Toward a Contingent-Configurational Perspective on Configuration Systems in the AEC Industry

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Abstract

The Architecture, Engineering, and Construction (AEC) industry faces increasing pressure to deliver customized solutions at scale, yet research and practice remain fragmented around configuration systems. This configuration-centric systematic literature review synthesizes 137 publications, mapping customization strategies, enabling mechanisms, and performance outcomes. Results highlight configuration systems as essential for advanced customization but reveal significant gaps in theory, terminology, and empirical validation. To address this, we propose an integrative analytical framework—structured around customization strategies, enablers, and outcomes—interpreted through the Technology–Organization–Environment (TOE) lens. We outline a research agenda to bridge theory and practice and support scalable and adaptive customization in digitalized AEC industry. This review provides a foundation for more context-sensitive, theory-driven approaches to configuration in the sector.

Keywords

Product configuration systems, Mass customization, Architecture, Engineering, and Construction (AEC), Systematic literature review, Technology–Organization–Environment (TOE) Framework

1. Introduction

The Architecture, Engineering, and Construction (AEC) industry is undergoing rapid transformation in response to increasing demand for flexibility, efficiency, and end-user customization [1, 2, 3]. Driven by the twin forces of digitalization and industrialization [4], construction stakeholders are seeking new strategies and tools to deliver bespoke solutions at scale, moving beyond traditional approaches toward better performing modes of production [5, 6]. However, despite significant technological advancements and a proliferation of customization practices, the systematic integration of configuration systems in AEC remains under considered in both research and in practice [7, 8]. This is further complicated by the socio-technical complexity, fragmentation and the need for integrated systems approaches in digitalized AEC and modular construction, as shown by recent work on the complementarity of systems integration and Building Information Modeling (BIM) [29], and the foundational challenges of complexity in modular construction [30].

Product configuration systems, long established in sectors such as manufacturing, automotive, and Information and Communication Technology (ICT) [9, 10], offer the potential to manage complexity, enable mass customization, and bridge the gap between client requirements and industrialized delivery in building construction. Yet, in the AEC domain, research on customization strategies is fragmented, with limited adoption of theoretical background and terminology which is established for configuration systems and configuration-based customization approaches. The AEC sector therefore faces a critical need for structured frameworks that can guide the design, implementation, and

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evaluation of configuration-based customization strategies, especially as project delivery grows increasingly complex and multi-actor in nature [1, 11, 24].

This paper addresses these gaps by presenting a configuration-centric systematic literature review (SLR) that classifies and synthesizes the current body of literature on customization in AEC. Using a novel analytical framework that integrates both established customization strategies and core mass customization (MC) enablers [10, 13] alongside inductively identified enablers and performance outcomes, the review maps sector-specific patterns, trade-offs, and theoretical limitations in existing studies. In particular, the findings highlight the limited uptake of configuration concepts (such as the operationalization of established models and terminology from configuration body of knowledge) and the absence of context-sensitive, theory-driven frameworks that address the contingent nature of configuration system integration in AEC.

Based on this comprehensive synthesis, the paper develops an integrative analytical framework that structures the field around customization strategies, enabling mechanisms, and performance outcomes, employing the Technology–Organization–Environment (TOE) theoretical lens to interpret how technological, organizational, and environmental contingencies influence mass customization strategies in the AEC sector [14]. Building on these insights, we outline a future research agenda, to ground further theory development and contribute to bridge the gap between academic research and practical application on this topic.

This paper systematically synthesizes evidence from 137 publications on configuration systems, customization strategies, and enabling mechanisms in the AEC sector. By combining this evidence with a forward-looking research agenda, this work provides a structured evaluation of the current configuration body of knowledge. This approach lays a robust foundation for advancing both research and practice at the intersection of configuration knowledge, digital transformation, and innovation in building construction. In summary, the current literature is characterized by persistent fragmentation, socio-technical complexity, and a lack of context-sensitive, theory-driven frameworks for configuration system integration in AEC.

To address these challenges, we propose a contingent-configurational perspective of configuration system integration in the AEC sector. The "configurational perspective" emphasizes the importance of internal consistency among multiple interdependent elements within an organization or system to achieve effectiveness. In our context, successful outcomes depend on achieving a good fit among various enablers, so that they work coherently together. The "contingent perspective" highlights that the effectiveness of enabler configurations depends on contingency factors—such as technological, organizational, and environmental conditions, as interpreted through the TOE framework. This theoretical perspective argues that optimal outcomes are not achieved by rigidly applying the same enablers in every situation, but by adapting them to the specific strategy and context. By explicitly articulating this contingent-configurational perspective, the paper offers a new way to interpret the diverse patterns, trade-offs, and gaps identified in the literature, and establishes a foundation for both research and practice to move toward more adaptive, scalable, and effective customization in the digitalized AEC industry.

2. Background & related work

Product configuration systems have long been established as essential enablers of mass customization in industries such as manufacturing and automotive, where rule-based logic, modular product platforms, and digital tools allow organizations to deliver individualized solutions efficiently at scale [5, 10]. Over the past two decades, configuration research has produced robust models for the design and management of customizable product families, supporting both academic inquiry and practical implementation [15, 10].

In the AEC sector, however, the adoption and theoretical integration of configuration systems remains limited. Although interest in mass customization, modularization, and digitalization has grown, reflected in studies on off-site construction, prefabrication, and BIM-enabled processes—most AEC research continues to focus on isolated technologies or project-level innovations [16, 11, 8, 12].

Explicit application of configuration logic, and systematic frameworks for linking customization strategies to enabling mechanisms and performance outcomes, are still rarely found in the AEC literature.

