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Strategies for Digital Transformation: an exploratory analysis of Digital Twins projects

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Resumo: Industry 4.0, also known as the Fourth Industrial Revolution, entails the incorporation of new technologies such as the Internet of Things (IoT), cloud computing, artificial intelligence (AI), virtual reality, and digital twins (DT) into manufacturing processes, allowing for the development of new business models and decision support systems with the goal of improving performance and optimization (Aheleroff et al., 2021; Cimino et al., 2019; Kritzinger et al., 2018; VanDerHorn & Mahadevan, 2021).

According to existing literature, Digital Twin is the creation of a virtual model of a physical system using a digital approach, which is accomplished by collecting and processing data from physical reality. A DT intends to digitally simulate a physical entity and/or its behaviour in a real-world situation (Bao et al., 2019). The adoption of this technology allows companies to benefit from cost and risk reduction, increased efficiency, improved service delivery, increased security, and decision support in industry (VanDerHorn & Mahadevan, 2021).

Grieves (2005) introduced one of the first digital twin definitions in 2005, referring to it as the "Mirrored Spaces Model", and given the recent and expanding digitization of industry, the concept has received significant interest not just from the academic community but also from the corporate world (Bergs et al., 2021; Grieves, 2005; Semeraro et al., 2021). However, according to VanDerHorn and Mahadevan (2021), the majority of research focuses on technological solutions, analysis methodologies, and challenges associated with the Digital Twins date. Therefore, there is a need for implementation models as well as practical examples of DTs implementation in companies, and, in this sense, the importance of the Technology Roadmapping (TRM) concept should be noted (VanDerHorn and Mahadevan, 2021). Technology Roadmapping is a tool for managing and planning the implementation of a specific technology in a particular company, linking the organization's strategy to the product/service features and technologies required to achieve its goal. (Alcantara & Martens, 2019)

In this paper, Digital Twins technology will be addressed as a Digital Transformation strategy associated with Industry 4.0. The focus will be on the Implementation of process Digital Twins based on the Technology Roadmapping Approach, through an exploratory analysis of SMEs with participation in the Change2Twin project.

Códigos JEL: O14; O22; O23; O32; O33

Palavras-chave: Industry 4.0; Digital Twins, Digital Transformation Strategy; Digital Strategy; Technology Roadmap

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1. Introduction

The manufacturing industry is now experiencing a period of significant transformation marked by an increase in automation and the application of new digital technologies, resulting in a new level of efficiency and greater flexibility in responsiveness (IBM, 2022). This new phase, Industry 4.0, is characterised by the high connectivity of manufacturing systems with virtual systems (Ghobakhloo, 2018). Industry 4.0 combines disruptive technologies and methodologies such as the Internet of Things (IoT), Cloud computing, AI and machine learning, Cybersecurity, Edge computing, and Digital Twin (Reis et al., 2018). Studies indicate that the transition to Industry 4.0 offers benefits not only to the company's competitiveness but also to its survival in the context in which it operates (Ghobakhloo & Iranmanesh, 2021).

In recent years, there has been a growing interest by companies related to the manufacturing industry in the Digital Twin technology, given its relationship with Industry 4.0 and the benefits associated with its implementation (Abraham et al., 2022). According to VanDerHorn and Mahadevan (2021), a Digital Twin "*is a virtual representation of a physical system (and its associated environment and processes) that is updated through the exchange of information between the physical and virtual systems*", consisting of three components: the physical reality, the virtual representation, and the interconnections that exchange information between the physical reality and the virtual representation. The implementation of DT helps monitoring the processes, encourages collaboration, and facilitates decision-making (Holopainen et al., 2022). In particular, the implementation of this technology in manufacturing companies can contribute to a better understanding and optimization of production processes; as a result, they are mostly employed in failure detection, preventative maintenance, and performance analysis (Holopainen et al., 2022).

However, the adoption of new technologies has a short and long-term impact on a company's performance; thus, it is critical to develop a digitisation strategy that includes the necessary steps, tools, methodologies, and know-how to ensure the success of the transition to Industry 4.0 (Ghobakhloo & Iranmanesh, 2021). In this sense, companies employ technology roadmapping methodology to strategically assist the process of technology adoption and maintain their competitive advantage (Ghobakhloo, 2018). According to Sarvari et al., (2017) "*The technology roadmap process addresses the identification, selection, acquisition,* *development, exploitation, and protection of technologies (product, process, and infrastructural) needed to achieve, maintain, and grow a market position and business performance matching with the company's objectives*". The use of roadmapping enables the alignment of business and technology strategies, the identification of gaps between technology, market, and product, the establishment, determination, and exploration of competitive objectives and methods to achieve them, and the analysis of technology implementation results (Sarvari et al., 2017).

There are several contributions in the existing literature, both at the level of Digital Twin technology and roadmapping for Industry 4.0. There are articles that describe the characteristics of a DT (Aheleroff et al., 2021; Li et al., 2022; Semeraro et al., 2021; VanDerHorn & Mahadevan, 2021), the main adoption factors or benefits from adoption (Aheleroff et al., 2021; Lu et al., 2020; Millwater et al., 2019; Perno et al., 2022; VanDerHorn & Mahadevan, 2021) and the relevance of DT to the digitalization process of SMEs (Holopainen et al., 2022). However, there is a research gap regarding specific implementation models and roadmapping for Digital Twins technology (VanDerHorn & Mahadevan, 2021). In this sense, it is not clear how the digital technology is and should be integrated to current manufacturing processes or what are the main types of Digital twin technologies used by manufacturing companies. For the reason, the objective of this thesis is to characterize what types of Digital Twin are being used by manufacturing companies who wants to digitalize their process. It will also be analysed what are the implementation roadmaps for the DT identified.

In this regard, there is a need to further discuss the implementation of Digital Twins in industrial organisations using a Technology Roadmapping approach. Therefore, in this research, we will explore the process of roadmapping the implementations of DTs in SMEs and the types of Digital Twin solutions available by analysing ten case studies developed by the project Change2Twin.

The relevance of this research stems from the current change in the manufacturing industry's technological paradigm—the transition to Industry 4.0—and the need for guidelines for businesses at the management level in the implementation of Digital Twins as a Digital Transformation strategy. The inclusion of an action plan for the technology's implementation is critical to its success (Bray & Garcia, 1997). The outcomes of this research intend to contribute to the literature by providing a guideline to assist companies in the implementation of process Digital Twins based on the Technology Roadmapping Approach in order to achieve the established goals.

The next chapter presents the literature review, which covers the topics of Digital Strategy, Digital Twins and Technology Roadamp. Chapter 3 presents the research method, while Chapter 4 presents the results and their discussion. Finally, Chapter 5 will present the conclusion as well as the limitations of this study and suggestions for future research.

2. Literature Review

This section will address key concepts to understand and explore guidelines for implementing Digital Twins as a Digital Strategy in SMEs. In this line, we will proceed to the conceptualization of the terms Digital Strategy, Digital Twins, and Technology Roadmap.

2.1. Digital Strategy

Currently, society is in a period known as the "Digital Age," in which digital technology is an usual component of daily life, if not fundamental to its proper functioning. Similarly, as reliability and performance improve, there is a considerable increase in the presence of digital technology in businesses (https://www.forbes.com/sites/blakemorgan/2019/12/16/100-stats-on-digital-transformation-and-customer-experience/). Companies's digital transformation can improve their competitiveness (in terms of efficiency and customer satisfaction) while also facilitating cross-industry exchange and continuous data access (Correani et al., 2020).

However, digital transformation includes more than just the use of digital technologies. According to Troise et al. (2022), digital transformation entails changes at the strategic, competitive, business model, decision-making, innovation, entrepreneurial, and productivity levels. As a result, "*digital transformation is a journey, and a journey needs a map—in this case, a clear roadmap driven by a digital strategy*"(Gobble, 2018).

The digital transformation strategy entails the creation of a "*plan of action to attain a defined objective through the strategic renewal of the organization*" (Correani et al., 2020). According to Gobble (2018), the adoption of digital technologies results in creating more value when they are integrated and supported by a risk-taking culture, and the investment in technology should match the investments in the cultural and organisational transformation of the company.

