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Investigation: How can the jewellery manufacturing industry embed industry 4.0 technologies adopted by Aerospace and the Medical sectors?

A study examining the impact of Blockchain and Additive Manufacturing on the aerospace and medical sectors, as well as the potential for the jewellery manufacturing industry to adopt Industry 4.0 technologies.

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1 Abstract

This dissertation presents a comprehensive investigation into the impact of Industry 4.0 technologies, specifically Blockchain and Additive Manufacturing (AM), on the aerospace and medical industries, while critically exploring their potential integration into the traditionally artisanal jewellery manufacturing sector. While both aerospace and medical sectors have effectively embedded these technologies to enhance design complexity, supply chain traceability, and production efficiency, the jewellery industry has remained comparatively slow to adopt technological innovations. This reluctance is often rooted in longstanding traditions, a lack of digital literacy, and economic barriers that challenge smaller businesses.

The research aims to evaluate how the successful strategies employed in the aerospace and medical sectors can be transferred to the jewellery industry to promote sustainable growth, innovation, and competitiveness. A mixed-methods approach was adopted to explore this intersection, combining qualitative data from expert interviews and a case study with quantitative data gathered through structured questionnaires distributed to small and medium-sized enterprises (SMEs) across the UK jewellery sector. The case study of Diamond Centre Wales (DCW), a pioneering SME experimenting with additive manufacturing, provides a real-world context illustrating both the promises and pitfalls of adopting high-tech innovations in a resource-constrained environment.

The study identifies that Additive Manufacturing, particularly through 3D printing, offers jewellery businesses an opportunity to produce highly customised, intricate designs with reduced lead times and material waste. Moreover, Blockchain technology holds the potential to revolutionise supply chain transparency, ensuring traceability and authenticity of precious metals and gemstones—key concerns in an industry fraught with ethical sourcing challenges. However, widespread adoption is hindered by factors such as high capital expenditure, lack of technical skills within the workforce, and limited industry awareness or trust in digital tools.

Through a detailed literature review, analysis of primary data, and triangulation of findings, this research demonstrates that while there is clear potential for Industry 4.0 technologies to modernise and revitalise the jewellery manufacturing sector, the transition requires strategic planning, sector-specific training, and collaborative efforts across educational institutions, technology providers, and industry leaders. The dissertation concludes by offering targeted recommendations to support SMEs in navigating this technological shift, including the development of knowledge transfer partnerships, training hubs, and policy incentives that lower the barrier to innovation.

Ultimately, this study positions the jewellery industry at a critical juncture—where embracing digital transformation can both preserve its rich heritage and propel it into a competitive, sustainable, and technologically agile future.

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Acronym table

Full name	Acronym
Artificial Intelligence	AI
Birmingham City University	BCU
Business-to-business	B2B
Diamond Centre Wales	DCW
Electro Optical Systems GMBH	EOS
Innovation UK	IUK
Intellectual property	IP
School of Jewellery	SOJ
Selective laser melting	SLM
Small medium enterprise	SME
Virtual reality	VR

1. Introduction

The Luxury Jewellery Market was valued at USD 78,957.3 million in 2023 and is poised to grow at a compound annual growth rate of 3.4% from 2024 to 2030.

Demand for sustainable and gender-fluid jewellery is rising, helping propel the luxury jewellery market forward (Business Insights, 2023). However, jewellery manufacturing methods have remained essentially unchanged for thousands of years, with the earliest recorded use of investment casting dating back to 3700 BC (Precision Investment Castings, 2024). My research aims to explore how Industry 4.0 technologies, which the aerospace and automation industries have adopted, could propel the archaic jewellery manufacturing sector towards optimising production and driving growth.

Integrating Industry 4.0 technologies into the jewellery manufacturing sector can draw valuable insights from the advancements in the aerospace and medical industries. The application of additive manufacturing, particularly 3d printing, has been transformative across these sectors, and its adoption in jewellery manufacturing could enhance design flexibility and production efficiency.

Moreover, the implementation of advanced technologies, such as molecular engineering through additive manufacturing and augmented reality, can facilitate the creation of intricate designs inspired by complex geometries. (Alfaisal, 2024). This approach streamlines the design process and allows for the creation of unique and customised pieces, such as tailored solutions in aerospace and medical applications.

Using integrated manufacturing systems that embed AI and incorporate parametric modelling with computer-aided design (CAD), optimisation can further enhance the efficiency of jewellery production by identifying faults in production before they occur and utilising the full capacity of production capabilities to encourage a higher output of products. By ensuring effective communication between various IT platforms, such as Rhino-Grasshopper for modelling and specialised slicing software for 3d printing, the jewellery industry can achieve a level of precision and adaptability akin to that seen in other high-tech sectors (Pietro, et al., 2021).

The evolution of iconic jewellery houses such as Cartier, Harry Winston, and Tiffany & Co. illustrates how foundational design philosophies and traditional practices can guide innovation. These houses have navigated their legacies by balancing tradition with modern trends, thereby ensuring their continued prestige in a changing market (Vanderford, 2024). Cartier and Tiffany both have Innovation and research departments that solely research industry 4.0 technologies to gain traction over their competitors. Cartier has incorporated 3d printing into their manufacturing suite and created jewellery that fits into their jewellery range. Please see Figure 1, in which they have designed a ring for their



Figure 1 (cartier, 2024)

Panthera collection based on the design principles of direct-to-metal additive manufacturing. Traditional lost-wax casting techniques would not have enabled the creation of this ring, proving that there is value in incorporating innovative technologies into the jewellery manufacturing offering, as the possibilities of diversifying their product range can add value to their jewellery offerings.

1.1 Justification

A study exploring how the jewellery manufacturing industry can successfully integrate Industry 4.0 technologies, as adopted by the aerospace and medical sectors, offers compelling justification across several strategic scopes. It considers how small to medium-sized jewellery businesses in the UK can engage with these new 4.0 technologies and identify the barriers and enablers to their adoption.

The aerospace and medical industries have leveraged Industry 4.0 technologies to achieve high levels of automation and precision. For instance, the aerospace sector employs advanced robotics and real-time data analytics to streamline manufacturing processes and ensure stringent quality standards. Similarly, the medical industry utilises Artificial Intelligence and additive manufacturing for predictive maintenance to enhance equipment reliability and performance. By adopting these technologies, the jewellery manufacturing industry can improve operational efficiency, reduce errors, and maintain consistent product quality whilst enhancing its profit margins with reduced wastage.

Industry 4.0 enables rapid prototyping and customisation, which are crucial in sectors like aerospace and medical device manufacturing. These industries use additive manufacturing and digital twins to create bespoke components and simulate real-world conditions. Applying similar approaches in jewellery manufacturing could lead to innovative designs and personalised products, meeting the growing consumer demand for unique and customised jewellery pieces.

The aerospace and medical sectors have implemented robust supply chain management systems using blockchain and IoT technologies to ensure traceability and compliance. For example, aerospace manufacturers track the lifecycle of components to adhere to safety regulations, while the medical industry monitors the provenance of materials to meet regulatory standards. Integrating such systems in jewellery manufacturing can enhance transparency, build consumer trust, and ensure ethical sourcing of materials.

Both the aerospace and medical industries face challenges related to skill gaps and workforce shortages. To mitigate these issues, they have invested in training programs and collaborative partnerships with educational institutions. For instance, aerospace companies collaborate with universities to develop specialised prospectuses, and medical device manufacturers offer apprenticeships to attract and retain talent. The jewellery industry can adopt similar strategies, such as establishing training hubs and partnering with educational institutions, to rejuvenate its workforce and ensure the preservation of traditional craftsmanship alongside technological advancements.

Global industries are increasingly adopting Industry 4.0 technologies to stay competitive. The aerospace sector has embraced digital transformation to enhance manufacturing capabilities, and the medical industry has adopted innovative technologies to improve patient outcomes. By aligning with these global trends, the jewellery manufacturing sector can meet evolving consumer expectations for quality, innovation, and sustainability.

Integrating Industry 4.0 technologies into jewellery manufacturing is not simply a technological upgrade but a strategic move to enhance efficiency, foster innovation, ensure ethical practices, address workforce challenges, and align with global industry standards. By learning from the aerospace and medical sectors, the jewellery industry can navigate the complexities of modern manufacturing and position itself for sustainable growth in the digital age.

1.2 Aims and objectives

To examine the industry 4.0 technologies adopted by the Automotive and Aerospace industries, and to what extent the jewellery industry can integrate them into its manufacturing processes.

Secondly, to gather data through interviews, questionnaires, and case studies to gain an in-depth understanding of the range of views in the jewellery industry regarding their technological offerings and what businesses are looking towards in the future.

In summary, the aim is:

- To understand the potential benefits of implementing Industry 4.0 technologies into the jewellery manufacturing sector.

The objectives are as follows:

- To gain an understanding of how the Aerospace and medical sector has successfully embedded Industry 4.0 technologies into their markets.
- To recognise the barriers that the jewellery industry could face by embedding Industry 4.0 technologies into their sector.
- To conduct a literature review to gather an in-depth knowledge of how the jewellery manufacturing sector has already adopted Industry 4.0 technologies.
- To undertake primary research through surveys and interviews to gather data to identify the adoption of Industry 4.0 and to analyse results from primary research data.
- To make recommendations on how the jewellery industry can further adopt Industry 4.0 technologies.

1.3 Summary of the chapter

The introduction outlines the context of the research that will be explored and proposes the aim of the Study, which is to examine how Industry 4.0 technologies, such as additive manufacturing, blockchain, and AI, are extensively used in the aerospace and medical

sectors and can be applied to modernise the jewellery industry, this will be explored more in the next section.

2. Literature review

Industry 4.0 technologies have been successfully embedded in the aerospace and medical sectors. This next section will highlight how new technologies have been leveraged, their impact on the development of these sectors, and how the jewellery industry can integrate Industry 4.0 technologies into its market. These industries have embraced advanced digital technologies to enhance efficiency, precision, customisation, and sustainability. Below, the author will be discussing key lessons that can be adapted to jewellery manufacturing.

2.1 Traditional manufacturing for jewellery

Traditional jewellery manufacturing has remained essentially unchanged for centuries, with many artisans still employing time-honoured techniques such as handcrafting, casting, and stone setting. These methods have been passed down through generations, preserving cultural heritage and artisanal skills. However, the advent of the Industrial Revolution introduced mass production techniques, making jewellery more accessible to the broader public.

The evolution of jewellery manufacturing in the UK since the 1850s has been marked by significant changes influenced by various socio-economic factors and technological advancements. The Birmingham Jewellery Quarter, a notable industrial district, has experienced a decline over recent decades due to manufacturing being sent abroad, driven by cheaper labour, quicker manufacturing times, and higher product output. This, combined with the rise of European designer fashion and the increasing popularity of jewellery houses, has resulted in a decline in the number of jewellers. The economic importance of these smaller entities within the policy environment, leading to their symbolic and decorative value being prioritised over their actual economic contributions (Hughes, 2012), which reflects broader trends in the jewellery manufacturing sector. This decline has been followed by UK economists and market experts who combine historical and economic analyses, revealing patterns in firm birth and mortality rates, as well as changes in production activities within the district (De Propriis & Lazzeretti, 2009)

The UK fashion industry, which includes jewellery, has faced challenges due to global competition, particularly for small and medium-sized enterprises (SMEs). The ability of fast fashion to produce large quantities of inexpensive goods, such as those from Pandora, shifts consumers away from small jewellery SMES in favour of mass-produced goods for gifts, as they still hold sentimental and precious value, but do not come with a price tag that is inaccessible to the general public. These companies have had to adapt their project management strategies to remain competitive, focusing on dynamic capabilities that allow them to sense new opportunities and enhance their manufacturing processes. This adaptability is essential for survival in a fast-changing market. (Godhania, 2015).

Before the industry 4.0 revolution, the last significant innovation was in 1805, Electroplating and electroforming innovations allowed for the bonding and coating of textiles with precious metals, enhancing their aesthetic and functional qualities. Horton discusses how these

techniques were historically rooted in metallurgical work and evolved through advancements in electrochemistry and electrometallurgy, leading to the application of electrodeposition on various materials, including cloth and thread used in Jewellery and dress (Horton, 2022). This transformed the UK's precious metal industry in the 1800s as we became leaders in jewellery innovation and manufacturing; however, our need to produce a larger quantity of jewellery for profits over being innovators in the space has meant that larger jewellery firms have moved their manufacturing sites to India and China to create better profit margins due to cheaper manufacturing (Schupak, 2006).

Traditional practices have a considerable influence on the innovative landscape in jewellery production, providing a foundation upon which contemporary techniques and designs can be developed. (Avidano, 2023). The interplay between heritage and innovation is evident in the strategies employed by jewellery companies to maintain their traditional craftsmanship while

adapting to modern market demands. For instance, companies like Pandora, Courbet, and INBILICO have demonstrated that innovative sourcing methods, by entirely focusing on using lab-grown stones in their repertoire, can enhance transparency and promote ethical practices, all while utilising classic materials that reflect their heritage. (Avidano, 2023). Pandora publishes a yearly Sustainability report (please see figure 2), in which they set out their environmental Target and compare them to previous years to see if they have been reached. Until 2024, recycled metals were more challenging to acquire due to the complexities of production, which meant that larger companies like Pandora could establish their recycled processing plants to produce recycled precious metals, reducing their overhead bullion costs. This allowed smaller companies to compete with them now economically. As a result, Pandora was able to dominate the high street jewellery market and create a cult following for their product (Chen, et al., 2016). However, recycled metals are now competitively priced and easy to acquire. In 2025, we could see a landscape change for smaller firms and independent jewellers.

The social aspects of jewellery production, particularly local communities, underscore the importance of traditional practices in enhancing the socio-economic value of jewellery. By innovating traditional products and promoting educational activities, jewellery can support local cultural heritage, thereby enriching the innovation landscape (D'Eusanio, et al., 2019).



Figure 2 (Pandora, 2025)

A distinction exists between traditional practices that emphasise skill and the inherent beauty of materials and conceptually motivated work that may neglect these conventional skills. This dichotomy highlights the innovation potential when conventional techniques are combined with contemporary ideas, suggesting that a fusion of talent and creativity can lead to genuinely innovative outcomes (Turrell, 2010)

Additionally, the Craftswoman's Imperative highlights the importance of artisanship in Jewellery making, emphasising the duality between emotional commitment and structural challenges designer-makers face. This concept illustrates how the hopes and aspirations of these artisans align with broader policy goals aimed at revitalising their craftsmanship, suggesting that traditional techniques are not only about the physical processes but also about the cultural and emotional narratives that sustain them. (Hughes 2013).

The jewellery industry worldwide is traditionally secretive, reluctant to share, and slow to adopt new technologies. This has resulted in slow growth within the industry. According to Camilo Riviera (2024), the jewellery industry could benefit dramatically from adopting Industry 4.0 technologies. In the next section, the author discusses how Industry 4.0 technologies could help the jewellery industry within the UK.

2.2 Adoption of Advanced Manufacturing Techniques

Industry 4.0 technologies are widely used in aerospace and medical sectors to create complex, customised parts with high precision. This enables the production of intricate designs, creates 24-hour manufacturing capabilities and reduces material waste. (Gebhart, 2019).

Manufacturing industries are increasingly adopting advanced manufacturing techniques, which emphasise automation, data exchange, and the integration of emerging technologies. A study focusing on Indian manufacturing industries identified 15 challenges related to implementing Industry 4.0, highlighting high adoption costs, the need for a skilled workforce, and the necessity for training and consultancy. (Das Gidwani & Nimawat, 2022). This empirical research underscores the importance of understanding these challenges to facilitate the adoption of advanced manufacturing practices in developing countries.

Murmura & Bravi revealed that a significant number of companies are investing in this technology, which allows for more efficient and innovative production methods. (Murmura & Bravi, 2018). The focus on design and customer satisfaction indicates a shift towards more responsive manufacturing practices.

Furthermore, a systematic literature review has proposed a conceptual framework for adopting Industry 4.0 in manufacturing environments, particularly in developing economies. This framework emphasises the integration of technologies such as IoT, blockchain, and big data analytics, which are essential for bridging the gap between physical and cyber systems (Panwar, et al., 2024). The study also highlights the benefits and challenges of these technologies, suggesting that successful implementation requires addressing specific obstacles manufacturers face.

A framework tailored for small and medium-sized enterprises (SMEs) outlines essential steps for adopting innovative manufacturing practices, emphasising the need for readiness assessments and the identification of appropriate tools. (Menon, et al., 2020).

2.3 Artificial Intelligence

In this section, the Author will discuss how Artificial intelligence (AI) has been incorporated into the medical industry and Aerospace to reduce costly mistakes and enhance patient care. It will finally cover the benefits and barriers that the jewellery industry could face if it adopted AI technology.

2.3.1 Medical use of AI

The medical industry is increasingly utilising artificial intelligence (AI) to tailor products and services to individual needs, particularly through the lens of personalised medicine. AI technologies enable the analysis of vast amounts of patient data, including genetic, clinical, and lifestyle information, to create customised treatment plans (Arshi, et al., 2023). For instance, AI systems can gather personal data upon patient arrival, which is then used to generate healthcare recommendations that assist professionals in clinical decision-making, thereby enhancing the precision of treatment regimens (Shaikh, et al., 2023).

The application of AI in personalised medicine is evident in the ability to identify patterns and correlations within patient data. This capability allows for improved diagnostic accuracy and the selection of optimal treatment strategies based on individual genetic and clinical profiles. AI algorithms, such as machine learning and deep learning, are particularly effective in oncology, where they can evaluate patient responses to therapies and suggest tailored interventions (Ugwu & Alum, 2025).

Moreover, AI plays a significant role in drug discovery and development, predicting the efficacy and safety of new drugs while identifying potential targets for treatment. This process accelerates the development of personalised therapies and enhances the overall effectiveness of medical interventions. (Ugwu & Alum, 2025).

Despite these advancements, integrating AI into healthcare systems necessitates addressing key ethical concerns, including data privacy and the reliability of algorithms. Collaboration among technologists, healthcare providers, and regulators is essential to ensure that AI applications in personalised medicine are practical and ethically sound (Fatima & Parthiban, 2024).

2.3.2 Aerospace uses of AI

AI has been increasingly integrated into various aspects of Aerospace manufacturing, particularly machine learning and advanced analytics, which are utilised to optimise production processes and enhance quality control. In the context of smart manufacturing, AI has been shown to improve fault diagnosis, remaining functional life prediction, and quality inspection, all of which are critical in aerospace manufacturing, where precision and reliability are paramount (Ding, et al., 2020). The integration of AI into manufacturing

processes can lead to significant improvements in efficiency and effectiveness, particularly using data-driven approaches that leverage the vast amounts of data generated in production environments (Andrian Johanesa, et al., 2024).

Moreover, the application of AI in predictive maintenance is particularly relevant, as it can help in anticipating equipment failures and minimising downtime, which is crucial in aerospace manufacturing, where operational reliability is essential (Andrian Johanesa, et al., 2024). The use of AI models for process optimisation and quality enhancement can also be beneficial, as they allow for real-time monitoring and adjustments, ensuring that manufacturing processes meet stringent aerospace standards (Sachdeva, et al., 2022).

2.3.3 Jewellery use of AI

AI-driven design tools can enable customers to co-create their jewellery pieces, thereby enhancing personalisation and customer satisfaction (Berman, 2012). The jewellery industry relies on customisation to drive up profit margins. One significant area of impact is in the integration of AI with 3d printing technologies, which facilitates advancements in graphic creative design, modelling, and material selection. This collaboration aligns with the growing trend towards personalised jewellery design, reflecting consumer preferences for unique and individualised products (Duan, 2021).

Machine learning is being utilised to estimate gross loss in the manufacturing process, particularly for wax patterns used in investment casting. By analysing historical data and attributes from CAD files, machine learning algorithms have demonstrated the potential to significantly reduce estimation errors, thereby optimising material usage and production efficiency. (Jain, et al., 2021). This application underscores the role of AI in enhancing decision-making capabilities within the manufacturing workflow.

The main barrier to the adoption of AI within the jewellery sector is a workforce that could be reluctant to adopt due to a lack of technological education and an ageing workforce that does not see the value in retraining to incorporate AI into their offering (Sharma, 2025).

Furthermore, the difficulty of human-AI collaboration and communicating stylistic details and design practices could constrain designers and inhibit the creative process (Lyu, et al., 2024); a more likely outcome is that designers will use AI to design the bulk of the jewellery pieces and finish the design process using CAD. This will be discussed further in the next section

2.4 Computer-aided design

In this section, the Author will discuss how computer-aided design has been incorporated into the medical industry and the Aerospace sector to innovate patient care and enhance aerospace design. It will finally cover the benefits and barriers that the jewellery industry faced when it adopted CAD.

2.4.1 CAD uses for the medical sector

The medical industry employs Computer-Aided Design (CAD) in various innovative ways, particularly in the fields of surgery and prosthetics. CAD enables the creation of precise

models tailored to individual patients' anatomies, enhancing the design flexibility and functionality of medical devices. This technology allows for the production of intricate geometries, leading to improved aesthetic outcomes and better-fitting prosthetic limbs and orthoses, thereby significantly contributing to personalised medical interventions (Zahid, et al., 2024).

Moreover, CAD is essential in the design and manufacturing of surgical templates, which guide implant placements and other surgical interventions. This technology streamlines the workflow from preoperative planning to actual surgical application, thereby improving the precision, safety, and reliability of surgical procedures. (Chen, et al., 2016).

In the realm of oral and maxillofacial reconstruction, CAD, along with additive manufacturing, has transformed traditional surgical techniques by addressing challenges such as risks and complications. These technologies enhance workflow efficiency and facilitate the creation of complex dental implants with high accuracy, improving therapeutic results and aesthetic outcomes. (Alfayez, 2025).

2.4.2 The use of CAD in the Aerospace sector

The adoption of Computer-Aided Design (CAD) in the aerospace sector is characterised by its integration into various design and manufacturing processes, enhancing efficiency and precision. CAD systems facilitate the concurrent design of aircraft, which is an interdisciplinary activity that requires the simultaneous consideration of complex systems and requirements. This integration aims to achieve optimal performance while minimising technical and financial risks associated with aircraft development (Jungo, et al., 2018).

One significant application of CAD in the aerospace industry is the development of generative models that enable the rapid creation of conceptual aircraft designs. This approach not only streamlines the design process but also supports the creation of modular structures that can be adapted for several types of aircraft, making the design process more fluid and supporting the notion that design for parts is constantly evolving (Skarka, et al., 2023). The use of CAD in this context is essential for ensuring that the design meets the necessary performance and safety standards.

Additionally, the integration of CAD with other tools, such as computational fluid dynamics (CFD) and structural analysis, enhances the ability to conduct aerodynamic analysis and flight simulations. This integration allows for a more thorough evaluation of design options and their implications on aircraft performance (Jungo, et al., 2018).

2.4.3 The uses of CAD in the jewellery sector

The jewellery manufacturing industry has widely adopted CAD, with graduates from a British-based jewellery university committing to teaching CAD to all students from 2016 onwards. (Thorley, 2023).

The jewellery industry utilises Computer-Aided Design (CAD) to enhance its design and production processes significantly. CAD technology enables the creation of detailed

geometric models, which can be manipulated by jewellery designers and refined to meet specific design intents (Masood, 2002). This capability is particularly beneficial in the reverse engineering of jewellery, where existing physical models are scanned to obtain 3d data (Fudos 2006). The process involves generating editable CAD models that capture design intent through feature-based and constraint-based representations, essential for accurate manufacturing. (Stamati, Fudos 2005).

Moreover, CAD facilitates rapid prototyping and tooling, enabling designers to create jewellery prototypes quickly and efficiently. The integration of Rapid Prototyping (RP) technologies, such as Stereolithography Apparatus (SLA), an arm of the 3D printing industry, allows for the swift production of jewellery models and moulds, thereby reducing the time and costs associated with traditional manufacturing methods (Wannarumon and Bohez, 2004). This technological advancement not only streamlines the design process but also enhances the quality of the final products. This will be discussed further in section 2.7.

The jewellery market is also experiencing a transformation due to the increased use of CAD and Additive Manufacturing, which empowers designers and consumers with greater creative control and personalisation options. This shift indicates a merging of technology with consumer preferences, allowing for customised jewellery designs that reflect individual tastes. (Hughes, 2013).

Despite the advantages of CAD in jewellery design and manufacturing, a gap remains in educational institutions regarding the incorporation of CAD/CAM technologies into curricula in the UK before 2016. While faculty members with knowledge of these technologies are prepared to teach them, many institutions have yet to fully integrate CAD/CAM into their jewellery design programs globally. (Awotwe, 2016). This highlights the ongoing need for educational advancements to keep pace with industry developments. CAD can also help embed blockchain technology into the jewellery sector, enhancing the reliability of planning, the transparency of product and the security of design using digital design and Cloud data (Varveris, 2023) (Please see Appendix 7.1 and 7.2 for more detailed analysis on Big Data and digital twins) In the next section, the author will explore how blockchain technology can transform the jewellery industry.

2.5 Blockchain technology

In this section, the Author will discuss how Blockchain has embedded into the medical industry and the Aerospace sector to innovate patient care and enhance aerospace design. It will cover the benefits and barriers that the jewellery industry faced when it adopted blockchain.