Foundational theories of mass customization [6, 10] offer important conceptual tools for understanding the design and implementation of customized solutions. Yet, their translation into the AEC context remains patchy and inconsistent. Recent systematic reviews have highlighted the fragmented nature of AEC customization research, the absence of performance-based classification schemes, and the lack of theory-driven approaches that address organizational, technological, and project-level contingencies [17, 18, 19, 20]. Similar integration challenges, arising from the interplay of technical systems and organizational processes, are widely recognized in recent studies of modular construction and digital integration in AEC, where the socio-technical complexities of managing systems, technologies, and collaborations have been explicitly highlighted [29; 30].

To address these limitations, this paper presents a configuration-centric SLR that classifies and synthesizes 137 publications at the intersection of customization and configuration in the AEC industry. By building on an integrative analytical framework, this review provides a structured synthesis of current knowledge, identifies sector-specific patterns and gaps, and establishes a foundation for future research directions, including the potential development of more context-sensitive and theory-driven frameworks tailored to the complexities of the AEC industry.

3. Method

This study employs a configuration-centric SLR to synthesize and classify research on configuration systems and customization strategies in the AEC industry. The SLR approach was selected for its capacity to rigorously map a fragmented field, identify theoretical and empirical gaps, and establish an evidence-based foundation for future research. The review protocol was developed and implemented in accordance with established SLR guidelines [21, 22].

The review focused exclusively on literature that addresses the integration, implementation, or evaluation of configuration systems, configuration logic, or related strategies within the AEC context. A comprehensive search was performed in the Scopus database, using a set of keywords and Boolean operators targeting configuration, customization, modularization, and AEC-specific terms. The final search string was: (configurat* OR customi* OR personali* OR individuali* OR "made to measure" OR "engineer* to order" OR "custom made" OR variet*) AND (aec OR architect* OR construction OR building OR hous* OR dwelling OR "infrastructure project") AND ("mass customi*" OR "mass personali*" OR "industrial construct*" OR "off-site construction" OR modular* OR platform OR "additive manufacturing" OR "3d print*" OR bim OR "build* information system*" OR "prefabricated" OR "precast" OR "volumetric" OR "paneli*" OR "industriali*").

Scopus is used as the sole indexing source due to its broad, cross-disciplinary coverage of engineering, construction, and information systems; unified metadata (e.g., DOIs, affiliations) enabling consistent coding and de-duplication; and export functions that support transparent replication of the search. This choice entails potential database bias and the omission of niche or regional outlets not indexed by Scopus. To mitigate this limitation in future replications, the search may be triangulated with complementary sources (e.g., Web of Science).

Scopus was searched on October 2024 for records from database inception–October 2024, querying title–abstract–keywords using the Boolean string reported above. At import, English-language and document-type limits were applied (articles, reviews, conference papers, books/chapters). The search retrieved 138,603 records. A quality-filtering step was then applied to manage volume while preserving influence: books/chapters/conference papers published before 2021 were retained only if cited at least once, whereas all journal articles were retained regardless of year. After these automated filters, 123,188 records proceeded to screening. A summary of the selection process is shown in Figure 1 (PRISMA), and stage counts by source type are listed in Table 1.

Studies were included in the review if they described, analyzed, or deployed a configuration system, or a functionally equivalent mechanism (such as a rules-based process, platform logic, or systematized modularization that enables user-driven product configuration), as part of their customization approach in the AEC sector. The inclusion criteria were also extended to studies providing empirical, theoretical, or conceptual insights into these mechanisms, even if not labeled explicitly as configuration systems. Conversely, studies focused solely on isolated digital or manufacturing technologies, or on general customization practices without explicit or implicit links to configuration logic, were excluded to ensure a targeted, configuration-centric dataset.

The screening process followed a multi-stage approach, beginning with title and abstract screening and followed by a full-text review and snowballing. Title screening identified 717 publications, abstract screening narrowed these to 215 publications and full-text review yielded 132 publications. Snowballing identified five additional sources (three journal articles and two conference papers), resulting in a final dataset of 137 publications: 74 journal articles or reviews and 63 books and conference papers. The selection process is summarized in Figure 1, with stage counts by source type in Table 1.

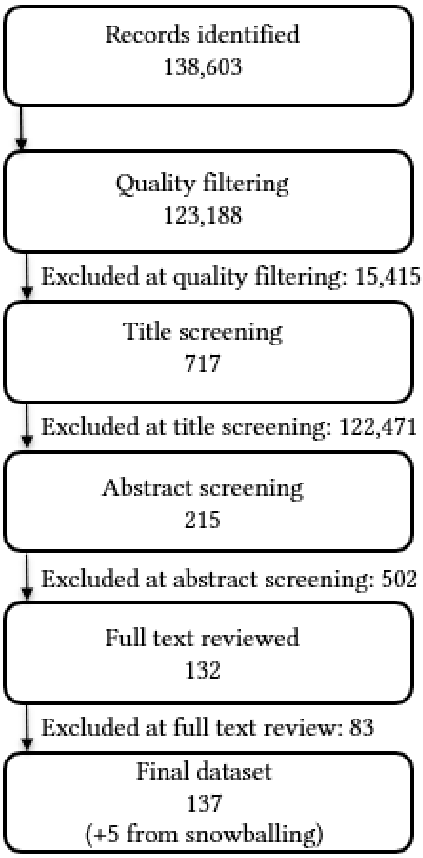

Figure 1: PRISMA flow diagram summarizing the review process from identification to inclusion, with counts at each stage; final included studies = 137.

Each retained study was systematically coded using an analytical framework adapted from [6, 10], tailored for application in the AEC context. The customization strategy component of the framework used in coding comprised five categories (pure customization, customized fabrication, customized assembly, customized distribution, and variety without customization) deductively derived from established literature [6, 10].

