*Review*

# Literature Search of Key Factors for the Development of Generic and Specific Maturity Models for Industry 4.0

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**Abstract:** The adequacy of business models to Industry 4.0 (I4.0) is an urgent requirement and a clear concern. Ways to recognize the relative position of a company and ways to evolve towards this new paradigm are an important step both for researchers and professionals. In general, most small and medium enterprises (SME) do not have their own resources or do not have the means to be fully supported by consultancies, to develop a specific model, and they do not recognize themselves as ready to initiate any action to adapt to this new paradigm. Based on the idea of identification of directions and opportunities of research about the conditions for the adoption of approaches involving readiness assessment, implementation framework, roadmap and maturity model, the main objective of this article is the identification of factors for the development of specific maturity models, oriented towards unique conditions, located in specific contexts, and that can cover both the need for self-diagnosis of the level of preparation, as well as the actions that aim to achieve a progressive reconfiguration and guided by continuous improvement towards Industry 4.0. A Systematic Literature Review (SLR) of 67 articles was conducted and resulted in the identification of two approaches to address maturity models, which are the application of existing generic models and the process of building specific ones focused on the peculiarities of certain contexts. Moreover, this work points out five factors for development of a specific maturity model: context characterization, conceptual characterization, interaction with practitioners and experts, development of surveys, and qualitative research. Additionally, this work identified the need for development of methodologies that can be applied in a more autonomous way for the development of specific maturity models.

**Keywords:** Industry 4.0; maturity model; systematic literature

## 1. Introduction

The term Industry 4.0 was coined in Germany in 2011 and refers to the process of vertical and horizontal integration of people, objects, equipment and other resources in order to provide agility, flexibility and autonomy, responding to a fast-changing demand from an intensely dynamic environment [1–7]. Crnjac et al. [8] present the following basic components of a typical Industry 4.0 business model:

- Technology, integrating Big Data Analytics, cloud computing, prototype and simulation, additive manufacturing or 3D printing, augmented reality and robotic systems.
- Process horizontal and vertical integration, i.e., human–machine collaboration, equipment integration on the factory floor.

The authors consider that these dimensions are enabled by resources and designs composed of the Internet of Things (IoT), Internet of Services (IoS) and Internet of Data (IoD). Other authors may refer

to other principles when defining the identity of the Industry 4.0. Bakkari and Khatory [9] highlight each of these elementary principles:

(a)　Interoperability or the ability to achieve results by different means, to perform the same functions, despite possible exchanges of equipment and manufacturers.
(b)　Decentralization, which corresponds to the ability to make decisions without dependence on a data processing center or a decision-making body of human resources.
(c)　Virtualization, reproduction resources or simulations of the real world in virtual mode.
(d)　Modularity, capacity for change, to make processes more comfortable and adherent depending on environmental configurations and the need for variations in product design.
(e)　Real-time reaction through analysis of large volumes of data that allow the identification of profiles and even subtle changes in scenarios.
(f)　Orientation to services made possible by the integration of processes, since they present themselves as adequate means to mediate the relationship of the market with the companies, as an opportunity for improvements in the final use of the product.

The strong technological appeal of Industry 4.0 may raise the belief that the simple acquisition of a sophisticated apparatus of technology and connectivity services can raise the organization to a new level of competitiveness. Kagermann et al. [1] state that Industry 4.0 should be dealt with from an interdisciplinary approach and through close cooperation between key areas. This leads to the hypothesis that the successful experiences of one company cannot simply be copied and reproduced in another. Veile et al. [4] suggest addressing the requirements in the following dimensions: Technological, Organizational and Human. The first refers to infrastructure resources and tools, the second to process architecture and, finally, the human dimension concerns to the organizational culture and the specific competences appropriate to the Industry 4.0 paradigm.

Since the 1990s, organizational reconfiguration project models based on the fundamentals of business process reengineering have been adopted. The models have variations, but in general they follow a similar route [10]: (1) definition or review of strategic parameters such as scope and boundaries of organizational objectives, mission, vision, values and SWOT (strengths, weaknesses, opportunities and threats); (2) mapping and optimization of processes; (3) analysis of return on investment (ROI); (4) planning; (5) execution; (6) monitoring, evaluation and continuous improvement. In theory this trajectory is still valid and can be applied for the implementation of Industry 4.0. In the meantime, there are demands of Industry 4.0 that are unprecedented and may require specific paths of development. Considering this line of thought, Sony and Naik [3] show that the maturity models, since they started to be used in software development projects, have evolved into valuable instruments for the management of projects of greater complexity and scope. These authors demonstrated, after a survey and study of the available instruments, that the traditional script for projects of organizational reconfiguration were improved in the maturity models. However, Mittal et al. [11] warn about the different nuances of implementation models that are dealt with in the literature, highlighting different terminology and meaning used in different works:

- Readiness assessments are evaluation and analysis tools that aim to determine the level of preparedness of an organization in terms of conditions, attitudes, and resources.
- Maturity models are models that help organizations achieve expected skills in specific dimensions such as culture, processes, resources, etc., through continuous improvement processes.
- Roadmaps are "plans that match short-term and long-term goals with specific technology solutions to help meet those goals".
- Frameworks are collections of procedures, methods and tools focused on the design of an organizational architecture or a system.

These perspectives point to the breadth of the theme and open opportunities for future research. The current article aims to study maturity models in the literature, considering the definition by

Mittal et al. [11]. Considering that the models proposed so far are generic and differ between them, lacking a unicity in terms of direction, this study aims to identify factors that contribute to the development or selection of general or specific maturity models, which may support the transformation for Industry 4.0.

