Industry 4.0 and micro and small enterprises: systematic literature review and analysis

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ABSTRACT
Industry 4.0 technologies are a trend in the organizational environments of Micro and Small Enterprises (SMEs). Identifying which technologies need to be implemented to assist the value chain is a challenge for many Micro and Small Business managers. The objective of this study was to identify the relationships between Industry 4.0 technologies and Micro and Small Enterprises. To achieve this, a systematic literature review and content analysis were conducted. A total of 60 articles from the sample were coded, using selection criteria designed to find relevant studies in the domains of Industry 4.0 and Micro and Small Enterprises. Thus, 16 Industry 4.0 technologies were identified, as well as nine possible barriers to implementing them, and eight performance outcomes after adoption in such enterprises.

1. Introduction
The application of digital technologies in production systems generates opportunities to improve operations and develop new products and services. Both, organizations in particular and entire industries, are being transformed by this phenomenon, significantly changing the competitive landscape (Barata et al., 2019; Martínez-Olvera & Mora-Vargas, 2019; Porter & Heppelmann, 2014). Companies of all sizes must adapt to these advances to meet the new market needs and become more competitive (Lugert et al., 2018).

Industry 4.0 (I4.0) – a term coined in Germany in 2011 to refer to the digital transformation of production systems – includes a collection of enabling concepts and technologies to reorganize and empower the value chain (Ayoobkhan, 2019). I4.0 technologies can contribute to the creation of appropriate value propositions based on quality, flexibility, and fast reliable delivery (Szász et al., 2020). On one hand, large companies invest massively in these technologies, expanding their competitiveness (Ayoobkhan, 2019). On the other, Micro and Small Enterprises (SMEs) face difficulties in adopting the new paradigm (Szász et al., 2020). The transition to I4.0 requires appropriate strategies and organizational models (Pirola et al., 2019), which require intellectual development (Ghadge et al., 2020; Klingenberg et al., 2019) and investment capacity, factors that are
often scarce in these organizations. In addition, the availability of human capital is critical for successful operations in the context of I4.0 (Mukhuty et al., 2022).

Although it is often discussed in the literature and business environments, there is no uniformity regarding the definition of SMEs (Berisha & Pula, 2015; (Lunardi et al., 2010). Many countries use the number of employees and/or revenues to classify them (Razak et al., 2018). However, different classifications are used, making the convergence of the results obtained and the possibility of generalization difficult. The study sought to follow the definition used by the European Union, consisting of companies that employ fewer than 250 and whose annual turnover does not exceed 50 million euros, or whose annual balance sheet total does not exceed 43 million euros (Ghadge et al., 2020; Lussier & Sonfield, 2015). Despite this, SMEs represent a very significant proportion in the world market (Matt et al., 2020), in fact, 99% of all firms, 10–15% of direct exports, 16% of investment in cutting-edge technology, and 70% of total employment (OECD, 2021), thus making evident the need for efforts by governments and academia to help SMEs embrace digitization (Ayoobkhan, 2019).

In different countries, it is possible to identify programs directed to this end (Dassisti et al., 2019; Singh et al., 2019; Subramanian et al., 2021; Vivek & Chandrasekar, 2019). Academia has also been making contributions in this direction (Darbanhosseiniamirkhiz & Wan Ismail, 2012; Pech & Vrchota, 2020; Salimon et al., 2019). Even so, no studies devoted to understanding the specifics of implementing I4.0 technologies in SMEs have been found in the literature. This approach is important in helping these companies develop an appropriate strategy to effectively manage the transition to smart manufacturing (Cimini et al., 2021). It is believed that I4.0 can help SMEs improve their competitiveness by building flexible, smart, cost-effective, eco-friendly and socially responsible production ecosystems (Kamble et al., 2020; Srivastava et al., 2022). However, the implementation process and its challenges in the literature must be discussed, as well as in the practical world to demistify the theme for these companies. In this sense, the motivation of this study is the need to organize and systematize the contributions of different authors to I4.0 implementation in SMEs. Thus, this paper seeks to contribute to the body of knowledge about I4.0 in SMEs by answering two questions: (i) What are the main I4.0 technologies adopted in SME business environments? (ii) What are the results of implementing and applying I4.0 technologies in SME production systems?

In this sense, the research aims to identify the I4.0 technologies adopted and display the impacts of the implementation of digital technologies in SME business environments. To achieve this goal, a Systematic Literature Review and a Meta-Synthesis were developed. As a result, a set of I4.0 digital technologies frequently used by SMEs in their organizational environments, the main barriers to their implementation, and the consequences of using these technologies, were identified.

This study is structured in seven sections. The first presents the Introduction. The second deals with the theoretical foundation. The third conceptual framework. The 4 describes the method and procedures used. Section 5 presents the results of the study. Section 6 discusses and analyzes the results identified. Finally, Section 7 presents the conclusions.
2. Theoretical foundation

This section presents the results of the SRL – Systematic Literature Review, showing the main concepts as to the objective of this research. It also presents a brief review of SMEs and their importance to the economic ecosystem.

2.1. Micro and small enterprises

Micro and Small Enterprises (SMEs) are significant in the growth of Gross Domestic Product (GDP), involve a broad customer and employment base, and densify the economic structure (B. Huang et al., 2013; Singh et al., 2019). They are considered the foundation for the stability and competitiveness of any economy (Garay-Rontero et al., 2020; Martinez-Olvera & Mora-Vargas, 2019; Matt et al., 2020; Safar et al., 2018). Even so, SMEs are usually characterized by having limited resources regarding professional skills, infrastructure, technology, and budget (Axmann & Harmoko, 2020; Garay-Rontero et al., 2020; Grube et al., 2017; X. L. Wang et al., 2016). Their survival and competitiveness depend on the ability to react quickly to change, efficiently and reliably, and can use I4.0 technologies to assist in transformations (Ghobakhloo & Ching, 2019; Martinez-Olvera & Mora-Vargas, 2019). Given the above, a dynamic, competitive environment motivates companies to seek initiatives that help prepare for economic, social, political, structural, and technological changes (Dresch et al., 2019).

As technology advances at a rapid pace, SMEs must adapt to the new technological environment and market changes to remain competitive (Ghobakhloo & Ching, 2019; Raymond et al., 2015; Safar et al., 2018). The main motivation for firms to adopt new technologies is the potential benefits they generate (C. J. Huang et al., 2019). Like large companies, SMEs must use them to serve a dynamic, heterogeneous market while achieving high productivity and quality, with fast response, sufficient flexibility, and short lead times (Ghafoorpoor Yazdi et al., 2018). To become international, SMEs need to meet global standards of quality, technology, sustainability, and price (Kumar et al., 2020). Consistently, it is believed that the adoption of I4.0 technologies can assist with achievement of this goal (Gamache et al., 2020; Ghobakhloo & Ching, 2019), because it focuses on the integration of processes aiming to add value throughout the production (Cimini et al., 2021).

If the implementation of I4.0 technologies is a challenge for large companies, SMEs present even greater difficulties due to environmental conditions, technological complexity, economic uncertainties, and limited financial resources (Neirotti et al., 2018; Batz et al., 2018). The process of adopting I4.0 technologies in SMEs is different from that in large organizations, due to their particular characteristics (Ghobakhloo & Ching, 2019). Although SMEs are considered the driving force of economic development (Ayoobkhan, 2019; Dutta et al., 2021), their investment-directed values are modest (Subramanian et al., 2021). However, these companies often lack the knowledge and skills necessary to define their own innovation programs (Taurino & Villa, 2019).

The effectiveness of I4.0 technology adoption depends on organizational characteristics and, specifically, on the company’s readiness to leverage such technologies (Cimini et al., 2021). The more an organization brings forward its moves towards digitalization, the greater the chances that it will benefit from these adaptations and lower the risks of
adopting new technologies (Da Costa et al., 2022). In this sense, SMEs need to adapt to the requirements of technological evolution, knowing the peculiarities of the various existing technologies in order to advance in the transformation process (Nwaiwu et al., 2020). Nara et al. (2021) asserts that, in fact, these companies are struggling to adapt to change and technological turbulence.

2.2. Industry 4.0 and technologies

I4.0 is considered a revolutionary production model (Pech & Vrchota, 2020), and has become a pillar in the quest for quality and flexibility to extend the profits and competitive advantage of companies (Dawal et al., 2015; Narwane et al., 2020; Saniuk & Saniuk, 2018; Swamy & Nanjundeswaraswamy, 2017). The phenomenon has become universal (Yunus, 2020), and is transforming the way businesses exploit the market (Sevinç et al., 2018) and changing the work characteristics and structure of organizations (Gabriel & Pessl, 2016; Mahmood & Mubarik, 2020). As a result, new business models have emerged (C. J. Huang et al., 2019), significantly modifying the production systems (Singh et al., 2019).

The new paradigm presents an accelerated, turbulent (by competition and shortening technology life cycles), exponential dynamic (Mahmood & Mubarik, 2020). The wide range of technologies (Michlowicz, 2021; Türkmen, 2016) is considered a key factor for value creation through data (Darbanhosseinamirkhiz & Wan Ismail, 2012; Klingenberg et al., 2019; Somohano-Rodriguez et al., 2020). Data are considered an inexhaustible new key resource for organizational success (Klingenberg et al., 2019). They enable the creation of intelligent systems, which, in addition to providing more efficiency and flexibility (Vivek & Chandrasekar, 2019), create new revenue possibilities for organizations. In addition to assisting with the search and consolidation in various markets, heading towards global demand for products presents different characteristics (Eidelwein et al., 2018; Gauss et al., 2019; Piran et al., 2017).

The combination of existing technologies and the emergence of disruptive I4.0 ones promotes new opportunities (Agrawal et al., 2022). They can assist in both product and process innovation (Somohano-Rodriguez et al., 2020). The main objective of I4.0 is to strengthen and expand the company’s long-term competitiveness by increasing the flexibility and efficiency of production through communication, information and intelligence (Gabriel & Pessl, 2016). In this context, it is important that companies have strategies directed to the adoption and implementation of digital technologies (Somohano-Rodriguez et al., 2020). I4.0 technologies support seamless operations throughout the organization, while realizing networked cooperation for production (Chen, 2020). The list of which technologies are part of this paradigm is extensive and can vary according to the author’s approach. For this reason, the next section presents the conceptual framework used in this study.

3. Conceptual framework

This section presents a conceptual framework for understanding the adoption of I4.0 technologies in SMEs. Due to the large number of technologies related to I4.0, we sought studies that could serve as a basis for analyzing the problem of this research. As a guideline for the classification of digital technologies, we used the studies of
Klingenberg et al. (2019), Gurría (2017) and (Chiarini & Kumar, 2021). The surveys of Dawal et al. (2015), Gamache et al. (2020), Somohano-Rodríguez et al. (2020), and Agrawal et al. (2022) have helped to understand I4.0 in the context of SMEs. The uptake of and barriers to technologies were addressed in Ghobakhloo and Ching (2019), Narwane et al. (2020), Chen (2020), Gamache et al. (2020), and Subramanian et al. (2021), and Dutta et al. (2021), and Gavrilá and Ancillo (2021). Finally, Neirotti et al. (2018) and Ghobakhloo and Ching (2019) were the basis for understanding the internal and external influences. Figure 1, presents the conceptual model that highlights the different dimensions considered in this study.

4. Methodological procedures

We conducted this study through a Systematic Literature Review (SLR). A literature review is important because it creates a solid foundation for advancing knowledge, facilitates the development of theory, closes off areas where there is a plethora of research, and reveals areas where research is needed (Webster & Watson, 2002). As the subject of I4.0 and its technologies is constantly evolving, it is understood that systematic reviews addressing specific aspects related to the phenomenon are pertinent. In this sense, the importance and the growing need to organize and systematize existing studies related to I4.0 and SMEs is evident. The results of this systematic review generate new perspectives on the topic and help advance the field of research. This revision was applying the strategy of conducting the Literature Grounded Theory (LGT) method, which is used.
to review, analyze, and synthesize the literature (Cardoso Ermel et al., 2021). The following steps were conducted: literature review, literature analysis, literature synthesis, and a projection of the outcome of the LGT method.

