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Article

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Surround yourself with your betters: Recommendations for adopting Industry 4.0 technologies in SMEs

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ABSTRACT

The purpose of this paper is to review the state-of-the-art literature on Industry 4.0 and digitalisation in small and mid-sized enterprises (SMEs). The paper aims to extrapolate and organise recommendations for how to progress in these disciplines from a substantial number of studies. This is accomplished by a systematic literature review on publications within the period 2018–2021. For this purpose, a rigorous metadata analytics process is deployed to retrieve, filter, and structure large amounts of metadata to increase inclusiveness and transparency. The findings consist of 11 focus areas that are developed by extrapolating recommendations from the reviewed literature. These focus areas are structured using the technology-organisation-environment (TOE) framework, which is divided into subcategories. From these, three specific technology-focused recommendations are developed. Furthermore, the paper identifies some concerns with the current research methods due to the overall low implementation of Industry 4.0 in SMEs. This leads to suggesting that future research should engage in pragmatic research methods with attention to how digital technologies are applied in SMEs.

1. Introduction

Industry 4.0 has been central to industrial digital transformation (DT) since 2011, discussing new ways of connecting devices and systems, resulting in new data insights, customisable products, and technological autonomy (Horváth & Szabó, 2019; Matt, Rauch, & Zsifkovits, 2020; Sevinç, Gür, & Eren, 2018; Xu, David, & Kim, 2018). This industrial revolution has introduced many new digital technologies and, by extension, vast amounts of possibilities for new business development opportunities. Industry 4.0 describes the DT of manufacturing, in which interconnected processes and equipment allow the mass customisation of products and responses to market demands (Bakkari & Khatory, 2017; Decker, 2017; Horváth & Szabó, 2019; Karki, Basnet, Xiang, Montoya, & Porras, 2022). DT, inspired by Industry 4.0, is vital in many industries where it is especially important for small and medium-sized enterprises (SMEs) not to be excluded from such opportunities, as these companies make up 99% of the companies in Europe (Andulkar, Le, & Berger, 2018; Bidan, Rowe, & Truex, 2012; Bouwman, Nikou, & de Reuver, 2019; Crupi et al., 2020; De Marco, Martelli, & Di Minin, 2020; Masood & Sonntag, 2020; Matt et al., 2020; Ulas, 2019). However, several authors have raised concerns about the engagement of SMEs in the Industry 4.0 paradigm. This is highlighted by Sommer (2015), who finds that smaller

SMEs may become victims of Industry 4.0, as they do not possess the necessary resources to participate in comprehensive digitalisation initiatives. Holopainen, Ukko, and Saunila (2022) similarly find that most of the studied companies struggle with adjusting their operations in DT. Furthermore, both Ganzarain and Errasti (2016) and Sommer (2015) highlight that SMEs simply do not know where to start their DT. Numerous papers have already investigated the barriers to implementing Industry 4.0 in the context of SMEs. Generally, they find that unlike larger corporations, SMEs experience grave shortcomings when it comes to financial resources and availability of technical competences (Bidan et al., 2012; Rassool & Dissanayake, 2019; Sommer, 2015). These issues are not new, and throughout the literature, authors have proposed future research directions that should be explored to help SMEs implement Industry 4.0 technologies. For example, Menon and Shah (2020) suggest creating an extensive master plan for digitalisation for SMEs. Similarly, Coleman et al. (2016) request a mechanism that can assist SMEs in getting started. Ghobakhloo and Ching (2019) conclude that there is a need for research that addresses the identification of the key determinants that make SMEs adopt and implement digital technologies. Matt et al. (2020) and Sommer (2015) highlight the need for further research on action plans that can support SMEs when introducing Industry 4.0 initiatives. Veile, Kiel, Müller, and Voigt (2020) brings

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learnings from 13 interviews with Industry 4.0-experienced automotive companies in Germany, thereby providing practical insights into how to implement Industry 4.0 initiatives. However, as these insights originate from large corporations, it remains unclear how SMEs can achieve the same given their resource restraints. Furthermore, the authors suggest broadening these aspects to other industries. Similarly, [Ortt, Stolwijk, and Punter \(2020\)](#), who discuss 11 papers on the implementation of Industry 4.0, call on research on specific methods and insights for introducing Industry 4.0 initiatives in different types of companies. This suggests that there is a lack of research that targets specific focus areas and recommendations for SMEs that can help them enter the Industry 4.0 paradigm and that some focused attention should be given to investigate how these can introduce Industry 4.0 initiatives. Therefore, this research will take a first step towards this goal by conducting a systematic literature review to uncover and consolidate the recommendations for implementing digitalisation and Industry 4.0 initiatives in SMEs. Hence, the following research question is proposed: *What are the current recommendations for adopting Industry 4.0 technology in SMEs based on contemporary research?*

This work is meant as a starting point for companies and researchers venturing into new digitalisation and Industry 4.0 research projects as it provides the basic enablers of the technological, organisational, and environmental aspects of Industry 4.0. The remaining sections are organised as follows: [Section 2](#) will describe the methods used to gather data for the systematic literature review, and it will comment on the data. [Section 3](#) will describe the findings of the review. [Section 4](#) will discuss the results, and [Section 6](#) will conclude the paper.

2. Methodology

This research followed a rigorous process that will be described in this section. The goal was to provide a completely transparent search and filtering process, which, at the same time, was as inclusive as possible. This was achieved using several Python scripts, which can rigorously process large amounts of metadata. First, query strings were generated using lists of keywords. Second, these query strings were copied into the search fields of the selected databases, and the metadata from the search results were downloaded. Third, after downloading the metadata from all queries and all included databases, the metadata was further processed by further scripts. These scripts provided information about the filtering process and a list of references to be manually screened. From this list, the title was read for each entry, and irrelevant papers were filtered out. Lastly, this was repeated for the abstracts, narrowing down the list of papers. Finally, the papers that remained in the dataset were acquired and read.

According to [Kitchenham et al. \(2009\)](#), four databases is enough to conduct a reliable literature review, while [Yilma, Panetto, and Naudet \(2021\)](#) use six. This research uses seven databases: ACM, IEEE, Sage, ScienceDirect, Scopus, Taylor & Francis, and Web of Science. These databases were searched based on the search strings generated by the scripts. The keywords for the query generation were divided into two categories: *technology* keywords and *implementation* keywords. Technology keywords are keywords that relate to specific digital technologies. Furthermore, these keywords were combined with their known aliases, as different authors use different terms. Each technology keyword was combined with its most common synonyms. The list of implementation keywords contains keywords that relate to the implementation and introduction of these digital technologies. This list contains not only synonyms per se but also words that are simply related to each other or are relevant to the context of implementing the technologies. For example, some authors use the words ‘deploy’ and/or ‘implement’ to describe putting an IoT device into an operational environment. Furthermore, the keywords were combined with the search terms ‘SME’ and ‘small and medium’, as this review focuses on SMEs. The keywords generated a total of 60 queries that were used to search the seven different databases. Examples of queries can be found

in [Fig. 1](#).

To control the filtering of the metadata, the following inclusion criteria were set:

- C1. Only recent studies, published in 2018 or later, should be included. This is to ensure relevance of the publications
- C2. Only unique papers should be included; duplicates must be removed.
- C3. Papers must include the keyword combinations (as presented in the query strings) in the title, abstract, and/or keywords.

From all the metadata acquired, a total of 15,347 unique papers were identified using the queries from all seven databases. After removing entries with duplicate DOIs, 6931 papers remained. From there, entries with duplicate titles were removed. This operation was performed because not all entries had an available DOI. This led to the removal of an additional 85 entries. Lastly, all entries that did not meet the rigorous query requirements were filtered out. This was achieved by checking to see if the combination of keywords in each query string was present in the title, abstract, or keywords of each entry. Filtering out all entries that did not meet this requirement left 801 papers in the dataset; thus, a large proportion of the papers were filtered out. The remaining 801 papers underwent a manual process consisting of reading the titles and abstracts of each paper and filtering out the papers that seemed irrelevant. To steer this process, further criteria were set:

- C4. Publications must be peer-reviewed conferences or journal publications. This means that books, patents, reports, and theses are not included.
- C5. The language of the papers must be English.
- C6. The studies must contain empirical work – this means that other literature review papers will be discarded. This is to avoid accumulated interpretation bias.

This left 201 papers in the final dataset. Each of the 201 papers was downloaded and read from start to finish to determine its relevance for this review. To control the filtering, the following inclusion criteria were set:

- C7. The studies must make recommendations or propose drivers for introducing digitalisation/Industry 4.0 initiatives. Papers that focus only on barriers or only highlight issues will not be included, as converting these into recommendations may introduce interpretation bias.
- C8. The studies must be technology focused. Some papers discuss business aspects of technology initiatives but do not discuss technology itself.
- C9. The papers must also study the impact of technology initiatives on business.

As a result of this process, 148 papers were discarded, leaving 50 papers to be included in this literature review.

Looking at the year of publication for the included papers, there seems to be an increasing trend of such papers being published over the last four years. The data were obtained up until October 2021; more papers will likely be published throughout 2021, thus continuing the trend ([Fig. 2](#)).

Scanning the methodology sections from the included papers revealed that 23 papers used quantitative research methods, 20 papers used qualitative methods, and seven papers used mixed methods. While all of the quantitative papers used questionnaires, the qualitative papers performed different types of studies. As shown in [Fig. 2](#), the majority of the qualitative papers mainly conducted case studies. Most of these papers performed multiple case studies, while three papers perform single case studies and two papers conducted cross-case studies. The remaining papers conducted expert interviews or design science

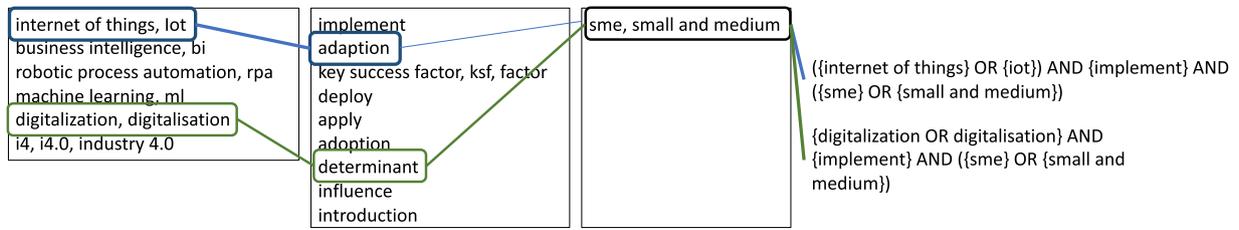


Fig. 1. Queries generated from the listed keywords.

