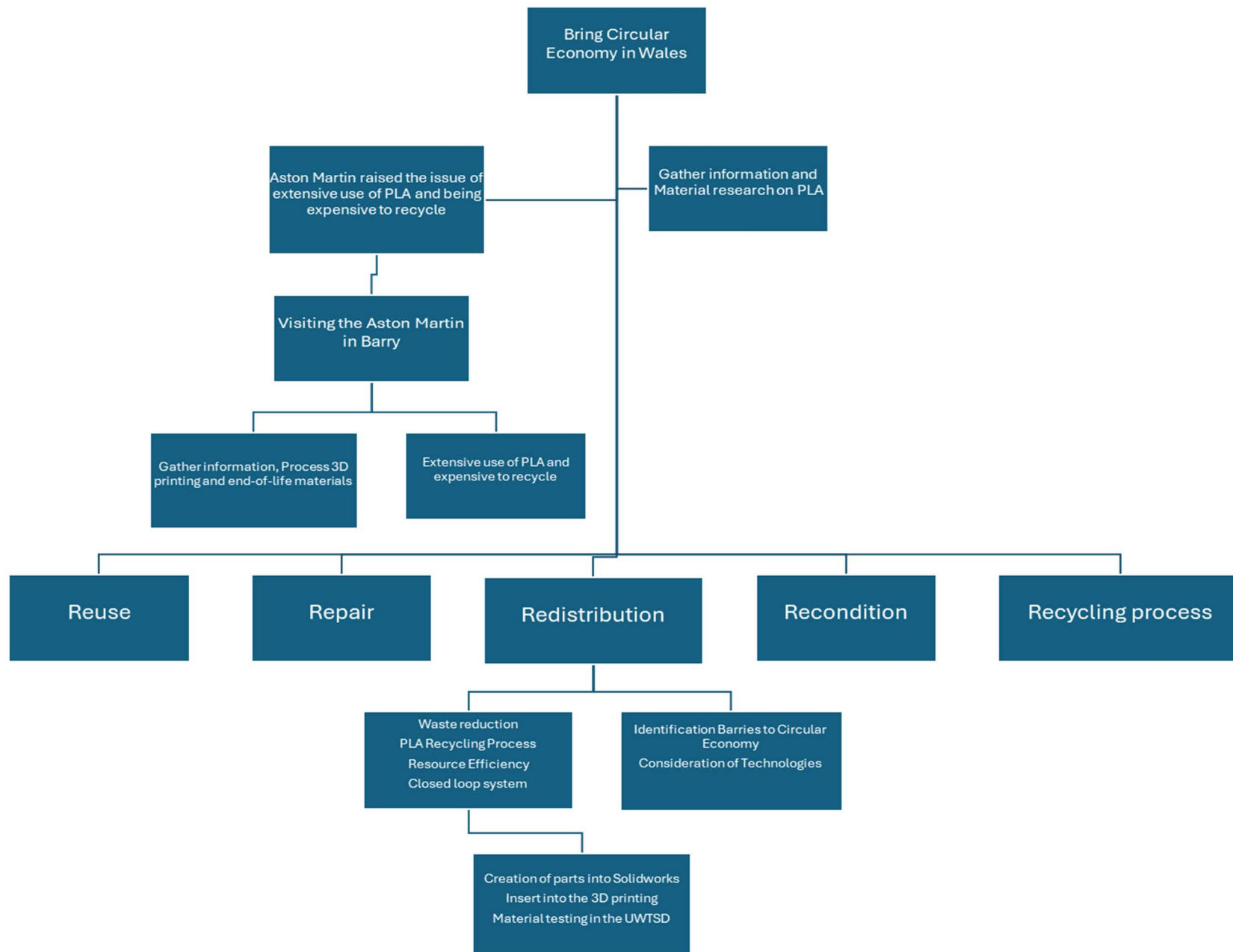


Figure 14. Organisation flow-chart after the visit of Aston Martin by the author

Business Modelling Circular Economy

MADE CYMBRU plans to use specialised equipment to implement an in-house recycling system for PLA and Hyper-Speed PLA materials. This initiative aligns with Aston Martin's sustainability objectives, aiming to decrease dependence on external recycling services, improve cost-effectiveness, and minimise environmental impact. Furthermore, Aston Martin has provided both types of PLA: the standard red colour and the hyper-speed PLA, as illustrated in Figure 15 and Figure 16.