With this intention, we began by formulating the research question, using the CIMO tool – Context, Intervention, Mechanisms, and Outcomes (Table 1). Subsequently, the research protocol was organized (Table 2), which can be defined as the formalization of the search strategy (Morandi & Camargo, 2015). The protocol contains the research question, objectives, definition of the research scope in its breadth, extent and dimension, opting for a broad, configurative scope. It also presents a conceptual framework, justifying the importance of the study. The protocol was validated by four experts in the area, whose selection requirements were as follows: (i) had published systematic reviews or possessed knowledge of the subject; and (ii) were researchers who had, as a minimum qualification, a doctorate in their research area, identified by the analysis of the Lattes curriculum, as can be seen in Table 3.

Next, the search strategy, search strings, time horizon, search sources, and subject area were defined. After searching the databases, the corpus identified was refined, and duplicate articles excluded. Then, seeking to include only articles that were related to the study’s objective, two reviewers analyzed the titles, keywords and abstracts. The results of this step were compared, and if any discrepancy was identified in the choice, it was solved by discussion between the reviewers, seeking to ensure agreement. After this step, the articles selected were analyzed in their entirety. Figure 2 illustrates the structure of the search process, with the results of each step.

The flow presented characterizes the selection process of the studies that made up the research corpus of this article. In this process, we used eligibility criteria to exclude and include the studies. These can be seen in Table 4.

Research that contributed to the purpose of the review was included (Table 5). Papers that only cited I4.0 technologies as context, but did not discuss these, technologies, were excluded (Table 6).

Next, it was defined how to perform the data analysis. The choice was made for scientific development and mapping, with the review strategy being of the aggregative type, in which the results of primary studies are aggregated to obtain the results and a meta-synthesis. The latter is defined as a set of techniques used to synthesize the results of multiple qualitative studies developing a new interpretation for the phenomenon of interest (Cardoso Ermel et al., 2021; Finfgeld, 2003). Additionally, scientometric and bibliometric analyses of the research corpus were conducted. The former is concerned with the evaluation of scientific production (Cardoso Ermel et al., 2021; Danuello et al., 2012). The bibliometric analysis provides information about the growth of literature and the flow of knowledge within a specific field over some time by analyzing information collected in databases, such as citations, authors, keywords, or the variety of journals

| Table 1. CIMO Tool – Context, Intervention, Mechanisms and Outcomes. | Source: Adapted from Denyer and Tranfield (2009). |
|---|---|
| Context | Intervention | Mechanisms | Outcomes |
| | I4.0 Technologies | Implementation of I4.0 technologies | Identify the relationship between I4.0 technologies and SMEs |
Table 2. Protocol for Systematic Literature Review – SLR. Source: Adapted from Cardoso Ermel et al. (2021).

| Research Protocol |
|-------------------|
| **Research Title:** Industry 4.0 and Micro and Small Enterprises (SMEs): Systematic Literature Review. |
| **Research Team:** DA SILVA, N. A., ABREU, J. L., KLINGENBERG, C. O., ANTUNES JR., J. A. V., LACERDA, D. P. |
| **Stakeholders:** Companies, managers, and researchers |
| **Revision:** | **Date:** | **Revised by:** | **4 specialists** |
| | | 2021 |

1. **Research Question(s):**

How can Industry 4.0 (I4.0) technologies be implemented in Micro and Small Enterprises (SMEs) in the manufacturing area to improve production systems?

2. **Research Objective(s)**

Identify the relationship between I4.0 technologies and SMEs based on a systematic literature review.

i) Identify the main I4.0 technologies used in SMEs;

ii) Verify which are the results of the implementation of these technologies in the production systems of SMEs;

iii) Find out which techniques are used to apply these technologies.

3. **Review Scope:**

| 3.1 Amplitude: | □ Narrow | X Broad |
|---------------|---------|--------|
| 3.2 Deepness:  | □ Superficial | X Deep |
| 3.3 Review Type: | □ Aggregative | X Configurative |

4. **Theoretical Framework:**

Technological advances are impacting the competitiveness of organizations (Barata et al., 2019). Thus, companies must adapt to advance to market needs and raise their productivity and efficiency rates to remain competitive (Lugert et al., 2018). Industry 4.0 (I4.0) includes a collection of enabling technologies and methods for organizing the value chain that impacts these rates (Ayoobkhan, 2019).

I4.0 technologies can contribute to the creation of appropriate value propositions based on quality, flexibility, fast and reliable delivery (Szász et al., 2020). With this, large-sized companies, which have investments in such technologies, grow in competitiveness (Ayoobkhan, 2019), while Micro and Small Enterprises (MSEs) face difficulties in investing in technologies and becoming competitive in the market (Szász et al., 2020). Therefore, efforts to implement I4.0 technologies in SMEs have become necessary (Ayoobkhan, 2019).

The transition to I4.0 requires appropriate strategies and organizational models (Pirola et al., 2019), since it includes the application of different tools and technologies that provide intelligent development of organizations (Ghadge et al., 2020; Klingenberg et al., 2019). To assess the current position of SMEs in this context, new methods and tools of analysis need to be built.

Thus, it becomes relevant to understand the specificities of the implementation of I4.0 technologies in SMEs, since companies of this size occupy a significant proportion in the global market. Thus, this study aims to analyze which I4.0 technologies are being applied in SMEs and what their effects on companies in this segment are, providing understanding of the subject via the literature and identifying the existing gaps in the use of I4.0 technologies.

5. **Time Horizon:**

Since 2011.

6. **Search String:**

TITLE-ABS-KEY (‘advanced manufacturing’ OR ‘industry* 4.0’ OR ‘smart manufacturing’ OR ‘industrial internet’) AND (‘micro-business’ OR ‘small business’ OR ‘small and medium enterprises’ OR ‘micro and small enterprises’) AND LIMITE-TO (DOCTYPE, ‘ar’)

7. **Search Sources:**

Insert the search sources recovered from step 1.4, e.g. Scopus, Web of Science, and Science Direct.

8. **Searching Approach:**

X Direct searching □ Experts contacting □ Snowballing □ Other:

9. **Eligibility Criteria:**

9.1 Inclusion criteria:
Documents that contain I4.0 technologies;
Documents that address SMEs;
Documents from the engineering and management study area;
Documents that present results from the implementation of I4.0 technologies.

9.2 Exclusion criteria:
Documents that do not meet the inclusion criteria.

(Continued)
Table 2. (Continued).

Research Protocol

10. Data Analysis:
10.1 Scientometric analysis: [X] Scientific development
10.2 Bibliometric analysis: [☐] Research performance [☐] Thematic analysis [☐] Structural analysis
10.3 Content analysis: [X] Aggregative [☐] Thematic analysis [☐] Structural analysis

11. Data Synthesis:
11.1 Aggregative synthesis: [☐] Quantitative meta-analysis [☐] Qualitative meta-analysis
11.2 Configurative synthesis: [X] Meta-synthesis [☐] Other:

Table 3. Identification of the experts. Source: Prepared by the authors based on the Lattes résumé.

| Specialist | Education | Program and Institution |
|------------|-----------|-------------------------|
| 1          | Ph.D. in Production Engineering UFRGS (2005) | Graduate Programs in Production and Systems Engineering and Graduate Program in Accounting – UNISINOS |
| 2          | Ph.D. in Management Science Lancaster University (2000) | Graduate Program in Production Engineering – UFRGS |
| 3          | Ph.D. in Production and Systems Engineering UNISINOS (2020) | School of Management and Business and Polytechnic School – UNISINOS |
| 4          | Ph.D. in Production Engineering UFSC (2005) | Graduate Program in Industrial Systems and Processes – UNISC |

Figure 2. Search flow, filters, and results. Source: Prepared by the authors.
consulted (Cardoso Ermel et al., 2021; Raan, 2009). The computational resource used for data manipulation was Software Biblioshiny – R Studio*.

Next, the process of corpus analysis began, first by defining the coding system. Coding allows identification of relevant information in each article, facilitating analysis of terms and trends in all the studies included in the review (Gough et al., 2012). To assist this process, the qualitative data analysis software Atlas.ti 9* was used. Some categories were defined *a priori* to facilitate the process of analysis and interpretation of the data collected in the articles (Gauss et al., 2021). To deepen the analysis, other codes were included with the use of open, selective, and axial coding (Strauss & Corbin, 1990) that complemented the study. Thus, each article was analyzed and coded according to the criteria presented in Table 7.

It is important to note that there is no convergence among researchers and practitioners as to the classification of I4.0 technologies, the topic being under constant questioning and evolution (Bhandari et al., 2018; Darbanhosseiniamirkhiz & Wan Ismail, 2012; Klingenberg et al., 2019). Seeking to understand the phenomenon and verify significant differences, this study chose to organize and analyze I4.0 technologies concerning three classifications. The first division, proposed by Klingenberg et al. (2019) took into account the use of data and value creation to classify the technologies. Being distributed into four groups, with different data-related functions: (i) Data generation and capture; (ii) Data transmission; (iii) Data conditioning, storage and processing; and (iv) Data application.

The second classification, organized by Gurria (2017), took into consideration the use of digital systems, which considers three classes: (i) Digital technology enablers; (ii) Digital system integrators; and (iii) Application technologies. However, it does not involve the following technologies: Sensors, Radio Frequency Identification Tracking, Optical Character Recognition, Horizontal and Vertical Integration, Virtual Reality, Augmented Reality, and Robotic Systems. However, by the convergence of technologies for digital transformation and their characteristics in data integration, it is believed that these technologies can be absorbed. Thus we defined Horizontal and Vertical Integration as Enabling Technologies: Virtual Reality and Augmented Reality as Integrating Technologies; Robotic Systems as Application Technologies; and Sensors, Radio Frequency Identification Tracking, Optical Character Recognition as Enabling Technologies. This means that many technologies constitute systems and subsystems of other technology (Klingenberg et al., 2019). Next, the third classification organized by Chiarini and Kumar (2021), took into consideration the interaction between Lean Six Sigma tools and principles with I4.0 technologies and systems.

