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YILDIZ TECHNICAL UNIVERSITY
GRADUATE SCHOOL OF SCIENCE AND ENGINEERING

COMPARATIVE ANALYSIS OF CONSTRUCTION PROJECT DELIVERY SYSTEMS IN ACHIEVING SUSTAINABLE DEVELOPMENT GOALS: A TOPSIS-BASED APPROACH

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A thesis submitted by Mulham MASRI in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE** is approved by the committee on 27.02.2025 in Department of Civil Engineering , Program of Civil Engineering English.

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Mulham MASRI

Signature

Dedicated to my family

and my best friend

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LIST OF SYMBOLS

C_i	Closeness Coefficient
S_i^+	Positive Ideal Solution Distance
S_i^-	Negative Ideal Solution Distance
w_i	Weight of the ith criterion
a_{ij}	Performance score of the jth alternative on the ith criterion
V^+	Ideal solution vector
V^-	Negative-ideal solution vector
n	Number of alternatives
m	Number of criteria
CR	Consistency Ratio in AHP

LIST OF ABBREVIATIONS

SDGs	Sustainable Development Goals
PDS	Project Delivery Systems
IPD	Integrated Project Delivery
DB	Design-Build
CMR	Construction Manager-at-Risk
DBB	Design-Bid-Build
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
AHP	Analytic Hierarchy Process
EPT	Entegre Proje Teslimi (Integrated Project Delivery in Turkish)
TY	Tasarım-Yapım (Design-Build in Turkish)
RİM	Riskli İnşaat Yöneticisi (Construction Manager-at-Risk in Turkish)
GIY	Geleneksel İhale Yöntemi (Design-Bid-Build in Turkish)
PMI	Project Management Institute
LEED	Leadership in Energy and Environmental Design
BIM	Building Information Modeling

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ABSTRACT

COMPARATIVE ANALYSIS OF CONSTRUCTION PROJECT DELIVERY SYSTEMS IN ACHIEVING SUSTAINABLE DEVELOPMENT GOALS: A TOPSIS-BASED APPROACH

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Program of Civil Engineering (English)

Master of Science Thesis

Supervisor: Prof. Dr. Aslı Pelin GÜRGÜN

The construction industry plays a pivotal role in achieving the Sustainable Development Goals (SDGs), but the effectiveness of different Project Delivery Systems (PDS) in promoting sustainability remains underexplored. This thesis evaluates the alignment of four major PDS—Design-Bid-Build (DBB), Design-Build (DB), Construction Manager-at-Risk (CMR), and Integrated Project Delivery (IPD)—with the SDGs using a Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) framework enhanced by Analytic Hierarchy Process (AHP) weighting. The study's aim was to identify which PDS best facilitates the integration of sustainability into construction projects, thus contributing to the SDGs.

Results from the TOPSIS analysis revealed that IPD ranked highest in terms of SDG alignment, followed by CMR, DB, and DBB. The superior performance of IPD is attributed to its highly collaborative nature, which integrates stakeholders throughout the project lifecycle, fostering innovative and sustainable practices. In contrast, DBB's segmented and traditional approach limited its effectiveness in

addressing sustainability criteria. The study provides a quantitative method for assessing PDS against sustainability criteria, offering valuable insights for industry stakeholders and policymakers.

This research contributes to the field by providing a systematic approach to evaluate the sustainability potential of PDS and suggests that adopting integrated project delivery methods can significantly enhance the construction industry's impact on sustainable development. Future research should focus on refining the evaluation criteria and applying this framework to specific types of projects to tailor recommendations for practice and policy adjustments.

Keywords: Sustainable Development Goals (SDGs), Project Delivery Systems (PDS), Integrated Project Delivery (IPD), Design-Build (DB), Construction Manager-at-Risk (CMR), Design-Bid-Build (DBB), TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), Analytic Hierarchy Process (AHP), Sustainability in Construction, Project Management

ÖZET

SÜRDÜRÜLEBİLİR KALKINMA AMAÇLARINA ULAŞMADA İNŞAAT PROJE TESLİM SİSTEMLERİNİN KARŞILAŞTIRMALI ANALİZİ: TOPSIS TABANLI BİR YAKLAŞIM

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İnşaat sektörü, Sürdürülebilir Kalkınma Hedefleri'ni (SKH) gerçekleştirmede kilit bir rol oynar, ancak farklı Proje Teslim Sistemlerinin (PTS) sürdürülebilirliği teşvik etmedeki etkinliği yeterince araştırılmamıştır. Bu tez, dört ana PTS—Geleneksel İhale Yöntemi (GIY), Tasarım-Yapım (TY), Riskli İnşaat Yöneticisi (RİM) ve Entegre Proje Teslimi (EPT)—arasında Sürdürülebilir Kalkınma Hedefleri ile uyumunu, Analitik Hiyerarşi Süreci (AHS) ağırlıklandırması ile güçlendirilmiş Ideal Çözüme Benzerlik için Tercih Sıralama Tekniği (TOPSIS) çerçevesi kullanarak değerlendirmektedir. Çalışmanın amacı, hangi PTS'nin inşaat projelerine sürdürülebilirlik entegrasyonunu en iyi şekilde kolaylaştırdığını belirlemek ve böylece SKH'ye katkıda bulunmaktır.

TOPSIS analiz sonuçları, EPT'nin SKH uyumu açısından en yüksek sıralamada olduğunu, ardından RİM, TY ve GIY'nin geldiğini ortaya koymuştur. EPT'nin üstün performansı, proje yaşam döngüsü boyunca tüm paydaşları entegre eden yüksek derecede işbirlikçi doğasına atfedilmektedir, bu da yenilikçi ve sürdürülebilir

uygulamaları teşvik etmektedir. Buna karşılık, GIY'nin bölümlenmiş ve geleneksel yaklaşımı, sürdürülebilirlik kriterlerini ele almadaki etkinliğini sınırlamıştır. Çalışma, PTS'leri sürdürülebilirlik kriterlerine göre değerlendirmek için nicel bir yöntem sağlamakta, endüstri paydaşları ve politika yapıcılar için değerli içgörüler sunmaktadır.

Bu araştırma, proje teslim yöntemlerinin inşaat sektöründe sürdürülebilir kalkınmayı nasıl etkilediğine dair bilgi birikimine önemli katkılarda bulunmakta ve entegre proje teslim yöntemlerinin benimsenmesinin inşaat sektörünün sürdürülebilir kalkınma üzerindeki etkisini önemli ölçüde artırabileceğini öne sürmektedir. Gelecekteki araştırmalar, bu çerçevenin değerlendirme kriterlerini geliştirmeye ve belirli türdeki projelere uygulamaya odaklanmalıdır.

Anahtar Kelimeler: Sürdürülebilir Kalkınma Hedefleri (SKH), Proje Teslim Sistemleri (PTS), Entegre Proje Teslimi (EPT), Tasarım-Yapım (TY), Riskli İnşaat Yöneticisi (RİM), Geleneksel İhale Yöntemi (GIY), TOPSIS (Ideal Çözüme Benzerlik için Tercih Sıralama Tekniği), Analitik Hiyerarşi Süreci (AHS), İnşaatta Sürdürülebilirlik, Proje Yönetimi

1
INTRODUCTION

1.1 Literature Review

1.1.1 Introduction

This literature review critically examines the integration of Project Delivery Systems (PDS) with Sustainable Development Goals (SDGs) within the construction industry. It provides a comprehensive overview of the existing body of knowledge, highlighting how various PDS contribute to or hinder sustainable construction practices. The review establishes a foundation for understanding the dynamic interplay between construction project delivery and sustainability goals, setting the stage for evaluating the effectiveness of different PDS in promoting sustainability.

1.1.2 Construction Industry and the SDGs

The construction industry plays a pivotal role in achieving the Sustainable Development Goals (SDGs) by addressing environmental, social, and economic dimensions of sustainability. It is responsible for a significant portion of global resource consumption, including 40 to 75 percent of materials extracted and 25 percent of global water use, as well as contributing to 36 percent of final energy use and 39 percent of CO2 emissions in 2017 [1]. The industry can drive the realization of the SDGs by integrating sustainable practices into project delivery processes, which include reducing waste, maximizing resource efficiency, and adopting circular economy principles[2]. The construction sector's activities impact nearly all 17 SDGs, with particular emphasis on sustainable cities and communities (SDG 11), climate action (SDG 13), clean water and sanitation (SDG 6), and responsible consumption and production (SDG 12)[2]. Furthermore, the construction industry is encouraged to align with the SDGs by focusing on the agenda's five Ps: people,

planet, prosperity, peace, and partnerships, which can help in creating synergies and managing trade-offs between different goals [3]. Sustainable construction practices are essential for balancing environmental, economic, and social solutions, and they require collaboration across the value chain to ensure that the SDGs are part of the early goal-setting in construction projects [4]. The industry's potential to contribute to the SDGs is also evident in its ability to create employment opportunities and improve infrastructure, which are crucial for achieving goals related to decent work and economic growth (SDG 8) and industry, innovation, and infrastructure (SDG 9)[3]. In developing countries, sustainable construction is seen as a means to address specific regional challenges, emphasizing the need for a dynamic balance between equity, prosperity, and ecological sustainability[5]. Overall, the construction industry is a key partner in the global effort to achieve sustainable development by 2030, requiring the involvement of governments and stakeholders to integrate sustainability into policies and practices[5].