Digital transformation strategies differ according to the industry as well as the company's goals and specifications. However, Matt et al. (2015) state that every digital transformation strategy must have four pillar dimensions: "use of technologies, changes in value creation, structural changes, and financial aspects". According to Gobble (2018), the two fundamental factors of a successful digital strategy are flexibility in strategy, organisational structure, technology, and human resources, as well as collaboration throughout the entire organisation and partners.

A digital transformation may occur in any organisation; nevertheless, it has always had a strong connection with industry, particularly with the current situation of substantial changes related to Industry 4.0 (Reis et al., 2018). The foundation of Industry 4.0 is a digital transformation defined by the merging of operational technologies with digital technologies, the latter being divided into two categories: low-level technologies such as smart sensors, industrial robots, smart wearables, and machine controllers, and high-level technologies such as the Internet of Things (IoT), Cloud Computing, Artificial Intelligence (AI), Virtual Reality, and Digital Twins (DT). It is important to note that low-level technologies are complementary to high-level technologies, since they are created by combining different low-level technologies with industrial machinery (Ghobakhloo & Iranmanesh, 2021).

The digital transformation under Industry 4.0 provides substantial advantages for companies in terms of competitiveness and survival (Schlaepfer et al., 2015). This transition, in particular, enables the business to increase industrial efficiency, improve product quality and innovation, and lower operational costs (Industry 4.0 for SMEs, 2021; Matt & Rauch, 2020).

Summing up, the Digital transformation of manufacturing companies will be observed in this thesis through the following dimensions: structural changes (Human Resources); use of technologies (Technology Strategy); changes in value creation (Value Offer); and financial aspects (Finances).

2.2. Digital Twins

In the Industry 4.0 paradigm, the Digital Twin emerges as one of the technologies adopted by manufacturing industries to improve their performance in the sector. A Digital Twin (DT), according to VanDerHorn and Mahadevan (2021), is "*a virtual representation of a physical system (and its associated environment and processes) that is updated through the exchange of information between the physical and virtual systems*" and is made up of three components: physical reality, virtual representation, and the interconnections that exchange information between the physical reality and the virtual representation. However, considering its newness, the definition of Digital Twin is not unique. A DT, according to Semeraro et al. (2021), is "*a virtual and computerized counterpart of a physical system that can exploit a real-time synchronization of the sensed data coming from the field and is deeply linked with Industry 4.0.*", while according to Zhang et al. (2017), it is *"a set of realistic product and production process models linking enormous amounts of data to fast simulation and allowing the early and efficient assessment of the consequences, performance, quality of the design decisions on products and production line"*. Nonetheless, all definitions of DT, at their core, pertain to a virtual representation of something in the real world.

Depending on the needs and requirements of the project for which the DT will be used, each of these components will have distinct elements. However, there are several fundamental aspects to the technology's operation (Botín-Sanabria et al., 2022):

- Physical reality: a physical object or process; sensors (applied in the real world to collect information).
- Virtual representation: a virtual representation of a physical object or process; 3D representation; data processing (machine learning, artificial intelligence, cloud computing, etc.).
- Connection: Internet; Bluetooth; cables; interfaces; Internet of Things (IoT).

Digital Twins are classified according to their function as Product DT, Process DT, or Performance DT (Singh et al., 2021). The first (product DT) is used in prototyping because it analyses the product in a variety of situations and environments to forecast how it will behave in the physical world, but it also allows assurance that the product to be created will perform its functions in physical world settings. The second type of DT is process DT, which is used to verify processes through simulation to aid in the development of an efficient production methodology under various conditions and to monitor production. Finally, Performance DT is utilised to assist decision making by gathering, processing, and analysing data (Singh et al., 2021).

To build a Digital Twin, three components are required: an information model to collect the specific data of the physical system in question, a communication mechanism that allows data transfer between the physical system and the digital twin, and a data processing model capable of extracting and processing the data in order to build a virtual representation in real-time (Lu et al., 2020). The development of a Digital Twin implies the use of Industry 4.0 technologies such as IoT, Cloud, Extended Reality (XR), Big Data, and Machine Learning (ML), making the adoption of some features associated with these technologies possible (Aheleroff et al., 2021).

Manufacturing DTs are designed for specific applications and there are a variety of different purposes for which DTs are built (Cimino et al., 2019): (1)"Support the production system management", (2)"Monitor (real-time) and improve the production process", (3)"Support the lifecycle of a machine process", (4)"Maintenance" and predictive maintenance.

2.2.1 Support the production system management (SPSM)

The implementation of digital twins to support production system management requires continuous evaluation, control, and planning of the manufacturing process (Kritzinger et al., 2018). These management services include "*searching, matching, scheduling, combination, transaction, and fault- tolerance*," which enable conflict resolution prior to and during production (Qi et al., 2018). To accomplish this, data is gathered from the company's existing IT systems, such as ERP, CRM, and MES, as well as real-time data from the machinery itself (Olivotti et al., 2019).

The compilation of this data enables, in particular, order planning based on statistical assumptions, autonomous planning and executions, improved decision-making by previous data analysis, making them faster and more informed, and increased transparency (Kritzinger et al., 2018; Rasheed et al., 2020; Rosen et al., 2015). It is also crucial to highlight that keeping the history of stakeholder choices, market trends, and consumer preferences enables companies to serve a more tailored demand (Rasheed et al., 2020).

2.2.2 Monitor (real-time) and improve the production process (MIPP)

One of the main purposes for the adoption of Digital Twins by companies in the manufacturing industry is their ability to monitor, in real time, the production process as well as, using AI, to continuously improve their performance (Aheleroff et al., 2021).

Production monitoring is accomplished through the "*virtualization of manufacturing machines*" systems and the monitoring of machine tools and parameters during production at both the equipment level (e.g., temperature, dust level, needle tension, etc.) and at the product level (e.g., burst tension, product anomalies and quality, etc.) (Cimino et al., 2019).

The Digital Twins rely on real-time data collected by smart devices integrated into the environment, such as smart sensors and CCTV, that are connected to each other (Aheleroff et al., 2021; Choi et al., 2022), as well as stored from past records and enterprise information systems, to perform real-time monitoring of the production process (Sharma et al., 2022).

Implementing this technology in factories facilitates the monitoring and management of production at any time from any place, allowing for the identification of issues and quick response (Choi et al., 2022). As a result, analysing this data will allow for improvements in the manufacturing process, such as lower energy consumption, increased productivity, and fewer failures (Cimino et al., 2019).

2.2.3 Maintenance and predictive maintenance (MPM)

The use of Digital Twins for maintenance is another popular use in the manufacturing industry since it is feasible to ascertain when the machinery requires maintenance by monitoring the production process. The capacity of DTs to monitor the whole operating system adds to their maintenance purpose by alerting employees to the necessity for repairs throughout the manufacturing process (Hosamo et al., 2022).

However, it is in predictive maintenance that DT technology has the most impact. Maintenance expenditures account for about *65% of yearly facility management costs* (Hosamo et al., 2022). As a result, the adoption of technologies with predictive maintenance functions, such as Digital Twins, allows for increased machinery useful life, increased efficiency, and cost reductions by allowing for the planning of plant maintenance for downtime moments and the minimization of the number of maintenance operations(Hosamo et al., 2022; Tao & Zhang, 2017).

In this manner, Digital Twin collects historical and real-time data on health status and degradation information, which is then treated, analysed, and processed to generate the most accurate maintenance prediction (Luo et al., 2020).

2.2.4 Support the lifecycle of a machine process (SLMP)

As the technology associated with Digital Twin evolved, so did its purposes, particularly regarding the product. It may now be utilised not just for the product but also for its whole lifespan, including the manufacturing process and post-production phases (Cimino et al., 2019; Tao et al., 2019). This purpose is an accumulation of previous ones that are applied to a greater dimension, meaning that they are applied throughout the entire process rather than confined to a single phase. The application of DT at this level supports the production lifecycle by monitoring, analysing, simulating, and controlling the stages "*manufacturing, distribution, usage, maintenance, and recycling* " (Konstantinov et al., 2017; Wang et al., 2020).