## 2. Research Methodology

A systematic literature review [12] aims to systematically analyze the published evidence to answer specific research questions, using an objective and replicable search strategy. According to Popay et al. [13], the systematic literature review process should go through the following steps: (1) identification of the focus of review, research and mapping of available evidence; (2) specification of the question to be answered by the review; (3) identification of the studies that will be included in the review; (4) data extraction and evaluation of the quality of the studies performed; (5) development of the synthesis; (6) communication of the results of the analysis and dissemination. The process referred to by Popay et al. [13] is aligned with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) recommendations [14] and the current work will follow both.

Considering the first steps referred to by Popay et al. [13], the objective of this research was used as the driver for the identification of the following themes as the main ones for this study:

- Fundamental concepts about Industry 4.0 and Business Process Engineering, acting mainly as a conceptual context for the entire article.
- Existing generic and specific maturity models.
- The process of building specific maturity models and evaluation instruments.
- Researching qualitative and quantitative methods of research, as a way to identify factors to support the process of developing surveys for specific maturity models.

The first screening of these themes allowed the identification of the context, research gap, and objective, as stated in the introduction. Moreover, the questions that this literature review aims at answering are the following:

1. What are the main differences among maturity models described in the literature?
2. Which factors should be adopted for selection or development of a maturity model?

Having defined the overall context of the study and the research questions allowed the following of the process recommended by the PRISMA Statement [14], including the following four main steps, as adapted to this study (Figure 1): (1) identify records through database searching and other sources; (2) screen and exclude records; (3) assess full-text articles for eligibility; and (4) include studies for qualitative. The bibliography software package Zotero was used as the reference manager system.

For the identification of papers to be analyzed, three databases were used: Emerald Insight, JSTOR, and SciELO. Papers were searched using the following terms:

- "Fourth Industrial Revolution" OR "Industry 4.0" OR "Smart Manufacturing".
- ("Business Process Management" OR "Business Process Reengineering" OR "Organizational Architecture") AND ("Maturity Model" OR "Maturity Assessment" OR "Readiness Assessment").

The search results were filtered in order to include only articles published in scientific journals, in the English language, from the year 2000 onwards, and belonging to the Business, Engineering, Management and Organizational Behavior, Science and Technology Studies. Removing duplicate records resulted in 1220 papers as a starting point.

After screening the title and abstracts considering the research themes mentioned above, there were more than 900 papers excluded. The remaining 268 articles were analyzed and 208 were excluded because they did not allow to respond to the objectives of this article. A typical example of excluded articles are papers with too narrow and specific areas that would not add relevant information for the objective of the current article. After that, 60 papers were selected for a full text qualitative analysis.

As surveys are particularly relevant for the development of maturity models, 7 key references were included to support the identification of factors for the Development of Generic and Specific Maturity Models for Industry 4.0.
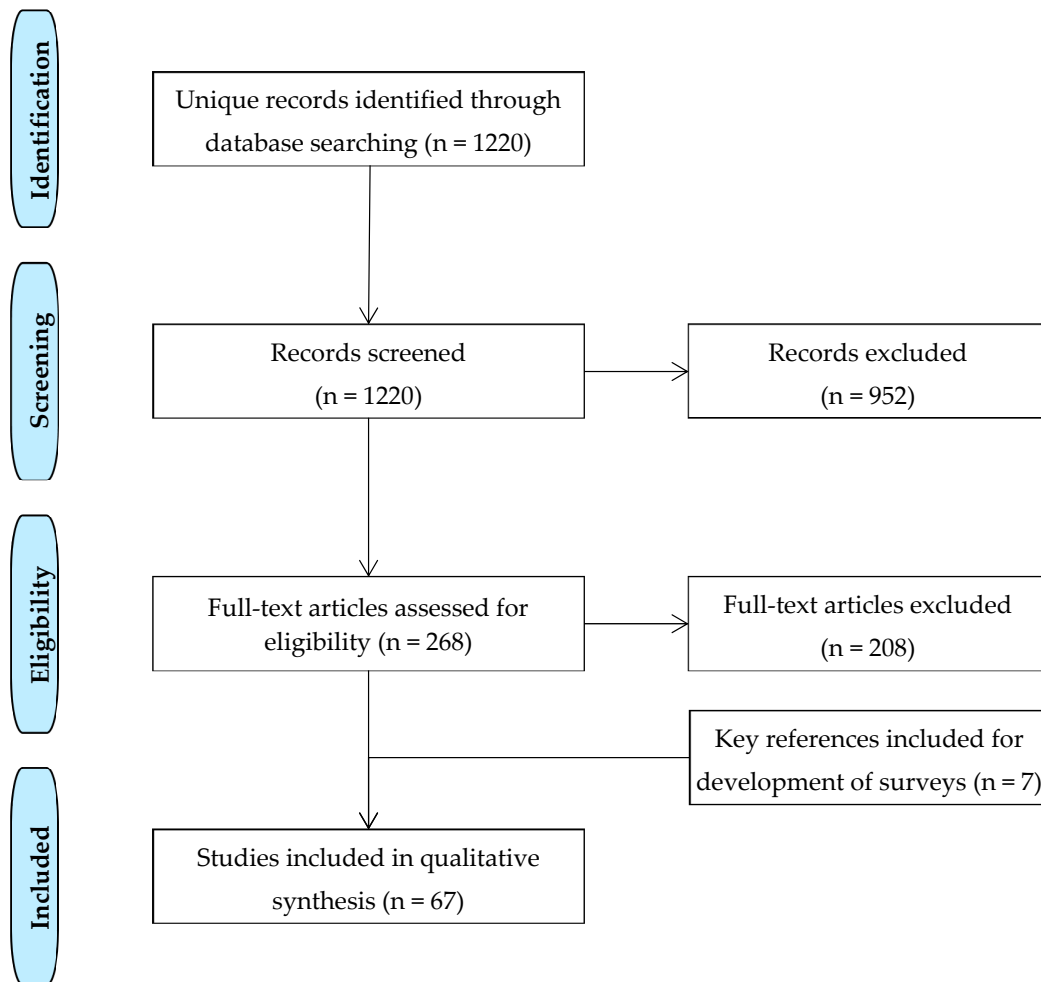


**Figure 1.** Systematic review methodology according Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement, adapted from [14].

