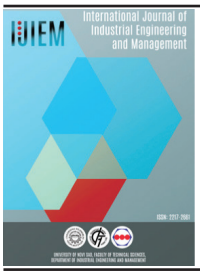
ISSN 2683-345X



journal homepage: http://ijiemjournal.uns.ac.rs/

International Journal of Industrial Engineering and Management

Volume 17 / No 4 / December 2026 / 498 - 524

Review article

Mass-customization enablers and capability: a comparative analysis of implementation guidelines and theory-testing research findings

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ABSTRACT

Building Mass-Customization Capability (MCC) is becoming an imperative for a growing number of manufacturers. Both the research stream that develops guidelines to assist practitioners in this endeavor and the one that tests the effectiveness of posited enablers of MCC contribute to the understanding of how to build MCC. However, these two streams have remained surprisingly unrelated. To bridge the gap between them, the present study pursues a threefold objective. First, it extends the latest systematic review of the literature on mass-customization implementation guidelines, finding incipient attention to organizational and inter-organizational factors, besides technological enablers, and to mutual interdependencies among enablers, besides precedence relationships, but an empirical base that remains very limited. Second, it systematically reviews, for the first time, theory-testing research on the enablers of MCC, finding a broad set of supported antecedents, including many organizational and inter-organizational factors, but relatively few relationships among them, besides other theoretical and empirical limitations. Finally, it conceptually compares the results of these two literature reviews, deriving a more comprehensive picture of what we already know about how to build MCC and identifying several directions for advancing this body of knowledge in the short, mid, and long term.

ARTICLE INFO

Article history:

Received September 3, 2025
Revised July 9, 2026
Accepted August 26, 2026
Published online October 23, 2026

Keywords:
Mass-customization enablers;
Implementation guidelines;
Theory-testing research;
Literature review

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1. Introduction

Customers' demands for product customization continue to drive the evolution of the manufacturing sector [1], [2]. In response to these demands, mass customization seeks to combine the best of custom manufacturing with the best of mass production by offering individualized products without substantial trade-offs in cost, delivery, and quality performance [3]-[5]. Accordingly, Mass-Customization Capability (MCC) is defined as the ambidextrous ability of an organization to overcome the traditional manufacturing trade-offs between product customization and cost, delivery, and quality performance [4]-[9]. As highlighted by Spasojevic et al. [10], mass customization has been one of the most frequently addressed topics in the International Journal of Industrial Engineering and Management (IJIEM) over the last decade, and recent contributions continue to explore different facets of the topic (e.g., [11]-[13]), confirming its central role in industrial engineering and management research.

Published by the University of Novi Sad, Faculty of Technical Sciences, Novi Sad, Serbia.
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https://doi.org/10.24867/IJIEM-431

Building MCC is complex, requiring the implementation of multiple, inter-related enablers [5], [14], [15]. One stream of research seeks to develop guidelines to assist practitioners in this endeavor. The results of this stream were analyzed, from the perspectives of practitioners and researchers, respectively, by Suzić et al. [14] and Suzić et al. [16].[1] Content-wise, the former work identified eight, chiefly technological enablers mentioned in the guidelines: three enablers related to product technology (i.e., parts standardization, product modularity, and product platform development), two tied to process technology (i.e., group technology and process modularity), one linked to product and/or process technology (i.e., form postponement), one relying on Information Technology (IT) (i.e., IT-based product configuration), and one spanning product, process, and supply chain design (i.e., three-dimensional concurrent engineering). Regarding the linkages among these eight enablers, Suzić et al. [14] found agreement in the literature on five relationships that, taken together, outline a mostly sequential implementation process: Group technology precedes parts standardization, the latter comes before product modularity, which in turn precedes IT-based product configuration, while product platform development embeds both parts standardization and product modularity. Method-wise, Suzić et al. [16] found that the guidelines had been developed mainly through conceptual modeling and had been assessed typically through case studies. More recently, Suzic and Forza [15] have extended the search strategy and selection process followed by Suzić et al. [14] and Suzić et al. [16] to the years 2015-2020 but have found no changes compared to the characteristics summarized above. The guidelines appeared after 2020, however, still await to be reviewed. Additionally, all previous reviews of this stream of research have focused on articles which explicitly state the objective of developing guidelines or explicitly claim to contribute to guiding the implementation of mass customization. This criterion has left outside another stream of research, which pursues different objectives and, nonetheless, offers valuable insights into how to build MCC, that is, theory-testing research on the enablers of MCC. Although the mass-customization literature has been reviewed repeatedly, even of late (e.g., [2]), a comprehensive picture of the MCC enablers that have been submitted to empirical scrutiny, of the results of such scrutiny, and of the data on which such results rely is still lacking. Finally, although both theory-testing research and research developing implementation guidelines shed light on how to build MCC, no attempt has surprisingly been made to bridge the gap between these two streams of research.

To address these research gaps, the present study pursues the following, related objectives: 1) updating the latest systematic literature review on mass-customization implementation guidelines; 2) systematically reviewing theory-testing research on the enablers of MCC; and, finally, 3) comparing the results of these two streams of research to derive a more comprehensive picture of what we already know about how to build MCC and to identify directions for advancing this body of knowledge.

The rest of this paper is structured as follows: Section 2 details the method adopted for the reviews. The subsequent section presents the results of our analyses. Section 4 discusses the implications of our results for theory, practice, and future research. Finally, Section 5 summarizes the key contributions of this study and acknowledges its limitations.

2. Method

As regards prior research developing guidelines for the implementation of mass customization, we replicated exactly the same search strategy and selection process followed by Suzić et al. [14] and Suzić et al. [16] in their review of this body of knowledge. For the sake of conciseness, we refer the reader to Suzić et al. [14] and Suzić et al. [16] for details on the literature review method. Since this method had been replicated before, by Suzic and Forza [15], for the years 2015-2020, we restricted our review to the articles published after 2020. The initial search, performed on May 20th, 2026, yielded 396 articles, which were reduced to 355 after publication quality selection. After title and abstract reading, we focused on 18 articles, which were analyzed in their entirety. The final set of articles complying with Suzić et al.'s [14] criteria includes Formoso et al. [17], Jain et al. [18], Suzic and Forza [15], and Bouchard et al. [19].

Instead, for prior research testing the effectiveness of posited enablers of MCC, the search strategy and the publication selection process are described in Figure 1. In accord with the scope of this review, the search phrase combined the expression "mass custom*" with at least one of five keywords related to hypotheses-testing research, which can use survey data or experimental data or case study data. The search was conducted on May 4th, 2026 in the "Topic" field

[1] The set of analyzed articles is the same for the two works.

of the Web of Science database and was limited to journal articles written in English, yielding 1,261 results. Subsequently, from this set we selected the papers published in journals with the highest rankings in the Academic Journal Guide 2024 from the Chartered Association of Business Schools (https://charteredabs.org/academic-journal-guide). For each of the 349 articles thus selected, we read the title and abstract to understand if the study under consideration tests predictors of MCC and we identified 29 works that comply with this criterion. In the full-text reading phase, we discarded one of these papers because of its focus on variables driving a company to increase its MCC rather than on technological and/or (inter)organizational solutions to achieve this goal. Finally, snowballing led to the addition of three papers, resulting in a final set of 31 analyzed articles (see the Appendix for the list).

For each of these 31 studies, the hypothesized enablers and the posited relationships--if any--among them were identified, distinguishing between supported and unsupported hypotheses. Furthermore, in the case of enablers modeled as second-order constructs, we identified their first-order components and examined whether the study under consideration offers additional insights into their interrelationships beyond the mere fact that, if reflective, a valid second-order construct implies that the underlying constructs tend to co-vary [20]. According to Tanriverdi and Venkatraman [21], if a study properly compares the model that captures the effect on MCC of a valid reflective second-order construct with the model that captures the individual effects of the underlying first-order constructs on the same outcome variable, then a conclusion can be drawn as to the existence, or not, of a synergistic effect of the lower-order constructs on MCC.

3. Results

3.1 Updated review of the research on mass-customization implementation guidelines

Content-wise, our analysis revealed two developments compared to the picture provided by the latest review in this area: First, the expansion of the set of enablers that are mentioned in the guidelines. With the purpose of guiding mass-customization implementation in small and medium enterprises, Suzic and Forza [15] tailored the picture provided by Suzić et al. [14] as follows: They removed two enablers deemed too advanced or confusing for such companies (i.e., three-dimensional concurrent engineering and process modularity), split other enablers perceived as overly complex by such firms (e.g., IT-based product configuration, divided into technical configuration and commercial configuration), and added three enablers considered particularly important for such enterprises (i.e., quick changeover, mixed-model assembly lines, and virtual-build-to-order). These changes, however, remained clearly focused on technological enablers. Conversely, Jain et al. [18] introduced several organizational or inter-organizational enablers: namely, an organizational culture of innovation and change, support from the top management team, employee involvement combined with employee cross-training, a marketing team able "to identify customer requirements and meet emerging market needs" [18: p. 176], and supplier integration/development. On the whole, since the latest review in this area, the count of the enablers mentioned in the guidelines has doubled, from eight to 16, though most of them remain technological factors.