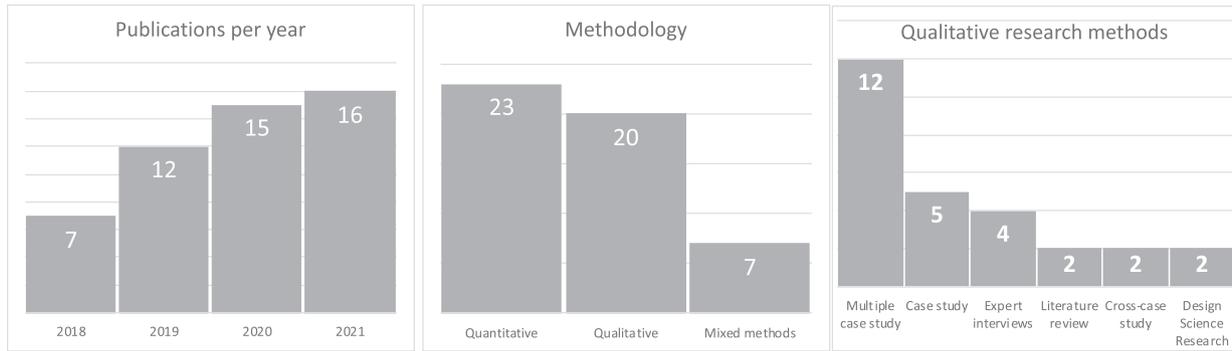


Fig. 2. Descriptive statistics of the year of publication, type of research, and methodology.

research (Fig. 2). Looking at the geographical distribution (Fig. 3), most of the papers originated in Europe, specifically Western Europe. Most of the papers from Western Europe (10) were from Germany. Most papers from Eastern Europe were from the Czech Republic (4). Most papers from Southern Europe were from Italy (8).

To gain a deeper understanding of the papers in the dataset, a cross-reference analysis was performed. This was done by determining which of the references in each paper existed in the dataset. This analysis provides an overview of the interlinkages between the papers in the dataset and thereby highlights defining papers in the field. This

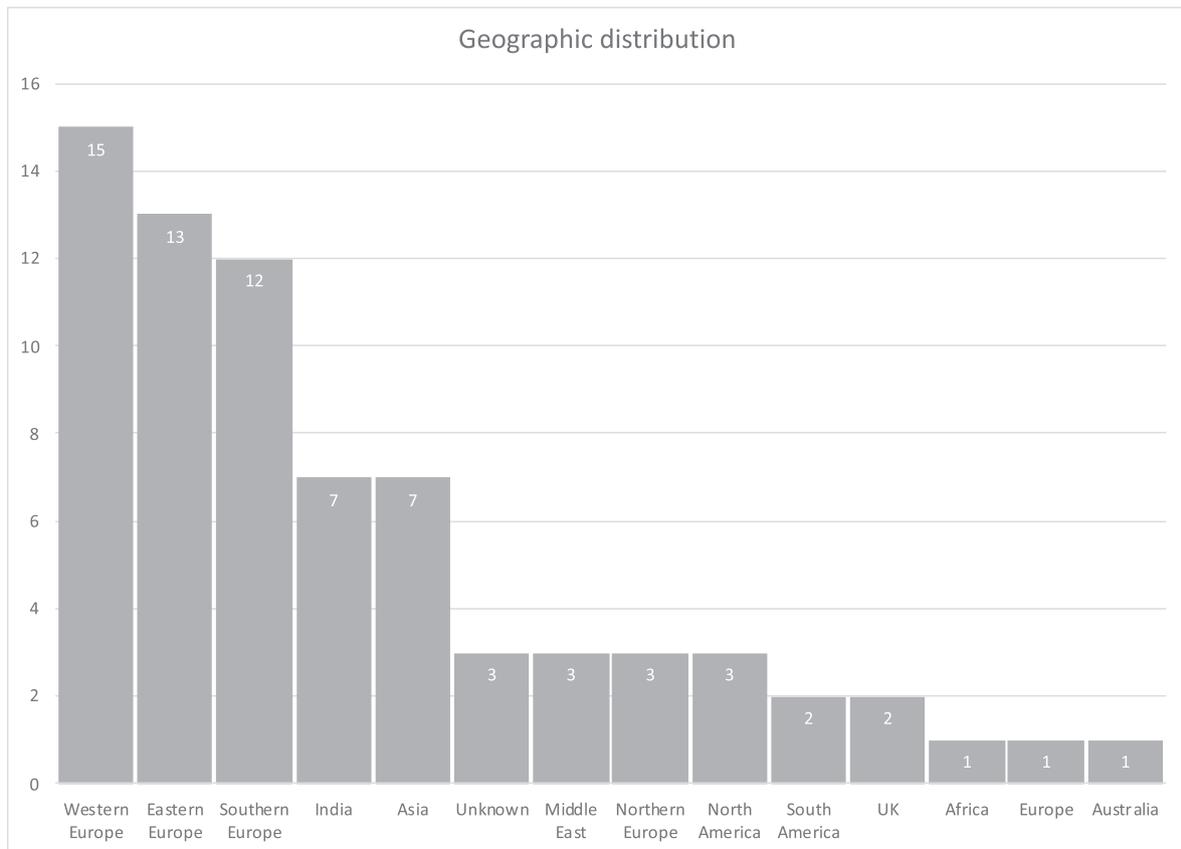


Fig. 3. Geographical sources of the included papers.

interrelationship between the papers can usually be illustrated using a network graph (Mariani & Borghi, 2019). However, due to the number of entries, this graph became rather large and quite unreadable. Instead, the centrality score for each node in the network was saved in the dataset. The centrality score indicates the importance of each node in the network; it represents the number of connections to the node.

Finally, the papers were clustered based on each paper’s number of citations and centrality score. This was achieved through k-means clustering; the Elbow method suggested four clusters. According to Fig. 4, the clusters are mainly controlled by the number of citations, except for Cluster 3, which contains two papers with significantly higher centralities. This suggests that the Cluster 0 papers are the most prominent papers within the field and that the Cluster 3 papers are the most connected papers in the dataset. This sets the order of review, so that the most central work is prioritised. (See Figs. 5–7.)

3. Results

From the reviewed papers, focus areas were extrapolated and categorised using the high-level categories from the technology-organisation-environment (TOE) framework. The TOE framework is a theoretical framework describing the adoption of technology in socio-environmental contexts (Oliveira & Martins, 2010). Subcategories were established under each TOE area to theme the recommendations further. As each author addresses multiple areas and categories, they will be referred to multiple times within the framework. Furthermore, it is important to emphasise that some authors’ recommendations may be relevant to multiple categories. Hence, some of the boundaries between the sections should be considered fluid, as some of the recommendations touch on multiple aspects. However, the following sections describe the main points extrapolated from the papers. An overview of the categories that the authors address can be found in Table 1.

3.1. Technology

3.1.1. System integration and information flow

Several authors highlight the importance of system integration and interoperability, which can be described from both internal and external perspectives (Agostini & Nosella, 2019; Jayashree et al., 2021). Keywords in this field can be dynamic capabilities in SMEs, top management commitment, IT infrastructure and supply chain integration, and triple bottom line sustainability. From a technology perspective, system integration is the most influential factor. Narwane et al. (2020), who identify issues with implementing the Cloud of Things (CoT) (IoT + cloud computing) in SMEs state that the requirements are stable systems

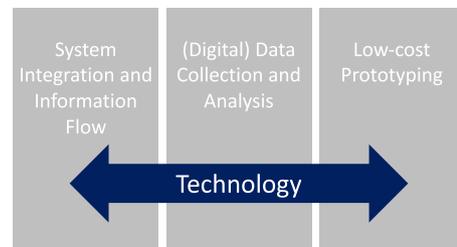


Fig. 5. Relationship between technological themes.



Fig. 6. Relationship between organisational themes.



Fig. 7. Relationships between environmental themes.

and information structures to provide interoperable and secure solutions transparent to stakeholders in the supply chain with proper risk management, compliance, and the use of standards and protocols. Chang et al. (2021) and Nwaiwu et al. (2020) investigate how SMEs adopt Industry 4.0 technologies to establish the potential for performance progress underscoring technology readiness. Vrchota et al. (2019) conclude that the renewal and optimal use of technologies and IT systems in SMEs is a major factor in the integration of Industry 4.0 initiatives. Chen (2019), Ghobakhloo and Ching (2019), Siemen et al. (2018), and Türkes et al. (2019) find that compatibility and data integration is

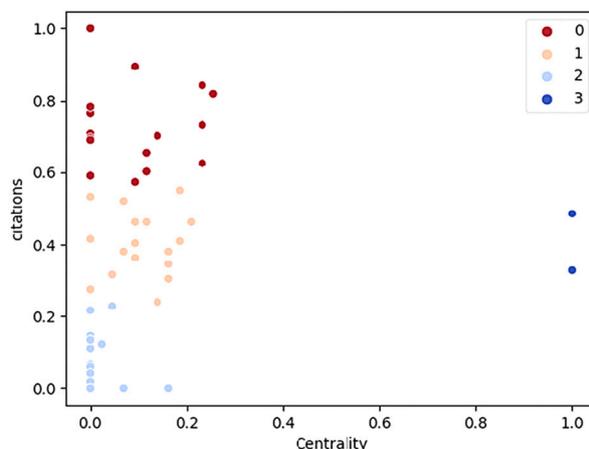


Fig. 4. Results from k-means clustering.