1.1.3 Historical Context and Evolution of PDS

The historical context and evolution of project delivery systems (PDS) in the construction industry reflect a shift from traditional methods to more integrated and collaborative approaches. Initially, the industry relied heavily on the Design-Bid-Build (DBB) model, which emphasized competitive bidding and often resulted in adversarial relationships among stakeholders[6], [7] . Over time, the limitations of DBB, particularly in terms of cost overruns and schedule delays, prompted the exploration of alternative 0methods such as Design-Build (DB) and Construction Manager-at-Risk (CMAR), which offer varying degrees of integration and risk-sharing[8]. The introduction of Integrated Project Delivery (IPD) marked a significant evolution, focusing on relational contracts and collaborative environments to enhance project outcomes [9], [10]. IPD, along with alliancing, emerged as a response to the need for more synergy and shared objectives among project stakeholders, particularly in complex projects [10]. Despite the potential benefits, the adoption of IPD has been slow, primarily due to challenges in stakeholder collaboration and the need for gradual implementation strategies [9]. Recent studies suggest that the construction industry is increasingly recognizing the importance of digital integration, sustainability, and stakeholder well-being in selecting PDS, with advanced technologies like AI poised to further transform

decision-making processes [11], [12]. Comparative analyses have shown that IPD and similar collaborative models outperform traditional methods like DBB in key performance areas such as cost, schedule, and quality, encouraging a shift towards these modern approaches [13]. The evolution of PDS is thus characterized by a gradual transition towards methods that prioritize integration, collaboration, and adaptability to the changing demands of the construction industry [14].

1.1.4 PDS and Sustainability

In the construction industry, the selection of project delivery systems plays a crucial role in achieving sustainability goals, as these systems influence the integration, collaboration, and overall project management approach necessary for sustainable outcomes. Traditional delivery methods like Design-Bid-Build (DBB) are often inadequate for sustainable construction projects due to their limited capacity for integration and collaboration, which are essential for addressing the complex requirements of sustainability[15]. Alternative delivery methods such as Design-Build (DB) and Construction Management at Risk (CMR) are better suited to meet these needs, as they facilitate greater integration and collaboration among stakeholders [15]. The Envision sustainability rating system, when combined with alternative project delivery methods, can enhance the sustainability performance of infrastructure projects by promoting integrated design and stakeholder engagement [16]. Furthermore, the construction industry faces significant challenges in adopting sustainable practices, including a lack of awareness and understanding among key actors, inadequate legislation, and insufficient application of sustainability guidelines [17]. To overcome these barriers, it is essential to develop relevant selection criteria for project delivery methods that prioritize integration, green teams, and green liability, which are critical for the success of sustainable construction projects [18]. Additionally, the Industrialized Building System (IBS) offers a promising approach to improving sustainability in construction by enhancing site performance, reducing waste, and increasing efficiency, although its implementation is currently limited due to technological and labor constraints [19]. The integration of modern technologies, such as Big Data, can further enhance the efficiency and decision-making processes in construction projects, contributing to improved sustainability outcomes [12]. Overall, the adoption of sustainable project management practices, including resource optimization and rework reduction, can

significantly improve the social and environmental performance of construction companies, as evidenced by studies conducted in regions like Lagos State, Nigeria [20]. These practices are interrelated and mutually reinforcing, highlighting the importance of a comprehensive approach to project delivery systems in achieving sustainability in the construction industry.

1.2 Objectives of the Thesis

The primary objective of this thesis is to evaluate and compare the effectiveness of various Project Delivery Systems (PDS) in promoting sustainability within the construction industry, aligned with the Sustainable Development Goals (SDGs). This analysis aims to provide an understanding of how different PDS can facilitate or hinder the achievement of sustainability targets.

1.3 Hypothesis

It is hypothesized that Integrated Project Delivery (IPD) and Design-Build (DB) will significantly outperform Design-Bid-Build (DBB) and Construction Management at Risk (CMR) in contributing to the achievement of Sustainable Development Goals (SDGs). This expected performance difference is primarily due to the higher levels of stakeholder integration and collaboration inherent in IPD and DB systems [21]. IPD, with its fully integrated, multi-disciplinary team approach from project inception to completion, facilitates comprehensive stakeholder engagement, which is crucial for incorporating sustainable design and construction practices effectively. Similarly, the Design-Build framework, by combining design and construction phases under a single contract, promotes a unified workflow that enhances decision-making efficiency and responsiveness to sustainability criteria [22]. These systems are predicted to be more adept at addressing complex sustainability challenges such as reducing environmental impact, optimizing resource use, and enhancing community well-being. In contrast, the more segmented and phase-oriented approaches of DBB and CMR, though well-established, typically involve less collaborative stakeholder engagement, which may limit their ability to effectively implement and innovate on sustainability objectives across all project stages [23]. Therefore, this thesis will explore the extent to which the collaborative frameworks of IPD and DB lead to superior

sustainability outcomes compared to the more traditional approaches of DBB and CMR

1.4 Problem Statement

In the quest for sustainable solutions within the construction industry, practitioners and project owners often prioritize technical solutions such as implementing solar systems, grey water recycling, waste reduction, and improved insulation [24]. While these practices are beneficial, they typically focus on integrating specific technologies or practices without considering the foundational influence of the Project Delivery System (PDS) used. This approach can overlook critical elements such as innovation, collaboration, and early stakeholder involvement, which are crucial for achieving sustainability comprehensively and effectively[25].

Current practices in the industry show a tendency to add sustainable technologies to projects irrespective of the chosen PDS, underestimating the significance of selecting a PDS that inherently supports sustainable outcomes from the project's inception [26]. This oversight can lead to suboptimal integration of sustainability goals, particularly the broader objectives outlined in the Sustainable Development Goals (SDGs), which require a holistic approach encompassing environmental, economic, and social dimensions[27].

The existing literature and industry practices reveal a gap: there is no comprehensive evaluation that guides stakeholders in selecting a PDS that best aligns with and supports the achievement of SDGs. This lack of guidance can hinder the construction industry's potential to contribute effectively to global sustainability targets.

This thesis contends that the initial selection of an appropriate PDS is critical for the effective integration of sustainable practices. By evaluating and ranking the major PDS in terms of their capacity to support SDGs, this research aims to address this gap. The goal is to provide a systematic framework that assists industry stakeholders in making informed decisions about PDS selection, ensuring that sustainability is embedded at the core of project delivery processes. This approach not only enhances the potential for achieving specific technical sustainability

outcomes but also promotes a culture of sustainability that permeates all aspects of a construction project.

1.5 Research Questions

The primary goal of this thesis is to ascertain which Project Delivery Systems best support the achievement of Sustainable Development Goals within the construction industry. The research questions are designed to explore the effectiveness of these systems in facilitating sustainable practices and to guide the selection process for stakeholders. The following key question will structure the inquiry:

Which Project Delivery System is most effective in achieving the Sustainable Development Goals within the construction industry?

1.6 Research Significance

The significance of this research stems from an extensive review of literature, indicating a critical gap in the systematic evaluation of Project Delivery Systems (PDS) against Sustainable Development Goals (SDGs). Studies such as those by Gunhan [28], who analyzed sustainable building practices from builders' perspectives, and Mollaoglu-Korkmaz et al. [29], who examined the influence of project delivery methods on sustainable outcomes, have laid foundational insights. Yet, there is a substantial need for a consolidated approach that ranks these systems for their effectiveness in achieving SDGs.

Research by Raouf et al. [30] and Ahmad and Aibinu [31] explores green building project outcomes and their relationship to various PDS, highlighting the complexity of integrating sustainability. However, despite these extensive analyses, few have offered a comparative ranking focused explicitly on SDGs as noted by Ahmed and El-Sayegh [18], who discuss the criteria for selecting PDS in sustainable construction without a definitive conclusion on their relative effectiveness.

The need for a nuanced evaluation is further supported by works like those of Franz et al. [21], who emphasize the impact of team integration on project delivery performance, and Ibbs and Chih [32], who discuss alternative methods for selecting an appropriate PDS. El Asmar et al. [33], Ibrahim and Hanna [34], and Franz et al.

[35] contribute significantly to understanding PDS performance but do not anchor their analyses firmly within the framework of SDGs.