Figure 15. Standard PLA given by the Aston-Martin



Figure 16. Hyper speed PLA given by the Aston-Martin

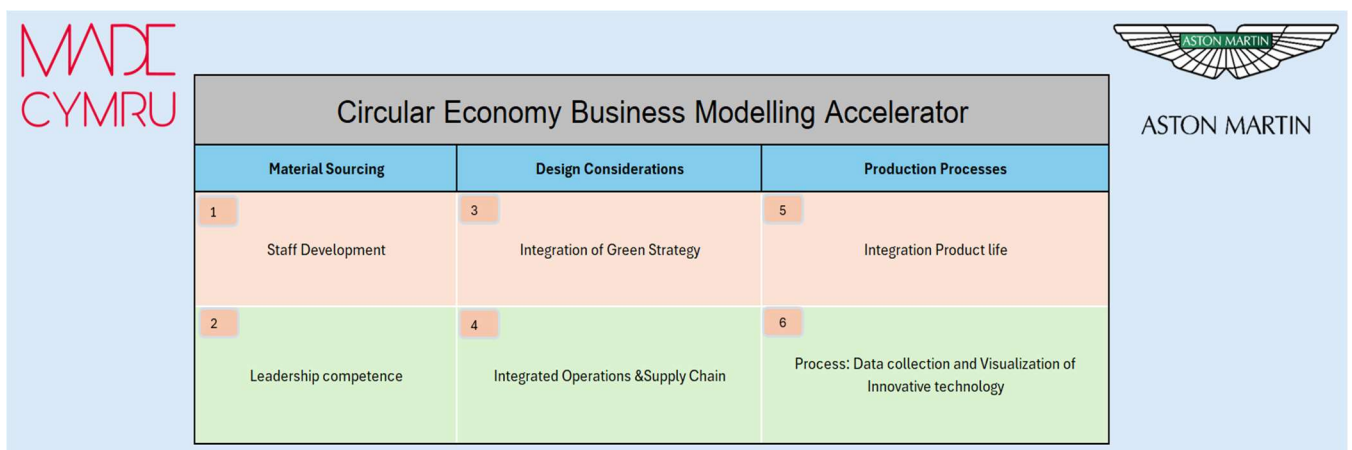


Figure 17. The main framework that will be utilised to inspect the recycling of the Aston Martin

The main framework that will be utilised to inspect the Aston Martin will be the “Circular Economy Business Modelling Accelerator,” as shown in Figure 17. The Aston Martin will be assessed first, and then a ranking score from 1 to 5 will be given to assess the knowledge of the operator working in the Aston Martin.

The significance of Tensile Testing for PLA and Hyper-Speed PLA

The tensile test is a crucial method employed to evaluate the mechanical properties of materials, including PLA and Hyper Speed PLA. This test involves subjecting a specimen to controlled tension until it reaches failure. Various properties, such as ultimate tensile strength, yield strength, and modulus of elasticity, can be determined by measuring the applied force and the resulting elongation. In addition, the main aim of interest will be when the material's ductility refers to how much deformation it can undergo before failure occurs.

The primary test to be conducted on PLA and Hyper Speed PLA involves gradually stretching the material using force, as illustrated in Figure 18.

Nominal stress holds significant importance in providing engineers with insights into material behaviour under diverse loads. However, it's essential to emphasise that factors like cross-sectional area or material properties could impact a material's stress response over time (Testbook, 2023).

The Nominal stress can be defined as (Davis, 2004):

Equation 1. *Nominal stress*

$$\alpha = \frac{F}{A}$$

Where α = *alpha stress*, F = Force, A = Cross-sectional area

Nominal strain refers to the strain observed when plastic deformation occurs, considering the sensitivity of strain measurements. Also, Equation 2 will explain the Nominal strain (Davis, 2004).

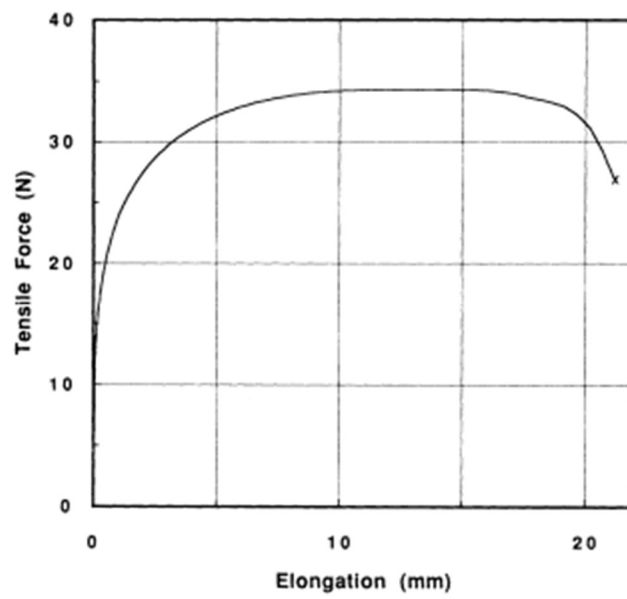
Equation 2. *Nominal strain*

$$e = \frac{\Delta L}{L}$$

Where e = strain, ΔL = is the change in gage length, and L = initial gage length

The advantage of utilising stress and strain rather than a load-against-elongation is that it can be independent of the specimen dimensions. This characteristic renders the stress-strain curve more reliable and universally applicable for characterising material behaviour under tensile loading, as it remains unaffected by variations in specimen size (Davis, 2004).