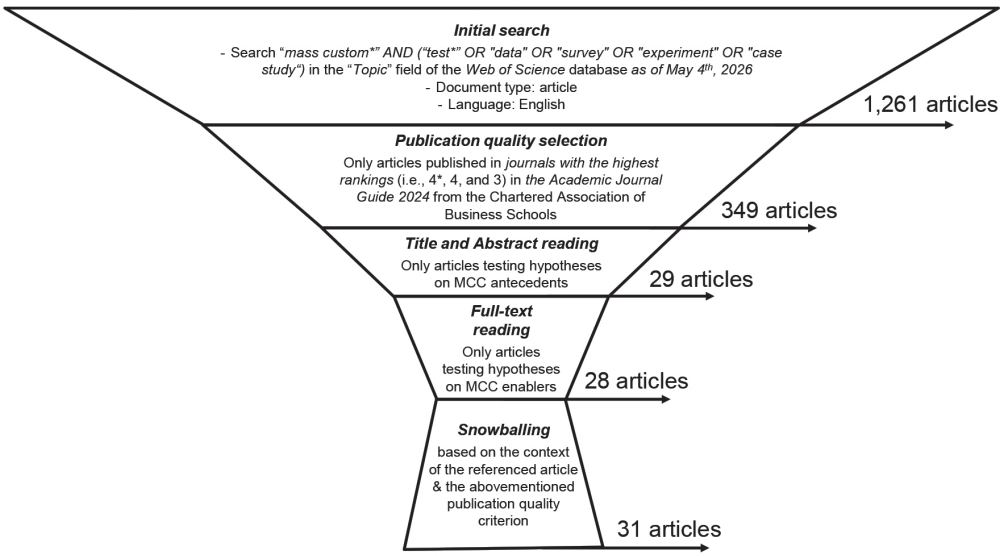


Figure 1. Search strategy and publication selection. *Authors' own work*

A second advancement concerns the relationships among enablers and the implementation process outlined by these relationships. As opposed to the fixed sequence emerged from Suzić et al.'s [14] review, Suzic and Forza [15] proposed a "co-alignment approach" [15: p. 553] that does not indicate any specific enabler to start from and does not prescribe that certain enablers should be fully implemented before beginning to work on others, thus allowing for parallel implementation. Even Jain et al.'s [18] model, whose hierarchical nature undeniably suggests an implementation process in which organizational antecedents precede technological enablers, contains many mutual dependencies within almost all of the levels of the hierarchy, which contrasts with a purely linear implementation process.

Method-wise, our analysis revealed few changes compared to the picture provided by the latest review in this area. Unquestionably, the development of guidelines has increasingly relied on empirical data, while Suzić et al. [16] had found that 90% of the guidelines were based on conceptual modeling. For example, Jain et al. [18] complemented a literature review with the opinions of nine experts from three Indian companies. Similarly, Suzic and Forza [15] integrated conceptual work and interviews with 24 experts, while Formoso et al. [17] and Bouchard et al. [19] relied on single case studies, respectively in one Brazilian company and one Canadian firm. However, for the assessment of the proposed guidelines, these studies continue to rely on one or, at most, two case studies. In summary, the empirical base of the guidelines remains very limited, not only in terms of number of cases, but also in terms of their heterogeneity, as the latest works, not unlike the ones reviewed in the past, predominantly rely on case studies taken from discrete manufacturing industries. The only notable change, in terms of heterogeneity, is represented by the growing number of cases involving small or medium enterprises.

3.2 Review of theory-testing research on mass-customization enablers

Our analysis revealed 78, at times (partially) overlapping constructs tested for their positive association with MCC (see the Appendix for greater details). Of these, 14 are second-order constructs, which are either reflected (11 constructs) or formed (three constructs) by a median of four lower-order constructs. While most of the components of these higher-order constructs coincide with enablers tested individually in other studies, 12 components remain untested individually. By adding these 12 to the overall count and by removing fully overlapping constructs, we came to identify 74 enablers of MCC, which are listed and classified in Table 1 using categories inspired by prior reviews of the mass-customization literature (e.g., [22], [23]). Common to the majority of these enablers is the fact that they have been studied (individually and/or as components of second-order enablers) using samples predominantly, if not exclusively, comprised of discrete manufacturers (mostly in the auto/transportation equipment, electronics/communication equipment, and machinery industries) having at least 100 employees and located in countries with advanced economies. For only 15 enablers, the results come from samples that certainly[2] include at least 10% of observations outside the discrete manufacturing sector[3], and no enabler has been studied in samples where this percentage exceeds 50%. Similarly, for only 15 enablers, the results come from samples with at least 10% of observations from organizations having less than 100 employees, and only one enabler (i.e., external integration) has been studied in a sample where this percentage exceeds 50%. Finally, even though the number of enablers studied in samples with more than 50% of observations taken from developing/emerging economies is larger (i.e., 21), this number remains in the minority even if we settle for a 10% threshold. Overall, these figures suggest that large-scale empirical evidence on MCC enablers comes predominantly from discrete manufacturers with at least 100 employees operating in advanced economies.

Approximately one third of the 74 enablers listed in Table 1 relates to technology, be it product or process or information technology, and to technological innovation, be it incremental or radical. However, only product modularity, cellular manufacturing, continuous improvement, and process innovation have been tested individually in multiple studies using at least partially different samples. In particular, the effectiveness of process innovation has emerged not only in the typical settings mentioned in the preceding paragraph, but also in samples with a substantial presence of smaller manufacturers and/or of process industries and/or of developing/emerging countries. Likewise, the effectiveness of continuous improvement has found support in samples of substantially different compositions, at least in terms of industry

[2] Some studies do not report enough information about the sample characteristics, leaving this uncertain.

[3] Typically in process industry, but sometimes even in the service sector (see Zhang et al. [24] and Zhang et al. [25]).

and country. Conversely, the effectiveness of product modularity and that of cellular manufacturing have been supported predominantly in larger organizations operating in discrete manufacturing industries of advanced economies, although the applicability of these enablers may not be confined to such contexts [e.g., 26]. In summary, only process innovation and continuous improvement have been proven effective in a wide variety of settings.

Another large part of the 74 enablers listed in Table 1 concerns various aspects of organization design and, collectively, outlines a type of organization in which self-sufficient subunits are created according to an output-based criterion and continually trained, highly skilled, highly motivated employees capable of executing a variety of tasks interact intensively and collaborate fruitfully at all levels of the organization. However, only inter-functional integration has been tested individually in multiple studies using at least partially different samples. The other enablers in this area have been tested individually only once and, almost exclusively, in the typical settings mentioned above. The only exceptions are human capital and social capital, which respectively capture knowledge residing in individual employees and knowledge generated from social interactions within an organization, as these enablers have been proven effective in a sample with a substantial presence of smaller manufacturers operating in process industries of developing/emerging economies.

The rest of the 74 factors listed in Table 1 relate to an organization's strategy and its culture or concern the organization's relationships with its external stakeholders (mainly, suppliers and customers) or, finally, span multiple categories. Again, very few of these enablers have been tested individually in multiple samples of substantially different compositions: one is certainly external integration and the other is, in our view, customer integration, given the partial overlap of the four customer-related enablers listed in Table 1 and the variety of samples in which one or another of these enablers has been tested. Instead, when it comes to the five supplier-related enablers listed in Table 1, the picture is more problematic, as two different studies using partially different samples have failed to find support for the positive association between supplier integration and MCC.

Overall, almost two thirds of the enablers listed in Table 1 (i.e., 48) have been supported when tested individually. Typically, the hypotheses that have been submitted to empirical scrutiny adopt a universalistic perspective, according to which the proposed enablers are expected to improve MCC in each and every context (see [27]). Only three contextual variables have been posited to influence the effectiveness of just a handful of enablers. Specifically, Huang et al. [28] and Sandrin et al. [29] found that a high degree of product customization is the condition for the effectiveness of, respectively, an organic structure and high involvement of employees. In addition, Wang et al. [30] found that competitor orientation is more effective in the maturity stage of a product's life cycle than in the growth stage, while the opposite holds for innovation orientation, and customer orientation is equally important in the two stages. Finally, Zhang et al. [25] found that competitive intensity weakens the effectiveness of performance goal orientation, while not influencing that of learning goal orientation.

Notably, more than one third of the 48 enablers that have been found to have a significant, independent, positive effect on MCC also appear as components of second-order constructs positively and significantly associated with MCC. However, being part of a supported higher-order enabler does not imply having a significant, independent, positive effect on MCC. This fact is illustrated by quality assurance in production, organizational flatness, employee empowerment, product innovation, and supplier integration, which appear as components of supported second-order enablers in some studies but are not significantly associated with MCC when tested individually in other studies. Interpreted through the lens of Tanriverdi and Venkatraman's [21] work, these mixed findings imply that the effectiveness of these five enablers depends on the presence of the other enablers with which they are bundled in the respective second-order constructs, according to a configurational rather than universalistic view of their effectiveness (e.g., supplier integration becomes effective when bundled with customer integration within the higher-order construct of external integration). This observation entails that no conclusion can be drawn as to the independent effects of the 10 enablers (e.g., pull production, demand stability focus, and top management leadership for quality) that appear in Table 1 only as components of supported second-order enablers: There is no guarantee that they also work as independent drivers of MCC. Besides quality assurance in production, organizational flatness, employee empowerment, product innovation, and supplier integration, there are other nine enablers that have been tested individually but have not found support at conventional p values. Surprisingly, this set includes widely recognized enablers, such as form postponement [31], lean production [32], and IT-based product configuration [33].

