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Implementing a Design Thinking Approach to De-Risk the Digitalisation of Manufacturing SMEs

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Abstract: Industry 4.0 (I4.0) has proposed a significant shift in the way companies approach manufacturing. However, this new paradigm is not without faults. The integration of processes and equipment ('digitalisation') can be prohibitively expensive or too technically complex for small-to-medium enterprises (SMEs) with limited resources and technical expertise. Another barrier to digitalisation lies in the ambiguity of not knowing what precise practices to adopt to improve productivity. Although these challenges have been identified in the literature, there is still little evidence on how to tackle them. Thus, we explore how design thinking can help overcome these challenges, given that it has been used in many organisations and disciplines to deal with complex and ambiguous problems. We do so by investigating the research question 'How can designers and design thinking processes assist manufacturing SMEs' digitalisation?' We address this research question by presenting a case study of a university–industry collaboration where the authors utilised a design-thinking process to select and implement technologies to capture, process and analyse data for an Australian medical device manufacturer. By reflecting on the case study, we identified the user-centeredness of design thinking as crucial in selecting technologies for implementation that prioritised usability and brought value to all stakeholders. Furthermore, iterative prototyping was critical to scale up the required expertise and deliver a successful sustainable solution without investing vast resources. Our work suggests that designers and design thinking have the potential to help de-risk digitalisation. Finally, we suggest a framework that may assist in guiding other SMEs approaching digitalisation and provide a starting point for further design thinking research in this area.

Keywords: design thinking; digitalisation; industry 4.0; design; advanced manufacturing; IoT

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1. Introduction

Industry 4.0 (I4.0) is a broad term increasingly used across industries to refer to organisational, social and economic changes that result from the intensive use of digital technologies. It generally implies the adoption of a series of practices that rely heavily on the Internet and other technologies to share and analyse data [1], most notably, the Internet of Things (IoT), cloud computing and artificial intelligence (AI) [2]. I4.0 data-driven processes are touted to enhance productivity and expand supply and value chains in new product development [3]. In manufacturing, I4.0 practices include collecting and sharing data using sensors in interconnected devices and using digital technologies for processing and analysing data to take new actions. This article will refer to the process of adopting such data-capturing and analysis technologies as 'digitalisation'. We argue the importance of digitalisation for manufacturers to change production patterns to become more sustainable-both in terms of physical sustainability through more efficient manufacturing processes, as well as financial sustainability through minimising the number of processes required to produce a product [4].

Despite academics, policymakers and technology suppliers stressing the relevance of digitalisation to increase productivity, many manufacturing companies, notably small-to-medium enterprises (SMEs), often struggle to identify suitable methods to exploit the benefits offered by it [5,6]. One of the critical obstacles for manufacturers to opt for digitalisation is the lack of clarity on how it precisely provides value to the business [7], as productivity is a broad term and every company has different needs. As a result, there is a lagging digitalisation of SMEs compared to large enterprises, which have better access to talent and more resources to invest [8]. This disadvantage may impact the world's productivity and economy, given the crucial role of SMEs in the supply chain and in creating employment [9]. In the Organisation for Economic Co-operation and Development (OECD) countries alone, SMEs represent 99 percent of all businesses, generate around 60 percent of the employment and contribute nearly 60 percent of global Gross Domestic Product (GDP) [10]. Therefore, making digitalisation more approachable to SMEs to improve their productivity could have profound societal and economic benefits.

Studies have reviewed the I4.0 technologies used in manufacturing [1] and provided frameworks to help companies assess their I4.0 maturity [11–13], a significant step to help them understand the requirements to adopt technologies for digitalisation. There are also several recent case studies in the literature on manufacturing digitalisation [14–19]. However, these describe tailor-made solutions that rely on high technical expertise in computer science and programming. Still, studies of accessible, programming-free implementation approaches tailored for manufacturing SMEs are rare [8].

Thus, further exploration of the gap between research (theory) and industry (practice) is required to help facilitate the digitalisation of the manufacturing sector [20]. Case studies help to unpack the contextual conditions that lead to specific approaches and decision-making [21]. As such, case studies with real-world examples focusing on the processes to de-risk digitalisation and make it more approachable for SMEs could provide new frameworks to help them adopt I4.0 technologies [9,21]. In this context, case studies should focus on generating data on how to scale up technical capabilities, focusing on the users of the technologies. There is a need for more emphasis on how to explore and leverage the value of digitalisation when there is low technical expertise and limited resources at hand [8]. How can SMEs, with these limitations, select, implement and maintain the required technologies to achieve increased productivity? Even when the general value of digitalisation is understood, SMEs still face two implementation challenges: (1) what system needs to be designed? And (2) how should this system operate? This type of complex problem, where the general value to be achieved is known (productivity), but it is unclear what needs to be changed (equipment or process) and how it should be changed (working principle), can be tackled using the reasoning behind design thinking. In design reasoning, problems are reframed within a broad situation [22] to unpack achievable goals [23].

This paper aims to explore how a design thinking framework can be used to assist SMEs in approaching digitalisation and will analyse the role designers can play in this process. In this context, design thinking will be considered a set of principles, methods and tools derived from the design discipline relying on creativity, user-centredness and iterative prototyping [24]. Although design thinking has been used to deal with problems in many professional and organisational contexts [22], its use in digitalisation is underexplored. We believe that by exploring design thinking in digitalisation, we can help unveil strategies to deal with ambiguity, and limited technical expertise and resources-significant underexplored barriers that restrain SMEs from digitalising [8].

Using a case study, this work analyses what characteristics of design thinking can help navigate the lack of technical expertise while having the user of the technologies at the centre of decision-making. We use an autoethnographic approach, a research method that considers personal experiences to interpret context and practices [25], to reflect on our implementation of the design thinking process. We chose this method to retrospectively analyse how the approach we took on a digitalisation project helped us navigate challenges identified in the literature. Furthermore, ethnography lets us reflect on the rationale of the project and the role prototypes played in it; described as a benefit in other design studies [25,26]. This study focuses on the research question:

'How can designers and design thinking processes assist manufacturing SMEs' digitalisation?'

First, the literature review explores how some I4.0 technologies are implemented in manufacturing SMEs, the challenges and enablers for their digitalisation and the new roles designers take in this changing industry. Then, the paper explains the context of the case study, its relevance to the field of study, and the design thinking approach taken to execute the collaborative project. After presenting the case study, the authors reflect on their participation in the project to discuss how design thinking practices were used to execute the project at low cost and with low risk and explore the value designers can bring to manufacturing digitalisation. The tools that facilitated the remote collaboration are also described to show the flexibility of the approach. Finally, the paper discusses how the project suggests that designers' user-centredness could play a relevant role in transforming the manufacturing sector and that design-inspired processes could help de-risk the digitalisation of SMEs through iterative prototyping. This work illustrates an explorative approach for engaging in digitalisation rapidly, with low investment and limited technical expertise to be further explored and validated in different industries. We identify iterative prototyping as a crucial element to scale-up technical capability with low resources and suggest it should be further explored in the context of digitalisation.

