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BEST PROCUREMENT PRACTICES FOR OFF-SITE CONSTRUCTION: A SYSTEMATIC LITERATURE REVIEW

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Abstract: Off-site construction has been promoted as a solution to persistent challenges in the construction industry, including low productivity, labour shortages, cost overruns, and schedule delays. While many studies have focused on technical and process optimizations, procurement remains an underexplored factor influencing the successful delivery of off-site construction projects. Procurement decisions shape early stakeholder involvement, design–manufacturing integration, cash flow mechanisms, supply chain coordination, and risk allocation; consequently, many traditional procurement approaches are poorly suited to realize the benefits of off-site construction. This paper is based on a systematic literature review of 30 peer-reviewed studies supported by bibliometric and thematic analyses. A systematic review was conducted, including scoping, database searches, and a PRISMA-based screening process to identify the final set of studies. For each study, structured data were extracted, and bibliometric analysis was used to identify overall research patterns and trends. A comparative procurement matrix was developed to evaluate model performance against key OSC operational criteria. The results indicate a clear increase in research on off-site construction procurement since 2020, with most contributions originating from Australia, China, Hong Kong, and the United Kingdom. The literature consistently shows that conventional procurement approaches, such as design–bid-build are poorly aligned with off-site construction requirements. In contrast, more collaborative and integrated models, including progressive design-build, integrated project delivery, construction management, early contractor involvement, and just-in-time strategies, demonstrate greater potential to support off-site construction by enabling early cash flow, improving coordination with manufacturers, and enhancing supply chain resilience. Key challenges identified include fragmented supply chains, a lack of standardized codes and contractual frameworks, ineffective payment mechanisms, logistics and storage constraints, limited real-time information sharing, and low trust among project stakeholders. The paper concludes by identifying research gaps and outlining future directions for developing context-specific procurement frameworks to support scalable off-site construction.

Keywords: Off-site construction; Procurement models; Optimization; Collaborative delivery models; Supply chain integration

1 INTRODUCTION

The construction industry continues to face persistent challenges, including low productivity, labour shortages, cost overruns, schedule delays, and fragmented supply chains (Akinradewo et al., 2023; Li et al., 2024a; Rahimian et al., 2017). In response, off-site construction (OSC) has emerged as a promising approach to improve efficiency, quality, and sustainability by shifting production to controlled manufacturing

environments (Bekdik et al., n.d.; Molavi & Barral, 2016; Ofori-Kuragu et al., 2022). This transition enables standardized processes, enhanced quality control, reduced waste, and accelerated project delivery (Bekdik et al., 2016; Li et al., 2024a; Ofori-Kuragu et al., 2022).

However, the successful implementation of OSC is not solely dependent on technological or manufacturing advancements. While existing research has largely focused on design standardization, production workflows, logistics, and digital integration (Pan, Pan, et al., 2023; Si et al., 2021; Wang et al., 2020; Ye et al., 2025), the role of procurement as a governing mechanism remains comparatively underexplored (Charlson & Dimka, 2021; Nesarnobari et al., 2025; M. Tennakoon et al., 2025; T. M. M. P. Tennakoon et al., 2024). Procurement structures define how stakeholders interact, how risks and responsibilities are distributed, and how financial and information flows are organized across the project lifecycle (Charlson & Dimka, 2021; Hu & Chong, 2022; T. M. M. P. Tennakoon et al., 2024). As a result, procurement directly influences the level of integration and coordination achievable in OSC projects (Assaf et al., 2023; Hu & Chong, 2022; M. Tennakoon et al., 2025).

Traditional procurement approaches, such as Design–Bid–Build (DBB), are typically based on sequential workflows, delayed stakeholder involvement, and fragmented supply chains (Charlson & Dimka, 2021; Finnie et al., 2018). Although these models provide cost certainty, they are often misaligned with the requirements of OSC, where early manufacturer involvement, synchronized design–manufacturing processes, and coordinated logistics are essential (Agapiou, 2022; Molavi & Barral, 2016). This misalignment can limit the realization of OSC benefits and reduce overall project performance (Akinradewo et al., 2023; Li et al., 2024a).