Moreover, specific PDS and technologies linked to sustainability, such as those discussed by Datta et al. [36] and Hasan et al. [37], often do not fully account for the overarching goals of SDGs. This disjointed approach is prevalent in studies focused on particular contexts or perspectives on sustainability, such as the works by Xia et al. [38] on green design-build projects and Maslova [39] on public-private partnerships aimed at achieving SDGs.

By integrating methodologies like TOPSIS and AHP, this thesis aims to fill these gaps by providing a clear, ranked evaluation of PDS in terms of their capacity to support SDGs. This research will offer construction industry stakeholders actionable insights for selecting PDS that align with sustainable development objectives, thereby contributing to broader goals of sustainable construction practices. The pioneering nature of this study in explicitly linking PDS selection with SDG achievement has the potential to transform project management practices towards more sustainable outcomes, addressing both industry needs and academic inquiry.

1.7 Methodology

The methodology for this research is designed to evaluate and rank project delivery systems (PDSs) by their potential to contribute to the achievement of Sustainable Development Goals (SDGs). To achieve this, we have adopted the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), a Multi-Criteria Decision-Making (MCDM) tool that systematically evaluates alternatives against a set of criteria. The following subsections outline the essential components and processes involved in applying TOPSIS: alternatives, criteria, criteria weighting, and matrix input.

1.7.1 Alternatives

The alternatives represent the project delivery systems selected for evaluation. After a thorough review of the literature and industry practices, we identified four PDSs that are widely used and represent a range of traditional and integrated approaches:

Design-Bid-Build (DBB): The most conventional and widely used PDS, characterized by its sequential process where design and construction are contracted separately[40].

Design-Build (DB): An enhanced traditional system that integrates design and construction under a single contract to improve efficiency and reduce project timelines[41].

Construction Manager at Risk (CMR): A collaborative system where a construction manager provides pre-construction services and assumes financial risk for the project's construction phase[8].

Integrated Project Delivery (IPD): A modern, collaborative system that aligns the interests of all stakeholders by integrating processes and responsibilities to optimize project outcomes[42].

While other delivery systems, such as Integrated Design Process (IDP) and Integrated Design Delivery Solutions (IDDS), exist, they share fundamental similarities with IPD. Given their overlapping principles, IPD was selected to represent integrated systems to maintain clarity and avoid redundancy[43].

1.7.2 Criteria

The evaluation criteria were derived from key performance indicators (KPIs) relevant to the construction industry’s contribution to the SDGs. These KPIs were categorized under five primary categories, as illustrated in Table 1.1. The rationale for selecting these criteria and their alignment with the SDGs is further detailed in Chapter 4. By assessing the performance of each alternative against these criteria, the methodology provides insights into their potential contributions to achieving SDGs [44].

1.7.3 Criteria Weighting

To assign weights to the selected criteria, we employed the Analytic Hierarchy Process (AHP), another MCDM method. AHP facilitates the prioritization of criteria by capturing expert judgments through pairwise comparisons. This ensures that the relative importance of each criterion reflects the perspectives of industry professionals and researchers [45].

1.7.4 Matrix Input

The input for the TOPSIS matrix was gathered through Key Informant Interviews (KIIs) with subject matter experts [46]. To facilitate these interviews and ensure clarity for respondents, the matrices were converted into Google Forms designed as scaled questions. The questions used a five-point Likert scale, where 1 represented the lowest level of agreement or performance, and 5 represented the highest. This approach streamlined data collection and ensured consistency in responses[47].

1.7.5 Calculation Process

The data from the Key Informant Interviews (KIIs) were aggregated into a unified decision matrix using the arithmetic mean for the TOPSIS analysis. Conversely, for the Analytic Hierarchy Process (AHP), the decision matrix was developed through a collective group decision-making process, culminating in the pairwise comparisons matrix. This matrix was then used to derive criteria weights. Subsequently, these weights were applied within the TOPSIS methodology to assess the alternatives against the defined criteria, following a series of defined steps in the TOPSIS process.

Normalization of the Decision Matrix: Each value in the matrix was normalized to account for varying scales of measurement [48].

Weight Application: The normalized values were weighted using the criteria weights derived from AHP.

Determination of Ideal and Negative-Ideal Solutions: The ideal solution (best values) and negative-ideal solution (worst values) were identified for each criterion.

Distance Calculation: The Euclidean distance of each alternative from the ideal and negative-ideal solutions was computed.

Calculation of Relative Closeness: The relative closeness of each alternative to the ideal solution was calculated, providing a ranking of the alternatives.

This systematic approach ensured that the evaluation process was transparent, consistent, and aligned with the objectives of the study. The final rankings provided actionable insights into the potential of each PDS to contribute to the SDGs, offering a valuable decision-making tool for stakeholders in the construction industry.

1.8 Thesis Structure

The thesis is structured to comprehensively evaluate Project Delivery Systems (PDS) in relation to Sustainable Development Goals (SDGs) within the construction industry. Chapter 1: Introduction outlines the research context, objectives, hypothesis, problem statement, and significance, leading into a detailed literature review that sets the stage for the study. It also breaks down the research methodology including the evaluation criteria and the TOPSIS calculation process. Chapter 2: Sustainable Development Goals and the Construction Industry examines the role of the construction sector in achieving SDGs, highlighting key goals relevant to the industry and the challenges and opportunities present. Chapter 3: Project Delivery Systems analyzes various systems such as Design-Bid-Build, Design-Build, and Construction Management at Risk, discussing their advantages, limitations, and sustainability implications. Chapter 4: Research Methodology details the research design and methodologies used, including AHP and TOPSIS, for data collection and analysis. Chapter 5: Results presents the findings from the TOPSIS analysis, ranking the PDS and their performance against individual criteria. Chapter 6: Discussion interprets these results in relation to the research questions, discussing their implications for industry practices and policy. Chapter 7: Conclusions and Recommendations summarizes the findings and outlines recommendations for stakeholders and suggestions for future research.

2
SDGs AND CONSTRUCTION INDUSTRY

2.1 Introduction

The Sustainable Development Goals (SDGs), established by the United Nations in 2015, present a global blueprint for dignity, peace, and prosperity for the planet, now and in the future [49]. These goals (SDGs) are designed to address the global challenges we face, including those related to poverty, inequality, climate change, environmental degradation, peace, and justice [50].Among the various industries impacted by and pivotal to the achievement of these goals, the construction industry plays a significant role [51]. As one of the largest sectors globally, construction not only significantly impacts the economy but also has profound implications for social and environmental outcomes [52].

The purpose of this chapter is to explore the intersection of the construction industry with the Sustainable Development Goals. It aims to delineate the industry's potential to either propel or impede progress towards these ambitious goals. By dissecting the role that construction plays in achieving the SDGs, this discussion sets the groundwork for understanding how integrated and sustainable project delivery methods can enhance industry alignment with these global objectives.

The construction industry is uniquely positioned to contribute to the SDGs due to its extensive reach and impact [53]. From the development of infrastructure that stimulates economic growth and job creation to the enhancement of energy efficiency in buildings that contributes to sustainability, the construction sector's influence is far-reaching. However, this influence brings with it a responsibility to operate sustainably, as the industry is also a significant consumer of global resources and a major generator of waste [54].

Therefore, this chapter will provide context on the global push for sustainability within the framework of the SDGs and discuss the pivotal role that the construction industry plays in this scenario. By focusing on the construction sector, we can uncover both the challenges and opportunities that lie in aligning construction practices with global sustainability goals, thereby fostering a deeper understanding of the path forward towards a more sustainable future.

2.2 The Role of the Construction Industry in Achieving SDGs

The construction industry profoundly impacts several Sustainable Development Goals (SDGs), acting as a fundamental driver for achieving global sustainability objectives. This sector directly contributes to SDG 9 (Industry, Innovation, and Infrastructure) by building robust and resilient infrastructure that supports economic development and human well-being. It also plays a critical role in SDG 11 (Sustainable Cities and Communities) by constructing sustainable, safe, and inclusive urban environments. These efforts include the development of affordable and sustainable housing, enhancing public transport systems, and creating green public spaces, which are essential for sustainable urban development[2].

Indirectly, the industry impacts SDG 8 (Decent Work and Economic Growth) by generating employment and driving economic growth through large-scale projects that require extensive manpower and materials. This employment generation spans from onsite construction work to offsite manufacturing jobs, contributing to broader economic stability and growth[55]. Furthermore, the industry's advancements in incorporating sustainable practices contribute significantly to SDG 13 (Climate Action) by implementing construction methods and materials that reduce carbon emissions and improve energy efficiency [56].

2.3 Key SDGs Relevant to Construction

SDG 11 (Sustainable Cities and Communities) is directly relevant to the construction industry as it seeks to make cities and human settlements inclusive, safe, resilient, and sustainable. The construction sector enhances the sustainability of urban areas by integrating green building technologies and improving infrastructure, which helps to manage urban sprawl and reduce the environmental impact of cities [3].