Figure 19 illustrates the main Gantt chart of this project, along with the main milestones highlighted in red.



(a)

Figure 18. The Load-elongation curve from a tensile test (Davis,2004,p.4)

Gantt Chart

MADE CYMRU

Project: Circular Economy Accelerator programme

Gantt Chart

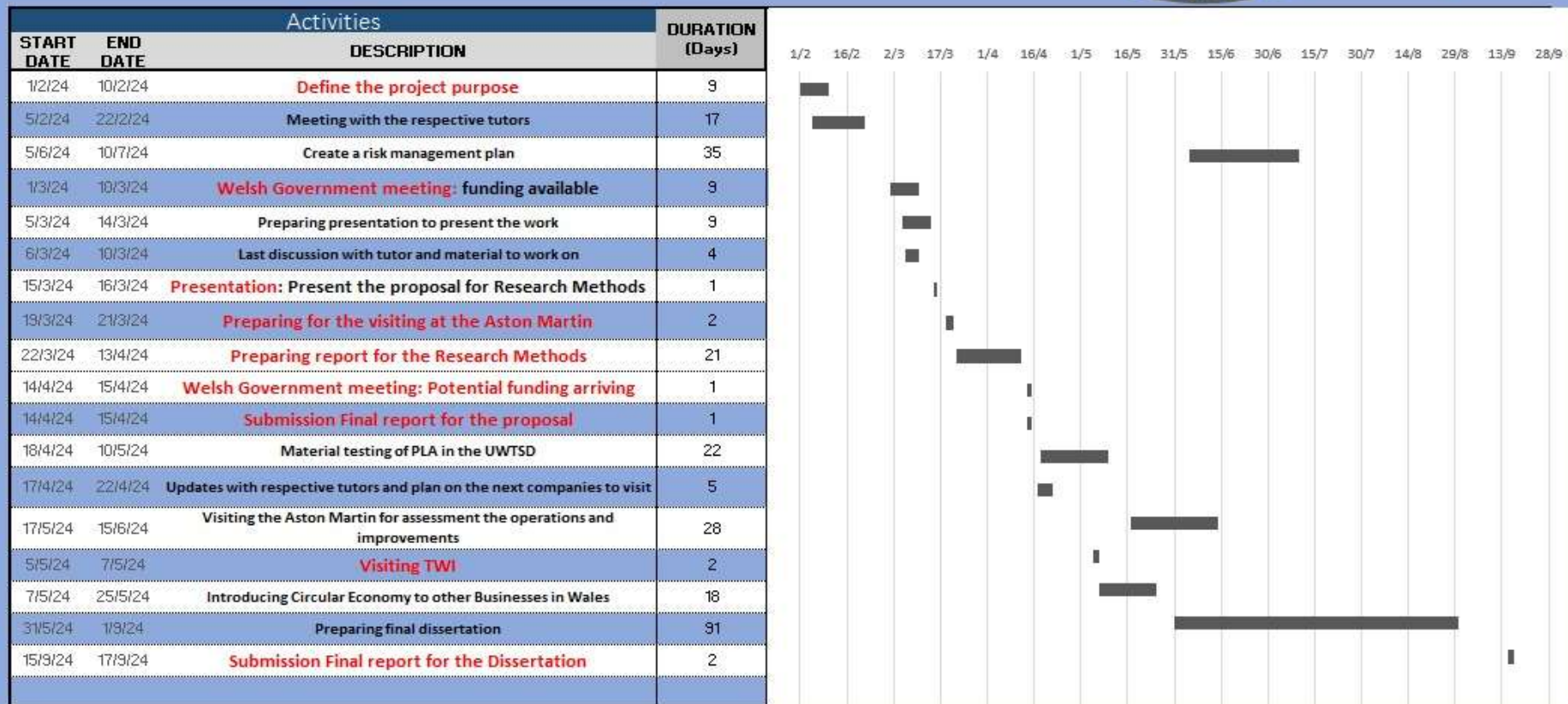


Figure 19. Gantt Chart

Justification of the process used and the principle of recycling PLA

Several studies have demonstrated that virgin PLA (VPLA) 3D printer parts exhibit high mechanical strength compared to other polymers (Pinho, et al., 2020) (Hasan, et al., 2024).

Moreover, many authors have conducted a mechanical test to check the reliability of recycled filaments as the materials experience tensile forces when extruded through an extruder and printer nozzle. Moreover, incorporating recycling PLA (derived from post-consumer and unsuccessful 3D printing parts) can contribute to energy conservation by reducing the demand for energy-intensive manufacturing and processing methods typically utilised in the production of virgin PLA (Budin & Jaafar, 2021).

Therefore (Hasan, Davies, Pramanik, John, & Biswas, 2024,p.9),

Q2: “Integrating 3D printing and recycling plays a vital role in promoting waste reduction and advancing the principles of a circular economy. In a linear economic model, products are manufactured, used, and discarded, accumulating waste and losing valuable resources”.