### Table 4. Eligibility Criteria. Source: Prepared by the authors.

| Exclusion Criteria | No. of exclusions | Percentage (%) |
|--------------------|------------------|----------------|
| Duplicate studies  | 79               | 57.7           |
| Lack of I4.0 technology or techniques | 31 | 22.6 |
| Article not found  | 3                | 2.2            |
| Articles that are not related to the research objective | 24 | 17.5 |
| Total              | 137              | 100            |
Table 5. Primary studies included in the review. Source: Prepared by the authors.

| No. | Title                                                                 | (Author, Year)                       |
|-----|------------------------------------------------------------------------|--------------------------------------|
| D1  | Adoption of Digital Technologies of Smart Manufacturing in SMEs         | (Gobakhloo & Ching, 2019)            |
| D2  | Mediating role of Cloud of Things in improving performance of small and medium enterprises in the Indian context | (Narwane et al., 2020)               |
| D3  | Evaluation of enablers of Cloud technology to boost industry 4.0 adoption in the micro, small and medium manufacturing enterprises | (Subramanian et al., 2021)           |
| D4  | A method for applying Industry 4.0 in Small Enterprises                | (Taurino & Villa, 2019)              |
| D5  | Cross-disciplinary innovations by Taiwanese manufacturing SMEs in the context of Industry 4.0 | (Chen, 2020)                         |
| D6  | Integrated application in intelligent production and logistics management: technical architectures concepts and business model analyses for the customized facial masks manufacturing | (Liu et al., 2019)                   |
| D7  | Does Industry 4.0 really matter for SME innovation?                   | (Somohano-Rodríguez et al., 2020)   |
| D8  | An Industry 4.0 maturity model for machine tool companies              | (Rafael et al., 2020)                |
| D9  | Developing the Digital Manufacturing Commons: A National Initiative for US Manufacturing Innovation | (Beckmann et al., 2016)             |
| D10 | Spanish SMEs’ digitalization enablers: E-Receipt applications in the offline retail market | (Gavrila & Ancillo, 2021)           |
| D11 | Robots in Industry                                                    | (Grau et al., 2021)                  |
| D12 | Empirical Evidence of AMT Practices and Sustainable Environmental Initiatives in Malaysian Automotive SMEs | (Dawal et al., 2015)                 |
| D13 | Data analytics framework for Industry 4.0: enabling collaboration for added benefits | (Lazarova-Molnar et al., 2019)       |
| D14 | Cloud manufacturing service platform for small and medium-sized enterprises | (B. Huang et al., 2013)             |
| D15 | Classification of Small and Medium-Sized Enterprises based on the Level of Industry 4.0 Implementation | (Pech & Vrchota, 2020)               |
| D16 | Generic Challenges and Automation Solutions in Manufacturing SMEs       | (Hansen et al., 2017)                |
| D17 | Justification of advanced manufacturing technologies for small and medium enterprises from the auto component sector: AHP approach | (Bhandari et al., 2018)              |
| D18 | Advanced Manufacturing Technology Adoption in SMEs: an Integrative Model | (Darbanhosseini-mirkhiz & Wan Ismail, 2012) |
| D19 | Framework and modeling of an inclusive manufacturing system            | (Singh et al., 2019)                 |
| D20 | Smart manufacturing with the Internet of makers                        | (Chiang & Lee, 2017)                 |
| D21 | Challenges of Industry 4.0 for production enterprises functioning within cyber industry networks | (Saniuk & Saniuk, 2018)             |
| D22 | An approach to support Industry 4.0 adoption in SMEs using a core-metamodel | (Dassisti et al., 2019)             |
| D23 | A Low-Cost Vision-Based Monitoring of Computer Numerical Control (CNC) Machine Tools for Small and Medium-Sized Enterprises (SMEs) | (Kim et al., 2019)                   |
| D24 | Digitalization of MSMEs in India in the context of Industry 4.0: Challenges and Opportunities | (Vivek & Chandrasekar, 2019)         |
| D25 | Advanced manufacturing technology and demographic factors in small and medium manufacturing enterprises – an exploratory study | (Swamy & Nanjundeswaraswamy, 2017)   |
| D26 | Factors Affecting Adoption of Industry 4.0 by Small and Medium-Sized Enterprises: A Case in Ho Chi Minh City, Vietnam | (Nguyen & Luu, 2020)                 |
| D27 | Adoption of Industrial IoT (IIoT) in Auto-Component Manufacturing SMEs in India | (Sivathanu, 2019)                    |
| D28 | A Comprehensive Framework for the Analysis of Industry 4.0 Value Domains | (Martínez-Olvera & Mora-Vargas, 2019) |
| D29 | Discrepancies between cluster services and SMEs’ needs constraining the creation of a culture of innovation amidst industry 4.0 | (Batz et al., 2018)                  |
| D30 | Concept of SME Business Model for the Industry 4.0 Environment         | (Safar et al., 2018)                 |
| D31 | A Maturity Level-Based Assessment Tool to Enhance the Implementation of Industry 4.0 in Small and Medium-Sized Enterprises | (Rauch et al., 2020)                 |
| D32 | Analysis on application level based on ordinal logistic regression and the best of advanced manufacturing technologies (AMT) selection based on fuzzy-TOPSIS integration approach | (G. Wang et al., 2021)               |
| D33 | Integrated process planning and scheduling in networked manufacturing systems for Industry 4.0: a review and framework proposal | (Varela et al., 2021)                |
| D34 | Cloud computing in a human resource management (HRM) system for small and medium enterprises (SMEs) | (X. L. Wang et al., 2016)            |
| D35 | Cloud manufacturing: from concept to practice                          | (Ren et al., 2015)                   |

(Continued)
Table 5. (Continued).

| No. | Title                                                                 | Author(s), Year            |
|-----|-----------------------------------------------------------------------|----------------------------|
| D36 | Evaluating the Factors that are Affecting the Implementation of Industry 4.0 Technologies in Manufacturing MSMEs, the Case of Peru | (C. J. Huang et al., 2019)  |
| D37 | A Hybrid Methodology for Validation of Optimization Solutions Effects on Manufacturing Sustainability with Time Study and Simulation Approach for SMEs | (Yazdi et al., 2019)       |
| D38 | An Empirical Investigation of the Relationship between Overall Equipment Efficiency (OEE) and Manufacturing Sustainability in Industry 4.0 with a Time Study Approach | (Yazdi et al., 2018)       |
| D39 | Common engines of a Cloud manufacturing service platform for SMEs        | (Song et al., 2014)         |
| D40 | Structured analysis of ICT adoption in the European construction industry | (Turk, 2021)               |
| D41 | How SMEs develop ICT-based capabilities in response to their environment: past evidence and implications for the uptake of the new ICT paradigm | (Neirotti et al., 2018)     |
| D42 | An empirical study of real-time information-receiving using Industry 4.0 technologies in downstream operations | (Ghouri et al., 2021)       |
| D43 | Assessment of CIM implementation in SMEs: a multiple case study approach | (Marri et al., 2017)        |
| D44 | Analysis of the Difficulties of SMEs in Industry 4.0 Applications by Analytical Hierarchy Process and Analytical Network Process | (Sevinç et al., 2018)      |
| D45 | A Research on Cloud Computing Adoption Practices in the Context of Online Business SMEs in Sri Lanka | (Ayoobkhan, 2019)          |
| D46 | Industry 4.0 and sustainability impacts: critical discussion of sustainability aspects with a special focus on the future of work and the ecological consequences | (Gabriel & Pessl, 2016)     |
| D47 | A Parameter-Free Vibration Analysis Solution for Legacy Manufacturing Machines’ Operation Tracking | (Ooi et al., 2020)         |
| D48 | Application of Industry 4.0 technologies in SMEs for ethical and sustainable operations: Analysis of challenges | (Kumar et al., 2020)        |
| D49 | Technology enablers for the implementation of Industry 4.0 in traditional manufacturing sectors: A review | (Jimeno-Morenilla et al., 2021) |
| D50 | Modeling the Industry 4.0 adoption for sustainable production in Micro, Small & Medium Enterprises | (Khanzode et al., 2021)    |
| D51 | Intention in Adoption of Industry 4.0 Technology among Small and Medium Enterprises | (Saeedi et al., 2020)      |
| D52 | Smart Hybrid Manufacturing Control Using Cloud Computing and the Internet-of-Things | (Erasmus et al., 2018)     |
| D53 | Ubiquitous knowledge empowers the Smart Factory: The impacts of a Service-oriented Digital Twin on enterprises’ performance | (Longo et al., 2019)       |
| D54 | A dynamic order acceptance and scheduling approach for additive manufacturing on-demand production | (Li et al., 2019)           |
| D55 | How do Industry 4.0 technologies influence organizational change? An empirical analysis of Italian SMEs | (Cimini et al., 2020)       |
| D56 | Analysis of barriers of cyberphysical system adoption in small and medium enterprises using interpretive ranking process | (Wankhede & Vinodh, 2021)  |
| D57 | IIoT implementation challenges: analysis and mitigation by blockchain | (Kumar et al., 2021)        |
| D58 | Adopting open innovation for SMEs in the Industrial Revolution 4.0. | (Anshari & Almunawar, 2021) |
| D59 | External knowledge search, opportunity recognition and Industry 4.0 adoption in SMEs | (Ricci et al., 2021)        |
| D60 | The Impact of Big Data Adoption on SMEs Performance | (Nasrollahi et al., 2021)   |

In addition to the coding scheme mentioned, the relations of occurrence, co-occurrence and frequency were analyzed. According to Bardin (1977), frequency is the most commonly used measure, representing as the frequency of its application the importance of the unit of register. In this study, this measure was determined as the number of times each code occurred in a context unit, the marking being made only once in each context unit. The co-occurrence measure, on the other hand, takes into account the distribution of elements and their association, and tries to extract from the text the
relations between the elements of the message, whereas the occurrence is related to the presence of code in a context unit (Bardin, 1993).

After the data-coding process, a matrix was generated among the analytical categories: Motivators (Antecedents) and Objectives (Consequences), allowing identification of the relationships among the codified variables. The aim was to seek understanding of the motivators that led SMEs to implement Industry 4.0 technologies, and what results they achieved as a result.

5. Results
This section begins with an appreciation of the scientific production of the corpus studied. Subsequently, the findings are identified via content analysis. Then there is a focus on the narrative analysis arising from the data found.
| Id. | 4.0 Concept | Codes | Studies that refer to these factors |
|-----|-------------|-------|------------------------------------|
| 1   | I4.0 Concept |       |                                    |
| 2   | I4.0 Digital Technologies |       |                                    |
| 2.1 | Radio Frequency Identification (RFID) | Klingenberg et al. (2019), Chiarini and Kumar (2021) |
| 2.2 | Security Cybersystems (CSS)/Cyber-Physical System (CPS) | Gurria (2017) |
| 2.3 | Sensors | Klingenberg et al. (2019) |
| 2.4 | Internet of Things (IoT) | Klingenberg et al. (2019), Gurria (2017), Chiarini and Kumar (2021) |
| 2.5 | Horizontal and vertical integration (IHV) | Klingenberg et al. (2019), Gurria (2017) |
| 2.6 | Big Data Analytics (BDA) | Klingenberg et al. (2019), Gurria (2017), Chiarini and Kumar (2021) |
| 2.7 | Cloud Computing (CC) | Klingenberg et al. (2019), Gurria (2017) |
| 2.8 | Virtual Simulation (VS) | Klingenberg et al. (2019); Gurria (2017) |
| 2.9 | Augmented Reality (AR) | Klingenberg et al. (2019); Gurria (2017) |
| 2.10 | Virtual Reality (VR) | Klingenberg et al. (2019); Gurria (2017) |
| 2.11 | Automated Guided Vehicles (AGVs) | Klingenberg et al. (2019); Gurria (2017) |
| 2.12 | Additive Manufacturing (AM) | Klingenberg et al. (2019); Gurria (2017), Chiarini and Kumar (2021) |
| 2.13 | Collaborative/Autonomous Robots (AR) | Klingenberg et al. (2019); Gurria (2017), Chiarini and Kumar (2021) |
| 2.14 | Robotic Systems (RS) | Klingenberg et al. (2019); Gurria (2017), Chiarini and Kumar (2021) |
| 2.15 | Artificial Intelligence (AI) | Klingenberg et al. (2019); Gurria (2017), Chiarini and Kumar (2021) |
| 2.16 | Optical Character Recognition (OCR) | Klingenberg et al. (2019) |
| 3   | Background |       |                                    |
| 3.1 | Competitiveness | (Ghobakhloo & Ching, 2019) |
| 3.2 | Survival | (Ghobakhloo & Ching, 2019) |
| 3.3 | Commercial pressure | (Ghobakhloo & Ching, 2019) |
| 3.4 | Create Value Chain | (Chen, 2020) |
| 3.5 | Innovation | (Somohano-Rodriguez et al., 2020) |
| 3.6 | Quality | (Dutta et al., 2021) |
| 3.7 | Data Analysis | (Lazarova-Molnar et al., 2019) |
| 3.8 | Organizational Improvements/Cost Reduction | (Bhandari et al., 2018) |
| 3.9 | Sustainability | (Martinez-Obreja & Mora-Vargas, 2019) |
| 4   | Consequences acquired with the implementation of the technologies |       |                                    |
| 4.1 | Organizational Improvements | (Ghobakhloo & Ching, 2019) |
| 4.2 | System Integration | (Subramanian et al., 2021) |
| 4.3 | Innovation | (Somohano-Rodriguez et al., 2020) |
| 4.4 | Improve Value Chain | (Somohano-Rodriguez et al., 2020) |
| 4.5 | Software Service | (Beckmann et al., 2016) |
| 4.6 | Environmental Footprint | (Gavril & Ancillo, 2021) |
| 4.7 | Flexibility | (Darbansheiniamirikhzi & Wan Ismail, 2012) |
| 4.8 | Cooperation between Companies | (X. L. Wang et al., 2016) |
| 5   | Barriers identified in the implementation of 4.0 |       |                                    |
| 5.1 | Investment | (Ghobakhloo & Ching, 2019) |
| 5.2 | Qualification/Training and Development (employees) | (Ghobakhloo & Ching, 2019) |
| 5.3 | Government Support Policies/Incentives | (Ghobakhloo & Ching, 2019) |
| 5.4 | Inadequate Information with technologies (managers) | (Ghobakhloo & Ching, 2019) |
| 5.5 | Inadequate Implementation | (Subramanian et al., 2021) |
| 5.6 | Data Security | (Subramanian et al., 2021) |
| 5.7 | Cooperation between Companies | (Saniuk & Saniuk, 2018) |
| 5.8 | Organizational Change | (Nguyen & Luu, 2020) |
| 5.9 | Uncertainty about the return on the implementation investment | (Turk, 2021) |
Between 2011 and 2021, scientific productions showed, until 2013, an average of 2 articles per year. From 2014 to 2017, there was an increase in the volume of publications to 10 articles per year. After 2017, there was constant, significant growth until 2021, practically tripling the article volume. Thus, considering the production of the authors who contributed to the area, and, in view of the bibliographic portfolio analyzed, our research related the total number of publications with the number of citations received per author. Among the main authors was Gardas Bhaskar, with five publications, making him the most cited in 2019, followed by Raut Rakesh, with four addressing Industry 4.0 Technologies. It is worth noting that, in some publications, Bhaskar and Rakesh were coauthors. Both had links to institutions headquartered in India, one of the countries that produce a vast quantity of publications on the theme addressed in the study (Table 8).