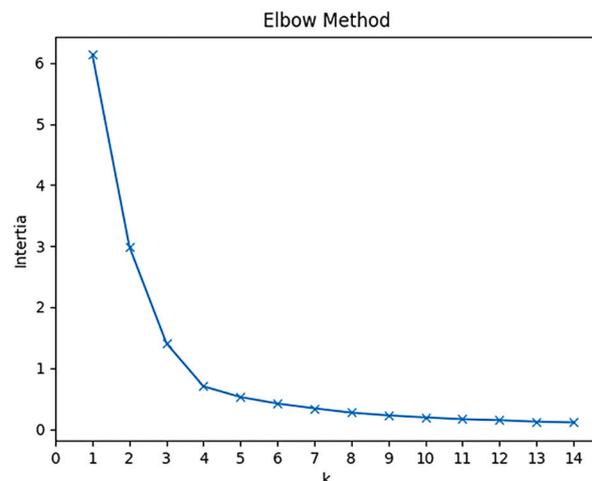


Table 1
References to developed categories in included papers^a.

| Authors | Technology | | | Organisation | | | | | Environment | | |
|--|------------|-----|--------|--------------|--------|----|----|----|-------------|----|----|
| | SI & IF | DCA | LC PoC | SA | MS & L | HC | OC | FE | EKS | SC | SP |
| Jayashree, Reza, Malarvizhi, & Mohiuddin, 2021 | x | | | | x | | | | | | x |
| Agostini & Nosella, 2019 | x | | | x | x | | | x | x | | |
| Subramanian, Patil, & Gardas, 2021 | x | | | | | | | | | | |
| Müller, Veile, & Voigt, 2020 | x | | | | | | | | | | x |
| Narwane et al., 2020 | x | x | | | x | | | | | | |
| Chang, Chang, & Lu, 2021 | x | | | | | | | | | | |
| Nwaiwu, Duduci, Chromjakova, & Otekhile, 2020 | x | | | x | | | | | | | |
| Vrchota, Volek, & Novotná, 2019 | x | | | | x | x | x | x | x | | |
| Ghobakhloo & Ching, 2019 | x | x | x | x | | x | | x | | | x |
| Siemen, Clever, Barann, & Becker, 2018 | x | | x | x | | | | | | | x |
| Türkeş et al., 2019 | x | x | | | | x | | x | | | x |
| Chen, 2019 | x | x | | | | | | | | | x |
| Bär, Herbert-Hansen, & Khalid, 2018 | x | | | x | | x | | | | | x |
| Moeuf et al., 2020 | x | x | x | x | x | x | | | x | | |
| Trstenjak, Opetuk, Cajner, & Tosanovic, 2020 | x | | | | | x | x | | | | |
| Welte, Estler, & Lucke, 2020 | x | | x | x | | x | x | | | | |
| Sivathanu, 2019) | x | x | | | x | x | | | | | x |
| Molero et al., 2019 | x | | | | | | | | | | |
| Dutta, Kumar, Sindhvani, & Singh, 2020 | x | x | | | | x | | x | | | |
| Gamache, Abdul-Nour, & Baril, 2020 | x | x | | | x | x | | | | | |
| Kilimis, Zou, Lehmann, & Berger, 2019 | x | | | | | | x | | | | |
| Hamzeh, Zhong, & Xu, 2018 | x | x | x | | | x | x | | x | | |
| Puklavec, Oliveira, & Popović, 2018 | x | | | | x | | | | | | |
| Moica, Ganzarain, Ibarra, & Ferencz, 2018 | x | | | | x | x | | | | | x |
| Jiwangkura, Sophatsathit, & Chandrachai, 2020 | | x | x | | x | | | | | | |
| Bosman, Hartman, & Sutherland, 2019 | | x | | x | | | x | | | | |
| Ricci, Battaglia, & Neirotti, 2021 | | x | | | | | | | x | | x |
| Haseeb, Hussain, Slusarczyk, & Jermittiparsert, 2019 | | x | | | | | | | | | |
| Cimini, Boffelli, Lagorio, Kalchschmidt, & Pinto, 2021 | | x | x | | x | x | | | | | |
| Somohano-Rodríguez, Madrid-Guijarro, & López-Fernández, 2020 | | x | | x | | | | | | | x |
| Amal Krishnan, Sasidharan, Prakash, & Vivek, 2021 | | x | | | | x | | | | | |
| Sriram & Vinodh, 2021 | | | x | | | x | | x | x | | |
| Maroufkhani, Tseng, Iranmanesh, Ismail, & Khalid, 2020 | | | x | | x | | | x | | | x |
| Amaral & Peças, 2021 | | | x | | | | | | | | |
| Soluk & Kammerlander, 2021 | | | x | x | | | x | x | | | x |
| Yu & Schweisfurth, 2020 | | | x | | | x | | | | | |
| Müller, Buliga, & Voigt, 2021 | | | | x | | | | x | | | x |
| Spalinger, Grivas, & de la Harpe, 2019 | | | | x | | x | | | | x | x |
| Eleftheriadis & Myklebust, 2018 | | | | x | x | x | | | | | |
| Canhoto, Quinton, Pera, Molinillo, & Simkin, 2021 | | | | x | | | x | | x | | |
| Arcidiacono, Ancarani, Di Mauro, & Schupp, 2019 | | | | x | x | | | | x | | |
| Vrchota, Rehoř, Maríková, & Pech, 2021 | | | | | x | | | | | | |
| Müller, Buliga, & Voigt, 2018 | | | | | x | x | | | | | |
| Chatterjee, Rana, Dwivedi, & Baabdullah, 2021 | | | | | x | x | | | | | |
| Annosì, Brunetta, Monti, & Nat, 2019 | | | | | x | | | | | | |
| Roblek, Meško, Pušavec, & Likar, 2021 | | | | | | x | x | | | | |
| Tortora, Maria, Valentina, Iannone, & Pianese, 2021 | | | | | | x | x | | x | | |
| Ascúa, 2021 | | | | | | x | | | | | x |
| Mična & Kmiecik, 2020 | | | | | | | x | | | | |
| Stentoft, Adsbøll Wickstrøm, Philipsen, & Haug, 2021 | | | | | | | | x | | | |
| Sriboonlue & Puangpronpitag, 2019 | | | | | | | | | x | x | x |

System Integration and Information Flow (SI & IF), Data Collection and Analysis (DCA), Low-cost Proof-of-Concept (LC PoC), Strategic Alignment (SA), Management Support and Leadership (MS & L), Human Capital (HC), Organisational Culture (OC), Financial Expectations (FE), External Knowledge Search (EKS), Stakeholder Collaboration (SC), Support Programmes (SP).

central for seeing how SMEs can employ technology to participate in global supply chains based on interoperable systems. [Bär et al. \(2018\)](#) investigate which Industry 4.0 technologies influence the supply chains of SMEs and how SMEs can use Industry 4.0 initiatives in their supply chains. The authors find that it is vital to scope out and select digital technologies that assist in optimising information flows. These technologies must support the SME's organisational needs and make it possible to integrate stakeholders into supply chains. [Moeuf et al. \(2020\)](#) emphasise that IT infrastructure should facilitate the flow of information. [Trstenjak et al. \(2020\)](#) and [Welte et al. \(2020\)](#) provide a detailed overview of possibilities of digital concept strategies and implementations and find that companies should increase their internet infrastructure and software flexibility, including databases. [Sivathanu \(2019\)](#) studied the adoption of Industrial Internet of Things (IIoT) in auto-component manufacturing SMEs finding that infrastructure,

compatibility, and security influence whether or not companies choose to adopt IoT, as heterogeneity leads to difficulties in managing devices and data. This also reflects compatibility with other IT infrastructure, such as machines, programming logic controllers (PLCs), enterprise resource planning (ERP), manufacturing execution systems (MES), etc. Compatibility is also highlighted in [Molero et al. \(2019\)](#), who identify key factors for implementing a new modular IT solution in a transportation SME.

3.1.2. (Digital) data collection and analysis

Several papers highlight the importance of digitalising data collection and conducting data analytics. [Dutta et al. \(2020\)](#) conclude that it is imperative to capture real-time machine data and analyse these data to establish improvement opportunities in both manufacturing and design decisions. The authors highlight the need to connect equipment and

implement IoT devices to generate data that can be used to prioritise areas of improvement in both products and processes. Furthermore, SMEs should generate analytics and digital documentation that can be used to improve processes and maintain traceability. This will help track changes in costs, which will eventually ensure profitability (Ghobakhloo & Ching, 2019; Jiwangkura et al., 2020; Ricci et al., 2021; Sivathanu, 2019). The latter suggest focusing on cybersecurity, data analytics, ERP, PLCs, and actuators, i.e. technologies that enhance data collection and information processing. Haseeb et al. (2019) investigate the relationships between big data, IoT, and smart factories, and their relationships with IT implementation. The study finds that they all have a positive relationship with IT implementation. Haseeb et al. (2019) find that IoT initiatives increase IT implementation, which ultimately can have a positive effect on business performance (Chen, 2019; Cimini et al., 2021; Moeuf et al., 2020; Somohano-Rodríguez et al., 2020; Türkeş et al., 2019). Moeuf et al. (2020) show that the first step for SMEs is to exploit existing data resources. By doing this, SMEs can develop their business models and skill sets with fewer risks (Narwane et al., 2020). Amal Krishnan et al. (2021) and Gamache et al. (2020) find that digital architecture, automation, and quality data can increase digital performance for SMEs, but SMEs seek data before they seek automation. Hamzeh et al. (2018) highlight the need for SMEs to identify and collect relevant data alongside their business processes. To summarise, introducing data collection and analytics in SMEs offers low-risk, baseline technologies that SMEs will be able to use in most of their business areas, and they can function as incubators for future and more advanced technologies.