The main process of recycling the PLA is (Boissonneault, 2023) (Hasan, et al., 2024):

1. It is fundamental that when recycling, the PLA cannot be mixed with other types of plastic, and it should be on a separate process; the main reason is that the melting point is around 60°C, whereas ABS exhibits a higher glass transition temperature of 105°C. Mixing PLA and ABS can result in contamination issues, as PLA may not fully melt.
2. The next step is to wash the PLA particles and dry them to eliminate any residual moisture. This precaution is necessary to prevent potential complications, such as the formation of bubbles or defects, during subsequent reprocessing stages.
3. In the washing process, the surfactant detergents and a sodium hydroxide (NaOH) solution are utilised to eliminate contaminants like dust, grease, stickers, oil and other pollutants (Roosen, et al., 2022).
4. Importantly, Lee et al., cited in Hasan, Davies, Pramanik, John, & Biswas (2024), argue that the right size should be around 5mm; if they are too large, it can create serious difficulty in recycling (Hasan, et al., 2024).
5. Once entirely shredded, the material underwent drying in an oven at 80-90 degrees Celsius for approximately 4-5 hours. This duration and temperature were maintained to ensure the complete moisture removal from the material.
6. The PLA particles are melted and extruded through a filament to create various new products, including pellets, fibres, sheets, or filaments.

Results

The sample test drawn from Figure 19 was followed using the standard procedure ASTM D638, where the test was made to follow the test done by Kumar & Narayan. Once the dimensions have been taken correctly, the test started (Kumar & Narayan, 2019).

Table 2. Dimension ASTM D638 Type IV dimensions (Kumar & Narayan, 2019, p.81)

Dimensions	Type IV (mm)
<i>L</i> - Length of narrow section	33
<i>W</i> - Width of narrow section	6
<i>LO</i> - Length overall	115
<i>WO</i> - Width overall	19
<i>R</i> - Fillet radius	14
<i>RO</i> - Outer radius	25
<i>D</i> - Distance between grips	65
<i>G</i> - Gage length	25

The dimensions from Table 2 have been inserted into SolidWorks, where the PLA sample was created to create the sample and understand the material properties of the PLA.

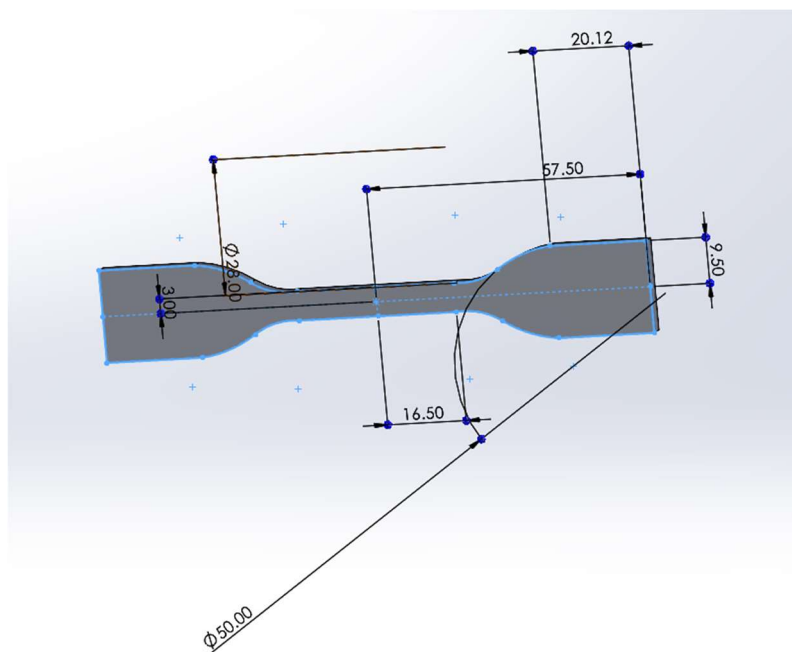


Figure 20. Model replicate in Solidworks along the measurements ASTM D638

The aim will be to insert the component created in SolidWorks, as illustrated in Figure 20, then it will be moved into an Autodesk fusion and saved into SD cards to replicate the model in one of the 3D printers, as illustrated in Figure 21, located in the workshop of the University Trinity Saint David Waterfront Campus.



Figure 21. 3d printer that will be used to create the model from the model

Tensile predicted results

The goal is to place the CAD model into the UWTSD's 3D printer to replicate PLA, which will then be tested in the Workshop using a hydraulic pressure machine. In addition, the PLA is considered to be mainly brittle. This means that PLA can be subject to catastrophic failure when subjected to high stress or impact loads, in other words, without significant warning signs such as plastic deformation or yielding. Appendix 4 clearly shows that a PLA has a lower elongation at break compared to polystyrene (PS); while biopolymers like PLA hold promise as substitutes for traditional petroleum-based polymers, specific properties such as brittleness and low heat distortion temperature limit their widespread application. Consequently, there is a pressing need for polymer scientists worldwide to address these limitations through the modification of PLA (Sangeetha, et al., 2018). Manufacturers can ensure that PLA meets specified standards and will perform as intended in service by conducting mechanical tests to assess its tensile properties. Considering the tensile test of PLA is essential, especially by plotting stress-strain curves. (Yao, et al., 2020).