2.2.5 Design (or Redesign) of a machine, product, or production environment (DMPE)

One of the stages of the lifecycle where the presence of a digital twin may have a significant influence is in product and production line design. The Barricelli et al. (2019) recommend using DT for factory design to establish the ideal layout and equipment configuration, design the logistic unit control strategy, and create a plan for the integration of all equipment in the production line. This enables an increase in manufacturing speed while also lowering production costs (Barricelli et al., 2019). Implementing DT at this stage of the process allows a link between the product design to its production environment (Anand et al., 2018). This connection helps the designers to fully adapt the product to the customer's vision, assess the performance of virtual products under different conditions, and swiftly redesign a current or a totally new product (Tao et al., 2019). These abilities also result in increased production speed and lower costs due to reduced time and resource allocation in product design and testing (Tao et al., 2019).

In addition to Cimino et al. (2019), the project Change2Twin has also created a list of Digital Twinning Objectives, as presented in Table 1.

Table 1 - Digital Twinning Objectives by C2T

Digital Twinning Objectives	Definition (according to C2T)	Examples
Virtual Design	*Model-based system engineering, incl. analysis and design, ensuring that requirements are met and providing for seamless integration, teste, verification and validation.*	Leng et al. (2021); Kalantari et al. (2022); Wang et al. (2020); Schleich et al. (2017); Tao et al. (2019); White et al. (2021)
Customer Engagement	*Interactive display of system and its capabilities, for customers to understand how it meets their needs and how they will use.*	Wang et al. (2021); Zhang et al. (2020); White et al. (2021)
Commissioning	*Checking the on-site implementation of a system against its design as captured in the digital twin to detect commissioning faults or anomalies.*	Xia et al. (2021); Leng et al. (2021); Iglesias et al. (2017)
Feedback to Engineering	*Capturing usage characteristics with the digital twin to inform engineering of needs to change designs, or for future designs, or of operational risks.*	Ogunseiju et al. (2021)
Monitoring	*Monitoring of system's operation by the digital twin that is then able to, e.g., detect anomalies, performance degradation, etc.*	VanDerHorn and Mahadevan (2021); El Saddik (2018); Detzner and Eigner ; Tao and Zhang (2017)
Optimization & Best Quality	*Process control with the digital twin to optimize a systems operation for best performance and efficiency.*	Guo et al. (2021); El Saddik (2018)
Scheduling	*Organization of workflows based on actual data and insights provided by the digital twin.*	Tao and Zhang (2017)
Diagnosis	*Investigation of the cause or nature of a fault condition, situation, or problem in the physical system by reasoning on live data within the digital twin.*	(VanDerHorn & Mahadevan, 2021) VanDerHorn and Mahadevan (2021)
Preventive Maintenance	*Maintenance and service of a physical systems that lessens the likelihood of failures based on the observed and inferred system state as visible in the digital twin.*	VanDerHorn and Mahadevan (2021)

Smart Logistics	*Logistic processes that adapt to live data of needs and options as visible in the digital twin.*	Tao and Zhang (2017); Qi et al. (2018); Xia et al. (2021); Leng et al. (2021)
Smart Systems	*Systems that adapt to their dynamic environment, state, or tasks and potentially learn how to do that best. The digital twin is then a core part of the system's control.*	White et al. (2021); Xia et al. (2021)

Given the overlapping characteristics between the digital twin purposes presented by Cimino and the digital twinning objectives presented by C2T, only the first will be considered for the evaluation of the results. The Figure 1 shows the association between the purposes identified in the literature and the digital twin's purposes used by C2T.

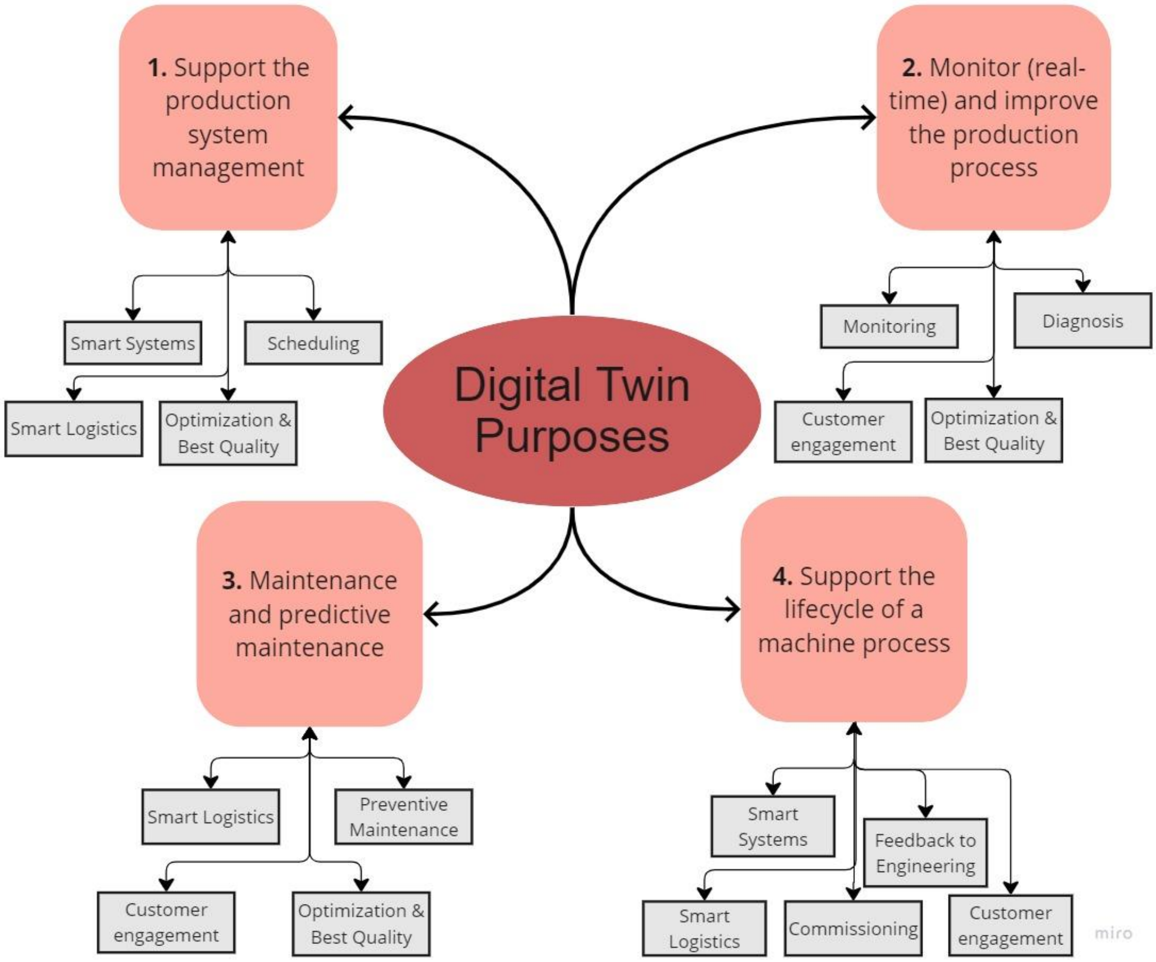

Figure 1 - Connection between purposes from the literature and purposes used by C2T

Digital Twins are still an emerging technology, and, therefore, for a more large-scale implementation by organisations, they need to understand the advantages resulting from the implementation of DTs (Singh et al., 2021). The main advantages of this technology include reduced errors, uncertainties, inefficiencies, and costs, as well as increased connectivity and sharing amongst multiple systems, allowing for improved performance (Singh et al., 2021).

Given the new nature of this technology, and for a deeper understanding of Digital Twins implementation planning, it is important to analyse how the digitisation strategy connects to the company's present and future business plans. Therefore, tools as Technology Roadmapping are essential for assisting with implementation and ensuring the efficacy of this process. (Phaal et al., 2004).