As for the countries, 20 were involved in studies on this theme. India stood out with 22 publications, accounting for 16.42% of the total. Malaysia had 19 (14.18%), and the USA, 16 (11.94%). Both of the latter had taken initiatives for industrial development aimed at the Fourth Industrial Revolution. In continental terms, of the three countries that published the most, two were in Asia (India and Malaysia), and the other in North America (USA), but the high volume of publications in Asian and European countries is noticeable (Figure 3).

Sixteen different I4.0 technologies used by SMEs in their organizational environments have been identified (Figure 4).

After reading and coding the articles, the technologies were classified based on the division proposed by Klingenberg et al. (2019). The authors did not classify Cyber-Physical Systems (CPS) as a technology belonging to a single group, because for them it involved all four data-related functions. According to this approach, the use of CPS suggests that the company has a greater maturity in I4.0, as it has a system of technologies that involves enabling and value-creating functions. However, as the term has become widely known, it is often misused. CPS was identified as a technology employed in SMEs in 21 studies, corresponding to 12.35% of the total of all technologies identified in the corpus of 60 articles analyzed in the study, as can be seen in Table 9.

| Author            | Number of articles | Year of publication |
|-------------------|--------------------|---------------------|
| Gasdas B.         | 5                  | 2019                |
| Raut R.           | 4                  | 2019                |
| Akpan I           | 3                  | 2020                |
| Hossain M.        | 3                  | 2020                |
| Kumar V.          | 3                  | 2016                |
| Privadarshinee P. | 3                  | 2017                |
| Singh R.          | 3                  | 2020                |
| Abdullah A.       | 2                  | 2017                |
| Chen C.           | 2                  | 2018                |
| Ghobakhloo M.     | 2                  | 2019                |
| Heng L.           | 2                  | 2015                |
| Jha M.            | 2                  | 2017                |
| Jusoh Y.          | 2                  | 2017                |
| Kamble S.         | 2                  | 2021                |
| Khayer A.         | 2                  | 2020                |
| Kumar R.          | 2                  | 2020                |
| Li Z.             | 2                  | 2019                |
| Lim S.            | 2                  | 2019                |
| Mahmood A.        | 2                  | 2015                |
We organized these same technologies according to the Gurría (2017) proposition (Table 10).

The same technologies were organized based on the approach proposed by Chiarini & Kimar (2021), Table 11.

The total frequency per year of the technologies identified in the study suggests the growth of acceptance and implementation of technologies by SMEs over time. The years 2019 (54 technologies) and 2020 (40) presented the highest volumes. The total frequency of occurrences per year confirms the acceptance and relevance of the Internet of Things as the technology most used by SMEs, the frequency occurrence being 32 (sum of the occurrences in which the technologies were implemented in the studies per year), followed by Cloud Computing with 26, and Big Data Analytics, 20, as can be seen below (Table 12).

Additionally, it is worth analyzing the technologies used jointly, where we sought to verify how the technologies complemented each other, i.e. their dependencies regarding the application in the SME business environments. The most used technologies simultaneously were the Internet of Things with Cloud Computing (15 occurrences), followed by Big Data Analytics (13), and Cyber-Physical Systems (10). Furthermore, it can be observed that the most used technology together with the other technologies was the Internet of Things with 75 occurrences, Cloud Computing with 55, and Cyber-Physical System with 49, as can be seen in Table 13.

Thus, one can see that SMEs were implementing in their organizational environments technologies classified as enabling and integrative, a fact that can be justified by being technologies linked mainly to the capture and interpretation of data, contributing to the storage, sharing, and acceleration of information flow. This allows companies to keep their data stored in the Cloud, therefore they can be used in the development of innovations, improvements to their information flow, identification of customers’ needs, and the flexibility of production processes.

Another fact, to be considered is the popularization of technologies. The reduction of investments in the acquisition and implementation of these technologies can help the
growth of adoption by SMEs, which are companies that obviously have smaller budgets compared to large companies. Also, it can be seen that the technologies identified are mostly related to each other. Moreover, the complexity and integrative nature of the technologies suggest that they have a systemic and evolutionary nature. This means that studying technologies in an interconnected way in the light of the systems view is not only appropriate, but can bring both theoretical and practical insight. Systems thinking aims to seek an integral understanding of reality through circular flows (Andrade et al., 2006; Senge, 1990). The technologies, when used together in an interconnected way, can provide better results to organizational environments, since each technology has different characteristics and purposes, thus complementing each other and providing improvements to the system as a whole.

Also based on the approach used to code the data, the main barriers emphasized by SMEs to implementation of I4.0 technologies were identified. Investment in technologies
was the main barrier highlighted, followed by poor qualification/training and other forms of employee development, few government support policies/incentives, and lack of knowledge of the technologies. Investment in the acquisition and implementation of technologies is related to other barriers identified in the study, as the use of technologies

| Classification                        | Technologies                                      | Frequency identified in the corpus (%) |
|---------------------------------------|--------------------------------------------------|----------------------------------------|
| Data Generation and Capture           | Sensors                                          | 5.88                                   |
|                                       | Radio Frequency Identification (RFID)             | 1.76                                   |
|                                       | Optical Character Recognition (OCR)              | 0.59                                   |
| Data Transmission                     | Internet of Things (IoT)                         | 19.41                                  |
|                                       | Horizontal and Vertical Integration (HMI)         | 1.76                                   |
| Data Conditioning, Storage and Processing | Cloud Computing (CC)                           | 15.88                                  |
|                                       | Big Data Analytics (BDA)                         | 12.35                                  |
|                                       | Augmented Reality (AR)                           | 4.71                                   |
|                                       | Virtual Simulation (VS)                          | 4.71                                   |
|                                       | Artificial Intelligence (AI)                     | 2.94                                   |
|                                       | Virtual Reality (VR)                             | 1.76                                   |
| Data Application                      | Collaborative/Autonomous Robots                  | 5.88                                   |
|                                       | Robotic Systems (RS)                             | 4.12                                   |
|                                       | Additive Manufacturing (AM)                      | 4.12                                   |
|                                       | Automated Guided Vehicles (AGVs)                 | 1.76                                   |

Table 10. Technologies classified by the division proposed by Gurría (2017). Source: Adapted from Gurría (2017).

| Classification        | Technologies                                      |
|-----------------------|--------------------------------------------------|
| Enabling Technologies | Internet of Things (IoT)                         |
|                       | Big Data Analytics (BDA)                         |
|                       | Cloud Computing (CC)                             |
|                       | Horizontal and Vertical Integration (HVI)         |
| Integrating Technologies | Virtual Simulation (VS)                         |
|                       | Cyber-Physical System (CPS)                      |
|                       | Artificial Intelligence (AI)                     |
|                       | Virtual Reality (VR)                             |
|                       | Augmented Reality (AR)                           |
| Application Technologies | Additive Manufacturing (AM)                      |
|                       | Collaborative/Autonomous Robots                  |
|                       | Automated Guided Vehicles (AGVs)                 |
|                       | Robotic Systems (RS)                             |

Table 11. Technologies in relation to the DMAIC (Define, Measure, Analyse, Improve, and Control Phases) steps organized by the approach proposed by Chiarini & Kimar (2021). Source: Adapted from Chiarini & Kimar (2021).

| DMAIC                  | Technology                                      | Frequency identified in the corpus (%) |
|-----------------------|--------------------------------------------------|----------------------------------------|
| Measure-Analyse-Improve| Big Data Analytics (BDA)                         | 32.81                                  |
| Measure-Control        | Sensors                                          | 15.63                                  |
| Improve                | Collaborative/Autonomous Robots                  | 15.63                                  |
| Measure-Analyse-Improve-Control | Augmented Reality (AR)                         | 12.50                                  |
| Improve                | Additive Manufacturing (AM)                      | 10.94                                  |
| Define-Measure-Analyse-Improve-Control | Artificial Intelligence (AI)               | 7.80                                   |
| Measure-Control        | Radio Frequency Identification (RFID)             | 4.69                                   |
Table 12. Technologies by year. Source: Prepared by the authors.

| Technologies / Year | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | Totals |
|---------------------|------|------|------|------|------|------|------|------|------|--------|
| Radio Frequency Identification (RFID) | 1 | | | | | | | | | 3 |
| Virtual Simulation (VS) | | 1 | | | | | | | | 3 |
| Automated Guided Vehicles (AGVs) | 1 | | 1 | | | | | | | 3 |
| Additive Manufacturing (AM) | | | | | | | | | | 7 |
| Collaborative/Autonomous Robots | | 2 | | | | | | | | 10 |
| Robotic Systems (RS) | | | | | | | | | | 5 |
| Artificial Intelligence (AI) | | | | | | | | | | 1 |
| Optical Character Recognition (OCR) | | 1 | | | | | | | | 19 |
| Cyber-Physical System (CPS) | | | | 1 | 1 | 2 | 8 | 6 | 2 | |
| Sensors | | | | | | 1 | | | | |
| Internet of Things (IoT) | | 1 | 1 | | | | 1 | 2 | 4 | 10 | 7 | 7 |
| Horizontal and vertical integration (HIV) | | | | | | | | | | 3 |
| Big Data Analytics (BDA) | | | | | | | | | | 20 |
| Cloud Computing (CC) | | | | | | | | | | 26 |
| Virtual Simulation (VS) | | | | | | | | | | 8 |
| Augmented Reality (AR) | | | | | | | | | | 8 |
| **Totals** | 2 | 5 | 2 | | | | 11 | 14 | 54 | 40 | 34 | 165 |
| **Caption:** | 3 e 4 | 5 e 6 | 5 e 8 | 9 e 10 | |

Table 13. Technologies implemented together with other technologies in the SME environments. Source: Prepared by the authors.