The industry's role in promoting SDG 12 (Responsible Consumption and Production) is evidenced by its increasing adoption of sustainable practices such as recycling building materials, utilizing renewable energy resources, and reducing overall waste during the construction process. These practices are essential for minimizing the environmental footprint of building projects and promoting long-term sustainability in construction practices [2].

Additionally, the construction industry is instrumental in advancing SDG 9 (Industry, Innovation, and Infrastructure) by fostering innovation through the integration of new technologies that enhance building efficiency and resilience. These innovations include the development of smart building solutions and the use of sustainable materials that are less harmful to the environment [55].

By focusing on these SDGs, the construction industry not only helps to address specific global challenges but also sets a precedent for other sectors to follow in terms of sustainability and innovation. The industry's broad reach and impact on these goals highlight its crucial role in not only shaping the physical environment but also in influencing broader socio-economic and environmental outcomes.

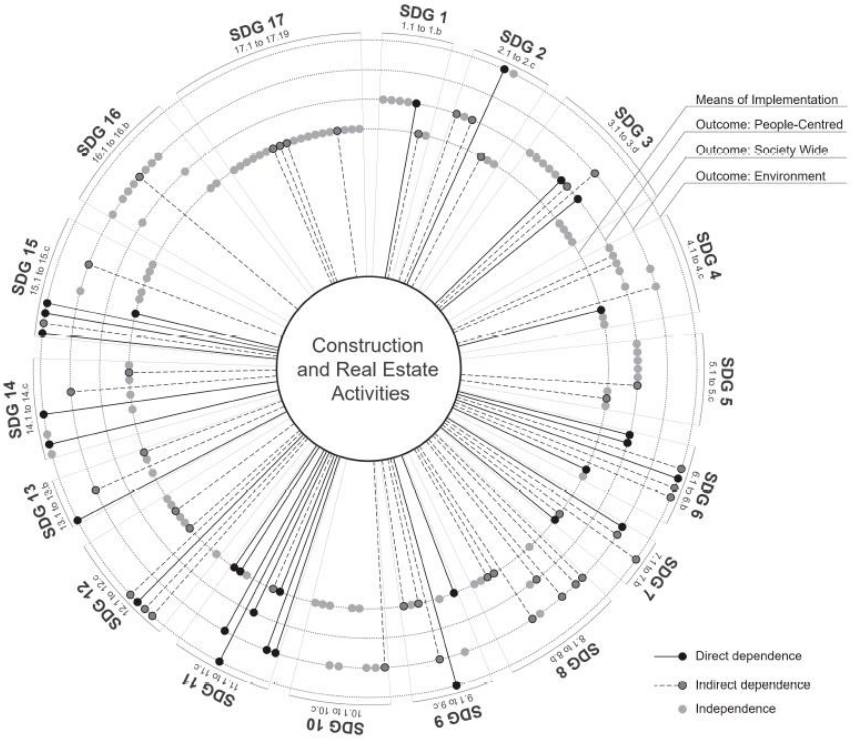


Figure 2.1 The dependency of the SDGs on the Construction activities [3]

2.4 Challenges in Aligning Construction Practices with SDGs

Aligning construction practices with the Sustainable Development Goals (SDGs) presents several challenges, as highlighted by various studies including high costs, lack of standardized frameworks, insufficient knowledge among stakeholders, and significant environmental impacts. Financial barriers, resistance to change, and low consumer demand for sustainable buildings further impede progress, highlighting the complex barriers to integrating SDGs into construction practices. One significant challenge is the high cost associated with sustainable construction practices, particularly in developing countries, where the focus often remains on cost rather than on growth accelerators like policy instruments that could facilitate Green Building (GB) development and SDG achievement [57]. Additionally, the construction industry faces a lack of unified evaluation frameworks and measurable benchmarks, which complicates the integration of sustainable design principles and the SDGs into construction projects [58], [59]. In Denmark, for instance, the integration of SDGs in construction projects is hindered by the absence of local indicators and tools to support implementation, as well as a general lack of knowledge about the SDGs among building owners [60]. Furthermore, the construction sector's significant environmental impact necessitates the adoption of practices that reduce waste and promote resource efficiency, yet this requires substantial organizational learning and policy formulation, which are not yet fully realized [61], [62]. In Brazil, while there are efforts to align construction practices with the SDGs, challenges remain in promoting sustainability-focused education and community projects, which are crucial for achieving goals like eradicating poverty and ensuring clean energy access [63]. The Danish case study also reveals that SDGs are not a primary driver in decision-making processes due to the lack of measurability and benchmarking, which further complicates their implementation [59]. Overall, the construction industry must overcome these challenges by developing new tools, methods, and policies that support the practical application of the SDGs, alongside fostering a deeper understanding and commitment to sustainable practices across all stakeholders [60]. In many regions, existing regulations and policies may not sufficiently support or incentivize sustainable construction practices. Lack of government support and incentives can slow down the adoption of green technologies and sustainable practices [64]. Achieving

sustainability in construction often requires a sustainable supply chain. However, ensuring that all materials and practices along the supply chain meet sustainability criteria can be challenging due to lack of control, transparency, and cooperation among suppliers [65]. Access to financing for sustainable projects can be a significant barrier, particularly for large-scale projects. Banks and financial institutions may be hesitant to fund projects that incorporate unproven or risky sustainable technologies [66]. Changing the mindset and behaviors of those involved in the construction industry—from developers to contractors to end-users—towards more sustainable practices can be difficult. Traditional practices are deeply ingrained, and there is often resistance to change [67]. Consumer demand for sustainable buildings, while growing, is still not at a level that compels the industry to change universally. Market dynamics play a crucial role, and without strong consumer demand, the shift towards sustainability can be slow [68].

2.5 Opportunities for Construction in Promoting Sustainability

The construction industry holds significant potential to advance the United Nations Sustainable Development Goals (SDGs) through various strategic opportunities. One of the primary avenues is the integration of sustainable practices, such as promoting sustainability-focused events, education, and community projects, which align with several SDGs, including eradicating poverty (SDG 1), promoting inclusive education (SDG 4), and ensuring access to clean water and energy (SDGs 6 and 7)[63]. Organizational learning and efficient resource management are also crucial, as they enable construction firms to adopt sustainable practices and reduce waste, thereby contributing to the realization of the SDGs [61]. Lean construction principles further enhance this by focusing on reducing non-value-adding activities and continuous improvement, which are linked to economic, environmental, and social factors, thus supporting goals like clean water and sanitation, clean energy, and sustainable cities (SDGs 6, 7, and 11) [37]. The construction sector can also leverage digitalization and automation, as seen in the Construction 4.0 era, to innovate and improve infrastructure, aligning with SDG 9 (Industry Innovation & Infrastructure) [69]. Moreover, construction procurement and social procurement strategies can drive social innovation, reduce poverty, and promote economic growth, directly impacting SDGs 1 and 8, and indirectly influencing health and

well-being (SDG 3)[70], [71]. The industry's role is further emphasized by its potential to influence nearly all SDGs, with significant contributions to sustainable cities, climate action, and responsible consumption (SDGs 11, 13, and 12)[2]. However, to avoid "greenwashing," it is essential for the industry to adopt robust SDG assessment frameworks that align with climate targets and consider the entire value chain, ensuring genuine progress towards sustainability [72]. Overall, by aligning business strategies with the SDGs and fostering partnerships, the construction industry can significantly contribute to the 2030 Agenda for Sustainable Development [3], [62].

3
PROJECT DELIVERY SYSTEMS

3.1 Introduction

This chapter explores the various Project Delivery Systems (PDS) utilized in the construction industry, focusing on how these systems facilitate or hinder the achievement of Sustainable Development Goals (SDGs). A PDS in the construction sector is defined as the organizational and procedural framework used to manage, design, construct, and deliver a building or facility to its owner. It encompasses the contractual relationships, administrative processes, and the sequence of activities from project inception to completion [73]. The choice of a PDS significantly influences the project's success, affecting its quality, timeliness, cost, and particularly its alignment with sustainability goals [74].

Project delivery systems play a crucial role in aligning construction projects with the SDGs by integrating sustainability into their core processes [75]. Systems such as Design-Build (DB) and Construction Management at Risk (CMR) are known for their high levels of integration, which are essential for optimizing sustainability outcomes [76], [77]. This integration facilitates interdisciplinary interactions that are necessary for addressing complex requirements of sustainable projects, such as energy efficiency and resource management [18]. Moreover, the use of technologies like Building Information Modeling (BIM) within these systems enhances the efficiency of project lifecycles and supports sustainable practices by enabling sophisticated energy simulations and life-cycle analyses [30]. The choice of a PDS also impacts the economic, social, and environmental pillars of sustainability, which are central to the SDGs. For example, methods like DB are associated with faster delivery speeds and better cost control, which can contribute to economic sustainability by reducing project costs and timelines[78].