3.1.3. Low-cost proofs of concepts

In this last technology-related category, various authors highlight the benefits of simplifying Industry 4.0 initiatives to increase the chances of success (Moeuf et al., 2020; Sriram & Vinodh, 2021). Maroufkhani et al. (2020) investigate how 11 different TOE factors influence the adoption of big data analytics in SMEs, concluding that the complexity of technologies, uncertainty about the results, and the possibility of trying out solutions all influence the adoption of big data analytics in SMEs. Similar findings can be observed in Amaral and Peças (2021), who conducted two SME case studies. The authors conclude that SMEs can benefit from digitalising processes gradually by exploiting existing resources to make small and inexpensive advancements. This advocates for an internal grassroots innovation strategy where innovation is primarily bottom-up and focuses on gradually developing technical solutions and growing competences. Jiwangkura et al. (2020) add lightweight flexibility as influencing the adoption of IIoT implementation strategies. Specifically, the authors recommend implementing simple, inexpensive, pilot IoT, pain-point-driven solutions in a manufacturing setting. Bosman et al. (2019), Soluk and Kammerlander (2021), and Welte et al. (2020) highlight that SMEs should look for third-party funding from innovation or DT grants from governmental initiatives. Yu and Schweisfurth (2020) investigate the reason for SMEs' lack of Industry 4.0 technologies, finding that companies are more likely to implement technologies with which they have experience and in which they can recognise opportunities. Hamzeh et al. (2018) also incite SMEs to develop prototypes and demonstrate technologies to learn from them. Likewise, Cimini et al. (2021) state that companies should experiment with technology and use this experimentation to open themselves up to change. Lastly, this is repeated in Siemen et al. (2018), who uncover that SMEs prefer low setup costs over low subscription costs. Overall, there is a consensus between the authors mentioned here that SMEs should work with low-cost solutions and engage in trial programmes, as this allows the testing of proof-of-concept solutions.

3.2. Organisation

3.2.1. Strategic alignment

Strategic alignment is key to adopting Industry 4.0 initiatives done,

e.g., by developing digital strategies, ensuring compatibility with business goals, and ensuring alignment with innovation strategies. Eleftheriadis and Myklebust (2018), Nwaiwu et al. (2020), Siemen et al. (2018), Soluk and Kammerlander (2021), Spalinger et al. (2019), and Welte et al. (2020) discuss that a strategic plan for any Industry 4.0 transition should exist to ensure alignment with the organisational, operational, and technical characteristics of the organisation. Agostini and Nosella (2019), Canhoto et al. (2021), and Somohano-Rodríguez et al. (2020) highlight that integration, beyond technology, is the foundation of Industry 4.0 and that social capacity is a determinant for this integration. Arcidiacono et al. (2019) aim to highlight strategic decisions that support SMEs' adoption of Industry 4.0 technologies. The authors conclude that a strong strategic vision is a proactive approach to Industry 4.0 adoption. This will facilitate a gradual grasping of Industry 4.0 concepts and application scenarios, allowing SMEs to plan their next steps. This is also likely to contribute to building the capabilities that allow digital information exchange with customers, in addition to building confidence and trust in this exchange. Additionally, Bär et al. (2018) and Moeuf et al. (2020) find that Industry 4.0 initiatives should appear in long-term strategies, and they should be aligned across the organisation. Ghobakhloo and Ching (2019) specifically suggest that SMEs create strategic roadmaps, as this facilitates digital technology adoption. They find that this is one of the discriminators between non-adopters and adopters. Likewise, Bosman et al. (2019) recommend that companies conduct strategic analyses regularly. Müller et al. (2021), who investigate how SMEs differ from larger companies in terms of relationships between their absorptive capacities, innovation strategies, and business model innovations, conclude that companies should focus on novelty-centred business models instead of just focusing on becoming more efficient in existing processes. This is supported by Canhoto et al. (2021), who also uncover patterns that show how SMEs' behaviour changes with increasing technology use and technology adoption. Generally, the authors suggest that as the companies adopt more technology, they become less focused on reducing change and risks and more focused on embracing change and disrupting their industry. To summarise, the authors above mainly highlight the importance of developing long-term plans and strategies for digital initiatives to ensure coherence among different investments in technology. Furthermore, the authors also highlight the importance of aligning these digital strategies with business goals to ensure that these goals support and develop the core functions of the business.

3.2.2. Management support and leadership

Gamache et al. (2020) find that developing a sophisticated digital strategy or engaging in many digital investments does not have a significant impact on a company's digital performance. According to the authors, highly committed management, the utilisation of quality data, and effective change management are far more important. Several authors address the importance of having strong support from top management. This is observed in the paper by Chatterjee et al. (2021), who seek to identify the antecedents of AI adoption in manufacturing. The study finds that strong leadership support accelerates the adoption of AI.

The need for strong management and leadership support is further more elaborated in, e.g., Jayashree et al. (2021), Maroufkhani et al. (2020) and Sivathanu (2019). Moreover, Agostini and Nosella (2019) conclude that with the presence of strong top management support and absorptive capacity, the relationship between external social capacity and Industry 4.0 adoption becomes positive and significant. Puklavec et al. (2018) point to top management support being more important in the evaluation stage than in the adoption stage. However, management support is stronger when the manager is a part of the adoption team. According to Cimini et al. (2021), managers should ensure that technology investments are co-designed with the organisation. Annosi et al. (2019) find a positive correlation between managers' ability to collect evidence-based information about the technologies and technology adaptation. Eleftheriadis and Myklebust (2018) highlight that managers

must teach themselves about relevant technologies. [Jiwangkura et al. \(2020\)](#) also point out that top management's ability to make real-time decisions impacts IoT adoption strategies. Like [Annosi et al. \(2019\)](#), [Agostini and Nosella \(2019\)](#) find that management support also controls the impact of investments in advanced manufacturing technologies and internal social capacity, and the intensiveness of Industry 4.0 technology adoption. [Müller et al. \(2018\)](#) investigate how Industry 4.0 triggers changes in the business models of SMEs in Germany: SMEs need to sense the right timing for implementing Industry 4.0 technology, based on their human and financial capital. [Arcidiacono et al. \(2019\)](#), [Moeuf et al. \(2020\)](#), [Narwane et al. \(2020\)](#), and [Subramanian et al. \(2021\)](#) support the importance of top management, and state that managers must ensure the training of their workforce to ensure success and increase confidence in the workforce. [Moica et al. \(2018\)](#) and [Vrchota et al. \(2021\)](#) find success in establishing multidisciplinary project teams with associated key performance indicators (KPIs). [Puklavec et al. \(2018\)](#) and [Subramanian et al. \(2021\)](#) also highlight project management as an assisting factor.

3.2.3. Human capital

Human capital, knowledge, skills, and insight are critical in Industry 4.0 initiatives. [Naushad and Sulphrey \(2020\)](#) investigate the potential ICT adoption dynamics of SMEs. The authors find that 'technological self-efficacy' is the most influential factor in ICT adoption, leading to perspectives of training. [Roblek et al. \(2021\)](#) highlight investment in employee training as a key organisational factor. [Gamache et al. \(2020\)](#) and [Welte et al. \(2020\)](#) observe that the acquisition and development of skills is among the factors with the greatest potential for increasing digital performance. This is also supported by [Müller et al. \(2018\)](#), [Tortora et al. \(2021\)](#), [Trstenjak et al. \(2020\)](#), and [Yu and Schweisfurth \(2020\)](#), who find that organisations need to develop knowledge, skills, and confidence. In conjunction with the previous section on management and leadership, several papers specifically treat education and competence development on management levels ([Amal Krishnan et al., 2021](#); [Ascúa, 2021](#); [Bär et al., 2018](#); [Hamzeh et al., 2018](#); [Moica et al., 2018](#); [Spalinger et al., 2019](#); [Tortora et al., 2021](#)). [Dutta et al. \(2020\)](#) conclude that skilled talent in manufacturing is a critical success factor for implementing Industry 4.0 initiatives. This is further supported by [Eleftheriadis and Myklebust \(2018\)](#) and [Maroufkhani et al. \(2020\)](#) who both state that employees' skill sets are important for digital initiatives. Additionally, [Chatterjee et al. \(2021\)](#) highlight that competencies in the organisation positively influence the perceived usefulness of AI technology. [Vrchota et al. \(2019\)](#) find that there is a constant need to develop skills and knowledge among staff. [Sriram and Vinodh \(2021\)](#) suggest that technology workshops can be used to improve employees' technical skills and awareness and to keep them up to date. [Ghobakhloo and Ching \(2019\)](#) emphasise the importance of having great information processing capabilities in the organisation with competencies that can facilitate and speed up the adoption of digital technologies. [Sriram and Vinodh \(2021\)](#) and [Trstenjak et al. \(2020\)](#) also recommend that companies learn about big data and its possibilities.

3.2.4. Organisational culture

Organisational factors describe organisational structure, culture, formal and informal processes, and communication as determining factors for implementing Industry 4.0 initiatives. As a general term, 'digital culture' is understood as cultural characteristics that relate to the implementation of Industry 4.0 initiatives and digitalisation ([Hamzeh et al., 2018](#); [Tortora et al., 2021](#)). [Soluk and Kammerlander \(2021\)](#) highlight employee resistance as a significant barrier for Industry 4.0 initiatives, namely resistance related to fear of obsolescence or deskilling. This can be mitigated by the early communication of success stories.