2.3. Technology Roadmap

It is critical for effective and successful technology integration that it align with the business plan; that is, digital strategy and business strategy should not be established independently (Phaal et al., 2004). As a result, Technology Roadmapping has emerged as a critical digital strategy tool in business (Groenveld, 1997; Phaal et al., 2001; R. Phaal et al., 2003).

Technology Roadmapping is essentially the schematization of the connection between technology, company, and market, addressing the following issues: 1) "Where are we going?" 2) "Where are we now?" 3) "How are we going to get there?"(Phaal et al., 2007; Probert et al., 2003). This approach is flexible allowing for the formation of several types of roadmaps and techniques for developing them (R. Phaal et al., 2003). The most used technology roadmap shows the connection between three layers: technology, product/service and market (Probert et al., 2003). This format enables the exploration of each layer while also analyzing its connections with the other layers, facilitating the integration of technology in the company (Phaal et al., 2004).

Given the Technology Roadmap tool's enormous versatility, several processes for its development have been proposed (Phaal et al., 2013). The "Fast-Start Technology Roadmapping" concept will be the subject of this research. This model attempts to connect technology resources to business drivers, identify gaps in the market and inside the business, develop a first version of the technology roadmap, and assist in technology strategy and organizational planning(R. Phaal et al., 2003). According to Phaal et al. (2013), the model has two approaches, the S-Plan and the T-Plan, which may be combined or applied independently in the roadmapping process. The first focuses on the business' strategic side, assisting in the identification and exploitation of strategic possibilities connected to innovation (technology) and the business(Phaal et al., 2007). The second approach focuses on product technology, i. e., understanding the client and the market (Phaal et al., 2007). Regardless of their differences, both exhibit common steps for roadmap development because the S-Plan is a result of the T-Plan's development (Phaal et al., 2013; Phaal et al., 2007). As a result, in order to comprehend the technology roadmapping process, this research will only address the T-Plan approach.

Phaal et al. (2007), define T-Plan as a workshop-based method that brings stakeholders together to collect, understand, and structure information in order to identify strategic issues and determine the next steps. This method enables the construction of a first draft, bringing direct challenges and consists of the following steps (R. Phaal et al., 2003):

1. Planning: This phase is critical for roadmapping because it enables the articulation of the company's process objectives, the determination of scope and focus, as well as the resources and participants required for the following phase (Robert Phaal et al., 2003).
2. Roadmapping workshops: The standard process for this phase consists of four workshops, three of which are dedicated to gathering information relating to the roadmap's three layers. The fourth workshop connects and structures the information from the previous three workshops, allowing the formulation of a preliminary roadmap (R. Phaal et al., 2003).
3. Roll-out: maintenance and support to make roadmapping a dynamic and operational process (R. Phaal et al., 2003).

Technology roadmapping should be customised to the demands and characteristics of the business. If this process is properly developed, the results will enable the identification of success factors and barriers to the use of digital technologies, notably digital twins (Robert Phaal et al., 2003).

3. Research Method

Given the objective of this theses – to characterize what types of Digital Twin can be used by manufacturing companies who wants to digitalize their process, a qualitative exploratory and descriptive analysis of a case study will be carried out using data triangulation. Qualitative research consists of the attempt to interpret the meaning of a phenomenon in its natural state, i.e., it focuses on understanding and explaining a problem through observations and identification of patterns, regularities/irregularities to reach generalised conclusions Denzin and Lincoln (2005) Therefore, the use of this methodology makes it possible to answer the research question since it enables the identification of the DT typologies, in terms of purpose, most used by companies in the manufacturing industry.

Given the recent nature of the topic and the desire to further understand the phenomena in question, this study can be characterized as an exploratory analysis. At the same time, it is a descriptive analysis due to the fact that the project outcomes are observed and described in order to draw conclusions(Babbie, 2008). To achieve our objective, a Case Study Research was implemented , as defined by Creswell (2007) *"a qualitative approach in which the investigator explores a bounded system (a case) or multiple bounded systems (cases) over time, through detailed, in-depth data collection involving multiple sources of information (e.g., observations, interviews, audiovisual material, and documents and reports), and reports a case description",* which allows a holistic description and explanation of phenomena (Merriam, 2009). The present research is a single instrumental case study (Creswell, 2007; Stake, 1995) because: 1) only the Change2Twin project is considered, which includes 10 companies from the manufacturing industry; and 2) the case study is only used as a tool to find more generalisations (Sharan B. Merriam's Qualitative Research Book). a single case study allows the identification of factors related to an event, and their interconnections, which meets the intended purpose of this thesis: the identification of the main purposes that lead to the adoption of DT by manufacturing companies through an analysis of the companies that participated in the Change2Twin project (Merriam, 2009). The 11 companies involved in the C2T project served as the "unit of analysis" in the case study developed as part of this thesis.

3.2. Unit of Analysis

Change2Twin is a Horizon 2020-funded project that intends to help the digitalization process of SMEs by supporting the adoption of Digital Twin solutions and simplifying access to the necessary technologies required for that (*Change2Twin*). The C2T consists of two sequential phases (open calls) with funding: (1) Assessment Voucher[1], which provides the organisation with three DT implementation plans; (2) Deployment Voucher[2], which is a

[1] https://www.change2twin.eu/open-calls/assessment-voucher/
[2] https://www.change2twin.eu/open-calls/deployment-voucher/

support programme for adopting digital twinning technologies and it could be based on the Assessment Voucher solutions (*CHANGE2TWIN: Digital Twin for every manufacturing SME*, 2021). The first phase must always be conducted by a Digital Innovation Hub (DIH)[3]; however, the second phase is optional. Only data from the Assessment Voucher has been assessed for the purposes of this study.

This case study featured 11 organisations (SMEs or midcaps[4]) that participated in the Assessment Voucher open call in 2021 and 2023 and consented to participate in this research.

[3] https://portugaldigital.gov.pt/en/accelerating-digital-transition-in-portugal/testing-and-incorporating-new-technologies/digital-innovation-hubs-dih/

[4] **Middle-capitalization company'** or **'mid-cap'** means an enterprise that is not a SME and that has up to 3000 employees.

Table 2 - Information on the companies and its representatives

Company	Sector	Company's Dimension (number of employees)	Representative's profile (company position)	The time of the representative's employment with the company (+/-)	Representative's education background
1	Warp-knitting manufacture	110	Management/Executive Head of R&D	6 years	Textile Engineering
2	Automotive components manufacture	201-500	Director of Research, Development and Technology	12 years	PhD in Mechanical Engineering
3	Metal-working manufacture	89	CEO	18 years	Bachelor in Industrial Electronics Engineering
4	Textile manufacture	11-50	Manager and Founder	10 years	Executive Master Business Administration
5	Maritime Transportation manufacture	11-50	System Engineer and Founder	3 years	PhD in Computer Engineering
6	Plastic Packaging Manufacture	51-200	Management/Executive Director of Research and Development	1,5 years	PhD in Industrial and Systems Engineering
7	Aviation, aerospace, and medical components manufacture	80	Management/Executive	22 years	Master's Degree in Quality Management, Lean Systems
8	Engineering company	10	Operations Manager	12 years	B.Sc. in Quality Engineering B.A. in Business
9	Fiberglass manufacture	11-50	Management	9 years	Master's degree in Business Administration and Management
10	Specialized Additive Manufacture	11-50	Management Engineer	6 years 5 months	Master's degree in Engineering for Direct Digital Manufacturing Postgraduate degree in Product Design Engineering

3.3. Data Collection

The case study data was collected through data triangulation (Patton, 2015). This research included data from direct observation of the assessment workshops and secondary sources, including videos of interviews conducted by other project teams, reports, and videos that involve interviews and experiences from the companies in the project.

The data collection with the companies participating in the Assessment Voucher was performed using an approach resembling the Technology Roadmapping methodology, in particular the "Fast-Start Technology Roadmapping" model (Robert Phaal et al., 2003). In this sense, the Assessment Voucher was carried out as follows:

1. **Planning** with each company to prepare and collect the required information for the following step.