Table 1
Overview of screening phases and publication counts

Stage	Journals	Books & Conferences	Total
Initial search results	74,139	64,464	138,603
Phase 1: Quality Filtering	74,139	49,049	123,188
Phase 2: Title Screening	378	339	717
Phase 3: Abstract Screening	123	92	215
Phase 4: Full-Text Review	71	61	132
Phase 5: Snowballing	3	2	5
Final dataset	74	63	137

Enabling mechanisms were coded into core and other classes using operational criteria. An enabler was classified as core when it directly instantiated configuration by generating or validating options and/or enforcing product–process rules; practically, removing it would break configuration because choices could no longer be translated into a feasible, manufacturable or constructible solution. An enabler was classified as other when it supported, integrated, extended or scaled configuration (e.g., via data environments, automation, or delivery methods) without itself encoding option-generation or rule logic. Consistent with prior implementation-guideline reviews, the core set comprises IT-based product configuration (PC), product platform development (PP), product modularization (M), process modularity (PM), part standardization (S), group technology (GT), form postponement (P), and concurrent product–process–supply-chain engineering (CE). Suzić et al. [13] explicitly identify these eight as foundational mass-customization enablers and discuss their typical interdependencies and sequencing in implementation guidelines, reinforcing their classification as "core" [13]. Each enabler is classified as core because it directly instantiates configuration: PC encodes options and constraints and emits validated solutions; PP provides common architectures and parameters that generate families of variants; M enables variety through re-combinable modules; PM decouples subprocesses so configured variants can be executed or substituted without global disruption; S constrains part variety to keep the rules and option space tractable; GT structures similarity families that discipline variant rules; P defers differentiation so configuration rules drive late-stage options; and CE integrates design, manufacture and logistics early to maintain feasibility of configured options [13].

By contrast, Digital Integration (e.g., BIM, CAD, digital twins), Emerging Technologies (e.g., 3D printing, AI, IoT, AR/VR), and Off-site construction methods (panelised, volumetric, hybrid) were identified inductively from recurrent patterns in the AEC literature and are classified as other (supportive) mechanisms: they connect actors and systems, extend capability, or industrialize delivery, but do not themselves instantiate configuration.

Each publication was further classified according to the performance dimensions it addressed (cost, time, quality, flexibility, scalability, and sustainability) and the type of evidence reported (quantitative, qualitative, conceptual, or not reported). The performance dimensions of cost, time, quality and sustainability were deductively derived from established literature on mass customization and configuration in AEC [16, 18, 26]. Here, flexibility encompasses both design flexibility (the ability to accommodate a variety of customer and project requirements through modularization and kit-of-parts) and process flexibility (the ability to adapt production and assembly processes across project phases). The additional performance dimension of scalability was included inductively as it emerged as a significant theme during the review process. Evidence types were defined deductively, following established SLR guidelines [21, 22].

The analysis and synthesis combined descriptive statistics, heatmaps, and cross-tabulation to analyze the distribution and co-occurrence of enabling mechanisms and customization strategies, and to map performance outcomes across the literature. Each publication was first coded for its primary customization strategy, forming the basis for further analysis. All discussed enablers (core MC and others), were identified and recorded, allowing for a detailed mapping of enabler presence by customization strategy. The analysis distinguished between studies examining single versus bundled enablers, with "bundled" referring to cases where two or more enablers were present, regardless of whether they were explicitly integrated. In a further step, the review sought to identify cases of genuine synergy—where two or more enablers were not just present, but functionally integrated or operationally combined, resulting in demonstrable mutual benefit or new capabilities. Synergy types were classified as core MC to core MC, core MC to other, and other to other enabler integrations.

Finally, thematic coding was applied to extract insights across the six performance dimensions. This multi-step synthesis enabled the identification of sector-specific patterns, trade-offs, and context-sensitive high-performing configurations. Studies were systematically grouped by customization strategy and by the presence, bundling, and synergy of enablers, supporting systematic comparisons that highlight both theoretical and practical implications for the integration of configuration systems in the AEC industry. This structured and transparent approach provides a rigorous basis for mapping the current state of research and identifying critical gaps in the literature on configuration systems within the AEC sector. Figure 2 summarizes the four analysis domains; results follow in section 4.

The objective of the review is to explain how customization strategies interact with enabler types to influence cost, time, quality, flexibility, scalability and sustainability. Guided by prior theory and patterns observed in the reviewed literature, three propositions are examined: first, fit—that configurations exhibiting stronger internal alignment between the chosen strategy and core enablers are associated with superior operational outcomes; second, complementarity—that bundles of mutually reinforcing enablers (for example, PP with PC, anchored in robust digital integration) yield super-additive performance relative to piecemeal adoption; and third, contingency—that Technology–Organization–Environment (TOE) conditions moderate these relationships, such that ostensibly similar bundles can perform differently across contexts. These propositions structure the synthesis and motivate the cross-tabulations and thematic analyses reported in Section 4.

4. Results

This section presents the findings of the SLR according to the analytical framework developed for this study (see Figure 2). The framework structures the analysis and the synthesis around four interdependent domains: customization strategies, core enablers, other enablers, and performance outcomes. The arrows show how each domain influences the others. Specifically, the choice of customization strategy (top of the framework) shapes which performance outcomes are prioritized and achieved. For example, adopting a pure customization strategy may maximize design flexibility and user satisfaction, but can increase cost and reduce scalability. In contrast, a variety without customization strategy (standardized products) might enhance efficiency, reduce cost, and speed up delivery, but may offer less flexibility or personalization. Customized fabrication and customized assembly offer trade-offs between flexibility, scalability, and efficiency, depending on how enablers are integrated. This direct link is represented by the arrow from "Customization strategy" to "Performance outcomes. This framework guided both the coding of studies and the thematic analysis, enabling a systematic mapping of research patterns, gaps, and actionable implications for the AEC sector. Each study was coded customisation strategy, enablers, outcomes, evidence type, the aggregated distribution are reported in the figures and tables in section 4 (Results).

