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COMPREHENSIVE REVIEW OF A DIGITAL MATURITY MODEL AND PROPOSAL FOR A CONTINUOUS DIGITAL TRANSFORMATION PROCESS WITH DIGITAL MATURITY MODEL INTEGRATION

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ABSTRACT

In recent years, digital transformation has become one of the most popular trends for enterprises worldwide. The global trend of digital technologies and the COVID-19 pandemic have made the growth speed of digital transformation steadier than ever. In this condition, practitioners and academic researchers believe that the Digital Maturity Model is one of the most effective weapons in helping managers and the workforce manage to transform their businesses digitally. However, the Digital Maturity Model (DMM) is a type of maturity model (MM) that is relatively new in model development and digital maturity assessment methodologies, especially when integrated into an extensive digital transformation process. With this paper, the authors aim to conduct a comprehensive review to clarify the current state of the DMM field, including its essential characteristics, popular elements belonging to its structures, the number of methods, and techniques used in developing and applying them. In addition, these papers identify significant areas of research underway. Moreover, the authors raise some challenges for the field in the capture of results by reviewing them: i) the need to standardize its component names; ii) a contextualized but low-cost DMM for SMEs to use in their business; iii) the need for positioning DMM applied processes in a master digital transformation process and in a dynamics context that help applications of DMM more efficient. The authors proposed a solution for the third challenge through a conceptual model integrating DMM into a continuous digital transformation process.

Keywords: Digital Transformation; Digital Maturity Model; Continuous Transformation Process; Change Management.

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RESEARCH BACKGROUND

The booming of digital transformation

Most modern-day enterprises are being confronted with dealing with digital transformation challenges. Digital transformation (DT/DX) is defined as "the use of technology to radically improve the performance or reach of enterprises" (Westerman *et. al.*, 2014b). DX is seen as a radical and complex type of Enterprise Transformation, commonly referring to a disruptive process that profoundly changes companies' ways of competing, interacting, and creating value. Moreover, Bordeleau & Felden (2019) state that high levels of digitalization are presented as good for a country's economic performance because they increase an organization's efficiency and productivity.

According to IDC (2020a), despite the challenges presented by the COVID-19 pandemic, global spending on DX investment will continually grow from 10.4% in 2020 to $1.3 trillion. Even though this is significantly smaller than the 17.9% growth in 2019, the growth remains one of the few bright spots if overall technology spending reduces dramatically. The global consulting giant also reveals that direct DX investment is growing at 15.5% annually, driving over 6.8 trillion from 2020 to 2023 as companies struggle to become digital-at-scale future enterprises. By 2022, the digitalized economy will account for about 65% of global GDP (IDC, 2020b).

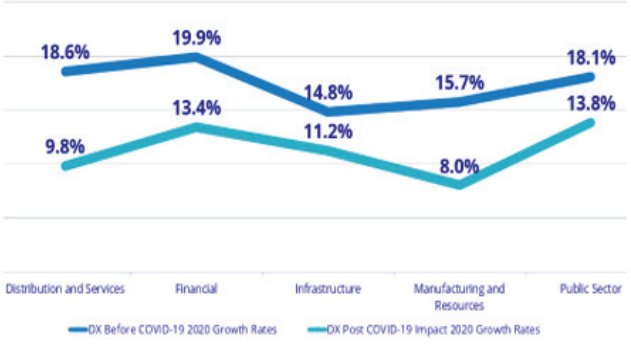

Figure 1. Worldwide spending for DX in 2020 Source: IDC (IDC, 2020a)

Applications of Digital Maturity Model in digital transformation

The maturity model (MM) concept first appeared in the 1970s and is dedicated to software engineering (Chanias & Hess, 2016; Rafael *et. al.*, 2020). Since then, the MM concept has evolved into an important tool for improving business practices (Schäffer *et. al.*, 2018) by assessing their status-quos, establishing a desirable path for advancing them, and making internal or external benchmarking to realize gaps in competencies manner (Röglinger *et. al.*, 2012).

Due to the broad range of potential applications, MMs have gained popularity in management and science (Becker *et. al.*, 2009; Rafael *et. al.*, 2020). There are lots of MMs published focusing on different fields of organizations' capabilities, such as Process Management (ISO, 2015), Six Sigma (ISO, 2011), "IT service capability, innovation management, program management, enterprise architecture, strategic alignment, or knowledge management maturity" (De Bruin *et. al.*, 2005). The most well-known MM is the Capability Maturity Model (CMM), derived from Phillip Crosby's Quality Management Maturity Grid (QMMG) model, which aims to help evaluate the quality of the information systems and processes (Williams *et. al.*, 2019).

Meanwhile, DX is a modern revolution where companies use new digital technologies such as SMACIT (Warner and Wäger, 2019) to enable significant business improvements such as enhancing customer experience, advancing operations excellence, and innovating in business models (Fitzgerald *et. al.*, 2014). It is a strategic change that must follow several aspects (Singh & Hess, 2017), such as operational, functional, financial, and corporate strategy (Matt *et. al.*, 2015). However, all previously mentioned MMs just applied to improve specific organizations' capabilities, meaning the need to develop a type of maturity model that covers the number of capabilities required for DX (Kane, 2017). The Digital Maturity Model (DMM) is a type of MM focused on supporting firms to assess and develop their digital capabilities (Becker *et. al.*, 2009). With the booming of the DX trend, DMM has become one of the most important fields for both academia and practitioners to research and pursue.