2. **Workshops** were held to assist the DIH in gaining insight into the operation of the company as well as filling out the Compass Tool and the Readiness Tool.

3.3.1. Assessment Voucher Process

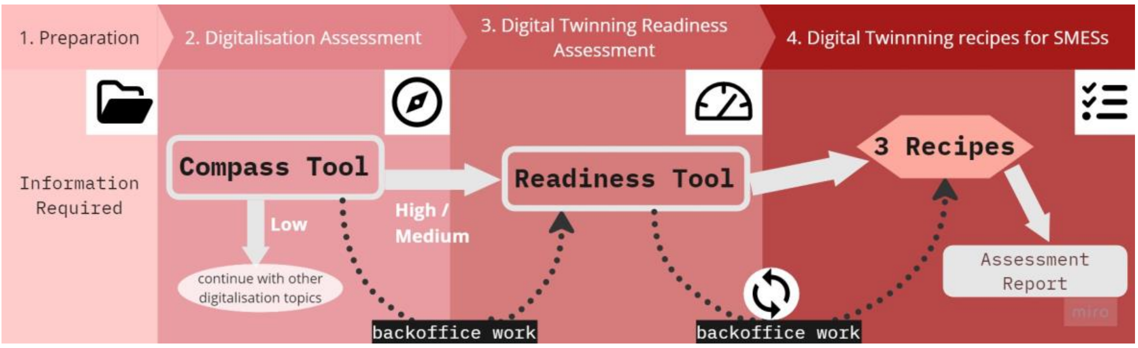

Figure 2 – Assessment Voucher Process Diagram

The Assessment is divided into four steps (Aarssen, 2021):

1. **Preparation:** the company gathers preliminary internal information (e.g., KPIs).
2. **Compass Tool - Digitisation Assessment**: two sessions (interviews/workshops) are held with company representatives to identifies the business demands that could potentially be solved through digitization and the importance of DT to the business.
3. **Readiness Tool - Digital Twinning Assessment:** indicates the readiness of the company for a given DT- based on the company's objectives. A session (interview) is

held at this stage in order to complete the Change2Twin Digital Twinning Readiness Tool.

4. **Digital Twinning Recipes for SMEs:** Making use of the two preceding techniques, three ready-to-use recipes are provided, presenting which enabling technologies and services are required to implement the adoption of DT technologies by the organisation. The process concludes with the submission of an Assessment Report.

3.3.2. Assessment Voucher Tools

During the Assessment Voucher process, one or two workshops are dedicated to step 2, Digitalization Assessment, and one is devoted to step 3, Digital Twinning Readiness Assessment. The workshops must be attended by one to three corporate representatives. Participants should include someone from management (e.g., the CEO) and someone with technical understanding so that an overview of the company's business and strategy, as well as its demands, may be obtained.

A representative from DIH leads workshops following a questionnaire containing a variety of open and closed questions about the company, its business model, and its technology. This questionnaire's information allows to complete of the two Assessment Voucher tools - the Compass Tool and the Readiness Tool. These two very important instruments, consequently, enabled the gathering of the information required to carry out the plans for a successful deployment of the Digital Twin technology in line with the company's vision and objectives.

1. Compass Tool

The Compass tool is composed of 5 parts (Aarssen, 2021):

a) Current Status

In this first step, the company's representatives should clarify why they began the digitisation process, which KPIs are important for business operations, their level of digitisation, and which level of digitisation best fits the current business situation, according to the Acatech Industry 4.0 Maturity index. Furthermore, the business's offer is explained, as are the customer relationships and the business operations that require improvement.

b) Future ambitions

In this stage, the DIH will discuss with company representatives the long-term goals for the company, which KPIs are crucial for future business operations, and what their level of digitalisation is. They additionally select the level of digitalisation they want to achieve using the Acatech Industry 4.0 Maturity Index. In addition, the aspects where the organisation believes it can strengthen its offering via digitisation and the goals the company hopes to achieve through digitalisation at the level of business operations and commerce are pointed out.

c) Digital transformations

This section highlights the digitisation options - Digital Transformations - as well as their relevance to the company's business (Relevance score). The relevance score for each Digital Transformation is calculated considering the company's KPIs for future ambitions.

d) Digital twinning

The "Digital Twinning" section of the Compass Tool provides an estimate of the relevance of digital twinning in the business (low, medium, or high), the number of future KPIs to which DT adoption will contribute, and the estimated effort to implement the new technology in the company (low, medium, or high). It should also be highlighted that the predicted level of digitisation should be four or higher.

Following, a list of DT solutions is offered based on their objectives. Each purpose has a business relevance score that is calculated using future KPIs. Based on this score, the SME representatives and the DIH determine which digital twinning purpose is most suitable.

Table 3 – Digital Twin Purposes

Digital Twin Purposes	
Scheduling	Virtual Design
Diagnosis	Customer Engagement
Preventive Maintenance	Commissioning
Smart Logistics	Feedback to Engineering
Smart Systems	Optimization & Best Quality
Monitoring	

e) Dashboard

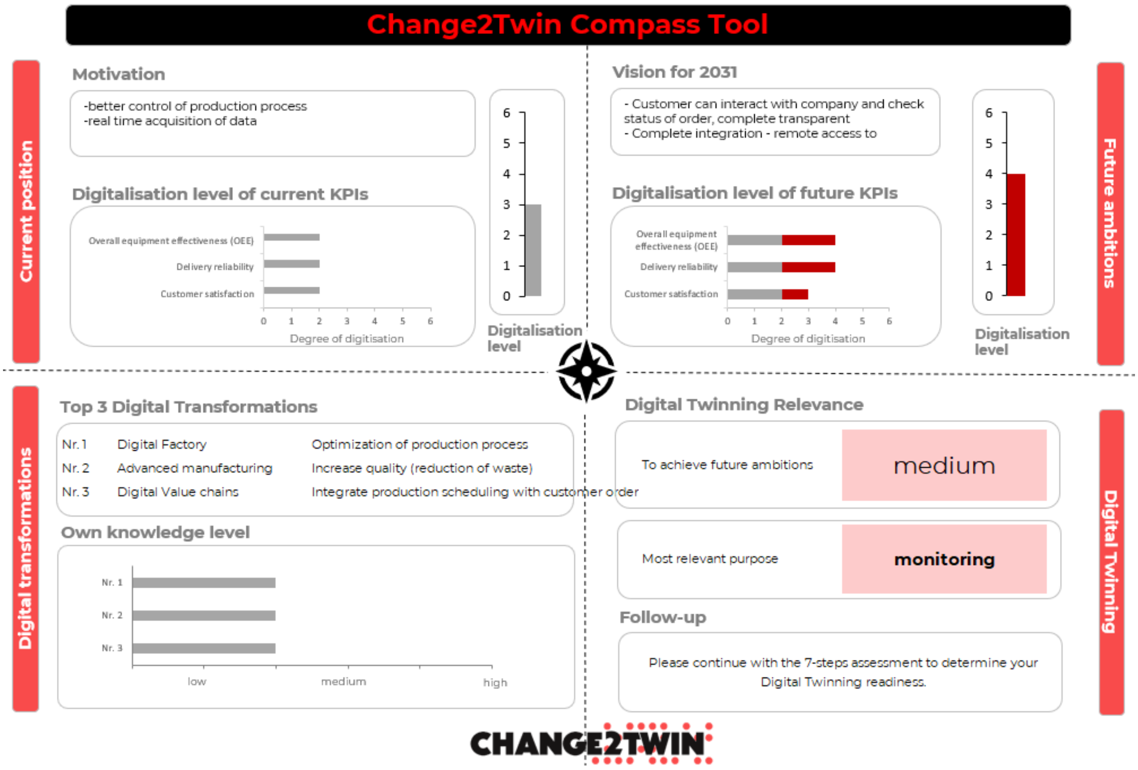

Figure 3 - An example of a company's compass tool dashboard

Finally, the Dashboard presents a summary of the Digitalization Assessment process, including the most significant findings reached from this phase - Purposes, Digital Twinning Relevance, and Top 3 Digital Transformations. It is important to bear in mind that the SME should only advance to the Readiness Assessment phase if it has a medium or high level of relevancy.