Table 1. Theory-testing research findings on MCC enablers.

Enabler category	*Enabler*	*Tested individually and supported by...*	*Tested individually and NOT supported by...*	*First-order construct of the second-order enabler termed "X" supported by...*	*First-order construct of the second-order enabler termed "X" NOT supported by...*	*Sample(s) certainly including manufacturing organizations with less than 100 employees (percentage of the entire sample)*	*Sample(s) certainly including manufacturing organizations not operating in discrete manufacturing industries (percentage of the entire sample [industries])*	*Sample(s) certainly including manufacturing organizations operating in emerging/developing economies [34] (percentage of the entire sample [countries])*
Product-related	Product modularity	[35, 36, 37, 38]		"Modularity-based manufacturing practices," [39] "Endowment of flexible manufacturing resources," [40]		[39] (1.7%)	[39] (3% [Rubber and plastic products])	[37, 38] (16.1% [China])
	Parts standardization	[41]					[41] (35.3% [Chemicals, Food and beverage, Non-metallic mineral products, Pharmaceutical, Rubber and plastic products])	[41] (100% [China])
Process-related	Cellular manufacturing	[42, 43]		"Time-based manufacturing practices," [44] "Self-containment of tasks," [45] "Endowment of flexible manufacturing resources," [40]		[42, 44] (1.7%)	[42, 44] (3% [Rubber and plastic products])	
	Quick changeover	[42]		"Time-based manufacturing practices," [44] "Endowment of flexible manufacturing resources," [40]		[42, 44] (1.7%)	[42, 44] (3% [Rubber and plastic products])	
	Quality assurance in production		[42]	"Time-based manufacturing practices," [44] "Quality management," [46]		[42, 44] (1.7%)	[42, 44] (3% [Rubber and plastic products])	
	Process modularity	[47]		"Modularity-based manufacturing practices," [39]		[47] (15.4%), [39] (1.7%)	[39] (3% [Rubber and plastic products])	[47] (100% [China])
	Preventive maintenance	[42]		"Time-based manufacturing practices," [44]		[42, 44] (1.7%)	[42, 44] (3% [Rubber and plastic products])	
	Autonomous maintenance	[43]		"Self-containment of tasks," [45]				
	Pull production			"Time-based manufacturing practices," [44]		[44] (1.7%)	[44] (3% [Rubber and plastic products])	

	Production schedule stability			“Supply chain capability,” [48]				[48] ([Brazil, China, Vietnam])
	Lean production		[49]			[49] (44.4%)	[49] (34.5% [Chemicals and allied products, Food and kindred products, Petroleum refining and related industries, Primary metal industries, Rubber and miscellaneous plastic products, Stone, clay, glass, and concrete products, Textile mill products, Tobacco products])	[49] (54.9% [China, India, Vietnam, Hungary, Poland])
Both product- and process-related	Postponement		[47]			[47] (15.4%)		[47] (100% [China])
	Bidimensional concurrent product-process engineering			“Product development capability,” [48]				[48] ([Brazil, China, Vietnam])
IT-related	Enterprise-wide information systems use		[45]					
	Product management tools	[40]						
	Product configurator IT		[36]	“Product management tools,” [40]	“Enterprise-wide information systems use,” [45]			
	Manufacturing IT		[36]		“Enterprise-wide information systems use,” [45]			
	Supplier collaboration IT	[36]						
	Product data management system			“Product management tools,” [40]	“Enterprise-wide information systems use,” [45]			
	Business intelligence applications			“Product management tools,” [40]	“Enterprise-wide information systems use,” [45]			
	Big data analytical intelligence	[24]				[24] (27.9%)	[24] (51% [Information service, Transportation, Wholesale])	[24] (100% [China])
Organizational structure / Division of labor	Organic structure	[28]						
	Organizational flatness		[37]	“Organic structure,” [28]				[37] (16.1% [China])
	Self-containment of tasks	[45]						

	Decentralization/Employee empowerment		[43]	"Organic structure," [28] "Self-containment of tasks," [45] "Coalignment of high-involvement practices," [29]			
	Shop-floor employee involvement in problem solving			"Time-based manufacturing practices," [44]	[44] (1.7%)	[44] (3% [Rubber and plastic products])	
	Multifunctional employees	[43]		"Organic structure," [28] "Self-containment of tasks," [45] "Endowment of flexible manufacturing resources," [40]			
	Modular structure			"Modularity-based manufacturing practices," [39]	[39] (1.7%)	[39] (3% [Rubber and plastic products])	
Information and decision processes / Coordination mechanisms	Use of lateral relations	[45]					
	Inter-functional integration	[35, 37, 50, 51]		"Use of lateral relations," [45]			[50] (17.6% [China]), [37] (16.1% [China])
	Coordination of decision-making			"Use of lateral relations," [45]			
	Information to employees	[43]		"Quality management," [46] "Coalignment of high-involvement practices," [29]			
	Small-group problem solving			"Quality management," [46] "Use of lateral relations," [45]			
	Cross-plant coordination		[37]				[37] (16.1% [China])
	Structural capital (disciplined methods and codified knowledge)		[52]		[52] (44.8%)		[52] (54.9% : [China, India, Vietnam, Hungary, Poland])
People and Rewards	Human capital (the expertise, skills and abilities residing in and utilized by individual employees)	[52]			[52] (44.8%)	[52] (26.7% [Chemicals and allied products, Food and kindred products, Primary metal industries, Rubber and miscellaneous plastic products])	[52] (54.9% [China, India, Vietnam, Hungary, Poland])

	Social capital (knowledge that emerges from interactions among employees)	[52]		[52] (44.8%)	[52] (26.7% [Chemicals and allied products, Food and kindred products, Primary metal industries, Rubber and miscellaneous plastic products])	[52] (54.9% [China, India, Vietnam, Hungary, Poland])
	Continual (task-related) training for employees	[43]	"Coalignment of high-involvement practices," [29]			
	High standards for recruiting	[43]				
	Employee contribution willingness	[43]				
	Plant performance-based incentives	[43]	"Coalignment of high-involvement practices," [29]			
Strategy / Culture	Customer orientation	[30]	"Quality management," [46]		[30] (35.3% [Chemicals, Food and beverage, Non-metallic mineral products, Pharmaceutical, Rubber and plastic products])	[30] (100% [China])
	Competitor orientation	[30]			[30] (35.3% [Chemicals, Food and beverage, Non-metallic mineral products, Pharmaceutical, Rubber and plastic products])	[30] (100% [China])
	Innovation orientation	[30]			[30] (35.3% [Chemicals, Food and beverage, Non-metallic mineral products, Pharmaceutical, Rubber and plastic products])	[30] (100% [China])
	Learning goal orientation	[25]			[25] (43.4% [Alcohol and beverage industry, Chemical materials and products, Cultural, educational, and sports goods, Food processing, Food production, Medical and pharmaceutical products, Nonmetal mineral products, Petroleum refining and coking, Rubber and plastic products, Smelting and pressing of nonferrous])	[25] (100% [China])

	Performance goal orientation	[25]				[25] (43.4% [Alcohol and beverage industry, Chemical materials and products, Cultural, educational, and sports goods, Food processing, Food production, Medical and pharmaceutical products, Nonmetal mineral products, Petroleum refining and coking, Rubber and plastic products, Smelting and pressing of nonferrous])	[25] (100% [China])
	Top management leadership for quality			"Quality management," [46]			
Innovation-related	Continuous improvement	[30, 43, 53]				[30, 53] (35.3% [Chemicals, Food and beverage, Non-metallic mineral products, Pharmaceutical, Rubber and plastic products])	[30, 53] (100% [China])
	Innovation	[41]				[41] (35.3% [Chemicals, Food and beverage, Non-metallic mineral products, Pharmaceutical, Rubber and plastic products])	[41] (100% [China])
	Operational innovation	[54]					
	Process innovation	[52, 53, 55]		"Operational innovation," [54]	[52] (44.8%)	[53] (35.3% [Chemicals, Food and beverage, Non-metallic mineral products, Pharmaceutical, Rubber and plastic products]), [52] (26.7% [Chemicals and allied products, Food and kindred products, Primary metal industries, Rubber and miscellaneous plastic products])	[53] (100% [China]), [52] (54.9% [China, India, Vietnam, Hungary, Poland])
	Product innovation		[48]	"Operational innovation," [54]			[48] ([Brazil, China, Vietnam])
	Front-end loading in new product development (effective scanning and selection of ideas)			"Product development capability," [48]			[48] ([Brazil, China, Vietnam])