Additionally, early involvement of contractors and continuous communication, as emphasized in Integrated Project Delivery (IPD) methods, help mitigate design and financial challenges, thereby supporting the social and environmental aspects of sustainability by ensuring projects meet their green goals efficiently [18]. Furthermore, the assignment of green responsibilities and liabilities within PDS ensures accountability and commitment to sustainability targets, aligning with the SDGs' emphasis on responsible consumption and production [18], [76].

Overall, the strategic selection and implementation of PDS can significantly influence the achievement of the SDGs by embedding sustainability into the project's lifecycle, from planning and design to construction and operation, thereby ensuring that construction projects contribute positively to sustainable development.

3.2 Design-Bid-Build

3.2.1 Overview

Design-Bid-Build (DBB) is a traditional project delivery method that has been widely used in both public and private sectors since the late 19th century. It involves two separate contracts: one for design and another for construction, typically awarded to the lowest bidder, which is perceived as providing the best financial deal for project owners [79]. Despite its long-standing use, DBB has several inherent disadvantages, particularly in terms of fostering collaborative partnerships among stakeholders, which can lead to project inefficiencies and increased risks [80]. The competitive nature of DBB often results in adversarial relationships between owners, contractors, and designers, which can hinder project performance and sustainability [80]. Moreover, DBB projects are prone to cost overruns due to fixed construction costs at contract award and the sequential nature of design and construction, which can lead to design errors and change orders [81]. To address these challenges, variations of DBB, such as DBB Best Value and Design Sequencing, have been developed to incorporate contractor input earlier in the process and evaluate past performance, thereby enhancing project outcomes [82]. Additionally, the integration of lean management tools, like the Last Planner System, has been suggested to improve communication and collaboration within DBB projects, potentially mitigating some of its negative effects [83]. Despite some

disadvantages, DBB remains prevalent, particularly in regions like Germany and the UK, due to its familiarity and established legal frameworks [83]. However, the ongoing evolution of project delivery methods continues to challenge the dominance of DBB, encouraging stakeholders to consider more collaborative and efficient alternatives for future projects.

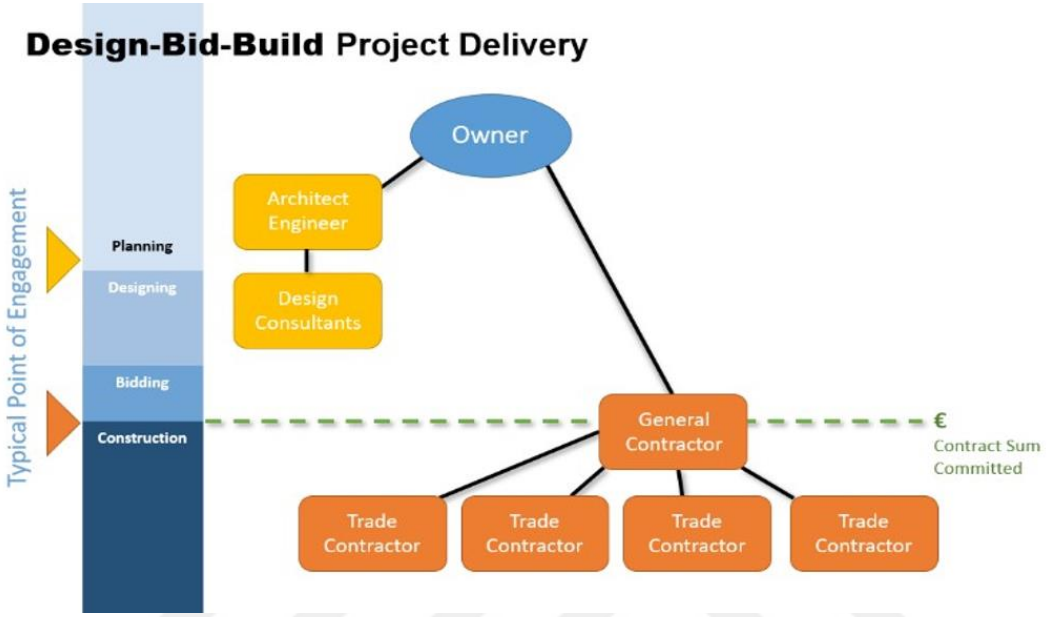


Figure 3.1 DBB Project Delivery. Source (DB Institute of America)

3.2.2 Advantages

Design-Bid-Build (DBB) is a traditional project delivery method that offers several advantages, particularly in terms of cost management and procurement transparency. One of the primary benefits of DBB is its ability to provide owners with the best financial deal through a competitive bidding process, where the lowest priced bidder is typically selected, thus helping to meet budget constraints [79]. This method is especially advantageous in public projects where transparency and fairness in contractor selection are paramount. Additionally, DBB allows for a clear separation of design and construction phases, which can lead to more detailed and complete design documents before construction begins, potentially reducing the risk of costly changes during the construction phase[79]. While DBB is often critiqued for its slower delivery speed compared to Design-Build (DB), it remains a preferred choice for projects where cost certainty and design quality are prioritized over speed [84]. Furthermore, variations of DBB, such as DBB Best Value (DBB-BV), incorporate additional evaluation criteria beyond cost, such as

contractor past performance, which can enhance project quality and performance [85]. These variations allow for a more nuanced selection process that can lead to better project outcomes, although they are less commonly used compared to traditional low-bid DBB [86]. Despite the growing popularity of alternative methods like DB, DBB continues to be a viable option for projects where its specific advantages align with the project goals and constraints.

3.2.3 Limitations

The Design Bid Build (DBB) procurement method faces several limitations when considering sustainability, primarily due to its traditional structure and focus on cost and time efficiency, which often sidelines environmental and social goals. The DBB approach typically separates the design and construction phases, which can lead to a lack of integration and communication between designers and builders, ultimately hindering the incorporation of sustainable practices throughout the project lifecycle [87]. This separation can result in missed opportunities for implementing sustainable design strategies that require early collaboration and integration, such as life cycle cost analysis and energy modeling, which are crucial for achieving long-term sustainability goals [23]. Furthermore, the DBB method often prioritizes initial cost savings over long-term environmental benefits, making it challenging to justify the upfront investment required for sustainable materials and technologies [88]. Additionally, the DBB method's rigid structure can impede the flexibility needed to adapt to innovative sustainable practices, such as the use of recycled materials and the implementation of circular economy principles, which are increasingly recognized as essential for reducing environmental impact [89]. Overall, while DBB remains a prevalent procurement method, its limitations in addressing sustainability highlight the need for more integrated and flexible approaches that prioritize environmental and social considerations alongside economic objectives.

3.3 Design-Build

3.3.1 Overview

The Design-Build (DB) project delivery method is increasingly recognized for its effectiveness in various sectors, including commercial interior design, civil aviation

infrastructure, and transportation projects. This method integrates design and construction services under a single contract, providing a streamlined process that can lead to improved project timelines, cost efficiency, and quality outcomes. In the context of commercial interior design and fit-out projects in New Zealand, the DB method has been found to enhance project delivery by aligning with client satisfaction and project objectives, such as cost and quality, more effectively than traditional methods [90]. Similarly, in China's civil aviation sector, the DB method has been adopted to address the complexities and rapid development needs of airport projects, demonstrating superior performance with a median schedule change of 22% and no cost change in completed projects [91]. The method's inherent advantage lies in its single-source responsibility, which simplifies communication and coordination, thus reducing potential conflicts and delays [92]. Furthermore, the DB method has shown long-term performance benefits in road pavement projects in the U.S., extending pavement life by an equivalent of eight years compared to traditional methods, which translates into significant lifecycle cost savings [93]. Despite these advantages, the DB method requires careful consideration of project-specific factors to ensure successful implementation, as highlighted in studies on progressive design-build (PDB), which emphasize the importance of early and ongoing owner involvement [94]. Overall, the DB method's ability to integrate design and construction phases under one contract makes it a compelling choice for projects requiring efficiency and adaptability, although it necessitates a thorough understanding of project requirements and stakeholder engagement to maximize its benefits [8].