2.5.1 Medical uses of blockchain technology

The medical industry has begun to adopt blockchain technology to address various challenges related to data management, security, and interoperability. Blockchain's decentralised nature offers a solution to the issues of data sharing and patient privacy, which are prevalent in current healthcare systems. By utilising a peer-to-peer network, blockchain

can enhance the management of healthcare data, thereby improving trust and transparency among patients, medical professionals and organisations (Sara, et al., 2022) (Poquiz, 2022). However, the adoption of blockchain is not without its challenges. Barriers, including a lack of standardisation, technical complexity, and regulatory hurdles, have been noted as significant obstacles to widespread implementation (Maghrabi, et al., 2024).

Moreover, the combination of AI, Big Data and blockchain technology has the potential to transform public health surveillance by ensuring tamper-proof records and enhancing data security (please see Appendix 7.1 for a more detailed description of Big Data). This capability enables the better identification of errors within the medical sector and empowers patients by providing them with greater control over their health information (Sahu, et al., 2024). The future of blockchain in healthcare may lead to more personalised and secure healthcare solutions, as it can integrate real-time clinical data to support effective diagnosis and treatment (Siyal, et al., 2019).

2.5.2 Aerospace uses for blockchain technology

The aerospace sector utilises blockchain technology in various ways to enhance operational efficiency, ensure data integrity, and improve supply chain management. One significant application is in the management of aircraft maintenance records. The Air Chain system has been designed to secure record integrity and traceability, addressing the critical need for reliable maintenance data in civil aviation, which is essential for safety standards (Lang Jensen, et al., 2022).

Blockchain technology also plays a pivotal role in mitigating the issue of counterfeit aircraft engine parts. By providing a decentralised and immutable record of maintenance history, blockchain can help ensure that only legitimate components are used, thereby reducing the risk of mishaps due to faulty parts (Gulmesoff, 2024). This application highlights the importance of accurate historical data in maintaining airworthiness and enhancing safety.

In the context of supply chain management, blockchain technology is being explored for its potential to improve transparency, traceability, and auditability of data and transactions. The integration of blockchain can facilitate the digitisation of crew certificates and enhance customer loyalty programs, thereby streamlining various operational processes within the aviation industry (Ahmad, et al., 2021). Furthermore, the use of blockchain in aerospace supply chains is linked to achieving sustainable development goals by introducing transparency and operational excellence, which can strengthen market positions and improve overall productivity (Ibrahim, et al., 2024).

Overall, the aerospace sector is increasingly recognising the transformative potential of blockchain technology, particularly in enhancing safety, operational efficiency, and sustainability within its various processes and systems. The ongoing research and development in this area indicate a growing interest in addressing the legal, regulatory, and technological challenges that accompany the adoption of these innovative solutions (Abdulrahman, et al., 2023).

2.5.3 Jewellery adoption of blockchain technology

Blockchain technology can significantly enhance the jewellery industry by improving traceability, transparency, and efficiency throughout the supply chain. One of the primary applications of blockchain in this sector is its ability to create a secure and immutable ledger that ensures data integrity. This is particularly important in the jewellery supply chain, where trust and provenance are critical. By utilising platforms like Ethereum, the industry can develop tailored blockchain networks that facilitate secure transactions and prevent fraud and tampering due to the technology's decentralised nature. (Akolekar, et al., 2025).

Blockchain implementation can address the growing consumer demand for detailed information regarding the provenance of gems, including diamonds, coloured stones, and pearls. As consumers increasingly seek assurance about the ethical sourcing of materials, blockchain can provide a reliable certification mechanism that tracks the journey of gems from their origin to the final product. This includes the integration of existing gemmological approaches to enhance traceability and transparency measures (Ali, et al., 2018).

Moreover, the luxury jewellery sector faces challenges related to counterfeiting and grey market activities. Blockchain can help mitigate these issues by ensuring the traceability and authenticity of luxury goods. By promoting greater transparency within supply chains, blockchain can build consumer trust and potentially improve brand revenue (Baudier, et al., 2021).

Technological advancements, such as Radio Frequency Identification (RFID) and Non-Fungible Tokens (NFTS), can further enhance traceability in high jewellery processes. These technologies can provide superior alternatives to traditional paper-based methods, ensuring verifiability and security throughout the extraction and manufacturing phases. (Cappellieri, et al., 2023)

The diamond Centre Wales (DCW) has incorporated blockchain into their manufacturing. It tracks products from their rawest material, particularly diamonds, throughout their lifecycle, claiming ownership of a high-value and highly sought-after natural element. Block training will help eliminate illegal or unethical mining practices and make it easier for insurance companies to keep track of insured products, which will result in fewer thefts in the future, as it will become less desirable to steal a diamond that is easily traced (James, 2021).

The adoption of blockchain technology in the jewellery industry faces several challenges that may hinder its implementation. One significant barrier is the knowledge gap among stakeholders regarding blockchain applications. Many luxury brands are hesitant to adopt this technology due to a lack of understanding of its benefits and functionalities, which can impede the decision-making process for implementation (Baudier, et al., 2021).

Additionally, the complexity of the supply chain in the fine jewellery sector presents another obstacle. The involvement of multiple third parties in the production process complicates the integration of blockchain solutions, as coordination and collaboration among these entities are essential for successful implementation. (Baudier, et al., 2021) (Cappellieri, et al., 2023).

This complexity can lead to resistance from stakeholders who may be reluctant to change established practices.

Moreover, there is a prevailing bias towards short-term returns on investment within the luxury sector. Companies may prioritise immediate financial gains over the long-term benefits of blockchain technology, such as enhanced traceability and consumer trust (Baudier, et al., 2021). This short-sightedness can deter investment in the infrastructure and training required for effective blockchain integration (Udokwu, et al., 2023).

The high-value jewellery industry also grapples with sustainability concerns, particularly in the mining process, which is often viewed as the most challenging aspect of traceability (Cartier, Ali et al. 2018) (Cappellieri, et al., 2023). The integration of blockchain technology, while potentially beneficial, requires significant changes to existing practices, which may be met with resistance from companies accustomed to traditional methods (Ciurel, 2024). Blockchain technology can enhance other Industry 4.0 technologies and innovations by improving efficiency. For example, integrating QR codes into manufactured parts makes it easy for robotics to recognise and assemble parts to create a more efficient assembly line (Jum'a, 2023)

2.6 Additive manufacturing

In this section, the Author will discuss how Additive manufacturing (AM) has embedded into the medical industry and the aerospace sector to innovate patient treatment and enhance aerospace production capabilities. It will cover the benefits and barriers that the jewellery industry faces when it adopts Additive manufacturing.

2.6.1 Medical use of Additive manufacturing

The adoption of additive manufacturing (AM) in the medical industry is branded by its transformative potential, particularly in the production of customised medical devices and pharmaceuticals. Various AM technologies, such as stereolithography, selective laser sintering, and fused deposition modelling, are being systematically examined for their applications in creating patient-specific implants, prosthetics, anatomical models, and surgical guides. These technologies enable the fabrication of complex geometries tailored to individual patient anatomies, which can lead to improved patient outcomes and enhanced surgical precision (Singh, 2024).

Additionally, the integration of 3D printing in cardiovascular medicine has been explored for creating anatomical models that aid in surgical planning and patient communication. The technology is also being applied to bioprint fully functional cardiovascular tissues, including myocardium and heart valves, which could address the growing organ shortage crisis (Gardin, et al., 2020)

The medical industry has seen significant advancements in the use of 3d printing for developing multifunctional drug delivery systems, personalised dosage forms, and implants that correspond to specific patient anatomy. This has been facilitated by the growing demand for customised pharmaceuticals and medical devices, which has accelerated the impact of additive manufacturing in recent years (Jamróz, et al., 2018). The literature indicates that while the benefits of AM are notable, including decreased operating time and improved surgical outcomes, the technology remains underutilised due to the lack of training for medical professionals and access to correct machinery, (Zhang, et al., 2019).

Recent advancements in additive manufacturing have expanded its applications in dentistry, moving from basic surgical guides to more complex structures such as personalised restoration crowns and root implants please see figure 4. This evolution underscores the technology's potential in bioprinting, which aims to regenerate dental tissues and improve overall patient outcomes (Huang, et al., 2022). The ability to create patient-specific devices has been identified as a new frontier in dental and maxillofacial rehabilitation, allowing for more effective treatment strategies (Kouhi, et al., 2024).



Figure 3 (Jackson, 2017)

Despite the promising applications, the adoption of additive manufacturing in healthcare faces several challenges, including regulatory hurdles, material biocompatibility issues, and cost considerations. These obstacles must be addressed to realise the potential of 3d printing in healthcare fully (Jamróz, et al., 2018) (Prakash, et al., 2024). Furthermore, the need for ongoing research into cost-effectiveness and the exploration of innovative materials is essential for advancing the implementation of AM technologies in the medical field (Ramola, et al., 2019) (Jamróz, et al., 2018).

In conclusion, while the medical industry is gradually adopting additive manufacturing for various applications, significant challenges remain that must be overcome to enhance its integration and effectiveness in healthcare settings.

2.6.2 Application of additive manufacturing in Aerospace

Additive manufacturing (AM) is significantly transforming aircraft design and production by enhancing efficiency, reducing weight, and enabling innovative design methodologies. This technology allows for the creation of complex geometries and cellular structures that are difficult or impossible to achieve with traditional manufacturing methods. For instance, the ability to produce three-dimensional components with varying levels of detail facilitates weight reduction while maintaining the necessary mechanical properties, such as stiffness and temperature distribution, which is crucial in the aerospace industry (Vu, 2024) .

The integration of Additive Manufacturing (AM) into the aircraft supply chain is also noteworthy. Research indicates that AM can improve supply chain efficiency by balancing inventory levels, increasing responsiveness, and reducing disruptions and carbon emissions (Ghadge, et al., 2018). This transformation is particularly relevant as the aviation industry seeks to adapt to new technologies that can streamline operations and enhance sustainability.

Moreover, the application of AM in the design of aircraft components, such as the use of minimal surfaces for reinforcement, demonstrates its potential to improve mechanical properties and reduce environmental impact using renewable energy



Figure 4 (Petch, 2023)

sources (García-Gascón, et al., 2022). The development of innovative design methodologies, such as the use of gyroids as filling materials, further illustrates how AM can lead to stronger and lighter parts, thereby enhancing the overall performance of aircraft (García-Gascón, et al., 2022).

Additionally, the ability to produce thin-walled and intricate parts, such as jewellery components, is improved through advanced manufacturing processes like Selective Laser Melting (SLM) and investment casting. Furthermore, AM offers the opportunity to develop engineering by having the ability to incorporate internal fixtures and small cooling fans. According to (Dejene, et al., 2023) SLM offers design freedom and tool-free production directly from CAD data, resulting in parts with improved tensile strength and fine microstructure. On the other hand, investment casting provides superior surface quality, fatigue load resistance, ductility, and residual stress, making it a viable option for manufacturing intricate parts like turbine blades. The comparison between SLM and investment casting highlights the importance of mechanical characterisation, quality parameters, and residual stress in achieving the desired quality and reliability in thin-walled parts (Dejene, et al., 2023).

In summary, additive manufacturing is reshaping aircraft design and production by enabling more efficient supply chains, facilitating innovative design approaches, and contributing to

weight reduction and sustainability efforts within the aviation sector. The ongoing evolution of AM technologies promises further to influence the future of aircraft manufacturing and design practices (Wagner, 2016) (Mami, et al., 2017.).

2.6.3 The jewellery industry's adoption of Additive manufacturing and 3d printing

Throughout sections 2.7.4 to 2.7.6, the author will discuss the different types of Additive manufacturing that the jewellery industry has adopted and what the industry is looking to adopt in the future.

2.6.4 Wax printing and Fused deposition printing.

Wax printing has been widely adopted in the jewellery manufacturing sector to enhance production efficiency and design capabilities. Before the commercial release of the Stratasys' first Fused deposition modelling printer in 1992 (see figure 7), jewellery would have been hand-carved by artisans to create a master mould assembled onto a casting tree (see figure 6) and then cast into metal. (The Art of Jewelry Making. 2009).

Advancements have introduced Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) systems, which facilitate the design and production of intricate jewellery pieces. These systems enable the creation of wax patterns through rapid prototyping, replacing traditional mould injection methods. This shift not only enhances the flexibility in design but also allows the production of more complex shapes with greater ease (Masood 2002). Moreover, the integration of 3d printing technologies is emerging as a significant trend in the jewellery sector.



Figure 5 Wax casting tree (Hathaway, 2024)



Figure 6 (RA Design, 2025)

2.6.5 Direct into Metal Additive Manufacturing

This process utilises a composite of metal powder which is printed layer by layer (Yan, Hao et al. 2017). The transition towards these advanced techniques, including the potential for metal 3d printing, indicates a shift in the jewellery manufacturing landscape, moving away from traditional wax moulds and casting processes (King 2014).

Direct metal 3D printing (DMLS) involves the layer-by-layer addition of metallic powder to create complex parts directly from CAD models. This technique utilises a laser to selectively sinter the powder, which means that the laser heats specific areas of the powder bed to the point where the particles fuse, forming a solid structure (Fig. 8). The process has been successfully adopted for its application in industries such as aerospace, medical, and automotive, where precision and material properties are critical (Nandy, et al., 2019) (Nancharaiah, et al., 2023).

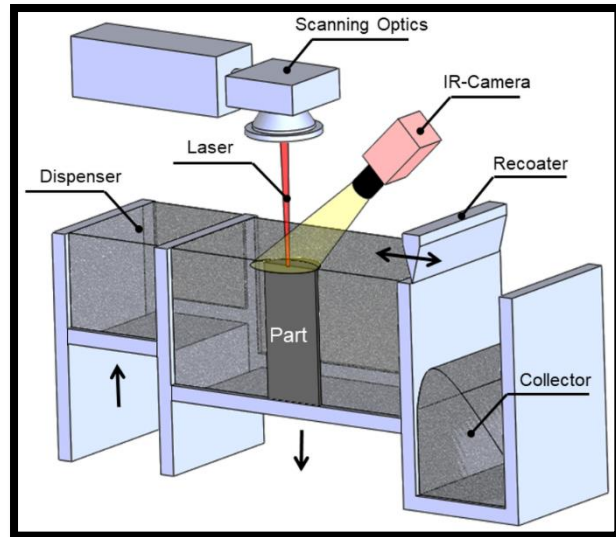


Figure 7 (Abbas Razavykia, 2020)

Various process parameters, including laser power, scanning speed, and hatching distance, influence the effectiveness of DMLS. These parameters have a substantial impact on the build time and accuracy of the final components. For instance, higher laser power can lead to increased phase formation but may also introduce residual stresses and deformations, which can compromise the mechanical properties of the parts produced (Nancharaiah, et al., 2023). Experimental studies have shown that optimising these parameters is essential for achieving desired material characteristics and minimising defects such as cracks and porosity (Nancharaiah, et al., 2023) (Korium, et al., 2021).

In addition to traditional metals, DMLS has been explored for the printing of precious metals in jewellery applications. The process allows for the creation of intricate designs while maintaining quality comparable to conventional manufacturing methods (Fig. 1). The microstructure of the printed parts can vary based on the material used, with some metals exhibiting internal defects while others achieve a more homogeneous surface (Korium, et al., 2021)

Overall, DMLS represents a versatile and evolving technology in additive manufacturing, enabling the production of high-strength components with complex geometries that are difficult to achieve through traditional methods, which in turn opens up further revenue streams for UK SMES to develop their product offering (Martin, et al., 2017). The integration of advanced materials and process optimisation continues to enhance the capabilities and applications of direct metal 3d printing (Khondoker, et al., 2019).

In 2003, Gomelsky predicted that the jewellery sector would adopt metal 3d printing to allow small and medium enterprises to expand into global markets with the ability to mass produce luxury parts (Gomelsky, 2023), but the attitudes towards innovation have still not been fully

embraced by the UK market, with slow adoption and struggles to embed due to a lack of education within the workforce and the costly capital needed to adopt direct to metal 3d printing. The businesses adopting these new technologies are high-value, large enterprises such as Tiffany and Cartier.

The adoption of 3D printing in jewellery making has been divisive due to a lack of understanding of the technology, with a large proportion of the jewellery industry believing that 3D printers will take their jobs. Within the jewellery sector, enabling the creation of unique and customisable pieces with reduced lead times and costs (Nazir, et al., 2019). This has streamlined the manufacturing process but has also opened new possibilities for innovation and personalisation in the industry (Nazir, et al., 2019) Incorporating additive manufacturing techniques has proven to be beneficial for small to medium enterprises in the jewellery sector, offering time-saving and cost-effective solutions that enhance competitiveness in the global market (Rooney, et al., 2023). By leveraging these techniques, businesses can tailor their products to a diverse range of customers while maintaining quality control throughout the manufacturing process (Rooney, et al., 2023)

However, incorporating additive manufacturing techniques has proven to be beneficial for small to medium enterprises in the jewellery sector, offering time-saving and cost-effective solutions that enhance competitiveness in the global market (Rooney, et al., 2023). By leveraging these techniques, businesses can tailor their products to a diverse range of customers while maintaining quality control throughout the manufacturing process (Rooney, et al., 2023)

Jewellery manufacturers could therefore leverage 3d printing for prototyping and production of intricate designs, enabling cost-effective customisation. However, the barriers that deter the wider jewellery industry from using additive manufacturing are significantly different from those faced by the aerospace industry, mainly regarding material and research costs. (L.E.J. Thomas-Seale a, 2018)

2.6.6 Electrochemical Additive Manufacturing

Electrochemical additive manufacturing (AM) presents a unique opportunity for the jewellery industry by enabling the production of intricate designs with enhanced material properties. Although the technology is still in its infancy stage of development, its integration can lead to significant advancements in the design and fabrication processes of jewellery, particularly in precious metals. The ability to build jewellery with electrochemical AM adds a distinctive visual appeal to jewellery pieces, allowing for innovative design possibilities that align with contemporary consumer preferences (Del Curto, Garbagnoli et al. 2014).

The adoption of electrochemical methods in additive manufacturing (AM) can facilitate the creation of complex geometries that are often challenging to achieve with traditional manufacturing techniques. This layer-by-layer approach not only reduces material waste comparatively from DMLS but also allows the production of lightweight components with high strength and fewer potential failure points, which is particularly beneficial in the jewellery sector, where both durability and aesthetics are paramount (Calignano 2020a).

Moreover, applying rapid prototyping and mechanical finishing techniques in conjunction with electrochemical processes can enhance the quality and finish of jewellery items. This combination can lead to the development of unique surface textures and colours, further differentiating products in a competitive market (Calignano 2020b).

The jewellery industry can benefit from electrochemical additive manufacturing through improved design flexibility, reduced waste, and enhanced material properties. The potential for innovative applications and the ability to create visually appealing products align well with the evolving demands of consumers in the jewellery market.

2.7 Summary

The literature review systematically examines the adoption of Industry 4.0 technologies within the aerospace and medical sectors, highlighting their successful integration and transformative impact on these industries. Subsequently, the study explores the potential applicability and current implementation status of these technologies in the jewellery industry. A notable limitation identified is the nascent stage of technologies such as Artificial Intelligence (AI), Electrochemical Machining (ECM), and Blockchain within the jewellery sector, leading to a scarcity of diverse and comprehensive literature on their adoption and impact. This gap underscores the need for further empirical research to assess the feasibility and benefits of integrating these advanced technologies into jewellery manufacturing and design processes. The forthcoming methodology section will outline the approach for collecting primary data, aiming to augment the literature review by providing practical insights and addressing the identified research gaps.

3. Methodology

3.1 Introduction to the chapter

Employing both questionnaires and interviews, as well as a case study, quantitative and qualitative data were collected from small and medium-sized jewellery businesses. By combining this data with the case study, I will be able to explore the extent to which these technologies have been adopted and consider how they can be more fully integrated into their businesses. Using a mixed-methods approach to gathering data, a comprehensive understanding of the sector can be formed (Tang, 2020). Tang demonstrates in Figure 7 that triangulating between a case study, questionnaire, and interviews means that a more varied basis of primary research can be gathered, providing validity and in-depth findings through multiple data sources.

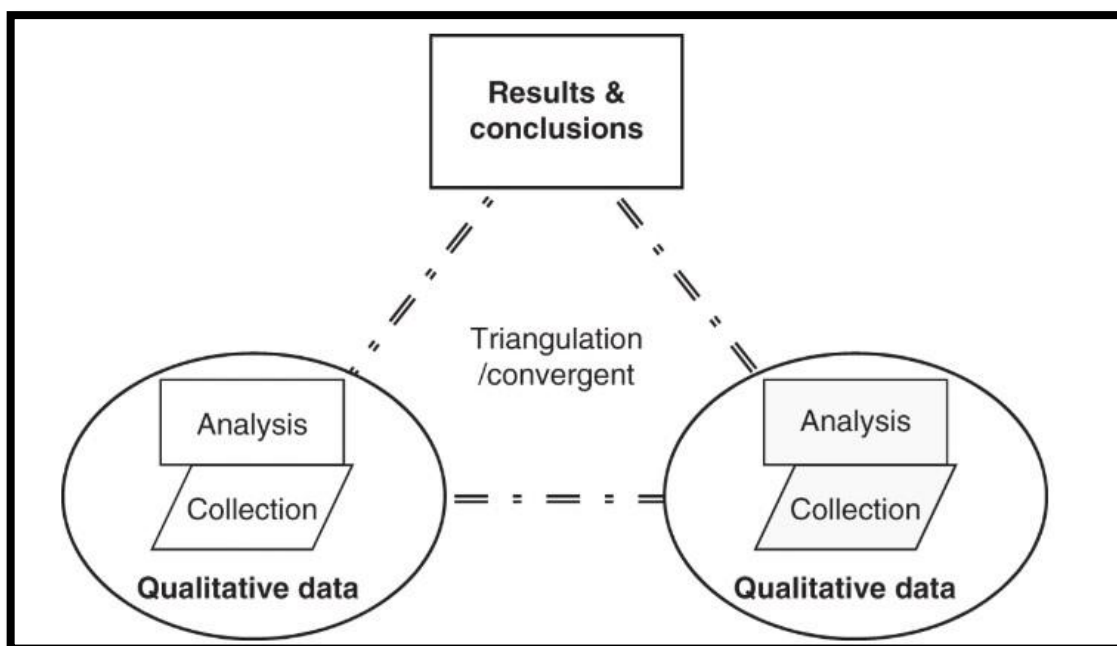


Figure 8 (Tang, 2020)

3.2 Questionnaire design

Questionnaires provide the researcher with a broader spectrum of results, as they can be distributed to a wider audience and yield unbiased answers due to anonymity. The questionnaires are designed to produce both quantitative and qualitative data. For reference, please see Appendix 1, which contains the questionnaire distributed.

The questionnaires were created in an electronic format to reach a wider audience. They were posted on social media and emailed to jewellery businesses and senior managers in the sector, as they possess a broader understanding of the industry and its innovation potential. The questionnaires were circulated over two weeks for respondents to answer remotely.

3.2.1 Ethical implications

For this study, an Ethics form was not required by the university. Importantly, the first page of the Questionnaire is an informative notice which will inform the respondent why this research is being conducted. By partaking in the questionnaire, they understand the following:

- understand that participating in this questionnaire is voluntary and not obligatory.
- Agree that answers are recorded exclusively for this study
- Permission for my study data to be used anonymously during this academic study to strengthen and verify research, and to serve as a source of reference.
- Understand that the researcher, academic supervisor, and marking board may review the data provided, and I authorise this review.
- Understand that I will neither benefit from nor be at risk from participating in this study.
- Understand that my information will be treated with the up most care and discretion, protecting my identity and the identities of anyone else identified. I understand that my data will not be shared with third parties.
- Voluntarily provide permission to participate in this research.

3.2.2 Barriers and limitations of using Questionnaires

As the jewellery industry is famously secretive about sharing its trade secrets, potential respondents may be reluctant to divulge accurate data. Secondly, a significant challenge is participant engagement, which can often lead to low response rates, especially in highly competitive industries and when the questionnaires are distributed to very time-poor individuals (Ghouchani, et al., 2021).

Thirdly, questionnaires can lead to misinterpretation of answers or vague answers that leave the data gatherer with incomplete information. Additionally, making sure the respondent doesn't lose interest whilst completing the questionnaires, to ensure that the maximum number of returned and completed questionnaires are returned (Sharma & Ruikar, 2025). For this reason, I amended the questionnaires so that, depending on the answer given, it would vary and tailor subsequent questions to gather more detailed and relevant data.

3.3 Interviews

The Author chose experts within the blockchain and Additive manufacturing sectors of the Jewellery industry. The questions covered how innovation within their respective knowledge spaces has led to innovations in the jewellery space. Please see Appendices 10, 11 and 12 to see the questions asked.

Interviews provide an in-depth and expert opinion on a focused topic area within the industry, which enhances the reliability of the collected data. Additionally, interviews facilitate the gathering of economic data and offer rich, nuanced insights into participants' experiences, providing a real-world perspective on a subject area. Additionally, it allows the interviewer the opportunity to expand and ask further questions to create a deeper understanding of the interviewee's stance on the subject matter (Cridland, et al., 2016).

3.3.1 Ethical implications of interviews

When conducting interviews in qualitative research, several ethical requirements must be observed to ensure the protection and respect of participants. A primary consideration is the need for anonymity and confidentiality, which are essential to make participants feel safe and secure during the interview process. Researchers must ensure that participants' identities are protected and that their responses are kept confidential to foster trust and encourage honest communication (Nii Laryeafio & Ogbewe, 2023).