Customer-related	Customer involvement (interactions with customers to understand and respond to their needs and to receive feedback).	[40]		"Environmental management," [45] "Supply chain capability," [48]			[48] ([Brazil, China, Vietnam])
	Customer integration (information sharing and collaboration with customers)	[50, 56]				[56] ([Rubber and plastic products])	[50] (17.6% [China])
	Customer closeness (keeping close contact with customers, communicating with them effectively, and understanding their needs)	[39]			[39] (1.7%)	[39] (3% [Rubber and plastic products])	
	Knowledge absorption from customers (acquisition, assimilation, and application of knowledge from customers'	[57]			[57] (15.6%)		[57] (100% [China])
Supplier-related	Supplier integration		[50, 58]	"Quality management," [46] "Environmental management," [45] "Supply chain capability," [48]			[50] (17.6% [China]), [48] ([Brazil, China, Vietnam])
	Knowledge absorption from suppliers		[57]		[57] (15.6%)		[57] (100% [China])
	Supplier flexibility	[58]		"Endowment of flexible manufacturing resources," [40]			
	Supplier dependability	[58]		"Time-based manufacturing practices," [44]	[44] (1.7%)	[44] (3% [Rubber and plastic products])	
	Modular supply base	[47]			[47] (15.4%)		[47] (100% [China])
External-stakeholder-related	External integration	[37, 45, 59]			[59] (95%)	[59] (17% [Manufacture of food products, Manufacture of rubber and plastic products, Manufacture of other nonmetallic mineral products])	[37] (16.1% [China])
	Supply chain capability	[48]					[48] ([Brazil, China, Vietnam])
	Just-in-time with suppliers and customers			"Supply chain capability," [48]			[48] ([Brazil, China, Vietnam])

	Shared cognitive capital (the common objectives and values, and shared language and codes between a supplier and a customer)	[60]			[60] (15.6%)		[60] (100% [China])
	Relational capital (the trust and commitment between a supplier and a customer)		[60]		[60] (15.6%)		[60] (100%)
Miscellaneous	Lead-time compression	[44]		"Supply chain capability," [48]	[44] (1.7%),	[44] (3% [Rubber and plastic products])	[48] ([Brazil, China, Vietnam]),
	Modularity-based manufacturing practices	[39]			[39] (1.7%)	[39] (3% [Rubber and plastic products])	
	Quality management	[46]		"Supply chain capability," [48]			[48] ([Brazil, China, Vietnam])
	Endowment of flexible manufacturing resources	[40]					
	Coalignment of practices of high involvement of employees	[29]					
	Strategic flexibility	[8]					[8] (45% [India])
	Agile practices	[49]			[49] (44.4%)	[49] (34.5% [Chemicals and allied products, Food and kindred products, Petroleum refining and related industries, Primary metal industries, Rubber and miscellaneous plastic products, Stone, clay, glass, and concrete products, Textile mill products, Tobacco products])	[49] (54.9% [China, India, Vietnam, Hungary, Poland])

Coming to the relationships among MCC enablers, if we exclude the covariation of the first-order constructs that underlie a valid, reflective, second-order enabler (covariation explicitly posited only by Huang et al. [28] and Kristal et al. [46]), there remain 11 studies that formulate hypotheses on such relationships. Collectively, these studies propose 28, at times overlapping, hypotheses, which involve around one third of the 74 enablers identified by our review. Only two hypotheses involve more than two enablers (see Salvador et al. [40] and Morita et al. [48]). The other hypotheses always link pairs of enablers, usually in the form of a positive direct effect of one enabler on the other or, in two cases, in the form of a positive interaction effect of the two enablers on MCC. Admittedly, the concatenation of direct-effect hypotheses concerning pairs of enablers in Zhang et al. [37] and Zhang et al. [52] outlines causal chains linking triplets of enablers, but neither Zhang et al. [37] nor Zhang et al. [52] explicitly hypothesized full/partial mediation by the intervening variable(s). In Zhang et al. [37], the question of whether the impact of organizational flatness on product modularity is fully or partially mediated by cross-functional/cross-plant/supply-chain coordination remains unexplored not only conceptually, but also empirically. Conversely, in the case of Zhang et al. [52], at least their empirical results indicate that structural capital (i.e., disciplined methods and codified knowledge) fully mediates the impact of social capital (i.e., knowledge generated from social interactions within an organization) on process innovation and partially mediates the impact of human capital (i.e., knowledge residing in individual employees) on the same outcome variable. Similarly, Sandrin et al. [29] reported empirical results which support the existence of a synergistic effect of four practices of high involvement of employees on MCC, but this complementary effect was not explicitly posited in their study.

The overall picture of the direct and interaction effects among MCC enablers is provided, respectively, by Figures 2 and 3, where supported linkages are represented by solid lines, while unsupported linkages are depicted by dashed lines. Most of the posited direct effects have been supported, while most of the interaction effects have not. Notably, the supported relationships linking technical and social factors are complex, including reinforcing loops (see the one from inter-functional integration to customer integration to modularity-based manufacturing practices back to inter-functional integration through product modularity) and positive interaction effects on MCC (see the one between parts standardization and innovation capability). In addition, inter-functional integration seems to be a central node in this network of relationships, as it drives the reinforcing loop mentioned above, improves supplier integration and, by that means, supplier flexibility and supplier dependability, and fully mediates the impact of organizational flatness on MCC [37].

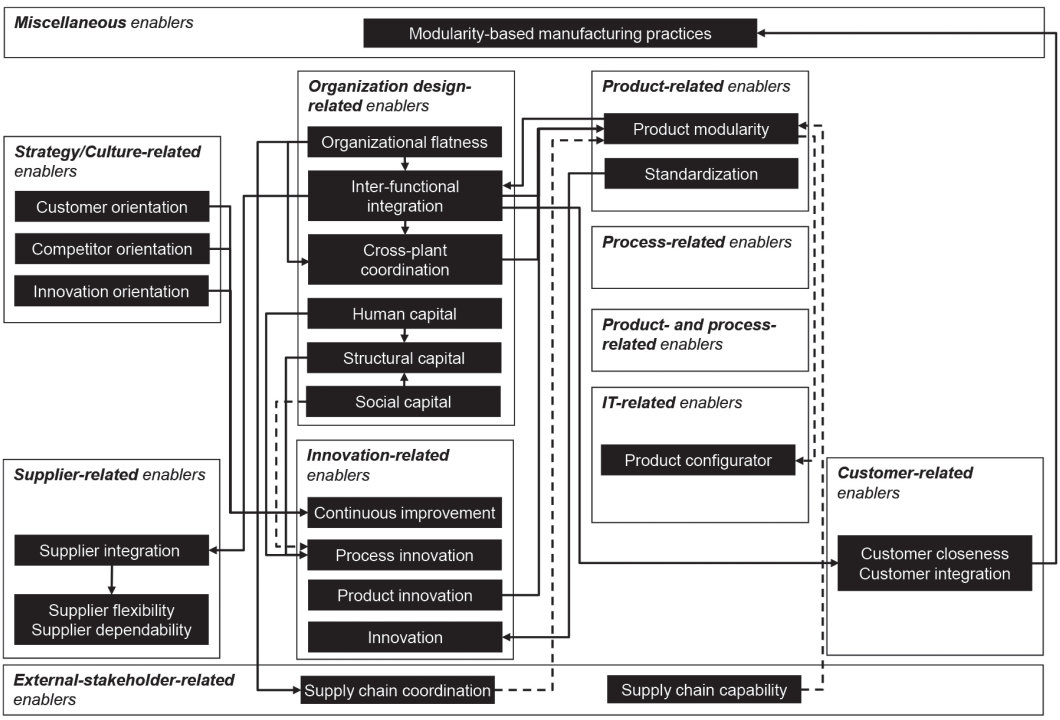


Figure 2. Relationships among MCC enablers: positive direct effect of one enabler on another (solid line: supported effect; dashed line: unsupported effect). *Authors' own work*

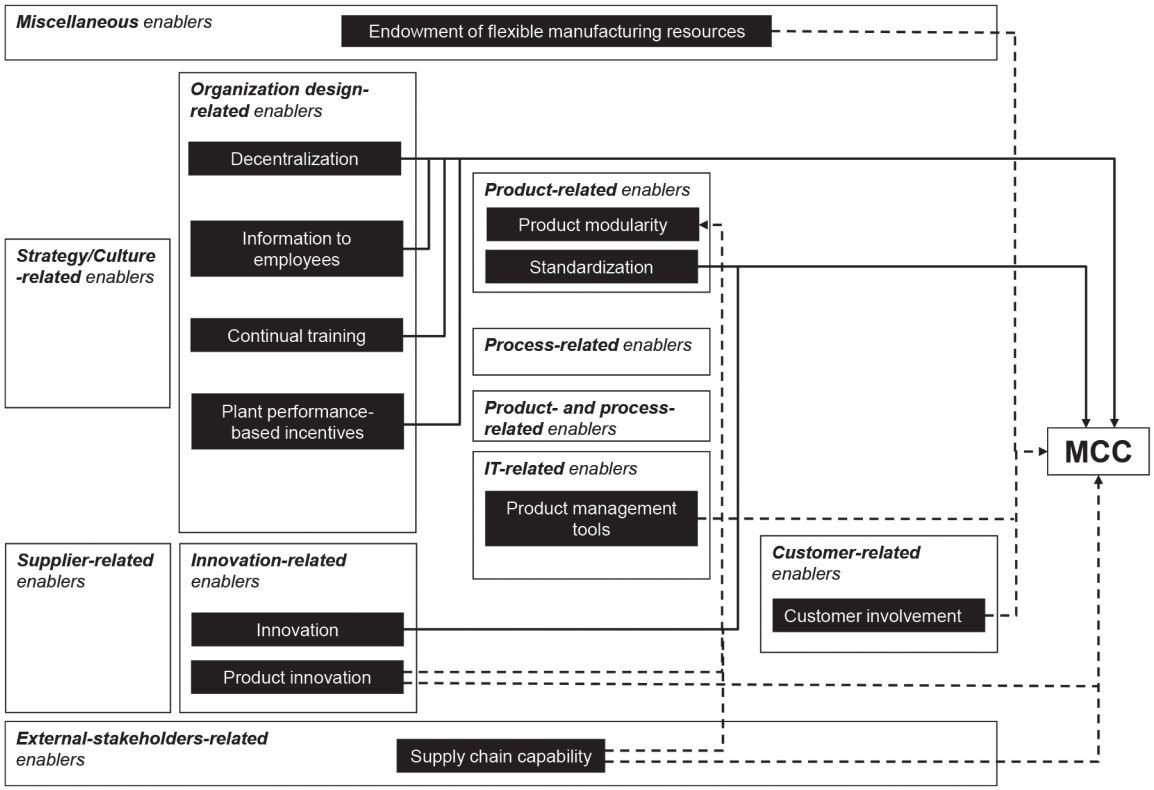


Figure 3. Relationships among MCC enablers: positive interaction effects on MCC (solid line: supported effect; dashed line: unsupported effect). *Authors' own work*