In contrast, more integrated and collaborative procurement models—including Design–Build (DB), Progressive Design–Build, Construction Management (CM), Integrated Project Delivery (IPD), and Alliance contracting—offer improved alignment with OSC by enabling earlier engagement, flexible financial structures, and stronger supply chain coordination. Despite this shift, the literature remains fragmented, with limited comparative analysis of procurement models based on their ability to support OSC-specific operational requirements (Assaf et al., 2023; Nesarnobari et al., 2025; T. M. M. P. Tennakoon et al., 2024).

Although several review studies have examined procurement challenges, supply chain resilience, and delivery strategies in OSC (Hu and Chong, 2022; Tennakoon et al., 2024; Nesarnobari et al., 2025), existing reviews primarily focus on describing barriers, procurement trends, and conceptual relationships. Limited attention has been given to systematically comparing procurement models according to their ability to satisfy operational requirements unique to OSC, such as early manufacturer involvement, design–manufacturing integration, supply chain coordination, and cash-flow alignment. Consequently, practitioners lack a structured framework for evaluating procurement approaches based on their suitability for OSC delivery. This study seeks to address this gap through a comparative synthesis of procurement models using OSC-specific performance criteria.

This study addresses this gap by examining procurement through an industrialization and supply chain integration perspective. OSC is treated as a manufacturing-oriented system that requires early integration, coordinated decision-making, and alignment between design, production, and logistics (Molavi & Barral, 2016; Pan, Pan, et al., 2023; Si et al., 2021). Within this context, procurement is conceptualized as a key enabler of integration rather than solely a contractual arrangement (Assaf et al., 2023; Charlson & Dimka, 2021; M. Tennakoon et al., 2025).

The aim of this study is to systematically synthesize procurement approaches in OSC and evaluate their performance in relation to key operational criteria. Specifically, the study aims to:

1. Identify and classify procurement models applied in OSC;
2. Evaluate their alignment with OSC requirements, including integration, coordination, and financial structuring;
3. Examine recurring procurement-related challenges and barriers; and

4. Identify research gaps and directions for developing procurement frameworks that support scalable OSC delivery.

To achieve this, a mixed-method systematic literature review was conducted following a PRISMA-based approach, supported by bibliometric analysis to identify research trends and thematic clusters. By positioning procurement as a structural mechanism that shapes integration, risk distribution, and coordination, this study contributes to a more comprehensive understanding of procurement in OSC systems. The findings provide practical insights for researchers, policymakers, and industry stakeholders seeking to align procurement strategies with the operational logic of OSC.

2 METHODOLOGY

This study adopts a systematic literature review supported by bibliometric and thematic analyses to examine procurement approaches in OSC.. Relevant peer-reviewed articles were retrieved from Scopus, Web of Science, and ScienceDirect using targeted keywords. After screening and removing duplicates, 30 studies were selected. Key data on procurement models, challenges, and benefits were extracted and analyzed using thematic coding, alongside a descriptive bibliometric analysis to identify publication trends and research focus areas. The overall research process is illustrated in Figure 1.