Voluntary participation is another critical ethical requirement. Participants should be fully informed about the nature of the research and must provide their consent to participate without any coercion (Petrova, et al., 2016). This includes the right to opt out at any stage of the research process, which reinforces the principle of respect for autonomy (Nii Laryeafio & Ogbewe, 2023). All participants were pre-notified of the recording of the interview before the interview took place and reminded at the beginning of the interview.

3.3.2 Barriers and limitations of conducting interviews

One significant issue is establishing a horizontal relationship between the researcher and the participant, which can be difficult in traditional interview settings. The shift to online platforms for conducting interviews, accelerated by the COVID-19 pandemic, introduces additional complexities. Researchers often lose control over the study environment, as participants may be in varied locations, which can compromise confidentiality and privacy. This is especially critical when discussing sensitive or confidential topics, as participants might feel uncomfortable disclosing personal information in the presence of colleagues (Meherali & Louie-Poon, 2021).

Finally, while platforms like Zoom or Microsoft Teams offer innovative opportunities for data collection, they also present technical challenges that can affect the interview experience. Despite some participants facing difficulties, many reported satisfactory experiences, indicating that with careful management, online methods can be viable for qualitative research (Archibald, et al., 2019).

3.4 Case study

Diamond Centre Wales (DCW) is a small to medium-sized enterprise (SME) jewellery manufacturer based in South Wales, with an annual turnover of £2 million. Founded in the late 1980s, their jewellery business has grown from strength to strength. During the COVID-19 pandemic and the cost-of-living crisis, like most of the UK jewellery sector, it experienced a significant decline in revenue due to consumers' limited disposable income. To overcome this, the Chief Executive Officer (CEO) sought to expand the company's offering by incorporating innovation within its business. However, having the business situated in a remote part of Wales created further logistical issues, such as relying on the postal network for high-value orders, which can be delivered only with adequate foot traffic, or outsourcing casting due to the workshop's inability to house high temperatures safely or having the right workforce locally to operate the machinery.

After partnering with Sheffield University on an Additive manufacturing viability study In 2020, DCW was awarded a grant by Innovate UK, which enabled a Knowledge Transfer Partnership employee to sit within the business and partner with Birmingham City University's School of Jewellery to gain more knowledge about the commercial applications of Additive manufacturing. During the study, the KTP candidate conducted extensive research on all aspects of Additive manufacturing for precious metals. The candidate had a £280,000 budget to explore the feasibility of embedding additive manufacturing into their workshop.

AM was identified as a technology that could have a positive impact on the jewellery offering presented at DCW, as it allows for the creation of highly intricate and complex designs that might be difficult or impossible to achieve with traditional casting methods. This is particularly useful for custom or bespoke pieces, where unique geometries are desired. SLM can rapidly produce prototypes or one-off pieces without the need for moulds, making it ideal for personalised jewellery. This can significantly speed up the design-to-production process.

The author realised that, despite the investment from IUK, DCW did not have sufficient financial capital to expand into SLM printing. As a result, it sought to alleviate these financial difficulties by creating a collaborative research project between DCW, the School of Jewellery, and Alpha Lazer, the machine provider. All the parties shared financial responsibility for the project and benefited from shared intellectual property ownership (IP) that was created during the project's period.

Secondly, the installation and setup of printers incurs high, one-off costs to ensure it is properly calibrated and integrated into the existing infrastructure of the SME. This often includes global travel of a small team of technicians sitting within the business for a week, and training employees in the correct and complex technical skills required to run the printer. It should also be noted that to gain a good grasp of these printers, new employees (especially if the employee who received the initial training has left) should receive training from the printing provider to ensure the printer is not damaged and that costly, precious metals are not wasted.

DCW needed to allocate dedicated space for the SLM printer. This required renovating the space to

accommodate the machines and their needs.

Firstly, the flooring and walls needed to be cleaned to facilitate the reclaiming of precious metal powders. Three-phase plugs with

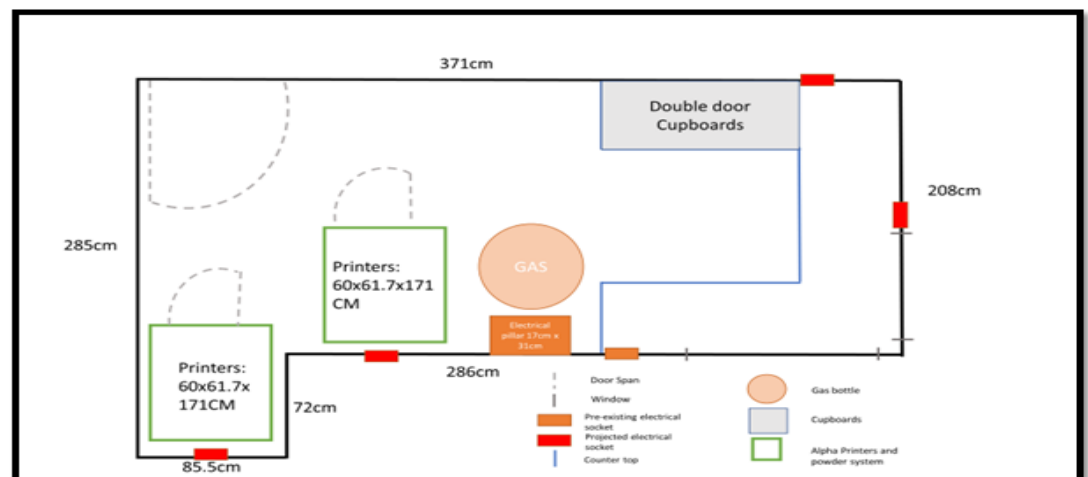


Figure 9

compatible electrical points had to be fitted for the polishing equipment. Air con needed to be installed to keep the room cool but not create a breeze that would move powder around the 3D printing room. Please refer to Figure 8 for room layout plans.

Once DCW and the Author managed to embed the Alpha laser system into DCW, research builds in white gold started to take place. These are costly, necessary studies that can prove if the technology works for the jewellery sector with the Alpha laser system for production. The builds were challenging and yielded mixed results, not achieving a reasonable return rate on the capital invested. It could be evaluated that, while the technology was interesting for DCW in the future, the current level of the technology at the time was insufficient to replace traditional casting methods.

3.5 Use of triangulation

The use of triangulation in research is recognised for its ability to enhance the validity and credibility of findings. By employing multiple methods, Such as Questionnaires, interviews, and a Case study, researchers can converge on results that aim to verify and strengthen the validity of their conclusions. This approach allows for a more nuanced understanding of the phenomenon under investigation, as complementary results can highlight different aspects or illustrate various phenomena. At the same time, divergent findings may lead to new insights and explanations (Heale, 2013).

Triangulation is particularly valuable in qualitative research, which often faces criticism regarding rigour and potential researcher bias. By integrating different triangulation strategies, researchers can bolster the trustworthiness of their studies. It is essential, however, for researchers to identify the types of triangulations they employ, as confusion about these strategies can undermine the rigour of their work. (Morgan, 2024).

Moreover, the combination of qualitative and quantitative methods through triangulation can address the limitations inherent in each paradigm. This methodological blending allows researchers to neutralise the weaknesses of one approach while enhancing the strengths of the other, ultimately leading to more reliable research outcomes (Hussein, 2015).

In practical applications, methodological triangulation has been shown to provide confirmation of findings and enrich the data collected. For instance, qualitative data can clarify and complement quantitative results, thereby enhancing the overall understanding of the studied phenomena (Bekhet, 2013). In summary, triangulation serves as a robust strategy for gathering data, strengthening the validity, credibility, and overall rigour of research findings.

Furthermore, the case study in section 3.4 examines the real-life limitations and challenges a business faces when attempting to embed an Industry 4.0 technology, comparing this to the results of the questionnaire, and it should be possible to evaluate whether the obstacles correlate across the industry for other SMEs.

3.6 Project plan timelines

This section outlines the timeline for conducting the research and gathering data. Table 1 displays the timeline of tasks carried out, shaded in grey, which spans from September 2024 to May 2025.

Time Plan for the proposed Project work: gathering data for the final project									
Project stage	Project Months								
	0-3			3-6			6-9		
	1	2	3	4	5	6	7	8	9
Literature review									
Questionnaires disbursed									
Interviews conducted									
Methodology									
Editing									
Conclusion									

Table 1 Gantt chart of Final Project timeline

3.7 Summary

The primary research methods chosen to provide a varied data pool from experts in AM and Blockchain to gain an in-depth knowledge of the topics. To supplement this, a questionnaire was distributed within the jewellery workforce. Results are shown in section 4 below.

4. Results

4.1 Questionnaires

In total, six responses were received for the questionnaires. Figure 9 illustrates a preliminary set of questions designed to understand the size of the organisation in which the respondent is employed. The number of people working in their organisation ranges from 3 to 197.

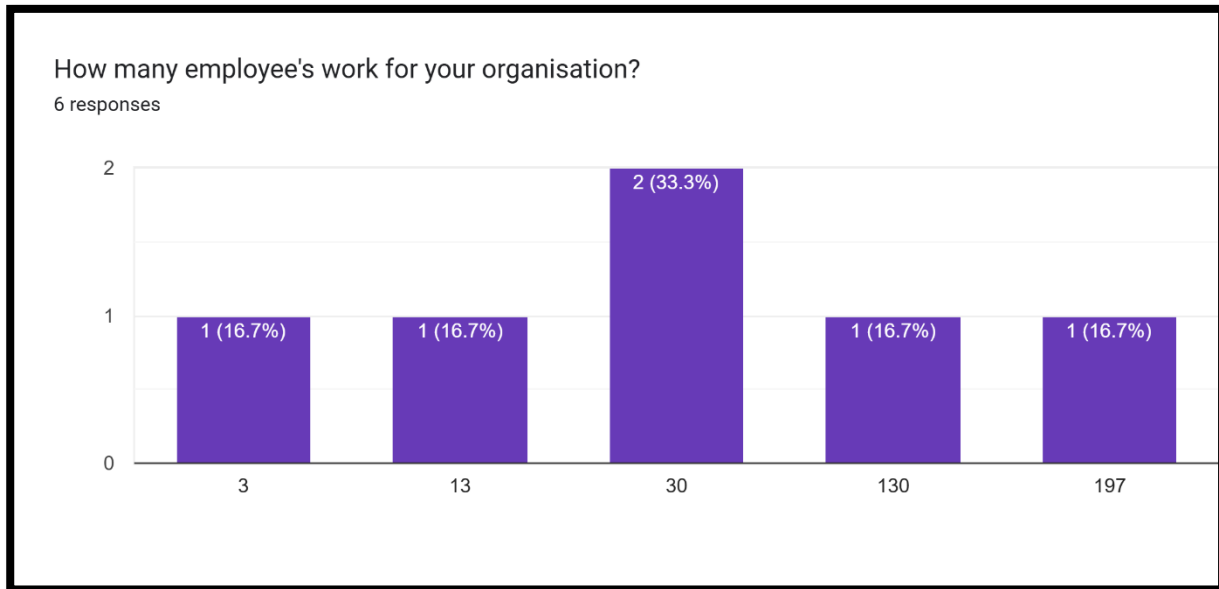


Figure 10 Employee head count

For question 1, shown in Figure 10, 66.7% of respondents believed that Blockchain was not essential for their company, 33.3% of respondents would be interested in blockchain technology but require more information before implementing it into their company.

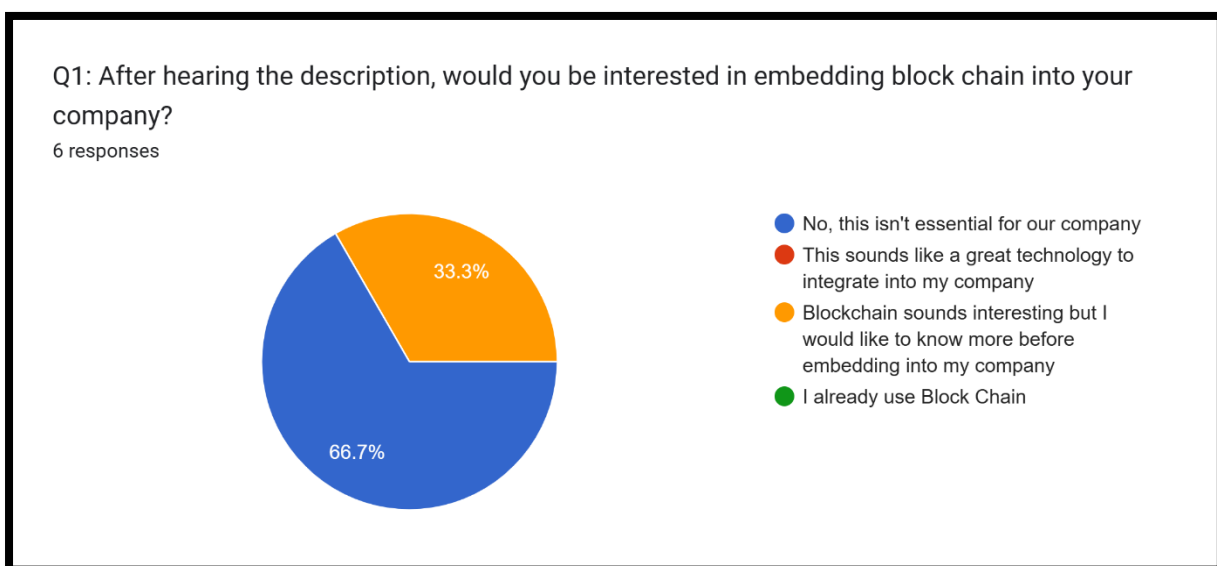


Figure 11 Blockchain interest

For Question 2, the researcher wanted to gain a qualitative understanding of what would stop organisations from embedding Blockchain technology.

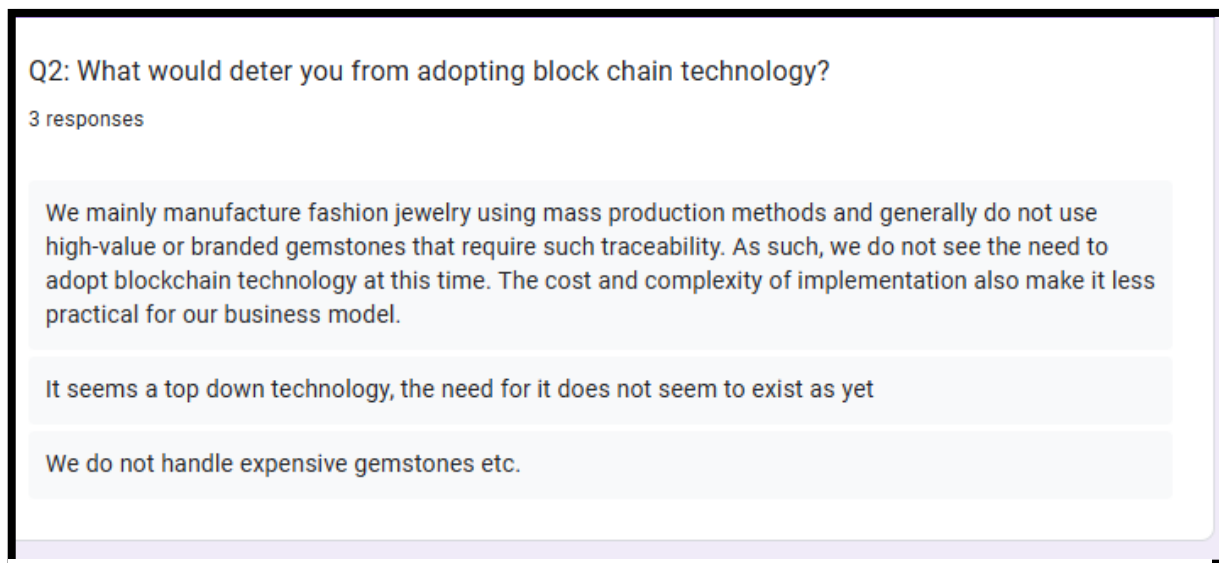


Figure 12 Adoption of block chain technology

Question 3 explores what the organisations would need to gather from the blockchain technology provider to embed the technology into their business. This question could be answered multiple times, and from the two respondents who answered, one said that staff training would be essential, and the other voted for the tools and machinery to be provided. There was also a vote for external marketing campaigns to educate consumers. Additionally, there was a vote for an incentivised bonus scheme to encourage the jewellery sector to use the service. Furthermore, there was a vote for providing and embedding services within the company, as well as case studies that consumers could use to educate themselves.

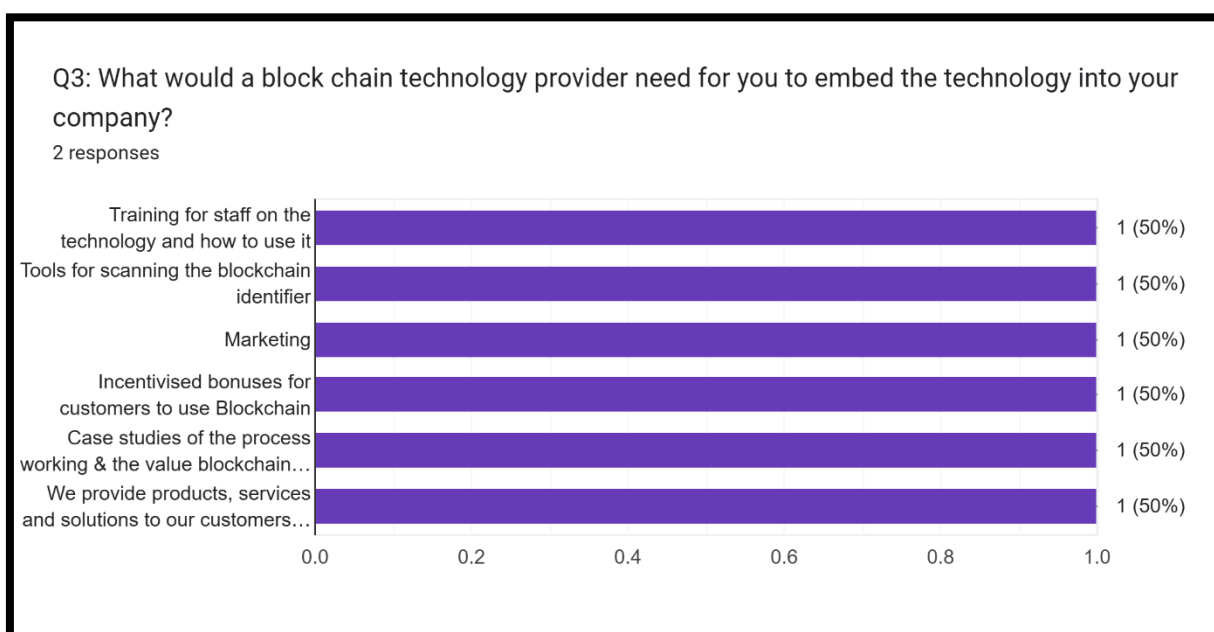


Figure 13 Needs of respondents for embedding Block chain technology

Question 4 explores what the respondents currently use to ensure traceability for their consumers.

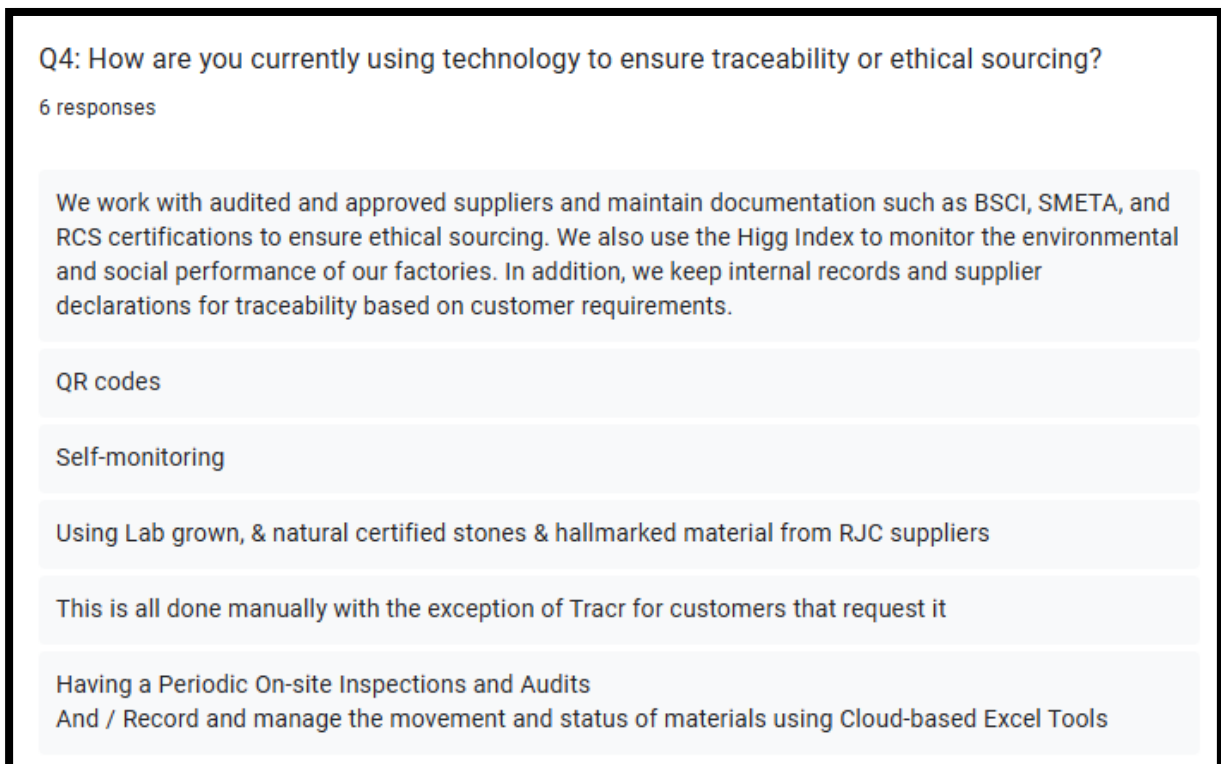


Figure 14 Traceability questionnaire

Question 5 asks respondents if they have heard of CAD. All respondents (100%) said yes, they knew what CAD is and have used it within their business shown in figure 14.

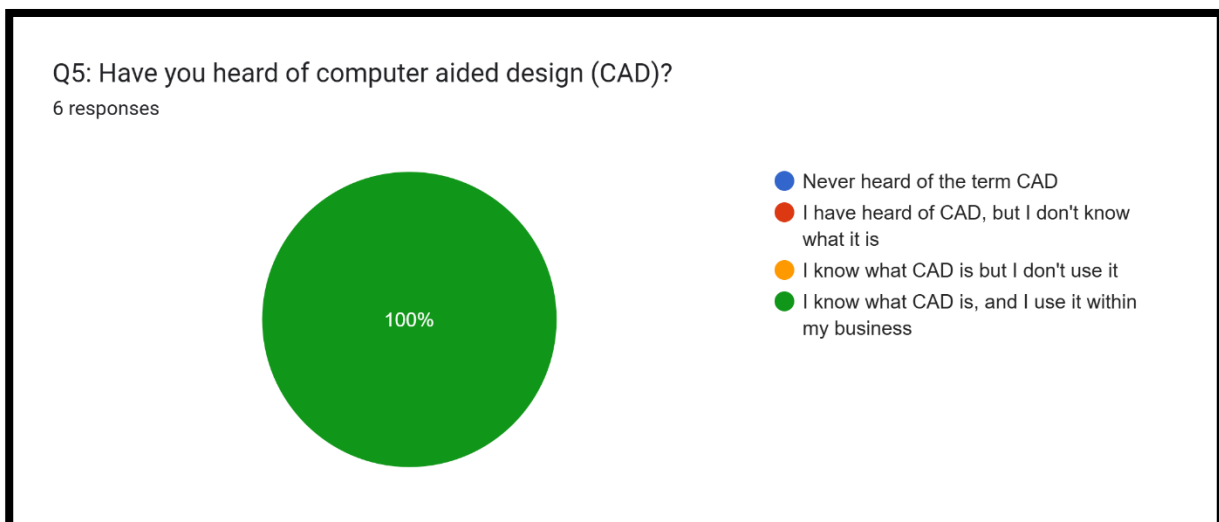


Figure 15 Initial CAD Questionnaire

No one answered question six.

Q6: After hearing the description, would you now be interested in embedding CAD into your company?

0 responses

No responses yet for this question.

Figure 16 CAD

No one answered question seven.

Q7: What deters you from embedding CAD into your business?

0 responses

No responses yet for this question.

Figure 17 CAD 2

No one answered question eight.

Q8: What would you need to embed CAD into your business?

0 responses

No responses yet for this question.

Figure 18 CAD 3

The respondents answered question 9 as follows: 33.3% of respondents use 3D printing for all customer orders, shown in Figure 18, and 16.7% of respondents use 3D printing for most orders. 33.3% of respondents occasionally use 3d printing, and 16.7% never use 3d printing within their business.