The **Yield Strength** of point 9 from Figure 22, defined as the maximum stress PLA can withstand before plastic deformation begins, is 19.774 (MPa) (Team_Xometry, 2023), whereas the **Ultimate Tensile Strength (UTS)** is characterised as the highest applied force by the initial cross-sectional area, given

the value of 35.618 (Mpa). However, as illustrated in the point the fracture stress of point 9 occurs after the UTS approximately at 36 (Mpa) (Davis, 2004) (Subramaniam, et al., 2019).

A similar test will be conducted using the Hydraulic testing material machines located in the University Trinity Saint David workshop.

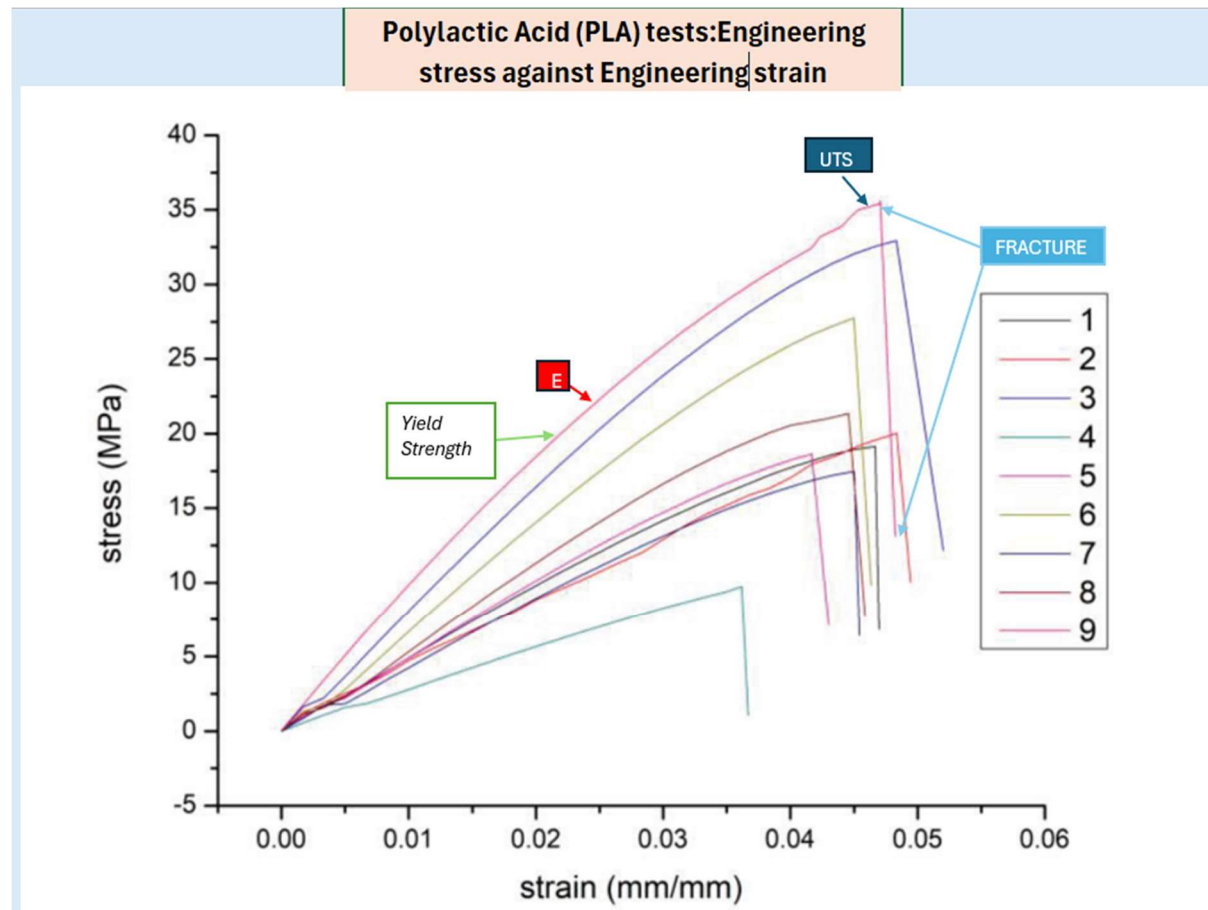


Figure 22. Stress-strain curve over the nine different parameters (Subramaniam, et al., 2019,p.4)

Evaluation

Main activities

While the Circular Economy project presents an intriguing opportunity, the author, who serves as the project manager for MADE CYMBRU, has outlined several key activities:

1. Conduct a thorough investigation into daily waste consumption at Aston Martin Lagonda.
2. Conduct advanced research on PLA and hyper-speed PLA to develop effective strategies for recycling them correctly and establishing a closed-loop system.
3. Complete the Business Model Circular Economy specific for the Aston Martin.
4. Utilise Autodesk to create models for 3D printing and conduct tensile tests on the components.
5. Purchase a Filament Extruder to create filaments.
6. Conduct a comparative analysis between the **Virgin PLA** filaments against the **recycled filaments PLA**.
7. Establish an in-house system for waste management, transforming waste into reusable products following Circular Economy principles.