Research questions

By understanding DMM's importance in assisting companies' transformation to become future digital-at-scale enterprises, this paper aims to investigate research papers to gain insights into DMMs in general and DMM applications in particular. To this end, we raise and research answers to the following research questions:

- What are the different types of models, approaches, methods, techniques, dimensions, and maturity levels that are used to develop and apply DMMs?
- What are the potential research areas in the field of DMM development?

RESEARCH METHODOLOGY

Data collection

The authors collected papers that were peer-reviewed and published between 2000 and May 2021 through structured keyword search and cross-referencing to ensure the quality and reliability of this review. The keywords applied to the search for articles in the database of Google Scholar were: "Digital transformation" OR "digital maturity" OR "maturity model" OR "readiness index". The authors limit the sources of papers to several well-known databases, including Elsevier, EBSCOhost, Emerald, Taylor & Francis, AIS eLibrary, IEEE, and ResearchGate. We only considered articles in English, not those for literature reviews and enterprises.

Within our research, characteristics, structured elements, methods, techniques, focus, and challenges of DMM research are defined and classified. To this end, our review analysis research papers have new contributions to this research field, such as:

- Specifying DMMs' functions and roles in the DX process.
- Developing and/or implementing a new DMM for a firm.
- Empirically investigating how firms from specific sectors apply their DMMs.
- After carrying out screening titles, abstracts, and conclusions to choose the appropriate papers to review, we selected and reviewed 96 papers altogether.

Data analysis

The authors used the content analysis method defined by Berelson (1952) and developed by Mayring (2015) to investigate the collected papers. This method is quite efficient at combining rich meaning qualitative approaches with robust quantitative analyses by (i) enabling manifest content of text and documents and (ii) uncovering latent content and more profound meaning embodied in the text and document (Duriau *et. al.*, 2007; Wilding *et. al.*, 2012).

Firstly, we coded selected papers according to a number of categories that were also revised during the coding process. **Figure** 2 presents our analytic categories that include two groups, namely descriptive analysis and content analysis. Secondly, in the analysis phase, we synthesized and linked two groups to gain insights into critical points and trends in DMM applications in the DX space.

RESULTS AND DISCUSSION

Descriptive analysis of reviewed papers

Our review investigated the theoretical-based (77 papers) and empirical-based (19 papers) research papers. **Figure** 3

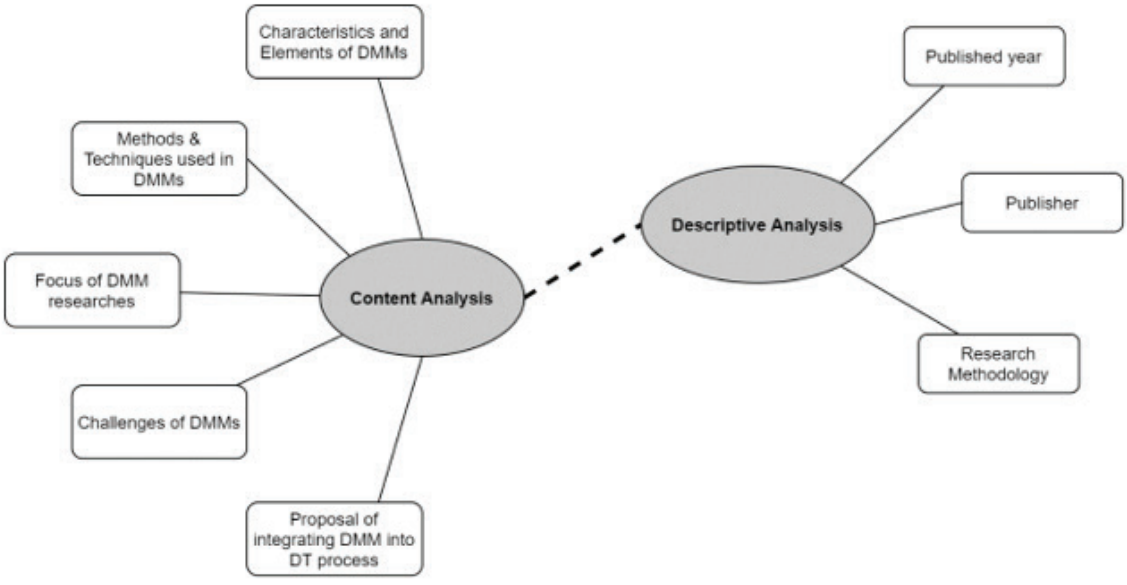

Figure 2. Categories to analyze reviewed papers

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shows the distribution of reviewed papers by published year. In line with DMM prevalence in particular and DX in general, the number of papers has increased over time. **Figure** 4 shows the distribution of reviewed papers by publishers.