[Kilimis et al. \(2019\)](#) suggest including blue-collar workers when introducing digital technologies in operational processes, as this will help them to utilise and develop in-house capabilities and ease change

management. [Roblek et al. \(2021\)](#) find the determinants of innovation culture to be a tolerance of failures and openness and willingness to change. [Welte et al. \(2020\)](#) highlight that a machine-learning project is only successful if the employees think that it is successful and not imposing a situation of stress. [Trstenjak et al. \(2020\)](#) recommend a communicative levelled approach. [Bosman et al. \(2019\)](#) highlight that SMEs must identify their own industry-sanctioned credentials, and they must identify the incentives their employees should implement along with open-mindedness through sharing knowledge. [Michna and Kmiecik \(2020\)](#) find a positive relationship between open-mindedness and the willingness to implement Industry 4.0 initiatives in SMEs. The authors propose a bidirectional relationship, suggesting that increased financial performance can also increase knowledge sharing and open-mindedness. [Müller et al. \(2021\)](#) conclude that an adequate corporate culture that encourages cross-functional thinking and innovation search is required. [Vrchota et al. \(2019\)](#) assume a need for the optimal culture, which makes it possible to introduce innovations and changes and to continuously monitor these changes. [Roblek et al. \(2021\)](#) highlight innovation culture as determining the introduction of disruptive innovations in SMEs. According to [Canhoto et al. \(2021\)](#), companies that are less focused on reducing change and risks and more focused on embracing change and disrupting their business are also the companies that experience a culture that goes from resisting to embracing change. The authors describe the most transformational companies as having a culture that promotes discovery, vigilance, and the implementation of opportunities. The authors above, to some degree, all describe the need for strong cultural support, which can be obtained through strong communication and the inclusion of employees, open-mindedness, and idea sharing. Ultimately, SMEs need to develop a culture that embraces changes rather than perceiving them as disturbances.

3.2.5. Financial expectations

From the literature, it is evident that no Industry 4.0 initiative can take place without some sort of financial investment. This imposes serious restrictions to digitalisation in SMEs ([Agostini & Nosella, 2019](#); [Maroufkhani et al., 2020](#)). [Sriram and Vinodh \(2021\)](#) and [Türkeş et al. \(2019\)](#) conclude that the shift to Industry 4.0 requires determination, and high capital to implement new technologies. [Ghobakhloo and Ching \(2019\)](#) state that the future of an SME can be put in danger by unsuccessful investments; hence, companies must allocate carefully. [Soluk and Kammerlander \(2021\)](#) argue that a strong barrier in family-controlled SMEs is paternalistic decision-making unaware of opportunities related to digital technologies ([Stentoft et al., 2021](#); [Vrchota et al., 2019](#)). According to the authors, it is important to develop effective processes for determining the effectiveness of investments, such as the recovery rate or return on investment, and risk analysis is a big part of this. [Dutta et al. \(2020\)](#) conclude that it is critical to relate operational performance to KPIs, such as cost, efficiency, reliability, and maintainability. To summarise, SMEs must not expect Industry 4.0 initiatives to be free to engage in; however, they should rely heavily on developing business cases to objectively assess the different investments and thereby reduce risks.

3.3. Environment

3.3.1. External knowledge search

There is a need for SMEs to look for knowledge and expertise outside their organisations, ([Canhoto et al., 2021](#); [Hamzeh et al., 2018](#)). The external environment goes from managing external pressure to seeking opportunities as the company adopts more technology, and the approach generally goes from being reactive to being more purposeful. [Vrchota et al. \(2019\)](#) discuss factors such as the market, technological development, competition, government, and ecology. Several authors specifically recommend that SMEs engage in collaborations with universities and research institutions to transfer knowledge from academia to industry ([Moeuf et al., 2020](#); [Sriboonlue & Puangpronpitag, 2019](#)).

Leaders should get involved in business-to-business (B2B) networks to estimate the opportunities offered by Industry 4.0 initiatives. Generally, the problem of a lack of knowledge resources should be mitigated by having external experts make a preliminary audit of the state of machinery, workshops, and processes. After this, the SME will need to be supported in implementing its chosen technology. The authors recommend relying on academia, as knowledge transfer is not always guaranteed with consultants. The adapted competencies should then be generated by training employees (Section 3.2.3). Although this training is time-consuming, it does promote better integration. Ricci et al. (2021) find that the breadth and depth of an external knowledge search do indeed affect the adoption of Industry 4.0 technologies, based on the sensing and seizing of different types of innovation opportunities. Agostini and Nosella (2019) find that a strong external social capacity, including a culture of openness and integration, can help with Industry 4.0 adoption and that external knowledge can accelerate this adoption but only with strong management support. Sriram and Vinodh (2021) also find that SMEs should establish connections with partners across the globe to increase awareness of new opportunities and share their own facilities. Finally, Arcidiacono et al. (2019) and Tortora et al. (2021) both highlight that close collaborations with universities, research institutions, consultants, and innovation managers can be a determining factor for implementing Industry 4.0 initiatives in SMEs. To summarise, this section highlights the importance of SMEs searching for knowledge outside themselves. This can be done through collaboration with universities, engagement in B2B networks, and/or the use of external experts.

3.3.2. Stakeholder collaboration and information sharing

External collaboration and information sharing are vital success factors for SMEs engaging in Industry 4.0 initiatives, (Ascúa, 2021; Soluk & Kammerlander, 2021; Sriboonlue & Puangpronpitag, 2019; Türkeş et al., 2019). Ricci et al. (2021) suggest building collaborations with universities, technology vendors, or consultancies. The key is to develop trust and a shared vocabulary so that parties can share data confidently. Müller et al. (2021) conclude that SMEs that are successful in working with external knowledge are better prepared to engage in exploratory and exploitive innovation, which allows them to find new business models. Companies should learn to share information across the entire organisation and its value creation network, which includes more than just the closest suppliers and customers. Chen (2019) and Somohano-Rodríguez et al. (2020) also report a relationship between innovation strategy and firm innovation regarding Industry 4.0. This is grounded in the fact that Industry 4.0 suggests collaboration and idea sharing between partners with complementary technologies, which allows SMEs to focus on the aspects that contribute the most to value creation. Siemen et al. (2018) find that companies can benefit from intercompany data analysis; however, it is important that SMEs have the power to decide what information to share, as trust must be developed throughout the process. On the contrary, Jayashree et al. (2021) do not find a positive relationship between supply chain integration and the effective implementation of Industry 4.0. They do, however, still recommend integrating the supply chain and explain that there is a lack of correlation because this process is still quite new to SMEs. Moica et al. (2018) also recommend the implementation of logistics functions to respond to the market and extend processes towards customers. Ghobakhloo and Ching (2019) find that pressure from external stakeholders is a discriminator between non-adopters and adopters of digital technologies. Likewise, Sivathanu (2019) finds that competitive pressure is the most influential factor in the adoption of IIoT and that support from vendors is important. Additionally, Maroufkhani et al. (2020) conclude that external support influences the adoption of big data analytics. Finally, Amal Krishnan et al. (2021), Arcidiacono et al. (2019), and Spalinger et al. (2019) all find that SMEs must collaborate with vendors and customers. Furthermore, it was noticed that the literature recommends collaboration with both customers and vendors and that no one

recommends transactional endeavours where digital initiatives are blindly outsourced in one-time purchases. This suggests that in all external collaborations there should exist a learning element for the SME which seeks to develop digital competences in the business whenever new digital activities are initiated.

3.3.3. Support programmes

Lastly, some authors recommend that companies should look for external funding sources. This can be seen in the papers by Soluk and Kammerlander (2021) and Spalinger et al. (2019). The authors emphasise that SMEs should look for subsidy programmes for ICT adoption, as these programmes can help reduce the costs for SMEs. Finally, Sriboonlue and Puangpronpitag (2019) also highlight that for SMEs with entrepreneurial capabilities, private funds are an option; in this case, well-developed business planning is a part of receiving funding.

4. Recommendations for SMEs

This review covers many different aspects of Industry 4.0 implementation, which raises questions like the following: *Is it better to start building relationships or to start researching the optimal IT infrastructure? Is it better to first focus on competence development rather than changing the organisational culture?* Based on Section 3, a set of recommendations has been extrapolated. These take their origin in “technology” as this domain is the overall driver for Industry 4.0 and central to many of the themes described in this review. The recommendations are anchored in the most clearly linked themes across the domains described in this review (Section 3), visualised in Fig. 8. These recommendations assume technology to be the basic enabler, and it should therefore be prioritised, as also suggested by Sundberg, Gidlund, and Olsson (2019). To the best of our knowledge, this paper is the first to present specific recommendations that take this approach while remaining true to the existing accumulated literature and remaining TOE factors.

4.1. Recommendation 1: prioritise the integration of IT systems across the value chain

This review describes the importance of purposeful IT infrastructure where coherent system integration and efficient information flow supports the business in its core activities (Section 3.1.1). From a technical perspective, this suggests data integration between IT systems that allows for the consolidation of data from various sources. This should not only take place inside the company but should also reach further into the external environment of the company where trust and relations should be built with stakeholders, with the purpose of integrating IT solutions and establishing data exchanges. Furthermore, from the sections, it is obvious that building a purposeful IT architecture for a company is something that must be done in close collaboration with customers and vendors. As highlighted in this review, these activities must originate at the strategic level of the business to ensure alignment with business goals (Section 3.1.1 and 3.1.3).

4.2. Recommendation 2: develop human capital with competences in knowledge exploration and data analytics

This review describes the importance of collecting useful data that can be used to support business decisions (Section 3.1.2). Several of the organisational subsections describe the importance of data-driven decision-making and analytics skills. This requires human capital that can analyse and understand the potential in large amounts of data. This is important, as Industry 4.0 is highly data driven. This must take place at both the managerial and operational levels of the organisation (Sections 3.2.2 and 3.2.3). Furthermore, the review also highlights the importance of having internal human capital that can develop new competences on their own to stay educated about the possibilities of new technologies.