The complete list of these articles is referenced in Table 1. It should be noted that Table 1 presents two articles [15,16] classified in two themes of analysis. Thus, even though the total number of articles considered in the analysis is 67, the numbers in Table 1 sum up to 69.

**Table 1.** Classification of the articles examined according to the themes under study in this work.

| Themes | Papers |
|---|---|
| Survey methods (7) | [17–23] |
| Fundamental Concepts (21) | [1,2,4,8–10,15,16,24–36] |
| Generic maturity models (18) | [3,5–7,11,15,16,37–47] |
| Developing specific maturity models (23) | [48–70] |

## 3. Thematic Analysis of the Literature

Most of the studies carried out on Industry 4.0 frameworks focus more attention on technological requirements [26–35]. Although with different nuances, as for example in Jabbour et al. [26], who

present the objective to reconcile Industry 4.0 with the theme of sustainability. In this work, the approach adopted by these authors focuses on the presentation of the potential impact of new technologies. Moreover, despite the fact that Saucedo-Martínez et al. [31] mention studies that point to the importance of a holistic system formed by technology and people, providing an integration of the value chain, the work is then directed to the technological infrastructure that in theory would enable a model of Industry 4.0.

A definition in a few words of the Industry 4.0 model is given by Oztemel and Gursev [30], stating that this movement aims to generate a transformation from a predominantly mechanical manufacturing to a digital manufacturing model. This implies not only structural but also philosophical changes about the productive systems that are based on four pillars: intelligence, smart products, communication, and information networks. These authors highlight in their works which categories of technology can shape this scenario to provide an environment where companies can be fast, agile and flexible, providing high quality goods and services. They consider, however, that these principles cannot be thought of in isolation, but must involve the entire production chain, so that they form cooperation networks, not only between companies, but also between countries capable of sustaining better economies, with a new workforce profile, with increased productivity and industrial growth.

It is worthwhile presenting divergent perspectives over some issues. Crnjac et al. [8] present a strong focus on technological aspects in their research and present the view that the Lean Manufacturing philosophy belongs to the Industry 3.0 manufacturing model, suggesting in contrast that Industry 4.0 converges on a new paradigm called Smart Manufacturing. Following a different line of thought, Tortorella and Fettermann [34] deal with the technological framework of Industry 4.0 and present Lean tools as being a complementary support. In their study, they develop a research among Brazilian companies to identify the level of adherence and purposes that motivate the implementation of Industry 4.0 (I4.0). Moeuf et al. [28] also consider Lean tools and Just in Time (JIT) as being aligned with Industry 4.0 technologies to ensure management and industrial process capabilities such as monitoring, control, automation and autonomy in order to increase performance in indicators such as flexibility, costs, productivity, quality and lead times.

As referred to above, Crnjac et al. [8] highlight articles that specifically address not only Industry 4.0 technologies, but also issues such as horizontal and vertical integration of processes and new business models. They consider that changes should occur at the strategic, tactical, and operational levels. At the strategic level, the reformulation occurs in the company's vision, which expresses its repositioning in relation to its customers and competitors, making the transition from mass production to mass customization. At the tactical level, the technology is applied according to the defined strategy. Finally, at the operational level, the objectives related to Industry 4.0 are defined and implemented in five dimensions: (1) project management; (2) process management; (3) technology management; (4) organizational management; and (5) people management.

## 3.1. Maturity Models

The diagnosis and improvement project approach based on maturity models has gained more and more followers since its emergence in the fields of Business Management and Software Engineering. Two definitions of maturity models can be considered. According to Kluth et al. [40], "a maturity model is a (simplified) representation of reality to measure the quality of business processes. Here, depending on the model, different stages of 'maturity' of business processes are described". For Kohlegger et al. [42] "a maturity model conceptually represents phases of increasing quantitative or qualitative capability changes of a maturing element in order to assess its advances with respect to defined focus areas." Therefore, maturity models are important tools for evaluation in strategic management so that they offer parameters for companies to have clarity about the result of their efforts to achieve their objectives. Table 2 presents a generic procedure for the selection or development of maturity models, which integrates the works by De Bruin et al. [53], Menon et al. [16] and Mettler [59].

**Table 2.** Procedure for selection or development of Maturity Models, adapted from De Bruin et al. [53], Menon et al. [16] and Mettler [59].

| Phase | Decision Parameters | Characteristics |
|---|---|---|
| Define Scope | Focus/Breadth | Generic Model |
| | | Specific Model |
| | Audience | Management-oriented |
| | | Technology-oriented |
| Design Model | Maturity Definition | Object-focused, parameters/dimensions |
| | Goal Function | Multi-Dimensional |
| | Design Process | Literature and Practitioner Based |
| | Application Method | Self-Assessment or Third Party certified professional |
| | Respondents | Combination of internal (staff) and external (partners) |
| Populate | Measures | What needs to be measured and how |
| Evaluate Design | Test Model Structure | Evaluate deployment measures |
| Reflect Evolution | Deploy and Maintain the Model | Synthesis of design and continuous learning |

### 3.2. Generic Maturity Model

There are several maturity models related to I4.0. In Table 3 several maturity models are listed. Most of them are directed at I4.0, others were considered because they served as a basis for I4.0 maturity models. They have in common the fact that they are generic and their application depends on consulting and external evaluations of the processes to identify the level of maturity. Colli et al. [37] synthesize the fundamental dimensions of maturity models in the following dimensions:

- Governance, which corresponds to the existence of strategic planning, resource allocation, digital awareness and engagement of all organizational levels.
- Technology, that is, technological infrastructure that supports I4.0 concepts.
- Connectivity, or availability of technical apparatus for data transmission and communication.
- Value Creation, which is the ability to generate value from the analysis of data.
- Competence, which deals with the management and development of new skills.