2. Related Literature

2.1. Implementation of I4.0 Solutions in SMEs

Industry 4.0 practices and solutions essentially involve the optimisation and digitalisation of computer technologies that were implemented toward the end of the 3rd industrial revolution. Digitalisation aims to allow interconnectivity, automation, machine learning, and real-time data collection as techniques to improve product, supply and consumer life cycles. As noted by Matt et al. [27], large companies have rapidly embraced digitalisation and are working intensively on introducing the required technologies. Conversely, they describe that small and medium-sized enterprises (SMEs) face significant hurdles in digitalisation by possessing neither the readily available human nor financial resources [27,28]. In many developed countries, SMEs form the backbone of the economy; they account for the largest share of the gross domestic product and are also significant employers [8,9]. Thus, new concepts, examples and applications of digitalisation in SMEs have to be explicitly provided to pave the way for a successful implementation of I4.0 and increased economic impact. Matt, Modrák and Zsifkovits [27] describe how-over the past 10-year development of I4.0-the primary I4.0 mechanism that SMEs have successfully been able to implement has been to optimise manufacturing processes via a frugal combination of cyber and physical worlds to improve manufacturing outcomes.

Withing the I4.0 landscape, digitalisation is supported by vertical data integration, cloud computing, IoT, big data analysis, advanced automation and robotics, simulation, cyber security, virtual and augmented reality and artificial intelligence [1,7]. With a multitude of options available and limited resources, it is paramount that guidelines and frameworks are developed to help SMEs approach digitalisation [20]. Furthermore, to achieve a tangible impact on the transformation of manufacturing, such frameworks must consider the main challenges SMEs face. For example, a report by the World Economic Forum identified that technology vendors focus on offering services and developing solutions for large manufacturers as such sales are likely to offer more significant returns [9]. As a result, there is a limited offer of data capture and analysis solutions tailored for SMEs, which suggests a need for creativity and resourcefulness to not only adopt these new technologies but also integrate them into business activities that translate the benefit to sales, partnerships, or other returns on investment. Moreover, the OECD found that many SMEs lack managerial awareness of IoT solutions and the value of data-driven decision-making, are incapable of assessing risks in the digital space, and lack specialists with the required technical expertise to manage data collection [8]. With a limited understanding of the benefits of adopting data capture and analysis practices, SMEs fail to perceive a clear return on investment.

Although barriers exist to SMEs' digitalisation, opportunities and enablers for the required transformation exist. After an extensive analysis of manufacturing SMEs in Italy, Ricci et al. [29] found that openness to collaborate with external stakeholders is crucial to digitalisation because external stakeholders can assist companies in recognising and adopting new technologies. Furthermore, as noted by Cotrino, Sebastián and González-Gaya [20], IoT cost has reduced dramatically over the last few years, and the number of available technologies has multiplied. Similarly, cloud computing is a well-established technology with low cost, and virtual reality (VR) is flexible and can now be readily implemented in many production processes [20]. For example, there are support models with case studies implementing VR technologies to design assembly systems [30] and assistive technologies to improve productivity [31].

Furthermore, SMEs have historically demonstrated an ability to innovate and implement novel solutions via their simple organisational structures and small size. This characteristic typically allows them to react faster to market, technological and environmental changes [9]. Therefore, research should focus on developing flexible approaches for reducing digitalisation's financial risk. Veneri and Capasso [32] predict that the IoT era will undergo continuous shifts and evolution. Given this expected rapid change, we believe that to reduce financial risks, SMEs should leverage IoT by continuously improving infrastructure, skills and technologies instead of incurring one-time, large-scale transformations.

Although the aforementioned challenges and enablers are common in SMEs, companies might face different hurdles depending on their existing technologies, production processes and people [12]. Thus, another essential aspect of approaching digitalisation is understanding how to assess I4.0 readiness and maturity. Using I4.0 maturity models allows companies to conduct a self-assessment of areas they need to tackle to position themselves better to implement I4.0 technologies [13]. Amaral and Peças [12] thoroughly review different frameworks to assess manufacturing I4.0 maturity and propose a method that explicitly targets SMEs. Thus, there is a great benefit for SMEs to explore these tools when defining digitalisation strategies, which should focus on adopting technologies to strengthen competitive advantages and improve internal weaknesses [33].

Moreover, existing works that focus on processes to assist digitalisation of manufacturing companies have taken different approaches and leave room for further exploration. On the one hand, Stoldt et al. [34] have proposed a framework to approach digitalisation that focuses on detecting and addressing production inefficiencies to improve productivity. However, their framework focuses on technical aspects and ignores critical human factors that affect how technologies are used. For example, as previously explained, the lack of talent to operate and maintain complex systems is a significant barrier to SMEs' digitalisation. Similarly, Abdulnour et al. [35] present an approach for SMEs to adopt technologies to increase productivity using simulation and mathematical models. Still, many SMEs lack the expertise required to adopt such solutions. On the other hand, Sampayo and Peças [36] propose a comprehensive framework for designing and developing cyber-physical systems, but its design is not explicitly intended for the needs of SMEs. Nevertheless, although not much attention has been given to usability factors, these frameworks have an aspect that we believe is crucial for de-risking SMEs digitalisation, using strategic planning to recognise opportunities and prototyping to reduce risk. This is supported by Ramadan et al. [33], showing that the successful implementation of I4.0 practices is tied to internal organisational forces and strategy.

2.2. The Role of Designers in I4.0

I4.0 research usually focuses on manufacturing and supply chain processes, but little attention has been paid to how the products are designed within this new manufacturing paradigm [37]. However, as Kuys, Koch and Renda [37] explain, manufacturing and supply chain fundamentally exist to support the creation of products purchased and used by an end customer. Thus, it is critical to understand how designers adapt to the technologies that I4.0 encompasses. García Ferrari [38] states that designers must adjust to the amalgamation of the physical, biological and digital spheres that digitalisation brings. As he explains, the interconnectivity through the Internet and other technologies will enable the creation of different products and services; thus, although designers face challenges, there are also opportunities to transform the design practice.

Most literature regarding the transformation of design remains explorative. For example, Franzato [39] states that digitalisation is changing how products are produced and consumed and argues that with new tools and practices, such as open designs on the Internet, design is becoming a creative network where everyone can contribute. The changes in how products are made and consumed, and the changes in the disciplines involved in such processes, also suggest that design roles could vary depending on which area of I4.0 design interacts with. On the one hand, collaborative robotics and additive manufacturing for making products are relevant areas of increased importance in digitalisation [40]. On the other hand, the computerisation of objects in the IoT also brings opportunities for designers [40].

What Cross [41] discussed more than four decades ago still applies:

"Design is changing; its products and processes are changing, so too is the role demanded of the designer".

For example, years after Cross' statement, the accessibility to computers enabled 3D modelling and tactile-screen technologies allowed digital sketching. These design tools are now embedded in design education and practice and are considered standards [42]. The same may occur now; new technologies change manufacturing and supply chains, so the tools and role of design will likely change. However, designers' exact roles in I4.0 are still undefined as the digitalisation of manufacturing is still in its infancy.