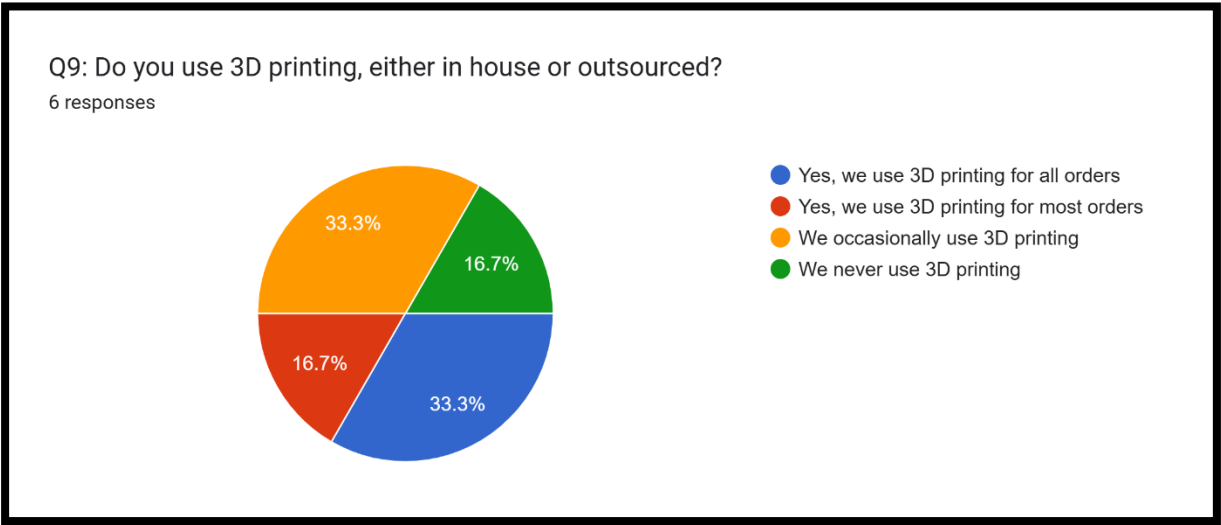


Figure 19 Use of 3D printing

For question 10, one respondent answered that they would not embed 3D printing within their business, as shown in Figure 19.

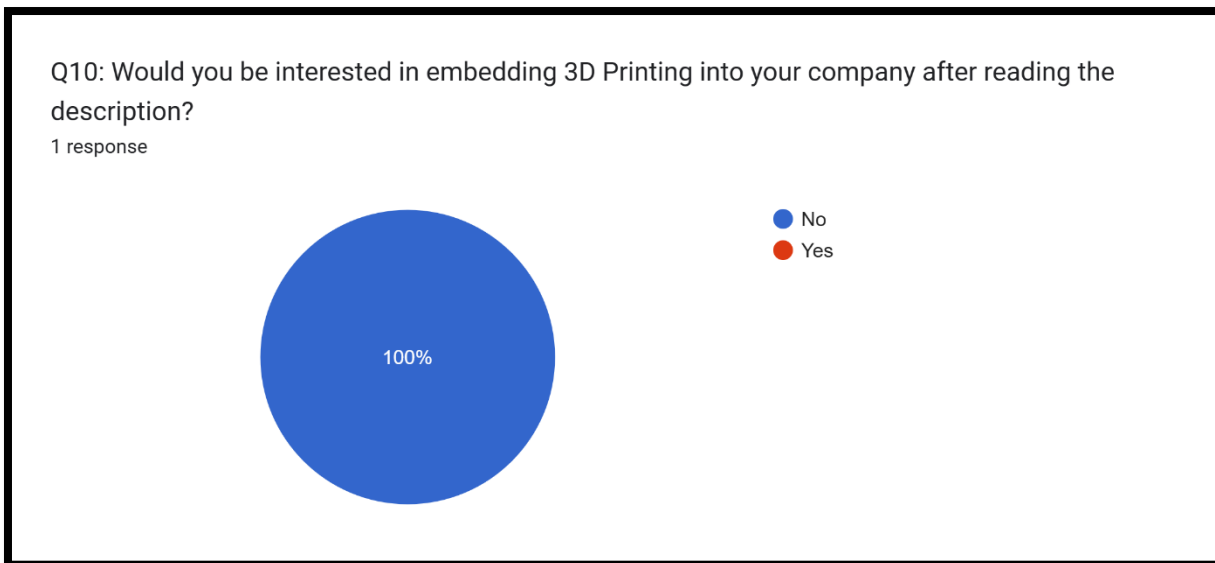


Figure 20 3D printing embed 1

No one answered question 11

Q11: What would you need to embed 3D printing into your business?

0 responses

No responses yet for this question.

Figure 21 3D printing embed necessities

One respondent answered question 12, declaring that 3D printing technology is too expensive, which is why they could not integrate 3D printing into their business, as shown in Figure 21.

Q12: What deters you from embedding 3D printing technology into your business?

1 response

too expensive

Figure 22 deter from 3D printing

Six respondents answered question 13, outlining the software and different printing technologies they have already embedded, which include Rhino CAD, wax printing, Formlabs, SLM, and Fused Deposition Modelling as shown in figure 22.

Q13: What 3D printing technology have you embedded in your business?

6 responses

We use Rhino 3D CAD software to create detailed designs, which are then 3D printed into wax molds for brass casting. This helps us quickly develop samples with high precision and supports efficient prototyping during the development phase.

We outsource to specialists

Not yet

Formlabs Form 4 (prototyping & casting) Projet (casting) SLM (direct fabrication)

We have 5 3D printing machines that cover a different range of applications for resin and wax printing

Fused Deposition Modeling

Figure 23 Current adoption of 3D printing

Six respondents answered Question 14 as shown in Figure 23. It showed three respondents invested over £30,000 a year in Research and development. One respondent reported investing over £50,000, and another respondent stated that the investment was over £100,000 a year. The final respondent suggested that this question would be better suited for the directors.

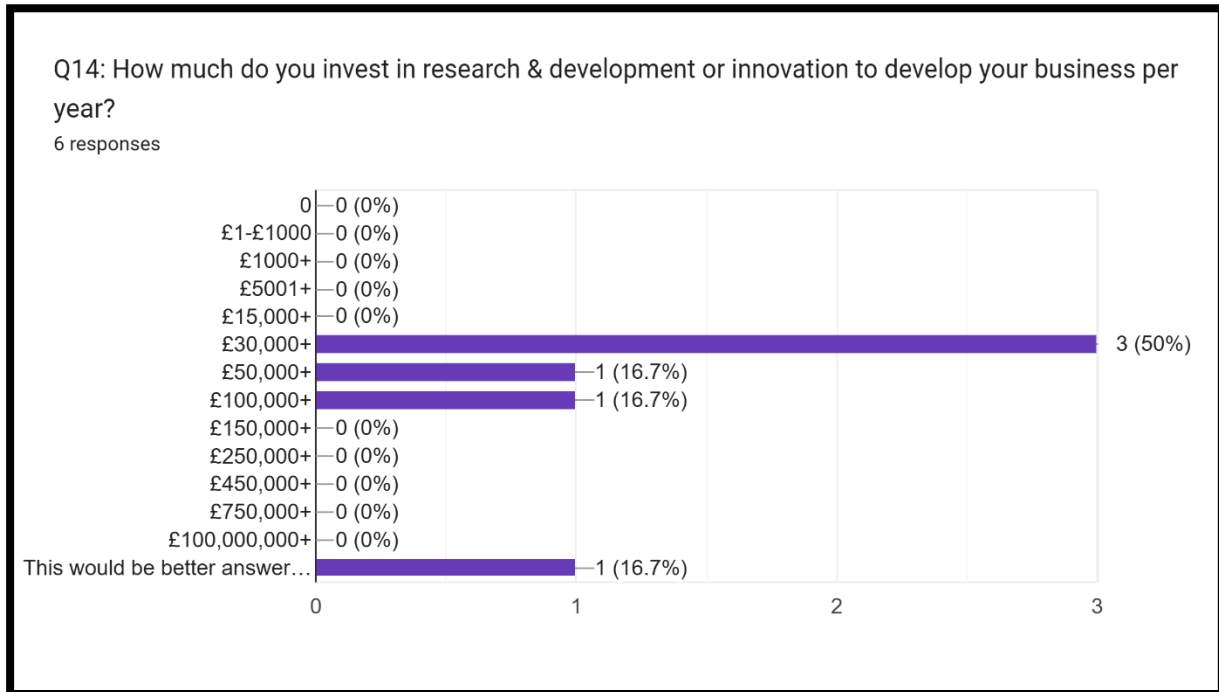


Figure 24 financial investment into SME

In question 15, the respondents were asked to indicate the percentage of their annual budget allocated to research and development; they provided varied responses, ranging from 3% to 50%, as illustrated in Figure 24.

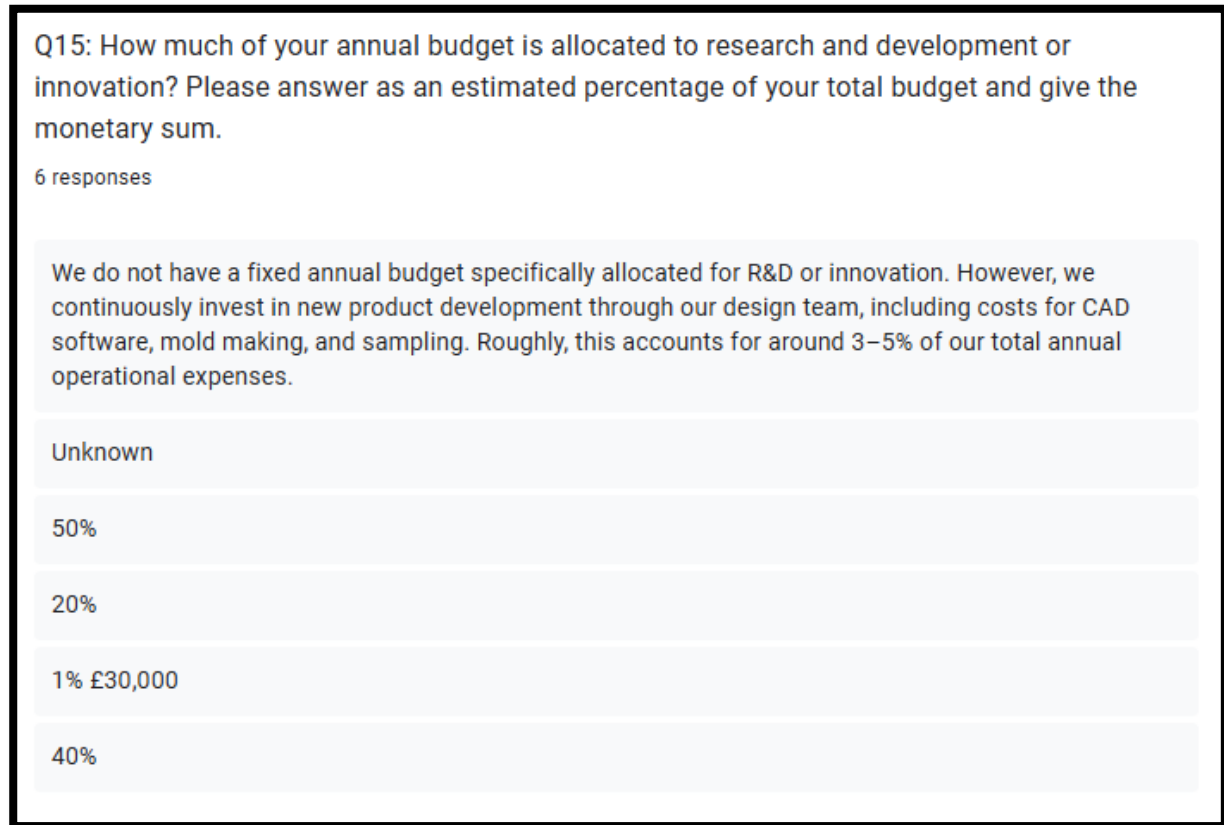


Figure 25 percentage of annual budget

In question 16, the respondents were asked if they had a dedicated research department. Two respondents indicated that they had a dedicated research department, two stated that they did not, and two reported that they had employees who performed research and development as part of their role (Fig 25).

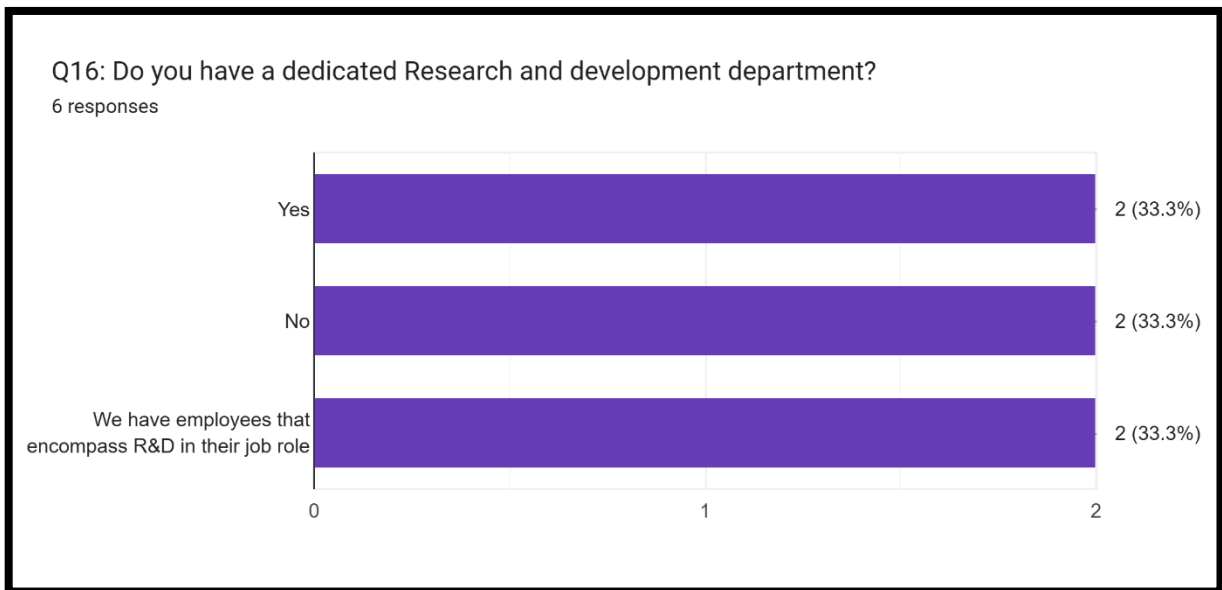


Figure 26 Research and Development department

In question 17, the respondents were asked about the technologies they had embedded into their company over the last 3 years, which yielded answers such as CAD, UV coating, 3D printing, plasma, and automated finishing (Fig 26).



Figure 27 Adoption of technologies

In question 18, the respondents were asked about the future technologies and innovations they planned to adopt in their organisations. The answers below are varied and include AI, SEM/EDX, and automated polishing (Fig 27).

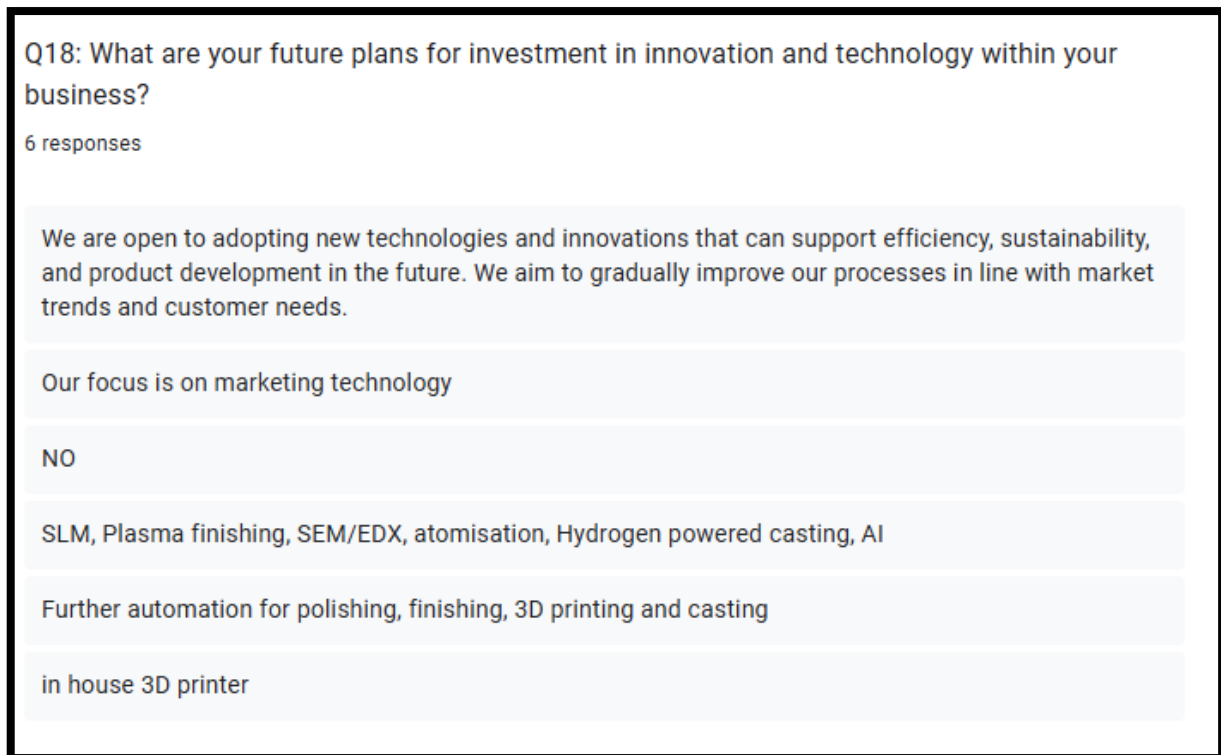


Figure 28 Future investment

Question 19 asks if respondents are exploring any further technologies, such as AI and VR. One respondent stated they were aware of the technology but are not directly exploring it. 1 uses AI for renders for their website, one is exploring plasma finishing, electrochemical AM and SLM. 3 respondents said they were not looking into AI or VR (Fig 28).

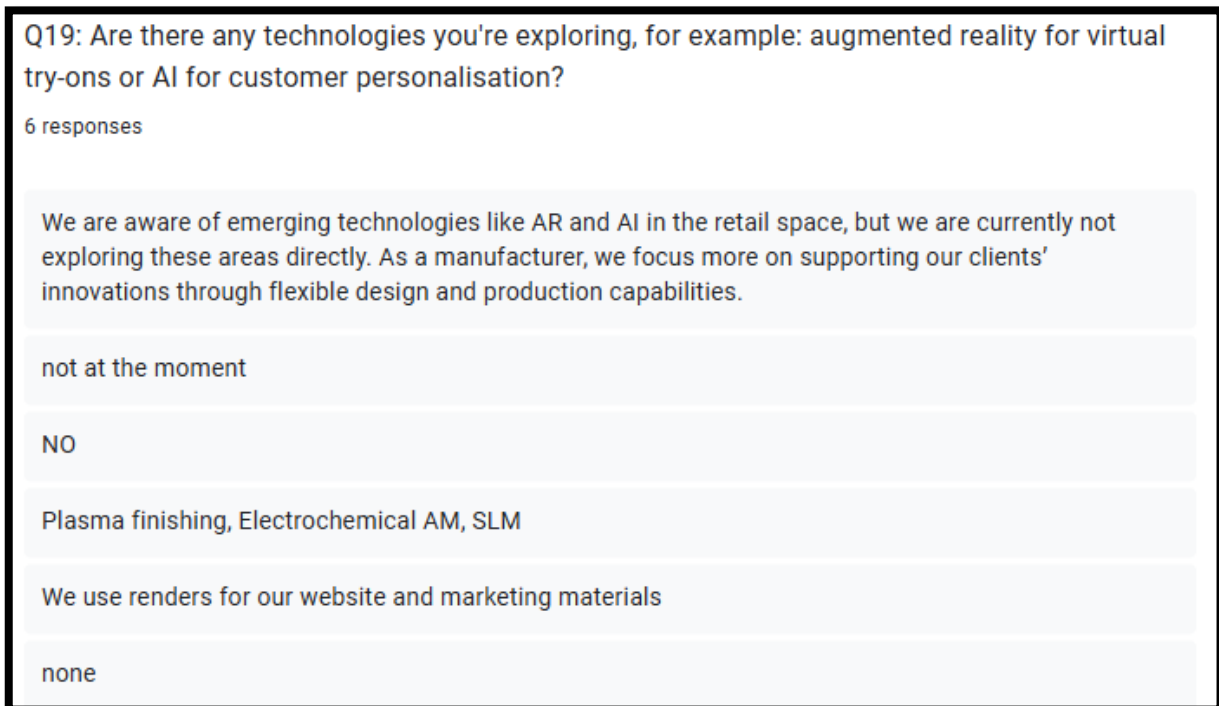


Figure 29 Explorations of Research and Development

Question 20 asks respondents how many external technology partnerships they have engaged in over the last year. Two respondents said they had engaged with one external partner; one respondent said that they had been involved with two external partnerships, a further respondent said they engaged with three external alliances, and finally, two respondents said they had not engaged with any external partnerships (Fig. 29).

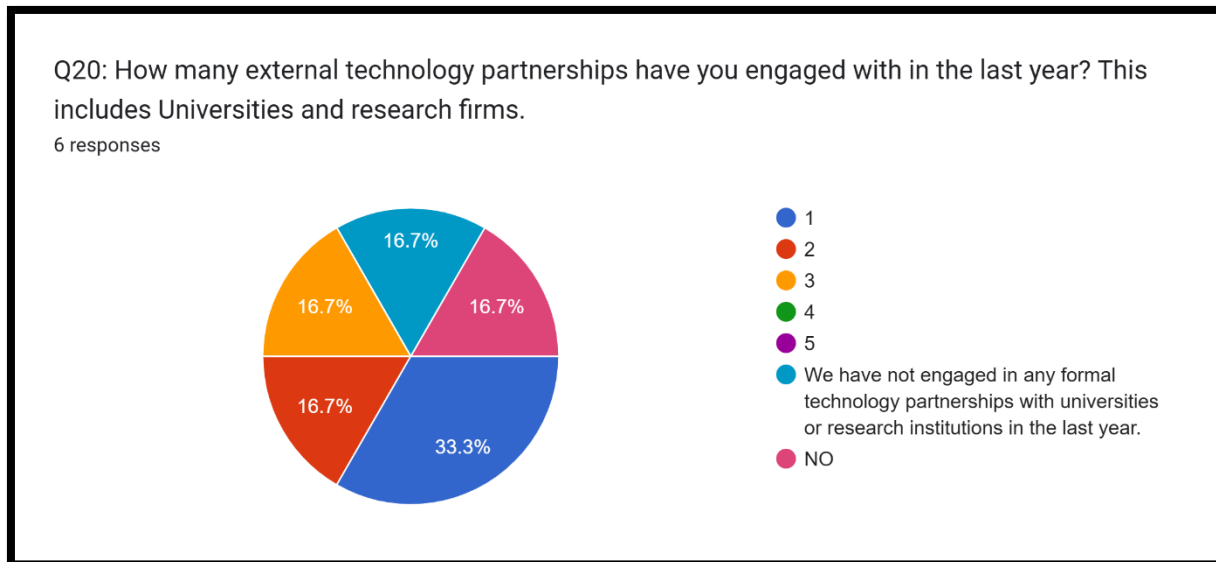


Figure 30 External partnerships

4.2 Interviews

This section presents tables of key points from the interviews conducted. For full transcripts and a list of questions asked, please see the appendices.

4.2.1 Additive manufacturing interview

Interview questions for the expert in additive manufacturing are in Appendix 10. The interview transcriptions are in Appendix 9. Please see Table 2 for the main themes and key comments.

Table 2 Additive manufacturing interview

Number	Questions asked	Quotes of interest
1	How has the jewellery manufacturing industry evolved with new technologies over the last 10 years?	<i>"They were already quite accustomed to adapting to 3D printing in wax and resin, and using those materials for lost-wax casting. It's not difficult to get them to move on to other ideas"</i>
2		<i>"You know what I mean; truly handmade jewellery doesn't exist except in the very high-end, utterly bespoke stuff. There are industrial applications throughout the entire jewellery manufacturing process."</i>
3	To what extent does 3D printing enable customisation and personalisation for consumers?	<i>"Enormously."</i>
4		<i>"It's what it's perfect at, but the downside is getting them to pay for it."</i>
5		<i>"You've got a personalised customised at the very high end for it to be cost effective."</i>
6	Are small-scale or independent jewellers adopting 3D printing differently than large manufacturers?	<i>"To some extent, yes, but I'm aware of that. There are some people who, again, going back to personalised and bespoke, will get their customer in, design it on a screen with</i>

		<i>them, print it on a little machine in the back of their shop and then send it to somebody like Western Beamor to get it printed"</i>
7	What are the barriers for small, medium and independent jewellers to adopting 3D printing.	<i>"The machines are just too expensive at the minute for them to adopt. So, they must go to a Bureau service of some sort."</i>
8	Does 3D printing contribute to more sustainable jewellery manufacturing practices?	<i>"No, I mean it opens an interesting series of debates. Where do you start? How much CO2 has been produced? To make the machine. How much CO2 has been produced to make the materials to go into the machine?"</i>
9		<i>The principle really should be that the machine should be right next to where you want it. Not in your workshop in Edinburgh to send it down to Birmingham, to be cast and then sent back to Edinburgh."</i>
10	How do customers perceive 3D printing or additive manufacturing jewellery versus traditionally made pieces, do you think?	<i>"90% of them haven't got a clue and don't care. It's only a selling point. If you've a slightly educated audience to sell to, a lot of that comes down to the</i>

		<i>perception of the end user, the ultimate purchaser."</i>
11	What trends are driving consumer interest for 3D printed or tech-enabled jewellery?	<i>"Comes down to money. It's all about the money."</i>
12		<i>"It used to be jewellery because then that jewellery was going to be handed down. It was an heirloom that your granny left to your mother, or your mother said. Don't worry, when I'm dead, you can have that. Take it off my finger. Didn't I say that, you know, jewellery, a lot of jewellery these days, is considered fast fashion?"</i>
13	What are the emerging technologies that might further disrupt the jewellery industry in the next 5 to 10 years?	<i>"Tui tech (automated gemstone grading) is gonna be the one."</i>
14	How is AI influencing design and customisation in combination with 3D printing? So, how do you think they'll feed into each other?	<i>"It covers several other topics, and we've done any personalisation or customisation. But if you can get them to sit in front of a screen and press buttons and do a few little tweaks which you're fully in control of behind. They think they've designed it for themselves, and they can. They can be encouraged to pay a realistic price for it."</i>
15		<i>"The industry itself is pretty good at taking in innovation."</i>

		<i>And the key with jewellery then and stuff like am 3D printing is that jewellery doesn't have any. What are they called? ISO standards. You don't have to qualify if you want to put it on an aeroplane and fly it around the world. You know you've got to jump through 150,000 hoops if you want to make a pair of earrings using it."</i>
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4.2.2 Blockchain interview

Interview questions for the expert in Blockchain are in Appendix 12. The interview transcriptions are in Appendix 13. Please see Table 3 for the main themes and key comments.