In a study conducted by Sony and Naik [3], in addition to these aspects, they also advocate a need for actions to be taken to digitalize not only the activities of the organization, but the entire supply chain, and the change from a strategy that focuses on the product to a new strategy in which the focus is on intelligent products and services.

There are common approaches for the adoption of distinct generic maturity models, applied according to the organizational levels and for specific purposes.

The present article is based on the thesis that the Industry 4.0 necessarily absorbs the organization based on processes. Therefore, it is worth mentioning the works published by Ongena and Ravesteyn [44] and Szelagowski and Berniak-Woźny [45] which propose the application of a maturity model in Business Process Management strategies. Although both articles present particularities, it is important to highlight the elementary maturity levels for business processes:

- Awareness, in which there is recognition of the value of process-oriented management.
- Description, in which processes have already been mapped and documented.
- Measurement, in which the performance of processes can already be monitored.
- Control, in which processes already have an "owner" or someone responsible.
- Improvement, in which there is a continuous practice aimed at improving processes.
- Resources and Knowledge, in which a process-oriented culture manifested in people's competencies is already established.

- Information Technology, in which information technology is used for the design, simulation and execution of processes.

**Table 3.** Generic maturity models identified in the researched literature.

| Maturity models | Contributions | Description |
| --- | --- | --- |
| Complexity Management Maturity [40] | It is based on the complexity management strategy which can "deal with complexity", "reduce complexity", "avoid complexity", "price complexity", "generate complexity". | Maturity levels predict an evolution that includes 0 to 6, being (0) initial, without understanding complexity, (1) defined: complexity fields are defined, (2) qualitative: complexity is qualitatively evaluated, (3) quantitative: quantitative Key Performance Indicators (KPI) are elaborated, (4) analyzed: complexity patterns are generated; (5) managed: measures are defined and initialized; (6) harmonized: internal and external complexity are harmonized. |
| Smart Manufacturing System Readiness Assessment (SMSRA) [11] | The authors propose a strategy of implementation with a readiness assessment, framework, roadmap and maturity model. They evaluate the level of maturity of the organization dimensions, which refers to the design of processes; information technology; performance, which aims to evaluate the instruments for monitoring indicators and information connectivity. | The levels can be initial (does not exist), managed (roadmap available), defined (value proposition and key resources defined), transformed (strategy divided into tasks) and detailed business model (the business model is transformed). |
| C3M Maturity Model [41] | Designed for application in "case management" that defines how a complex situation is managed and how services respond to customer needs. The acronym C3M combines CM-Case Management with 3 aspects that the model aims to address: characterization of the model of maturity, benefits and risks. | The maturity model involves the dimensions Strategy, Processes, Technology, Organization and People. It considers that levels should measure capabilities, benefits and risks and can be as follows: Individualistic, supported, managed, standardized, transformative. |
| Capability Maturity Model (CMM) and Capability Maturity Model Integration (CMMI) [15,16,38,39,41,44,45] | CMM is one of the first maturity model initiatives and was built in 1986 by the Institute of Software Engineering to respond to management and monitoring demands. In 2006 the model also started to consider the integration between technology and processes (CMMI), and also started to converge with models and standards of governance of information technology as Control Objectives for Information and Related Technologies (COBIT), Information Technology Infrastructure Library (ITIL), Project Management Institute (PMI), and International Organization for Standardization (ISO). | It foresees the following maturity levels: Initial, Repeatable, Defined, Managed, Optimizing. |
| IMPULS Industrie 4.0 Readiness Model, by VDMA, Rheinisch-Westfälische Technische Hochschule Aachen (RWTH) Aachen and IW Consult [3,11,37] | Presented by the German Engineering Federation (VDMA), Cologne Institute for Economic Research Consult GmbH (IW Consult) and Institute for Industrial Management (FIR) at RWTH Aachen, it considers 6 dimensions: organizational strategy, smart factory, smart operation, smart products, data-driven services and employees. | Organizational strategy directs plans and actions for the achievement of Industry 4.0, smart factory refers to automation in production, smart operation indicates the level of integration between the activities, smart products on products designed to favor new data-driven services, data-driven services support services added to the products and employees support the digital transformation. |