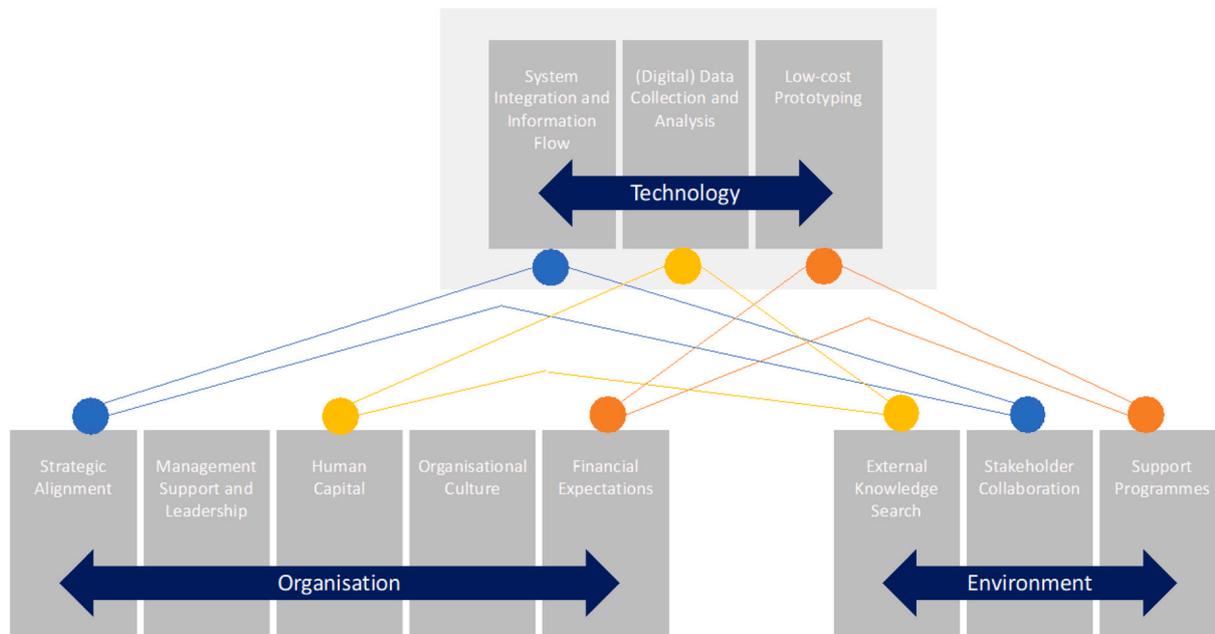


Fig. 8. Anchoring of the recommendations.

4.3. Recommendation 3: explore the possibilities in existing resources

In the review, several authors discuss how SMEs can ‘do more with less’ when it comes to digitalisation initiatives (Sections 3.1.2 and 3.1.3). Various authors describe how companies can exploit the fact that many ‘base’ technologies, with the purpose of collecting data, can be used in low-risk experiments with other technologies to establish their usability for the company. Similarly, the authors describe how low-cost proofs of concepts can be used for the same purpose. This suggests that companies should make an effort to exploit their existing infrastructure and resources before engaging in new innovations, as this may satisfy their resource constraints more efficiently. This also makes for an interesting topic for further research; however, companies should allocate budgets to explore new technologies and opportunities (Section 3.2.5). Yet, exploring existing technologies in the company may result in stronger business cases, which can help mitigate low trust, which acts as a barrier to digitalisation.

5. Discussion and future research

The literature on Industry 4.0 and digitalisation initiatives in SMEs is undoubtedly rich, yet this review manifests some concerns for the typical SME. Generally, it seems that the current research and the applied research methods are not fundamentally contributing to the progression of Industry 4.0 implementation in SMEs. While this argument seems bold, there is a particular need for critical assessment of research from the perspective of practical and industrial applicability (Sundberg et al., 2019). For example, Sundberg et al. (2019) survey Swedish companies on digital maturity and conclude that the companies have not implemented anything that resembles Industry 4.0 concepts. In fact, the authors highlight that companies tend to score their organisational maturity higher than their technology maturity, which indicates that companies tend to believe they are more mature than they are. A chasm can thus be empirically established on the discrepancy between mainstream academia and industrial practices. Engaging in digital initiatives inevitably adds to the number of activities to which an SME has to attend and subsequently adds to the load within dynamic capabilities. While digitalisation is a long-running process that requires both financial investment and competence development, this collides with the fact that SMEs are the fundamental key deficiencies of this type of company.

SMEs are generally known to be focused on revenue and profit generation. This means that these organisations usually operate in a relatively lean fashion, in which employees fill multiple roles, with little room for non-direct value-adding activities. The longevity of digital projects therefore challenges the abilities of SMEs, as they must develop in numerous domains without compromising their core business performance. This puts the SMEs in an impossible situation where they must employ or develop competences and invest in digital technology that may not yield immediate benefits, and which may leave them in vulnerable situations. Yet, eventually, the SME is forced to develop if it wishes to remain competitive. Returning to the initial premise of this paper, the risk aversion of the typical SME creates a vicious circle that must be broken. Hence there is a need for short routes from the identification of needs to the development and implementation of solutions. While these issues are continuously highlighted through the reviewed literature, very few papers actually attempt to solve this problem. Additionally, there seems to be a noticeable lack of interdisciplinary research. Most of the presented papers conduct qualitative or quantitative research using interviews and surveys to draw conclusions and propose recommendations. These papers take a snapshot of a specific moment in time and analyse the data post-capture. While this, in most cases, provides valuable insights from organisations, it fails to fully document the grounded “hows” of digitalisation and rarely helps the companies with respect to what to do. Building on this premise, it also obstructs the spread of knowledge from academia to industry, as the main, current research methods fail to deliver actionable insights to SMEs. To mitigate this, future research must make a targeted effort to reduce this gap between academia and industry by bridging knowledge through SME-targeted research. A similar point can be found in Estensoro, Larrea, Müller, and Sisti (2021), who recommend operational research on Industry 4.0 implementation in SMEs. The authors research SMEs’ transition towards different stages of Industry 4.0 implementation from a resource-based view. Of 354 SMEs, the authors find that more than half have not effectively implemented Industry 4.0 initiatives. Furthermore, more than half of the SMEs that have, have done so without any formal process, which manifests the operational perspectives of SMEs. Amaral and Peças (2021), who demonstrate such methods, argue for more pragmatic research on Industry 4.0 in SMEs. Hence, we suggest that future research should study the practical implementation of digitalisation initiatives as they progress. Based on

the results of this literature review and the findings of [Amaral and Peças \(2021\)](#) and [Sundberg et al. \(2019\)](#), we specifically suggest prioritising practical research on the three recommendations from this paper through multiple case studies. Therefore, this literature review finds its novel academic standpoint in recommending a shifting research focus to pragmatic research on how SMEs can initiate and fully implement digital initiatives from an applied technology perspective. This review has been especially dedicated to SMEs from which the contributions and future research agenda are derived. Future research should explore whether the same recommendations and research issues are common for larger organisations as well.

The broad set of definitions of Industry 4.0 and digitalisation results in extremely broad research topics. This makes it challenging to define exactly what qualifies as Industry 4.0/digitalisation initiatives and to decide which other topics to include. During this literature review, many different types of papers were encountered. Some papers conduct surveys and statistical analyses, while others take more qualitative approaches with semi-structured interviews. It is also challenging to balance business and technology aspects, as some papers focus more on one than the other, yet somewhere a line must be drawn. This review of recommendations for introducing Industry 4.0 initiatives in SMEs was structured using the three main themes of the TOE framework. These were further divided into subcategories to cluster the content of each of the three main themes. This creates a taxonomy that steers the direction of the research, as the subcategories are derived from the data identified for this review. Furthermore, we observed many internal relationships in the TOE sections. For example, multiple subcategories under the 'Organisation' category treat different aspects of education, which becomes imperative for both managers and employees and is a prerequisite for changing the organisational culture. Likewise, there are also significant overlaps between organisational culture and competence development. When studying these attributes, it becomes difficult to strictly agree to which category the company's ability to educate itself belongs.

6. Conclusion

This structured literature review sought to answer the following research question: *What are the current recommendations for adopting Industry 4.0 technology in SMEs based on contemporary research?* To choose the papers to review, a rigorous approach for processing meta-data was developed. This led to a final dataset of 50 papers for review. From reviewing the papers, recommendations were extrapolated and grouped into three categories using the TOE framework. Within each category, subcategories were developed to cluster the content of these categories. This led to a total of 11 focus areas, which are strongly interrelated for SMEs to use within their own contexts; however, as previous research has emphasised a lack of technology focus in SMEs, three recommendations have been extrapolated from the focus areas, which prioritise the technological focus areas while respecting the interdependency to the organisational and environmental domains. In short, SMEs should do the following: prioritise the integration of IT systems across the value chain, invest in human capital with competences in knowledge exploration and data analytics, and explore possibilities in existing resources. These recommendations facilitate the SMEs' need to create an infrastructure through which information can flow, like roads and highways for data between information systems. With this infrastructure established, there would be a foundation for collecting and analysing data from different sources that would allow companies to gain insights from their data. The combination of ensuring efficient IT infrastructure and the collection and analysis of data allows companies to experiment with digital technologies and explore new opportunities while minimising risks. This points towards strong interrelationships between these three disciplines, suggesting that a single discipline cannot stand alone. Building on these recommendations, this literature reviews highlights some concerns regarding the implementation of Industry 4.0 in SMEs. As the overall implementation across SMEs

is very low, this study questions the current research methods and points to a discrepancy between academia and industry. To correct this, this review suggests adopting technological and pragmatic research methods to ensure that future research encapsulates the entireties of how SMEs can digitalise their businesses.