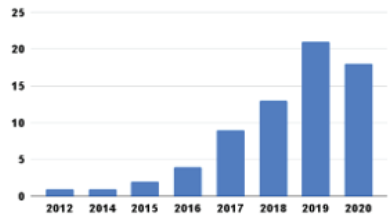

Figure 3. Distribution of papers by published year

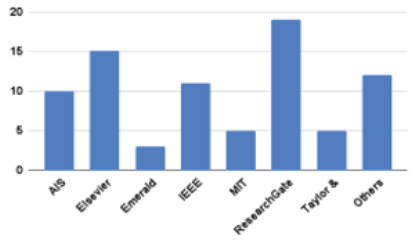

Figure 4. Distribution of reviewed papers by publisher

Content analysis of reviewed papers

Concerning the research questions, the content of the reviewed papers is analyzed as follows: i) to clarify the characteristics, structure, methods, and techniques used in the DMM field; and ii) to find potential research areas. Firstly, to gain insights into the DX phenomenon, it is necessary to understand the characteristics and structure of DMMs (Berghaus & Back, 2016; Chanias & Hess, 2016; Rafael *et. al.*, 2020; Zapata *et. al.*, 2020). The characteristics of DMMs are analyzed, and synthetics are in **Table** 1. The most important DMM attributes presented in **Table** 1 are their purposes, scope, and approach type. The purpose attribute includes descriptive, prescriptive, and benchmarking functions. It is suggested that the descriptive function leads to a contextualized context so that the prescriptive function can give context-specific recommendations for firms that have similar digital maturity levels. DMMs' scopes can cover a specific industry or cross-industries so that firms decide to select an appropriate DMM for them. DMMs' approach can cover a specific capability that the firms' are concerned with or all the capabilities (multi-dimensions) they need to advance as digital enterprises. **Table** 2 shows the popular components used to construct DMMs: dimension, scale items, weighting factors, maturity level, assessment tools, and evolution path. A comprehensive comparison of well-known DMMs is shown in **Table** 3, showing that the most important dimensions are Organization, Process, Strategy, Customer, People, Culture, and IT Technology. The **Table** also reveals that only a few rather complex DMMs use weighting factors for firms to prioritize their initiatives on reducing digital gaps as addressed by assessments. The assessment tools are built based on assessment methods and techniques that are detailed in **Table** 4, which shows various methods ranging from qualitative to quantitative and mixed methods, cover different techniques, and use different types of data and supported tools. These methods and techniques are used in the assessment process and model development projects. As for its evolution path, most DMMs develop their evolution paths based on their maturity levels, which implies a linear path to the next maturity level. This implication is criticized for its oversimplification of the current context of firms, which cannot give them context-specific and particular paths to their next levels (Remane *et. al.*, 2017).

Next, from the reviewed papers, the authors can find potential research areas that are ongoingly researched and could be embedded into DMMs in the future. They are: Change Management, Dynamics capabilities, Firm size, Non-linear evolution path, Evaluation methods, and DMM Dynamics. From **Table** 3, the Transformation Management dimension is the least popular one, but due to DX, it is a type of complex change, which should not only focus on what capabilities need to be changed but also on how these changes are managed (Bordeleau & Felden, 2019). For this reason, Change Management, Dynamics capabilities should be seen as capabilities that need to be assessed by DMMs. Firm size is another factor that should be considered because big companies tend to create their own DMM for their specific and frequent use (Schallmo *et. al.* 2020). The non-linear evolution path is also a potential research area due to giving context-specific recommendations for firms to escalate their digital maturity (Remane *et. al.*, 2017). The firms' evaluation methods to select a suitable DMM for their digital visions need to be researched because they do not have any current guidance for this activity (Felch *et. al.*, 2019). The last one is the DMMs' dynamics, which means that DMMs are currently seen in a one-time static manner rather than gradually enhanced and accessed to reflect the fast pace of change of external environments (Gollhardt *et. al.*, 2020).

Challenges in Digital Maturity Model development

Although DMM brings huge benefits to DX activities, the development of these models in academia and industry faces many challenges. Firstly, it lacks standardization in naming, especially in the naming of structured components of models. Different authors used these terms in different