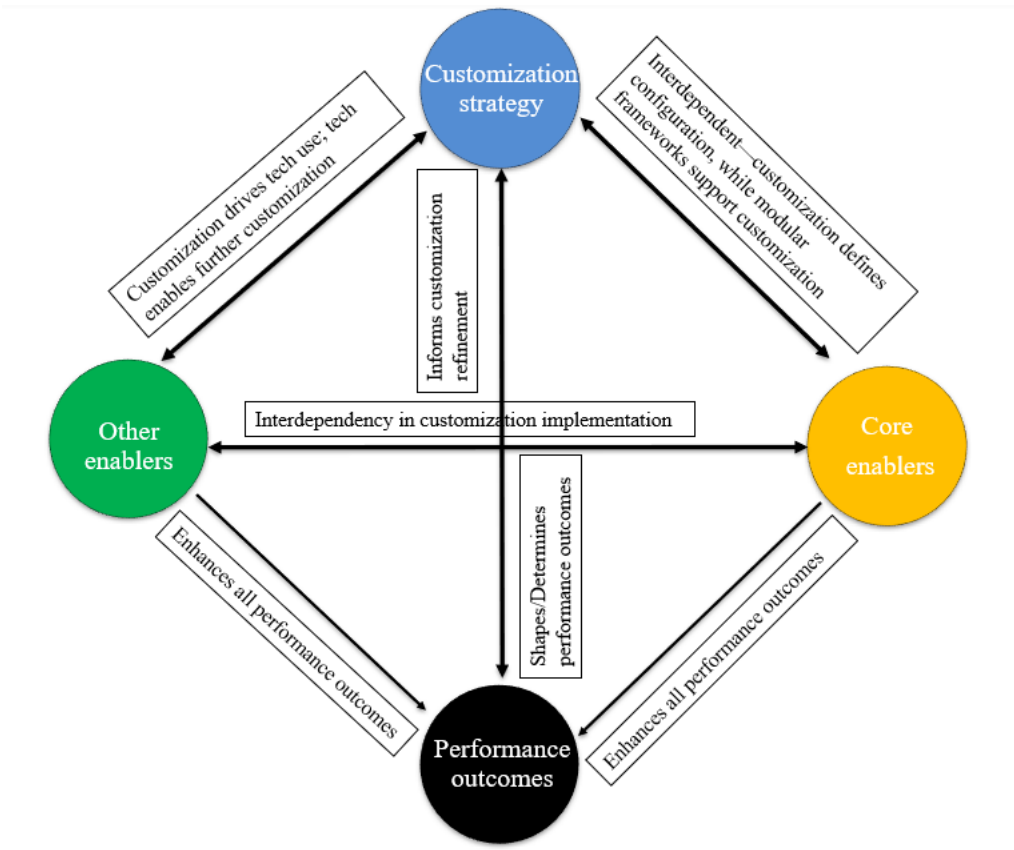

Figure 2: Analytical framework for coding and synthesis—block diagram showing four domains (customization strategy, core enablers, other enablers, and performance outcomes) with their interdependence (see Section 3).

4.1. Study and publications' set characteristics

The final SLR dataset comprises 137 publications spanning journal articles (74) and conference papers (63) published between 2005 and 2024 (conference papers published before 2021 have been retained only if they received at least one citation). The sample covers a broad spectrum of AEC contexts, including building construction, modular housing, and off-site manufacturing. Most studies appeared in the last ten years (72%), reflecting growing academic and industry attention to configuration and mass customization in AEC (Figure 3).

In terms of research methods, there is a predominance of conceptual and qualitative studies, with relatively few papers employing robust quantitative studies. This limited methodological rigor, particularly in assessing performance outcomes, highlights the need for more empirical validation in future research.

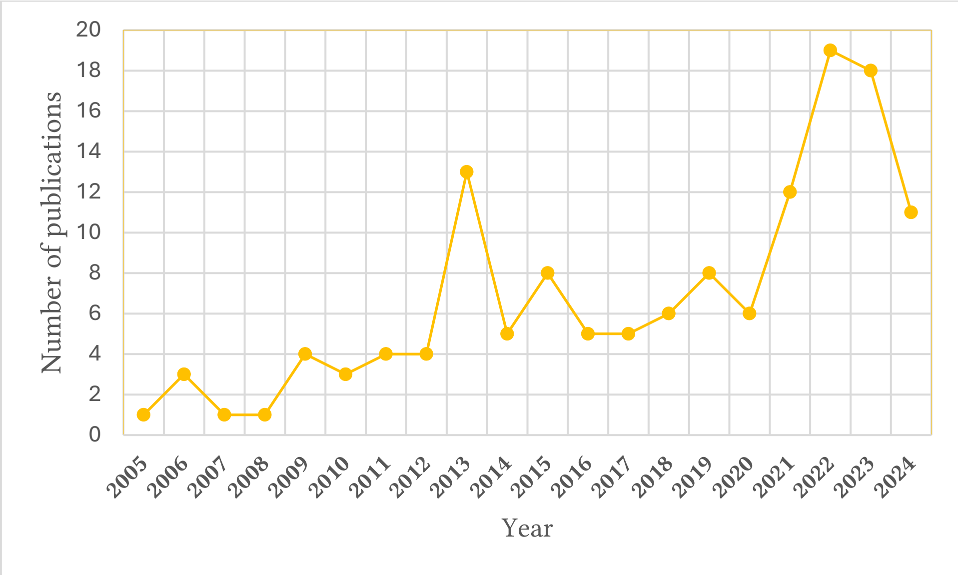

Figure 3: Annual number of included publications (2005–2024)—line chart showing a clear upward trend.