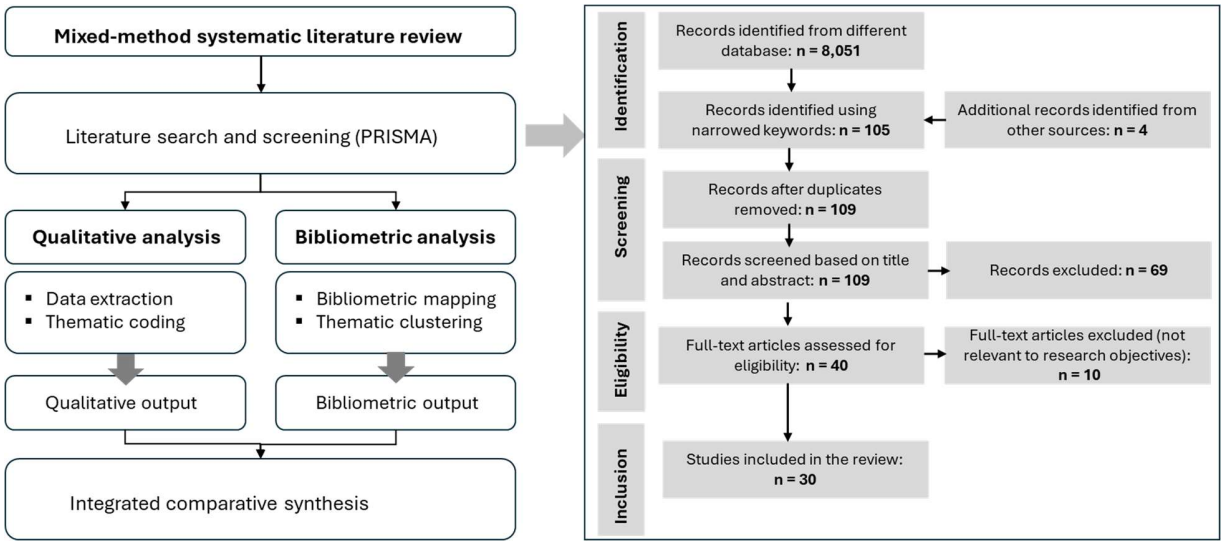

Figure 1: Methodological framework

3 BIBLIOMETRIC TRENDS IN OSC PROCUREMENT RESEARCH

The bibliometric review reveals a clear acceleration of procurement-focused OSC research after 2020. Earlier studies primarily examined technical and manufacturing aspects of modular construction, while procurement was treated as a secondary topic. Since 2020, research has increasingly framed procurement as a strategic enabler of industrialized construction performance. Leading contributors include the United Kingdom, China, Australia, and Canada. These regions share strong policy interest in modular construction, housing acceleration programs, and collaborative contracting reforms, Figure 2.

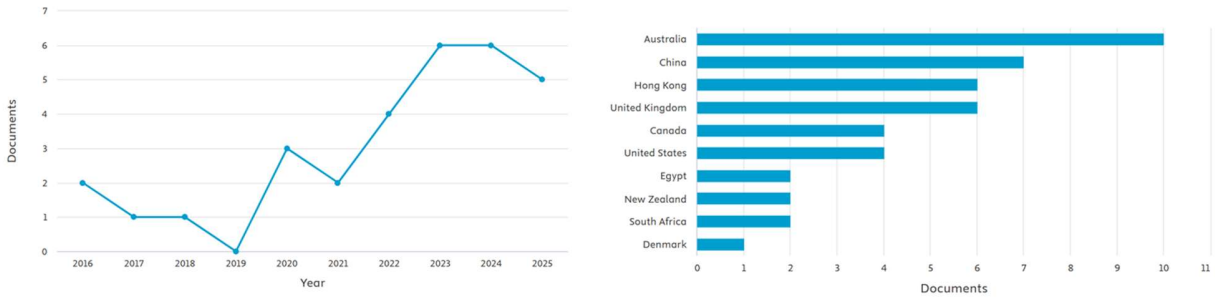

Figure 2: Bibliometric trends in OSC procurement research: (a) annual publication output (2016–2025) and (b) geographic distribution of peer-reviewed studies (n = 30)

Thematic clustering indicates five dominant research streams aligned with the proposed categorization: emerging procurement innovations, existing procurement models, procurement challenges and barriers, supply chain and operational considerations, and application contexts.

This classification is consistent with the bibliometric mapping results Figure 3, which highlight key clusters around off-site construction, procurement, supply chain management, and digitalization. Additional themes such as cash flow, blockchain, and sustainability further reflect emerging innovations and ongoing challenges.