| Technology / Technology | RFID | VR | AGVs | AM | RA | RS | AI | OCR | CPS | Sensors | IoT | HMI | BDA | CC | VS | AR | Total |
|-------------------------|------|----|------|----|----|----|----|-----|-----|--------|-----|------|-----|----|----|----|-------|
| Radio Frequency Identification (RFID) | 1 | | | | | | | | | | | | | | | | |
| Virtual Reality (VR) | | 1 | | | | | | | | | | | | | | | 14 |
| Automated Guided Vehicles (AGVs) | 1 | 1 | | | | | | | | | | | | | | | 7 |
| Additive Manufacturing (AM) | | 1 | | | | | | | | | | | | | | | 23 |
| Collaborative/Autonomous Robots (RA) | | | | | | | | | | | | | | | | | 23 |
| Robotic Systems (RS) | | | | | | | | | | | | | | | | | 19 |
| Artificial Intelligence (AI) | | | | | | | | | | | | | | | | | 19 |
| Optical Character Recognition (OCR) | | | | | | | | | | | | | | | | | 0 |
| Cyber-Physical System (CPS) | 1 | | | | | | | | | | | | | | | | |
| Sensors | | 1 | | | | | | | | | | | | | | | 11 |
| Internet of Things (IoT) | | | | | | | | | | | | | | | | | 75 |
| Horizontal and Vertical Integration (HIMI) | | | | | | | | | | | | | | | | | 12 |
| Big Data Analytics (BDA) | | | | | | | | | | | | | | | | | 53 |
| Cloud Computing (CC) | | | | | | | | | | | | | | | | | 55 |
| Virtual Simulation (VS) | | | | | | | | | | | | | | | | | 32 |
| Augmented Reality (AR) | | | | | | | | | | | | | | | | | 36 |
| **Total** | 11 | 14 | 7 | 29 | 28 | 23 | 19 | 0 | | | | | | | | | |
| **Caption:** | 1 e 2 | 3 e 4 | 5 e 6 | 5 e 8 | 9 e 10 | 11 e 12 | 13 e 14 | 35 e 16 | 36 |

requires qualified professionals, which increases the use of resources for planning and professional development. While the lack of support, incentives and government policies aimed at boosting I4.0 are shown as an inhibitor of the initiatives, since SMEs lack access
to information and financial resources. Public policies aimed at spreading innovation and collaboration-oriented culture are also important, since one of the barriers to the implementation of I4.0 identified was the lack of cooperation among companies. However, by understanding the evolution of technologies and the effect of technological changes on employment, governments can develop policies to support companies – encouraging and investing in data – especially for SMEs, which are massively responsible for providing employment. Thus, helping companies meet technological challenges, strengthening incentives in planning and development, can, consequently, provide economic and social benefits. Figure 5 shows the frequency with which these barriers appeared in the texts analyzed.

Another point to be considered in the analysis are the results of the implementation of technologies in the SMEs’ production systems. As can be observed, Organizational Improvements are the implication most emphasized by the implementation of I4.0 technologies in SMEs, followed by Innovation and Value Chain Improvements. It seems possible to state that there is a correlation between these elements, since developing digital capabilities in organizational environments can contribute to generating improvements in the business environment (Figure 6).

Next, we identified the relationships between the variables, Objectives (Consequences) and Motivators (Antecedents), found in the literature. The main motivators for the implementation of technologies were Competitiveness, Innovation and Cost Reduction. The main outcome was Organizational Improvements, making evident the concern of SMEs to seek strategic and technological initiatives linked to the competitiveness and sustainability of the products and services offered. However, it is possible to observe that Cooperation among Companies is a consequence little observed. Since the effective use of enabling technologies and I4.0 is only likely to be built through collaboration and partnerships (the so-called ‘relational gains’), the data suggest that this is an aspect to be strongly worked on in the SMEs. This is because the relational view expands the focus of analysis beyond the company’s resources, encompassing network resources, obtained through the relationships between partners (Dyer & Singh, 1998). It can be any

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**Figure 5.** Identified barriers. Source: Prepared by the authors.
kind of benefit generated by intra-organizational cooperation that takes the form of competitive advantage (Dyer & Singh, 1998). Thus, it is expected that the greater the relational resources, the greater the value creation. Table 14 presents these and other relationships.

The discussions of this data and coding are presented in the next section.

6. Discussions and implications

The results indicate that the frequency of the 16 technologies increased throughout the period studied, with emphasis on the years 2019 with 54 occurrences (35.3%) and 2020 with 40 (26.1%) of the corpus. The most frequent digital technologies were the Internet of Things with 19.41% and Cloud Computing, 15.88%. This popularization is justified because they are technologies that provide significant changes in organizational environments. They are developing rapidly and influencing the way companies do business (Ren et al., 2015). Both the Internet of Things and Cloud Computing are technologies that support the flow of information, offering benefits to SMEs (Chen, 2020), enabling connectivity between devices and equipment through the use of internet-based networks (Rafael et al., 2020). This is in agreement with the findings of Narwane et al. (2020) that the integration of Cloud Computing and the Internet of Things in SME environments may influence the transformation of business systems to high performance.

Analyzing the technologies together, Cloud Computing and the Internet of Things had the highest occurrence, 6.61% of the time, followed by Big Data Analytics and Internet of Things, corresponding to 5.73% of the results, and Cyber-Physical System and Internet of Things, representing 4.41%, of the total of all technologies practiced by SMEs simultaneously. These percentages indicate the consistent presence of these technologies in SME environments.

However, Big Data Analytics is used to identify patterns (Narwane et al., 2020) and serves to support information flow (Chen, 2020). Cyber-Physical Systems, among its various applications, is employed to perform Cloud processing (Liu et al., 2019). In other
Table 14. Double-entry matrix of the analysis variables. Source: Prepared by the authors.

| Articles                        | Objectives (Consequences)                                                                 |
|---------------------------------|------------------------------------------------------------------------------------------|
|                                 | Organizational Improvements | System Integration | Innovation | Improve value chain | Software Service | Environmental footprint | Flexibility | Cooperation between companies | Frequency |
| Motivators (Background)         | D1, D3, D5, D16, D17, D18, D21, D22, D27, D33, D39, D42, D43, D44, D45, D48, D49, D51, D55 | D3, D5            | D41, D44, D55 | D16, D21, D22, D27, D42 | D22, D22, D24 | D18, D41, D43, D49 | D39, D43 | 38 |
| Survival                        | D1, D3, D10, D11, D16, D17, D21, D40, D45 D51 | D3                | D10, D11     | D10, D11, D16, D21, D40 | D10           | D10                     | D10 | 20 |
| Commercial pressure             | D1, D10, D12, D18, D27, D40     | D10               | D10, D27 D40 | D10, D10, D12 D18 | D18           | 14 |
| Create value chain              | D5, D16, D29                  | D5, D29          | D16, D29     | D50, D29              | D10           | 9 |
| Innovation                      | D7, D16, D17, D18, D21, D26, D27, D29, D30, D42, D44, D45, D48, D49, D53, D55 | D7, D26, D44, D55, D58, D59 | D26 | D18, D29, D41, D49 | 35 |
| Quality                         | D16, D17, D18, D21, D22, D37, D43, D48, D55, D56, D57 | D54, D55          | D16, D21 D22 | D22, D22              | D18, D43, D43 | D43, D54 | 22 |
| Data Analysis                   | D13                           | D13               | D22          | D18, D43, D43, D54 | 3 |
| Cost Reduction/                 | D17, D21, D22, D25, D26, D27, D30, D33, D34, D37, D48, D53, D60 | D26, D28, D54 | D21, D26, D27, D60 | D34, D26, D54 | D34 | 26 |
| Organizational Improvements     | D34, D37, D38, D48, D49       | D28               | D34          | D46, D50, D34, D49, D49 | D34 | 12 |
| Sustainability                  |                               |                   |              |                      |                |                |              |
| Total Frequency                 | 84                           | 7                 | 18           | 29                   | 7              | 11              | 16           | 7 |
words, these technologies contribute data and information to the decision-making process of companies, enhancing resources with consistent information and helping to improve production systems. However, when Big Data Analytics jointly implements the Internet of Things in business environments, they are considered the key to improving the organizational performance of SMEs (Chen, 2020). These technologies have a strong correlation, because, in business environments, there are data that are captured (Internet of Things) and need to be analyzed and transformed into information (Big Data Analytics). They are enabling technologies and are considered crucial in the development of flexible production systems, capable of providing predictions regarding demand, cost, quality, and sustainability of products and services offered by SMEs (Singh et al., 2019). Other technologies analyzed at the same time were the Cyber-Physical System and the Internet of Things, which offer changes in the way industrial communication is carried out (Grau et al., 2021). They can improve relationships with suppliers, employees and customers by allowing information to be shared throughout the value chain, indicating that automated communication reduces production costs and time (Safar et al., 2018).

Although the technologies present correlation, according to the evidence, it is observed that the Internet of Things is part of all groups of technologies implemented together, and is the technology most implemented by SMEs (19.41%), a fact that can be justified by being a technology that allows the connectivity of personnel, machinery and equipment, thus, consequently, the entire value chain. It combines the ability to collect, transmit, analyze and distribute data, this being fundamental to collaboration and the development of new business models (Liu et al., 2019; Somohano-Rodríguez et al., 2020). Collaboration can ease the investment in implementing this technology, considered by managers as a high-investment technology. The use of these technologies indicates that SMEs are investing in supporting technologies that enable them to generate, transmit and process data. This approach can help SMEs improve their relationship with customers (Hansen et al., 2017).

The main benefit identified with the implementation of digital technologies was Organizational Improvements (41.67%). Therefore, for SMEs to achieve improvements in their organizational systems, they must migrate from adopting simple technology tools to smart methodologies with advanced, innovative digital technologies (Ghobakhloo & Ching, 2019). Therefore, by taking on these technologies, SMEs can improve decision-making, that is, helping decision-makers formulate a good adoption strategy to improve environmental, economic and social performance (Narwane et al., 2020; Subramanian et al., 2021). The second benefit identified was Innovation and Improvements to the Value Chain, each with a frequency of 12.96%. SMEs in possession of digital technologies can and should develop training and innovation programs, ones that aim at integration, automation and interconnection of their systems. In addition, innovation improves organizational performance (Subramanian et al., 2021). With technological innovation as a basis, new business models are being used to develop and promote value creation (Martínez-Olvera & Mora-Vargas, 2019), since I4.0 affects how SMEs deliver, create, and appropriate value (Nwaiwu et al., 2020). However, it is advisable to proceed with caution and take small steps in acquiring and developing of certain technologies (Cimini et al., 2021).

However, only 3.70% of the literature surveyed reported the consequence of Cooperation among Companies as a factor to be considered for the implementation of digital technologies in SMEs. However, in dynamic, uncertain environments, such as
those of SMEs, using relational efforts can be an advantageous strategy (Grönroos & Helle, 2012), as, when business partners are willing to make investments in collaborative partnerships, it leads to productivity improvements in the value chain (Dyer & Singh, 1998). This value creation occurs only through cooperation. (Dyer et al., 2018). For this to occur, cooperation and collaboration platforms can be used as support to share any services among the SMEs involved (X. L. Wang et al., 2016; Song et al., 2014). In addition, physical and financial cooperation methodologies should also be used among them (Marri et al., 2017). Collaboration among business managers is essential to achieve sustainable business performance in the digital age (Agrawal et al., 2022).