Table 1 Characteristics of Digital Maturity Models

Characteristics	Components	Sub-component	Description
Purpose	▪ Descriptive ▪ Prescriptive ▪ Benchmarking	▪ Impacted realization ▪ Contextual identification	MMs are reference models that deal with identifying the organizations' current state (AS-IS) and the evolution of maturity to the target state (TO-BE) (Pöppelbuß and Röglinger, 2011). Development states are synonymous with maturity levels. The change to a higher level is equivalent to an improvement in DX (Leyh *et al.*, 2017).
			There are three main MM purposes (Canetta *et al.*, 2018; Gollhardt *et al.*, 2020; Röglinger *et al.*, 2012): ▪ Descriptive purpose: to assess organizations' current situation (AS-IS). ▪ Prescriptive purpose: to indicate how to approach maturity improvement. ▪ Comparative purpose: to enable cross-company benchmarking.
			Descriptive models are the majority with 72%, thus limiting their scope to providing companies with some insights about their level of adoption of Industry 4.0 technologies (Canetta *et al.*, 2018).
			The prescriptive use of maturity models requires the ability to adapt to "organization-specific situational characteristics" (Colli *et al.*, 2019) for conceiving tailored roadmaps consisting of context-specific improvement recommendations for the firms in their DXs (Mittal *et al.*, 2018).
			Comparative use of maturity models is a suitable tool for comparing capabilities between business units and organizations (Felch *et al.*, 2019), in which standardized maturity levels are the basis of a benchmarking approach between them (Puchan *et al.*, 2018). Only a few models can provide this function (Chanias & Hess, 2016).
Sector scope	▪ Cross-Industry ▪ Specific (sector)	▪ SMEs ▪ IT Industry ▪ Manufacturing ▪ Banking ▪ Logistics/Supply Chains (SCM) ▪ Telecommunication	▪ The most recognized model within the area of information systems is the Capability Maturity Model (CMM) (Issa *et al.*, 2018) ▪ The two largest MM groups concentrate on manufacturing, specifically concerning smart manufacturing and SCM (Caiado *et al.*, 2021) ▪ Product and Service Systems (Blatz & Dietel, 2018); (Häckel *et al.*, 2021) ▪ Banking (Khanboubi & Boulmakoul, 2019) ▪ Telecommunication (Newman, 2017); Valdez-de-Leon (2016)
Approach type	▪ Holistic / Multi-Dimension ▪ Specific dimension	▪ Corporate Culture ▪ Data-Driven ▪ Enterprise Integration ▪ IoT Technology ▪ IT Governance (ITG) ▪ Process Management	There are two groups of strategic guidance in Industry 4.0 (Schumacher *et al.*, 2019): holistic and specific approaches. ▪ Holistic approaches: aim to assess elements of Industry 4.0 from all possible angles to derive encompassing success factors ▪ Specific approaches: focused on limited specific aspects (dimensions or capabilities) with greater detail, such as Corporate Culture (Schuh & Frank, 2020), Enterprise Integration (Khanboubi & Boulmakoul, 2019), IT Governance model (Steuperaert *et al.*, 2020), Process Assessment Model (Aguiar *et al.*, 2019)
Other characteristics	▪ Source	▪ Practitioners / Consultancy ▪ Academy ▪ Association ▪ Big Company	There are four main groups of DMM creators (Schallmo *et al.*, 2020): Consultancy, Associations, Scientific, and Big companies: ▪ Consulting firms like PwC (Geissbauer *et al.*, 2016), Forrester (Gill & VanBoskirk, 2016) use DMMs as a practical supporting tool for providing premium information and consultancy services to companies in need of improving their digital strategy. It shows that 70% of models are developed by practitioners (Canetta *et al.*, 2018). ▪ Academic organizations consist of universities and research institutes aimed at educating and supporting the public, such as ACATECH (Schuh *et al.*, 2017) and IMPULS (Lichtblau *et al.*, 2017), ▪ Associations such as Open ROADS (2019), SIRI (2019), and TM Forum (Newman, 2017) are representations of a sum of consultancy or academic organizations to inform and strengthen the industry sectors. Digital maturity should help create benchmarks and comparisons for members. ▪ Big companies such as Deutsche Telekom sometimes require their own DMM to improve their maturity level and collect market data (Schallmo *et al.*, 2020).
	▪ Requirements		The DMMs should fulfill the normative definitions for standardized MMs (ISO, 2015; 2007) (Rafael *et al.*, 2020), such as completeness, clarity, and unambiguity, to ensure that they gain objective, impartial, consistent, repeatable, comparable, and representative results of the assessed organizational units (ISO, 2007). Besides, they should be: ▪ Context-specific; descriptive, prescriptive, or comparative; comprised of mutually exclusive dimensions; describing the dimension of a maturity continuum; operationalizable (i.e., measurable levels) (Gollhardt *et al.*, 2020); ▪ Questionnaire's clarity; the modes of representation's transparency, understandability, comprehensibility, comprehensiveness, relevance, consistency, systematic structure, detailed level, conceptual reliability, and applicability (Asdecker and Felch, 2018; Schumacher *et al.*, 2016).

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Table 2. Principles elements of Digital Maturity Models