**Table 3.** *Cont.*

| Maturity models | Contributions | Description |
| --- | --- | --- |
| Manufacturing Value Modeling Methodology (MVMM)/Gartner Maturity Model [46] | Its objective is to initially develop a Value Map of the company to identify its position in the following items: Market trends; company objectives; practices; and business domain. After that, the Gartner Maturity Model is applied to measure the current state of the company in the repositioning project. | This model foresees the following stages: Stage 1, focus on operational activities and distribution level; Stage 2, anticipation of the objectives of the supply plan; Stage 3, integration of the supply plan to anticipate demands through service oriented responses; Stage 4, excellence in the supply plan; Stage 5, orchestration in the boundaries between demand and supply. |
| A Maturity Model for Data-Driven Manufacturing (M2DDM) [47] | Aims to evaluate the integration between information technology and automation engineering, with the different stages of the value chain, and with the other infrastructures necessary for the work. | It considers the following levels: (0) Non-existent IT integration; (1) Data and System Integration; (2) Integration of Cross-Life-Cycle Data; (3) Service-Orientation; (4) Digital Twin; (5) Self-Optimizing Factory. |
| System Integration Maturity Model Industry 4.0 (SIMMI 4.0) [3,37,43] | It focuses on the assessment of the technological infrastructure required by the Industry 4.0 model. | Provides the stages (1) Basic digitization; (2) Cross-departmental digitization; (3) Horizontal and vertical digitization; (4) Full digitization; (5) Optimized full digitization. All these stages evaluate the following dimensions: (1) Vertical integration; (2) Horizontal integration; (3) Digital product development; (4) Cross-sectional technology criteria. |
| ManuTech Maturity Model (MTMM) [6] | It focuses on the evaluation of functional areas of the operational level of organizations. It also pays special attention to the demands of companies in the manufacturing sector. | The dimensions evaluated are: Core Technologies; People and Culture; Knowledge Management; Real-Time Integration; Infrastructure; Strategic Awareness and Alignment; Process Excellence; Cybersecurity. |
| Industrie 4.0 Maturity Index, Acatech [37] | Developed by the National Academy of Science and Engineering of Germany. It foresees six stages of maturity that are computerization, connectivity, visibility, transparency, predictive capability and adaptability. These levels are applied in the dimensions of Resources, Information Systems, Organizational Structure and Culture. | Computerization refers the level which technological tools are used separately, in connectivity, the components are connected and represent the organizational processes, in visibility, there is wide use of sensing that allows the collection of data from beginning to end of the processes, in transparency level, it is possible to obtain a digital shadow that represents the situation of the organization, in predictive capability, capacity for simulation of scenarios, and in the adaptability stage, the organization has capacity for continuous adaptation. |
| Information and Communication Technology (ICT) Maturity [5] | Aims to assess maturity in relation to the adoption of information technology. | It basically considers two factors, competencies in new technologies and information security. |
| Master Data Management Maturity Model (MD3M) [7] | Maturity model to assess a very specific aspect of the companies that adhered to the Industry 4.0 model, which is the data processing capacity. It is based on other information technology management models of the same nature such as COBIT, Oracle, Information Management Network (IMN) and Dataflux. | It evaluates the preparation of organizations according to the following levels: Initial; Repeatable; Defined Process; Managed and Measurable; Optimized. Considers the following capabilities: Data Model; Data Quality; Usage and Ownership; Data Protection; Maintenance. |

Traditional maturity models like the Capability Maturity Model (CMM) and Capability Maturity Model Integration (CMMI), and professional models like IMPULS and System Integration Maturity Model Industry 4.0 (SMMI) are cited by several authors in their research work to describe their historical

importance and to identify them as success cases. Other professional and generic maturity models appear in exploratory research and are eventually mentioned in the literature as in the works of Sony and Naik [3] and Kohlegger et al. [42], however, the information about them is either not presented in depth or is apparently presented for commercial purposes. Some of these models are:

- PwC Industry 4.0—Enabling Digital Operations and Self-Assessment.
- Boston Consulting Group (BCG)—Digital Acceleration Index.
- The Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing, by Fraunhofer Austria.
- Minnosphere and Hochschule Neu-Ulm—University of Applied Sciences, online-assessment, digital readiness of companies.
- Federal Ministry for Economic Affairs and Energy Germany (BMWi), Industrie 4.0—Checkliste: Kommt Industrie 4.0 für unser Unternehmen in Frage.
- Deutscher Industrie-und Handelskammertag (DIHK)—Selbsttest zum digitalen Reifegrad.
- The Connected Enterprise Maturity Model, Rockwell Automation.
- Industry 4.0/Digital Operations Self-Assessment, Pricewaterhouse Coopers.
- Digitalization roadmap, by Siemens.

Generic maturity models share the derivation of process management models based on quality assurance and continuous improvement approaches. They are built for companies, by experts from companies and academia, based on traditional models. Therefore, they correspond to the product of those companies or providers who deliver them in the form of services. They depend on the support of consultancies that, before applying them, perform analysis, diagnosis, and, as a result, develop an adapted implementation strategy based on maturity models. Compliant with what is expected in Crnjac et al. [8], studies using this approach are in general guided by dimensions such as project management, process management, technology management, organizational management, and people management.

Another important factor that should be highlighted was mentioned by Mittal et al. [11], who, in order to support their proposal of the Smart Manufacturing System Readiness Assessment (SMSRA) model, performed both a comparative analysis with another model, namely IMPULS, and also identified other generic approaches of implementation of Industry 4.0. These other approaches use different terminology, as framework, roadmap, maturity model, readiness assessment, with varying meanings assigned to them. Vrchota and Pech [35], for example, investigate the level of preparedness of organizations, both large enterprises and small and medium enterprises, for Industry 4.0 with allusion to a perspective of maturity in addressing the need for reconfiguration. Thus, these terminology and conceptual differences create a research opportunity to better characterize these terms, as well as to present a proposal for a composite solution within the generic implementation models.

### 3.3. Specific Maturity Model

Another way to address the demand for maturity assessment is by choosing to build a model to meet a specific condition. It is common in such cases to use an existing model as a reference. In any case, the identification of success factors that should be considered is a fundamental element. Table 4 presents the result of the literature review in publications that presented methodologies for the construction of maturity models.