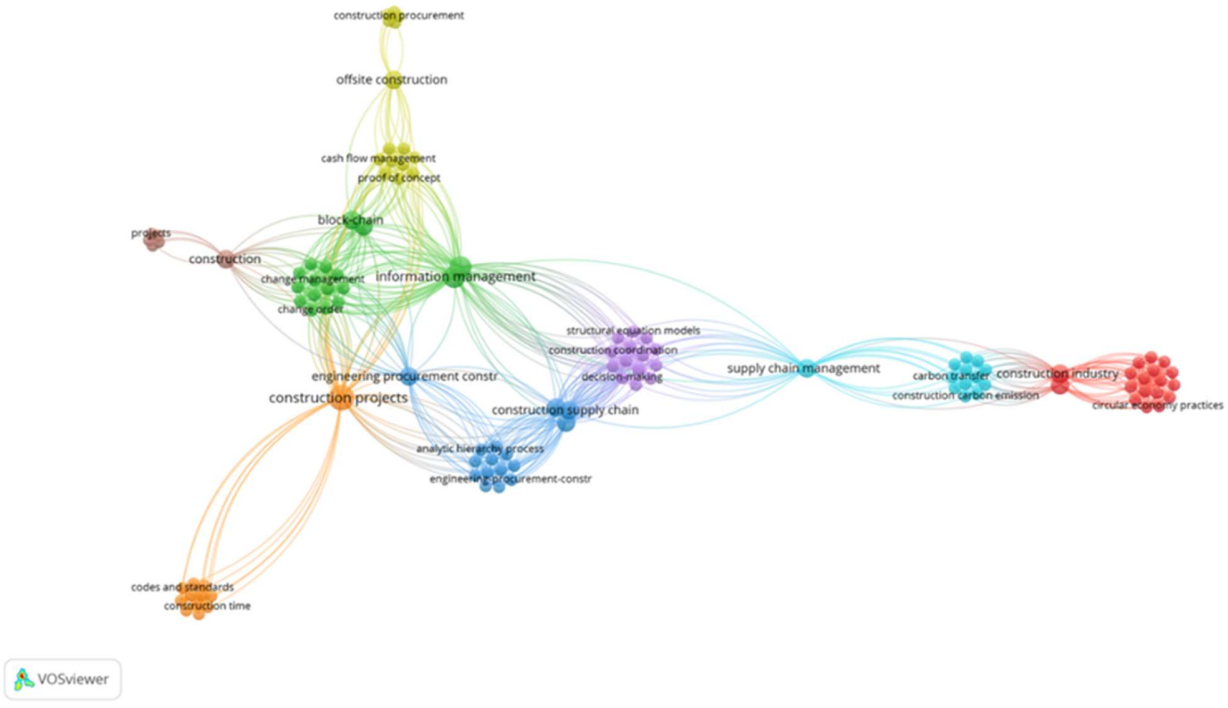

Figure 3: Keyword co-occurrence network of procurement research in OSC.

4 KEY ASPECTS OF PROCUREMENT IN OSC

Building on the preceding analysis, procurement in OSC can be understood through five interrelated themes. The following sections examine these themes in detail, as illustrated in Figure 4.

4.1 Emerging Procurement Innovations

Recent literature highlights a shift toward innovative procurement approaches designed to address the unique requirements of OSC. Unlike traditional procurement systems, these emerging approaches focus on improving decision-making, flexibility, and alignment with OSC processes (Assaf et al., 2023; Atiq-Ur-Rehman et al., 2026; Chen et al., 2023).

One key stream of innovation involves decision-support and optimization-based procurement tools. Studies such as Atiq-Ur-Rehman et al. (2025) introduce mixed-integer linear programming (MILP) models to optimize supplier selection and project planning, demonstrating significant improvements in cost efficiency and project performance. Similarly, Assaf et al. (2023) apply multi-criteria decision-making (MCDM) methods to support procurement method selection based on cost, quality, and risk considerations. Chen et al. (2023) further demonstrate that optimization-based procurement strategies significantly reduce cost and project duration through integrated decision-making.

Another area of innovation includes advanced procurement strategies and dynamic models, such as smart contracts and dynamic compensation mechanisms. These approaches aim to improve transparency, automate contractual processes, and better align financial incentives with production workflows (Assaf et al., 2025). Although still emerging, such models show strong potential for enhancing coordination and reducing inefficiencies in OSC projects.

Additionally, research explores new procurement approaches tailored to modular construction, emphasizing integrated decision-making across procurement, supply chain, and design (Molavi & Barral, 2016; Pan, Pan, et al., 2023). These approaches move beyond isolated decisions and treat procurement as a system-level function that influences the entire project lifecycle.

4.2 Existing Procurement Models

Existing procurement models form the foundation of project delivery in OSC, although their effectiveness varies depending on their level of integration and flexibility.

Traditional models such as Design–Bid–Build (DBB) are characterized by low early involvement, fragmented supply chains, and limited design–manufacturing integration(Charlson & Dimka, 2021; Finnie et al., 2018; Hu & Chong, 2022). Although they provide high-cost certainty through fixed pricing and late-stage payments, they are generally unsuitable for OSC(Alhawamdeh & Lee, 2025; T. M. M. P. Tennakoon et al., 2024). More integrated approaches, including Design–Build (DB), Progressive Design–Build, and Construction Management (CM/CMAR), enable earlier stakeholder engagement, improved coordination, and more flexible cash flow structures (Assaf et al., 2023; Hu & Chong, 2022). These models better support the alignment between design and manufacturing, making them more compatible with OSC.