3.3 Comparing implementation guidelines and theory-testing research findings

Only one half of the enablers mentioned in the analyzed guidelines has found support in the theory-testing studies reviewed here. On the technical side, three of these enablers are process-related (i.e., quick changeover, process modularity, and group technology, as far as the latter is employed to implement cellular manufacturing) and two are product-related (i.e., product modularity and parts standardization). Among the social factors introduced by Jain et al.'s [18] guidelines, one (i.e., an organizational culture of innovation and change) is indirectly supported by Wang et al.'s [30] results concerning innovation orientation, another (i.e., a marketing team able to understand customers' evolving needs) has been proven effective by the five studies testing one or another of the partially overlapping constructs of customer involvement/closeness/integration and knowledge absorption from customers and, finally, employee multifunctionality is corroborated by Liu et al.'s [43] results.

The rest of the enablers mentioned in the analyzed guidelines still lacks support from theory-testing research. Some of them have yet to be tested as predictors of MCC. This is the case of concurrent product-process-supply chain design, as Morita et al. [48] only considered bidimensional product-process concurrent engineering and, at any rate, examined this construct only as a component of a higher-order predictor of MCC. This is also the case of product platform development, since it includes not only modular product platforms, for which support can be inferred from the four studies testing product modularity, but also scalable product platforms [see 61], whose effectiveness has not been tested so far. Likewise, this is the case of mixed-model assembly lines and virtual-build-to-order, on the technical side, and of top management team support, on the social side.[4] On the other hand, three enablers (i.e., IT-based product configuration, form postponement, and supplier integration/development) have been tested individually, but no significant association with MCC has been found at conventional p values.

While one half of the enablers mentioned in the

[4] An aspect of top management support is top management leadership for quality, which however only appears as a component of a higher-order predictor of MCC.

analyzed guidelines lacks corroboration from theory-testing research, the same guidelines ignore many of the enablers supported by theory-testing studies. In particular, innovation-related enablers are completely absent from the guidelines, even though process innovation and continuous improvement have been proven effective by theory-testing research in a wide variety of settings.

Finally, as regards the relationships among MCC enablers, most of the linkages mentioned in the analyzed guidelines remain untested. Only Peng et al.'s [36] supported hypothesis that product modularity is positively associated with IT-based product configuration is consistent with their mutual interdependency suggested by Jain et al.'s [18] guidelines. While this result speaks in favor of the simultaneous implementation of these two enablers, other theory-testing results suggest caution before concluding that a holistic approach is corroborated by large-scale empirical scrutiny. For example, Salvador et al. [40] did not find support for the hypothesis that customer involvement, the endowment of five flexible manufacturing resources, and the use of three product management tools have a synergistic effect on MCC. At the same time, Salvador et al. [40] found that each pair of these three enablers has a synergistic effect on MCC when the third remains at a low level, which points to the possibility that simultaneous investment in too many enablers fails to improve MCC because of the excessive difficulty of orchestrating so many initiatives.

4. Discussion

4.1 Theoretical implications

The present paper contributes to the mass-customization literature in several ways. First, it extends the latest review, covering articles published till 2020 (see [15]), of the stream of research on mass-customization implementation guidelines. Our extension shows that such guidelines continue to focus mostly on technological enablers, with the notable exception of Jain et al.'s [18] hierarchical model, which prescribes to begin from social factors, such as a culture of innovation, proactive managers, and multifunctional employees, before engaging in the implementation of technological enablers. Likewise, though some recent guidelines have statedly been developed for specific contexts (e.g., small and medium enterprises), a universalistic view of the effectiveness of the proposed enablers remains predominant. Similarly, though both guideline development and guideline assessment have increasingly relied on empirical data, the empirical base remains very limited in terms of number and heterogeneity of collected observations. Conversely, one notable difference from the picture provided by the latest review in this area is the growing awareness that a purely sequential implementation process may be simplistic, as many enablers are actually linked by mutual interdependencies.

Second, this paper is the first to take stock of the stream of research that tests the effectiveness of posited enablers of MCC. Since the earliest review of the mass-customization literature observed that most claims in the field were "drawn from limited case examples or based on educated guesses from authors" [32: p. 11], the number of theory-testing studies on the enablers of MCC has grown considerably, producing results with a higher degree of generalizability. After this earliest review published in 2001, the mass-customization literature has been analyzed repeatedly, either in its entirety [e.g., 22, 62] or with a narrower focus, such as mass customization in small and medium manufacturers [63] or the impact of Industry 4.0 technologies on mass customization [2]. However, none of these reviews has provided a comprehensive picture of the MCC enablers that have been submitted to empirical scrutiny, of the results of such scrutiny, and of the data on which such results rely. The present work fills this gap and, in so doing, identifies a large set of supported antecedents, which has extended over time from a core of technological factors, such as product modularity or cellular manufacturing, to many organizational and inter-organizational variables, such as internal or external integration. Besides offering an overview of theory-testing research accomplishments, the present work unveils two, respectively theoretical and empirical, limitations of this body of literature. First, the effectiveness of the posited enablers has typically been examined from a universalistic perspective, with very few studies adopting more nuanced theoretical perspectives, such as the contingency perspective or the configurational one [see 64]. Second, the heterogeneity of the contexts in which many enablers have been proven effective is relatively limited: typically, discrete manufacturers with at least 100 employees operating in advanced economies. The joint effect of these two limitations is that we do not know, yet, if many of the supported factors are equally impactful regardless of the size of the organization, regardless of the type of industry/product/customer, or regardless of the country of operation. For example, none

of the studies analyzed here characterizes its data in terms of business-to-commerce/consumer (B2C) vs. business-to-business (B2B) manufacturers, leaving the question of whether a given enabler is equally impactful in B2C and B2B contexts wholly unaddressed. As a matter of fact, the "points of broad agreement" that qualify "mature theory" [65: p. 1158] are only a handful: process innovation, continuous improvement, inter-functional integration, customer integration and, more generally, external integration.

Finally, this paper is the first to compare the results of these two, inherently related streams of research and this comparative analysis produces several interesting messages. One concerns the scope of the analyzed guidelines. From a theoretical standpoint, the development of guidelines can be interpreted as the development of a process theory capable of explaining "how something [MCC, in this case] comes about" [66: p. 44]. While good theories should strike a balance between the competing virtues of parsimony and comprehensiveness [67], our findings show that the guidelines have generally sacrificed too much of comprehensiveness for parsimony, as they predominantly focus on technological (product- and/or process-related) enablers, with the notable exception of Jain et al.'s [18] guidelines. A much broader set of factors, which embraces both social and technical variables, has been supported by theory-testing research, consistent with the predictions of socio-technical systems theory applied to mass customization [68]. Undeniably, many of these factors have been supported only in discrete manufacturers with at least 100 employees operating in advanced economies. However, there are a few antecedents that have been proven effective in a much wider variety of settings and at least these few should be incorporated into implementation guidelines.

Another message concerns the effectiveness of the enablers proposed in the analyzed guidelines. The universalistic view that characterizes most of these guidelines is simplistic, at least for the enablers that have not been supported by theory-testing research. For example, IT-based product configuration is frequently mentioned as a key enabler in the analyzed guidelines, but Peng et al. [36] found no significant association with MCC (at $p < 0.10$) in a multi-industry and multi-country sample of mostly medium/large manufacturers. In an attempt to explain this unexpected finding, Peng et al. [36] implicitly suggested that either the internal-oriented functionalities or the customer-oriented functionalities of product configuration IT might be ineffective for the purpose of improving MCC. An alternative, perhaps more plausible explanation is suggested by our review, as Salvador et al. [40] found, in a very similar sample to that of Peng et al. [36], that product configurators become effective when bundled with product data management systems and business intelligence applications. In the same vein, Trentin et al. [5] found that online configurators are ineffective when implemented in isolation but improve MCC when bundled with product modularity and knowledge absorption from customers. Thus, it seems that IT-based product configuration contributes to improving MCC when it is part of a proper configuration of enablers, according to a configurational view of its effectiveness. Likewise, a universalistic view of the effectiveness of form postponement appears simplistic, as Liao et al. [47] did not find support for the positive association of postponement practices with MCC (again, at $p < 0.10$) in a sample of Chinese, generally large suppliers of the auto industry. Liao et al. [47] suggested that industry-specific factors and country-specific factors at the time of data collection (e.g., the relatively limited degree of product customization and the use of underdeveloped communication systems with customers) could explain this unexpected finding. Indeed, more recent research has argued that different degrees of product customization and, therefore, different mass-customization strategies require different types of form postponement [69], but these differences were not captured by Liao et al.'s [47] data. In summary, a contingency perspective could be more appropriate in this case. Similarly, a universalistic view is certainly simplistic for the factors that appear as components of supported second-order enablers in some studies but are not significantly associated with MCC when tested individually in other studies. A configurational perspective appears more appropriate in this case. Finally, even for the enablers whose independent positive effects on MCC have been supported by theory-testing research, a universalistic view of their effectiveness should be adopted with caution, as many of them have been examined only in discrete manufacturers with at least 100 employees operating in advanced economies.