4.2. Distribution of customization strategies

Applying the analytical framework, analysis reveals that customized fabrication (45 publications, 33%) and pure customization (42, 31%) are the most prevalent strategies, together accounting for about two-thirds of the sample (see Table 2). Customized assembly is represented in 31 studies (22%), while variety without customization is least frequent (19, 14%). No publications were classified under customized distribution.

Table 2
Distribution of publications by customization strategy

Customization strategy	Number of publications	Percentage (%)
Pure customization	42	31
Customized fabrication	45	33
Customized assembly	31	22
Customized distribution	0	0
Variety without customization	19	14

In this review, pure customization is coded whenever end-user or project requirements influence the design, within a bounded solution space. This includes parameterized variants and engineer-to-order practices implemented via configurator platforms, parametric/BIM workflows, or equivalent rules-based processes. Under this operational definition, pure customization represents a large share of the sample (42/137; 31%), second only to customized fabrication (45/137; 33%). This explains why many studies fall into pure customization even when a configurator is not explicitly referenced, because rules-based parametric/BIM workflows or engineer-to-order processes meet the operational definition. This absence may reflect the nature of the AEC industry, where products are typically large, immobile, and project-specific, thus limiting opportunities for customer-driven distribution customization. These findings indicate a strong research focus on strategies that maximize design flexibility and user input, while digital integration tools (e.g., BIM/CAD) co-occur across all strategies, with the highest counts in pure customization (37 studies; 30.8%) and customized fabrication (36; 30.0%), and fewer in variety without customization (18; 15.0%).

The breakdown by execution type and project scope is shown in Table 5.

4.3. Adoption and roles of configuration systems

A total of 81 studies explicitly deploy or analyze configuration systems as core elements of customization. Among these, 50 incorporate modularization as a configuration mechanism (i.e., process or tool that enables the systematic definition, selection, or assembly of customizable building elements), while the remaining 31 utilize approaches such as BIM-based platforms, parametric modeling, and rule-based systems. Additionally, 56 studies employ digital tools or methods that enable systematic configuration or customization, even though they are not formally labeled or explicitly referred to as "configuration systems" in the studies. Of these, 23 incorporate modularization as a mechanism for customization, while the remaining 33 utilize tools such as BIM-based platforms, parametric modeling, and rule-based systems and AI-assisted decision support—used for configuration-like purposes but described using different terminology. Collectively, these findings indicate that both formally identified configuration systems and a broad range of digital tools and platforms (even when described with different terminology) contribute to customization in the AEC sector, highlighting the centrality of digitalization in contemporary AEC-related configuration research.

4.4. Enabler combinations and patterns

Figure 4 shows clear patterns in enabler use across customization strategies. Pure customization relies most on IT-based product configuration and digital integration. Customized fabrication exhibits the most diverse enabler mix, with frequent use of product modularization, process modularity, digital integration, and off-site methods. Customized assembly also combines modularization, process modularity, and digital tools, while variety without customization depends almost entirely on digital integration. Strategies like customized fabrication and assembly are more likely to integrate multiple enablers in combination, supporting higher customization and improved performance.

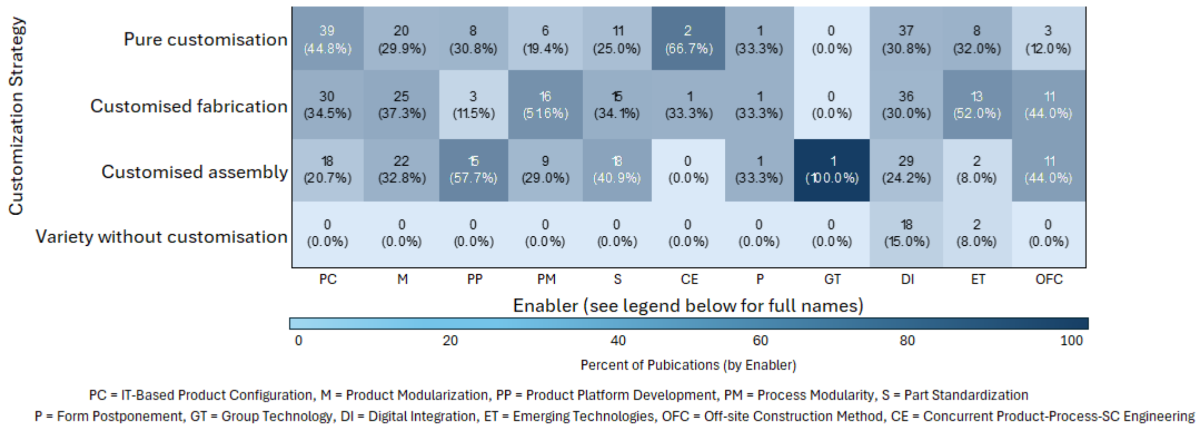

Figure 4: Co-occurrence of enablers per customization strategy. Darker cells indicate more frequent co-occurrence (e.g., IT-based configuration with modularization). Each cell reports the count and the column percentage (denominator = number of publications citing that enabler; column totals = 100%). Because publications can cite multiple enablers, row totals may exceed 100%. See legend for enabler abbreviations.

4.5. Enabler synergies

As seen in Figure 4, IT-based product configuration is the most considered enabler in pure customization, is the second most considered in customized fabrication and, though to a lesser extent, appear in customized assembly. Notably, all these three strategies involve the use of multiple enablers in combination.

To systematically identify patterns of enabler synergy, all 137 reviewed publications were coded not only for individual enablers, but also for the co-occurrence and integration of multiple enablers within each study. During data extraction, we specifically recorded instances where two or more enablers were functionally integrated (i.e., working together to enable or enhance customization outcomes), rather than merely present in the same project or case. Each instance of enabler co-occurrence was analyzed to determine whether it constituted a true synergy (i.e., an intentional and functional integration of two or more enablers resulting in enhanced customization, efficiency, or new capabilities, as reported by the study). This process enabled us to classify the observed synergies according to the nature of the enablers involved (Core MC ↔ Core MC, Core MC ↔ Other enabler, Other enabler ↔ Other enabler).