**Table 4.** Methodologies for the construction of maturity models identified in the literature researched.

| Paper | Description | Methodologies | Instruments |
|---|---|---|---|
| [61] | Aims to identify factors of greater impact in the implementation of Software Process Improvement (SPI) programs and factors of lesser impact, if there are variations in the perception of respondents from companies of high and low maturity and between companies that were successful and those that were not successful in the implementation of SPI. | The authors consulted the literature of case studies, surveys among companies evaluated by CMM and SPICE (Software Process Improvement and Capability dEtermination). The authors sent 1000 self-applied questionnaires. The data were analyzed according to the classification of the maturity level of the companies in order to identify how they attribute the impact of the factors: higher impact, lower impact, no impact and does not know. The validity of the diagnosis was evaluated by comparing the results obtained in the parallel application of a generic maturity model and the reliability of the responses was evaluated according to the level of experience of participants in the factors questioned. | Survey validated by a case study |
| [54] | Aims to evaluate the level of adoption by Brazilian companies associated to ABIMAQ-Sul (Brazilian Machinery and Equipment Builders' Association) of technologies that enable Industry 4.0 models such as sensors, ERP (Enterprise Resource Planning), MES (Manufacturing Execution System), SCADA (Supervisory Control and Data Acquisition), etc. Based on the results, the authors suggest a framework for implementing the Industry 4.0 model. | Quantitative research. A Likert scale questionnaire was prepared to evaluate the factors identified in the literature review and refined in interviews with academics and professional experts. The validity of the questionnaire was assessed by pre-test, test-retest and factor analysis procedures. For the analysis of the collected data, the clustering approach by similarity using the Hierarchical Cluster Analysis (HCA) technique was adopted. | Literature review, interviews with experts, interviews with practitioners, survey validated with pre-test, test-retest and factor analysis |
| [63,69] | Aims to identify the state of the art in road mapping for the implementation of the Industry 4.0 model and maturity models. The research revealed two main approaches, holistic and specific. | Literature review of more than 70 published works. Guided by the identified concepts and approaches, interviews with experts and workshops with professionals were developed. In order to arrive at the proposed maturity model, a further others 45 works were analyzed. | Literature review, interviews with experts, interviews with practitioners. |
| [62] | The article presents the process of building a maturity model for evaluating the supply chain in Mexico. | The methodology consists of the identification of factors in a literature review and, after that, through interviews with experts. To validate the model, the authors created two fictitious companies, defined their strategic profiles and asked 14 people to apply the model in these companies using a null hypothesis technique. | Literature review, interviews with experts, case study. |
| [60] | Presents a maturity model for evaluating supply chain operations. | The methodology consists of a literature review and pilot testing in companies. After repeated applications, the results are submitted for analysis by professionals and researchers and feedback is obtained. | Literature review, research action, interviews with experts, interviews with practitioners. |
| [58] | Study on key aspects for evaluation of the maturity index of processes in Business Process Management (BPM). | The methodology consists of a literature review from which the model was developed. The model was applied in 100 companies and the results were presented in workshops and working groups that developed from the visual roadmap analysis. | Literature review, case study. |

**Table 4.** *Cont.*

| Paper | Description | Methodologies | Instruments |
|---|---|---|---|
| [68] | Construction of a maturity model to evaluate the performance of industries in the construction industry. The model is based on the CMMI maturity model, designed and widely used in the software industry. | The methodology consists of extensive literature review research. | Literature review. |
| [65] | The objective of the work is to build a maturity model for digital library evaluation in the context of Iran based on the CMM model and through the Delphi technique. | The authors performed a literature review to identify key factors. Subsequently, the model developed was validated with the help of experts. The Delphi technique, used when there is no consensus about a phenomenon, was then applied through two questionnaires distributed by e-mail among researchers, academic staff and specialist directors from the private sector. The questionnaires consisted of items with a Likert scale. Respondents were motivated to suggest categories, concepts and codes not foreseen in the questionnaires. In a second round, the old and new features were again applied to the interviewees. The third round consists of data submission and analysis. | Literature review, interviews with experts, Delphi technique, survey. |
| [51] | Construction of a maturity model based on CMM to improve performance in project management. Aims at identification of the modus operandi of project management in companies. | The methodology consists of case studies, application of questionnaires and unstructured discussions in focus groups. The authors defend the validity of the construction of the instruments by the proper application of the concepts, the internal validity in the application of multiple cases, the external validity by the possibility of extension of the research, and the confirmation of the validity by the possibility of reproduction of the results. | Case study, survey, focus group. |
| [52] | Construction of a maturity model for the evaluation of companies in the treatment of big data. | The methodology consists of three stages. The first corresponds to the design of the maturity model based on a literature review on process management and unstructured interviews with specialized professionals with 8 to 27 years of experience. Interviewees were free to express their opinions on issues not foreseen in the literature. Subsequently, structured questionnaires were sent to specialists in big data and the answers were discussed with evaluators over the telephone. Finally, the participants in the first interview were again interviewed to evaluate the model achieved and the results of the quantitative research. | Literature review, interviews with practitioners, interviews with experts, survey validated by interviews. |

**Table 4.** *Cont.*

| Paper | Description | Methodologies | Instruments |
|---|---|---|---|
| [48] | Development of Industry 4.0 maturity model for application in supply chain delivery processes. | The methodology is based on Design Science Research (DSR) which consists of exploratory research for the development and application of artifacts that can be constructed, models and methods. In the first step, the scope of the research is defined based on stakeholder expectations. In the second stage, the model is designed based on the audience, application method, application direction, respondents and application. In the third phase, model components are defined through a literature review or interviews with stakeholders, surveys, focus groups and case studies. In the fourth phase, validity and reliability tests are performed using criteria such as comprehensibility, comprehensiveness, relevance, consistency, systematic structure, detachment, conceptual reliability and applicability, and finally, in the fifth phase, the application. | Exploratory research, literature review, interviews with practitioners, survey, focus group, case study. |
| [70] | Construction of a roadmap for implementation of the Industry 4.0 model and maturity model. | Compilation of an extensive and accurate literature review. | Literature review. |
| [67] | Construction of maturity model for manufacturing systems. | The methodology has 4 phases. In the first phase, a panel of experts is held to identify relevant factors. The second phase consists of a literature review on the aspects raised, refinement of the research in conjunction with experts and carrying out a survey and respective internal analysis of consistency. In the third phase, the model is designed and submitted to a new panel of experts to define the compilation procedures. In the fourth and final phase, the model is applied, and with the results an implementation framework is developed and a new expert is created to conclude a generic model. | Interviews with experts, literature review, survey. |
| [64] | Development of a maturity model for evaluating Brazilian companies that adopt a circular economy business model. | The basis of the model is obtained in a literature review and the validity of the model is evaluated in the return of results collected through a structured questionnaire. | Literature review and survey. |
| [50] | Definition of a maturity model for Industry 4.0 with the objective of application in companies in the defense sector. | The study collects data through semi-structured interviews, workshops and item scoring, incorporated into a case study logic, in order to test and validate the model. Built from a literature review, the model was presented and validated by expert employees of an English company. Afterwards, specialists from 12 other companies collaborated in the supply of data for benchmark purposes. | Interviews with practitioners, interviews with experts, literature review. |
| [56] | Construction of a maturity model to evaluate the adoption of intelligent services by German companies. | The model was conceived from a literature review and validation of the model in case study. A total of 30 companies participated in interviews and after the interactions a framework was designed which was refined from application in 3 companies. | Literature review, case study. |