Elements	Components	Sub-component	Description
Action Fields (or Focus Areas or Dimensions)	§ Capabilities (or Sub -Dimensions)		§ The Action Fields (Dimensions) cover essential business areas impacted by DX (Gollhardt et al., 2020; Rafael et al., 2020); § The Action Fields consist of specific capabilities such as subcategories (Häckel et al., 2021) or sub-dimensions.
			§ The resource-based view defines organizations as configurations of resources that consist of both assets and capabilities; capabilities are defined as an organizational entity's ability to perform certain activities to achieve a specific outcome (Häckel et al., 2021); § Organizational capabilities were developed by assessing the current state and future requirements (Schallmo & Williams, 2021), and continue to improve them (Häckel et al., 2021).
			According to Westerman et al. (2014a) and Rossmann (2018), two groups of capabilities are: § Digital capabilities, including strategy, technological expertise, business models, and customer experience; § Leadership capabilities, including governance, change management, culture.
			According to Schumacher et al. (2019), three groups of capabilities related to three realization phases towards Industry 4.0 are: § Enablement: items that build the bases for Industry 4.0's realization; § Implement: items that capture the enactment of Industry 4.0's concepts; § Formalize: items that help to sustain targets' states in Industry 4.0.
Maturity Levels	§ Scale items § Scale type § Weighting factor	§ Fix level: Staged, Continuous § Focus Area	Represent archetypal states of maturity of a certain dimension or domain (Rafael et al., 2020). Maturity level is based on the principle of Capability Dimension of Industry 4.0-MM (Gökalp et al., 2017), and Capability Maturity Model Integration's (CMMI) definition of maturity level (De Carolis et al., 2017a), which specifies six levels of maturity for assessment (Lin et al., 2020b).
			Standardized maturity levels are the basis of a benchmarking approach between companies (Puchan et al., 2018).
			Each level should have scale items that are descriptors that provide the intent of the level and a detailed description of its characteristics. The characteristics of scale items should be distinct, empirically testable, and have well-defined relationships with their predecessors, and successor levels should be (Rafael et al., 2020).
			According to Gollhardt et al. (2020) and Häckel et al. (2021), there are two scale types: fixed levels and focus area: § Maturity in the form of fixed levels is a rather classic approach, where the five-level scale is the most common. These fixed levels can be either (i) staged or (ii) continuous. The staged one requires an assignment of capabilities to exactly one maturity stage, while the continuous one requires the specification of capabilities for all maturity stages (Häckel et al., 2021); § In the maturity model focus area, each capability area has a number of specific maturity stages that have disparate levels of maturity in terms of quantity and distance to each other (Häckel et al., 2021).
			Some models rely on a (dynamic) weighting of dimensions and related indicators (Chanias & Hess, 2016), such as Deloitte's DMM (Anderson & William, 2018), Open ROADS (2019), and SIRI (2019).
Assessment Tools	§ Qualitative § Quantitative	Self-Assessment	Canetta et al. (2018) developed assessment tools aim to provide companies analytical frameworks that they could adopt to self-assess their conditions.
		Expert-guided Assessment	Assessment tools can be qualitative or quantitative, using Likert (1932)-based questionnaires and scoring models (Rafael et al., 2020).
		Continuous Assessment	Companies could self-assess their conditions using (online) questionnaires and online self-checks (Schallmo et al., 2020) or collaboratively analyze them in a guided interaction with framework developers (Canetta et al., 2018).
			Continuous assessment supported by integrating IoT technology helps promote data transparency in existing processes. It is a solid basis for defining transformation actions and project plans (Nygaard et al., 2020).
Evolution path	§ Boundary Conditions § Stage Boundaries		§ Development or maturation paths help to deal with the current state and the evolution of maturity in organizations (Pöppelbuß and Röglinger, 2011); § The evolution path is a linear and forward progression in which organizations develop and improve their capabilities, value creation, performance, etc. (Rafael et al., 2020).
			Each particular maturity level is composed of the respective characteristics of previously defined ones and their required characteristics (Becker et al. 2009).
			Boundary Conditions are particular conditions that organizations need to meet to progress from one level to another. They are considered the essential condition for a particular maturity level (Rafael et al., 2020).
			Stage Boundaries specific to the point at which the organization advances to the next level (Rafael et al., 2020).

contexts with different meanings, including the dimensions (Gill & Vanboskirk, 2016; Lichtblau *et. al.*, 2017; Open Roads, 2017; Pirola *et. al.*, 2019; SIRI, 2019; Santos & Martinho, 2019; Schuh *et. al.*, 2018; Szaniawski *et. al.*, 2020; Trotta & Garengo, 2019; Valdez-de-Leon, 2016), action fields (Bumann & Peter, 2019; Gimpel *et. al.*, 2018), focus areas (Corver & Elkhuizen, 2014; De Carolis *et. al.*, 2017a), capabilities (Rossmann, 2018; Westerman *et. al.*, 2011), congruence (Kane *et. al.*, 2016), domain (Rogers, 2016), and track (EARLEY, 2017). Due to the majority use of "dimensions" in recent years, and with the popularity of this term in other management frameworks such as ITIL 4 (2019), the authors suggest that "dimensions" should be used as a standard name for the first level components of DMM. Similarly, the authors suggest that "capabilities" should be used as a standard name for the second-level components.

Secondly, the majority of the models (72%) have a descriptive purpose (Canetta *et. al.*, 2018), thus limiting their scope to providing companies with some insights on their adoption level of Industry 4.0 technologies (von Leipzig *et. al.*, 2017; Canetta *et. al.*, 2018). In addition, multi-dimensional models are usually too high-level (Matt *et. al.*, 2015), i.e., they provide too little detail or are too general, which means that they do not consider industry-related characteristics (Berghaus and Back, 2016a) to deliver necessary insights for organizations. Meanwhile, specific models only focus on particular isolated dimensions or functional areas, resulting in potential risks (Schumacher *et. al.*, 2019). These limitations raise rather high requirements for both sides of DMM application contexts. From the development side, they require establishing development teams who can conduct multi-discipline approaches to build multi-dimensional models for their clients. **Table** 3 shows that the team must be composed of experts in diverse domain areas, such as Organizations Development and Design, Operation & Quality Management, Strategic Management, Business Management, IT Technology, Digital Technologies, Human Resource Management, Service Management, and Change Management. On the flip side, firms that use DMMs should make significant investments in DMM assessment missions to obtain significant results that are context-specific to their companies. The context-specific DMM assessment can lead to the application of multi-model assessments and multi-method assessments, including 360-degree (expert survey and interview) assessments (Colli *et. al.*, 2019), IoT integration

(Nygaard *et. al.*, 2020), DES simulation (Gajsek *et. al.*, 2019), and Fuzzy analysis (Caiado *et. al.*, 2021; Wagire *et. al.*, 2020). These serious DMM assessment deployments will lead to only some big companies paying for these types of assessments to achieve particular recommendations. The challenge of providing cheaper ways for SME firms to assess their digital maturity should be an outlook for future research.

Thirdly, as the DXs are integrated into the firms' strategies that are gradually revised to respond to the dynamic context of the environment, the DX implementation incrementally and continuously is suggested (Kane *et. al.*, 2018; Rogers, 2016). Hence, the DMM that reflects the impacts of digital technologies on firms should be applied to the DX process in a closed-loop manner. However, few models mentioned their assessment process (Colli *et. al.*, 2019), and in that case, they only introduced a one-time assessment context such as Deloitte's DMM (Anderson & William, 2018). These limitations raise a critical requirement for guidance that shows DMM actions in their whole lifecycle regarding the continuous DX process. The next section presents a suggestion for this challenge.