The main barrier identified was investment (26.35%), considered by SMEs as a matter of great concern due to their limited budgets (Narwane et al., 2020). This finding is in line with indications from previous research on barriers to adopting digital technologies (Beckmann et al., 2016; Grau et al., 2021). Therefore, although investment in digital technology is a significant factor in its adoption (Swamy & Nanjundeswaraswamy, 2017; Lazarova-Molnar et al., 2019; Sivathanu, 2019; Pech & Vrchota, 2020; Grau et al., 2021), it is not just about acquiring the technologies, given that the firms must also empower and train their employees, which constitute other barriers identified in the study (22.30%). SMEs lack skilled labor (Kumar et al., 2020). Qualification and training are known to have a positive relationship with technology acceptance, and exert a positive impact on the successful implementation of these technologies (Subramanian et al., 2021; G. Wang et al., 2021). In addition, technological and organizational challenges are concerns that SMEs have to face in applying I4.0 technologies (Nguyen & Luu, 2020). Conscious, goal-oriented implementation is important in this context.

Promoting financial programs and incentives can be a way of involving SMEs in technological systems. Government policies play an important role in the adoption of solutions arising from the implementation of digital technologies (Grau et al., 2021). Effective use of government programs helps SMEs to obtain financial resources, and integrate into development and infrastructure support programs, helping them assimilate digitalization and, consequently, grow (Vivek & Chandrasekar, 2019).

Another interesting point identified was the existence of interrelationships between the barriers, which makes it even more difficult for SMEs to implement I4.0 technologies. To offer training to employees the company must bear the investment in support associated with this training, ensuring that the new technologies are integrated into the company. Thus, government support plays an important role in helping the implementation of technologies, providing actions directed to technical and financial collaboration (Marri et al., 2017).

Finally, from the matrix presented in Table 14, the verification step was carried out to examine the relations between what companies aimed to implement I4.0 technologies and what was achieved as a result of their use. It was noted that some motivators for implementing the technologies were different from the results acquired by the SMEs at the end of their use, but the results were positive. Therefore, with judicious applications of digital technologies in their processes, SMEs can improve their performance (Bhandari et al., 2018).

The results also suggest that there is a relationship between motivators and consequences, that is, although the motivators appear separated, creating value chain, innovation, quality, data analysis, cost reduction and sustainability, all present a relationship with the consequence of organizational improvements. This relationship points to the
possibility that digital technologies applied to SMEs represent product and process improvements, in addition to the opportunity to develop innovation (Gamache et al., 2020). On the other hand, the motivators competitiveness, survival, and commercial pressure drive managers to seek innovative solutions that enable them to achieve a new competitive level. It is worth noting that the study results indicate that a set of motivators may determine SMEs’ decision to adopt I4.0 technologies. This finding is partially consistent with previous studies (Ghobakhloo & Ching, 2019; Somohano-Rodríguez et al., 2020; Subramanian et al., 2021).

Probably one of the most important issues in this study is the finding regarding the main technologies used jointly by SMEs. This information provides a better understanding of the classifications and uses of technologies in the SME business environments. It is worth noting the identification of the Internet of Things technology as the main technology, used both individually and in collaboration with other technologies. This indicates the concern of companies in this segment to use mainly enabling technologies. In addition, investment was considered a major barrier to the use of technologies by SMEs. Another point concerns the main benefit (Organizational improvements) identified after implementing digital technologies. However, to help achieve this, cooperation among companies (using collaborative digital platforms) and government incentives (training and acquisition programs) are determining factors in realizing the desired improvements.

7. Conclusions

The study presents the I4.0 technologies applied to SMEs, their consequences, and barriers. To achieve the proposed objective, this article conducted a systematic review of 60 articles from the literature. The result of the classification of the studies revealed 16 technologies used by SMEs, with the Internet of Things being the main one used by companies in this segment. With the implementation of digital technologies, organizational processes can be transformed, providing SMEs with cost reductions, competitiveness, innovation, advances in processes, and, consequently, improvements in their entire value chain.

Moreover, with the application of digital technologies, new business models are emerging, and, consequently, competitive pressures are increasing, shifting the market balance. However, despite being aware of the potentially positive effects of Industry 4.0 technologies, SMEs still have limited organizational resources and funds to enrich their technology investment portfolios. This could be mitigated with government support and policies, speeding up the implementation process and improving the value chain, thereby becoming able to achieve improvements in productivity, employability, income distribution, and welfare. The results also suggest that the search for competitiveness and innovation are factors that motivate SMEs to implement digital technologies, and, as a consequence, are achieving organizational improvements (flexibility, systems integration, information flow, cooperation, sustainable practices, and improvements in the value chain).

Thus the main contributions of this study can be summarized: (i) identification of the main digital technologies used by SMEs that resulted in 16 technologies; (ii) the finding that the technologies practiced by this segment are mainly enabling ones directed to data transmission, conditioning, storage and processing; (iii) identification of investment as
the main barrier to technology adoption; and (iv) the conclusion that the main consequence after implementation of digital technologies was organizational improvement. Thus, the study achieved the proposed objective by identifying the main I4.0 technologies adopted by SMEs and exhibiting the impacts of the implementation and application of digital technologies in the business environments of these companies.

Regarding the limitations of this study, three were identified. First, some important literature may have been omitted arising from the search and selection strategies used. The second was not having used the research approach known as snowballing to complement the search strategy used. Third, the challenges and variables faced by SMEs may be different considering company size, business area, and geographic location, which influence the choice and implementation of technologies in SME business environments. Thus, it is suggested that future studies could extend the research to different geographic contexts, business areas, and company sizes. It is also suggested that I4.0 be studied at different stages of maturity in SMEs. Another suggestion is to conduct research regarding ways of overcoming challenges related to the implementation of I4.0 technologies. Finally, the investigation of cases of success and failure in the implementation of I4.0 technologies in SMEs would contribute to the generation of propositions about the phenomenon.

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References
Agrawal, R., Wankhede, V. A., Kumar, A., Upadhyay, A., & Garza-Reyes, J. A. (2022). Nexus of circular economy and sustainable business performance in the era of digitalization. *International Journal of Productivity and Performance Management, 71*(3), 748–774. https://doi.org/10.1108/IJPPM-12-2020-0676
Andrade, A., Acr, S., Rodrigues, L. H., & Souto, R. (2006). *Pensamento Sistêmico Caderno de Campo*. Systems Thinking: Fieldbook.
Anshari, M., & Almunawar, M. N. (2021). Adopting open innovation for SMEs and industrial revolution 4.0. *Journal of Science and Technology Policy Management* 13(2), 405–427. https://doi.org/10.1108/JSTPM-03-2020-0061
Atlas.ti 9 Windows | ATLAS.ti. (2021). https://atlasti.com/product/windows/. Retrieved from August 31 2021
Axmann, B., & Harmoko, H. (2020). Industry 4.0 Readiness Assessment: Comparison of Tools and Introduction of New Tool for SME. *Tehnički glasnik, 14*(2), 212–217. https://doi.org/10.31803/tg-20200523195016
Ayyoobkhan, A. L. M. (2019). A research on cloud computing adoption practices in the context of online business SMEs in Sri Lanka. *International Journal of Recent Technology and Engineering, 8*(4), 12522–12528. https://doi.org/10.35940/ijrte.d5344.118419
Barata, J., Rupino Cunha, P., & Coyle, S. (2019). Evolving manufacturing mobility in Industry 4.0: The case of process industries. *Journal of Manufacturing Technology Management, 31*(1), 52–71. doi:10.1108/JMTM-10-2018-0361.
Bardin, L. (1977). *Análise do discurso* (pp. 70). Edições.
Bardin, L. (1993). *Content analysis*. Presses Universitaires de France Le Psychologue.
Batz, A., Kunath, M., & Winkler, H. (2018). Discrepancies between cluster services and SMEs’ needs constraining the creation of a culture of innovation amidst Industry 4.0. *LogForum, 14*(3), 387–405. https://doi.org/10.17270/J.LOG.2018.286
Beckmann, B., Giani, A., Carbone, J., Koudal, P., Salvo, J., & Barkley, J. (2016). Developing the digital manufacturing commons: A national initiative for US manufacturing innovation. *Procedia Manufacturing*, 5, 182–194. https://doi.org/10.1016/j.promfg.2016.08.017.

Berisha, G., & Pula, J. S. (2015). Defining Small and Medium Enterprises: A critical review. *Academic Journal of Business, Administration, Law and Social Science*, 1 (1), 17–28. www.iipcc.org

Bhandari, D., Singh, R. K., & Garg, S. K. (2018). Justification of advanced manufacturing technologies for small and medium enterprises from auto component sector: AHP approach. *International Journal of Productivity and Quality Management*, 23(4), 473–491. https://doi.org/10.1504/IJPQM.2018.090260

Cardoso Ermel, A. P., Lacerda, D. P., Morandi, M. I. W., & Gauss, L. (2021). Literature Grounded Theory (LGT). In *Literature Reviews* (pp. 85–146). Springer, Cham.

Chen, C. L. (2020). Cross-disciplinary innovations by Taiwanese manufacturing SMEs in the context of Industry 4.0. *Journal of Manufacturing Technology Management*, 31(6), 1145–1168. https://doi.org/10.1108/JMTM-08-2019-0301.

Chiang, Y., & Lee, D. (2017). Smart manufacturing with the internet of makers. *Journal of the Chinese Institute of Engineers*, 40(7), 585–592. https://doi.org/10.1080/02538389.2017.1362324.

Chiarini, A., & Kumar, M. (2021). Lean Six Sigma and Industry 4.0 integration for Operational Excellence: Evidence from Italian manufacturing companies. *Production Planning & Control*, 32(13), 1084–1101. https://doi.org/10.1080/09537287.2020.1784485.

Cimini, C., Boffelli, A., Lagorio, A., Kalchschmidt, M., & Pinto, R. (2021). How do industry 4.0 technologies influence organizational change? An empirical analysis of Italian SMEs. *Journal of Manufacturing Technology Management* 32(3) 695–721. https://doi.org/10.1108/JMTM-04-2019-0135

Da Costa, L. S., Munhoz, I. P., Pereira, L., & Akkari, A. C. (2022). Assessing the digital maturity of micro and small enterprises: A focus on an emerging market (pp. 175–184). Procedia Computer Science. https://doi.org/10.1016/j.procs.2022.01.216

Danuello, J. C., Francina, E., & Oliveira, T. (2012). Análise cientométrica: Produção científica e redes colaborativas a partir das publicações dos docentes dos programas de pós-graduação em Fonoaudiologia no Brasil. *Em Questão*, 18(3), 65–79. https://doi.org/10.19132/1808-5245183

Darbanhosseinamirkhiz, M., & Wan Ismail, W. K. (2012). Advanced manufacturing technology adoption in SMEs: An integrative model. *Journal of Technology Management & Innovation*, 7(4), 112–120. http://doi.org/10.4067/S0718-27242012000400009.

Dassisti, M., Giovannini, A., Merla, P., Chimienti, M., & Panetto, H. (2019). An approach to support Industry 4.0 adoption in SMEs using a core-metamodel. *Annual Reviews in Control*, 47, 266–274. https://doi.org/10.1016/j.arcontrol.2018.11.001.

Dawal, S. Z. M., Tahiri, F., Jen, Y. H., Case, K., Tho, N. H., Zuhdi, A., Mousavi, M., Amindoust, A., & Sakundarini, N. (2015). Empirical evidence of AMT practices and sustainable environmental initiatives in Malaysian automotive SMEs. *International Journal of Precision Engineering and Manufacturing*, 16(6), 1195–1203. https://doi.org/10.1007/s12541-015-0154-6.

Denyer, D., & Tranfield, D. (2009). Producing a systematic review. *The Sage handbook of organizational research methods* (1. ed., pp. 671–689). SAGE Publications.

Dresch, A., Veit, D. R., Lima, P. N. D., Lacerda, D. P., & Collatto, D. C. (2019). Inducing Brazilian manufacturing SMEs productivity with Lean tools. *International Journal of Productivity and Performance Management*, 68(1), 69–87. https://doi.org/10.1108/IJPPM-10-2017-0248.

Dutta, G., Kumar, R., Sindhwani, R., & Singh, R. K. (2021). Digitalization priorities of quality control processes for SMEs: A conceptual study in perspective of Industry 4.0 adoption. *Journal of Intelligent Manufacturing*, 32(6), 1679–1698. https://doi.org/10.1007/s10845-021-01783-2.