The most innovative and impactful approaches, as summarized in Table 3 were those in which studies provided empirical or conceptual evidence that such integration delivered substantial benefits (e.g., accelerated project delivery, improved information flow, increased client involvement, or operational efficiency).

Table 3
Detailed synergy examples

Study reference	Synergy type	Enablers involved	Context/Project type	Justification for synergy
Jensen et al. (2012), Automation in Construction	Core MC ↔ Core MC	Product Modularization, IT-based configuration	Prefabricated multi-storey timber building, floor slab modules	Modularization supplies standardized, parametric modules; the configurator operationalizes these by embedding rules/constraints, enabling automatic generation of buildable design variants.
Wang & Chen (2024), Buildings	Core MC ↔ Other enabler	Product configurator, BIM	Modular single-family housing (Canada)	BIM stores all parametric rules/data; the configurator uses this to auto-match user preferences with buildable, code-compliant solutions, enforcing constraints in real time.
Zhou et al. (2021), Automation in Construction	Other ↔ Other enabler	IoT, BIM	Modular public housing (Hong Kong, Modular Integrated Construction (MiC)	Functional integration of BIM and IoT (SBIM) supports the systematic configuration and real-time management of modular assembly, enabling real-time data-driven customization of on-site assembly processes.

The three principal types of synergy, derived from repeated patterns across the literature, are described below:

1. Core MC enabler ↔ Core MC enabler: This involves two or more core MC enablers (e.g., configuration systems, modular product/process/platform) are functionally integrated to enable customization
2. Core MC enabler ↔ Other enabler: This is when core MC enabler and other enabler are interconnected to enable data flow or operational feedback in support of customization
3. Other enabler ↔ Other enabler: This is when two or more other enablers (e.g., BIM, 4D, 3D Printing, AI) are used together in an integrated workflow to enhance customization outcomes

Table 3 provides detailed examples of these synergy types, the enablers involved, the context or project type, and the justification from recent studies. For instance, Jensen et al. [23] demonstrate how product modularization and IT-based configuration (core MC ↔ core MC) reduce design effort and accelerate time-to-market in prefabricated timber construction. Wang and Chen [24] exemplify core MC ↔ other enabler synergy by combining a product configurator with BIM to streamline planning and procurement in modular housing. Zhou et al. [25] showcase other enabler ↔ other enabler synergies, integrating IoT and BIM to automate workflows, enhance productivity, and reduce errors in both offsite and onsite construction contexts. It is worth noting that, consistent with our analytical approach, we included studies where digital platforms perform configuration-like functions, even if not explicitly referred to as "configuration systems" by the original authors.

These cases illustrate that intentional, well-designed enabler synergies, and not mere co-occurrence, are central to achieving advanced customization, operational efficiency, and new capabilities across the AEC sector. The evidence from the literature confirms that such integrations can drive substantial improvements in productivity, information flow, client involvement, and overall project outcomes.

4.6. Performance Outcomes and Evidence Quality

Performance outcomes are most often reported for cost and time, particularly in pure customization and customized fabrication. However, quantitative evidence is limited (12–32% for cost, 14–29% for time), with most studies relying on qualitative or conceptual arguments. For flexibility, scalability, and sustainability, empirical evidence is especially scarce; over 50% of studies offer only conceptual or no evidence for these dimensions. Overall, positive claims for customization are widespread, but supporting evidence is dominated by conceptual and qualitative findings, underlining the need for research with more quantitative empirical evidence. Table 4 summarizes the evidence distribution across six key performance dimensions by customization strategy. An overall summary of which outcomes are reported appears in Figure 5, while detailed breakdowns by strategy and evidence type are provided in Table 4.

Table 4
Performance outcomes across customization levels

Customization strategy	#	Cost (%)				Time (%)				Quality (%)				Flexibility (%)				Scalability (%)				Sustainability (%)			
		Q	D	C	N	Q	D	C	N	Q	D	C	N	Q	D	C	N	Q	D	C	N	Q	D	C	N
Pure Customization	42	12	5	71	12	14	17	67	2	2	24	74	0	2	73	25	0	1	4	82	13	3	13	39	45
Customized Fabrication	45	18	4	76	2	22	11	65	2	9	20	69	2	1	19	79	1	1	1	97	1	8	6	44	42
Customized Assembly	31	32	3	65	0	29	20	48	3	0	45	48	7	0	35	60	5	3	8	82	7	4	6	30	60
Variety Without Customization	19	26	5	58	11	16	11	63	10	10	26	53	11	0	6	44	50	0	6	44	50	14	5	41	40

Grading Key: Q = empirical quantitative, D = empirical qualitative/descriptive, C = conceptual/speculative, N = no evidence