Table 3 Blockchain interview

Number	Questions asked	Quotes of interest
1	How do you see blockchain adding value to the jewellery industry, beyond just hype?	<i>"I can see blockchain adding value, especially to the jewellery industry, by having the ability to trace and keep records that cannot be changed or altered. So you're keeping a sort of database or a security ledger that can trace the jewellery throughout its lifetime"</i>
2	What specific problems in the jewellery supply chain do you believe blockchain can solve?	<i>"Currently, in the jewellery industry, we are not aware of the origin of diamonds, including the specific mines and their locations worldwide. This is due to specific legal issues and restrictions imposed by various countries. Now, blockchain can help to solve that by creating immutability and transparency throughout the industry with these diamonds."</i>
3	How can blockchain enhance the provenance of gemstones or metals, particularly for ethical sourcing (e.g., conflict-free diamonds)?	<i>"Blockchain can be used to trace metal and gemstones. It can tell you where it's from, what country it was mined in, what mine it was from, and whether it was ethically sourced. You can even link it to a story or a tale of, you know, the mine, and some information about the mine, where it was sourced, in the local area, where the money goes back into the local area."</i>
4	Can blockchain be a reliable tool for authenticating luxury items and preventing counterfeiting?	<i>"Blockchain is pretty reliable, as long as it matches the stones, the date of the records, or matches the</i>

		<i>certification. Blockchain is what it is: you enter the data, and that's it. It's there forever. It can't be changed or tampered with. So, it, I think it's pretty good to authenticate and follow the life story of these pieces."</i>
5	How would blockchain change the resale or appraisal process of high-end jewellery?	<i>I think blockchain could add value to a diamond and change the appraisal process. I believe it'd be particularly relevant in the current climate and the way people interact with their items. I think they'd like to know where it came from and how it was sourced. I think it was sourced. I think it could be important for people to add some value definitely"</i>
6	What are the most significant barriers to adopting blockchain in traditional jewellery manufacturing settings?	<i>"I think the hardest thing is for people to understand what blockchain is and how blockchain works. I suppose if you were to approach it as a way of a secure database, it would help people to understand it. It can also be a fiddly tool to implement on a software level."</i>
7	How do you envision smaller brands or artisans integrating blockchain, considering their limited resources and technical expertise?	<i>"But if somebody were to capitalise on the industry and lead the way, you know, especially with a front-facing application that people find easy through adoption, I think it's just a case of marketing and awareness. I think it could be very successful, and people could use it. It's starting to touch the industry now where people, like I trace it and to be as are looking into it and using it for tracing diamonds through paperwork. So you could be adopted by the wider industry."</i>

	What would a blockchain-based customer experience look like—QR codes on pieces, digital certificates, or NFT-based ownership?	<i>“You'd want it to be a simple QR code, either on a piece of paper or the asset itself, that customers can scan using their smartphone application, and it gives them all their information and data, much like a digital wallet, making it nice and easy for people to use and enjoy.”</i>
8		<i>And, yeah, Blockchain, you know, if you're creating a digital application for it, like a wallet or something similar, you could use push notifications for servicing and repairs, warranty reminders, and to remind people to come in on the scheduled date. '</i>

4.3 Summary

Throughout this section, the results of the data gathered from questionnaires and interviews have been presented. In the next section, we will discuss the main themes that emerge from the data collected through interviews, questionnaires, and case study.

5. Analysis

In this section, we will gain a deeper understanding of the data gathered in the questionnaires and interviews.

5.1 Analysis of data

In Figure 9, we present the sizes of the organisations for which the respondents work; fortunately, they range from 3 employees to 197, providing a more varied perspective on the different answers received. However, these companies are still considered Small and Medium Enterprises. Hence, the data gathered is understood to be reflective of the size of the business in comparison to a large corporate jewellery firm like Tiffany or Cartier. This means that companies may not have the capital to invest in technology or have the workforce to research and subsequently embed in Industry 4.0 technology. In table 2, the interviewee states *"You know what I mean; truly handmade jewellery doesn't exist except in the very high-end, utterly bespoke stuff. There are industrial applications throughout the entire jewellery manufacturing process.* They go on to say (please see Appendix 10) that unless we are discussing large fine jewellery houses, most jewellery is not fabricated by hand; it is cast, and more recently, it's becoming more common to 3D print.

In Figure 10, we see that 66.7% of respondents stated that blockchain was not essential for their business. Furthermore, as shown in Figure 11, not all SMEs in the UK sell gemstone-based jewellery that could benefit from using Blockchain. The questionnaire, which explored the respondents' views on blockchain, revealed that blockchain is not a priority for SMEs in the jewellery manufacturing sector and didn't recognise the value for their business. In contrast to the two companies that would consider embedding blockchain into their operations, they would require a considerable amount of support to do so, as illustrated in Figure 12. This implores the thought of how accessible embedding blockchain within an SME is. However, in Table 3, quote1, the interviewee states, *"I can see blockchain adding value, especially to the jewellery industry, by having the ability to trace and keep records that cannot be changed or altered. So you're keeping a sort of database or a security ledger that can trace the jewellery throughout its lifetime."* So it could be argued that the technology is still too new for companies to see the merit of embedding the technology just yet. Secondly, the technology is not yet ready for consumer use, which is why the sector has not embraced it yet, this could be interpreted from the Block chain expert in the following quote from table 3 quote 1, quote 7, *"But if somebody were to capitalise on the industry and lead the way, you know, especially with a front-facing application that people find easy through adoption, I think it's just a case of marketing and awareness. I think it could be very successful, and people could use it."*

In Figure 14, we can see that all respondents had heard of CAD, which is not surprising, as it has been widely adopted across the jewellery industry. This indicates that innovation can be successfully integrated into the jewellery industry, providing a positive outlook for the broader adoption of innovation in jewellery manufacturing. However, the success of CAD integration

may depend on the size and cost of the equipment. CAD is relatively inexpensive to embed compared to AM. As discussed in Figure 21 regarding the limitations of embedding additive manufacturing, we can see that in Table 2, quote seven, the interviewee states, "The machines are just too expensive at the moment *for them to adopt*. So, they must go to a Bureau service of some sort."

All respondents had heard of AM, with two respondents using 3D printing for all orders, and 16.7% of respondents stated they use it for most customer orders (Fig. 18). This shows that the industry is responding positively to Industry 4.0 technologies and gradually implementing technology into their manufacturing suites, the Additive manufacturing expert supports this (please see table 2, quote 15) in which the interviewee states '*The industry itself is pretty good at taking in innovation.*'. Various additive manufacturing technologies have been used by three of the respondents, including wax printing, Formlabs, SLM, and Fused Deposition Modelling (Fig. 22). Whilst wax 3D printing is well known in the industry, we are seeing more organisations outsourcing SLM, DMLS and binder jetting within their production line. The case study demonstrates the success of adopting wax 3D printing into the production line, with the potential to reduce the cost of outsourcing casting and gain greater control over design capabilities and production lead times.

Figures 23 and 24 illustrate the financial investment companies allocate to research and development, as well as the percentage of their annual budget dedicated to this purpose. Interestingly, this range varied from 1% to 50% of their yearly budget, which could correlate with the positive growth of their business due to having funds that can be allocated to R&D. Additionally, we can look to the case study of an SME that fully embraces investing in innovation to overcome the challenges the jewellery industry faces.

The most significant limitation that's repeatedly highlighted throughout the literature review for embedding and investing in research on innovation is the companies' profit margins and profitability, as reflected in the interview with the AM expert: 'It comes down to money. It's all about the money' (Table 2, quote 11). This will be discussed further in the next section

6. Discussion

Throughout the final project, the author undertook an in-depth review of the literature that supported research into how the jewellery industry could look to the medical and Aerospace sector in terms of embedding Industry 4.0 technologies within their production lines. In this next section, the comparison of the literature review with the primary data gathered is presented. This will be set out in a SWOT analysis due to its effective method of comparing data through a structured approach, evaluating the Strengths, weaknesses, opportunities, and threats (Shinno, et al., 2006).

6.1 Strengths

In the section below, the author will discuss the strengths of the primary data gathered, compare it with the literature review, and outline the limitations of the technologies within the jewellery industry.

6.1.1 Established Technological Foundations

The widespread adoption of CAD among SMEs indicates a solid foundation in digital design, enhancing customisation capabilities and design precision. There is widespread adoption of CAD in Aerospace (Skarka, et al., 2023), Medical (Zahid, et al., 2024) and the Jewellery industry (Masood, 2002), with all three sectors embracing the ease of customisation and personalisation over traditional design, and all three industries acknowledging that CAD helps identify potential mistakes before they occur. This is supported by the data gathered from the questionnaires, with 100% of the respondent's using CAD within their jewellery organisation (see figure 14).

6.1.2 Diverse Technological Engagement

A significant portion of SMEs in the jewellery industry are incorporating additive manufacturing (AM) technologies, including wax printing and 3D printing, into their production processes (Fig. 18). This is supported by an interview with an AM expert, who stated in Table 2, Quote 1: *"They were already quite accustomed to adapting to 3D printing in wax and resin, and using those materials for lost-wax casting. It's not difficult to get them to move on to other ideas."* The comparison of the literature review and data gathered reflects a positive trend toward AM technological integration, which will only increase as the technology becomes more financially accessible for smaller companies. This trend is also followed across the medical and dentistry sectors due to the reduced patient recovery and the ability to create patient-centric implants (Jamróz, et al., 2018). Furthermore, the Aerospace industry has embedded AM into their production lines, not just for the ability to create rapid prototypes of customised parts, but also for a sustainable manufacturing technique that reduces wasted inventory by predicting successful AM builds due to the collaboration with CAD software (Ghadge, et al., 2018).

6.1.3 Commitment to Research and Development.

Respondents in the questionnaires who allocate up to 50% of their annual budgets to R&D demonstrate a strong commitment to innovation and staying competitive in the market (Figures 23 and 24). Conversely, it is well-documented throughout the literature review that there is a limitation to adopting Industry 4.0 technologies in the jewellery sector, especially within SMEs, due to the high cost of embedding; this is further supported by the AM expert, who states, "The machines are just too expensive at the moment *for them to adopt*. So, they must go to a Bureau service of some sort." (Table 2, quote 7).

6.2 Weaknesses

In the section below, the author will discuss the weaknesses of the primary data gathered, compare it with the literature review, and outline the limitations of the technologies within the jewellery industry.

6.2.1 Financial Constraints and Resistant to change

Limited capital hampers the ability to invest in advanced technologies, such as additive manufacturing (AM) and blockchain, thereby restricting full-scale adoption and integration. Furthermore, the investment in training the workforce could take time and capital that wouldn't be initially available to SME, this is supported by the Blockchain expert who, when interviewed, stated *"I think the hardest thing is for people to understand what blockchain is and how blockchain works. I suppose if you were to approach it as a way of a secure database, it would help people to understand it. It can also be a fiddly tool to implement on a software level."* (Table 3, quote 6). A lack of awareness and understanding of the benefits of blockchain among SMEs contributes to its low adoption, despite its potential advantages in terms of traceability and security. The aerospace and medical sectors support this, which are similar to the jewellery industry in that embedding blockchain technology is still in its infancy, and the full benefits and financial implications have not been fully understood yet. Larger luxury jewellery companies are tentative to implement Blockchain technology due to a lack of understanding of its gains and functionalities (Baudier, et al., 2021) Furthermore, the absence of widespread consumer interest in blockchain features diminishes the perceived value of its implementation for SMEs, as shown in the respondents' answers in Figures 10 and 11. These respondents, after hearing the description of blockchain, didn't see the value in incorporating it into their organisation.

6.2.2 Technology Accessibility

The high costs associated with advanced AM equipment and the need for specialised training pose significant barriers to entry for SMEs, which have been well documented throughout this research. Gomelsky forecast that the jewellery industry would adopt AM to allow SME's to expand into global markets (Gomelsky, 2023). But the feelings towards AM have still not been embraced by the UK market, with slow implementation and battles to entrench into the jewellery sector due to a lack of education within the labour force and the expensive capital

required to adopt Direct to metal 3d printing. This is supported in the primary data gathered, within the Case study – the Author couldn't launch 3d printing within an SME due to the rapidly growing capital needed to set up jewellery AM. It is further supported by the AM expert, who in Table 2 quoted, 'The machines are just too expensive at the moment *for them to adopt*. So, they must go to a Bureau service of some sort.'

6.3 Opportunities

In the section below, the author will discuss the opportunities outlined in the primary data gathered, compare them with the findings from the literature review, and highlight the limitations of the technologies within the jewellery industry.

6.3.1 Enhanced Traceability with Blockchain

Implementing blockchain can enhance product traceability, foster consumer trust, and potentially unlock new market segments. Blockchain will aid in the eradication of prohibited and immoral gemstone mining and support insurance companies to log insured customer items, resulting in smaller amounts of theft, as it will become less desirable to steal traceable gemstones (James, 2021). The Blockchain expert in the interview further supported this by stating *"Blockchain is pretty reliable, as long as it matches the stones, the date of the records, or matches the certification. Blockchain is what it is: you enter the data, and that's it. It's there forever. It can't be changed or tampered with. So, it, I think it's pretty good to authenticate and follow the life story of these pieces."* (Table 3, quote 4)

6.3.2 Cost Reduction through AM

Utilising AM can lower inventory costs and reduce material waste, offering financial benefits to SMEs. The incorporation of AM into the aircraft production line is also significant. Research suggests that AM can increase supply chain efficiency by calculating inventory amounts, encouraging responsiveness, and lowering interruptions and carbon emissions (Ghadge, et al., 2018).

6.3.3 Customisation and Market Differentiation

The ability to offer personalised products through CAD and AM can differentiate SMEs in a competitive market, attracting niche customer bases. Advancements in CAD software have enabled the design and fabrication of intricate jewellery pieces. These systems enable the creation of wax 3d prints through rapid prototyping, replacing conventional mould injection methods. This alteration increases the flexibility in design but also allows the production of more intricate forms with greater ease (Masood 2002). This is further proven with AM expert stating *"It's what it's perfect at, but the downside is getting them to pay for it."* In Table 3, quote 4. The expert also goes on to say *"You've got a personalised customised at the very high end for it to be cost effective."* Table 3, quote 5. Additionally, in the case study, it indicated *"allowing for the creation of highly intricate and complex designs that might be difficult or impossible to achieve with traditional casting methods. This is particularly useful for custom*

or bespoke pieces, where unique geometries are desired. SLM can rapidly produce prototypes or one-off pieces without the need for moulds, making it ideal for personalised jewellery.”

6.3.4 Collaborative Initiatives

Engaging in partnerships with technology providers and industry associations can facilitate knowledge sharing and resource pooling, thereby aiding in the adoption and progression of technology for the jewellery industry. This is supported by three respondents in our questionnaire pool, of whom 65% of respondents had their research projects in the last 12 months, with either an external research organisation or a university (Fig. 29). This is further supported by the case study that was a collaboration between Birmingham City University, Innovate UK and The Diamond Centre to progress the commercial viability of embedding AM into a jewellery SME.

6.4 Threats

In the section below, the author will discuss the Threats outlined in the primary data gathered, compare them with the findings from the literature review, and highlight the limitations of the technologies within the jewellery industry.

6.4.1 Technological Obsolescence

The rapid pace of technological advancements necessitates continuous investment in upgrades and training, posing challenges for SMEs with limited resources. CASE STUDY: How the technology isn't ready yet for AM.

6.4.2 Consumer Scepticism

A lack of consumer understanding and trust in blockchain and AM technology can hinder its adoption and the realisation of its benefits. This is confirmed by the AM expert, who *says that* "90% of them haven't got a clue and don't care. It's only a selling point. If you've a slightly educated audience to sell to, a lot of that comes down to the perception of the end user, the ultimate purchaser." Table 2, quote 10. This is further fortified with Baudier stating that one significant barrier is the knowledge gap among stakeholders regarding blockchain applications, due to hesitation to adopt this technology, due to a lack of understanding of its benefits and functionalities, (Baudier, et al., 2021)

6.5 Summary

This analysis underscores the dynamic interplay between technological advancements and the operational realities of SMEs in the jewellery manufacturing sector. While challenges persist, strategic initiatives focusing on education, collaboration, and consumer engagement can pave the way for the successful integration of Industry 4.0 technologies, final thoughts and conclusions will be detailed in the next section.

7.7. Conclusion

This project aims to understand the potential benefits of implementing Industry 4.0 technologies into the jewellery manufacturing sector. The study explored the feasibility and implications of integrating Industry 4.0 technologies into the jewellery manufacturing sector by drawing comparisons with the medical and aerospace industries. Through a detailed literature review and primary data collection, the study revealed a complex yet promising landscape for technological advancement for SME's in the jewellery industry.

The investigation emphasised that initial technologies, such as CAD, are already well-established and widely adopted, providing a strong basis for further innovation. AM is beginning to gain traction, particularly in its application to wax and resin printing for lost-wax casting. The case study and expert interviews confirmed that although AM presents significant opportunities in terms of cost reduction, waste minimisation, and product customisation, the high cost of direct-to-metal AM and the need for technical expertise remain substantial barriers.

Blockchain technology, while offering clear advantages in traceability and product authentication, is still largely misunderstood and underutilised. Both the literature and the data show that without stronger awareness and more apparent consumer demand, its widespread adoption will remain limited.

The SWOT analysis in Section 6 revealed that, despite promising opportunities, such as collaborative initiatives with research institutions and the potential for market differentiation through personalisation, considerable threats and limitations persist, including technological undesirability, financial constraints, and consumer scepticism. Without targeted interventions to address these issues, particularly in training, education, and cost-reduction strategies, adoption will remain uneven and slow.

Ultimately, the jewellery industry, particularly SME, stands at a critical juncture. By learning from the medical and aerospace sectors and embracing collaborative efforts, the sector can overcome its current challenges. The integration of Industry 4.0 technologies is not only feasible but essential for future-proofing the industry and securing a competitive advantage in a rapidly evolving global market. Moving forward, strategic investment and education will be key drivers for embedding innovation within the jewellery industry; this will be discussed further in section 8.

8. Recommendations

Based on the findings of this study, the following recommendations are proposed for the jewellery industry, particularly SMEs, to enable the successful integration of Industry 4.0 technologies and to guide future research and investment efforts:

1. Invest in Accessible Additive Manufacturing (AM) Solutions

- Research Focus: Investigate cost-effective methods for SMEs to adopt AM, including leasing models, shared facilities, or Bureau services.
- Investment Priority: Funding for R&D in direct-to-metal AM that reduces capital expenditure and enhances efficiency.

2. Expand Training and Upskilling Programs

- Research Focus: Investigate the most effective methods of delivering Industry 4.0 training to small-scale manufacturers.
- Priority: Develop training programs in CAD, AM, and blockchain to enhance in-house capabilities and reduce reliance on external experts.

3. Increase Awareness and Understanding of Blockchain Technology

- Research Focus: Conduct consumer behaviour studies to identify market demand and education gaps regarding blockchain-enabled traceability.
- Investment Priority: Allocate resources to pilot blockchain systems in collaboration with trusted gemmological institutions and insurers.

4. Foster Collaborative Innovation Hubs

- Research Focus: Analyse the effectiveness of existing collaborative initiatives between jewellery SMEs and academic or research institutions.
- Investment Priority: Support partnerships that enable shared access to advanced technology, facilitate knowledge transfer, and provide funding for innovation.

5. Improve Consumer Engagement and Education

- Research Focus: Examine how consumer education impacts purchasing decisions regarding technologically enhanced jewellery (e.g., blockchain-authenticated pieces).
- Investment Priority: Marketing campaigns and in-store education tools that highlight the benefits of Industry 4.0 features, such as personalisation and traceability.

6. Study Industry-Specific Barriers to Adoption

- Research Focus: Conduct sector-wide studies on the financial, cultural, and operational challenges faced by jewellery SMEs.
- Investment Priority: Policy development and grant funding to support SMEs in overcoming identified barriers.

7. Benchmark Against Other Sectors

- Research Focus: Conduct comparative analyses of successful Industry 4.0 integration in the medical and aerospace industries to adapt best practices.
- Investment Priority: Develop sector-specific implementation frameworks tailored to the jewellery industry, based on these models.

By promoting these areas for further research and strategic investment, the jewellery industry can lead to sustainable innovation, enhanced competitiveness, and long-term resilience.

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8. Appendices

8.1 Appendix 1 – Questionnaire

Innovations in Jewellery Manufacturing

Hello, My name is Maria Paparozzi-Shipman and I am studying for Master in Innovation Management 4.0 at Trinity St David's University. My area of study is Jewellery Manufacturing and how the industry is adopting modern technologies. I am conducting research to determine how many manufacturing companies are researching and embedding new technologies into their company.

This questionnaire should take less than 10 minutes to complete. All responses will be kept anonymous and no-one will be identifiable in my research. The data gathered in the questionnaire may be cited in the dissertation, specific questions may be used to substantiate the researchers observations and statements. All gathered data will be deleted once it is no longer necessary to store it.

By partaking in this questionnaire you understand the following:

- I understand that partaking in this questionnaire is voluntary and by no means is obligatory.
- I agree that my answers are recorded exclusively for this study
- I give permission for my study data to be used anonymously in the course of this academic study in order to strengthen and verify research and to be used as a source of reference.
- I understand the researcher, the academic supervisor and the marking board may review data that has been given and I authorise this review.
- I understand that I will not be at risk or benefit with the participation of this study.
- I understand that my information will be treated with the upmost care and discretion, protecting my identity and the identities of anyone else identified. I understand that my data will not be shared with third parties.
- I voluntarily provide permission to take part in this research.

* Indicates required question

1. What is your name? *

3. Please can you provide your company email? *

4. What position do you hold at the company? *

5. How long have you worked in the jewellery manufacturing industry? *

6. How many employee's work for your organisation? *

Block chain & its potential application in Jewellery:

Blockchain is a decentralised digital ledger. It can be used to record transactions of gems and precious metals by embedding a identifier into the item, the identifier can be so small that it cannot be seen by the naked eye. Blockchain can be used to track gemstones and precious metals from their source to the final consumer, ensuring authenticity and ethical sourcing. It deters theft of jewellery, ensures traceability for owners and can aid in the return of lost or stolen jewellery. It can aid insurance companies to replace items like for like using a digital record of the exact specification of the piece.

7. Q1: After hearing the description, would you be interested in embedding block chain into your company? *

Mark only one oval.

- ☐ No, this isn't essential for our company *Skip to question 8*
- ☐ This sounds like a great technology to integrate into my company
Skip to question 9
- ☐ Blockchain sounds interesting but I would like to know more before embedding into my company *Skip to question 9*
- ☐ I already use Block Chain *Skip to question 10*

I am not interested in integrating blockchain into my company

8. Q2: What would deter you from adopting block chain technology?

Skip to question 10

I am interested in integrating blockchain into my company

9. Q3: What would a block chain technology provider need for you to embed the technology into your company?

Check all that apply.

- ☐ Training for staff on the technology and how to use it
- ☐ Tools for scanning the blockchain identifier
- ☐ Marketing
- ☐ Incentivised bonuses for customers to use Blockchain
- ☐ Other: _____

Skip to question 10

Traceability and Ethical Sourcing

10. Q4: How are you currently using technology to ensure traceability or ethical sourcing? *

Skip to question 11

What is CAD:

CAD, which stands for Computer-Aided Design, is the process of creating digital representations of jewellery pieces through specialized 2D and 3D modelling software. It serves as a guide for manufacturing, allowing designers to create a jewellery cast that includes every detail of the piece from the placement of gemstones to the perfection of filigree work.

1 5: Have you heard of computer aided design (CAD)? *

Mark only one oval.

- ☐ Never heard of the term CAD *Skip to question 12*
- ☐ I have heard of CAD, but I don't know what it is *Skip to question 12*
- ☐ I know what CAD is but I don't use it *Skip to question 12*
- ☐ I know what CAD is, and I use it within my business *Skip to question 15*

Interest in integrating CAD into business

12. Q6: After hearing the description, would you now be interested in embedding CAD into your company? *

Mark only one oval.

- ☐ I am interested in embedding CAD into my business *Skip to question 14*
- ☐ I am not interested in embedding CAD into my business *Skip to question 13*

I am not interested in embedding CAD into my business

13. Q7: What deters you from embedding CAD into your business? *

Skip to question 15

Requirements for integrating CAD into business.

4 8: What would you need to embed CAD into your business? *

Check all that apply.