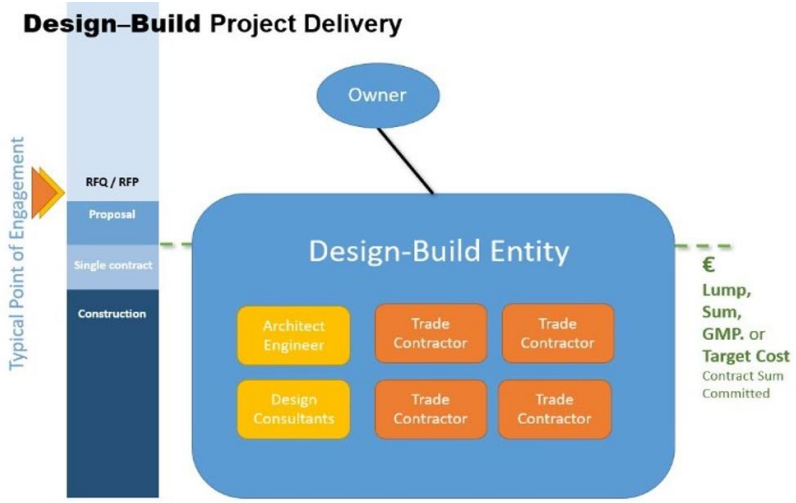


Figure 3.2 DB Project Delivery. Source (DB Institute of America)

3.3.2 Advantages

The Design-Build (DB) approach in construction projects offers several primary advantages, particularly in terms of cost efficiency, time savings, and project quality. Studies have consistently shown that DB outperforms the traditional Design-Bid-Build (DBB) method in reducing cost and schedule growth, as well as in accelerating delivery speed, all while maintaining similar quality standards [84]. In the context of the Brazilian public sector, the DB method is recognized for its streamlined process, as it consolidates design and construction under a single contract, which can lead to more efficient project execution and reduced administrative burdens [95]. Furthermore, empirical evidence from a large sample of DB projects in the United States indicates that over 75% of these projects are completed on time or ahead of schedule, although the cost-saving advantage remains less certain due to frequent cost overruns [96]. In Texas, the DB method has been a preferred choice for transportation projects, primarily due to its potential to reduce project duration and costs compared to traditional methods. Additionally, in Air Force military construction projects, the DB approach has demonstrated superior performance in terms of cost growth and the number of modifications required, making it particularly suitable for a variety of facility types [97]. Overall, the DB method's integration of design and construction phases under a single contract facilitates better coordination, potentially leading to enhanced project outcomes across different sectors and project types.

3.3.3 Limitations

The Design-Build approach in construction projects presents several limitations in achieving the Sustainable Development Goals (SDGs), primarily due to challenges in integration, measurement, and collaboration. One significant limitation is the lack of comprehensive integration of SDGs into construction practices, as many projects fail to prioritize these goals in decision-making processes, often due to the absence of measurable benchmarks and clear guidelines for implementation [59]. Additionally, the construction industry struggles with aligning current practices with the SDGs, which hinders the development of innovative methodologies specifically aimed at achieving these targets [98]. The industry's focus on competitive advantage over collaboration further exacerbates this issue, as contractors are often reluctant to share knowledge and practices that could

collectively advance SDG achievement [99]. Moreover, while there is a general willingness to measure SDG impacts, practical implementation remains problematic, with actions frequently not aligning with stated intentions [100]. Organizational learning and efficient resource management are crucial for overcoming these barriers, yet they are not sufficiently embraced across the sector, limiting the potential for sustainable change [61]. These limitations highlight the need for more robust frameworks and collaborative efforts to effectively integrate and measure the impact of SDGs within the Design-Build approach in construction projects.

3.4 Construction Management at Risk

3.4.1 Overview

Construction Management at Risk (CMAR) is a project delivery method that emphasizes proactive risk management to enhance project outcomes, particularly in terms of cost, schedule, and quality. The approach involves the construction manager acting as a consultant during the design phase and as a contractor during the construction phase, thereby assuming significant risk and responsibility for project delivery. Effective risk management is crucial in CMAR, as highlighted by the need for continuous risk assessment and mitigation strategies to prevent delays and cost overruns [101]. Despite the recognized importance of risk management, many construction projects still suffer from inadequate risk identification and management practices, leading to unforeseen challenges during execution . The integration of advanced technologies, such as AI, into risk management processes is becoming more prevalent, offering more dynamic and accurate risk assessments [102]. Additionally, strategic capitalization has been identified as a beneficial approach in managing risks sustainably, particularly in contexts like the Nigerian construction industry, where it contributes to increased turnover and improved project delivery [103]. Overall, CMAR requires a comprehensive risk management framework that includes early risk identification, stakeholder engagement, and the use of innovative technologies to ensure successful project outcomes.



Figure 3.3 CMR Project Delivery. Source (DB Institute of America)

3.4.2 Advantages

Construction Management at Risk (CMAR) offers several advantages in project delivery, primarily through its emphasis on proactive risk management and stakeholder collaboration. CMAR allows for early risk identification and mitigation, which is crucial for enhancing project efficiency and reducing disruptions, as highlighted by Alshehhi's study on the importance of early risk management in construction projects [104]. This approach aligns with the findings from the Vision City Project, where risk identification and response planning significantly contributed to successful project delivery [105]. Furthermore, CMAR facilitates a collaborative environment where stakeholders, including contractors and project managers, work closely to manage risks, as seen in the Nigerian construction industry, where strategic capitalization and risk management integration improved project outcomes [103]. The dynamic assessment of risks in residential construction projects also underscores the need for continuous risk monitoring and control, which CMAR inherently supports by involving the construction manager early in the design phase to anticipate and address potential issues [101]. Additionally, the integrated risk management framework proposed in the Ghanaian context emphasizes the importance of stakeholder consultation and education, which are integral to the CMAR process, ensuring that all parties are

aligned and informed about risk management strategies [106]. Overall, CMAR's structured approach to risk management, stakeholder engagement, and early involvement in project planning enhances the likelihood of meeting project objectives, minimizing delays, and adhering to budget constraints.

3.4.3 Limitations

The Construction Management at Risk (CMAR) project delivery method, while facilitating improved communication and early involvement of construction managers, encounters specific limitations in achieving Sustainable Development Goals (SDGs) [107]. Key challenges include potential budget overruns due to underestimated costs which can compromise economic sustainability (SDG 9 - Industry, Innovation, and Infrastructure) and affect project finances [108]. The limited competitive bidding inherent in CMAR may lead to higher project costs, undermining economic efficiency (SDG 8 - Decent Work and Economic Growth). The success of this method heavily relies on the construction manager's expertise in sustainability; any deficiency here can jeopardize environmental goals (SDG 13 - Climate Action, SDG 11 - Sustainable Cities and Communities). Furthermore, the complex coordination required in CMAR might lead to inefficiencies in integrating sustainable practices, potentially hindering responsible consumption and production (SDG 12). Lastly, the ambiguity in assigning accountability for sustainability targets can dilute the focus on achieving specified environmental and social objectives, highlighting the need for clearly defined roles and robust project management to ensure the alignment of construction projects with SDGs [109].

3.5 Integrated Project Delivery

3.5.1 Overview

Integrated Project Delivery (IPD) is a collaborative approach in the construction industry that aims to enhance project outcomes by involving all key stakeholders, such as owners, designers, and contractors, early in the project lifecycle. This method is particularly beneficial in complex and high-risk sectors like oil and gas, where it can optimize efficiency, reduce waste, and improve communication through shared risk and reward mechanisms and the use of collaborative tools like Building Information Modeling (BIM) [110]. The integration of IPD with advanced

technologies, such as digital twins and AI-driven analytics, further enhances real-time monitoring and predictive maintenance, leading to better project performance [110]. In the broader construction industry, IPD is seen as a means to achieve competitive advantages by fostering innovative competencies and reducing costs through improved productivity and energy efficiency [111]. Moreover, IPD is part of a larger framework that includes integration management components, which are essential for effective communication and coordination throughout the project lifecycle [112]. The development of maturity models, such as the BIM-IPD-LC Maturity Model, helps organizations assess and improve their integration and implementation strategies, ensuring effective collaboration and project success [113]. Despite its benefits, the adoption of IPD faces challenges such as resistance to change and the need for cultural shifts within organizations, which can be mitigated through training and the development of clear contractual frameworks [110]. Overall, IPD represents a transformative approach in construction, promoting more efficient, cost-effective, and sustainable project outcomes.



Figure 3.4 The seven Pillars of IPD [116]

3.5.2 Advantages

Integrated Project Delivery (IPD) offers numerous advantages in the construction industry, primarily through enhanced collaboration and efficiency. By involving key stakeholders such as owners, designers, and contractors early in the project

lifecycle, IPD optimizes efficiency, reduces waste, and improves communication, which is particularly beneficial in complex and high-risk sectors like oil and gas [110]. The integration of digital technologies, such as Building Information Modeling (BIM), further enhances these benefits by improving information exchange and management, leading to high-quality and faster design preparation [114]. Additionally, IPD's collaborative approach, supported by advanced technologies like blockchain and smart contracts, facilitates secure and efficient financial transactions, reducing potential conflicts and enhancing trust among stakeholders [115]. The use of BIM and Lean Construction principles within IPD frameworks also contributes to shorter project schedules and higher performance quality [113]. Moreover, the application of economic and mathematical models in IPD projects allows for effective monitoring and optimization of resources, thereby reducing costs and improving project outcomes [111].