Highly collaborative models such as Integrated Project Delivery (IPD) and alliance contracting provide the strongest alignment with OSC. They feature shared risk, transparent payment mechanisms, and fully integrated supply chains, enabling efficient prefabrication and industrialized construction (Husin & Aulia, 2022; T. M. M. P. Tennakoon et al., 2024). In contrast, Public–Private Partnerships (PPP/P3) and Engineering–Procurement–Construction (EPC) offer structured and centralized delivery but typically involve limited early manufacturer input and reduced flexibility, which can constrain their effectiveness in OSC contexts (M. Tennakoon et al., 2025).

4.3 Procurement challenges and barriers

Despite its critical role, procurement remains one of the main obstacles to the successful adoption of off-site construction (OSC). The literature consistently shows that procurement-related challenges are not isolated issues but interconnected problems affecting financial flows, contractual clarity, stakeholder coordination, and institutional readiness (T. M. M. P. Tennakoon et al., 2024).

One of the most significant barriers is the misalignment of financial structures, where OSC requires high upfront investment for manufacturing, while traditional payment systems are tied to on-site progress. This

mismatch creates cash flow constraints for suppliers and limits participation in modular projects. In addition, contractual and risk allocation issues are widely reported. Traditional contracts often fail to clearly define responsibilities among stakeholders, leading to disputes, inefficiencies, and increased uncertainty (M. Tennakoon et al., 2025). Another critical challenge is fragmentation and lack of coordination, where poor communication and limited trust between stakeholders reduce integration across the project lifecycle (Li et al., 2024a; Nesarnobari et al., 2025).

Finally, regulatory and industry-level limitations including lack of standardization, outdated policies, and low industry maturity, further constrain procurement effectiveness and slow OSC adoption (Akinradewo et al., 2023). The comparative performance of these procurement models is summarized in Table 1, which evaluates each model against key OSC operational criteria.

4.4 Supply Chain and Operational Considerations

In addition to strategic and contractual aspects, procurement in OSC must address a range of operational and supply chain realities that directly influence project execution. Unlike traditional construction, OSC depends on tightly coordinated workflows across manufacturing, transportation, and on-site assembly (Li et al., 2024b; Peiris et al., 2023). A key consideration is the capability and performance of manufacturers and suppliers, as procurement decisions must ensure alignment between production capacity and project requirements (Atiq-Ur-Rehman et al., 2026; Chen et al., 2023). Supplier reliability and productivity directly impact project timelines and cost efficiency.

Another important dimension is logistics and transportation management, where modules must be delivered in precise sequences. Inefficient logistics planning can result in delays, increased costs, and disruption of installation activities (Li et al., 2024b; Peiris et al., 2023). Procurement must also account for installation and on-site execution constraints, including sequencing, timing, and resource coordination (Ofori-Kuragu et al., 2022; Si et al., 2021). These operational factors require procurement strategies that go beyond contractual selection and consider execution feasibility.

Finally, risk management and stakeholder relationships play a crucial role. Procurement defines how risks are distributed and how effectively stakeholders such as owners, contractors, and suppliers collaborate throughout the project lifecycle (T. M. M. P. Tennakoon et al., 2024).

4.5 Application Contexts and Case Studies

The application of procurement models in OSC varies across different project types and contexts, reflecting the diversity of construction environments and requirements. Case studies demonstrate the use of procurement approaches in specific applications such as bathroom pods, housing projects, and hospital construction (Bekdik et al., n.d.; McCarney et al., 2023; Ofori-Kuragu et al., 2022). These studies provide practical insights into how procurement strategies perform under real-world conditions.

Additionally, procurement effectiveness varies across building typologies, including low-rise, mid-rise, and high-rise structures, where project complexity and logistical requirements differ significantly (Pan, Yang, et al., 2023). International comparisons also highlight variations in procurement practices across countries, reflecting differences in regulatory environments, industry maturity, and institutional frameworks (Agapiou, 2022).