- ☐ Training for staff
- ☐ Computers
- ☐ Capital for licence fees for software
- ☐ Other: _____

Skip to question 15

What is 3D printing:

3D printing, or additive manufacturing, is the construction of a three-dimensional object from a CAD model or a digital 3D model. It can be done in a variety of processes in which material is deposited, joined or solidified under computer control, with the material being added together, typically layer by layer.

15. Q9: Do you use 3D printing, either in house or outsourced? *

Mark only one oval.

- ☐ Yes, we use 3D printing for all orders *Skip to question 19*
- ☐ Yes, we use 3D printing for most orders *Skip to question 19*
- ☐ We occasionally use 3D printing *Skip to question 19*
- ☐ We never use 3D printing *Skip to question 16*

Do not currently use 3D printing

16. Q10: Would you be interested in embedding 3D Printing into your company after reading the description? *

Mark only one oval.

- ☐ No *Skip to question 18*
- ☐ Yes *Skip to question 17*

Interested in integrating 3D printing into my Business

7 1 What would you need to embed 3D printing into your business?

Check all that apply.

- ☐ Capital investment from external source
- ☐ Training current employees
- ☐ Hiring subject matter experts
- ☐ Change to manufacturing facility to enable 3D printing

Skip to question 20

Not interested in integrating 3D printing into my Business

18. Q12: What deters you from embedding 3D printing technology into your business?

I already use 3D printing in my business

19. Q13: What 3D printing technology have you embedded in your business? *

Innovation within your business

The researcher would like to understand more about the innovation that you embed into your business.

3 7 What technologies have you adopted in the last 3 years? *

0 4 How much do you invest in research & development or innovation to develop your business per year?

Check all that apply.

- ☐ 0
- ☐ £1-£1000
- ☐ £1000+
- ☐ £5001+
- ☐ £15,000+
- ☐ £30,000+
- ☐ £50,000+
- ☐ £100,000+
- ☐ £150,000+
- ☐ £250,000+
- ☐ £450,000+
- ☐ £750,000+
- ☐ £100,000,000+
- ☐ Other: _____

21. Q15: How much of your annual budget is allocated to research and development or innovation? Please answer as an estimated percentage of your total budget and give the monetary sum. *

22. Q16: Do you have a dedicated Research and development department? *

Check all that apply.

- ☐ Yes
- ☐ No
- ☐ We have employees that encompass R&D in their job role

24. Q18: What are your future plans for investment in innovation and technology within your business? *

25. Q19: Are there any technologies you're exploring, for example: augmented reality for virtual try-ons or AI for customer personalisation? *

6 Q20 How many external technology partnerships have you engaged with in the last year? This includes Universities and research firms. *

Mark only one oval.

☐ 1

☐ 2

☐ 3

☐ 4

☐ 5

☐ Other: _____

27. Thank you for answering this questionnaire, your responses are valuable to my masters and understanding the role innovation plays in the jewellery industry. *

Would you be open to being interviewed for 20 minutes so I can get a deeper understanding of your views of innovation in the jewellery industry? If yes, please let me know a date and time that would suit you.

8.2 Appendix 2 – Jewellery and fashion in the UK

Moreover, the historical context of Jewellery manufacturing is enriched by examining dress accessories from medieval rural communities in Central-Eastern Europe, which provides insights into the technological qualities and decorative aspects of prevalent artefacts during that period. This analysis indicates a continuity in material culture's significance in urban and rural settings, reflecting the shared practices in Jewellery and accessory production (Sawicki, Levá 2022).

The UK Jewellery manufacturing landscape has undergone significant transformations since 1970, influenced by various economic, social, and cultural factors. One notable change is the decline of traditional industrial districts, exemplified by the Birmingham Jewellery Quarter. Once a thriving hub for Jewellery production, this area has experienced a decrease in firm density and an increase in firm mortality rates, reflecting broader trends in the life cycle of industrial clusters (De Propriis, Lazzeretti, 2009). The study of this decline employs a multidisciplinary methodology, combining historical and economic analyses to understand the shifts in production activities and the challenges faced by local firms.

Additionally, the rise of fast fashion has impacted the Jewellery sector, tiny and medium-sized enterprises (SMEs) within the UK fashion industry. These companies are navigating a volatile market characterised by intense global competition, which has necessitated a focus on dynamic project management capabilities to maintain their market position and foster growth (Godhania 2015). The jewellery industry, contributing significantly to the UK's economy, has had to adapt to these pressures by developing new strategies and operational frameworks.

In recent years, the integration of technology into jewellery design and manufacturing has emerged, exemplified by brands like Covert, which blend fashion with wearable technology. This shift indicates a growing trend towards innovation in jewellery, reflecting changing consumer preferences and the need for brands to differentiate themselves in a crowded marketplace (Marketing, 2015) .

8.3 Appendix 3 -Emphasis on Data-Driven Decision Making

Aerospace and medical device manufacturers utilise big data analytics to streamline their supply chains and enhance quality assurance. By analysing customer preferences and market trends, jewellery manufacturers can predict demand, optimise inventory, and design products that align with customer expectations. (Ahaggach, 2023). They emphasise the role of big data analytics in creating value across manufacturing industries.

Data-driven decision-making is increasingly pivotal in the automotive sector, leveraging advanced analytics and machine learning to enhance operational efficiency and customer engagement. The automotive industry utilises data science and machine learning to optimise processes and products, which is essential for future advancements. These technologies are applied to various subprocesses within the automotive value chain, demonstrating their potential to transform operations and improve productivity while maintaining a strong customer focus throughout the product lifecycle. (Kapila, et al., 2023).

In predictive maintenance, the automotive sector benefits from integrating condition-monitoring data, such as vibration and temperature, which enables the development of advanced mathematical models and artificial intelligence techniques. These approaches facilitate timely maintenance actions, thereby preventing potential failures and extending the useful life of equipment. (Kapila, et al., 2023)The systematic review of statistical inference and AI techniques highlights the opportunities for enhancing vehicle maintenance through data-driven methodologies, which can lead to significant improvements in operational reliability (Hameed, et al., 2023).

Moreover, the principles of Industry 4.0 are being applied to maintenance decision-making processes, where advanced sensor infrastructures enable data analysis to predict emerging situations and recommend actions. This integration of data-driven decision-making with augmented reality and IoT devices is poised to enhance the efficiency of manufacturing and maintenance operations (Bousdekis, et al., 2021).

As an example of how big data is utilised in a retail context, in 2025, Primark and Pinterest launched a collaboration in which Primark will harvest data from Pinterest on style and trends, which will then be automatically integrated into production. Consequently, their stores will always feature products that consumers are looking for.

8.4 Appendix 4 - Use of Digital Twins

Digital twins benefit manufacturing by streamlining production and optimising the manufacturing process by adopting artificial intelligence replicas of physical systems in factories, which are integrated with various technologies and big data processing techniques. They can provide a crucial link between the physical and digital realms, which produces advanced analytics, detailed simulations, and informed decision-making across multiple industries, including healthcare, manufacturing, aerospace, and automotive manufacturing. (B. R. Barricelli, 2019) (Hananto, 2024).

Virtual replicas of physical assets are employed in the automotive sector to optimise performance and predict maintenance needs (Tao & Qi, 2018). Digital twins can simulate designs and manufacturing processes, ensuring optimal outcomes before production begins, reducing time-to-market and recognising errors in the production line before they occur. Many fashion industries, including apparel and footwear, depend on human labour. In the jewellery industry in the UK, the workforce is indispensable due to the ageing workforce*** and lack of appetite to train in the jewellery industry. and cannot be replaced by automation; however, having a digital twin can improve efficiency regarding human allocation and machine timetabling and analysis to create real-time planning. (Fei Lin, 2018). Tao et al. (2018) describe digital twins as critical in integrating design and manufacturing in Industry 4.0, applicable across diverse industries.

Adopting digital twins in the jewellery manufacturing industry could significantly enhance various aspects of the design and production processes. Digital twins, as virtual representations of physical products, can facilitate a deeper understanding of the intricate relationships between design tools, manufacturing processes, and the final products. This integration can improve control over the design process, fostering creativity and enhancing design skills among jewellery designers. (Corsini, 2017).

Moreover, implementing digital twins can streamline communication and integration within the innovative manufacturing ecosystem. By utilising parametric modelling and optimisation techniques, manufacturers can create a more efficient workflow that minimises errors and enhances the quality of the jewellery. Integrating platforms like Rhino-Grasshopper for parametric modelling with additive manufacturing technologies can address communication challenges and optimise the design process. (Francesca, 2021).

Additionally, exploring new digital design and manufacturing tools can lead to innovative methodologies that support rapid prototyping and customisation in the jewellery sector. The ability to quickly iterate designs and produce prototypes can cater to the growing consumer demand for personalised jewellery, allowing manufacturers to

respond effectively to market trends without significantly increasing costs. (Francesca, 2021) .

The potential for digital twins to enhance the sustainability and preservation of traditional craftsmanship is also noteworthy. By creating digital representations of traditional jewellery-making techniques, manufacturers can maintain cultural heritage while integrating modern technologies, thus ensuring the longevity of these practices in a contemporary context. (WANG, 2023).

The jewellery manufacturing industry benefits from adopting digital twins through improved design processes, enhanced communication within manufacturing ecosystems, and the preservation of traditional craftsmanship. These advancements could lead to a more efficient, creative, and sustainable approach to jewellery production.

The financial costs of embedding digital technologies into a jewellery manufacturing company can be inferred from various studies on manufacturing processes and economic analyses. One publication discusses the adoption of additive manufacturing in investment casting, which can significantly reduce lead time and costs compared to traditional methods. The techno-economic analysis framework allows for assessing key performance indicators, such as crossover points and payback periods, which are crucial for understanding the financial implications of transitioning to digital technologies in production processes. (Sartini, et al., 2024).

In jewellery manufacturing, integrating digital technologies may involve initial investments in equipment and software and ongoing operational costs related to training and maintenance. The analysis indicates that while the upfront costs can be substantial, the long-term benefits, including reduced production costs and improved efficiency, can offset these initial expenditures. (Glaubenskle, 2022) (Sartini, et al., 2024).

While the specific financial costs of embedding digital technologies in jewellery manufacturing are not explicitly detailed in the provided publications, the insights above into techno-economic analyses and sustainable practices suggest that careful consideration of initial investments, operational costs, and long-term benefits is essential for informed decision-making.

8.5 Appendix 5 - Focus on Sustainability

Industries such as the automotive sector have adopted sustainable practices, including closed-loop recycling and material efficiency, utilising Industry 4.0 technologies. The automotive industry is increasingly adopting sustainable practices, particularly through the integration of Industry 4.0 technologies, which facilitate closed-loop recycling and enhance material efficiency. One significant approach is developing a circular, sustainable 3d printing model to recycle metal scrap within the automotive sector. This model proposes using additive manufacturing (AM) to reintroduce waste as raw material for producing automotive components, thereby supporting sustainability and circularity in manufacturing processes. (Caiado, et al., 2022).

Empirical research indicates that Advanced Manufacturing Technology (AMT) practices positively influence the manufacturing capabilities of automotive SMES in Malaysia. The study highlights that many of these SMES have implemented AMT for flexibility and cost reduction, which aligns with sustainable environmental initiatives (Jen, et al., 2015). This integration of AMT enhances operational efficiency and contributes to the overall sustainability of manufacturing practices.

Furthermore, the principles of Overall Equipment Effectiveness (OEE) are being utilised in conjunction with sustainability efforts to optimise manufacturing processes. A case study revealed that the implementation of OEE led to significant improvements in operational metrics, including reductions in waste and carbon emissions, while enhancing product quality and efficiency (Zehra, et al., 2024). This demonstrates a clear link between adopting Industry 4.0 technologies and the achievement of sustainability goals in the automotive sector.

Additionally, the integration of Internet of Things (IoT) technology into sustainable automotive supply chains has been proposed to enhance connectivity and develop strategies for sustainable growth. This framework aims to address environmental challenges by promoting responsible practices within the supply chain (Samadhiya, et al., 2024).

Jewellery manufacturers can adopt similar approaches, such as recycling precious metals and minimising energy use in production (Beier et al., 2017). The Royal Mint launched its precious metal recycling scheme in 2020, where they took old electronic products, including phones, laptops, and plated jewellery, and extracted the precious metals from them. This recycled metal was then returned to the jewellery trade, creating a large-scale circular manufacturing process. (Fletcher, 2021)

8.6 Appendix 6 - Training and Workforce Development

The adoption of Industry 4.0 in the aerospace and automotive sectors has been accompanied by the upskilling of the workforce to manage advanced technologies. Jewellery firms must invest in training artisans and technicians to use digital tools effectively. Kumar et al. (2021) argue that workforce skill development is essential for successful Industry 4.0 adoption.

8.7 Appendix 7 - Aerospace

The aerospace industry has made significant strides in integrating Industry 4.0 technologies, which can provide valuable insights for the jewellery sector. One key aspect is the adoption of data-driven approaches that enhance flexibility and efficiency in manufacturing processes. A framework developed for assessing the smart level of data-driven processes in aerospace highlights the importance of evaluating process activities based on Industry 4.0 properties, which can lead to improved performance and interconnectivity within the industry (Bernabei, et al., 2023). This framework emphasises the need for a structured roadmap to achieve higher levels of digitisation. This lesson could benefit jewellery manufacturers seeking to modernise their processes. Aerospace uses lean manufacturing, which has a focus on optimising and exploiting new technologies. Lean manufacturing helps to eliminate waste and create continuous improvements. Ensure a just-in-time production method exists, so no surplus material is required; this could be critical for jewellery manufacturers' profit margins due to inflation and the temperamental price of gold.

Moreover, integrating big data and digital twin technologies has been pivotal in the aerospace sector, facilitating cyber-physical integration and enabling predictive maintenance, production planning, and product (Tao & Qi, 2018). These technologies allow for real-time data analysis, enhancing decision-making and operational efficiency. The jewellery sector could similarly leverage these technologies to optimise production processes and improve customer engagement through personalised offerings.

The impact of Industry 4.0 on supply chains, as observed in the aerospace industry, suggests that the geographical distribution of manufacturing may shift as new technologies are globalised (Hickie & Hickie, 2021). This insight could encourage jewellery manufacturers to consider their supply chain strategies and explore new markets or regions that may benefit from advanced manufacturing technologies. The impact of globalisation on the jewellery supply chain is multifaceted, particularly in terms of economic strategy and sustainability practices. A case study examining the global process of a US jewellery company highlights the challenges faced by a small Saudi Arabian jewellery company, which struggled with declining profits and business closures. The research suggests that a well-informed globalisation strategy could enhance profitability for this SME by leveraging specific economic attraction features of target countries.

Lastly, the emphasis on quality management and process integration within the aerospace industry underscores the importance of aligning operational practices with Industry 4.0 principles to enhance sustainability and competitiveness (Pop, et al., 2023). By adopting an integrated approach to quality management, the jewellery sector can improve its operational efficiency and product quality, ultimately meeting the evolving demands of consumers, with pressures from Movements such as COP and governments to be more sustainable. The jewellery sector has increasingly been influenced by the need for sustainable practices within the supply chain, with an outlook of ethical considerations in global efforts in mining gems, precious metals manufacturing and how we manufacture. Additionally, adopting Industry 4.0 Technologies has become Prevalent within the jewellery sector to help with ethical sourcing. The provenance of metals, which is crucial to meet the environmental, social and governance commitments, also highlights the long-standing network of globalisation use due to how we source and mine gems and metals, as we can't get these solely from the UK. As we look to China and India, (Pandit 2025) notes that they create industrial corridors as the leaders in jewellery manufacturing, it is no surprise that they are the first to produce and commercialise the technology needed to make an ethical and sustainable manufacturing suite for jewellery. This begs the question: Why would the UK jewellery industry not lean on these new technologies across the globe to produce the best economic jewellery for their businesses?

Such technology allows the manufacture of structurally optimised and customisable parts, which is crucial for the integrity of Aerospace parts where safety and integrity are paramount. (Khan, et al., 2023).

Aerospace is a largely research-led industry, whereas jewellery manufacturing typically operates a business-to-consumer model with very little capital expenditure allocated towards research. Consequently, innovation in the jewellery field tends to be slow. Where innovation has occurred, it has been adopted from industries that emphasise research and technological development.

8.8 Appendix 8 - Medical and dental

The medical and dental industries are increasingly integrating Industry 4.0 technologies to enhance healthcare delivery and improve patient outcomes. One significant aspect is the utilisation of digital transformation, which is recognised as a pivotal change in dental medicine. This transformation is primarily driven by electronic health data, enabling innovations such as rapid prototyping, augmented and virtual reality, artificial intelligence (AI), machine learning (ML), personalised medicine, and tele-healthcare. These technologies are expected to influence the direction of dental research and practice significantly (Bornstein et al., 2020). (Bornstein, et al., 2020).

AI and machine learning are crucial in personalising dental medicine by analysing extensive eHealth data. This capability allows for optimised treatment strategies and risk management tailored to individual patients (Joda, et al., 2021). This could be transferred into the jewellery industry with the use of AI to optimise on design-led capabilities and customer care, making the consumer feel they have 24-hour access to the jewellery business and their ability to customise their order. Furthermore, the integration of augmented intelligence, which combines digital applications with human

expertise, is essential for maintaining the quality of care while leveraging technological advancements (Bornstein, et al., 2020).

The impact of Industry 4.0 extends beyond advanced technologies to encompass the entire healthcare value chain. For instance, the shift towards automated medical production and healthcare robotics is reshaping system design paradigms, promoting efficiency and effectiveness in healthcare delivery (Khedri, et al., 2018). Additionally, the COVID-19 pandemic has accelerated the adoption of digital technologies, such as telemedicine and IoT, which have proven vital in ensuring healthcare accessibility during crises (Chandra, et al., 2022).

In low- and middle-income countries, the application of Industry 4.0 technologies has been somewhat fragmented, with a notable focus on mobile health and telemedicine. However, there are gaps in the adoption of other technologies like augmented reality and additive manufacturing, indicating areas for future research and development (Igusa, et al., 2023).

The medical and dental industries are leveraging Industry 4.0 technologies to enhance patient care, streamline operations, and address emerging challenges. However, there remain opportunities for further integration and research in specific areas. This can be mirrored by the jewellery sector, which can provide clean and efficient manufacturing with minimal waste. This will optimise profit margins by reducing the use of precious metals, while also giving customers a greater platform to enhance their experience and receive better customer service.

Integrating Industry 4.0 principles, particularly from the medical and dental sectors, into jewellery manufacturing can be facilitated through advancements in 3d printing technologies. The evolution of additive manufacturing has significantly impacted various industries, including jewellery. This technology allows to produce intricate designs and customised pieces, which aligns with the growing demand for personalised jewellery in the market (Nazir, et al., 2019).

Moreover, the principles of dimensional accuracy and surface quality, which are critical in medical and dental applications, can be applied to jewellery manufacturing. As explored in recent studies, techniques such as solid model geometry tuning can improve the precision of 3d-printed jewellery pieces. This involves refining the solid models based on measured errors during printing, enhancing the final product's quality. (Halder, 2023).

Additionally, low-cost 3d printing technologies, such as Fused Filament Fabrication (FFF) and Stereolithography (SLA), can make the jewellery manufacturing process more accessible and efficient. These methods reduce production costs and allow for the

creation of intricate designs that were previously challenging to achieve with traditional techniques (Halдар, 2023).

8.9 Appendix 9 – Additive manufacturing interview

Transcript

9 May 2025, 12:04 pm

Maria Shipman (2116519) started transcription.

AM interviewee 0:03

Think it, Wolverhampton University.

Maria Shipman (2116519) 0:03

I saw that they were doing loads of stuff on LinkedIn recently.

AM interviewee 0:09

Yeah. And I know a couple of guys there and they and they said, oh, they might be interested. So I'll just put them in touch with the school and see what happens.

Maria Shipman (2116519) 0:17

Yeah, yeah, they should do. And they look like they've really stormed ahead Wolverhampton with their research.

AM interviewee 0:22

Oh, they've got a great set up there, yeah.

Maria Shipman (2116519) 0:24

Yeah. What are they doing there?

AM interviewee 0:28

Mostly copper, mostly industrial applications.

Maria Shipman (2116519) 0:30

OK. Yeah.

AM interviewee 0:33

A lot of stuff around batteries for cars and stuff and lightweighting.

Maria Shipman (2116519) 0:41

That's good.

AM interviewee 0:41

By printing, copying copper and silver connections and stuff.

Maria Shipman (2116519) 0:45

I truly believe, especially after what's going on with the, I mean it's, I know it's changing every day, but with the the lack of steel works in the UK now. But I do believe that this is the only way to get industry back to the UK is bringing in this kind of bringing industry this way and bringing it in through electric batteries, yeah.

AM interviewee 1:03

Yeah. Specialised. Yeah, because one of the other things they're working on it, I think I sent you an Intuit once was diamond impregnated.

Old yeah. No, not golden copper, copper impregnated with, you know, diamond chips.

Maria Shipman (2116519) 1:11

I know the metal. Yeah, I forgot about that.

I forgot I completely forgot that.

AM interviewee 1:20

But they're they're finding.

Maria Shipman (2116519) 1:23

I completely forgot you sent me that it was. It was a couple of years ago.

AM interviewee 1:25

A yeah, but what they're finding is as soon as they start applying, applying sensible heat to it, the diamonds carbonised

Maria Shipman (2116519) 1:33

Oh no.

AM interviewee 1:34

Yeah. So, but you know.

Maria Shipman (2116519) 1:36

What are they using that for? What application would they use that copper for?

AM interviewee 1:41

Again, it's something to do with light waiting and electronics.

Maria Shipman (2116519) 1:45

Oh, OK, that makes sense.

AM interviewee 1:45

On PC BS.

Printing, printing motherboards and stuff.

Maria Shipman (2116519) 1:54

Oh, that's. No, that makes sense. That's interesting though, because my partner is out in Taiwan at the moment, looking at PC BS and stuff with his job, and we we we have these big philosophical chats and they were just saying it's going to be nearly impossible to take that all away back from China because they're just so set up for that industrial kind of technology there. Yeah.

AM interviewee 2:15

Big labour. Yeah, any of you. Just putting it in the machine and taking it out the machine.

Maria Shipman (2116519) 2:21

Yeah, true.

AM interviewee 2:22

Yeah, right. Let's if this is for your ma this this discussion.

Maria Shipman (2116519) 2:23

No.

Yeah. So I yeah, just finishing off my dissertation and I was realised that I kind of wanted to put some interviews in, especially because I'm doing a more broad it's just innovation in jewellery as my kind of topic. So I was going to talk to you obviously more about 3D printing, but I obviously know you've got fingers and a few pies. So if you want to go off and talk about something else more more than encouraged.

AM interviewee 2:49

She actually got it and we'll see where we end up.

We've we've touched on some things already, haven't we?

Maria Shipman (2116519) 2:54

Yeah.

Oh yeah, exactly. And and if we, if you think you've already. Yeah. Is that OK? Oh, sorry, I I did. Sorry. I should have said.

AM interviewee 2:58

I've just noticed your recording, which I'm quite happy with.
I'm quite happy with you recording and transcribing, yeah.

Maria Shipman (2116519) 3:06

Yeah. Is that all right? Sorry, I was meant to say I'm going to record this, OK. And obviously I will cite you as as everything.

AM interviewee 3:08

Yeah, that's fine.

OK, that I'm not frustrated.

Maria Shipman (2116519) 3:15

OK, cool.

OK, sorry.

AM interviewee 3:18

I'm not fussed about that anymore, but I'm I'm aware these meetings can only last about an hour, aren't they? So we need to crack on. So as you get what you need.

Maria Shipman (2116519) 3:23

Yeah, we.

OK. So we're going to start off with some kind of general questions. How is the jewellery manufacturing industry evolving with new technologies in comparison to the last 10 years?

AM interviewee 3:31

Yeah.

We're talking in general these terms. Yeah. So they were already quite used to adapting to 3D printing in waxes and resins and using those for lost wax casting. So it's not difficult to get them to move on to other ideas, but then other ideas have their own issues we've just discussed.

Maria Shipman (2116519) 3:45

Yeah.

Yeah.

AM interviewee 4:05

Laser printing into metal powders and it still suffers from Surface finish issues, particularly on downward-facing surfaces.

Or where supports have been and had to be removed, the great attraction of it is the ability to to manufacture very intricate things.

Complex structures, but those have usually got internal surfaces that you somehow want to Polish. If it's going to be a piece of jewellery. If it's a heat sink on a on a computer chip or something doesn't matter as long as it's got lots of surface area, the quality doesn't matter so.

Maria Shipman (2116519) 4:42

Yes.

AM interviewee 4:47

Surface finish is the thing that's got left behind.

Maria Shipman (2116519) 4:51

Yeah.

AM interviewee 4:51

In things to do with am of precious metals.

Maria Shipman (2116519) 4:58

Thank you.

What are the most significant innovations in the jewellery production in the past decade? I know that you might say the same thing again, so if you don't want to answer, that's fine.

AM interviewee 5:10

It is to some extent the same thing. Yeah, you know.

Maria Shipman (2116519) 5:12

Yeah.

AM interviewee 5:15

Los Rosa casting has been there since they were making bronze axe heads.

Maria Shipman (2116519) 5:19

Mm hmm mm hmm.

AM interviewee 5:20

And it's the last rest catching of a ring now is the same basic process, just industrialised. And it also makes me smile when they they sell a piece of jewellery that's been cast as handmade.

It's not. It's had it's had an industrial mechanical intervention.

Maria Shipman (2116519) 5:41

Yeah.