CRedit authorship contribution statement

Oliver Fuglsang Grooss: Conceptualization, Methodology, Investigation, Writing – original draft. **Mirko Presser:** Conceptualization, Supervision, Writing – review & editing. **Torben Tambo:** Conceptualization, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

References

- Agostini, L., & Nosella, A. (2019). The adoption of Industry 4.0 technologies in SMEs: Results of an international study. *Management Decision*, 58(4), 625–643. <https://doi.org/10.1108/MD-09-2018-0973>
- Amal Krishnan, U. C., Sasidharan, A. T., Prakash, T., & Vivek, C. P. (2021). Challenges in adoption of Industry 4.0 in apparel supply chain: A cross case study. *Lecture Notes in Electrical Engineering*, 355, 267–275. https://doi.org/10.1007/978-981-16-1244-2_23
- Amaral, A., & Peças, P. (2021). SMEs and Industry 4.0: Two case studies of digitalization for a smoother integration. *Computers in Industry*, 125, Article 103333. <https://doi.org/10.1016/j.compind.2020.103333>
- Andulkar, M., Le, D. T., & Berger, U. (2018). A multi-case study on Industry 4.0 for SME's in Brandenburg, Germany. In *Proceedings of the 51st Hawaii international conference on system sciences* (pp. 4544–4553). <https://doi.org/10.24251/HICSS.2018.574>
- Annosi, M. C., Brunetta, F., Monti, A., & Nat, F. (2019). Is the trend your friend? An analysis of technology 4.0 investment decisions in agricultural SMEs. *Computers in Industry*, 109, 59–71. <https://doi.org/10.1016/j.compind.2019.04.003>
- Arcidiacono, F., Ancarani, A., Di Mauro, C., & Schupp, F. (2019). Where the rubber meets the road. Industry 4.0 among SMEs in the automotive sector. *IEEE Engineering Management Review*, 47(4), 86–93. <https://doi.org/10.1109/EMR.2019.2932965>
- Ascúa, R. A. (2021). Industry 4.0 in manufacturing SMEs of Argentina and Brazil. *Journal of the International Council for Small Business*, 2(3), 203–222. <https://doi.org/10.1080/26437015.2021.1899773>
- Bakkari, M., & Khatory, A. (2017). Industry 4.0: Strategy for more sustainable industrial development in smes. In *Proceedings of the international conference on industrial engineering and operations management* (pp. 1693–1701).
- Bär, K., Herbert-Hansen, Z. N. L., & Khalid, W. (2018). Considering Industry 4.0 aspects in the supply chain for an SME. *Production Engineering*, 12(6), 747–758. <https://doi.org/10.1007/s11740-018-0851-y>
- Bidan, M., Rowe, F., & Truex, D. (2012). An empirical study of IS architectures in French SMEs: Integration approaches. *European Journal of Information Systems*, 21(3), 287–302. <https://doi.org/10.1057/ejis.2012.12>
- Bosman, L., Hartman, N., & Sutherland, J. (2019). How manufacturing firm characteristics can influence decision making for investing in Industry 4.0 technologies. *Journal of Manufacturing Technology Management*, 31(5), 1117–1141. <https://doi.org/10.1108/JMTM-09-2018-0283>
- Bouwman, H., Nikou, S., & de Reuver, M. (2019). Digitalization, business models, and SMEs: How do business model innovation practices improve performance of digitalizing SMEs? *Telecommunications Policy*, 43(9), Article 101828. <https://doi.org/10.1016/j.telpol.2019.101828>
- Canhoto, A. I., Quinton, S., Pera, R., Molinillo, S., & Simkin, L. (2021). Digital strategy aligning in SMEs: A dynamic capabilities perspective. *Journal of Strategic Information Systems*, 30(3). <https://doi.org/10.1016/j.jsis.2021.101682>
- Chang, S. C., Chang, H. H., & Lu, M. T. (2021). Evaluating industry 4.0 technology application in smes: Using a hybrid mcdm approach. *Mathematics*, 9(4), 1–20. <https://doi.org/10.3390/math9040414>
- Chatterjee, S., Rana, N. P., Dwivedi, Y. K., & Baabdullah, A. M. (2021). Understanding AI adoption in manufacturing and production firms using an integrated TAM-TOE model. *Technological Forecasting and Social Change*, 170(November 2020), Article 120880. <https://doi.org/10.1016/j.techfore.2021.120880>
- Chen, C. L. (2019). Value creation by SMEs participating in global value chains under Industry 4.0 trend: Case study of textile industry in Taiwan. *Journal of Global Information Technology Management*, 22(2), 120–145. <https://doi.org/10.1080/1097198X.2019.1603512>

- Cimini, C., Boffelli, A., Lagorio, A., Kalchschmidt, M., & Pinto, R. (2021). How do Industry 4.0 technologies influence organisational 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>
- Coleman, S., Göb, R., Manco, G., Pievatolo, A., Tort-Martorell, X., & Reis, M. S. (2016). How can SMEs benefit from big data? Challenges and a path forward. *Quality and Reliability Engineering International*, 32(6), 2151–2164. <https://doi.org/10.1002/qre.2008>
- Crupi, A., Del Sarto, N., Di Minin, A., Gregori, G. L., Lepore, D., Marinelli, L., & Spigarelli, F. (2020). The digital transformation of SMEs – A new knowledge broker called the digital innovation hub. *Journal of Knowledge Management*, 24(6), 1263–1288. <https://doi.org/10.1108/JKM-11-2019-0623>
- De Marco, C. E., Martelli, I., & Di Minin, A. (2020). European SMEs' engagement in open innovation. When the important thing is to win and not just to participate, what should innovation policy do? *Technological Forecasting and Social Change*, 152 (December 2019), Article 119843. <https://doi.org/10.1016/j.techfore.2019.119843>
- Decker, A. (2017). Industry 4.0 and SMEs in the Northern Jutland region. In S. Marinova, J. Larimo, & N. Nummela (Eds.), *Value creation in international business* (pp. 309–335). Springer International Publishing. https://doi.org/10.1007/978-3-319-39369-8_13
- Dutta, G., Kumar, R., Sindhvani, R., & Singh, R. K. (2020). Digital transformation priorities of India's discrete manufacturing SMEs – A conceptual study in perspective of Industry 4.0. *Competitiveness Review: An International Business Journal*, 30(3), 289–314. <https://doi.org/10.1108/CR-03-2019-0031>
- Eleftheriadis, R. J., & Myklebust, O. (2018). Industry 4.0 and cyber physical systems in a Norwegian industrial context. *Lecture Notes in Electrical Engineering*, 451, 491–499. https://doi.org/10.1007/978-981-10-5768-7_52
- Estensoro, M., Larrea, M., Müller, J. M., & Sisti, E. (2021). A resource-based view on SMEs regarding the transition to more sophisticated stages of industry 4.0. *European Management Journal*. <https://doi.org/10.1016/j.emj.2021.10.001>
- Gamache, S., Abdul-Nour, G., & Baril, C. (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), 0–31. <https://doi.org/10.1080/23311916.2020.1771818>
- Ganzarain, J., & Errasti, N. (2016). Three stage maturity model in SME's toward industry 4.0. *Journal of Industrial Engineering and Management*, 9(5), 1119. <https://doi.org/10.3926/jiem.2073>
- Ghobakhloo, M., & Ching, N. T. (2019). Adoption of digital technologies of smart manufacturing in SMEs. *Journal of Industrial Information Integration*, 16, Article 100107. <https://doi.org/10.1016/j.jiit.2019.100107>
- Hamzeh, R., Zhong, R., & Xu, X. W. (2018). A survey study on Industry 4.0 for New Zealand manufacturing. *Procedia Manufacturing*, 26, 49–57. <https://doi.org/10.1016/j.promfg.2018.07.007>
- Haseeb, M., Hussain, H. I., Ślusarczyk, B., & Jermittiparsert, K. (2019). Industry 4.0: A solution towards technology challenges of sustainable business performance. *Social Sciences*, 8(5), 154. <https://doi.org/10.3390/socsci8050154>
- Holopainen, M., Ukko, J., & Saunila, M. (2022). Managing the strategic readiness of industrial companies for digital operations. *Digital Business*, 2(2), Article 100039. <https://doi.org/10.1016/j.digbus.2022.100039>
- Horváth, D., & Szabó, R. Z. (2019). Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities? *Technological Forecasting and Social Change*, 146(October 2018), 119–132. <https://doi.org/10.1016/j.techfore.2019.05.021>
- Jayashree, S., Reza, M. N. H., Malarvizhi, C. A. N., & Mohiuddin, M. (2021). Industry 4.0 implementation and triple bottom line sustainability: An empirical study on small and medium manufacturing firms. *Heliyon*, 7(8), Article e07753. <https://doi.org/10.1016/j.heliyon.2021.e07753>
- Jiwangkura, S., Sophatsathit, P., & Chandrachai, A. (2020). Industrial internet of things implementation strategies with HCI for SME adoption. *International Journal of Automation and Smart Technology*, 10(1), 153–168. <https://doi.org/10.5875/ausmt.v10i1.2108>
- Karki, B. R., Basnet, S., Xiang, J., Montoya, J., & Porras, J. (2022). Digital maintenance and the functional blocks for sustainable asset maintenance service – A case study. *Digital Business*, 2(2), Article 100025. <https://doi.org/10.1016/j.digbus.2022.100025>
- Kilimis, P., Zou, W., Lehmann, M., & Berger, U. (2019). A survey on digitalization for SMEs in Brandenburg, Germany. *IFAC-PapersOnLine*, 52(13), 2140–2145. <https://doi.org/10.1016/j.ifacol.2019.11.522>
- Kitchenham, B., Pearl Brereton, O., Budgen, D., Turner, M., Bailey, J., & Linkman, S. (2009). Systematic literature reviews in software engineering – A systematic literature review. *Information and Software Technology*, 51(1), 7–15. <https://doi.org/10.1016/j.infsof.2008.09.009>
- Mariani, M., & Borghi, M. (2019). Industry 4.0: A bibliometric review of its managerial intellectual structure and potential evolution in the service industries. *Technological Forecasting and Social Change*, 149(November), Article 119752. <https://doi.org/10.1016/j.techfore.2019.119752>
- Maroufkhani, P., Tseng, M. L., Iranmanesh, M., Ismail, W. K. W., & Khalid, H. (2020). Big data analytics adoption: Determinants and performances among small to medium-sized enterprises. *International Journal of Information Management*, 54(June), Article 102190. <https://doi.org/10.1016/j.ijinfomgt.2020.102190>
- Masood, T., & Sonntag, P. (2020). Industry 4.0: Adoption challenges and benefits for SMEs. *Computers in Industry*, 121, Article 103261. <https://doi.org/10.1016/j.compind.2020.103261>
- Matt, D. T., Rauch, E., & Zsifkovits, H. (2020). SME 4.0: The role of small- and medium-sized enterprises in the digital transformation. In D. T. Matt, V. Modrák, & H. Zsifkovits (Eds.), *Industry 4.0 for SMEs* (pp. 3–36). Springer International. https://doi.org/10.1007/978-3-030-25425-4_1
- Menon, S., & Shah, S. (2020). Are SMEs ready for Industry 4.0 technologies: An exploratory study of i 4.0 technological impacts. In , 2020. *Proceedings of international conference on computation, automation and knowledge management* (pp. 203–208). ICCAKM. <https://doi.org/10.1109/ICCAKM46823.2020.9051550>
- Michna, A., & Kmiecik, R. (2020). Open-mindedness culture, knowledge-sharing, financial performance, and industry 4.0 in SMEs. *Sustainability (Switzerland)*, 12(21), 1–17. <https://doi.org/10.3390/su12219041>
- Moeuf, A., Lamouri, S., Pellerin, R., Tamayo-Reyes, S., Tobon-Valencia, E., & Eburdy, R. (2020). Identification of critical success factors, risks and opportunities of Industry 4.0 in SMEs. *International Journal of Production Research*, 58(5), 1384–1400. <https://doi.org/10.1080/00207543.2019.1636323>
- Moica, S., Ganzarain, J., Ibarra, D., & Ferencz, P. (2018). Change made in shop floor management to transform a conventional production system into an “Industry 4.0”: Case studies in SME automotive production manufacturing. In *2018 7th international conference on industrial technology and management, ICITM 2018, 2018-January (march)* (pp. 51–56). <https://doi.org/10.1109/ICITM.2018.8333919>
- Molero, G. D., Santarremigia, F. E., Poveda-Reyes, S., Mayrhofer, M., Awad-Núñez, S., & Kassabji, A. (2019). Key factors for the implementation and integration of innovative ICT solutions in SMEs and large companies involved in the multimodal transport of dangerous goods. *European Transport Research Review*, 11(1). <https://doi.org/10.1186/s12544-019-0362-8>
- Müller, J. M., Buliga, O., & Voigt, K. I. (2018). Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0. *Technological Forecasting and Social Change*, 132(January), 2–17. <https://doi.org/10.1016/j.techfore.2017.12.019>
- Müller, J. M., Buliga, O., & Voigt, K. I. (2021). The role of absorptive capacity and innovation strategy in the design of industry 4.0 business models – A comparison between SMEs and large enterprises. *European Management Journal*, 39(3), 333–343. <https://doi.org/10.1016/j.emj.2020.01.002>
- Müller, J. M., Veile, J. W., & Voigt, K.-I. (2020). Prerequisites and incentives for digital information sharing in Industry 4.0 – An international comparison across data types. *Computers & Industrial Engineering*, 148, Article 106733. <https://doi.org/10.1016/j.cie.2020.106733>
- 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*, 0123456789. <https://doi.org/10.1007/s10479-019-03502-w>
- Naushad, M., & Sulphay, M. M. (2020). Prioritizing technology adoption dynamics among SMEs. *TEM Journal*, 9(3), 983–991. <https://doi.org/10.18421/TEM93-21>
- 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>
- Oliveira, T., & Martins, M. F. (2010, May). Information technology adoption models at firm level: Review of literature. In , 2010. *4th European conference on information management and evaluation* (pp. 312–322). ECIME.
- Ortt, R., Stolwijk, C., & Punter, M. (2020). Implementing Industry 4.0: Assessing the current state. *Journal of Manufacturing Technology Management*, 31(5), 825–836. <https://doi.org/10.1108/JMTM-07-2020-0284>
- Puklavec, B., Oliveira, T., & Popović, A. (2018). Understanding the determinants of business intelligence system adoption stages an empirical study of SMEs. *Industrial Management and Data Systems*, 118(1), 236–261. <https://doi.org/10.1108/IMDS-05-2017-0170>
- Rassool, R., & Dissanayake, R. (2019). Digital transformation for small & medium enterprises (SMEs) with special focus on Sri Lankan context as an emerging economy. *International Journal of Business and Management*, 7(4), 55–76.
- 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(September 2020), Article 108234. <https://doi.org/10.1016/j.ijpe.2021.108234>
- Roblek, V., Meško, M., Pušavec, F., & Likar, B. (2021). The role and meaning of the digital transformation as a disruptive innovation on small and medium manufacturing enterprises. *Frontiers in Psychology*, 12(June), 1–18. <https://doi.org/10.3389/fpsyg.2021.592528>
- 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), 264. <https://doi.org/10.3390/pr6120264>
- Siemen, C., Clever, N., Barann, B., & Becker, J. (2018). Requirements elicitation for an inter-organizational business intelligence system for small and medium retail enterprises. In *Proceeding – 2018 20th IEEE international conference on business informatics, CBI 2018*, 1 (pp. 129–138). <https://doi.org/10.1109/CBI.2018.00023>
- Sivathanu, B. (2019). Adoption of industrial IoT (IIoT) in auto-component manufacturing SMEs in India. *Information Resources Management Journal*, 32(2), 52–75. <https://doi.org/10.4018/IRMJ.2019040103>
- Soluk, J., & Kammerlander, N. (2021). Digital transformation in family-owned Mittelstand firms: A dynamic capabilities perspective. *European Journal of Information Systems*, November. <https://doi.org/10.1080/0960085X.2020.1857666>
- Sommer, L. (2015). Industrial revolution – Industry 4.0: Are German manufacturing SMEs the first victims of this revolution? *Journal of Industrial Engineering and Management*, 8(5), 1512–1532. <https://doi.org/10.3926/jiem.1470>
- 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*, 60(04), 1001–1028. <https://doi.org/10.1080/00472778.2020.1780728>
- Spalinger, D., Grivas, S. G., & de la Harpe, A. (2019). TEA – A technology evaluation and adoption influence framework for small and medium sized enterprises. *Lecture Notes*