3.5.3 Limitations

Integrated Project Delivery (IPD) in the construction industry faces several limitations, as highlighted across various contexts. A significant challenge is the contractual drawbacks, which are the most prominent barriers to IPD implementation, particularly in the Iranian construction industry. These include issues related to the legal frameworks and the need for new contractual models that support collaboration and shared risk [116]. In public projects, the rigid procurement codes that mandate competitive bidding and fixed-price contracts hinder the adoption of IPD, which thrives on collaboration and flexibility [117]. In Egypt, the traditional separation of design and construction phases impedes communication and feedback, which are crucial for IPD's success [118]. These limitations suggest that while IPD offers potential benefits in terms of efficiency and sustainability, its successful implementation requires overcoming significant legal, cultural, and procedural hurdles across different regions and sectors. Addressing these challenges involves developing new guidelines, fostering a culture of collaboration, and creating flexible contractual frameworks that support IPD principles.

3.6 Comparing PDS in the Context of Sustainability

Comparative analysis of Project Delivery Systems (PDS) reveals varying degrees of alignment with Sustainable Development Goals (SDGs) due to differences in integration, stakeholder involvement, and technological utilization. Traditional systems like Design-Bid-Build (DBB), while providing clarity and cost control, often lag in integrating sustainable practices due to their segmented approach which can stifle collaborative innovation necessary for sustainable outcomes [119]. In contrast, Design-Build (DB) and Construction Management at Risk (CMR) show enhanced sustainability integration owing to their inherent collaborative frameworks that facilitate early stakeholder engagement and streamlined communication, crucial for embedding sustainable practices from project inception[119]. These systems support advanced technological integration, such as Building Information Modeling (BIM), which promotes efficient resource management and energy optimization. Integrated Project Delivery (IPD) excels in fostering holistic sustainability by mandating multi-disciplinary collaboration throughout the project's life cycle, significantly optimizing environmental, social, and economic pillars of SDGs [120]. The strategic selection of a PDS thus profoundly impacts the project's ability to contribute to sustainable development, with systems emphasizing early integration and collaboration proving more effective in meeting the complex demands of SDGs.

4
RESEARCH METHODOLOGY

4.1 Research Design

The research design for this study systematically evaluates various Project Delivery Systems (PDS) against their potential to contribute to the Sustainable Development Goals (SDGs) using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), a Multi-Criteria Decision-Making (MCDM) tool. This method was chosen for its ability to handle complex decision scenarios by ranking alternatives based on quantifiable criteria related to economic, environmental, and social sustainability. The process begins with the identification of PDS alternatives which are Design-Bid-Build (DBB), Design-Build (DB), Construction Manager at Risk (CMR), and Integrated Project Delivery (IPD), assessing each for its effectiveness in integrating sustainable practices. Following this, criteria directly tied to the SDGs are established and weighted using the Analytic Hierarchy Process (AHP) to reflect their importance in sustainable project execution.

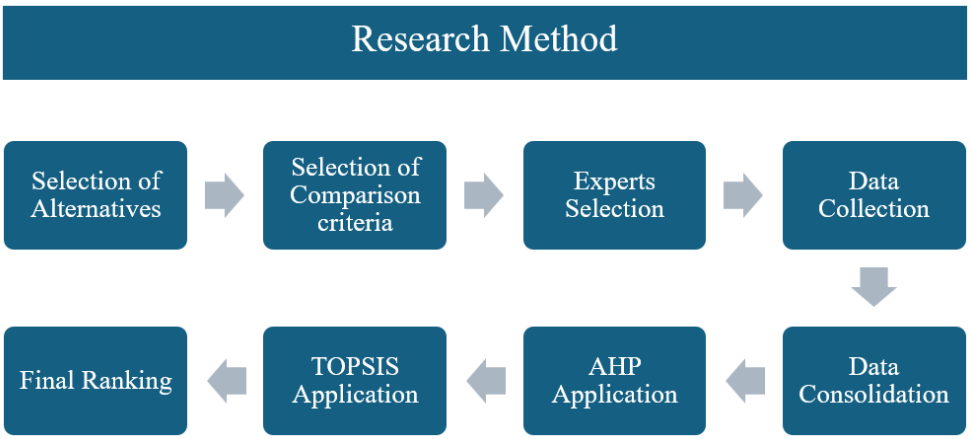


Figure 4.1 Research Method

TOPSIS is then applied to compute each system's distance from an ideal solution, determining their ranking based on how closely they align with optimal sustainability outcomes. This structured approach not only delineates the strengths and limitations of each PDS in promoting sustainability but also provides a clear, actionable framework to aid stakeholders in selecting the most appropriate delivery system for future projects.

4.2 Alternative PDSs

The alternatives assessed in this study include four widely used project delivery systems that represent both traditional and integrated approaches:

- **Design-Bid-Build (DBB)**: A conventional system known for its sequential process where design and construction phases are contracted separately.
- **Design-Build (DB)**: This system integrates design and construction into a single contract, aiming to enhance efficiency and reduce timelines.
- **Construction Manager at Risk (CMR)**: A collaborative approach where the construction manager is involved early in the project and assumes financial risk during the construction phase.
- **Integrated Project Delivery (IPD)**: Represents a modern, collaborative approach that integrates all stakeholders from the project outset to optimize outcomes.

4.3 Criteria Aligned with SDGs

4.3.1 Introduction to the criteria selection

The growing urgency to achieve sustainable development has placed a spotlight on construction practices and their alignment with the United Nations Sustainable Development Goals (SDGs). This research establishes a comprehensive decision matrix to evaluate project delivery systems (PDS) based on their environmental, economic, and social impacts. The selected criteria are designed to directly align with eight critical SDGs, reflecting their interconnected goals.The environmental criteria focus on energy efficiency, resource utilization, waste reduction, and carbon emissions, which contribute to SDG 7: Affordable and Clean Energy, SDG 12: Responsible Consumption and Production, and SDG 13: Climate Action, by

minimizing the environmental footprint of construction projects and promoting sustainability. Economic factors, including cost efficiency, project timeliness, and risk management, are essential to sustainable economic growth, directly supporting SDG 8: Decent Work and Economic Growth and SDG 9: Industry, Innovation, and Infrastructure by ensuring cost-effective, timely, and resilient project outcomes. Social criteria emphasize stakeholder collaboration, health and safety standards, and community impact, underscoring the importance of social equity and well-being in construction. These factors directly contribute to SDG 6: Clean Water and Sanitation (through health and safety considerations), SDG 11: Sustainable Cities and Communities (by fostering inclusive and sustainable urban development), and SDG 16: Peace, Justice, and Strong Institutions (through enhanced collaboration and engagement among stakeholders). In addition to these core dimensions, the matrix incorporates process efficiency, innovation, and long-term sustainability through criteria such as flexibility, technology integration, lifecycle costing, and resilience. These factors ensure alignment with SDG 12 (sustainable procurement and lifecycle impact) and SDG 13 (resilience and durability).

By directly aligning with these eight SDGs, the selected criteria form a robust framework for systematically assessing the sustainability contributions of PDS.

4.3.2 Comparison Criteria

The selected criteria for this reseach are presented the table below:

Table 4.1 Comparison Criteria

#	Criteria	#	Criteria
1	Environmental Impact (EI)	**4**	Process Efficiency & Innovation (PEI)
1.1	Energy Efficiency	**4.1**	Flexibility & Adaptability
1.2	Resource Utilization	**4.2**	Innovation & Technology
1.3	Waste Reduction	**4.3**	Quality of Design
1.4	Carbon Emissions	**5**	Sustainability & Long-term Impact (SLI)
2	Economic Factors (EF)	**5.1**	Lifecycle Costing
2.1	Cost Efficiency	**5.2**	Sustainable Procurement
2.2	Project Timeliness	**5.3**	Resilience & Durability
2.3	Risk Management		
3	Social Impact (SI)		
3.2	Health and Safety Standards		
3.3	Community Impact		
3.1	Stakeholder Collaboration		

4.3.3 Criteria selection rational

4.3.3.1 Environmental Impact

- **Energy Efficiency**: Energy efficiency in construction projects is critical for reducing environmental impact and achieving SDG 7 (Affordable and Clean Energy). Studies have emphasized that energy-efficient practices in construction reduce greenhouse gas emissions and operational costs, aligning with sustainability goals [121].
- **Resource Utilization**: Efficient resource use is essential for sustainable construction, minimizing environmental degradation and supporting SDG 12 (Responsible Consumption and Production). Research shows that optimal resource utilization contributes to reduced waste and cost savings, underscoring the importance of this criterion in evaluating sustainability [122].
- **Waste Reduction**: Waste management is a significant aspect of sustainable construction, with direct implications for environmental sustainability. Construction waste accounts for a large portion of global waste, making this criterion critical for assessing project delivery systems [123].
- **Carbon Emissions**: Reducing carbon emissions is a primary objective in sustainable development, linking closely to SDG 13 (Climate Action). Construction activities are a significant source of CO_2 emissions; thus, assessing carbon emissions can help identify delivery systems that contribute to climate mitigation [124].