AM interviewee 5:42

You know where you know, truly handmade jewellery doesn't really exist except in the very high end. Utterly bespoke stuff.

There are industrial applications all the way through in the jewellery manufacturing

processes now.

Maria Shipman (2116519) 5:57

Yeah.

I'm glad you said that because I say I say that all the time and I get pushed back from people that aren't jewellers and I've and I and I say basically that which companies or designers are leading the way for tech driven jewellery design. Would you what, who would you consider say again?

AM interviewee 6:05

Yeah.

What's gold?

Cost gold in Italy.

Maria Shipman (2116519) 6:17

First gold in Italy. Oh, OK, yeah.

AM interviewee 6:18

Number one number Uno Damiano Zito.

Maria Shipman (2116519) 6:21

Yeah, OK. Yeah, yeah.

AM interviewee 6:24

Yeah.

Maria Shipman (2116519) 6:25

Because I've met Damian here a few times. Has he changed? Is it changed? The name has always been plus gold.

AM interviewee 6:31

Pro Gold Pro gold not Plus Gold Pro gold gold in it pro gold.

Maria Shipman (2116519) 6:32

Oh God, I was going to say houses.

Yeah, I know. I was just doing checking it. Oh, I didn't see that they'd changed their name.

AM interviewee 6:40

And yeah, and and the other guys behind them are just behind them and Lego.

Maria Shipman (2116519) 6:45

I go OK.

AM interviewee 6:46

Yeah, in the UK, you know, it was to be more.

Maria Shipman (2116519) 6:51

Yeah.

AM interviewee 6:52

What we meant, you know, do do their best, but they are so focused on their bottom line profitability.

Maria Shipman (2116519) 7:01

Yeah.

AM interviewee 7:02

That getting them to take on anything really radical is difficult.

Maria Shipman (2116519) 7:06

Yeah.

AM interviewee 7:07

If they if they can't see a monetary return on their investments in time and money, then they're not keen to try and take it up. Whereas Pro Golden League or are.

Maria Shipman (2116519) 7:12

Yeah.

Yeah.

Yeah. OK. Yeah. OK, cool. Thank you.

AM interviewee 7:21

You got to remember about both of them. Sorry, Lego and pro goals. They're only in it to sell powders. It's like the old the old thing will will sell you a printer.

Maria Shipman (2116519) 7:27

Yeah.

AM interviewee 7:32

But we'll make our money on selling you the the cartridges to go in them. It's exactly it's exactly the same business principle for them, which is why they're happy to invest time and money in the research because they see a return coming to them through the selling the powders to go into the machines.

Maria Shipman (2116519) 7:34

The matter?

Yeah.

AM interviewee 7:52

Whereas an end use jewellery manufacturer.

It's down a different route, aren't they?

Maria Shipman (2116519) 8:00

Yeah.

No. Yeah, it is interesting to see how people are kind of. They seem to like fragment off from this kind of jewellery industry.

And I just kind of what do you think businesses will look like in the next 30 or 40 years looking at Lego looking at Pro Gold and how they're running their jewellery business to compare to what's going on into the UK, do you think we're going to have companies that follow kind of their lead or?

AM interviewee 8:23

Yeah.

Well, no, because the the big problem there is that the different.

Structure that these companies were in Europe generally.

Companies do everything they if you set up a jewellery manufacturer, you expect them to buy in the raw gold and the alloy materials. And from that point on cast melts form. Manufacture was in the UK.

You can run a quite successful jewellery business without actually owning any machinery, because you can subcontract it out.

Maria Shipman (2116519) 8:58

Yeah, yeah.

AM interviewee 9:01

It's. It's a bit like DCW, you know. They stop at the the casting.

Maria Shipman (2116519) 9:06

Asking.

AM interviewee 9:08

And and then people like western bee, more than they'll Polish it, finish it and eat hallmark it for you.

So that's a a totally different business model in the UK.

Maria Shipman (2116519) 9:19

Yeah.

OK, I'm good to know.

What types of 3D printings I know we've talked about the different a few different types already.

Are what type of 3D printing do you think are going to be more prevalent in the next coming decades compared to the ones that we've seen?

AM interviewee 9:42

And at the minute I think if anything is going to come up with direct printing, I am it's it's going to be down the route of buying to jetting in the draw in the drawing industry specifically.

Maria Shipman (2116519) 9:51

Yeah.

Mm hmm.

AM interviewee 9:57

If you get into other metals and more industrial applications, one of the interesting things I picked up in Wolverhampton.

They're they're now making machines that that can change the size and shape of the laser spots. So back in the day when you and I started, you were you were fixed to a laser spot of X and you had to work out how often that that scanned up, down, crossing around. Now they've got machines where you can go from a tiny little.

Maria Shipman (2116519) 10:10

Right. Oh.

Mm hmm.

AM interviewee 10:27

Couple of Micron spots to something that's a couple of inches across.

Maria Shipman (2116519) 10:32

Oh, wow, that's huge.

AM interviewee 10:33

And and they, they call it shaped laser.

Maria Shipman (2116519) 10:36

Shaped laser. OK, this is transcribing as not to write that down.

AM interviewee 10:38

Yeah, it'll be. It'll be on your transcribes, so don't worry. Yeah. So it's it's a shaped laser.

Maria Shipman (2116519) 10:44

OK.

AM interviewee 10:45

And.

That's quite interesting and and got lots of possibilities and again multi metals as well multi materials in one machine without having to empty and restart the machine.

Maria Shipman (2116519) 10:54

Yeah.

Yeah, I mean that would be incredible good.

AM interviewee 10:59

You're the one. You're the one that I'm. I'm quite keen to keep following and pops up in me now again is encapsulation.

Maria Shipman (2116519) 11:07

Encapsulation again.

AM interviewee 11:08

You start to print some, it stop, drop something into it and start it again, so it's encapsulated in whatever it is you're printing. I've seen some interesting stuff going on with that around and about.

Maria Shipman (2116519) 11:16

Yeah.

Yeah. OK. I did see. Well, we did have Cookson, we did Marie Bolton Stern and she we dropped stones in Bahar. Her was, yeah, hers was very yeah. Yeah, yeah, it's.

AM interviewee 11:28

Exactly. Yep. We were doing it over the road before then. Yeah. Yeah, we were. We were dropping pearls into baskets, basically, yeah.

Maria Shipman (2116519) 11:36

Yeah, it's. It's interesting though, because they obviously it comes with, I mean not if if you're dropping in below the print line, that's fine. But say if you wanted to set a diamond or something, how do it be really interesting to see how someone would overcome that problem of trying to set something that was maybe a bit more raised or a bit bit proud of the powder line.

AM interviewee 11:46

Yeah.

Yeah.

Maria Shipman (2116519) 11:59

Have you heard of Ecam electrochemical additive manufacturing?

AM interviewee 12:04

Can't I really have no.

Maria Shipman (2116519) 12:07

I haven't seen too much and I keep a tab on this company called Fabricate Labs. Oh, hello. Hello. Am I back? I've kept to. Oh, no. Oh, no. Hello.

AM interviewee 12:10

We stalled.

All right, you're back now.

Now you stalled again.

Maria Shipman (2116519) 12:22

Hello. Hello.

Oh, you're frozen as well.

AM interviewee 12:30

That's it. You're back.

Maria Shipman (2116519) 12:30

Oh, they're back.

No, I've just kept a tab on this. Yeah, ecam. It's called electrochemical additive manufacturing. And from what I understand.

AM interviewee 12:35

Ecosy.

Stem.

Maria Shipman (2116519) 12:42

They basically print in a plating tank so they shine a laser into the into the liquid and that that helps it form. So if it's gold plating tank it will it. Basically you can add a mod con to a plating tank and it will help printing in inside but I just in case you haven't heard them called fabricate labs. I think they're in San Diego in America.

AM interviewee 13:05

Yeah.

Maria Shipman (2116519) 13:06

But yeah, I was just wondering if you had heard any anything about that kind of printing suspension suspended printing?

AM interviewee 13:11

I'm afraid not, but I'm.

I haven't.

I'm making a note publicate labs.

Maria Shipman (2116519) 13:19

Yeah, it's fabricate with an 8, not a not spelled traditionally.

AM interviewee 13:25

Eight and San Diego, did you say?

Maria Shipman (2116519) 13:26

Yeah.

I think so. I think it's San Diego or San Francisco. It's one of the two sounds. I know it's on the West Coast.

AM interviewee 13:32

Yeah.

OK, I'll I'll have a look at that.

Maria Shipman (2116519) 13:41

What materials? Because I know that we we prefer other materials to others. But what materials do you think would benefit the most in us being able to adopt using

FC

3D printing? It doesn't have to necessarily just be precious metals.

But is there a particular material that we could print in that would be groundbreaking?

AM interviewee 14:03

You're looking at, you're looking at a broad spectrum there.

Maria Shipman (2116519) 14:07

Yeah.

AM interviewee 14:08

Industrial applications.

Neo medium.

Maria Shipman (2116519) 14:12

OK, well.

AM interviewee 14:13

Is that was that the one? I don't know. When people are getting quite interested about jet nozzles and jet engines, things that can withstand super heating but be printed one go with complex.

Maria Shipman (2116519) 14:24

Yeah.

AM interviewee 14:28

Internal structures.

Maria Shipman (2116519) 14:31

Heat sinks and channels.

AM interviewee 14:33

Yeah, he thinks. But as I say, nozzles, nozzles for jet engines and. And there's like there's I'm aware of stuff that's going on.

Maria Shipman (2116519) 14:39

Yeah.

AM interviewee 14:44

In the world of drones, which is being propelled by the war in Ukrain.

Maria Shipman (2116519) 14:49

Yeah.

AM interviewee 14:55

What can I say?

There's an awful lot of after books research going on in and around supplying.

Tiny little jets to Ukraine for putting into little rockets.

Maria Shipman (2116519) 15:10

OK.

I don't know whether to ask you more questions or if you're being consulted on that.

AM interviewee 15:14

Fry's phrase that up out you like. You know that you know, a little bird told me. Yeah.

Maria Shipman (2116519) 15:17

OK, is.

Yeah, I there's a company actually near reading. And I they recruited did message me about them. There are there are a bunch of boxer graduates and they're looking at 3D printing drones and I'm trying to remember what the company was called.

AM interviewee 15:29

Yeah.

Maria Shipman (2116519) 15:33

But if I remember, I will send it across to you, but yeah, they they got in contact for quite a lot of questions about how to 3D. Well, they were looking at research in 3D printing drones for.

AM interviewee 15:42

Saturday, Saturday forgot dozens and dozens of machines in your Ukraine. They're printing drone bodies, drone parts by the millions daily.

Maria Shipman (2116519) 15:54

It's interesting.

It's it's very interesting. Well, that's a whole nother subject talking about innovation in warfare anyway.

AM interviewee 15:59

Yeah.

Maria Shipman (2116519) 16:02

OK, how has 3D printing changed the design process for jewellery? I know we've touched on this quite a lot already, but.

AM interviewee 16:06

It is, it is now.

With the advent of reasonable AI as well.

Santa Face Symposium has been replaced by a new one in Detroit.

The The Jewellery symposium.

I saw one presentation last year there about.

AI inspired jewellery design.

At this year's, I think there's three.

Maria Shipman (2116519) 16:41

OK.

AM interviewee 16:42

It's it's worth just going online and looking at their website to just to see that your if you look at it, you'll see the opening speakers are somebody called Reese and Kelvin.

Maria Shipman (2116519) 16:46

Yeah.

Hmm.

AM interviewee 16:57

At this year's conference, it was supposed to be me, but I'm about to postpone it because of my operation.

Maria Shipman (2116519) 17:02

Or is it actually Reese and Kelvin?

AM interviewee 17:04

Yes, you will. Recent call me our recent Calvin. Yeah.

Maria Shipman (2116519) 17:05

Oh my God, I didn't know. I haven't talked to Kelvin in a while. I'll talk to Reese this morning.

AM interviewee 17:11

Now there you go. So, yeah, they're they're off to Detroit in a few days to to do that. But I'm. I'm recommending you have a look at that and look at the talks that are coming up

Maria Shipman (2116519) 17:12

But yeah. Oh well.

AM interviewee 17:22

And if they if they really trigger you, Reese will come away from it with a memory stick with all of the presentations, not the presentations, the papers on.

Maria Shipman (2116519) 17:28

OK.

So far.

AM interviewee 17:33

And just scrounge a copy of the papers off him.

Maria Shipman (2116519) 17:36

Oh, I will do that sounds great.

AM interviewee 17:37

That are there are relative and tell him I told you.

Maria Shipman (2116519) 17:40

Yeah, I will do.

AM interviewee 17:41

It's it's mine.

Maria Shipman (2116519) 17:42

No, that's fantastic. I'm so happy that they're they're doing that.

AM interviewee 17:45

Yeah, yeah.

Maria Shipman (2116519) 17:47

Oh, we're good. I'll have to text you after this. To what extent does 3D printing enable customization and personalization for consumers?

AM interviewee 17:55

Enormously.

Maria Shipman (2116519) 17:56

Mm hmm.

AM interviewee 17:57

It's. It's what it's perfect at, but the the downside is getting them to pay for it.

Maria Shipman (2116519) 17:59

Yeah.

AM interviewee 18:04

You've got you've got a personalised customised at the very high end for it to be cost effective.

Maria Shipman (2116519) 18:11

Yeah.

AM interviewee 18:13

So yeah, that is, you know, that is exactly what it's good for.

Maria Shipman (2116519) 18:19

Perfect.

AM interviewee 18:19

But it's it's got to be a, you know, but and it should be possible. You know, it should

be able to if you're making something specifically for somebody.
To their design or their they what they think they've designed.
To fit something exactly, then they should be prepared to pay for it.

Maria Shipman (2116519) 18:39

Yeah, absolutely.

AM interviewee 18:40

You know, not not getting August prices here.

Maria Shipman (2116519) 18:44

Yeah, there is A/C. Oh, it's quite funny because I I I work quite closely with Kelvin's daughter Chantelle for a lot of my precious metal orders because I kind of do my own thing on the side and and a lot of people. It's a race to the bottom with a lot of consumers, and I get it because there's a cost of living crisis.

AM interviewee 18:53

Yeah.

Maria Shipman (2116519) 19:00

But I know so many people that have just turned around and said I can just get it cheaper online and I just and I and I say I can't compete with that and I I commend you for doing that, but.

AM interviewee 19:08

Yeah.

Maria Shipman (2116519) 19:09

There is a real issue with people wanting for a lot less.

AM interviewee 19:13

Yeah. And as we said right at the beginning, look at the price of bloody gold now.

Maria Shipman (2116519) 19:14

But yeah.

Yes, insane. It's insane.

AM interviewee 19:19

It's only it's only \$3000 an ounce, isn't it?

Maria Shipman (2116519) 19:21

Is it? I can't believe I was kind of at work. I wasn't panicking at all. I was just kind of trying to make people aware. I was like, if we're doing this project just so you know that this is what the price is now.

AM interviewee 19:33

And it's it's.

Maria Shipman (2116519) 19:33

Because they come, they come from a clothing background. They don't really understand that.

AM interviewee 19:35

Yeah, yeah, yeah. And it's this thing, Platinum's cheaper now.

Maria Shipman (2116519) 19:40

Yeah, I mean, I was going to say it's been for a couple of years now, hasn't it? But I always tell everyone go to platinum. I just said use platinum unless you want yellow, go to platinum.

AM interviewee 19:41

And that's been for.

Yeah.

Yeah.

Maria Shipman (2116519) 19:51

But yeah.

AM interviewee 19:52

And it's it's, it's wider, more durable.

Maria Shipman (2116519) 19:55

Yeah, exactly. I don't know why you wouldn't go for that. Anyway, to be honest.

AM interviewee 19:56

Yeah.

Yeah.

Maria Shipman (2116519) 20:00

How is 3D printing impacted production timelines and inventory management's?

Yeah, yeah.

AM interviewee 20:10

I'm not happy to take much notice of it, so I'm not really the person to answer that I'm afraid.

Maria Shipman (2116519) 20:13

Yeah.

No, no, it's absolutely fine.

Our small scale or independent jewellers adopting 3D printing differently than large manufacturers.

AM interviewee 20:26

To some extent, yes, but that I'm aware of that.

There are some people who who again going back to personalised and bespoke, will get their customer in, design it on a screen with them, print it on a little machine in the back of their shop and then send it to somebody like Western beamwall to get it printed. But it's just as easy to send them the file and get them to print it, because then if the print files they they replace it, don't they.

Maria Shipman (2116519) 20:44

Yeah.

Yeah, yeah.

That's true, yeah.

AM interviewee 20:54

Yeah.

Maria Shipman (2116519) 20:55

Let me just check.

What are the barriers for small, medium and independent jewellers from adopting? 3D printing.

AM interviewee 21:08

Any pins in as opposed to AM.

Maria Shipman (2116519) 21:10

4:00 AM sorry.

AM interviewee 21:12

I am. I am. Yeah. The machines are just too expensive at the minute for them to adopt.

Maria Shipman (2116519) 21:16

OK.

AM interviewee 21:17

So they they have to go to a Bureau service of some sort.

Maria Shipman (2116519) 21:21

Mm hmm.

AM interviewee 21:22

It's so sheer sheer cost, but if you're going down the route of waxes and and resins. You know, there is very cheap, very durable, very quite good machines out there

now.

Maria Shipman (2116519) 21:32

Yeah.

Mm hmm. Yeah, absolutely that. I mean, I think most independent jewellers can afford them now, especially on the payment plans.

AM interviewee 21:42

Yeah, I'm there's. I've also some stuff I've come across recently, actually.

Some somebody was printing a ring so the customer could see it before they actually had it made.

So it was what they were expecting. They're just a cheap resin Prince, is this? Does this look like what you're expecting before they actually go into production?

Maria Shipman (2116519) 21:59

Yeah.

Besides, yeah.

Yeah, I know. That's what Chantelle and Simon Kelvin's daughter. That's what they do as well. They will send you off a wax one so you can you can. You can try it out.

AM interviewee 22:12

Yeah.

Well, there you go.

It's Phoenix or something.

Maria Shipman (2116519) 22:19

But.

Yeah. Jude. Phoenix. He's doing his. He's doing his pH. Di can't remember what the title of his PhD is. He's doing his PhD in jewellery innovation. He's a good contact to have. Simon, actually.

AM interviewee 22:22

That's it.

Yeah, yeah.

Maria Shipman (2116519) 22:32

Yeah.

Just 3D printing contribute to more sustainable jewellery manufacturing practises.

AM interviewee 22:43

Oh.

Maria Shipman (2116519) 22:44

Yeah, I know it's horrible.

AM interviewee 22:46

No, I mean it's it opens an interesting series of debates, doesn't it?

Maria Shipman (2116519) 22:51

Yeah.

AM interviewee 22:53

Where? Where do you start?

How much CO₂ has been produced?

To make the machine.

How much CO₂ has been produced to make the materials to go into the machine?

Maria Shipman (2116519) 23:06

Yeah.

AM interviewee 23:08

Which is again, why the principle really should be the machine should be right next to where you want it.

Maria Shipman (2116519) 23:14

Yeah.

AM interviewee 23:15

Not not in your workshop in Edinburgh to send it down to Birmingham, to be cast and then sent back to Edinburgh.

Maria Shipman (2116519) 23:17

Yeah.

Yeah.

AM interviewee 23:23

You know that there is there's, there's long been debates about how green 3D printing is and it's only getting down that roof when it's being done at at the source. If you're printing something to ship it across the world.

Maria Shipman (2116519) 23:35

Yeah.

AM interviewee 23:39

It's almost pointless. You're not saving anything if you're printing it where it's going to be used, then you're you're moving into slightly better territory.

Maria Shipman (2116519) 23:42

Yeah.

Yeah. Yeah, it is interesting because I was even talking about.

I was talking about this with because we have to meet sustainability, sustainability. What's called targets for accessorising monsoon for us to keep having the title that we have and I think they thought when they brought me in and I was interviewing for it and and they were like well, it's for sustainability reasons I thought that's OK if we're doing it in the UK, if we're doing it in the UK, that's fine. But you're wanting to 3D print out in China, there's not going to be anything more sustainable there.

AM interviewee 24:02

Yeah.

Yeah.

Yeah.

Maria Shipman (2116519) 24:24

And also I was trying to explain to them as well that actually it can be a little bit of green washing because the amount of gas atomisation that the amount of, yeah, CO2 that's used for gas optimization is so high and that's why I've tried to try to keep an eye on the the wire feed atomization because maybe that'll be I think that will be actually a lot better, but I there's arc welding, isn't it? It's arc.

AM interviewee 24:38

Yeah.

Yeah, it can be. Yeah. If if you want, if you want to follow up on that, look for a guy called Phil Reeves.

Maria Shipman (2116519) 24:51

It could be.

OK.

AM interviewee 24:58

Phil R EE VES.

Maria Shipman (2116519) 25:01

I feel like I know that name. What was he?

AM interviewee 25:03

Yeah, it's famous in the am 3D printing world.

He did in 10 years, 15 years ago, he was doing a lot of research.

Into the green credentials of printing, so he might he might have some stuff published online, but you can that you can tap into, yeah.

Maria Shipman (2116519) 25:16

OK.

OK, I'll have a look.

Well, definitely. I'll have a look.

Do you think that we will ever there'll ever be a time that they could be desktop director metal or?

Am machines. That means that independent jewellers could cast on their on in their workshops.

AM interviewee 25:42

Be a lovely thing if it could be made to happen. Yeah, but there's an awful lot of work and research gotta go in before you get to that point.

Maria Shipman (2116519) 25:44

Yeah.

Yeah, absolutely.

How do customers perceive 3D printing or additive manufacturing jewellery versus traditionally made pieces do you think?

AM interviewee 26:01

20% of them haven't got a clue and don't care.

Maria Shipman (2116519) 26:04

Yeah.

AM interviewee 26:06

It's a bit like the old.

You could sell people something made from titanium.

Maria Shipman (2116519) 26:12

Mm hmm.

AM interviewee 26:13

'Cause they were faintly aware that it was a high.

Aerospace high end alloy, although it's one of the most plentiful alloys in the ground, if you know where to dig it up and out of process it. So a lot of that comes down to theception of the of the end user of the end purchaser.

Maria Shipman (2116519) 26:24

Yeah.

Yeah.

AM interviewee 26:36

And sadly, the world's full of idiots who haven't got a clue.

Maria Shipman (2116519) 26:39

Yeah.

AM interviewee 26:41

It's it's only a. It's only a selling point.

If you've got a slightly educated audience that you that you're selling to.

Maria Shipman (2116519) 26:51

Perfect. OK. Yeah, I agree.

What trends are driving consumer interest for am printed or tech enabled jewellery?

AM interviewee 27:02

Comes down to money. It's all about the money.

It's been around for quite some time. You know how much disposable income have you got and what are you going to spend it on?

Maria Shipman (2116519) 27:10

Yeah.

Yeah.

AM interviewee 27:15

It used to be jewellery because then that jewellery was going to be handed down. It was an heirloom that your granny left to your mother or your mother said. Don't when I'm dead you can have that. Take it off my finger.

Maria Shipman (2116519) 27:19

Yeah, yeah.

AM interviewee 27:28

Not anymore. You know, I've seen that Ratner, Ratner and his prawn sandwich earrings.

Maria Shipman (2116519) 27:33

Yeah.

AM interviewee 27:34

Did the debt of that didn't I that, you know, jewellery's a lot of jewellery these days is considered fast fashion?

Maria Shipman (2116519) 27:36

Yeah.

Yeah, absolutely.

AM interviewee 27:44

You buy a piece of jewellery, wear it a few times, collect it up in a little box and every

every six months sell it on a scrap, a scrap gold, especially the way the price is going.

Maria Shipman (2116519) 27:51

Yeah, I know it a massive.

Yeah, a massive part of our income or what I sent to Chantelle to get done is people upgrading their engagement ring or their wedding bands, which I'm not going to say no to any more. Money is trade for us, but it is interesting because, like, I can't imagine that happened very regularly, you know, 30-40 plus years ago.

AM interviewee 28:03

Yeah.

Yeah.

Maria Shipman (2116519) 28:16

But yeah, it's interesting.

Are there any notable collaborations between tech companies and jewellery brands?

That you that you are aware of that you would like to tell me about? No. OK.

And last, sorry.

AM interviewee 28:32

K There's only. There's only those two. I've I've spoken. I've pro golden Lego.

Maria Shipman (2116519) 28:36

Yeah.

AM interviewee 28:38

But neither of them are very open about who they're working with.

Maria Shipman (2116519) 28:41

No, they're they're impossible to impregnate as well sometimes. And I've met Damian a few times and he's he's actually very good at getting back to me.

AM interviewee 28:46

Yeah, yeah.

Yeah, he's he's lovely bloke, yeah.

Maria Shipman (2116519) 28:52

Yeah, he's really nice.

What are the emerging technologies that might further disrupt the jewellery industry in the next 5 to 10 years? It doesn't have to be am can be anything.

AM interviewee 29:03

Tui tech is gonna be the one.

Maria Shipman (2116519) 29:06

Yeah.

AM interviewee 29:08

The reason I've got to say there is the stuff I'm doing with DCW, with the tewitek and and the other one.

Maria Shipman (2116519) 29:13

OK.

Talk to what's it called?

AM interviewee 29:17

Yeah, you know.

Maria Shipman (2116519) 29:19

Can't even what it's called.

AM interviewee 29:22

Yeah.

To me, check for identifying diamonds and and giving them a repeatable clarification classification.