Although much is unknown, a recent study by Kuys, Koch and Renda [37] that surveyed 190 product/industrial design practitioners worldwide suggests tools and activities that may become general practice in design in the I4.0 era. For example, they said, VR and augmented reality facilitate designers' and users' interaction with objects in the digital space, merging it with the physical. This could speed up the design process and facilitate 3D modelling. Furthermore, topology optimisation tools, which use software to refine designs for additive manufacturing, could become widespread [37]. These technologies and the accessibility to 3D printing equipment at low prices may allow designers to manufacture products themselves and reach the end customers directly [37], thus, changing the traditional relationship of designers with engineering and manufacturing facilities. The elimination of traditional stakeholders usually involved in commercialising a product towards a new paradigm of blended design and technological processes could lead to a market transformation. However, this new designer-customer process may only represent a portion of the market and apply to certain products. Is there room for designers to bring value to large-scale manufacturing processes within the factory of the future? We believe there is an opportunity to exploit designers' creativity, user-centredness and visualisation skills in this context. Furthermore, design processes can bring value to the manufacturing transformation. Design thinking processes, for example, rely on re-phrasing problems, prototyping and visualisation techniques to rapidly evaluate solutions for innovation, having human needs as the foundation of the approach [43]. Such flexibility to solve complex problems could be leveraged when analysing how to adopt new technologies, using prototypes and evaluation tools that consider the benefits digitalisation will bring to all stakeholders.

2.3. Design Practice as Research

If we look at design as a process that is influenced by designers' skills and societal, environmental, historical and technological factors, we can assert that the design practice generates knowledge; it involves tacit knowledge and explicit knowledge to produce insights that inform decisions. As can be seen in the following case study, some design professions try to articulate design thinking and design activity to bring tacit knowledge to explicit knowledge. However, it is still ambiguous to distinguish the work of research from the work of practice because not only design knowledge grows partly from design practice, but also design knowledge and design research overlap [44]. From this standpoint, Friedman claims that design practice is one of the foundations of design knowledge. Design knowledge can be viewed in many aspects, and practice is one form [44]. Eisenbart et al. [45] expand on this, stating that the focus should be on applying design thinking practically in technology-focused organisations (p. 15). This is an important aspect within modern design thinking literature showing practical applications in the modern era of manufacturing (I4.0). Our case provides one unit of study to help other organisations better understand the key stages of a design thinking approach and how practical solutions were delivered to transform an SME into areas of I4.0 that were challenging without design intervention.

3. Method Development and Case Study

An example of the role designers and design thinking can play in digitalisation is presented through a case study of a project executed by the authors. The case study allows an in-depth and contextualised analysis [46,47] to explain how design thinking influenced our digitalisation approach. The case study is described by reviewing documentation, reports and prototypes. Then, these are analysed using autoethnography; we reflect on the project to provide a detailed description of the rationale and decision-making behind the activities conducted. We have selected a case from a recent university-industry collaboration so that other researchers can relate to and use this research as an exemplar study for their own work. We did so because we faced the same SMEs' digitalisation challenges identified in the literature review. These challenges were overcome using design thinking and delivered valuable outcomes for Australian manufacturing SMEs'. Through this work, we aim to explore what specific aspects of design thinking allowed us to do so, as this area of research lacks depth in the literature and could unveil strategies to accelerate SMEs' digitalisation.

The digitalisation of Australian manufacturing is a relevant exemple to learn from for other countries who are experiencing a growing need for manufacturing SMEs to embrace design thinking to achieve innovation and compete sustainably with offshore production. In Australia, SMEs account for 97 percent of businesses by employee size [48] and the manufacturing sector has struggled to replace lost manufacturing revenue from cheaper labour markets. As a result, the Australian manufacturing sector is experiencing an industry revenue decline, at an annualised 0.5 percent over the five years through 2017–2021, to $165 billion [48,49]. Thus, in order to stimulate innovation and compete sustainably with offshore production, the manufacturing industry has to develop and embrace digitalisation. This might relieve the strain of cheaper manufacturing markets.

3.1. Case Study Context

The university-industry collaboration took place in Australia between a Sydney-based MedTech SME and two design researchers based in Melbourne. It occurred during intermittent, limited travelling periods in response to the COVID19 pandemic. Eudaemon Technologies Pty Ltd. (referred to herein as Eudaemon), the industry partner, is an early stage company with nine employees that combines material science expertise with advanced manufacturing to develop next-generation medical devices and equipment [50]. Eudaemon required a dashboard to visualise existing production data from their manufacturing processes to assist in experimentation and quality control. Because I4.0 encompasses so many technologies, Eudaemon wanted experts to help them select the best digitalisation strategy before talking to specific technology vendors that would lock them into their solutions. Thus, Eudaemon had previously tried to engage with universities to digitalise their processes. Still, the efforts did not offer clear guidance into practical solutions, mainly due to the communication barriers with academics in the field and the lack of alignment with the company's interests. This type of communication challenge is not a surprise, as it is a common barrier to university-industry collaborations [51], among other researchers' practical skills and incentive-related impediments [52,53].

The collaboration was established through the Australian Postgraduate Research (APR) intern program. This program allows companies to have doctoral candidates working on six-month projects. Unlike other university-industry collaborations, the companies define the project goals and structure, so there is more emphasis on practical deliverables. Due to Eudaemon's previous exposure to design thinking and academic research, they were open to this approach to help define the requirements for their digitalisation process. The six-month APR intern project started in February 2021 with the primary goal of identifying how I4.0 technologies and practices could enhance Eudaemon's advanced manufacturing capabilities. When the collaboration was planned, Eudaemon had a data management system where production and quality control data were recorded manually (on a tablet device) based on sensors' measurements and visual inspection. Then, that data was submitted to a cloud-based application (stored in remote data centres and accessed through the Internet) and exported weekly into Excel spreadsheets for manual analysis. The manual analysis also required the inspection of PDF files that contained pictures of the products to infer trends in quality control. This process influenced research and development practices, experimental design, and production quality and enabled translation in Medical Device Design ISO 13485. However, due to limitations from COVID-19 (inability to travel due to restrictions), Eudaemon required a more robust data collection and tracking process to manage physical production in Sydney virtually. Although Eudaemon possessed highly automated manufacturing facilities with low labour dependency, the data collection and processing were exhausting human-dependent processes. In other words, the facilities had IoT-capable equipment, but its full potential was not exploited.

Therefore, the project was initially set to identify commercial tools for creating dashboards and virtual twins, which required connecting Eudaemon's equipment to the Internet to allow real-time visualisation of manufacturing data and assist in its analysis. Such connectivity was expected to simplify data analysis and enable remote control and supervision of the manufacturing processes. Once the capabilities of the IoT platforms were understood and tested, the following objective was to identify how these capabilities could be leveraged to adapt Eudaemon's manufacturing process to other projects and products.