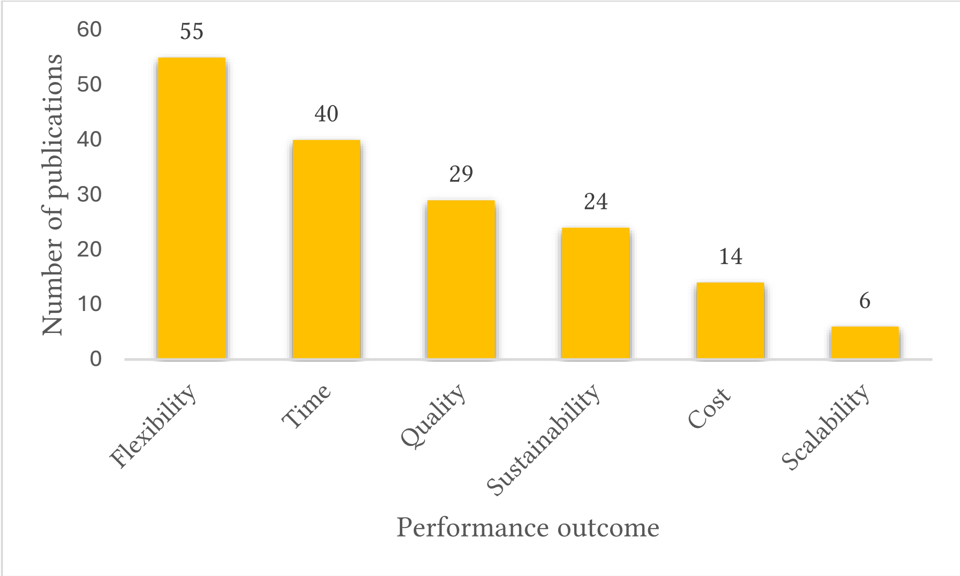

Figure 5: Share of publications reporting each performance outcome (n = 137). Totals exceed 100% because studies can report multiple outcomes.

4.7. Sector-specific patterns and trade-offs

Off-site and hybrid execution modes are most frequently reported in research on customization strategies. In this context, “research on customization strategies” refers to studies identified and classified in the review according to the primary customization strategy addressed—such as pure customization, customized fabrication, customized assembly, and so on—as described in Section 3. Research on customized fabrication is heavily concentrated in off-site contexts, whereas research on pure customization spans off-site, hybrid, and on-site implementations. Research on customized assembly is also closely associated with hybrid and off-site execution. In terms of application scope, research on pure customization often targets whole-building solutions, while research on customized fabrication and assembly is oriented toward component-level interventions. Most reviewed projects are new-builds, but some evidence of retrofit applications exists, particularly in research on customized fabrication and assembly.

Actor involvement differs across strategies: architects are central to pure customization, engineers to customized fabrication and assembly, and manufacturers are more visible in customized assembly. Client involvement is highest in pure customization, aligning with its user-driven nature.

These sector specific patterns highlight the contingent nature of customization strategies in the AEC industry. Execution mode, project scope, actor roles, and client involvement each condition the choice and effectiveness of a given customization strategy—demonstrating that configuration solutions must be tailored to specific technological, organizational, and environmental contexts. This reinforces the value of adopting a contingent-configurational perspective in analyzing and implementing customization in the sector.

Table 5
Distribution of customization strategies by execution type, project scope, project type, and actor involvement

Customization strategy	Execution Type				Scope			Project Type			Architect		Engineer		Client		Developer		Manufacturer	
	On-site	Off-site	Hybrid	Unstated/ unclear	Whole building	Component level	Unstated /unclear	New	Retrofi	Both	#	%	#	%	#	%	#	%	#	%
Pure Customization	10	16	12	4	22	20	0	39	0	3	18	25%	17	23%	16	22%	11	15%	11	15%
Customized Fabrication	4	30	9	2	15	30	0	38	4	3	19	32%	30	48%	3	5%	5	8%	5	8%
Customized Assembly	3	14	11	3	6	24	1	24	2	5	12	26%	15	32%	2	4%	9	19%	9	19%
Variety Without Customization	9	0	3	7	7	11	1	13	0	6	6	29%	12	57%	1	5%	1	5%	1	5%

As summarized in Table 5, these patterns reveal important trade-offs: strategies that maximize flexibility and whole-building customization increase complexity and demand strong digital infrastructure and collaboration, while component-level, engineer-driven strategies are more scalable but may offer less deep personalization. The diversity of execution modes, project scopes, and actor roles emphasizes the context-dependent nature of successful configuration implementation—a relationship captured by the framework and interpreted through the TOE lens.

4.8. Theoretical and practical gaps

Despite substantial progress, several limitations persist in the literature:

1. Enablers are often considered in isolation by researchers, rather than being studied considering their interactions, which limits understanding of their combined effectiveness and scalability in real world applications.
2. Empirical evidence for key performance outcomes, especially flexibility, scalability, and sustainability is limited.
3. Scalability challenges affect all customization strategies, with little empirical evidence showing that any approach can be effectively scaled for broader deployment.
4. Implementation frameworks need for robust empirical validation, and emerging technologies remain under-researched in actual contexts.
5. Sustainability research is often limited to environmental aspects, with economic and social dimensions underexplored.

Addressing these gaps will require:

1. Future research systematically exploring and empirically validating enabler synergies, using, for example, expert knowledge as a primary data source, given their efficiency and suitability for rapid theory-building.
2. Increased methodological rigor, including integrating qualitative insights (e.g. from experts) with quantitative findings (e.g. drawn from existing studies or from company reports) where feasible.
3. Broader research attention to flexibility, scalability, sustainability (across all dimensions), and sectoral diversity is needed, as these areas remain underexplored in the current literature.
4. Empirical validation of implementation frameworks, particularly in less-studied project types and contexts.

In summary, from this review it emerges that the most impactful and innovative configuration strategies in the AEC sector arise from the intentional, synergistic integration of enablers—as captured by the analytical framework. Closing the identified gaps will require coordinated efforts to develop, implement, and empirically validate context-sensitive, scalable, and sustainable configuration approaches for the digitalized AEC sector.

5. Discussion: Advancing a contingent-configurational perspective for configuration in AEC

This review shows that scalable and adaptive customization in the AEC sector depends on systematic, integrated use of core enablers and other enablers across all project stages, rather than fragmented tools adoption [8, 12]. The most successful cases integrate digital platforms, modularization, and configuration systems, effectively bridging mass production efficiency and user-specific outcomes [16, 25]. In contrast, fragmented or isolated efforts tend to deliver only limited and often costly gains [4, 18].