Dyer, J. H., & Singh, H. (1998). The relational view: Cooperative strategy and sources of inter-organizational competitive advantage. *Academy of Management Review*, 23(4), 660–679. https://doi.org/10.5465/amr.1998.1255632.

Dyer, J. H., Singh, H., & Hesterly, W. S. (2018). The relational view revisited: A dynamic perspective on value creation and value capture. *Strategic Management Journal*, 39(12), 3140–3162. https://doi.org/10.1002/smj.2785.
Eidelwein, F., Piran, F. A. S., Lacerda, D. P., Dresch, A., & Rodrigues, L. H. (2018). Exploratory Analysis of Modularization Strategy Based on the Theory of Constraints Thinking Process. *Global Journal of Flexible Systems Management, 19*(2), 111–122. https://doi.org/10.1007/s40171-017-0177-1.

Erasmus, J., Grefen, P., Vanderfêesten, I., & Traganos, K. (2018). Smart hybrid manufacturing control using cloud computing and the internet-of-things. *Machines, 6*(4), 62. https://doi.org/10.3390/machines6040062.

Finfgeld, D. L. (2003). Metasynthesis: The State of the Art—So Far. *Qualitative Health Research, 13*(7), 893–904. https://doi.org/10.1177/1049732303253462.

Gabriel, M., & Pessl, E. (2016). Industry 4.0 and sustainability impacts: Critical discussion of sustainability aspects with a special focus on future of work and ecological consequences. *Annals of the Faculty of Engineering Hunedoara, 14*(2), 131 https://annals.fih.upt.ro/pdf-full/2016/ANNALS-2016-2-21.pdf.

Gamache, S., Abdul-Nour, G., Baril, C., & Xu, W. (2020). Evaluation of the influence parameters of Industry 4.0 and their impact on the Quebec manufacturing SMEs: The first findings. *Cogent Engineering, 7*(1), 1771818 https://doi.org/10.1080/23311916.2020.1771818.

Garay-Rondero, C. L., Martinez-Flores, J. L., Smith, N. R., Morales, S. O. C., & Aldrette-Malacara, A. (2020). Digital supply chain model in Industry 4.0. *Journal of Manufacturing Technology Management, 31*(5), 887–933. https://doi.org/10.1108/JMTM-08-2018-0280.

Gauss, L., Lacerda, D. P., & Cauchick Miguel, P. A. (2021). Module-based product family design: Systematic literature review and meta-synthesis. *Journal of Intelligent Manufacturing, 32*(1), 265–312. https://doi.org/10.1007/s10845-020-01572-3.

Gauss, L., Lacerda, D. P., & Sellitto, M. A. (2019). Module-based machinery design: A method to support the design of modular machine families for reconfigurable manufacturing systems. *International Journal of Advanced Manufacturing Technology, 102*(9–12), 3911–3936. https://doi.org/10.1007/s00170-019-03358-1.

Gavrila, S. G., & Ancillo, L. A. (2021). Spanish SMEs’ digitalization enablers: E-Receipt applications to the offline retail market. *Technological Forecasting and Social Change, 162*, 120381 https://doi.org/10.1016/j.techfore.2020.120381.

Ghadge, A., Kara, M. E., Moradlou, H., & Goswami, M. (2020). The impact of Industry 4.0 implementation on supply chains. *Journal of Manufacturing Technology Management, 31*(4), 669–686.

Ghobakhloo, M., & Ching, N. T. (2019). Adoption of digital technologies of smart manufacturing in SMEs. *Journal of Industrial Information Integration, 16*, 100107. https://doi.org/10.1016/j.jii.2019.100107.

Ghobakhloo, M., & Fathi, M. (2020). Corporate survival in Industry 4.0 era: The enabling role of lean-digitized manufacturing. *Journal of Manufacturing Technology Management, 31*(1), 1–30.

Ghouri, A. M., Mani, V., Jiao, Z., Venkatesh, V. G., Shi, Y., & Kamble, S. S. (2021). An empirical study of real-time information-receiving using industry 4.0 technologies in downstream operations. *Technological Forecasting and Social Change, 165* (120551), 1–14. https://doi.org/10.1016/j.techfore.2020.120551.

Gomes Júnior, M. A. (2020). MPE: Conceitos universais e desafios contemporâneos. *Revista. Observatorio de la Economía Latinoamericana* (6), 1–19. https://www.eumed.net/rev/ool/2020/06/conceitos-universais-empresas.html.

Gough, D., Oliver, S., & Thomas, J. (2012). *An introduction to systemic reviews*. SAGE Publications Ltd.

Grau, A., Indri, M., Bello, L. L., & Sauter, T. (2021). Robots in Industry. *IEEE Industrial Electronics Magazine, 21*(March), 58–61. https://doi.org/10.1094/iesn.1983.0038.

Grönonroos, C., Helle, P., & Bettis-Outland, H. (2012). Return on relationships: Conceptual understanding and measurement of mutual gains from relational business engagements. *Journal of Business & Industrial Marketing, 27*(5), 344–359. https://doi.org/10.1108/08858621211236025.

Grube, D., Malik, A. A., & Bilberg, A. (2017). Generic Challenges and automation solutions in manufacturing SMES. *Annals of DAAAM & Proceedings, 28*, pp. 1161–1169. https://doi.org/10.2507/28th.daaam.proceedings.161.
Longo, A., Nicoletti, L., & Padovano, A. (2019). Ubiquitous knowledge empowers the Smart Factory: The impacts of a Service-oriented Digital Twin on enterprises' performance. *Annual Reviews in Control, 47*, 221–236.

Lugert, A., Batz, A., & Winkler, H. (2018). Empirical assessment of the future adequacy of value stream mapping in manufacturing industries. *Journal of Manufacturing Technology Management, 29*, 886–906.

Gurría, A. (2017). *The Next Production Revolution: Implications for Governments and Business*. OECD Publishing.

Hansen, D. G., Malik, A. A., & Bilberg, A. (2017). Generic challenges and automation solutions in manufacturing SMEs. *Annals of DAAAM and Proceedings of the International DAAAM Symposium, January*, 1161–1169. https://doi.org/10.2507/28th.daaam.proceedings.161.

Huang, B., Li, C., Yin, C., & Zhao, X. (2013). Cloud manufacturing service platform for small- and medium-sized enterprises. *The International Journal of Advanced Manufacturing Technology, 65*(9), 1261–1272. https://doi.org/10.1007/s00170-012-4255-4.

Huang, C. J., Talla Chicoma, E. D., & Huang, Y. H. (2019). Evaluating the factors that are affecting the implementation of Industry 4.0 technologies in manufacturing MSMEs, the case of Peru. *Processes, 7*(3), 1–24. https://doi.org/10.3390/PR7030161

Jimeno-Morenilla, A., Azariadis, P., Molina-Carmona, R., Kyratzi, S., & Moulianitis, V. (2021). Technology enablers for the implementation of Industry 4.0 to traditional manufacturing sectors: A review. *Computers in Industry, 125*(103390), 1–13. https://doi.org/10.1016/j.compind.2020.103390

Kamble, S., Gunasekaran, A., & Dhone, N. C. (2020). Industry 40 and lean manufacturing practices for sustainable organizational performance in Indian manufacturing companies. *International Journal of Production Research, 58*(5), 1319–1337. https://doi.org/10.1080/00207543.2019.1630772

Khanzode, A. G., Sarma, P. R. S., Mangla, S. K., & Yuan, H. (2021). Modeling the Industry 4.0 adoption for sustainable production in Micro. *Small & Medium Enterprises. Journal of Cleaner Production, 279* (123489), 1–14. https://doi.org/10.1016/j.jclepro.2020.123489

Kim, H., Jung, W. K., Choi, I. G., & Ahn, S. H. (2019). A low-cost vision-based monitoring of computer numerical control (CNC) machine tools for small and medium-sized enterprises (SMEs). *Sensors, 19*(20), 4506. https://doi.org/10.3390/s19204506

Klingenberg, C. O., Borges, M. A. V., & Antunes, J. A. V., Jr. (2019). Industry 4.0 as a data-driven paradigm: A systematic literature review on technologies. *Journal of Manufacturing Technology Management, 88881*, 23. https://doi.org/10.1108/JMTM-09-2018-0325

Kumar, R., Sindhwani, R., & Singh, P. L. (2021). IIoT implementation challenges: Analysis and mitigation by blockchain. *Journal of Global Operations and Strategic Sourcing 15*(3), 363–379. https://doi.org/10.1108/JGoss-08-2021-0056

Kumar, R., Singh, R. K., & Dwivedi, Y. K. (2020). Application of Industry 4.0 technologies in Indian SMEs for sustainable growth: Analysis of challenges. *Journal of Cleaner Production, 257* (124063), 1–13.

Lazarova-Molnar, S., Mohamed, N., & Al-Jaroodi, J. (2019). Data analytics framework for industry 4.0: Enabling collaboration for added benefits. *IET Collaborative Intelligent Manufacturing, 1*(4), 117–125. https://doi.org/10.1049/iet-cim.2019.0012

Lazarova-Molnar, S., Mohamed, N., & Al-Jaroodi, J. (2019). Data analytics framework for industry 4.0: Enabling collaboration for added benefits. *IET Collaborative Intelligent Manufacturing, 1*(4), 117–125. doi:10.1049/iet-cim.2019.0012

Liu, C., Zhou, Y., Cen, Y., & Lin, D. (2019). Integrated application in intelligent production and logistics management: Technical architectures concepts and business model analyses for the customized facial masks manufacturing. *International Journal of Computer Integrated Manufacturing, 32*(4–5), 522–532. https://doi.org/10.1080/095192X.2019.1599434

Li, Q., Zhang, D., Wang, S., & Kucukkoc, I. (2019). A dynamic order acceptance and scheduling approach for additive manufacturing on-demand production. *The International Journal of Advanced Manufacturing Technology, 105*(9), 3711–3729. https://link.springer.com/article/10.1007/s00170-019-03796-x

Longo, F., Nicoletti, L., & Padovano, A. (2019). Ubiquitous knowledge empowers the Smart Factory: The impacts of a Service-oriented Digital Twin on enterprises’ performance. *Annual Reviews in Control, 47*, 221–236.
Lunardi, G. L., Dolci, P. C., & Maçada, A. C. G. (2010). Adoção de tecnologia de informação e seu impacto no desempenho organizacional: Um estudo realizado com micro e pequenas empresas. Revista de Administração, 45(1), 5–17. https://doi.org/10.1016/S0080-2107(16)30505-2

Lussier, R. N., & Sonfield, M. C. (2015). Micro versus small family businesses: A multinational analysis. Journal of Small Business and Enterprise Development, 22(3), 380–396.

Mahmood, T., & Mubarik, M. S. (2020). Balancing innovation and exploitation in the fourth industrial revolution: Role of intellectual capital and technology absorptive capacity. Technological Forecasting and Social Change, 160, 120248.

Marri, H. B., Gunasekaran, A., Gopang, M. A., Nebhwani, M., & Soomro, A. S. (2017). Assessment of CLM implementation in SMEs: A multiple case study approach. The International Journal of Advanced Manufacturing Technology, 90(5), 2193–2206.

Martinez-Olvera, C., & Mora-Vargas, J. (2019). A comprehensive framework for the analysis of Industry 4.0 Value Domains. Sustainability (Switzerland), 11(10), 1–21. https://doi.org/10.3390/su11102960

Matt, D. T., Modrák, V., & Zsifkovits, H. (2020). Industry 4.0 for SMEs: Challenges, opportunities and requirements. Springer Nature.