Limitations of this project

- **Businesses are reluctant to changes:** Businesses may face challenges in participating in the Circular Accelerator program due to resistance to change, concerns about increased costs, and limited awareness of the benefits of circular economy practices.
- **Resource/funding limitations:** The Welsh Government may be focused on cost-saving measures, potentially affecting funding for the University. Also, many businesses might resist implementing circular economy practices due to entrenched operational habits and a lack of knowledge.
- **Limited infrastructure and technology:** Recycling and refurbishing pose significant challenges, as they rely on new technologies that may be difficult to find, especially for effectively recycling materials like PLA.

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Appendices

Appendix 1

Table 3. *Considerations of Supply Chain and Cobalt (Fortier, et al., 2018p.12)*

Mineral commodity	Summary
Chromium	Chromium is used predominantly in the production of stainless steel and superalloys where it adds temperature and corrosion resistance. U.S. chromite reserves are small, with no mining, resulting in chromium-bearing materials being produced from imported chromite ores and ferrochromium. Globally, South Africa has the largest chromite reserves and is the leading source of chromium-bearing imports. Limited substitutes exist for chromium in alloy applications; however, recycling is extensive, accounting for about 40 percent of consumption.
Cobalt	Congo (Kinshasa) is increasingly becoming a dominant miner of cobalt, with more than one-half of world production in 2016. This production was mainly a byproduct of copper operations. Cobalt also is recovered as a byproduct of nickel mining in Russia and other countries. Like the United States, China lacks sufficient domestic supplies for its industries and, thus, has aggressively sought to secure its supplies through overseas acquisitions. Cobalt demand is expected to grow significantly because of its use in rechargeable batteries for electric vehicles and other technologies. Other uses of cobalt are in superalloys for jet engines and cemented carbides for cutting tools and wear-resistant applications.
Fluorspar	The United States is highly import reliant on foreign sources of fluorspar, chiefly Mexico, with limited domestic production. Fluorspar's uses typically are categorized into three broad categories: in the production of hydrofluoric acid, in the production of aluminum fluoride (essential for aluminum smelting), uranium processing, and as a flux in steelmaking. Fluorspar also is important in the manufacturing of welding rods. Through its use in the production of hydrofluoric acid, it is the main source of fluorine in almost all chemical applications. The United States produces fluorsilicic acid from phosphate processing; however, this potential domestic fluorine source has not been widely adopted for acid generation and metallurgical uses.
Gallium	Gallium is recovered primarily as a byproduct of processing bauxite; smaller quantities are recovered from zinc processing residues. No primary gallium has been recovered in the United States since 1987. Current production of low-grade, unrefined gallium is dominated by China; however, the United States can and does refine gallium to high-grade from primary low-grade gallium imports and from new scrap (recycled materials). Gallium finds major application in integrated circuits and optoelectronic devices such as light emitting diodes, photodetectors, and solar cells.
Germanium	Germanium is a minor constituent of some lead and zinc ores mined in the United States. The United States lacks processing facilities for recovering germanium from primary ores. Zinc concentrates containing germanium are exported to Canada and Belgium for processing and germanium recovery. The United States is reliant on imports of processed material or end products. Currently (February 2018), China is by far the world's largest germanium producer. Germanium is used in fiber optics, infrared optics, electronics, and solar cells.
Graphite (natural)	China is by far the largest producer of natural graphite, accounting for roughly two-thirds of world production. Only 4 percent of the world's natural graphite comes from North America, with no U.S. production in decades. Although natural graphite was not produced in the United States in 2016, about 98 U.S. firms, primarily in the Northeastern and Great Lakes regions, consumed graphite in various forms from imported sources for use in brake linings, foundry operations, lubricants, refractory applications, and steelmaking. Graphite's use in rechargeable batteries, as well as technologies under development (such as large-scale fuel-cell applications), could consume as much graphite as all other uses combined.
Helium	Helium is extracted from natural gas produced in the United States. Crude helium production exceeds domestic consumption, making the United States a net exporter of helium. Helium is used in magnetic resonance imaging, welding, semiconductor manufacturing, analytical and laboratory applications, engineering and scientific applications, and various other uses. The Bureau of Land Management manages the Federal Helium Program. Public law requires the Bureau of Land Management to dispose of all Federal helium-related assets when the remaining helium stockpile falls below 83 million cubic meters or no later than 2021.
Indium	Indium is primarily consumed as indium tin oxide, largely in flat-panel displays. Other notable uses of indium include semiconductors and low-temperature alloys. Indium is recovered as a byproduct of zinc ores. Although the United States has substantial production of zinc ore, there is no recovery of indium from ores in the United States. The United States is, therefore, exclusively reliant on imports. China is the world's largest producer of indium; however, Canada is the largest source of United States imports. New indium tin oxide (manufacturer's) scrap is recycled domestically, though there is limited information on the quantity of this production. There are no known commercial substitutes for indium tin oxide in flat-panel displays.