2. Readiness Tool

At this stage, the Readiness Tool will be utilised three times, one for each Purpose or Digital Transformation determined to be relevant for the organisation based on its objectives and for which a technology implementation plan is developed. The Readiness Tool is divided into three parts (Aarssen, 2021):

a) Current Status

With the goal of establishing the company's readiness for a specific DT solution (with a certain purpose), this section provides questions based on the 7-steps method and the Acatech index. These multiple-choice questions will be addressed by corporate representatives with the help of the DIH.

b) Intended

The Assessment Tool identified the three most relevant digital twinning purposes for the company's business. As a result, in this section, one of those purposes is selected, and if necessary, specifications are identified, for which a DT technology implementation report is developed.

c) Dashboard

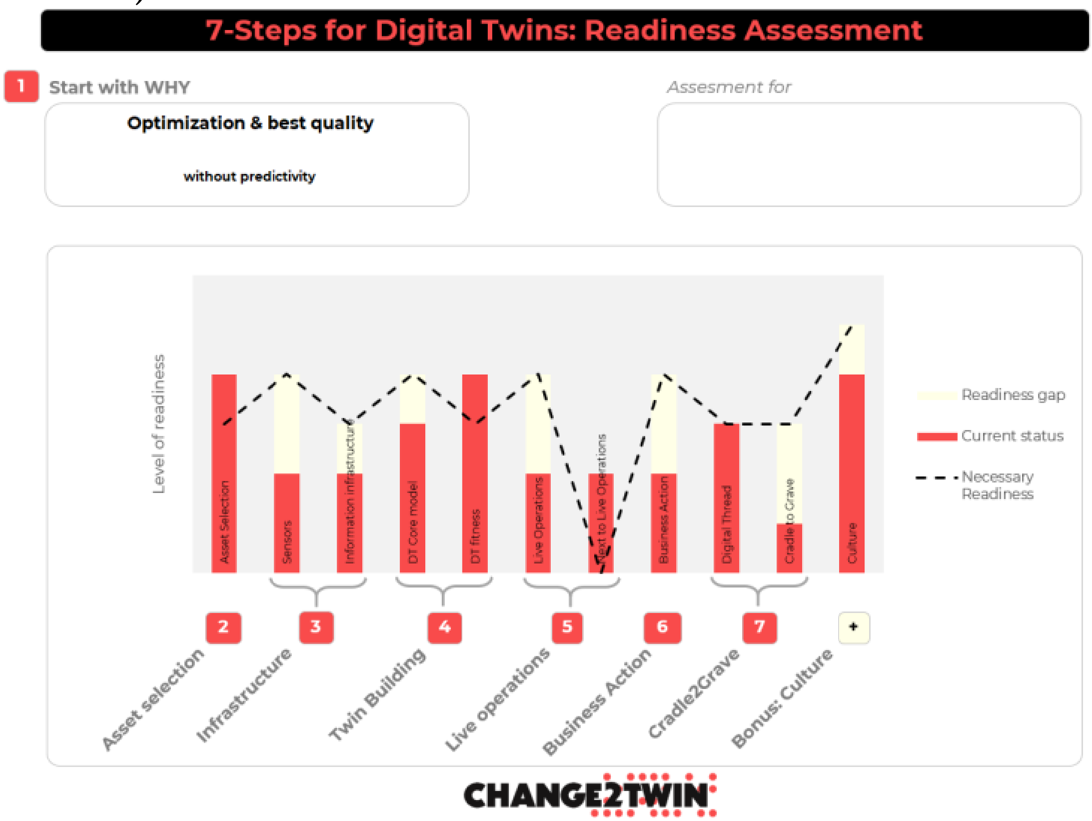

Figure 4 - An example of a company's readiness tool dashboard

Finally, the Dashboard provides a brief overview of the findings. The purpose and its specifications are identified, accompanied by a graph that allows you to assess the following:

- current readiness levels.
- necessary readiness levels.
- the gap between current and required readiness levels.

These outcomes enable the company to determine where it should invest both time and resources in order to properly implement the technology and hence maximise its potential.

3.4. Data Analysis

The Data Analysis process of the present investigation began with the visualisation and analysis of recorded interviews, followed by a transcription into text of the answers to the questions in the Interview Guide. The software NVivo was the programme used to assist in the analysis of the case study data since it allows not only the examination of qualitative data but also its organisation according to categories and sub-categories created by the researcher. The "Assessment Reports" of each company and the transcripts stated above were incorporated into the programme.

The Content Analysis method will be used to examine all documents, videos, and reports. As defined by Merriam (2009), content analysis is "*a systematic procedure for describing the content of communications*". This process begins with the creation of categories and sub-categories that emphasise significant elements in the analysed documents (Merriam, 2009). Categorization is the process of classifying elements (words, photos, etc.) of collected information (Bardin, 2016). The classification is carried out by differentiating the elements, allowing information to be organised into categories (elements in the same category indicate information related to the same subject or theme), which helps in the interpretation and analysis of the data (Bardin, 2016).

The categories applied in Nvivo to answer the research question in this study originated from the literature. The categorization was divided into two main categories: digital strategy and digital twinning. The data has been categorised into four sections within the Digital Strategy macro theme: Human Resources, which is associated with the concept of "structural changes" found in the literature; Technology Strategy, which is associated with the concept of "use of technologies" found in the literature; Value Offer, which is associated with the concept of "changes in value creation" found in the literature; and Financials, which is associated with the concept of "financial aspect" found in the literature. The data in the Digital Twinning section was categorised into the five purposes mentioned in the literature: "support the production system management", "monitoring (real-time) and improving the production process", "maintenance and predictive maintenance", “support the lifecycle of a machine process", and "design (or redesign) of a machine, product, or production environment".

Depois de recolhidos os dados, estes foram analisados através da análise de conteúdo. As entrevistas gravadas em áudio foram transcritas e analisadas através do software NVivo 12 Pro. Esse software auxiliou na interpretação e sistematização das informações obtidas durante as entrevistas transcritas e na análise dos documentos (Bardin, 2016). Inicialmente, foi feita uma triagem dos documentos públicos que contivessem informações relevantes à esta investigação. Em seguida, as transcrições das entrevistas foram lidas e codificadas. Num primeiro momento, as transcrições foram categorizadas de acordo com as 4 secções abordadas durante as entrevistas (Informações Gerais sobre o Entrevistado, Servitização, Digitalização e Ecossistema de Inovação). Posteriormente foi feita uma codificação e sistematização de acordo com os componentes do BMC de Osterwalder and Pigneur (2010). Finalmente, foram contrastadas as duas fontes de dados e identificadas as concordâncias ou discordâncias entre elas. A metodologia desta investigação está ilustrada de forma sintética na figura 3 abaixo. Os resultados obtidos através desta análise permitiram contextualizar, interpretar e explicar as alterações ocorridas nos modelos de negócios das empresas decorrentes dos efeitos da servitização e digitalização. Para além de ter sido possível perceber o papel dos agentes do ecossistema de inovação em empresas industriais participantes dos projetos europeus, especialmente no que concerne à sua participação nas propostas de valor

4. Results and Discussion

4.1 Digital Twin Aplication

In this section will be presented the processes that the companies wish to digitalize by implementing Digital Twin solutions.