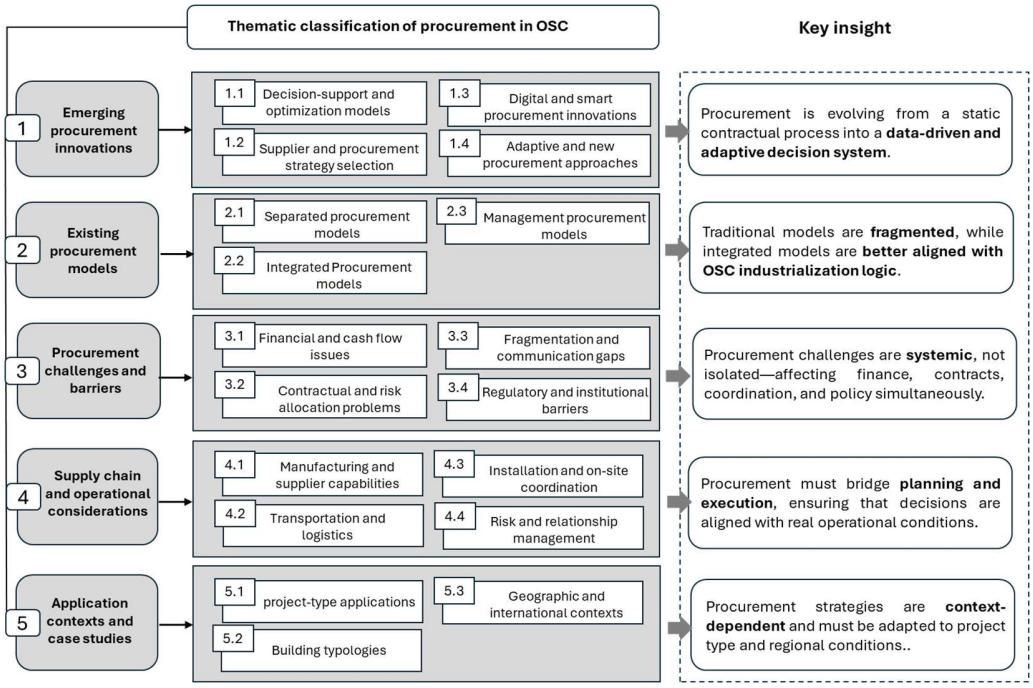

Figure 4: Classification of procurement literature in OSC.

5 PROCUREMENT MODELS AND OSC PERFORMANCE COMPARISON

To further examine procurement from a project structuring perspective, a comparison matrix was developed to evaluate the performance of different procurement models in relation to the operational requirements of OSC. While Section 5 highlighted the multiple roles of procurement, this section focuses specifically on how procurement models influence project structure and, consequently, their ability to support integrated and industrialized construction processes.

The matrix assesses each procurement model against key OSC performance criteria derived from the literature, including early manufacturer involvement, risk allocation, cash flow timing, design–manufacturing integration, and supply chain coordination. These criteria reflect not only contractual structure but also the broader capacity of procurement systems to support decision-making and enable effective coordination across the supply chain.

5.1 Development of the Procurement Evaluation Framework

The comparison matrix was developed through thematic synthesis of the reviewed studies. Procurement characteristics repeatedly identified in the literature were extracted and grouped into five evaluation dimensions:

1. Early manufacturer involvement;
2. Risk allocation structure;
3. Cash-flow timing and payment flexibility;
4. Design–manufacturing integration;
5. Supply chain coordination.

These dimensions were selected because they consistently emerged as critical enablers of OSC performance across the reviewed literature (Hu and Chong, 2022; Assaf et al., 2023; Tennakoon et al., 2025).

Procurement models were evaluated using an ordinal qualitative scale comprising Very Low, Low, Medium, High, and Very High. Ratings were assigned based on evidence reported in the reviewed studies regarding the extent to which each procurement model supports the five evaluation dimensions. Equal weighting was adopted for all criteria because the objective of the matrix was comparative synthesis rather than project-specific optimization.

5.2 Procurement Model and Comparison Matrix

Table 1: Comparative evaluation of procurement models against OSC operational criteria (adapted from Assaf et al., 2023; Hu and Chong, 2022; Tennakoon et al., 2024, 2025a, 2026; Husin and Aulia, 2022).