Proposal for a continuous digital transformation process with Digital Maturity Model integration

As the analysis in previous sections, it should be critical

Table 3. Comparison of well-known Digital Maturity Models

No.	DMM	Author/s	Year	Source	Scope	Dimensions												
						Size	Culture	Customer	Digital Technologies	IT Technology	Innovation	Organization	Partner	People	Process	Products	Strategy	Transformation Mgmt.
1	Multi-dimensional Maturity Model	*Berger et al. (2020)*	2020	A	C	7	x	x	x				x	x	x		x	
2	OMDIA Digital Telco Maturity Map	*Szaniawski et al. (2020)*	2020	P	S	4		x		x	x				x			
3	Smart Industry Readiness Index*	SIRI (2019)	2019	O	S	5				x		x		x	x	x		
4	Deloitte's Digital Maturity Model*	Anderson & William (2018)	2018	P	C	10	x	x	x	x		x	x	x	x	x	x	
5	Structuring Digital Transformation	*Gimpel et al. (2018)*	2018	A	C	8		x	x			x	x		x	x	x	x
6	Digital Maturity	Rossmann (2018)	2018	A	C	7	o			o		o		o	o	o	o	
7	ACATECH Industries 4.0 Maturity Index	*Schuh et al. (2018)*	2018	A	S	6	x		x	x		x		x	x			
8	Gartner's Digital Business Maturity Model	Iyengar (2018)	2018	P	C	7		x	x	x	x	x				x	x	
9	Maturity Model for Leveraging Digitalization in Manufacturing	*Sjödin et al. (2018)*	2018	A	S				o	o				o	o			
10	MM for Assessing the Digital Readiness of Manufacturing Companies	*De Carolis et al. (2017a)*	2017	A	S	4	x			x		x			x			
11	IMPULS	*Lichtblau et al. (2017)*	2017	P	S	6			x			x		x	x	x	x	
12	Open Digital Maturity Model (ODMM)*	Open ROADS (2017)	2017	O	C	10	x	x	x	x	x	x	x	x		x	x	
13	Digital Transformation Roadmap	Earley (2017)	2017	P	C	5				x			x	x	x		x	
14	TM Forum's Digital Maturity Model	Newman (2017)	2017	O	S	7	x	x	x	x		x		x	x			
15	Maturity Model for Industry 4.0 Readiness and Maturity	*Schumacher et al. (2016)*	2016	A	S	7	x	x		x		x		x		x	x	
16	Digital Business Transformation Stages	Berghaus & Back (2016)	2016	A	C	10	x	x		x	x	x		x	x	x	x	x
17	Forrester's The Digital Maturity Model 4.0	Gill & Vanboskirk (2016)	2016	P	C	4	o	o		o		o						
18	Aligning the Organization for its Digital Future	*Kane et al. (2016)*	2016	A	C	5	x					x		x	x		x	
19	The Digital Transformation Playbook	Rogers (2016)	2016	A	C	4		x			x	x					x	
20	SIMMI 4.0 – System Integration Maturity Model Industry 4.0	*Leyh et al. (2016)*	2016	A	S	5	x		x				x		x	x		
21	DMM for Telecommunications Service Provider	Valdez-de-Leon (2016)	2016	P	S	7	o			o	o	o	o		o		o	
22	PwC's Maturity Model	*Geissbauer et al. (2016)*	2015	P	C	9	o	o	o			o	o	o	o	o	o	
23	Cognizant's Digital Transformation Framework	Corver & Elkhuizen (2014)	2014	P	C	5		x				x	x		x	x		
24	Digital Transformation Roadmap for Bilion-Dolar Organizations	*Westerman et al. (2011)*	2011	A	C	6	o	o				o		o	o		o	
Total							**15**	**14**	**11**	**15**	**6**	**19**	**9**	**14**	**19**	**11**	**15**	**2**

Legend: A: Academy, P: Practitioner; C: Cross-Industry, S: Specific Industry; o – DMM does not have sub-dimensions; x - DMM has sub-dimensions; : weighting

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Table 4. Methods & techniques used in Digital Maturity Model applications