Table 4 - Companies' production process to be digitalized

Company	Production Process to be Digitalized
1	The company's production process mainly focusing on the knitting machines area, production planning and scheduling.
2	The company wants to focus the implementation of the technology in the plastic injection molding's machines and tools. The company also aims to standardize the data collection and analysis among the different departments.
3	The company's manufacturing cell dedicated to the production of a specific product (a metal sleeve used in the automotive industry). This cell consists

	of a CNC lathe machine, a CNC milling machine, a laser engraving machine, a measuring/inspection equipment, and a material handling robot.
4	Connection between ERP system, website, and production status.
5	The company's design process has a few drawbacks, including in data collection and processing. As a result, it makes sense to incorporate modelling and design tools, as well as field test data, into the design process.
6	Data collection by equipment responsible for measuring and automatically rejecting non-conforming bottles, transporting completed bottles, and printing.
7	Controlling and modelling production scheduling through inputs across all site activities and continuously monitor our business in terms of man, material and machines to provide management support.
8	Production Scheduling
9	In the Malimo machines, the fiber fabrics are stitched ones with the others in order to create multiple layer products, which are combined as well with small fiber filaments distributed between layers.
10	The company receives the file in CAD format, performs some changes to the project in order to correct some aspects of the mesh, or adds some details that were not initially contemplated or develop the project based only on an idea, sketch, or rendered images. The project in question is manually budgeted and forwarded to the client to be approved by them.

4.2 Digital Transformation Strategy

After thoroughly analysing the data collected, it was possible to identify elements of the companies' strategy associated with each of the four pillar dimensions on which a digital transformation strategy should be based - "use of technologies, changes in value creation, structural changes, and financial aspects" (Matt et al., 2015).

4.2.1 Human Resouces (structural changes)

This dimension takes into account all the elements related to the company's culture and structure, namely the receptiveness of employees and management to change, investment in training, the level of knowledge of the technologies to be implemented, the involvement of employees in the digitisation process, etc.

The data collected showed that the companies that intend to implement this type of technology in their businesses have a very similar corporate culture when it comes to introducing new technologies. In most of the companies analysed, the administration/management is responsible for introducing changes on the production process and disseminating those changes amongst all workers. The administration leads the digital transformation, evaluating new digital technologies, but employees have full autonomy to suggest improvements and discuss ideas for improvements, prioritising the involvement of the workers from the beginning to the end of the digitalisation process. To ensure successful implementations most companies provide training for workers according to the planning, adoption and implementation of technologies, ensuring the full diffusion of knowledge needed to operate of new technologies and equipment.

With this analysis it was possible to ascertain that, although in most companies' employees were comfortable and in agreement with the adoption of new technologies, employee receptiveness to the implementation of new technologies is higher the more employees belong to the younger age groups. It was also possible to notice a evidence of a potential relationship between the company's area of activity and employee receptiveness - the more technological the company, the greater the receptiveness.

4.2.2 Tecnhology Strategy (use of technologies)

For the purposes of this study, associated with the Technology Strategy dimension are the elements of the companies' reports relating to the more technical side of implementing the new technology. In particular, it refers to the existing and necessary equipment for implementing the digital twin proposed by the project in each of the companies, as well as the technology (e.g., information systems, ...) that needs to be incorporated for the DT to work.

All the companies that entered the project had a minimum digitisation level of 3, meaning that the organisation is monitoring important data for its business processes using sensors and dashboards, for example. Even so, it was possible to see that all the companies would need to install more sensors with different functions to those already in operation.

It can be seen that in the majority of companies, the way in which information systems are implemented does not allow for the rapid sharing of data with each other - an essential condition for the functioning of a DT - and their reorganisation is part of the plan for implementing the technology. There are still some companies that enter data manually and/or use very basic programmes, such as Excel, to process data. In this sense, for the DT to work, it is necessary to adopt more advanced information systems, such as ERP, MES, CAP, SAS, but it is essential that the systems are interconnected to allow information to be shared in real time. This sharing and connection sometimes requires the installation of Ethernet infrastructures.

From the company reports, it was possible to see that although about two companies have departments in their organisation dedicated to implementing new technologies and maintaining them, all the companies that took part in the project will have to turn to external suppliers to obtain DT solutions capable of meeting their needs.

4.2.3 Value Offer (*value creation*)

In this analysis, the Value Offer dimension was associated with the creation of value generated directly by the implementation of digital twins in the companies under study. It was possible to verify that the value created by the technology is the result of the purpose established for it at the start of planning its adoption. The most chosen purpose when they decided to implement the technology in their organisation was "monitoring (real-time) and improve the production" (with more than 50% of the companies choosing this purpose) and, in general, the following value creation was associated with it:

- Reduction in errors/defects
- Improved product quality
- Reduced delivery times
- Improved decision-making

It was also possible to observe that all the companies whose focus was on the production process had the optimisation of the production process and increased productivity as their main value gains.

4.2.4 Financial Aspects

The Financial Aspects dimension shows the monetary gains that companies obtain from the successful implementation of DT. These gains are a direct consequence of the gains in value that the adoption of this technology has had for the company and, although they depend on the purpose of the DT, it was possible to see that there are great similarities between the various companies.

After analysing the data collected, it was possible to conclude that there is a top 4 list of monetary gains resulting from the implementation of DT:

- decreased operational costs.
- increased overall production efficiency.
- increased volume of sales
- decreased costs of finished goods

4.3 Purposes

This section will present the results for each of the purposes (found in the literature) for which companies intend to implement Digital Twins, in particular, the objectives of each and why DT should be implemented. As a result of analysing the data, it was possible to draw the diagram below (Figure 4), which shows which purposes have the most impact when companies intend to adopt this technology.

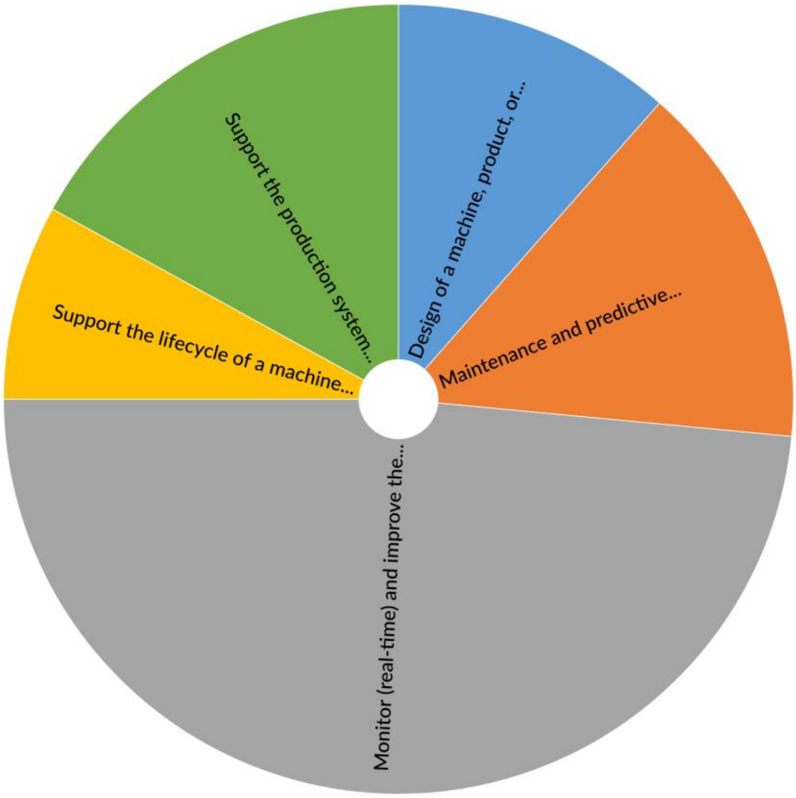

Figure 5 - Impact of purposes on companies

From this diagram, it can be concluded that most of the companies that took part in the project intend to implement Digital Twin in their processes for the purpose of "monitoring (real-time) and improving the process" (with seven of the ten companies), with "maintenance in predictive maintenance" (with six of the ten companies) in second, and "support the production system management" (with four of the ten companies) in third.

By analysing the reports, it was possible to see that the purpose of each Digital Twin solution is chosen based on the company's objectives for introducing this new technology into the company. These objectives are the first stage in building a digital strategy and developing a plan for implementing Digital Twin technology in the company's operations.

Below are presented the common reasons why each purpose was chosen by the companies that took part in the C2T project and a discussion of this results.

4.3.1 Support the production system management (SPSM)

From the reports analysed, it was possible to collect the common reasons (shown in the Table 5) that companies consider to be reasons for wanting to introduce DT technology into their processes with a view to supporting the production system management.