**Table 4.** *Cont.*

| Paper | Description | Methodologies | Instruments |
|---|---|---|---|
| [66] | Construction of maturity model for application in medium and small companies. | The model was built from a literature review and validated in a case study with 4 participating Italian companies. | Literature review, case study. |
| [55] | Construction of maturity model for application in medium and small companies. | The model was built from a literature review and workshop with companies. The data collected were evaluated in unstructured interviews with experts. Companies in the process of implementing the Industry 4.0 model were subsequently selected for case studies and roadmap development. | Literature review, interviews with practitioners, interviews with experts. |
| [57] | Development of a maturity model for the Turkish context. | A questionnaire on key factors was constructed from a literature review. The questionnaire was translated into Turkish and submitted to an expert for analysis and refinement and then applied to 5 other experts from Turkish companies. | Literature review, survey. |
| [49] | Development of a maturity model for non-metal mineral industries in Portugal. | The methodology initially consisted of a qualitative study by means of interviews and observation research with three companies for evaluation of existing maturity models. The data collected and a literature review served as the basis for a workshop on the topic with 120 participants. The conclusions obtained in the workshop were used to refine the framework. | Interviews with practitioners, observation research, literature review. |

The need to cover very specific requirements was identified in the articles that meet the objective of building maturity models, involving factors such as functional areas (e.g., logistics and supply chain), economic sectors (e.g., software industry, machinery builders, construction and mining), and countries (e.g., Italy, Portugal, Germany, Brazil, Mexico, Turkey and Iran). In some situations, these variables appear isolated, and in others they appear combined. These papers make contributions with different methodological strategies, which are still very specific to the contexts in which they are developed. The analysis of the contextual environment is carried out through exploratory research with interviews and workshops and the gathering of critical knowledge through literature reviews. The research procedure of surveys is widely used but the method of validation is different. In a few cases the surveys are validated by quantitative analysis, and most are validated by comparative analysis in case studies, observation researches, action research or interviews with practitioners and experts. Thus, the development of a more generic strategy that may be applied to broad areas still constitutes an opportunity of research. This would be especially relevant if these strategies could be applied in a more autonomous way by SMEs.

## 4. Factors for the Systematization of a Survey for Specific Maturity Models

After an extensive and systematic literature review on business model reconfiguration approaches for Industry 4.0 implementation and research methodology exploration in Business Research, as well as for its empirical validation, it was found that researchers can guide themselves considering the following factors:

- Exploratory research to characterize the application context.
- Development of the theoretical background through literature review and validation of experts in order to clarify relevant aspects and concepts. It was observed that the objective in these

cases is the identification of constructs and other important elements that serve as a basis for the elaboration of surveys and for the targeting of semi-structured interviews.

- Usually the interventions related to the previous factors are made possible by workshops with possible stakeholders, both experts and practitioners, who collaborate in the refinement of the material elaborated until then.
- Surveys are conducted when there is a substantial number of participants and thus the research take on a quantitative nature. Therefore, in order to avoid false precision in the results, the Bayesian Model of Factorial Analysis for Mixed Data in research projects in the management area can be proposed because it is able to model ordinal data (qualitative measurement) and intervals (quantitative measurement).
- Qualitative research through case studies, action research and observational research with a smaller number of participants and consequently more engaged and interested in the results can prove to be a promising strategy.

A survey is a fundamental instrument of a maturity model. For the development of such an instrument, Araújo et al. [18], influenced by the work of Churchill [19], propose the following ten stages grouped into three categories, for the creation of a survey:

1. Theoretical importance and existence of constructs

    (a)　Literature review and interview, or focus group, with experts
    (b)　Generation of items
    (c)　Validation of items by experts

2. Representativeness and adequacy of data collection

    (a)　Development and evaluation of the questionnaire
    (b)　Translation of the questionnaire
    (c)　Pilot study
    (d)　Sampling and data

3. Statistical analysis and statistical evidence of the construction

    (a)　Assessment of dimensionality
    (b)　Assessment of reliability
    (c)　Assessment of the validity of the construction (converging and discriminatory validity)

According to Parente and Federo [21], causal complexity is an attribute present in management research. It is guided by three principles, namely, (1) conjunction, which refers to the result that derives from the interdependence of multiple conditions, (2) equifinality, which is the possibility of multiple paths to the same result, and (3) asymmetry, which indicates that the causal relationships that explain one phenomenon may not explain another similar phenomenon. Therefore, research tools based on correlations, characterized by linear and symmetric logic, are not able to deal with these three principles of causal complexity. Qualitative Comparative Analysis (QCA) is the methodological tool suitable for the empirical investigation of conditions of this nature. Its application involves probabilistic approaches that take into account nonlinearity, omitted variables and case-based causal inferences and helps to assess how multiple and distinct conditions are combined and associated with a certain outcome (conjunction), as well as to identify possible conditions associated with an outcome (equifinality), and, finally, how the presence and absence of attributes can be related to an outcome (asymmetry).