Maria Shipman (2116519) 29:30

What are you doing?

AM interviewee 29:34

And then there's there's the little hallmark, the little QR code.

Maria Shipman (2116519) 29:38

Yeah.

AM interviewee 29:40

Working on that with them, you know, it's it's it's spreading out outside of the jewellery industry.

Maria Shipman (2116519) 29:45

Oh, absolutely. You'll be on everything.

AM interviewee 29:46

Have you come across? Has anybody mentioned Scotch whisky to you, Barry?

Maria Shipman (2116519) 29:51

No.

AM interviewee 29:52

Apparently Scotch whisky stuff suffers an awful lot with it was on BBC News today. Scotch whisky and wines.

Are suffering from what's the word?

Maria Shipman (2116519) 30:09

If it's imitations.

Doesn't say.

AM interviewee 30:15

You could you could put a tiny little QR code on the bottle.

In the Scottish distillery, where it's been bottled and you know it's genuine and it's quite easy, it's quite easy to be read.

Maria Shipman (2116519) 30:24

I think so.

I wouldn't. I would never have even thought that people would be imitating alcohol.

AM interviewee 30:31

Yeah, they are. Yeah, I'd like to say have a look at on iPlayer. It's on BBC News today.

Maria Shipman (2116519) 30:37

Let's have a look. Have a look.

AM interviewee 30:38

Yep.

Maria Shipman (2116519) 30:40

And the last one, to be fair, I think we've actually covered this one. How is AI influencing design and customization in combination with 3D printing? So how do you think they'll feed into each other?

AM interviewee 30:53

It it it covers several other topics we've we've done any personalization customization.

Maria Shipman (2116519) 30:55

Yeah.

AM interviewee 30:59

Does does this thing that if the customer thinks they're involved in its design? And they're going to be far more prepared to pay a proper price for it.

Maria Shipman (2116519) 31:10

Mm hmm.

AM interviewee 31:11

And if you give them 10 designs on a page and say pick which one you want.

But if you can get them to sit in front of a screen and and press buttons and and do

a few little little tweaks which you're fully in control of behind.

Maria Shipman (2116519) 31:20

Design it themselves.

Mm hmm.

AM interviewee 31:27

They think they've designed it for themselves and they can. They can be encouraged to pay a realistic price for it.

Maria Shipman (2116519) 31:36

No, it's interesting to see how it's going to see how it's going to go.

AM interviewee 31:37

Yeah.

Uh huh.

Maria Shipman (2116519) 31:41

I think there's going to be a lot of pushback from traditional jewellery and traditional jewellery industry.

AM interviewee 31:47

Now it's it's it's always, it's always innovative and and moved on. You know they use like they use the laser welders came in from the dental industry.

You know the jewellery industry is great adapting and stealing other people, other people's ideas.

Maria Shipman (2116519) 32:06

Yeah.

That's good to know.

AM interviewee 32:10

You know.

Laser scanning. You know, the fact that you could.

Maria Shipman (2116519) 32:12

Well.

AM interviewee 32:15

And then go back to what? What's the name of the KTP?

Maria Shipman (2116519) 32:19

Yeah.

AM interviewee 32:20

Is she still working at Cooksons?

Oh God.

Maria Shipman (2116519) 32:25

Kate.

AM interviewee 32:27

She did a KTP with an insurance company.

Maria Shipman (2116519) 32:30

No, jade.

AM interviewee 32:31

Jade. Jade. Sorry.

Maria Shipman (2116519) 32:33

Not 100% sure if she is actually having.

AM interviewee 32:35

But doesn't matter. I'm just trying to remember Jade and her KTP projects was all about how you could replace it. Was called how you replace the irreplaceable.

Maria Shipman (2116519) 32:45

Yeah.

AM interviewee 32:46

But if you had a picture of a piece of jewellery, that again, that your grandma had handed down to you, if you had a picture of it, you could cut it and and get it replaced and near identical copy.

Maria Shipman (2116519) 32:53

Yeah.

AM interviewee 33:01

If you had an earring and a pair of earrings, you'd lost one. You could laser scan the one you've got and get a a pair of that made-up.

So you know the the industry itself is quite good at at taking in innovation. And the key with jewellery then and stuff like am 3D printing is jewellery doesn't have any. What are they called? ISO standards. You don't have to qualify if you want to put it on an aeroplane and fly it around the world. You know you've got to jump through 150,000 hoops if you want to make a pair of earrings using it. There you go.

Maria Shipman (2116519) 33:27

Yeah.

AM interviewee 33:38

Just just make sure it's something to rock the person's ear.

Maria Shipman (2116519) 33:38

Yeah.

AM interviewee 33:42

'Cause it's made of **** metal, but beyond that, you know there there are no. There's no qualification required. So you jewellery and and that type of world that we live living used to live in. It's quite good at testing things out for people.

Maria Shipman (2116519) 33:44

Yeah.

Yeah, that's good. You touched on how we look at other industries like dental. Is there any other industries that we as jewellers look at and and you know amend or embed their technology into ours?

AM interviewee 34:16

Yeah, to some extent that's happened with electronics, hasn't it? And back to *****, getting bonded jetting was developed early on to try and help with electronic work. You know, building stuff for electronics and in some Bright's, but oh, we could take that and switch this switch, this material for gold and away we go.

Maria Shipman (2116519) 34:20

Yeah.

Yeah.

Mm hmm.

That's good. And that was that was pretty much it. Is there anything that I haven't asked you that I maybe should?

AM interviewee 38:22

Damn.

Yeah, yeah, it's fine. I'll let you know. No worries.

All right. Are we done?

Maria Shipman (2116519) 38:34

Yeah. Yeah. Thank you so much. I really appreciate it.

AM interviewee 38:37

Pleasure.

8.10 Appendix 10 - AM interviewee interview questions

AM interviewee :

1. General Industry Innovation

- How is the jewellery manufacturing industry evolving with new technologies?
- What are the most significant innovations in jewellery production in the past decade?
- Which companies or designers are leading the way in tech-driven jewellery design?

2. 3D Printing Technology

- What types of 3d printing technologies are commonly used in jewellery manufacturing (e.g., SLA, DLP, SLS)?
- How does 3d printing compare to traditional jewellery-making methods in terms of cost, time, and quality?
- What materials are most used in 3d-printed jewellery, and how do they affect the final product?

3. Design & Customisation

- How has 3d printing changed the design process for jewellery?
- To what extent does 3d printing enable customisation and personalisation for consumers?

- What CAD (Computer-Aided Design) tools are most popular in the jewellery sector?

4. Business and Production

- How has 3D printing impacted production timelines and inventory management?
- Are small-scale or independent jewellers adopting 3D printing differently than large manufacturers?
- What are the cost implications of adopting 3D printing for a jewellery business?

5. Sustainability and Materials

- Does 3d printing contribute to more sustainable jewellery manufacturing practices?
- Are there eco-friendly or recycled materials available for 3D printing jewellery?

6. Consumer Perspective and Market Trends

- How do customers perceive 3d-printed jewellery versus traditionally made pieces?
- What trends are driving consumer interest in 3d-printed or tech-enabled jewellery?
- Are there any notable collaborations between tech companies and jewellery brands?

7. Outlook

- What emerging technologies might further disrupt the jewellery industry in the next 5–10 years?
- How is AI influencing design and customisation in combination with 3d printing?

8.11 Appendix 11 – interview questions for Kate Thorley

1. Industry Trends & Outlook

- What emerging trends do you see shaping the future of jewellery manufacturing?
- How is consumer demand changing in terms of customisation, sustainability, and technology?
- What role do you think digital platforms (e.g., e-commerce, social media, NFTS) will play in the jewellery industry in the next 5–10 years?

2. Materials & Sustainability

- Are there innovative materials or alternative metals/gemstones gaining traction in the industry?
- How can jewellery manufacturers address environmental and ethical concerns, particularly with sourcing and waste?
- What innovations are happening in recycled or lab-grown materials?

3. Manufacturing Technology

- How are technologies like 3d printing, CAD, or AI being used in modern jewellery design and production?
- What are the most significant technological hurdles facing traditional manufacturers trying to innovate?

- How can smaller, artisanal jewellers leverage modern manufacturing techniques without losing authenticity?

4. Design & Personalisation

- What innovations are helping to make jewellery design more personalised or collaborative with customers?
- How can technology assist in reducing the time from concept to finished product?
- Do you see generative design or AI playing a role in future jewellery aesthetics?

5. Business & Market Disruption

- What business models are disrupting the traditional jewellery market (e.g., direct-to-consumer, subscription, rental)?
- How can legacy brands adapt to new market expectations without losing their identity?
- What startups or companies do you think are leading the way in jewellery innovation?

6. Digital & Smart Jewellery

- How do you view the integration of technology into jewellery (e.g., smart rings, wearable tech)?
- Are consumers ready for tech-enabled jewellery, or is it still a niche market?
- What challenges exist in combining functionality and luxury?

7. Personal Experience & Vision

- Can you describe a project or product where you felt innovation truly succeeded?
- What advice would you give to someone trying to innovate in such a tradition-bound industry?
- If you had no constraints, what would your ideal innovation in jewellery look like?

8.12 Appendix 12 – Blockchain interviewee Diamond centre wales interview questions

1. Understanding the Value

- How do you see blockchain adding value to the jewellery industry, beyond just hype?
- What specific problems in the jewellery supply chain do you believe blockchain can solve?
- Do you think customers truly care about traceability and transparency, or is it primarily a marketing tool?

2. Provenance & Authenticity

- How can blockchain improve gemstone or metal provenance, especially for ethical sourcing (e.g., conflict-free diamonds)?
- Can blockchain be a reliable tool to authenticate luxury items and prevent counterfeiting?
- How would blockchain change the resale or appraisal process of high-end jewellery?

3. Implementation & Adoption

- What are the most significant barriers to adopting blockchain in traditional jewellery manufacturing settings?
- How do you see smaller brands or artisans integrating blockchain, given limited resources and technical expertise?
- Do you think an industry-wide standard for blockchain in jewellery is necessary? If so, who should lead that effort?

4. Supply Chain & Logistics

- Can blockchain improve efficiency or accountability in the global supply chain of raw materials?
- How could blockchain help in tracking environmental or labour compliance across different regions?
- Are there successful case studies where blockchain has been integrated into jewellery logistics or sourcing?

5. Consumer Interaction & Experience

- What would a blockchain-based customer experience look like—QR codes on pieces, digital certificates, or NFT-based ownership?
- Do you see potential for blockchain to tie into personalized storytelling or product history for luxury buyers?
- Could blockchain tech help with things like digital warranties, repairs, or insurance claims?

6. Emerging Technologies & Integration

- How might blockchain intersect with other technologies in jewellery, such as AI, IoT (e.g. innovative jewellery), or 3D printing?
- Do you see a role for NFTs in digital jewellery ownership or in the metaverse?
- Could blockchain facilitate fractional ownership or investment in high-value pieces?

7. Ethical, Legal & Future Concerns

- What legal or regulatory challenges come with using blockchain for supply chain verification or consumer data?
- How do you ensure data input into a blockchain (e.g., origin of gems) is accurate and not manipulated upstream?

- **Where do you see blockchain in jewellery heading in the next 5–10 years? Is it a fundamental shift or a niche solution?**

8.13 Appendix 13 – Blockchain interviewee transcript

I can see blockchain adding value, especially to the jewellery industry, by having the ability to trace and keep records that cannot be changed or altered. So you're keeping a sort of database or a security ledger that can trace the jewellery throughout its lifetime.

Currently, in the jewellery industry, we are not aware of the origin of diamonds, including the specific mines and their locations worldwide. This is due to specific legal issues and restrictions imposed by various countries. Now, blockchain can help to solve that by creating immutability and transparency throughout the industry with these diamonds.

I think people do hear about transparency. I think, you know, we go shopping, we like to know where our produce comes from and that it's fairly produced, you know, for the suppliers and the people involved. And I think it's essential for people to understand and know where their diamonds come from too, and that they're ethically sourced and sound

so question two, blockchain can we're being used to trace metal and gemstones. It can tell you, you know, you can keep it to secure, to a ledger or a database, tell you where it's from, what country it was in, what mine it was in, whether it was ethically sourced. You can even link it to a story or a tale of, you know, the mine, and some information about the mine, where it was sourced, in the local area, where the money goes back into the local area.

Blockchain is pretty reliable, as long as it matches the stones, the date the records, or match the certification. Blockchain is what it is you enter the data, and that's it. It's there forever. It can't be changed or tampered with. So it, I think it's pretty good to authenticate and follow the life story of these pieces.

I think blockchain could add value, I think, to a diamond and change the appraisal process. I think it would be with the current climate and the way people are with their items. I think they'd like to know where it came from and how it was sourced. I think it was sourced. I think it could be important for people to definitely add some value.

So for Question three, implementation and adoption, I think the hardest thing is for people to understand what blockchain is and how blockchain works. I suppose if you were to approach it as a way of a secure database, it would help people to understand it. It can also be a fiddly tool to implement on a software level.

Blockchain is known as not being a very front end facing, helpful bit of tool, tool or toolkit. So it can be hard for people to put into their own custom services. But if somebody was to capitalize on the industry and lead the way, you know, especially with a front facing application that people find easy through adoption, I think it's just a case of marketing and awareness. I think it could be very successful, and people could use it. It's starting to touch the industry now where people, like I trace it and to be as are looking into it and using it for tracing diamonds through paperwork. So you could definitely, definitely be adopted by the wider industry. And question five for a customer, you'd want it to be a simple QR code, either on a piece of paper or the asset itself, that customers can scan using their smartphone application, and it gives them all their information and data on their simple like digital wallet make it nice and easy for people to use and enjoy.

I think blockchain could be used for storytelling. You can look on certain websites now for traceability, like coffee beans, and you can see where they came from and how they were made and who produced them. It tells the life story of them as a diamond is around forever. I think that could definitely be used. And you could follow that life story of that diamond throughout the years to different people and different industries and different pieces. You can secure it to CAD drawings and all sorts of information.

And, yeah, Blockchain, you know, if you if you're doing a digital application for it, like a wallet or so on so forth, you could use push notifications for servicing and repairs and warranty and remind people to come in the date. There is another revenue stream.

I think blockchain link with some sort of AI application could help. So maybe the basis the AI application identifies the mark or the piece of paper for you, or the diamond itself, or you're able to put in information, and it'll assist you find similar items or diamonds that or assets that you're looking for around your pipe price range, perhaps that are stored on this blockchain network, or things that are for sale that you're looking for that could help. I'm not sure about the role of nfts in digital jewelry ownership at the moment, because nfts is a very unstable market at the moment,

but yeah, I think blockchain could help facilitate the fractional ownership. Yeah, people could buy parts of or shares in maybe a rough cut, and then they could take the shares in that rough cut. Was it polished down to individual pieces and ethical legal and future concerns, obviously.

8.14 Appendix 14 - Traditional jewellery market

As the jewellery market evolves, the potential for growth in innovative jewellery, which combines aesthetic appeal with functional technology, suggests that the industry can

benefit from the same creative spirit driving advancements in aerospace and medical fields. (Salmela, 2021). The ongoing development of wearable technology and the Internet of Things can support this transition, positioning the jewellery sector to embrace the principles of Industry 4.0 effectively.

The influence of immigrant craftsmen has also played a crucial role in shaping the jewellery industry in London, particularly in the coloured-stone cutting sector. The arrival of skilled artisans from various countries introduced new cutting techniques and styles, contributing to London's prominence as a hub for gem cutting. This influx of talent and the subsequent evolution of cutting techniques have significantly impacted the styles and quality of jewellery produced in the UK (Prim, 2021).

The historical techniques used in traditional Jewellery manufacturing in the UK encompass a range of practices that have evolved, particularly in the context of craftsmanship and material innovation.

Additionally, the cultural heritage embedded in jewellery design can shape contemporary identity and concepts. In the context of Malaysia and Thailand, traditional elements are being modernised by designers who draw upon local wisdom and implicit knowledge, thereby preserving cultural significance while fostering innovation in design (Sirivesmas & Yussof, 2015).

8.15 Appendix 15 - Interview with Siantel James Diector of DCW

What does the average spend per engagement ring sold per customer?

£3500 per engagement ring – Platinum and diamond are the most popular.

What is the average spend per non-wedding jewellery per customer?

£1000

What is the percentage of Wedding ring to non-wedding ring jewellery sold?

wedding ratio – Wedding jewellery is bigger than engagement rings

What do we need to be bringing in a week to cover overheads?

Ask Kelvin CEO

What are the quarterly and yearly targets for DCW regarding revenue?

18 Carat Yellow, 18 carat Rose, 9 Carat White

What is the percentage of precious metal market share for DCW (I know platinum is the most popular but what are the % of other metals)

18 Carat Yellow, 18 carat Rose, 9 Carat White

How much do we spend per month with Weston Beamor?

Ask Rhianne Otters

How much do we sell through the website/ social media?

Data from Matt.

How many customers do we see a week?

30 Customers a week

How many of those customers convert to an order?

- 85% conversion rate to order (not all, customers just want 1 thing – more like 45 jobs a week)
- This doesn't include the shop – repairs, stock Jewellery.
- Re-makes and redesigns are more popular.
- Cluster Rings

Which are the most popular wedding/engagement styles?

1. Halos
2. Cluster rings
3. Oval diamond
4. Diamond shoulders

Which are the most popular non-wedding style jewellery ordered?

1. Pendants (hearts and solitaires)
2. Eternity rings (most popular)

Which Collection has been the most popular?

1. Enchanted
2. Spring dawn
3. We do monthly collection (look books)

What are the predictions of jewellery trends we think the DCW will see in the next year?

1. Modular, interchangeable jewellery
2. Hoops and studs

How does DCW calculate their pricing?

2. Stones
3. Labour
4. Profit margin per category

How much does one unit of jewellery cost from Weston Beamor

Platinum cast: £200 (per engagement ring per 5g)

What density and porosity would be expected from a cast part?

What should be the expected surface roughness for casting?

How much time is allocated for polishing per part (let's base this on a ring)

Who does DCW look at for local competition?

Northern Star – Matt -Penarth and Swansea

Who does DCW look at for national competition?

- Who does DCW look to as inspiration for branding/ marketing/ design styles/ customer service?

8.16 Appendix 16 - Robotics

In this section, the Author will discuss how Robotics has embedded into the medical industry and the Aerospace sector to innovate patient care and enhance aerospace assembly lines. It will cover the benefits and barriers that the jewellery industry faces when it adopts robotics.

8.17 Medical use of robotics

The medical industry has begun to adopt robotics in various capacities, primarily focusing on enhancing surgical precision, improving patient outcomes, and addressing operational efficiencies. Robotics in healthcare are still in the initial stages of adoption, yet it shows significant potential to transform clinical services by increasing efficiency and reducing human error during complex procedures. Studies indicate that robotic systems can improve precision and accessibility through less invasive techniques, which can lead to cost savings and better patient satisfaction (Alla & Pazos, 2019).

Robotic-assisted surgery (RAS) has emerged as a crucial component in modern healthcare, offering advantages such as increased surgical accuracy, reduced post-surgical discomfort, shorter hospital stays, and faster recovery times. These benefits contribute to improved patient outcomes and alleviate the strain on healthcare

resources (Handa, et al., 2024). The integration of robotics in surgical practices is also linked to advancements in artificial intelligence, which enhances decision-making and procedural efficiency, thereby addressing challenges related to surgical accuracy and healthcare accessibility (Wah, 2025).

Despite the promising advancements, the widespread adoption of robotics in healthcare faces several challenges, including prohibitive costs, the need for extensive training for healthcare professionals, and ethical considerations surrounding the use of automation and patient safety. Additionally, the integration of robotic systems into existing healthcare frameworks is complicated by regulatory hurdles and the necessity for collaboration among various stakeholders (Reddy, et al., 2023) (Singh & Dhiman, 2025).

8.18 Robotics in Aerospace Manufacturing

Collaborative robots, or cobots, are increasingly recognised by the Aerospace sector for their potential in aerospace manufacturing environments, primarily due to their ability to enhance productivity and flexibility while ensuring worker safety. These robots are designed to collaborate with human operators in shared spaces, eliminating the need for traditional safety barriers that are common in conventional robotic systems. This characteristic allows for more dynamic and adaptable manufacturing processes, which are essential in the aerospace sector where precision and efficiency are critical (Matheson, et al., 2019).

The integration of cobots into aerospace manufacturing can lead to significant improvements in operational efficiency. They can assist in various tasks such as assembly, material handling, and inspection, thereby streamlining workflows and reducing the time required for production cycles. The ability of cobots to perform repetitive tasks allows human workers to focus on more complex and value-added activities, which is particularly beneficial in high-skill environments like aerospace (Taesi, et al., 2023).

Moreover, the deployment of cobots can address ergonomic concerns and reduce mental stress among workers. By taking over physically demanding tasks, cobots can help mitigate the risk of injury and enhance overall workplace safety. This aspect is crucial in aerospace manufacturing, where the physical demands on workers can be significant (Faccio, et al., 2023).

Literature also highlights the importance of intuitive interfaces and user-friendly programming in facilitating the effective use of cobots. Such features enable workers to interact with robots seamlessly, ensuring minimal training and quick adaptation to new systems, which is vital in fast-paced manufacturing settings (Vikram, et al., 2025).

In conclusion, collaborative robots play a crucial role in aerospace manufacturing by enhancing productivity, improving safety, and facilitating greater flexibility in operations. Their integration into the manufacturing process can lead to more efficient workflows and a safer working environment for human operators.

8.19 The jewellery industry's adoption of robotics

The integration of robotics in the Jewellery manufacturing process offers several advantages that enhance efficiency and precision. One significant benefit is the ability to automate complex tasks, which can lead to improved accuracy in production, such as stone setting and polishing. The Cyberman replicator, a programmable manipulator, combines various manufacturing processes such as cutting, grinding, and polishing, allowing for high-accuracy 3d manoeuvrability (Connolly 2009). This capability is particularly valuable in small-batch production, including jewellery manufacture, where precision is crucial due to the cost of materials and their effect on profit margins if it goes wrong and cannot be used commercially. Furthermore, with the reduced numbers of people training and entering the jewellery manufacturing industry, this could provide a solution to the depleting work force.

Moreover, robotics facilitates the implementation of advanced design methodologies. The constructive collaboration between additive manufacturing (AM) technologies and computational design strategies enables the creation of intricate Jewellery designs that would be challenging to achieve manually. A dedicated computational algorithm developed for a bioinspired Jewellery collection demonstrates how robotics can exploit the complexities of shape and function, thereby enhancing the creative possibilities in Jewellery design (Cerrato, Gariboldi et al. 2024). The incorporation of robotics in Jewellery manufacturing not only improves precision and efficiency but also expands the creative potential of designers, contributing to a more innovative and responsive industry.

Additionally, the use of robotics in conjunction with additive manufacturing enables rapid prototyping, significantly reducing the time from design to production. This is particularly relevant in the Jewellery industry, where the ability to iterate on designs quickly can lead to faster market responsiveness and innovation (Rivera, Nuñez Rodriguez et al. 2024). The Input-Transformation-Output (ITO) process, as explored in the context of AM, highlights how robotics can streamline the manufacturing workflow, ensuring that each stage, from design to final product, benefits from enhanced efficiency and quality control (Rivera, Nuñez Rodriguez et al. 2024).

One of the quickest ways to increase the value of a product is to mass-produce it and add simple engraving, personalised gemstones, making the customer feel like they're getting a unique product. Combining this with computer-aided design, CNC machinery, and additive manufacturing can create manufacturing suites that have a higher output of jewellery products while offering consumers a tailored product. (Duan, 2021). We are now seeing it trickle

down to the High Street, with jewellery brands like Monica Venida offering in-store experiences where customers can watch a CNC machine being programmed with their design, which is then immediately engraved on a mass-produced bangle, allowing them

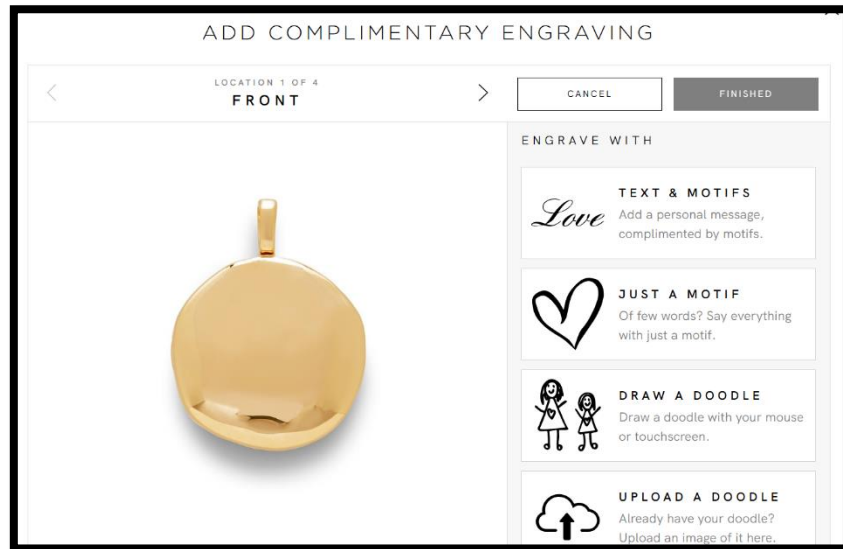


Figure (Monica Vinader, 2025)

to leave within minutes see Figure 3, where you can see the options for personalisation that customers can get immediately in-store while waiting or by uploading to their online store.