The analysis adopts a contingent-configurational perspective: the effectiveness of specific combinations of enablers is contingent upon the customization strategy employed. Distinct strategies (e.g., pure customization, customized fabrication, customized assembly, variety without customization) require different configurations of enablers to achieve desired performance outcomes. For example, pure customization and customized fabrication support high flexibility and user involvement but often struggle with scalability—gaps that can be addressed through the targeted integration of core enablers and other enablers. Customized assembly balances efficiency and personalization through enabler synergy, while strategies focusing on variety without customization primarily expand standardized offerings through digital tools (other enablers), limiting deep client-driven design. These differences underscore that the specific alignment or "fit" between strategy and enabler configuration must be tailored to the context and maturity of each case—consistent with the contingent-configurational perspective advanced in the literature [27].

However, strategy is not the only important contingency factor in the AEC context. In addition to the adopted customization strategy, other contextual factors, such as sector maturity, project complexity, delivery models, and stakeholder engagement, critically shape which configurations are most effective [8, 11]. Our findings show that the performance impact of configuration systems is not universal, but depends on their suitability with chosen strategy, project context and enabler synergy. Robust, context-sensitive integration can deliver substantial cost and time benefits, while mismatched or isolated enablers yield only marginal gains [18, 19]. This highlights that optimal outcomes cannot be achieved through a one-size-fits-all approach but require that configurations of strategies and enablers be tailored to specific technological, organizational, and environmental conditions.

These contextual factors align closely with the TOE framework, originally proposed by Tornatzky and Fleischer (1990) and widely adopted for studying technology adoption and integration in organizational settings [14, 28]. The TOE framework serves as a guiding lens for interpreting the findings. Specifically:

- Technological factors include the availability and maturity of digital platforms, BIM integration, IT infrastructure, and modular construction technologies. These determine the feasibility and performance of advanced configuration systems, influencing how easily customization strategies can be implemented and scaled.
- Organizational factors encompass delivery models, process maturity, stakeholder engagement, project governance, and organizational readiness for change. These shape the selection, integration, and synergy of enablers, as well as the ability to move from isolated to systematized approaches.
- Environmental factors comprise market dynamics, regulatory requirements, sectoral maturity, and client expectations. These set the external conditions for customization, impacting adoption rates and the prioritization of scalable versus flexible solutions.

Interpreting the results through the TOE lens clarifies how each dimension—technology, organization, and environment—uniquely contributes to the success or limitation of configuration system integration. This systematic consideration of context further substantiates the contingent-configurational perspective advanced in this paper.

Thus, the contingent-configurational perspective advanced in this paper explains and predicts how different combinations of customization strategies and enablers, tailored to organizational, technological, and environmental contexts, shape outcomes in the AEC sector. This theoretical perspective accounts for the dynamic interplay between configuration systems and contextual variables, providing practical guidance for selecting, integrating, and aligning enablers to achieve scalable, client-centric solutions.

For researchers, these findings highlight the need to systematically investigate both the mechanisms of enabler integration (configurational) and the contextual contingencies (contingent) that underpin successful outcomes, by moving beyond typologies to empirically grounded models that can inform theory and practice. For practitioners, the results offer actionable guidance: successful implementation requires not just investment in digital or modular tools, but also a strategic approach to synergy and adaptation to project-specific demands and organizational readiness.

Advancing contingent-configurational perspective will require continued empirical study to capture real-world complexities, overcome implementation barriers, and develop robust, context-sensitive approaches to scalable customization in the digitalized AEC sector.

6. Conclusion & Implications

This review advances understanding of scalable and adaptive customization in the AEC sector by systematically analyzing how configuration systems, enabler integration, and performance outcomes intersect across 137 publications. By positioning configuration systems at the core, the study clarifies where these approaches add the most value [10], identifies sector-specific patterns and trade-offs [8,11], and highlights persistent gaps—most notably the fragmented use of enablers, limited empirical validation, and the prevalence of isolated rather than synergistic adoption of digital and modular tools [8,12].

The findings make clear that current AEC customization efforts often fall short when configuration systems are implemented in isolation, without deliberate integration or alignment with project context. Such approaches typically lead to suboptimal outcomes, limited scalability, and missed opportunities for genuine client-centric solutions. Simply investing in digital tools or modularization, without ensuring synergy and contextual suitability, is unlikely to deliver the promised benefits of mass customization.

To address these limitations, this paper advances a contingent-configurational perspective for configuration system integration in the AEC sector. This theoretical contribution emphasizes that optimal outcomes are not achieved by universally applying the same strategies and enablers across all contexts. Instead, success depends on carefully selecting, integrating, and adapting customization strategies and enabling mechanisms to fit the specific technological, organizational, and environmental conditions of each project or organization. In other words, scalable and effective customization requires context-sensitive configuration, rather than a one-size-fits-all approach.

The integrative framework developed here connects customization strategies, enablers, and performance dimensions, providing both theoretical clarity and practical guidance for researchers and industry professionals at the intersection of digitalization, modularization, and user-driven design [10, 13]. For scholars, this work establishes a stronger theoretical basis for context-sensitive and empirically grounded research. For practitioners, it highlights actionable opportunities to leverage configuration logic and enabler synergies for scalable, client-centric solutions that are attuned to project and organizational realities.

Looking ahead, the AEC sector has significant potential to close the gap with leading industries like manufacturing—provided it adopts more context-sensitive, synergistic, and empirically validated approaches to configuration. Achieving this will depend on stronger alignment of technological, organizational, and environmental factors, as emphasized by the TOE framework and encapsulated in the contingent-configurational perspective advanced in this study.

Declaration on Generative AI

During the preparation of this work, the authors created all figures using Microsoft Excel. ChatGPT was consulted only for suggestions on color schemes, layout improvements, and label clarity. All data visualization, chart design, and content decisions were made entirely by human authors. No generative AI was used to create visual content.

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