A third and final message concerns the relationships among MCC enablers. Most of the linkages mentioned in the analyzed guidelines are precedence relationships and remain untested. Only a few recent contributions have highlighted mutual interdependencies and have spoken in favor of a co-alignment approach, but large-scale empirical evidence of these more complex linkages remains not only limited, as previously observed by Sheng et al. [68], but also in-

conclusive, as some bundles of enablers have been supported [e.g., 5] while others have not [e.g., 40]. In summary, the results of theory-testing research do not allow for drawing any conclusion on the superiority of a parallel vs. sequential implementation process yet.

4.2 Practical implications

Pragmatically, manufacturers pursuing mass customization can use our findings to check whether a given enabler of MCC has been supported in their contexts (in terms of organization size, industry, and country of operation) or not. In the latter case, investing in that enabler should be regarded as more risky. Particularly, the effectiveness of many enablers remains uncertain in small and medium enterprises, process industries, service organizations, or firms operating in developing economies. Likewise, no large-scale empirical evidence is available concerning possible differences in the effectiveness of any enabler across B2B and B2C contexts.

Secondly, our findings make practitioners aware of the limitations of the available guidelines, at least of those published in higher-quality journals. Only one half of the enablers mentioned in such guidelines has found support in the theory-testing studies reviewed in this paper, while several factors exhibit non-significant associations with MCC or mixed findings. Therefore, practitioners should not consider these enablers uncritically. Additionally, the available guidelines mostly focus on technological factors, but theory-testing research shows that the challenge of implementing mass customization extends well beyond technology and encompasses many organizational and inter-organizational aspects that should not be overlooked.

Thirdly, our findings make practitioners aware of the necessity of carefully evaluating complementarities among enablers before their implementation, as several solutions appear to become effective only when combined with other technological or (inter)organizational solutions. At the same time, our findings suggest caution against the simultaneous implementation of an excessive number of initiatives, as the difficulty of orchestrating numerous enablers may offset its potential benefits.

Finally, our findings can be useful for instructors of mass customization/product variety management courses. This paper provides them with a comprehensive picture of what is already known about how to build MCC and, at the same time, highlights a few serious limitations of this body of knowledge.

4.3 Future research directions

Our findings indicate several promising avenues for further research, both in the area of theory testing and in that of guideline development. In the short run, priority should be given to studies that, using available datasets, delve into the effectiveness of those enablers whose independent positive effects on MCC were not supported in the past. To this end, future studies should adopt more nuanced theoretical perspectives over the effectiveness of such factors. For example, lean production has been mentioned as one of the enablers of MCC by da Silveira et al.'s [32] literature review, but Qi et al. [49] unexpectedly did not find a significant positive association (at $p < 0.05$) between lean production and MCC in a rather heterogenous sample in terms of organization size, industry, and country of operation. If we go down to the level of detail of the individual building blocks of lean production that were identified by Shah and Ward [70], their independent positive effects on MCC have been supported for involved customers, low setup, flow (i.e., cellular manufacturing), involved employees (as pertains to the "employee multifunctionality" dimension of this building block), and preventive maintenance. Other three building blocks, that is controlled processes, pull production, and involved employees (as pertains to the "employee suggestions" dimension of this building block) remain untested individually. Finally, the remaining two, i.e., supplier feedback and supplier development/integration, present inconclusive results, with some hypotheses supported [e.g., 47] and others unsupported [e.g., 50, using a 0.05 p-value]. Undeniably, Shah and Ward's [70: p. 800] conceptualization of lean production as a bundle of "10 distinct but highly inter-related elements" speaks in favor of the adoption of a configurational view of their effectiveness in terms of MCC improvement. Additionally, Qi et al.'s [49] tentative explanation for their unexpected finding, calling into question the limited ability of lean production to address environmental uncertainty, suggests the opportunity of adopting a contingency perspective, too. In summary, future research could delve into the lean production-MCC link by adopting a contingent-configurational perspective. More specifically, since higher environmental uncertainty is associated with a higher degree of product customization [71], future research could test the moderating effect of the degree of product customization on the impact that the bundle of distinct building blocks of lean production has on MCC.

In the same short-term, but perhaps with less urgency, future research could use available datasets to test whether the numerous constructs that appear as components of supported second-order enablers but have not been tested individually, do remain effective when implemented in isolation. Instead, more urgent is to expand the limited body of knowledge concerning how MCC enablers are related to one another and how their combinations affect MCC. In this respect, Venkatraman's [72] discussion of the different manners of conceptualizing and modeling the notion of fit (e.g., fit as covariation or fit as gestalts) could prove useful to model and test the effects of different bundles of enablers on MCC. To be sure, as the number of enablers comprising a bundle increases, testing its effect on MCC becomes more statistically challenging data-wise and, therefore, could require collecting new data from larger samples of organizations, thus becoming a mid-term research objective. Finally, on the front of guideline development, an accomplishment that is clearly within reach is the incorporation of the few enablers whose effectiveness represents points of broad agreement in the theory-testing literature, such as process innovation, continuous improvement, and inter-functional integration, into implementation guidelines.

In the mid-term, new data collections should be planned and executed to understand whether the numerous enablers that have been supported predominantly, if not exclusively, in samples of discrete manufacturers with at least 100 employees operating in advanced economies can be safely recommended to smaller organizations, to manufacturers operating in process industries, to service organizations, or to firms located in countries with emerging/developing economies. Similarly, new data might be necessary to test the effectiveness of the enablers that remain untested, such as three-dimensional concurrent engineering or mixed-model assembly lines. Likewise, new data are likely to be needed to test the effectiveness of new enablers made available by recent technological developments, such as digital-twin applications [73], product commonality analysis tools [74], or artificial intelligence-based generative design [75] and artificial intelligence-based personalized interactions with humans [76]. Finally, new data could be necessary to examine possible contingency effects of contextual variables not considered before, such as the type of customers served (e.g., B2C vs. B2B), or the contingency effects of individual-level variables, such as designers' cognitive behavior [13].

Pursuing the short-term and mid-term research objectives discussed above is a prerequisite to understanding the extent to which mass-customization guidelines should be differentiated for different contexts and, if so, how. Indeed, if we exclude a few enablers that, by their definitions, are specific to certain settings, such as mixed-model assembly lines, which clearly apply to discrete manufacturing only, it is very difficult to identify boundaries of validity without sufficient breadth of empirical evidence [see 67]. Thus, long-term research projects could take advantage of the results of short-term and mid-term theory-testing research to develop guidelines more suitable to specific contexts. Take for example the case of small and medium enterprises, whose digital transformation still suffers from a lack of actionable guidelines tailored to their specific contexts [77] and whose resource constraints demand "prioritization of factors that favour the operationalization of mass customization" [63: p. 1]. In this case, a long-term research objective could be to identify the most effective implementation sequence in a given industry (e.g., process industry vs discrete manufacturing). At the same time, for larger organizations with resource affluence, long-term future research could seek to identify the most effective bundles of enablers in the respective sectors of operation.

5. Conclusion

The present work compares two streams of research within the mass-customization literature, both of which have generated valuable insights into how to build MCC, but which have remained surprisingly unrelated in the extant literature: the research stream that develops guidelines for the implementation of mass customization and the research stream that tests the effectiveness of posited enablers of MCC. Since both streams contribute to the development of a process theory capable of explaining how MCC comes about, the picture that emerges from this comparative analysis and the directions in which this picture should be extended in the future can be summarized using the building blocks of a theory [see 67].

In terms of the "what" of this theory, the analyzed guidelines continue to focus mostly on technological enablers, some of which remain untested or have not been supported in large samples. Conversely, theory-testing research has identified a much broader set of supported enablers, which includes many organizational and inter-organizational factors. Future research should focus on both untested and unsupported enablers, with the objective of understanding if, or under what conditions, they should be retained

in the theory. In addition, new enablers could be added to the theory, as they are made available by technological developments.

In terms of the "how" and "why" of the theory, the analyzed guidelines continue to focus mostly on precedence relationships between enablers and, therefore, on a mainly sequential implementation process. Most of these linkages, however, have remained untested, while several relationships supported by theory-testing research have been ignored by implementation guidelines. Additionally, even though recent contributions have challenged the sequential logic that dominates the literature on mass-customization implementation guidelines, mixed findings from theory-testing studies suggest caution before drawing any conclusion on the superiority of a parallel vs. sequential implementation process. In summary, the relationships among enablers and their joint effects on MCC are definitely an area that deserves additional research.