The general objectives of the project can be summarised as follows:

- To review the existing I4.0 landscape (applicable software packages and solutions).
- To define a design brief with componentry and systems required to create a digital dashboard of the manufacturing process.
- To refine the inputs required for the dashboard and associated prototypes with product design specifications.
- To list all the inputs required to create a dashboard, define more discrete componentry, and identify suitable software stack options.

The time allocation and contact points were as follows. The intern worked full-time on the project and met the academic supervisor weekly to review the project progress. These meetings were mainly conducted face-to-face for the first half of the project until strict isolation was required in Melbourne. Concurrently, the intern, the academic supervisor, and Eudaemon's CEO and CTO met online to review the project every two weeks. The industry partners were based in Sydney, and the researchers in Melbourne, so the meetings used platforms such as Microsoft Teams and Google Meet. The meetings included Powerpoint presentations, written reports, images, and screen-sharing tools to show some of the analysed I4.0 software packages and the demonstrations with Eudaemon's data. Furthermore, frequent contact was maintained by the collaborators via email, usually between the intern and the CTO, who shared access to Eudaemon's manufacturing information, facilities' 3D models and machine documentation. Furthermore, the intern was granted access to Eudaemon's existing data collection software so he could analyse integration with the reviewed I4.0 software packages.

3.2. Design Thinking Approach

As the project required the creation of solutions in the digital space, the team decided to use a design thinking framework instead of more structured design methodologies such as Ulrich's and Eppinger's product development process, intended to support the development of physical, discrete products [54], p.2. Design thinking comprises a set of principles and tools for creative problem-solving that relies on user-centredness, ideation and prototyping [24]. Due to the team's initial lack of technical expertise in IoT, it was appropriate to use iterative prototyping, a trial-and-error learning process that generates knowledge through failure [24]. The design thinking framework selected, known as the Double Diamond, comprises four main phases than involve convergent and divergent thinking; Discover, Define, Develop and Deliver [55]. These phases were adapted to the project goals, as shown in Figure 1.

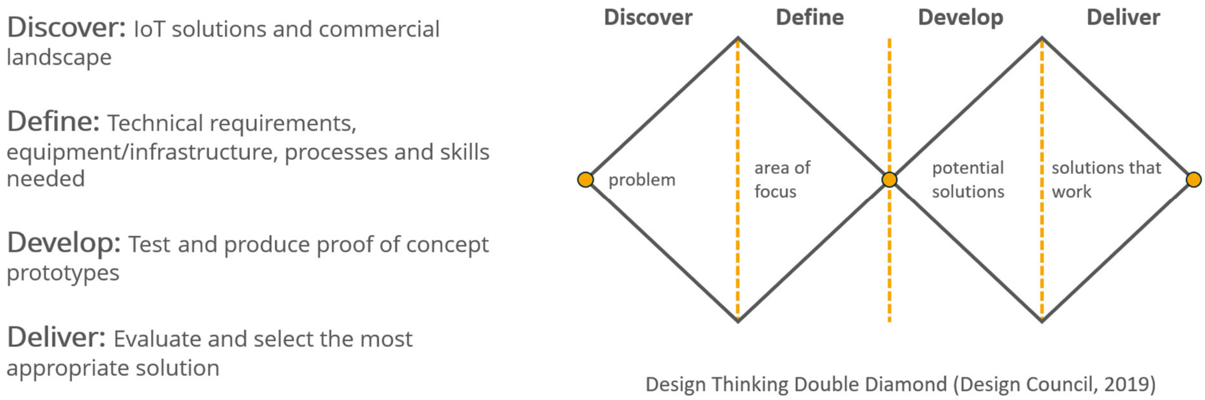

Figure 1. Design thinking approach used in the case study adapted from Design Council [55].

3.3. Discover

The early months of the project were used to understand the problem, which required an analysis of Eudaemon's existing data collection practices and how different stakeholders were involved in the process. Furthermore, the designer reviewed Eudaemon's manufacturing equipment (using videos and 3D models), the project goals and the existing solutions available in the market. The work in this phase, which aimed to explore opportunities in the I4.0 landscape, included consultations with experts at the University and contacting local technology vendors to analyse integration possibilities with Eudaemon's technologies.

3.4. Define

With the I4.0 landscape understood, a list of integration requirements was defined for some of the most relevant IoT platforms. Furthermore, selection criteria were defined, including the technical skills required for their use, componentry, the available technical support, flexibility for creating dashboards, local representation and implementation cost. With these criteria, some IoT platforms were screened.

3.5. Develop

Ideation was used to explore how to test selected IoT platforms remotely and with low resources. Prototypes were developed and tested using multiple sensors from portable devices and cellphones to send data into databases. The data generated was then visualised into dashboards on different IoT platforms, recreating the needs of Eudaemon. With this test, the team could analyse the complexity and features of each solution with simulated data. Finally, several proof-of-concept prototypes were developed and shown to the team.

3.6. Deliver

The team analysed the different proof-of-concept prototypes and criteria used in the 'Define' phase. The platform most suitable for Eudaemon's existing infrastructure was selected, and several prototypes were developed following incremental improvements. Once the pilot test showed promising results, the platform was fully integrated into Eudaemon's data capture and analysis process.

4. Results and Findings

This section describes the results of each of the design thinking phases listed in the previous section. After all design phases are covered, the results are discussed in relation to the research question and existing literature, exploring how design thinking contributed to the project and the role of the designers in the team.

4.1. Discover Phase

This phase, which required an analysis of the I4.0 landscape and a better understanding of the problem, took the team approximately four weeks and focused on using divergent thinking to identify several opportunities to improve existing practices. First, the intern was shown videos of Eudaemon's manufacturing process, and the whole data collection protocol was reviewed. The designer was invited to weekly data analysis meetings to identify the operators' issues when collecting data and the production managers' issues when reviewing it. Furthermore, the team analysed the different variables that affected production quality. It was identified that the more data was collected, the harder it became to compare production runs and make insightful decisions. The issue would only worsen with the existing practices as production scaled up. In parallel, the intern conducted market research. They searched for local technology service providers and IoT software to capture real-time data from multiple devices and visualise it in customised dashboards. A summary of the I4.0 landscape explored by the designer is illustrated in Figure 2.