Procurement model	Early manufacturer involvement	Risk allocation	Cash flow timing	Design–manufacturing integration	Supply chain coordination	OSC suitability
Design–Bid–Build (DBB)	Low	Transferred to contractor	Late-stage payments	Limited	Fragmented	Low
Design–Build (DB)	Medium	Primarily with contractor	Progress-based payments	Moderate	Partially coordinated	Medium
Progressive Design–Build	High	Collaborative pricing evolution	Phased negotiation	Strong	Coordinated	High
Construction Management/ Construction Manager at Risk (CM/CMAR)	Medium - High	Shared with client (CMAR: partial risk transfer)	Flexible/phased	Moderate - Strong	Managed coordination	Medium - High
Integrated Project Delivery (IPD)	Very High	Shared risk/reward	Transparent and milestone-based	Very Strong	Highly integrated	Very High
Alliance Contracting	Very High	Collective risk-sharing	Open-book/ performance-based	Very Strong	Fully integrated	Very High
Public–Private Partnership (PPP/P3)	Medium	Transferred to private consortium	Long-term / lifecycle payments	Moderate	Structured coordination	Medium
EPC (Turnkey)	Low–Medium	Transferred to contractor	Milestone / lump sum payments	Strong (internal)	Centralized	Medium

5.3 Insights from the Comparison Matrix

The comparison matrix highlights that procurement effectiveness in OSC is strongly linked to the level of integration it enables across project stages (Tennakoon et al. 2026; Nesarnobari et al. 2025). Models that support early manufacturer involvement consistently demonstrate better alignment with manufacturing-driven workflows, allowing for improved coordination between design, production, and logistics (Molavi and

Barral 2016; Pan, Pan, and Yang 2023). It is important to distinguish procurement methods from contract pricing mechanisms such as lump sum, cost-plus, and unit price, which can be applied within different procurement strategies (Hu and Chong 2022; Agapiou 2022).

The analysis also shows that flexible financial structures, such as phased or open-book payment mechanisms, are more compatible with OSC than rigid, late-stage payment schemes (Tennakoon et al. 2026; Alhawamdeh and Lee 2024). These approaches facilitate earlier input from key stakeholders and support more efficient decision-making throughout the project lifecycle (Assaf et al. 2023; Chen et al. 2023). In addition, the findings indicate that collaborative risk allocation plays a critical role in enhancing project performance (Husin and Aulia 2022; Tennakoon et al. 2025). Rather than relying solely on risk transfer, models that promote shared responsibility contribute to greater transparency and reduced fragmentation within the supply chain (Nesarnobari et al. 2025; Li et al. 2024).

Overall, the matrix demonstrates that procurement models function as key enablers of integration and coordination, directly influencing the efficiency and effectiveness of OSC project delivery (Tennakoon et al. 2026; Alhawamdeh and Lee 2024).

6 CONCLUSION AND FUTURE WORK

This study examined procurement in OSC from an integration and supply chain perspective, highlighting its role as a key enabler of industrialized project delivery. The findings demonstrate that the effectiveness of procurement models in OSC is primarily determined by their ability to support early manufacturer involvement, coordinated workflows, and alignment between design, production, and logistics.

The comparative analysis shows that traditional procurement approaches, such as Design–Bid–Build, are poorly suited to OSC due to fragmented structures, delayed stakeholder engagement, and limited integration. In contrast, integrated and collaborative models—including Progressive Design-Build, Construction Management, Integrated Project Delivery (IPD), and Alliance contracting—provide significantly better alignment with OSC requirements by enabling shared risk structures, flexible financial mechanisms, and enhanced supply chain coordination.

The study also highlights that procurement should not be viewed solely as a contractual or financial arrangement, but as a strategic framework that shapes decision-making, integration, and overall project performance. In particular, flexible payment structures and collaborative risk allocation are critical for supporting the manufacturing-driven nature of OSC. Furthermore, it is important to distinguish procurement methods from contract pricing mechanisms, such as lump sum or cost-plus, which may be applied within different procurement models.

Overall, the results emphasize that selecting an appropriate procurement model is essential for achieving efficient and scalable OSC delivery. Future research should focus on validating the proposed comparison matrix through application to real-world case studies across different project types and geographic contexts. Such validation would enable testing of the relative impact of procurement criteria on project performance and provide empirical evidence to refine the matrix. Additionally, further work is needed to develop hybrid and context-specific procurement frameworks, supported by digital tools and policy adaptations, to enhance integration and performance in industrialized construction systems.

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