- in *Business Information Processing*, 339, 433–444. https://doi.org/10.1007/978-3-030-04849-5_38
- Sriboonlue, P., & Puangpronpitag, S. (2019). Towards innovative SMEs: An empirical study of regional small and medium enterprises in Thailand. *Procedia Computer Science*, 158, 819–825. <https://doi.org/10.1016/j.procs.2019.09.119>
- Sriram, R. M., & Vinodh, S. (2021). Analysis of readiness factors for Industry 4.0 implementation in SMEs using COPRAS. *International Journal of Quality and Reliability Management*, 38(5), 1178–1192. <https://doi.org/10.1108/IJQRM-04-2020-0121>
- Stentoft, J., Adsbøll Wickstrøm, K., Philipsen, K., & Haug, A. (2021). Drivers and barriers for Industry 4.0 readiness and practice: Empirical evidence from small and medium-sized manufacturers. *Production Planning and Control*, 32(10), 811–828. <https://doi.org/10.1080/09537287.2020.1768318>
- 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. <https://doi.org/10.1108/JM2-08-2020-0207>
- Sundberg, L., Gidlund, K. L., & Olsson, L. (2019). Towards Industry 4.0? Digital maturity of the manufacturing industry in a Swedish region. In *2019 IEEE international conference on industrial engineering and engineering management (IEEM)* (pp. 731–735). <https://doi.org/10.1109/IEEM44572.2019.8978681>
- Tortora, A. M. R., Maria, A., Valentina, D. P., Iannone, R., & Pianese, C. (2021). A survey study on Industry 4.0 readiness level of Italian small and medium enterprises. *Procedia Computer Science*, 180, 744–753. <https://doi.org/10.1016/j.procs.2021.01.321>
- Trstenjak, M., Opetuk, T., Cajner, H., & Tosanovic, N. (2020). Process planning in industry 4.0-current state, potential and management of transformation. *Sustainability (Switzerland)*, 12(15). <https://doi.org/10.3390/SU12155878>
- Türkeş, M. C., Oncioiu, I., Aslam, H. D., Marin-Pantelescu, A., Topor, D. I., & Căpuşneanu, S. (2019). Drivers and barriers in using industry 4.0: A perspective of SMEs in Romania. *Processes*, 7(3), 1–20. <https://doi.org/10.3390/pr7030153>
- Ulas, D. (2019). Digital transformation process and SMEs. *Procedia Computer Science*, 158, 662–671. <https://doi.org/10.1016/j.procs.2019.09.101>
- 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. <https://doi.org/10.1108/JMTM-08-2018-0270>
- Vrchota, J., Řehoř, P., Maříková, M., & Pech, M. (2021). Critical success factors of the project management in relation to industry 4.0 for sustainability of projects. *Sustainability (Switzerland)*, 13(1), 1–19. <https://doi.org/10.3390/su13010281>
- Vrchota, J., Volek, T., & Novotná, M. (2019). Factors introducing Industry 4.0 to SMEs. *Social Sciences*, 8(5). <https://doi.org/10.3390/socsci8050130>
- Welte, R., Estler, M., & Lucke, D. (2020). A method for implementation of machine learning solutions for predictive maintenance in small and medium sized enterprises. *Procedia CIRP*, 93, 909–914. <https://doi.org/10.1016/j.procir.2020.04.052>
- Xu, M., David, J. M., & Kim, S. H. (2018). The fourth industrial revolution: Opportunities and challenges. *International Journal of Financial Research*, 9(2), 90. <https://doi.org/10.5430/ijfr.v9n2p90>
- Yilma, B. A., Panetto, H., & Naudet, Y. (2021). Systemic formalisation of cyber-physical-social system (CPSS): A systematic literature review. *Computers in Industry*, 129. <https://doi.org/10.1016/j.compind.2021.103458>
- Yu, F., & Schweisfurth, T. (2020). Industry 4.0 technology implementation in SMEs – A survey in the Danish-German border region. *International Journal of Innovation Studies*, 4(3), 76–84. <https://doi.org/10.1016/j.ijis.2020.05.001>