Appendix 2

Table 4. Lithium (p.13)

Mineral commodity	Summary
Lithium	Lithium can be recovered from hard-rock deposits and brines. Lithium demand is expected to grow substantially because of its use in rechargeable batteries, particularly for electric vehicles. Lithium hydroxide also is used for cooling water chemistry control in pressurized water reactors and may be required in some advanced concept nuclear reactors (molten salt). The U.S. import reliance is moderate, but increasing foreign consumption in addition to U.S. demand growth has driven a substantial exploration boom.
Magnesium	Magnesium metal is produced from brines, which are virtually unlimited in comparison to demand. The United States only has one magnesium metal producer, which creates a potential single point of failure. Magnesium metal production is an important component of domestic titanium production; therefore, the loss of this domestic producer could result in broader effects. The United States only has a moderate import reliance on magnesium metal; Israel and Canada provide more than 50 percent of imports. There is substantial secondary recovery from magnesium castings and aluminum alloys that is comparable to the reported primary consumption.
Manganese	The United States has not mined manganese in decades and is reliant entirely on imports of manganese for ferroalloys, silicomanganese, and chemical compounds, and ore and alloy imports largely come from African nations and Australia. The United States does not possess economically viable resources, and manganese only is recycled incidentally during steel scrap processing.
Niobium	Most of the world's niobium production comes from one country, Brazil. Niobium is used primarily in high-strength low-alloyed steels that are necessary for infrastructure development and superalloys in the aerospace industry. Like the United States, China has no domestic niobium primary production and has invested in overseas acquisitions to secure its supplies. As developing countries construct their infrastructure and developed nations, including the United States, redevelop theirs, demand for niobium will likely increase.
Platinum-group metals	Platinum-group-metal (PGM) production is concentrated in South Africa and, to a lesser degree, in Russia and Zimbabwe. Although some primary PGMs are produced in the United States, as well as secondary (recycled) production, these are insufficient to satisfy domestic demand. Economic conditions, labor issues, and electricity shortages in South Africa in recent years have highlighted the risk associated with high production concentration in a single country. PGMs are used in a wide variety of applications ranging from electronics to anticancer drugs and biomedical devices to glass manufacturing equipment but are especially widely used as catalysts. Use in catalytic converters for the reduction of harmful emissions from internal combustion engines is essential but are likely to decrease with increased use of electric vehicles. Given their high value, PGMs have relatively high recycling rates except in their use in electronic applications because of the lack of collection of postconsumer electronics. Substitution of PGMs is limited because PGMs often are the best substitutes for other PGMs.
Potash	Potash denotes a variety of mined and manufactured salts that contain the element potassium in water-soluble form. Potash is used extensively in agriculture; fertilizers account for more than 85 percent of use, and the chemical industry accounts for the remainder. The United States is 90 percent reliant on imports to meet domestic demand for potash, and 85 percent of potash imports originate in Canada. Potash is produced in New Mexico and Utah from underground mining of ores and processing of brines. Estimated domestic potash resources total about 7 billion tons, whereas domestic reserves are estimated to be about 520 million tons. No substitutes exist for potassium as an essential plant nutrient and as an essential nutritional requirement for animals and humans.
Rare earth elements	With the closure of the Mountain Pass Mine in California, rare earth elements (REEs) are not mined in the United States. Most REEs, especially heavy REEs, are mined and processed in China. REEs are used in a wide range of applications ranging from magnets to phosphors for which there are limited substitutes. Furthermore, little postconsumer recycling happens for most of the REEs. Efforts by the Critical Materials Institute to develop substitutes and enhance recycling technologies are ongoing.
Rhenium	Rhenium is used primarily as an alloying agent in high-temperature steels for jet engines. Rhenium is produced as a byproduct of molybdenum, which itself is often a byproduct of porphyry copper mining. Although rhenium is present in domestic molybdenum-copper resources, the United States has insufficient processing capacity to meet domestic demand for rhenium. The United States ships rhenium-bearing molybdenum concentrates to Chile for recovery and imports refined rhenium. Rhenium recycling plays an important role in its global supply, but demand for new commercial and military jet aircraft will likely make it impossible for recycling alone to be sufficient. Given its high value and small market, substitution of rhenium is evaluated continually, and some substitutes have achieved commercial success. Reduced rhenium and rhenium-free alloys are being evaluated currently (2018) by major aerospace