Methods	Techniques	Application phases	Main findings and related papers
A. Qualitative			
	Business model canvas (BMC)	Assessment	BMCs's (Osterwalder & Pigneur, 2010) help to map out the current state of the business model is rather straightforward (Cigaina & Riss, 2017; Ng et al., 2018)
	Delphi	Model development	The Delphi method was used to capture expert input for building new concepts or frameworks in areas with limited empirical evidence that is well suited for the development of reference models (Valdez-de-Leon et al., 2016).
	Problem Based Learning (PBL)	Assessment	PBL helps to facilitate the contextualization of the assessed company that proposes different improvement recommendations, including those cases at the same maturity stage (Colli et al., 2019).
	Value Chain Framework (VCF)	Assessment	VCF helps to address competitive advantages and the level of development of digital initiatives in each of the core areas of the organization that facilitates the connection between digital maturity and their contribution to the firm's success (Salviotti et al., 2019).
	Value Stream Mapping (VSM)	Assessment	The VSM - Lean tool has an extended focus on information flow to map the current state of the organization to consider logistics, product development, and other indirect business areas that are related to how the transformation is capitalized (Nygaard et al., 2020).
	Others	Model development	§ Conceptual Modelling (Angreani et al., 2020; Schallmo et al., 2020).
			§ Case Study (Angreani et al., 2020; Schallmo et al., 2020).
			§ Systematic literature review (Angreani et al., 2020; Schallmo et al., 2020).
			§ Workshop (Angreani et al., 2020; Schallmo et al., 2020).
B. Quantitative			
	Business Process Management (BPM)	Model development	BPM helps to address the requirements of digitalization (Imgrund et al., 2018).
	Discrete-Event Simulation (DES)	Assessment	The DES is used to simulate a firm's operation and analyze the firm's automation level (maturity index) (Gajsek et al., 2019).
	Fuzzy Analytic Hierarchy Process (FAHP)	Model development	A Fuzzy Analytic Hierarchy Process (FAHP) is used to prioritize the maturity items and dimensions based on their importance level resolution (Wagire et al., 2020).
	Fuzzy Inference Systems (FIS)	Assessment	FIS helps to overcome the inaccuracy and uncertainty of previous MMs, addressing the complexity of digitalization level perception (Caiado et al., 2021).
	Hierarchical Cluster Analysis (HCA)	Model development	HCA helps to build clusters of items that represent maturity stages (Berghaus & Back, 2016).
	IoT Integration	Assessment	IoT technology integration helps to promote data transparency in existing processes and then a continuous assessment (Nygaard et al., 2020).
	Monte Carlo Simulation	Model development	Input data from Monte Carlo simulation is used for evaluating the I4.0 maturity models that were designed with a probabilistic approach based on a fuzzy rule (Caiado et al., 2021).
	Others		§ Analytic Network Processing (Angreani et al., 2020).
			§ Factory Design and Improvement (Angreani et al., 2020).
C. Mixed-methods and Techniques			
	Design Science Research Method (DSRM)	Model development	The Design Science Research Method (DSRM) (Hevner et al., 2004) provides a rigor research methodology for resolving problems with newly developed IT artifacts, such as models or methods (Aguiar et al., 2019; Gollhardt et al., 2020).
			An MM can be regarded as an artifact and is thus subject to the principles of design science research (De Bruin et al., 2005; Becker et al., 2009). The theory founded by Becker et al. (2009) for the development and evaluation of maturity models is followed by DSRM (Leyh et al., 2017).
	Multi Models Assessments	Assessment	In case the company was in relatively low stages as assessed by an Industrial-specific model, then the use of a second holistic MM would give us a better insight into the necessary improvements. If the company is in the higher stages of the first assessment, no further evaluation would be necessary (Gajsek et al., 2019).
	Multi Techniques	Model development	Most MM development techniques are used in a combination context with others (Angreani et al., 2020).
		Assessment	In case the company was in relatively low stages, besides using second holistic DMM, Discrete-Event Simulation (DES) with recorded inputs from the AS-IS operation process helps to find out unnecessary activities that are not value-added and technological upgradable as inputs for improvement recommendations (Gajsek et al., 2019).
	Template-based	Model development	§ Template-based development helps to increase predictable quality and productivity; increase performance; decrease error; increase employee involvement; increase return on investment, and increase customer satisfaction (De Carolis et al., 2017b; Şener et al., 2018).
			§ Well-known templates (Şener et al., 2018) are CMMI-DEV (Team, 2006), TOGAF (Open Group, 2011), SPICE (ISO, 2015), and Mettler's template (Mettler, 2009).

Table 5. Focuses on the field of Digital Maturity Model

Focuses	Sub-objectives	Main findings and related papers
Change Management	▪ value creation ▪ organizational structure	Two subject areas should be explored in addition to the DX stages: capabilities and change management (Bordeleau & Felden, 2019)
		The DX strategy needs to be aligned with the operational, functional, and corporate strategies. Considering financial aspects, Matt *et al.* (2015) propose changes in value creation and organizational structure to exploit the emerging digital technologies' full potential.
DMM Dynamics		Digital maturity is a goal that is always changing and improving (Newman, 2017).
		MMs becomes outdated if reality changes; therefore, DMM needs to be changed over time, especially due to the fast pace of the DX (Gollhardt *et al.*, 2020),
		Organizations' need to develop their own transformation roadmap (Bordeleau & Felden, 2019).
Dynamics capabilities		Most maturity models cannot identify an organization's dynamic capability or examine this capability in a dynamic and competitive environment during the transition, as well as not provide dynamic capability-based guidance for enterprises to reevaluate their strategies and strengthen the capabilities they require to face a changing environment (Lin *et al.*, 2020a).
Non-linear evolution path	Impact of digital technology	▪ In cases the DX phenomenon is context-specific and can take idiosyncratic paths, the logic of a linear DX path seems to be critically oversimplified, thinking that it can result in wrong management decisions (Remane *et al.*, 2017). ▪ The impact that DX has on a specific firm should be a scale that describes a firm's digital maturity (Remane *et al.*, 2017).
Firm size		▪ Big companies sometimes create their own DMM to improve their maturity level and collect market data. (Schallmo *et al.*, 2020); ▪ Large companies are a step ahead in implementing Industry 4.0 compared to small and medium enterprises (SME's) (Machado *et al.*, 2019; Rafael *et al.*, 2020); SME's are waiting to see the advantages; lack of competence, and resources; uncertainties about risks and opportunities (Machado *et al.*, 2019)
Evaluation	NPS	NPS is suggested as an appropriate key performance indicator for MM satisfaction, which helps decision-makers select the most suitable MM from the many available ones (Felch *et al.*, 2019).