In terms of the "who/where/when" of the theory, most of the analyzed guidelines continue to adopt a universalistic perspective, despite an empirical base that remains very limited in terms of both number and heterogeneity of collected observations. However, if we consider theory-testing research results, this perspective appears simplistic. This certainly holds for those enablers whose independent positive effects on MCC have not been supported, as well as for those enablers that appear as components of supported second-order enablers in some studies but are not significantly associated with MCC when tested individually in other studies. However, this perspective could be simplistic even for those enablers whose effectiveness has been supported in large samples, as many of these enablers have been tested only in samples of discrete manufacturers with at least 100 employees operating in advanced economies. In summary, future research should adopt more nuanced theoretical perspectives and collect data from a wider variety of settings to better characterize the boundaries within which many enablers are effective.

Overall, we can conclude that many progresses have been made toward the development of process theory of MCC. However, much work remains to be done before reaching the state of a mature theory capable of explaining how MCC comes about in a wide variety of settings. This future work will be crucial to provide practitioners with guidelines more suitable to the specific contexts in which they work.

Not unlike any other piece of research, the present study has limitations. One is inherent in the choice of assessing publication quality using journal rankings. While these rankings can help mitigate subjective bias, we acknowledge the possibility that a different quality appraisal procedure, such as the one followed by Le et al. [78], leads to a broader final set of studies, thus influencing the results. Another limitation could be seen in the fact that the results of theory-testing research have been synthesized here in a narrative format, rather than in a quantitative fashion through a meta-analysis. The application of a quantitative approach, however, appears premature now, as there are few enablers that have been tested individually in multiple studies.

Funding

This research was supported by the following grant provided by the University of Padova (Italy): DOR.

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Appendix

Prior theory-testing research on MCC enablers and their interdependencies (second-order constructs are bolded; first-order constructs that have not been tested individually in other studies are italicized).

Reference	*Data* *- Sample size: No. observations* *- Firm/Plant size: No. employees (No. observations)* *- Country(ies) (No. observations)* *- Industry(ies) (No. observations)*	*Statistical method(s)*	*Hypothesized MCC enabler(s)*	*Hypothesized relationship(s) among MCC enablers**
Tu et al. [44]	- 303 - <100 (5), 100-499 (208), 500-1000 (41), >1000 (48), Unspecified (1) - US (303) - Appliances (11), Automotive or parts (40), Electrical equipment (21), Electronics (26), Fabricated metal products (85), Furniture and fixtures (7), Industrial machinery and equipment (52), Instruments and related products (20), Rubber and plastic products (9), Transportation equipment (9), Other (23)	Covariance-based structural equation modeling	**Time-based manufacturing practices** (second-order construct reflected by seven first-order constructs: *shop-floor employee involvement in problem-solving*, re-engineering set-ups, cellular manufacturing, preventive maintenance, quality assurance in production, dependable suppliers, and *pull production*)	None
Tu et al. [42]	Same as Tu et al. [44]	Regression analysis	(1) Re-engineering set-ups; (2) Preventive maintenance; (3) Cellular manufacturing; (4) Quality assurance in production (NOT supported)	None
Tu et al. [39]	Same as Tu et al. [44]	Covariance-based structural equation modeling	(1) Customer closeness; (2) **Modularity-based manufacturing practices** (second-order construct reflected by three first-order constructs: product modularity, process modularity, and *dynamic teaming*)	(1) enables (2)
Liu et al. [43]	- 189 - Median (average) plant size: 414 (1086) - America: US (29). Asia: Japan (34), South Korea (31). Europe: Finland (30), Sweden (24), Germany (41). - Auto suppliers (69), Electronics (59), Machinery (51)	- Regression analysis - MANOVA	(1) Feedback to shop-floor employees; (2) Autonomous maintenance; (3) Cellular manufacturing; (4) Multifunctional employees; (5) High standards for recruiting; (6) Task-related training for employees; (7) Differentiated rewards and incentive systems; (8) Employee-contribution willingness; (9) Continuous improvement and learning; (10) Employee empowerment (NOT supported)	None
Huang et al. [55]	Same as Liu et al. [43]	Covariance-based structural equation modeling	Effective process implementation (defined as process innovation)	None
Ahmad et al. [35]	- 208 - Average plant size: 861 - America: US. Asia: Japan, South Korea. Europe: Finland, Sweden, Austria, Germany, Italy. - Automotive, Electronics, Machinery	Covariance-based structural equation modeling	(1) Product modularity; (2) Inter-functional design coordination	(1) enables (2)

Huang et al. [28]	- 167 - At least 250 employees - America: US (13). Asia: Japan (21), South Korea (20). Europe: Finland (27), Sweden (19), Austria (15), Germany (31), Italy (21). - Auto suppliers (55), Electronics (59), Machinery (53)	Covariance-based structural equation modeling	**Organic structure** (second-order construct reflected by three first-order constructs: flatness, decentralization, and employee multifunctionality), provided that the degree of product customization is high	None
Kristal et al. [46]	Same as Huang et al. [28]	Covariance-based structural equation modeling	**Quality management** (second-order construct reflected by six first-order constructs: *small-group problem-solving, top management leadership for quality*, information and feedback, supplier involvement, customer focus, and process management)	None
Peng et al. [36]	- 164 - Average plant size: 265 - America: US (9). Asia: Japan (18), South Korea (20). Europe: Finland (25), Sweden (19), Austria (14), Germany (29), Italy (16), Spain (14). - Auto suppliers (61), Electronics (54), Machinery (49)	Covariance-based structural equation modeling	(1) Modular product design; (2) Configurator information technology (NOT supported); (3) Manufacturing information technology (NOT supported); (4) Supplier collaboration information technology	(1) enables (2)
Lai et al. [50]	- 289 - At least 100 employees - America: US (29). Asia: China (51), Japan (35), South Korea (31). Europe: Finland (30), Sweden (24), Germany (41), Italy (27). Oceania: Australia (21). - Auto suppliers (94), Electronics (100), Machinery (95)	Partial least squares structural equation modeling	(1) Internal integration; (2) Customer integration; (3) Supplier integration (NOT supported)	(1) enables (2); (1) enables (3)
Liu et al. [51]	- 266 - Not available - America: US (29). Asia: Japan (35), South Korea (31). Europe: Finland (30), Sweden (24), Austria (21), Germany (41), Italy (27), Spain (28). - Auto suppliers (90), Electronics (88), Machinery (88)	Covariance-based structural equation modeling	Functional integration	None
Trentin et al. [45]	- 238 - Mid- to large-sized plants - America: US (29). Asia: Japan (35), South Korea (31). Europe: Finland (30), Sweden (24), Austria (21), Germany (41), Italy (27). - Auto suppliers (90), Electronics (88), Machinery (88)	MANOVA	(1) **Self-containment of tasks** (second-order construct reflected by four first-order constructs: cellular manufacturing, employee empowerment, cross-functional training, and autonomous maintenance); (2) **Environmental management** (second-order construct reflected by three first-order constructs: supplier partnership, customer involvement and *external cooperation*); (3) **Enterprise-wide information systems use** (second-order construct formed by 31 separate areas of potential application of software) (NOT supported); (4) **Use of lateral relations** (second-order construct reflected by three first-order constructs: *coordination of decision making*, integration between functions, and *small-group problem-solving*)	None
Jitpaiboon et al. [56]	- 220 - Not available - North America - Fabricated metal products, Industrial machinery and equipment, Rubber and plastic products, Transportation equipment, Miscellaneous manufacturing	Partial least squares structural equation modeling	Customer integration	None