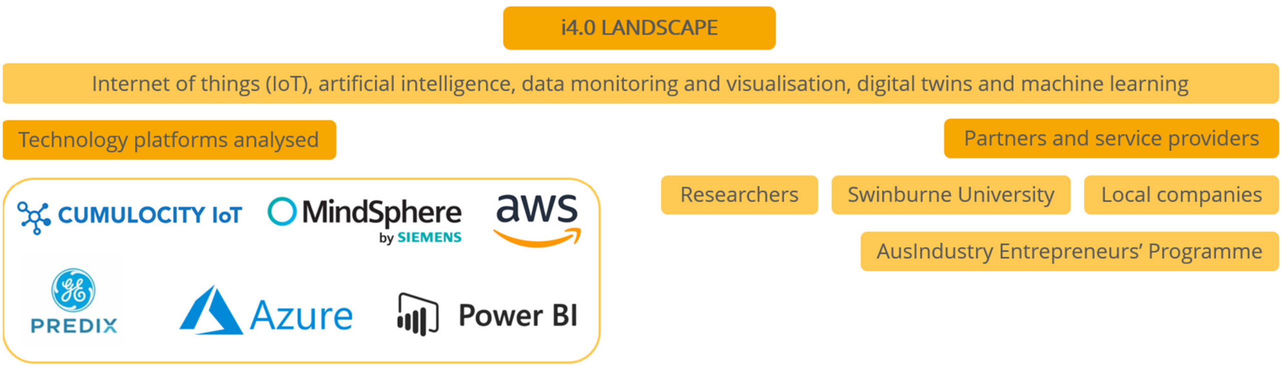

Figure 2. Industry 4.0 landscape explored by the designer.

Thirteen companies that offered IoT solutions were identified, but only the ones shown in Figure 2 offered enough information online to assess the compatibility with Eudaemon's goals. AWS was found to be similar to Azure, having over 300 different products that could be used according to the customer's particular needs. However, such flexibility and a broad offering had two downsides; it was difficult to know which products were needed, and the operation of these platforms required substantial training and skills in information technology, such as programming. In contrast, Mindsphere and Cumulocity IoT were described as industrial IoT services tailored to support the manufacturing industry and easier to use than those mentioned earlier. Predix did not have extensive information and support online; no case studies of it being applied in small manufacturing companies were found in the intern's research. Thus, it was not further explored. Finally, Microsoft Power BI had many examples of importing, editing and visualising information from databases, but it was not explicitly identified as an IoT platform. Thus, it required testing with Eudaemon's data and systems.

4.2. Define Phase

The Define phase of the design thinking double diamond framework represented convergent thinking. It included the selection process used for determining which platforms would be suitable for creating proof-of-concept prototypes. After the initial assessment described in the previous Discover phase was complete, the team selected different platforms for prototyping and testing. The selection was as follows:

- Between Microsoft Azure and AWS, AWS was selected for testing because it offered credit and technical assistance to the researchers and had hardware more readily available. Prototyping IoT devices could be purchased off-the-shelf at a low cost to explore the platform's different functions.
- Between Cumulocity IoT and Siemens Mindsphere, Cumulocity IoT was chosen because it offered a potentially more user-friendly interface without the need for training, as it claimed to be a coding-free service tailored to assist the digitalisation of manufacturing companies. Furthermore, Cumulocity IoT also offered tutorials to connect multiple smartphone sensors to test the platform's features and good customer support. Finally, as Siemens manufactures hardware, the team assumed Mindsphere had limited flexibility because the service could be tailored for Siemens products.
- Power BI was chosen for testing because-even though it was not specifically an IoT platform-it had compatibility with many database services that potentially included Eudaemon's existing software for collecting data. Furthermore, it had significant online tutorials, its visualisation tools were flexible, and its implementation cost was low. Furthermore, its operation seemed similar to other Microsoft products like Excel. Thus, the team could familiarise easier with the interface.

4.3. Develop Phase

The Develop phase of this project required divergent thinking to prototype multiple concept solutions. The team tested the three platforms selected in the Define phase that ranged in integration complexity and created interactive dashboards using data from sensors that emulated Eudaemon's production equipment. These tests aimed to further assess each platform's ease of operation, flexibility, visualisation features, skill requirements, and implementation costs. These criteria selected by the team gave particular importance to maximising the meaningfulness of the solution to the users, aligned with the user-centredness of the design thinking approach [24].

As explained by Crismond and Adams [56], trained designers delay decision-making until they explore multiple possible solutions in greater detail. Thus, three very different IoT software were explored to identify the best alignment with Eudaemon's needs. With such proof-of-concept prototypes, the team could define the most suitable one to integrate into Eudaemon's manufacturing and data management process, considering operability and cost. Although the designers were not familiar with this type of digital technology, their approach was similar to when designing a physical product; low-resolution prototypes were planned to explore the viability of the concepts as designers traditionally do through sketching and 3D modelling [57,58]. Such an approach allowed agile testing with low resources, and iterative changes were made until the prototypes could be compared. The prototypes developed were:

- Prototype using AWS: Amazon Web Services offers a learning experience for new users called IoT EduKit. There are tutorials for using a minicomputer device called M5Stack Core2 to train users to build IoT applications. The prototype developed by the intern allowed using several sensors in the device to collect data such as temperature and noise and publish it online in real-time through the Internet, to emulate some of the data-capturing needs of Eudaemon. The simple application developed also allowed controlling the device remotely to do simple tasks such as turning on a fan or changing the colour of a LED. More advanced tests allowed the device to perform tasks with logic represented in codes. However, the creation of these applications relied heavily on coding and, without programming skills, required substantial time investment to execute simple tasks.

- Prototype using Cumulocity IoT: This platform was used to connect a smartphone as an IoT device by following some tutorials provided on their website. The connection allowed testing all the platform's features, such as creating simple dashboards, using widgets, setting up alarms if specific values were identified and visualising multiple data entries over time. Furthermore, historical data from the sensors could be stored and compared to get insights. The platform was user-friendly, and once the device was connected, no coding was required to complete most functions. However, the team determined that connecting every sensor in Eudaemon's manufacturing facility would require substantial technical assistance and take too long. Moreover, the system would not be compatible with Eudaemon's existing data collection practices, so a whole data management process, with extra hardware, would have to be set up to exploit this platform's data analysis capabilities.
- Prototype using Microsoft Power BI: This prototype was created using historical data from Eudaemon's production. The data was uploaded into Power BI to create dashboards to test the software's capabilities and compatibility options. The team found that Power BI could automatically retrieve data from cloud-based databases and refresh the dashboards to provide real-time information. Furthermore, the data could be filtered, edited and rearranged with high flexibility and easily visualised in interactive dashboards. Surprisingly, all these functions were included in Eudaemon's Microsoft business account, so there was an excellent benefit for no extra cost. Additionally, the platform was user-friendly for the numerous features for processing and visualising data. The platform had many interface similarities with Excel. So, given that Eudaemon employees were already using Excel, it would be simpler to learn to operate compared to other platforms. Furthermore, this software could be integrated with other Microsoft applications, which would allow scaling up the solution as Eudaemon scaled up its manufacturing capabilities.

4.4. Deliver Phase

By analysing the three different proof-of-concept prototypes, it was clear that Power BI was the most resource and time-efficient way to improve Eudaemon's data capture, visualisation and analysis. Furthermore, the tests showed that it could offer substantial benefits compared to Eudaemon's data management process without requiring programming skills. Following this evaluation, the researcher conducted multiple tests and produced various dashboards to suit the different user needs, considering the production managers and the machine operators. Then, through an iterative process, these dashboards were improved with the users' feedback.