An important element of scales are the constructs. For Almeida and Freire [17], the process of building an evaluation instrument begins by defining what will be evaluated, what will it be evaluated

for, and with whom the evaluation will be carried out. This measurement is performed by means of constructs that express latent aptitudes, traces or dimensions.

Hair et al. [20], supported by Stevens [23], consider that two terms are often treated as synonyms, but have differences in destination, which are measure and measurement. The first is intended for the evaluation of physical quantities, or measurable phenomena, such as mass, temperature, time, etc., while the second is appropriate for attitudes, perceptions, opinions, behavior and other phenomena not directly measurable.

Hair et al. [20] state that constructs are mental creations and therefore do not actually exist, which implies difficulties in defining and measuring precisely what they are. Therefore, constructs cannot be defined or evaluated (measured) by means of a single item. Single items can measure variables, but never constructs. Similarly, other mental creations, such as attitudes and behaviors, must be measured with various indicators. Constructs are also often identified as latent, subscale, unobserved, unmeasured, factor, component, compound, and other variables. A construct composed of several elements should not be referred to with generic phrases. Researchers should create an operational set of elements that accurately reflect the concept being measured, that can serve as verbal substitutes for open actions, under penalty of obtaining neutral responses that do not reflect the provisions underlying the direct actions. The authors explain that for the creation of constructs the procedures of Literature Review or interviews with specialists are necessary. When information and scientific knowledge about the field under study are abundant and available, the literature review is adequate. Otherwise, the available resource is expert interviews.

In summary, supported by an extensive research, this work points out five factors for the development of a specific maturity model: Characterization of the application context; Literature review for conceptual characterization; Interaction with practitioners and experts; Development of surveys; Qualitative research. Additionally, supported by the conclusion of the previous sections, there is still the need to develop generic methodologies that can be applied in a more autonomous way for the development of specific maturity models.

## 5. Conclusions

From the investigation carried out some research gaps that this article proposes to for future works were identified. The findings will be presented in answer to the questions formulated as the objective of this article.

(1) What are the main differences among maturity models described in the literature?

The literature review allowed the identification the main characteristics of Maturity models (Table 2), integrating models from I4.0 and other areas of business process management. Additionally, a synthesis of maturity models is presented in Section 3.2, which is a useful resource for researchers and professionals aiming to select and understand these models. However, as the research progressed, it was observed that reconfiguration projects in the transformation for I4.0 are quite diverse, and that the LEs, for the most part, have the resources and critical knowledge to conduct, by themselves or with the support of consultancies, their initiatives to renew their business models. In such cases, generic maturity models are often adopted. However, SMEs and economic sectors suffering from very particular constraints have great difficulties. Numerous research initiatives have been identified to address these cases by building specific maturity models.

(2) Which factors should be adopted for selection or development of a maturity model?

There is a lack of studies on the ways in which companies can orient themselves to discover the approach of reconfiguration of business models best suited to their reality, i.e., whether they should employ their own efforts or seek support for the application of generic maturity Industry 4.0 models, or whether they identify the need for a specific strategy. In the latter case, an approach based on specific maturity models seems to be promising, but there are also no studies aimed at systematizing a methodology that guides researchers in the development and application of maturity models, nor for companies that recognize the need for a special development. Within the demands for generic and

wide-ranging models, it was found that there is confusion and difficulties in distinguishing among terms such as framework, roadmap, maturity models and readiness assessments, and this aspect denotes opportunities for research. Although much of the literature treats them as synonyms, there are particularities that need to be taken into consideration. Likewise, there is the lack of a study for the systematization of an integrated approach for an organizational reconfiguration model. This purpose can be pursued in future works. Concerning specific maturity models, although the authors report successful cases of building maturity models for specific contexts, there are also very diverse treatments in the methodological aspect adopted in these processes. However, it was possible to find approaches that allowed the identification of a set of important factors that can be used as the ground base for the development of a specific maturity model for I4.0.

An Industrial Revolution presupposes, to a certain extent, a movement of transformation driven by the emergence of a new scientific paradigm that, in turn, presents a new logical–conceptual matrix. Under these conditions, it is foreseeable that some ambiguities will arise in the discourse of different authors who, on the one hand, may assume biases related to old models and paradigms, and on the other hand, may use old terms to refer to new realities that still lack more appropriate terminology. This level of terminology ambiguity creates one of the limitations of a systematic literature review like the one proposed here. Another limitation is related to the methodology of selection and evaluation of articles that depend on the selected search terms and on the criteria of analysis and the consensus between both researchers. Finally, we consider that the results added valuable knowledge to the area of maturity models for Industry 4.0 both for interested researchers and professionals initiating their journey for I4.0.

Industry 4.0 depends on a chain of cooperation because it is a technological revolution. Thus, the lack of national policies for transforming the productive system into this reality can be a problem. However, many countries have development agendas, but, nevertheless, structural challenges can be seen by companies as obstacles to individual actions. Research projects aimed at reducing the polyphony around models and implementation tools will certainly be useful to achieve a complete model of generic and broad-ranging implementation, especially from the point of view of the small and medium enterprises who do not have their own resources and means to have specialized support to adapt to their specific needs. Moreover, exploratory research to characterize the context of nations in its peculiar conditions and in relation to the surrounding economic area would allow the identification of the relevance of focusing on small and medium enterprises, because they are usually the ones that employ the most and because they face the greatest difficulties in obtaining guidance in structuring competitive strategies, business models and organizational architecture.

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