Liao et al. [47]	- 173 - <50 (5.8%), 51-100 (9.6%), 101-250 (11.1%), 251-500 (22.1%), 501-1000 (13.9%), >1000 (15.9%), Unspecified (21.6%) - China - Auto suppliers	Covariance-based structural equation modeling	(1) Supplier segmentation, defined as 'the practice of applying modularity to a supply base' (p. 28); (2) Process modularity design; (3) Postponement practices (NOT supported)	None
Kortmann et al. [8]	- 169 - Not available - India (76), US (83) - Not available	Partial least squares structural equation modeling	Strategic flexibility	None
Wang et al. [53]	- 204 - Not available - China - Appliances (26), Automotive or parts (20), Chemicals (20), Computer and electronics (17), Fabricated metal products (23), Food and beverage (12), Industrial machinery and equipment (19), Non-metallic mineral products (26), Paper and printing (4), Pharmaceutical (4), Rubber and plastic products (10), Textiles and apparel (8), Toys (3), Other (12)	Covariance-based structural equation modeling	(1) Customization knowledge utilization; (2) Business process improvement	None
Zhang et al. [37]	- 317 - Not available - America: US (29). Asia: China (51), Japan (35), South Korea (31). Europe: Finland (30), Sweden (24), Austria (21), Germany (41), Italy (27), Spain (28). - Auto suppliers (104), Electronics (109), Machinery (104)	Partial least squares structural equation modeling	(1) Organizational flatness (NOT supported); (2) Cross-functional coordination; (3) Cross-plant coordination (NOT supported); (4) Supply chain coordination; (5) Product modularity	(1) enables (2); (2) enables (5); (1) enables (3); (3) enables (5); (1) enables (4); (4) enables (5) (NOT supported)
Salvador et al. [40]	Same as Trentin et al. [45]	Regression analysis	(1) Customer involvement; (2) **Endowment of flexible manufacturing resources** (second-order construct formed by five first-order constructs: multifunctional employees, setup time reduction, product modularity, line flow production, and flexible suppliers); (3) **Product management tools** (second-order construct formed by three first-order constructs: product configurator, *product data management system*, and *business intelligence applications*)	(1), (2) and (3) have a positive complementary effect on mass-customization capability (MCC) (NOT supported: Each pair of the three enablers has a synergistic effect on MCC, provided the remaining enabler is at a low level)
Wang et al. [30]	Same as Wang et al. [53]	Partial least squares structural equation modeling	(1) Customer orientation; (2) Competitor orientation; (3) Innovation orientation; (4) Customization knowledge utilization	(1) enables (4); (2) enables (4); (3) enables (4)
Zhang et al. [60]	- 276 - <100 (43), 101-300 (52), 301-500 (34), 501-1000 (29), 1001-3000 (38), >3000 (80) - China - Automobile (69), Electric appliances (30), Electronics and communication equipment (114), Textile and apparel (63)	Covariance-based structural equation modeling	(1) Cognitive capital; (2) Relational capital (NOT supported)	None

Zhang et al. [57]	Same as Zhang et al. [60]	Partial least squares structural equation modeling	(1) Knowledge absorption from customers; (2) Knowledge absorption from suppliers (NOT supported)	None
Wang et al. [41]	Same as Wang et al. [53]	Partial least squares structural equation modeling	(1) Standardization; (2) Innovation	(1) enables (2); (1) and (2) mutually reinforce their positive effects on MCC
Zhang et al. [52]	- 645 - <100 (289), 101-200 (98), 201-500 (132), 501-1000 (50), >1000 (78), Unspecified (2) - America: US (84). Asia: China (100), India (58), Taiwan (40), Vietnam (80). Europe: Croatia (113), Hungary (37), Ireland (30), Poland (79). Oceania: Australia (25). - Apparel, other finished products and textile (49), Chemicals and allied products (31), Electronic and other electrical equipment and components, except computer equipment (94), Fabricated metal products, except machinery, trailers, and transportation equipment (98), Food and kindred products (66), Industrial and commercial machinery and computer equipment (43), Lumber and wood products, furniture (43), Miscellaneous manufacturing industries (36), Primary metal industries (28), Rubber and miscellaneous plastic products (47), Others (82), Unspecified (28)	Covariance-based structural equation modeling	(1) Human capital; (2) Social capital; (3) Structural capital (NOT supported); (4) Process innovation	(1) enables (3); (2) enables (3); (3) enables (4); (1) enables (4); (2) enables (4) (NOT supported)
Morita et al. [48]	- 303 - At least 100 employees - America: Brazil. Asia: China, Israel, Japan, South Korea, Taiwan, Vietnam. Europe: Finland, Sweden, UK, Austria, Germany, Italy, Spain. - Automobiles (79), Electronics (114), Machinery (110)	- t test - Regression analysis	(1) **Product development capability** (second-order construct reflected by four first-order constructs: customer involvement in new product development, *manufacturing involvement in new product development*, supplier involvement in new product development, and *front-end loading in new product development*); (2) **Supply chain capability** (second-order construct reflected by four first-order constructs: lead time focus, *JIT focus*, quality focus, and *demand stability focus*)	(1) enables product modularity; (2) enables product modularity (NOT supported); (1) and (2) mutually reinforce their positive effect on product modularity (NOT supported); (1) and (2) mutually reinforce their positive effect on MCC (NOT supported)
Sandrin et al. [29]	- 195 - Mid- to large-sized plants - America: US (23). Asia: Japan (26), South Korea (22). Europe: Finland (27), Sweden (22), Austria (16), Germany (32), Italy (27). - Auto suppliers (63), Electronics (69), Machinery (63)	Covariance-based structural equation modeling	**Coalignment of high-involvement (HI) practices** (second-order construct reflected by four first-order practices: power-HI (captures employee empowerment), information-HI (captures information to employees), rewards-HI (captures plant performance-based incentives), and knowledge-HI (captures continual training for employees)), provided that the degree of product customization surpasses a certain threshold value	None explicit, but evidence is reported which supports the existence of a synergistic effect of the four HI practices on MCC, contingent on the degree of product customization

Zhang et al. [38]	- 317 - At least 250 employees - America: US (29). Asia: China (51), Japan (35), South Korea (31). Europe: Finland (30), Sweden (24), Austria (21), Germany (41), Italy (27), Spain (28). - Auto suppliers (104), Electronics (109), Machinery (104)	Covariance-based structural equation modeling	Product modularity	None
Qi et al. [49]	- 647 - <100 (287), 101-200 (97), 201-500 (132), 501-1000 (50), >1000 (77), Unspecified (2) - America: US (83). Asia: China (100), India (58), Taiwan (40), Vietnam (80). Europe: Croatia (113), Hungary (37), Ireland (30), Poland (80). Oceania: Australia (26). - Apparel, other finished products made from fabrics and similar material (31), Chemicals and allied products (31), Electronic and other electrical equipment and components, except computer equipment (93), Fabricated metal products, except machinery, trailers, and transportation equipment (59), Food and kindred products (66), Furniture and fixtures (17), Industrial and commercial machinery and computer equipment (42), Leather and leather products (6), Lumber and wood products, except furniture (26), Manufacture of motor vehicles, trailers, and semi-trailers (22), Manufacture of other transport equipment (17), Measuring, analyzing, and controlling instruments, photographic, medical and optical goods, watches and clocks (13), Miscellaneous manufacturing industries (36), Paper and allied products (22), Petroleum refining and related industries (7), Primary metal industries (28), Printing, publishing, and allied products (10), Rubber and miscellaneous plastic products (48), Stone, clay, glass, and concrete products (24), Textile mill products (18), Tobacco products (1), Unspecified (30)	Covariance-based structural equation modeling	(1) Agile practices (construct measured by the following items: flexible workforce, integrating manufacturing and design process, customer support, customer process integration, and supplier process integration); (2) Lean practices (construct measured by the following items: quality management practices, cost reduction programs, manufacturing lead-time reduction programs, and processing technologies) (NOT supported)	None
Zhang et al. [24]	- 147 - 21-100 (41), 101-500 (70), 501-1000 (27), >1000 (9) - China - Information service (3), Manufacturing (69), Transportation (2), Wholesale (70), Others (3)	- Partial least squares structural equation modeling - Regression analysis	Assimilation of big data analytical intelligence	None

Jafari et al. [59]	- 242 - <11 (165), 11-50 (65), 51-250 (12) - Sweden - Manufacture of fabricated metal products, except machinery and equipment (72), Manufacture of machinery and equipment (27), Manufacture of wood and of products of wood and cork, except furniture (20), Manufacture of food products (17), Manufacture of rubber and plastic products (17), Other manufacturing (15), Manufacture of computer, electronic and optical products (12), Manufacture of furniture (11), Manufacture of electrical equipment (10), Manufacture of other nonmetallic mineral products (7), Manufacture of textiles (7), Others (27)	Covariance-based structural equation modeling	Supply integration	None
Liu et al. [54]	- 498 - Not available - Nine countries from three cultural clusters (i.e., Anglo, Eastern Europe, and Asian) - Not available	Covariance-based structural equation modeling	**Operational innovation capability** (second-order construct reflected by two first-order constructs: product innovation and process innovation)	None
Zhang et al. [25]	- 129 - Not available - China - Alcohol and beverage industry (5), Automobile (7), Chemical materials and products (12), Cultural, educational, and sports goods (2), Electric equipment and machinery (18), Electronic and telecommunications (6), Food processing (4), Food production (3), Garments and other fibre products (1), Instruments and meters (2), Leather, furs, down, and related (1), Medical and pharmaceutical products (12), Metal products (1), Nonmetal mineral products (2), Ordinary machinery (16), Other transport equipment (2), Petroleum refining and coking (1), Printing and record medium (2), Rubber and plastic products (10), Smelting and pressing of nonferrous (5), Special proposes equipment (12), Textile industry (4), Timber processing (1)	Regression-based conditional process analysis	(1) Learning goal orientation (positively moderated by competitive intensity); (2) Performance goal orientation (negatively moderated by competitive intensity)	None
Madhavaram et al. [58]	- 189 - Not available - US (171). Others (18) - Industrial and commercial machinery and computer equipment, Electronic and other electrical equipment and components, except computer equipment, Transportation equipment, Measuring, analyzing, and controlling instruments; photographic, medical and optical goods; watches and clocks	Covariance-based structural equation modeling	(1) Supplier core offering capability (captures supplier dependability), (2) Supplier core operations capability (captures supplier flexibility), (3) Supplier communication (captures one dimension of supplier integration) (NOT supported)	(3) enables (1); (3) enables (2)

*In the column 'Hypothesized relationship(s) among MCC enablers', the covariation of the constructs that underlie a valid, reflective, second-order construct is excluded.