The information analysed in the initial dashboards served to inform changes and improvements to the production process in semi-real time. However, this iteration required some user intervention to populate, refine and import the databases, so more work was required to fully automate the process. Thus, the research team determined that the remaining internship time (about three months) would be used to improve Eudaemon's data-capturing processes and management and identify the best way to automate the visualisation of real-time data.

The Power BI automated process was achieved before the end of the project, visualised in dashboards, as shown in Figure 3. The data followed this sequence: first, the operators monitored the production and filled forms on a device based on the sensors and machine values. Numerical limits were set up in the forms to mitigate data entry errors. Second, the data was submitted to a cloud-based database. Third, Power BI automatically imported, processed and transformed the data using formulas, which did not require high technical skills to be developed. This information could then be analysed using an artificial intelligence algorithm offered in the software that used statistical analysis to find correlations between variables. Therefore, the solution installed offered a real-time visualisation of each production run data and allowed a simple, flexible analysis, with the possibility to compare and analyse all the data ever captured. As a result, this solution allowed for comparing production batches and identifying which parameters influenced product quality. Similarly, large databases could be easily analysed by applying several data filters.

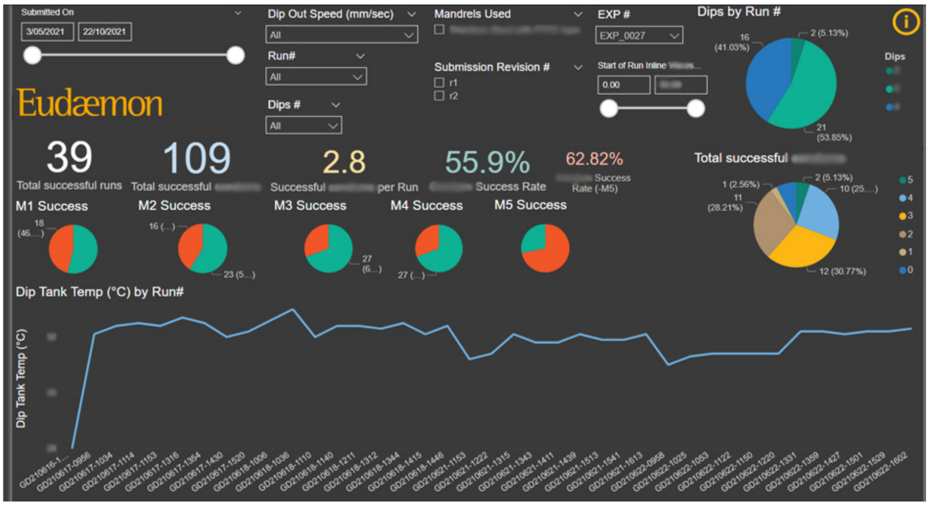

Figure 3. An example of a Power BI dashboard created for experimental production with the ability to populate specific production data, i.e., temperature, run number, success rates, etc., as it is generated in semi-real-time.

5. Discussion

5.1. Navigating the Barriers to SMEs Digitalisation

The digitalisation solution presented in this case study involved the creation of multiple dashboards to monitor and analyse the manufacturing variables that affect Eudaemon's production (i.e., temperature, humidity, cycle time, output volumes, viscosity, machine speed, etc.), drastically improving productivity. The main benefits and features of the solution are:

- High usability for easily comparing variables to find correlations, identify production bottlenecks and enable predictive maintenance, improving productivity and product quality.
- Flexible reporting with controlled security access to tailor information outputs for operators or managers.
- Automatic data transformation and real-time visualisation for quick analysis eliminate multiple time-consuming steps of Eudaemon's initial data-management process.
- Reduction of labour-intensive tasks and mitigation of data entry errors.
- Remote access through the Internet to all manufacturing data–facilitates supervision and aligns with the company's growth objectives of having production facilities in different parts of the world.
- Ease of use, flexibility and simple maintenance–does not require high technical skills like coding, matching the skillset of Eudaemon's employees.
- Simple integration with the company's existing software subscriptions with no extra implementation or management cost.
- COVID-19 resiliant, it allowed Eudaemon to keep R&D progressing even when key personnel were in lockdown.

In this discussion, we will reflect on the study described above and our participation to identify which aspects of design thinking assisted the digitalisation of Eudaemon's processes. We believe that the design thinking approach mitigated the lack of technical knowledge and awareness of the I4.0 landscape, a barrier to the digitalisation of SMEs [8] overlooked in other frameworks [34,36]. This was achieved in the following ways. First, the Discover phase allowed the team to analyse the problems in Eudaemon's existing practices, how they affected different users and the opportunities to improve. After exploring the I4.0 landscape in this phase, it was easier for the team to define Key Performance Indicators (KPIs) that required improvement. Hence, this phase allowed the definition of clear, achievable digitalisation goals that would provide immediate tangible use cases. Second, the human-centredness of the design thinking process and the iterative prototyping led to the selection of a solution that outperformed previous practices, and that can be managed and improved without high technical skills. That rationale influenced the whole process. For example, instead of focusing on collecting and processing more data in real time, the problem was phrased as how to simplify the data collection and analysis process for operators and managers. Thus, the selection process looked at how the tools were used, not only the tools' technical features. This prioritisation of usable tools allowed Eudaemon employees to understand and engage with the selected technologies without requiring high technical expertise in machine control.

We encountered the same digitalisation challenge of limited product offer tailored for SMEs identified by the World Economic Forum [9]. Most known I4.0 platforms we found tried to emphasise on their websites their flexibility and large product offer to many needs in many sectors, which made it very difficult to understand how they could solve Eudaemon's problems. Those one-fits-all solutions may be attractive for large corporations looking for a single supplier to facilitate a significant I4.0 transformation with large investments. Still, such solutions discourage SMEs with tighter budgets [28]. However, aligned with Cotrino, Sebastián and González-Gaya [20] comments, we also found some emerging IoT platforms tailored to the needs of manufacturing SMEs. Interestingly, the software selected in the case study was not even advertised as an IoT platform, and the company already had access to it.

Most importantly, the design thinking approach allowed the implementation of our solutions quickly and with minimal resources, mitigating the challenge of lack of financial support for digitalisation [28]. This finding supports that design-inspired processes help strategically plan digitalisation before constructing and implementing complex systems [36]. Furthermore, Eudaemon's approach to setting up the project through the APR Intern program enabled reducing the project's cost and a structured, focused process to complete the project and deliver outcomes, which were reviewed as part of the program.

With its divergent and convergent thinking, the design thinking process allowed for considering many possible solutions in a short time. It encouraged quick evaluation based on the defined project criteria. Perhaps non-design, traditional approaches would have led to prototyping only the solution that looked most suitable at the start of the project. However, exploring different concepts in parallel until later stages allowed developing knowledge for better-informed choices [56]. For example, three proof-of-concept/minimum viable prototypes were created before choosing an IoT platform for Eudaemon. These prototypes were explicitly designed to be simple and cost-effective, and the iterative process enabled learning through trial and error, a fundamental principle of design thinking [24] that can assist SMEs in scaling up technical skills. Initially, other more popular platforms looked suitable for the project, but prototyping and testing showed that their implementation would have cost the company substantial time and resources; thus, it can be said that this approach de-risked digitalisation.