Michlowicz, E. (2021). Logistics engineering and industry 4.0 and digital factory. Archives of Transport, 57. https://doi.org/10.5604/01.3001.0014.7484

Morandi, M. I. W. M., & Camargo, L. F. R. (2015). Revisão sistemática da literatura. Design science research: Método de pesquisa para avanço da ciência e tecnologia (pp. 141–175). Bookman.

Mukhuty, S., Upadhyay, A., & Rothwell, H. (2022, January). Strategic sustainable development of Industry 4.0 through the lens of social responsibility: The role of human resource practices. Business Strategy and the Environment, 1–14. https://doi.org/10.1002/bse.3008

Nara, E. O. B., Costa, M. B., Baierle, I. C., Schaefer, J. L., Benitez, G. B., Do Santos, L. M. A., & Benitez, L. B. (2021). Expected impact of industry 4.0 technologies on sustainable development: A study in the context of Brazil’s plastic industry. Sustainable Production and Consumption, 25, 102–122.

Narwane, V. S., Raut, R. D., Mangla, S. K., Gardas, B. B., Narkhede, B. E., Awasthi, A., & Priyadarshinee, P. (2020). Mediating role of cloud of things in improving performance of small and medium enterprises in the Indian context. Annals of Operations Research, 1–30. https://doi.org/10.1007/s10479-019-03502-w

Nasrollahi, M., Ramezani, J., & Sadraei, M. (2021). The Impact of Big Data Adoption on SMEs’ Performance. Performance. Big Data and Cognitive Computing, 5(4), 68.

Neirotti, P., Raguseo, E., & Paolucci, E. (2018). How SMEs develop ICT-based capabilities in response to their environment: Past evidence and implications for the uptake of the new ICT paradigm. Journal of Enterprise Information Management, 31(1), 10–37. https://doi.org/10.1108/JEIM-09-2016-0158

Nguyen, X. T., & Luu, Q. K. (2020). Factors Affecting Adoption of Industry 4.0 by Small- and Medium-Sized Enterprises: A Case in Ho Chi Minh City, Vietnam. Vietnam. The Journal of Asian Finance, Economics and Business, 7(6), 255–264.

Nwaiwu, F., Duduci, M., Chromjakova, F., & Otekhile, C. A. F. (2020). Industry 4.0 concepts within the Czech SME manufacturing sector: An empirical assessment of critical success factors. Business: Theory and Practice, 21(1), 58–70. https://doi.org/10.3846/btp.2020.10712

OECD. (2021). Discover the centre for entrepreneurship, SMEs, regions and cities. OECD Publishing. Disponível em: https://www.oecd.org/cfe/CFE-Brochure-2021-Final-web.pdf. Acesso em 16 fevereiro 2022

Ooi, B. Y., Beh, W. L., Lee, W. K., & Shirmohammadi, S. (2020). A parameter-free vibration analysis solution for legacy manufacturing machines operation tracking. IEEE Internet of Things Journal, 7(11), 11092–11102. https://doi.org/10.1109/JIOT.2020.2994395

Pech, M., & Vrchota, J. (2020). Classification of small-and medium-sized enterprises based on the level of industry 4.0 implementation. Applied Sciences, 10(15), 1–22.

Piran, F. A. S., Lacerda, D. P., Camargo, L. F. R., Viero, C. F., Dresch, A., & Dresch, A. (2017). Product modularity and its effects on the production process: An analysis in a bus
manufacturer. *The International Journal, Advanced Manufacturing Technology, 88*(5–8), 2331–2343.

Pirola, F., Cimini, C., & Pinto, R. (2019). Digital readiness assessment of Italian SMEs: A case study research. *Journal of Manufacturing Technology Management, 31*(5), 1045–1083.

Pisar, P., & Mazo, M. E. (2020). Controlling, communication and corporate culture—the opportunities for SMEs. *Economics & Sociology, 13*(3), 113–132.

Porter, M. E., & Heppelmann, J. E. (2014). How smart, connected products are transforming competition. *Harvard Business Review, 92*(11), 64–88.

Raan, A. V. (2009). For your citations only? Hot topics in bibliometric analysis. *Interdisciplinary Research and Perspectives, 3*(1), 50–62. October 2014, 37-41. https://doi.org/10.1207/s15366359mea0301_7

Rafael, L. D., Jaione, G. E., Cristina, L., & Ibón, S. L. (2020). An Industry 4.0 maturity model for machine tool companies. *Technological Forecasting and Social Change, 159*, 120203.

Rauch, E., Unterofer, M., Rojas, A. A., Gualtieri, L., Woschank, M., & Matt, D. T. (2020). A maturity level-based assessment tool to enhance the implementation of industry 4.0 in small and medium-sized enterprises. *Sustainability, 12*(9), 3559.

Raymond, L., Bergeron, F., Croteau, A. M., & St-Pierre, J. (2015). Developing absorptive capacity through e-business: The case of international SMEs. *Journal of Small Business Management, 53*, 75–94.

Razak, D. A., Abdullah, M. A., & Ersoy, A. (2018). Small medium enterprises (SMEs) in Turkey and Malaysia a comparative discussion on issues and challenges. *International Journal of Business, Economics and Law, 10*(49), 2–591.

Ren, L., Zhang, L., Tao, F., Zhao, C., Chai, X., & Zhao, X. (2015). Cloud manufacturing: From concept to practice. *Enterprise Information Systems, 9*(2), 186–209.

Ricci, R., Battaglia, D., & Neirotti, P. (2021). External knowledge search, opportunity recognition and industry 4.0 adoption in SMEs. *International Journal of Production Economics, 240*, 108234.

Saeedi, S. A. W., Sharifuddin, J., & Seng, K. W. K. Intention on Adoption of Industry 4.0 Technology Among Small And Medium Enterprises. *International Journal of Scientific and Technology Research, 9*(2), 4472–4478.

Safar, L., Sopko, J., Bednar, S., & Poklemba, R. (2018). Concept of SME business model for industry 4.0 environment. *Tem Journal, 7*(3), 626. https://doi.org/10.18421/TEM73-20

Salimon, M. G., Abdullah, H. H., Gorondutse, A. H., Bin Abdullah, S. S., Tafida, A., Ango, Y. I., Andow, H., & Abdul-Qadir, A. B. (2019). Empirical implementation of industry 4.0 model among Malaysian and Nigerian SMEs. *International Journal of Supply Chain Management, 8*(3), 622–632.

Saniuk, S., & Saniuk, A. (2018). Challenges of industry 4.0 for production enterprises functioning within cyber industry networks. *Management Systems in Production Engineering, 26*(4), 212–216.

Senge, P. (1990). *A Quinta disciplina. 14. ed.* Best Seller. 352. Trad.

Sevinç, A., Gür, Ş., & Eren, T. (2018). Analysis of the difficulties of SMEs in industry 4.0 applications by analytical hierarchy process and analytical network process. *Processes, 6*(12), 1–16. https://doi.org/10.3390/pr6120264

Singh, S., Mahanty, B., & Tiwari, M. K. (2019). Framework and modelling of inclusive manufacturing system. *International Journal of Computer Integrated Manufacturing, 32*(2), 105–123.

Sivathanu, B. (2019). Adoption of industrial IoT (IIoT) in auto-component manufacturing SMEs in India. *Information Resources Management Journal (IRMJ), 32*(2), 52–75.

Somohano-Rodríguez, F. M., Madrid-Guijarro, A., & López-Fernández, J. M. (2020). Does Industry 4.0 really matter for SME innovation? *Journal of Small Business Management, 1–28*. https://doi.org/10.1080/00472778.2020.1780728

Song, T., Liu, H., Wei, C., & Zhang, C. (2014). Common engines of cloud manufacturing service platform for SMEs. *The International Journal of Advanced Manufacturing Technology, 73*(1), 557–569.

Srivastava, D. K., Kumar, V., Ekren, B. Y., Upadhyay, A., Tyagi, M., & Kumari, A. (2022). Adopting Industry 4.0 by leveraging organisational factors. *Technological Forecasting and Social Change, 176.*
Strauss, A., & Corbin, J. (1990). *Basics of qualitative research*. Sage publications.

Subramanian, G., Patil, B. T., & Gardas, B. B. (2021). Evaluation of enablers of cloud technology to boost industry 4.0 adoption in the manufacturing micro, small and medium enterprises. *Journal of Modelling in Management, 16*(3), 944–962.

Swamy, D. R., & Nanjundeswaraswamy, T. S. (2017). Advanced Manufacturing Technology and Demographical Factors in Manufacturing Small and Medium Enterprises—an Exploratory Study. *Annals of the Faculty of Engineering Hunedoara, 15*(1), 175.

Szász, L., Demeter, K., Rácz, B. G., & Losonci, D. (2020). Industry 4.0: A review and analysis of contingency and performance effects. *Journal of Manufacturing Technology Management, 28*. https://doi.org/10.1108/JMTM-10-2019-0371

Taurino, T., & Villa, A. (2019). A method for applying Industry 4.0 in Small Enterprises. *IFAC Papers Online, 52*(13), 439–444.

Turk, Z. (2021). Structured analysis of ICT adoption in the European construction industry. *International Journal of Construction Management*, 1–7.

Türkmen, M. (2016). Effect of manufacturing strategy on business performance. *Uluslararası İktisadi ve İdari İncelemeler Dergisi, 16*, 45–60. https://doi.org/10.18092/iieds.50408

Varela, M. L., Putnik, G. D., Manupati, V. K., Rajyalakshmi, G., Trojanowska, J., & Machado, J. (2021). Integrated process planning and scheduling in networked manufacturing systems for 4.0: A review and framework proposal. *Wireless Networks, 27*(3), 1587–1599. https://link.springer.com/article/10.1007/s11276-019-02082-8

Veile, J. W., Kiel, D., Müller, J. M., & Voigt, K.-I. (2020). Lessons learned from Industry 4.0 implementation in the German manufacturing industry. *Journal of Manufacturing Technology Management, 31*(5), 977–997.

Vivek, M., & Chandrasekar, K. (2019). Digitalization of MSMEs in India in context to Industry 4.0: Challenges and opportunities. *International Journal of Advanced Science and Technology, 28*(19), 937–943.

Wang, X. L., Wang, L., Bi, Z., Li, Y. Y., & Xu, Y. (2016). Cloud computing in human resource management (HRM) system for small and medium enterprises (SMEs). *The International Journal of Advanced Manufacturing Technology, 84*(1), 485–496. https://doi.org/10.1007/s00170-016-8493-8

Wang, G., Zhang, L., & Guo, J. (2021). Analysis on application level based on ordinal logistic regression and best of advanced manufacturing technologies (AMT) selection based on fuzzy-TOPSIS integration approach. *Journal of Intelligent & Fuzzy Systems, Preprint*, 1–11. https://doi.org/10.3233/JIFS-189663

Wankhede, V. A., & Vinodh, S. (2021). Analysis of barriers of cyber-physical system adoption in small and medium enterprises using interpretive ranking process. *International Journal of Quality & Reliability Management, 28*(11), 1454–1466. https://doi.org/10.1108/ijqrm-09-2020-0188

Webster, J., & Watson, R. T. (2002). Analyzing the past to prepare for the future: Writing a literature review. *MIS Quarterly, 26*(2), 13–23. https://doi.org/10.1016/j.freeradbiomed.2005.02.032

Yazdi, P. G., Azizi, A., & Hashemipour, M. (2018). An empirical investigation of the relationship between overall equipment efficiency (OEE) and manufacturing sustainability in industry 4.0 with time study approach. *Sustainability, 10*(9), 3031.

Yazdi, P. G., Azizi, A., & Hashemipour, M. (2019). A hybrid methodology for validation of optimization solutions effects on manufacturing sustainability with time study and simulation approach for SMEs. *Sustainability, 11*(5), 1454. https://doi.org/10.3390/su11051454

Yunus, E. N. (2020). The mark of industry 4.0: How managers respond to key revolutionary changes. *International Journal of Productivity and Performance Management, 70*(5), 1213–1231.