Table 5 - Reasons associated with "Support the production system management"

Reasons:
1. Reduction of occurrences and knowledge the causes in near real time
2. Reduction of strong workforce dependency
3. Reduction of production lead times
4. Achieve Zero Defects and Zero Waste.
5. Real time planning and scheduling system so that it will also have the ability to detect patterns to improve production processes and the quality of scheduling solutions
6. Good customer service
7. Enable real-time knowledge and status of Production Orders
8. Proactive decision making

Despite all the reasons offered by the companies when asked "why" they wished to invest in this particular type of technology, reasons 1, 6, and 8 might be recognised as the most important in defining "Support the production system management" as the DT's purpose.

From the data collected, we may infer that companies that use DT for this purpose prioritise the organization’s improvements in efficiency and performance by focusing on how the company is managed and all the systems that support this management.

4.3.2 Monitor (real-time) and improve the production process (MIPP)

The common reasons that organisations consider to be the leads for wishing to implement DT technology into their operations in order to "monitor (real-time) and improve the production process" were gathered from the reports analysed and are listed in Table 6.

Table 6 - Reasons associeated with "monitor (real-time) and improve the production process"

Reasons:
1. Enable transparency and visualization of the production process both within the company and to stakeholders (suppliers and customers)
2. For better production understanding through the processing of information about fault conditions or manufacturing problems.
3. Improve quality control procedures set of simulation and optimization methods, supported by the real-time live data
4. Reduction of strong workforce dependency
5. Enabling real-time knowledge and status of Production Orders
6. Detect defects in real-time

Among all the reasons given by the companies for adopting Digital Twins with the purpose of " monitor ", the reasons 3 and 4 had the most influence on the development of the implementation strategy.

These motivations imply that there is evidence that companies that choose DT technology for the purpose of "monitoring (real-time) and improving the production process" are primarily concerned with their production process, looking for ways to reduce operating costs by cutting waste and optimising the production process.

4.3.3 Maintenance and predictive maintenance (MPM)

Table 7 displays the most common reasons among the companies that participated in the C2T project that indicated the purpose of digital twins as maintenance and predictive maintenance.

Table 7 - Reasons associated with "maintenance and predictive maintenance"

Reasons:
1. Estimate the risk of future occurrences errors
2. Present the risk analysis.
3. Support the identification and explanation of the causes errors and the definition of recommendations (prescriptive actions) to reduce or even eliminate them.
4. More proactive decision making
5. Minimization on the biggest reasons of stops

Based on the analysis of the reports, the reasons that had the greatest impact on the implementation plan's creation were reasons 1, 3, and 4.

The arguments given by the organisations in the context of the Digital Twin's purpose of maintenance and predictive maintenance demonstrate that when the companies decided to investigate the potential adoption of DT technology, their focus was on long-term results. In other words, these businesses had concerns about the performance and maintenance of the manufacturing process.

4.3.4 Support the lifecycle of a machine process (SLMP)

The most common reasons companies believe to be the leads for considering integrating DT technology into their operations in order to "Support the lifecycle of a machine process" were gathered from the reports studied and are summarised in Table 8.

Table 8 - Reasons associated with "support the lifecycle of a machine process"

Reasons:
1. Commissioning
2. Contributing to the day-to-day operations optimization.

Associated with this purpose are more specific motivations, i.e., motivations more linked to technical components such as machinery. As a result, few DT solutions were recommended to companies, as they are generally looking for broader solutions. Only three companies were suggested as DT solutions for this purpose.

4.3.5 Design (or Redesign) of a machine, product, or production environment (DMPE)

Based on the data analysis, it was possible to identify the most prevalent motives (as shown in Table 9) that companies consider to be reasons for wanting to incorporate DT technology into their organisation with a view to the design (or redesign) of a machine, product, or production environment.

Table 9 - Reasons associated with "design (or redesign) of a machine, product, or production environment "

Reasons:
1. Improve customer satisfaction
2. Minimize production errors
3. Reduce rate of returns
4. Reduce strong workforce dependency
5. Reduce production lead times
6. The minimization of the time-to-market as well as design and test costs.

Reasons 1, 3, 5, and 6 were identified as having a significant impact on the planning of the company's technology implementation strategy from the list of frequently discussed reasons between the companies for this purpose.

These reasons suggest that when incorporating this new technology, businesses prioritise their clients and the quality of the service that they provide. In this regard, the companies that have been proposed with DT solutions for this purpose set a high value on topics that include the services provided to their customers, the quality of the products, and the personalisation of the products/services, all while maintaining their customers' satisfaction in mind.

It is also significant to highlight that the data analysis revealed that there are common reasons among the digital twins's purposes. Some of the reasons associated with the purpose "monitoring (real-time) and improving the production process" were also present in purposes such as "maintenance and predictive maintenance", "support the production system management", and "design (or redesign) of a machine, product, or production environment". This is due to the fact that the core of Digital Twin technology is the real-time monitoring of elements through sensors and the collection of this data into a system that can subsequently be processed in accordance with the company's technology objectives.

Therefore, it is possible to conclude that, while three DT solutions were suggested to the companies with a specific purpose in mind, the purpose of "monitoring (real-time) and improving the production process" is also implicitly incorporated into these solutions, which is why this purpose appears more densely in the diagram shown in figure 3.

5. Conclusions

The goal of this study was to identify the types of Digital Twins solutions that can be implemented by different organisations in the manufacturing sector to progress in their digitisation process, as well as analyse their implementation strategies. To accomplish this, a single case study - the Change2Twin project - was studied, which analysed reports on the implementation of DT solutions from ten companies involved in the project.

Regarding the first goal, it was possible to identify the five types of digital twins that exist in the literature in the data studied: "support the production system management", "monitoring (real-time) and improving the production process", "maintenance and predictive maintenance", "support the lifecycle of a machine process", and "design (or redesign) of a machine, product, or production environment". It was also able to characterise each of them in terms of the motivating factors that drive businesses to seek for DT solutions. It was possible to deduce from this characterization that there is one purpose that is implicitly present in the other purposes - "monitoring (real-time) and improving the production."

Concerning the second objective, which was to analyse the Digital Twins plans, it was possible to identify and analyse each of the four dimensions presented in the literature in the implementation plans developed for the companies: use of technologies, changes in value creation, structural changes, and financial aspects. There were substantial cultural similarities between the organisations in the results for "structural changes" (Human Resources), as well as indications of a connection between the company's area of operation and its receptiveness to new technology. In terms of "use of technologies" (Technology Strategy), it was possible to determine that there is a strong reliance on external providers for the creation and implementation of Digital Twins in businesses. In terms of "value offer," it was determined that the introduction of Digital Twins in businesses creates value through reducing errors/defects, improving product quality, reducing delivery times, and improving decision-making. Finally, it was possible to establish that the "financial aspects" are closely related to the creation of value provided by the company's application of Digital Twins.

Therefore, given the industry's current period of change, which is associated with high connectivity and the implementation of new technologies, particularly Digital Twins, it is critical not only to have a better understanding of the technology to be implemented, but also of how it should be implemented. By intensively analysing these ten companies, it was possible to gain a better understanding of the reasons why companies are searching for DT solutions, the types of Digital Twins available for companies to adopt, and the plan for implementing the technology in the company, thereby helping to assist managers or those responsible for departments dedicated to introducing technology into companies in the initial steps of adopting DT and what they should do.

However, despite the positive contributions, this research has some limitations that must be considered. To begin with, the study only included ten European manufacturing businesses. Additional companies from different sectors and areas might supplement and extend the findings. Based on their importance for the companies under research, this study only investigated five of the reasons presented in the literature. Finally, because this study is based on qualitative research, some of the data was gathered through the visualization of interviews with three of the participating companies; therefore, the findings should be evaluated carefully within the relevant specific circumstances.

In future studies, we recommend analysing companies in other areas of the industry and using a more diverse portfolio of companies in terms of geographical location. Finally, it suggests that a standard roadmap be developed for the implementation of Industry 4.0 technologies, particularly Digital Twin technology, so that companies can use it as a foundation for their implementation.

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