In this project, the design thinking approach guided decision-making at different stages, prioritising usability and simplicity and considering machine operators, production managers and executives. Furthermore, the design skills of the research team allowed the creation of dashboards that communicated complex information simply, which facilitated data analysis. Perhaps these preferences led to selecting a platform with more tools for visualisation that required less coding, something that could be attractive for many manufacturing companies lacking technical capabilities [28]. Instead of attempting to implement a single-time and costly process transformation, the project strategically managed resources to target the problems identified in the Discover phase by opting for small incremental changes. The knowledge obtained during the iterative prototyping process using different platforms allowed the team to create a strategic roadmap for scaling up digitalisation in the short and long terms.

5.2. A Framework to Explore Design Thinking to De-Risking SME Digitalisation

As identified by Cotrino, Sebastián and González-Gaya [20], although multiple roadmaps for deploying I4.0 technologies exist, few make distinctions between large corporations and SMEs [34]. As we have explained in this paper, SMEs face different digitalisation challenges, so more tools are needed to facilitate their technological transition. Although step-by-step frameworks have been proposed for the fourth industrial revolution for SMEs [20,34], we believe there is room to address critical barriers to SMEs' adoption of these technologies; lack of technical expertise and unclear returns on investments. Thus, by reflecting on the approach presented in this case study, we propose an alternative framework for digitalisation that integrates design thinking (see Figure 4) to continue exploring and validating design processes' relevance to SMEs digitalisation.

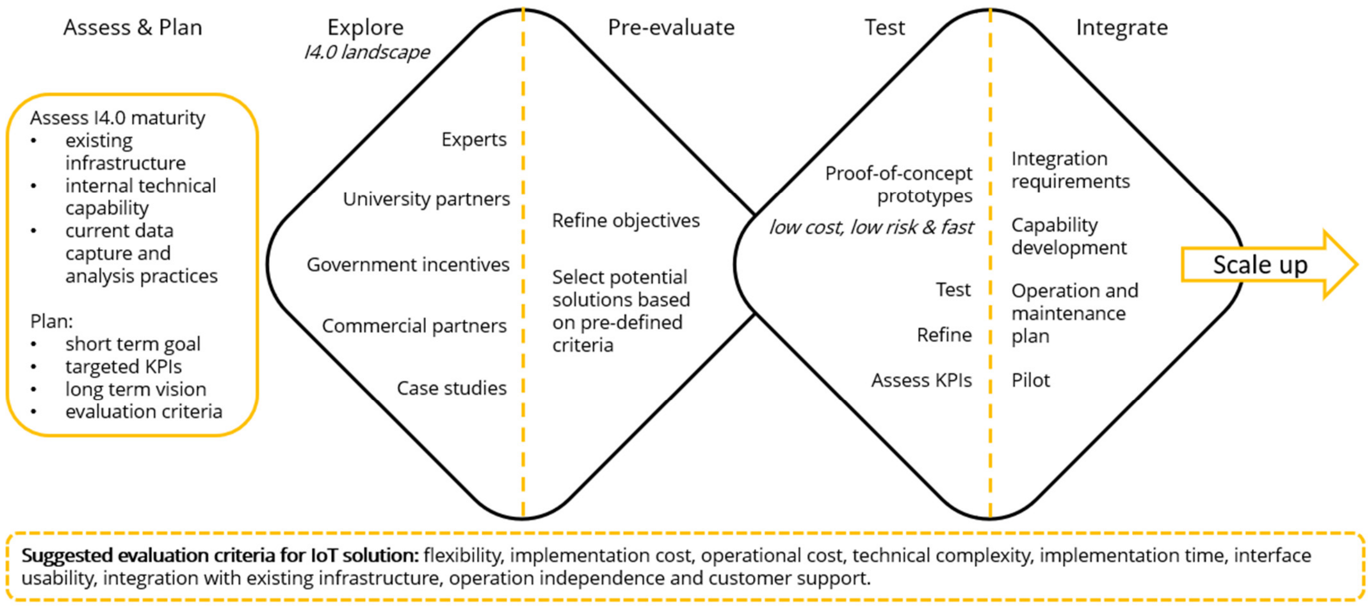

Figure 4. Framework for de-risking SMEs' digitalisation.

The framework includes the following phases:

Assess & Plan: the process starts by identifying the company's existing capabilities around I4.0 technologies; for digitalisation, specifically data management and analysis capabilities. I4.0 maturity assessment frameworks have shown to be successful for this purpose [11–13]. This assessment includes the company's technical capability, software and infrastructure. This phase can be assisted by asking: What data are we collecting? How are we collecting that data? Why are we collecting that data? We suggest emphasising the 'how' to determine usability issues and pain points and the 'why' for strategic thinking. Then, initial goals should be defined to improve key performance indicators and a long-term vision of the company to help define a strategy based on the current position in the I4.0 era [12]. Note that these goals and success criteria can change as the company develops expertise and tests different tools, so there needs to be room for reassessment in every phase.

Explore: after an initial assessment and planning, we propose exploring the I4.0 landscape. The scope of this search may depend on the initial goals and the company's initial knowledge. However, in this phase, divergent thinking is critical to explore as many potential solutions as possible. The exploration can include identifying experts that could assist with consultancy services, universities with programs to assist companies in adopting new manufacturing technologies, existing government incentives and potential commercial partners. We suggest looking outwards to explore opportunities to complement expertise, as collaboration with external stakeholders has shown to be a success factor in I4.0 implementation [29]. In addition, it is essential to identify how other manufacturing companies are leveraging digitalisation. Case studies like the one reported in this study are a good source of information. Furthermore, we suggest identifying different IoT platforms and collecting comparable information about them, for example, their costing model, available support, compatibility, ease of use, technical requirements, etc.

Pre-evaluate: once there is a better understanding of the possible return on the investment of different IoT solutions, there should be an initial screening to select the most appealing alternatives. This initial evaluation should be made with criteria defined at the start of the project and refined during the Explore phase. Furthermore, we recommend inviting key staff to assist with the evaluation. The weighted objective matrix is a suitable method that allows collaborative concept selection [54], p.154, and similar approaches have been used to evaluate cyber-physical systems [36]. We suggest some evaluation criteria in Figure 4, but companies will have different needs and priorities according to their I4.0 maturity assessments and defined strategies.

Test: design proof-of-concept prototypes for the potential solutions that allow assessing the criteria more precisely but in the simplest and quickest possible way. The test must allow for analysing the feasibility and complexity of the solution without disrupting existing processes. We also recommend testing multiple solutions and embracing iterative prototyping; failure can be used to generate knowledge. A small subset of the information is advisable to be processed to limit resources and complexity before expanding once functional options are developed. Then, select the solution that best fits the defined criteria and KPIs.