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to the need for guidance on how to apply DMMs in an integrated manner with the DX processes to reflect the frequent changes in customer expectations (Chanias, 2017) and the dynamics of external conditions, including digital technology disruptions (Römer *et. al.*, 2017; Vial, 2019).

In this section, the paper's authors propose a conceptual model for integrating DMMs into the DX process that respects the above requirements. The proposed model is based on the DX process suggested by Vial (2019) and focuses on showing DMM applications in its Strategic Response block, as presented in **Figure** 5. The process in **Figure** 5 shows that, after realizing the disruptions from markets, firms should redefine their business strategy, which should be based on the advancement of digital technology (El Sawy *et. al.*, 2015; Hess *et. al.*, 2016), and then identify the capabilities necessary for implementing the newly adjusted strategies (Ng *et. al.*, 2018). Then the firms develop a suitable DMM that reflects the firms' strategic visions and future needs. After that, the DMM assesses the firms contextually to consult the weaknesses they need to heal in the short-term and their gap from the current business model to the visions business model (Colli *et. al.*, 2019; Pierenkemper & Gausemeier, 2020). The DMM assessment also helps firms understand their gaps in terms of digital capabilities (Brunner & Jodlbauer, 2020). The assessment outputs will be used as guidelines for firms to plan and implement their transformations, consisting of transforming business models in parallel with the development of digital capabilities (Pavlou & El Sawy, 2010; Ng *et. al.*, 2018). The change management that should be considered (Bordeleau & Felden, 2019; Gimpel, 2018) due to transformation is a type of radical strategic and cultural change (Westerman *et. al.*, 2014a) and is the strongest and riskiest change for any organization (By, 2006). After each incremental loop within transformation action plans, the firms make a revision to the current DMM with respect to its performance (Felch *et. al.*, 2019) and the newest disruptions from outside, and make decisions to reuse them or build new ones (Gollhardt *et. al.*, 2020).

CONCLUSION

This paper used keyword search and cross-references to collect units of analysis and the method of content analysis to review gathered research papers from 2000 to 2021. This paper provided an overview of (i) characteristics and components of DMMs and (ii) methods and techniques used in DMM development and assessment. Moreover, besides the major focus subjects (iii) that are currently under development, the paper raises a need for further consideration of challenges (iv). One of these challenges that show the need to address the DMM position in the DX master process, the authors propose an integration of DMM development and assessment steps into the DX process in a continuous context. The integration is supplementary to the DMMs' reviewed studies and, together with them, provides both the development and application sides (enterprise) of DMMs' clearer functions and their position in the DX process. The continuity of the integration model suggests that not only

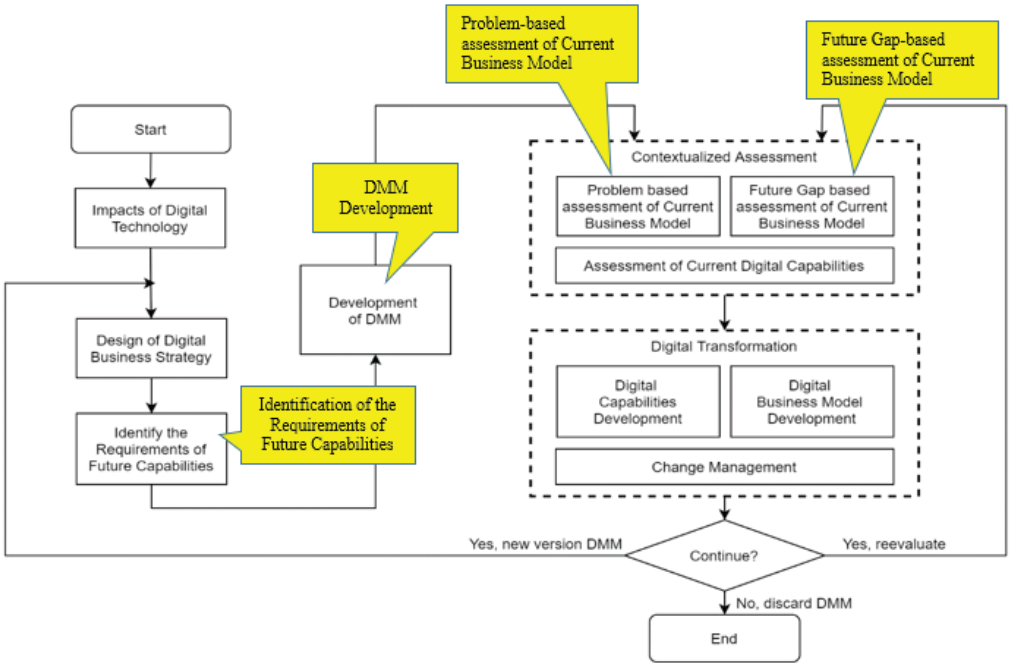

Figure 5. A proposal to integrate DMM into a continuous digital transformation process

the DMMs' assessment but also their development should be continuously conducted. Other challenges, especially the need to study appropriate development methods for multi-dimensional DMMs that SME firms can freely customize and effectively apply to their businesses without serious investment expenses, are also an outlook for future research.

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