Appendix 3

Table 5. The supply value risk value for materials that are relevant in the Welsh industry was calculated in 2014 (Constructing_Excellence_in_Wales, 2017,p.39)

Material	Supply risk value	Material	Supply risk value	Material	Supply risk value	Material	Supply risk value	Material	Supply risk value
Antimony	7.5	Cobalt	6.6	Indium	6.8	Niobium	6.5	Silicon metal	6.2
Arsenic	6.4	Coking coal	5.8	Lead	5.4	Phosphate rock	5.9	Silver	5.4
Barytes	6	Copper	4.3	Lithium	5.6	Platinum group metals	6.4	Strontium	7
Beryllium	6.5	Fluorspar	6.1	Magnesite	6.3	Rare earths (heavy)	9.5	Tantalum	5.9
Borates	5.3	Gallium	6.3	Magnesium	6.3	Rare earths (light)	8.4	Tellurium	5.3
Carbon/graphite	6.5	Germanium	6.8	Manganese	5.2	Rhenium	5.7	Tin	5.7
Chromium	5.5	Gold	5	Mercury	7	Selenium	5.8	Tungsten	7.6

Appendix 4

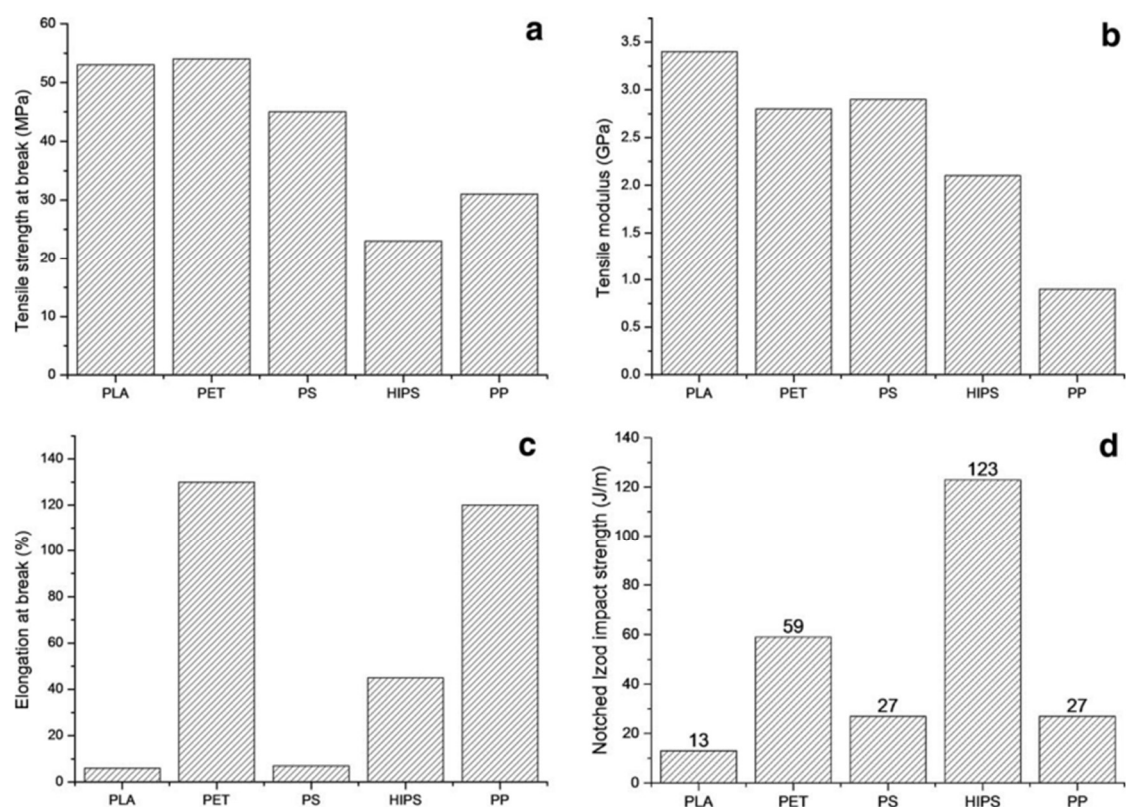


Figure 23. Comparison of other polymers and PLA

Appendix 5

Table 6. The average list of a tensile strength combination of 1 to 9 (Subramaniam, et al.,p.5)

Combination	Layer height (mm)	Raster angle (°)	Infill density (%)	Ultimate tensile strength (MPa)	Elastic Modulus (MPa)	Yield strength (MPa)
1	0.1	40	20	19.133	471.368	14.807
2	0.1	40	50	20.013	617.453	18.210
3	0.1	40	80	32.938	807.489	26.082
4	0.1	60	20	9.737	277.750	9.027
5	0.1	60	50	18.623	502.590	15.391
6	0.1	60	80	27.742	688.130	22.574
7	0.1	80	20	17.452	441.461	15.452
8	0.1	80	50	21.337	563.481	17.408
9	0.1	80	80	35.618	912.165	19.774