Integrate: define all the technical requirements needed for integrating the solution into the existing manufacturing process. Plan and execute a pilot test and analyse the results. If the results are promising, deploy and scale up the solution to make it fully operational. If not, go back to previous phases depending on the results.

Although the process may assist the implementation of other I4.0 technologies, it is initially intended to implement IoT solutions which delimited the case study. Because I4.0 includes so many technologies beneficial for manufacturing [1], more work is required to assess the success of the proposed framework in other contexts. This work was explorative to promote further research in an area underexplored by literature. Therefore, we recommend using the framework flexibly to validate the benefits of design thinking in digitalisation.

We want to stress the point that to de-risk digitalisation, SMEs should embrace it as a continuous improvement of practices, skills and infrastructure. Perhaps a solution like the one in this case study, where operators are still involved in data capturing, is considered limited for large manufacturing companies that could invest vast resources in a fully automated solution. However, the solution implemented brought substantial benefits to the company at a low cost. Human interfaces during data capture also allow for refinement of essential data to be captured as a function of available time versus manufacturing task productivity reductions. As the project was approached with strategic decision-making, the implemented solution can be increasingly improved with more automation as the company grows. Furthermore, creating a digitalisation roadmap gives the company more achievable long-term goals. We believe this practical approach can assist other SMEs that want to engage the benefits of I4.0 but do not have the resources to replace their equipment or the technical expertise to implement expensive and complex coding-dependant solutions. However, more research needs to be conducted to understand the applicability of our proposed approach.

5.3. Designers' Opportunities in Advanced Manufacturing

The case study showed that although the project required the implementation of digital solutions in an area previously unexplored by the design intern, their design skills were particularly relevant in different aspects of the project. For example, exploring multiple solutions to a problem and designing prototypes as 'minimum viable products' facilitated informed decision-making at different stages. As Crismond and Adams [56], p.748, explain, designers use multiple representations to investigate design ideas and generate more profound insights into how systems work. Thus, we believe there is an opportunity for designers to help manufacturers adopt new technologies, as their ability to explore and communicate ideas through different means can help translate complex information in multidisciplinary teams [59]. Furthermore, regardless of the field, designers have shown to be good at exploring opportunities to innovate using emerging technologies [60] and demonstrating their potential [61]. Moreover, the designers' knowledge of manufacturing processes and materials allowed them to fully understand Eudaemon's needs even without visiting their facilities. This knowledge also helped the intern suggest solutions focused on improving product quality and usability, as they are distinctive aspects of focus in product design. These aspects turned out to be crucial for selecting a solution that required low technical expertise, had an easy-to-use user interface, and brought benefits to all Eudaemon's staff members, from data collection to data analysis and reporting. This supports research from Eldem, Kluczek and Bagiński [43], where improving digitalisation of information and data sharing was a key finding to stabilise and improve productivity for global manufacturing companies. It is noted, however, that there is room for design practitioners and researchers to explore how the discipline can bring added value in this area. Nevertheless, this case study suggests that designers could play a critical role in solving complex problems that the I4.0 transformation will bring, not exclusively related to product design, as Celaschi [22] predicted. Furthermore, we believe there is room for IoT training in design education, as data will be critical in multiple aspects of product design, such as idea exploration, manufacturing and collecting user data for product refinement.

5.4. Practical Implications

In practice, the case study and the framework proposed can be used by manufacturing SMEs as a guide for adopting new technologies for which they do not have enough technical expertise. Furthermore, it is intended for managers to structure strategic digitalisation projects with a set of activities to navigate skill development and reduce financial risk. As shown through the case study, the different framework phases are intended to (1) assess current capabilities and areas for improvement aligned with the company's vision, (2) create awareness of potential external stakeholders and available solutions in the market, (3) analyse and evaluate several potential solutions, (4) develop low-cost proof-of-concept prototypes and (5) integrate and deploy the best solution(s). Although further work needs to be conducted to validate the process in other contexts, we believe examples such as this can give SMEs the confidence they require to undertake similar digitalisation projects.

6. Conclusions

This case study helped us unpack specific aspects that can assist in de-risking digitalisation, which could be the focus of future research. First, we argued that although I4.0 uses have been analysed in the literature, there is room for more information describing how SMEs can utilise and exploit these new technologies considering skill development and usability. Thus, after exploring the value of design thinking in digitalising an SME, we propose a practical roadmap to 'digitalisation' in an infant stage from a research perspective. Our approach aims to enable more sustainable production patterns by exploiting the manufacturing efficiencies inherent within an I4.0 manufacturing paradigm. This is supported by Kuys, Koch and Renda [37], who look specifically at the priority given to sustainability by industrial designers within an I4.0 manufacturing environment. Although this research contains aspects of other digitalisation frameworks [11,20], it uses aspects of design thinking which could help businesses implement IoT and data analysis solutions frugally without investing enormous resources and with progressive skill development. This potential value of design thinking needs to be further explored by analysing more cases and industries. In the case study presented in this paper, the design thinking approach allowed for exploring opportunities, evaluating concepts and prototyping quickly, and led to a successful solution in an area unfamiliar to the team. Thus, we found the design thinking approach suitable for developing the technical expertise that the team initially lacked. Furthermore, we found that focusing on usability factors allowed the team to select and develop easy-to-operate and maintain solutions aligned with the needs of SMEs [28]. Furthermore, regardless of the travelling barriers imposed in response to the pandemic during the project, the methodology allowed flexibility to complete the defined goals, helped by design expertise. For example, remotely analysing 3D models of the manufacturing facilities allowed a detailed understanding of the manufacturing process, and visualisation skills helped communicate the potential of different solutions at different stages of the project.

However, our approach has limitations related to the single-case nature. Further research is required to validate the usefulness of design thinking frameworks in a broader range of I4.0 projects. Before the project started, Eudaemon collaborators had high research expertise, had been exposed to design thinking approaches and were interested in adopting I4.0 practices. Although we believe the proposed framework is practical and designed to empower SMEs with the confidence required to transition to I4.0 technologies and practices to maintain global competitiveness, it may still contain unfamiliar concepts to some traditional manufacturers. Thus, more case studies of practical digitalisation or SMEs must be published and explained to help other companies in different industries benefit from these technologies. Furthermore, future studies should focus on the financial aspects of case studies of SMEs' digitalisation to demonstrate returns on investment; financial and operational benefits should encourage more SMEs to adopt new technologies.

We have shown that there is an opportunity for designers to bring value to the digitalisation of SMEs. In this case, study, the early clarification and definition of the problem, followed by a broad exploration of alternatives with swift evaluation parameters, served as well in the digital context as it serves in traditional product design [57]. For example, iterative prototyping was used to generate insights to facilitate the adoption of IoT practices and to quickly evaluate multiple potential solutions prioritising usability. Therefore, this research suggests that design-driven processes could be useful to de-risk SMEs' digitalisation. Furthermore, the research suggested designers could be translators of complex information and creators of practical user-centred solutions in the advanced manufacturing context.

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