4.3.3.2 Economic Factors

- **Cost Efficiency**: Cost management is essential for the economic sustainability of construction projects, with direct ties to SDG 8 (Decent Work and Economic Growth). Research highlights that cost-effective project delivery systems enhance project viability and sustainability by ensuring that resources are allocated efficiently [125].

- **Project Timeliness**: Timeliness is critical in construction, as delays often lead to increased costs and resource wastage. Timeliness is also associated with SDG 9 (Industry, Innovation, and Infrastructure), as timely completion supports sustainable infrastructure development. The choice of project delivery system can significantly impact the timeliness of construction projects[126].
- **Risk Management**: Effective risk management ensures that potential project challenges are anticipated and mitigated, reducing financial losses and promoting project success. Studies show that integrating risk management in delivery systems enhances resilience and project outcomes, which is crucial for sustainable development [127].

4.3.3.3 Social Impact

- **Stakeholder Collaboration and Engagement**: Collaboration among stakeholders improves project outcomes and fosters community involvement, aligning with SDG 16 (Peace, Justice, and Strong Institutions). Research indicates that participatory approaches in construction enhance transparency and trust, essential for sustainable development [128].
- **Health and Safety Standards**: Ensuring worker and community safety aligns with SDG 3 (Good Health and Well-being). Construction projects have significant safety implications, and compliance with health and safety standards is essential for sustainable and responsible project delivery [129].
- **Community Impact**: Construction projects should consider their impact on local communities, including job creation and infrastructure improvements. This criterion aligns with SDG 11 (Sustainable Cities and Communities), as sustainable construction contributes to inclusive and resilient urban development.

4.3.3.4 Process Efficiency and Innovation

- **Flexibility and Adaptability**: Flexibility allows for adjustments to changing circumstances, which is essential for managing risks and uncertainties. Adaptable systems can handle unexpected changes, aligning with resilient and sustainable construction practices [130].
- **Innovation and Technology Integration**: Integration of technology enhances construction efficiency, accuracy, and sustainability, aligning with SDG 9. Research shows that technology-driven project delivery systems contribute to better resource management and overall project performance [131].
- **Quality of Design and Construction**: High-quality design and construction ensure the longevity and durability of structures, reducing the need for future repairs and supporting sustainable urban development [132].

4.3.3.5 Sustainability and Long-term Impact

- **Lifecycle Costing**: Considering lifecycle costs ensures both economic and environmental sustainability, as it accounts for not just initial costs but also maintenance, operation, and disposal costs. This approach aligns with SDG 12 and promotes resource efficiency [133].
- **Sustainable Procurement**: Sustainable procurement practices promote the use of environmentally friendly materials and suppliers, supporting SDG 12. As procurement strategies that prioritize sustainability led to positive environmental and social outcomes [134], they also encourage innovation and the development of new technologies that can further enhance project efficiency and sustainability.
- **Resilience and Durability:** Building resilient structures is essential for withstanding environmental stresses, aligning with SDG 13 and SDG 11. Research emphasizes the importance of resilience in construction, particularly in the face of climate change. Effective design and construction practices can significantly reduce vulnerability to natural disasters, ensuring that communities are better prepared for future challenges while promoting long-term sustainability and safety [135].

These criteria collectively provide a balanced framework for assessing project delivery systems in the context of SDGs, supporting a compound systematic evaluation of their sustainability impacts.

4.4 Data Collection

To ensure robust and comprehensive data collection, this study was meticulously designed to capture expert insights on the alignment of various Project Delivery Systems (PDS) with Sustainable Development Goals (SDGs). Recognizing the complexity of the TOPSIS method, the process was streamlined so that experts did not need prior knowledge of this analytical framework.

A total of over 100 experts in construction project management and sustainable development were initially contacted, leveraging diverse professional networks. These experts included researchers and professionals identified through platforms like ResearchGate and LinkedIn, practitioners from the Project Management Institute (PMI) community, and academics affiliated with global universities. Out of this pool, 17 experts actively participated, with 14 completing the TOPSIS-related questionnaire and 3 contributing to the AHP collective group decision making process.

The selected participants were chosen based on their significant experience and expertise in the construction and sustainability fields, ensuring meaningful contributions to the study. Notably, 46% of the participants had more than 20 years of relevant experience, 28% had 10–20 years, and 7% had 5–10 years, underscoring the depth and diversity of knowledge informing the analysis.

To facilitate a smooth data collection process, the decision matrix—central to the TOPSIS analysis—was transformed into a series of clear and concise questions. Each column of the matrix, representing a specific criterion or key performance indicator (KPI), was reformulated into a question. Responses were gathered on a 5-point Likert scale, where 1 indicated the lowest agreement or performance, and 5 indicated the highest. This simplified approach ensured that experts could focus on evaluating the criteria's content without being burdened by the matrix's technical complexity.

To promote an unbiased and informed assessment, the data collection tool included a neutral summary of the fundamental concepts and characteristics of each PDS on the first page. This introductory section ensured all participants had a baseline understanding of the systems being evaluated. Additionally, relevant facts were provided alongside each question to clarify the criteria being assessed, enabling the experts to provide well-informed responses.

4.5 AHP Application

The Analytic Hierarchy Process (AHP) is a structured decision-making method developed by Thomas L. Saaty in the 1970s. It is widely used for tackling complex decisions by combining mathematical precision with human judgment, making it particularly effective for group decision-making scenarios. In this study, AHP was applied to determine the weights of the evaluation criteria, ensuring that the relative importance of each criterion was accurately captured in the context of contributing to the Sustainable Development Goals (SDGs).

Inputs were collected in a collective group decision making process from three experts with significant experience in construction management and sustainable development. Based on the resulted inputs, the pairwise comparison matrix was constructed. This approach ensured a balanced representation of expert perspectives.

The AHP process followed the standard calculation steps:

Pairwise Comparison: Experts compared each criterion against the others to express their relative importance.

Normalization of the Matrix: Each value in the matrix was normalized by dividing it by the sum of its respective column.

Priority Vector Calculation: The average of the normalized values in each row was calculated, resulting in a priority vector representing the relative weight of each criterion.

Consistency Check: The Consistency Index (CI) and Consistency Ratio (CR) were calculated to ensure the reliability of the judgments. The CR was computed by comparing the CI to the Random Index (RI).

The Consistency Ratio (CR) for the consolidated matrix was 0.051 below 0.1, indicating that the judgments were consistent and reliable. As a result, the derived weights were considered valid for use in the subsequent TOPSIS analysis.

The final consolidated matrix, along with the calculated weights for each criterion, is presented in the table below. The AHP outputs reflect the combined expertise of the contributors, providing a robust foundation for evaluating the significance of each criterion in achieving the SDGs. This process ensures that the decision-making framework is both mathematically sound and grounded in expert insights.

Table 4.2 AHP Matrix

AHP Pairwise matrix						
	EI	EF	SI	PEI	SLI	weight
EI	1	4	0.5	2	1	0.26
EF	0.25	1	0.667	1	0.667	0.13
SI	2	1.5	1	2	1	0.27
PEI	0.5	1	0.5	1	0.667	0.13
SLI	1	1.5	1	1.5	1	0.22

After determining the weights of the main criteria categories through the AHP process, the weight of each category was equally distributed among its corresponding sub-criteria. This approach ensured that all sub-criteria within a main category were treated with equal importance, maintaining consistency and simplifying the evaluation process. By dividing the main criteria weights equally among the sub-criteria, the analysis remained aligned with the framework's objectives while ensuring transparency and fairness in the weighting process.

4.6 TOPSIS Application

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) was employed to evaluate and rank the project delivery systems based on their alignment with the Sustainable Development Goals. This method, detailed extensively in the project document "TOPSIS Explained," is recognized for its effectiveness in handling complex decision-making scenarios where multiple criteria are considered. TOPSIS operates on the principle that the chosen alternative should have the shortest Euclidean distance from the positive ideal solution (PIS) and the farthest from the negative ideal solution (NIS).

4.6.1 Theoretical Framework and Process:

TOPSIS begins with the creation of a decision matrix consisting of m alternatives and n criteria, with the matrix then normalized to remove the impact of differing scales among the criteria. The normalization is performed using the formula:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}$$

where r_{ij} is the normalized value, x_{ij} is the original value, and m is the number of alternatives. Following normalization, the weighted normalized decision matrix is calculated by multiplying each normalized value by its corresponding criterion weight, derived from the AHP method. The weights reflect the relative importance of each criterion and are applied as follows: $v_{ij}=w_j \times r_{ij}$ where v_{ij} represents the weighted normalized value and w_j is the weight of the j-th criterion. The next steps involve determining the positive ideal (A*) and negative ideal (A-) solutions. The A^* is composed of the best values achievable for each criterion, while A- consists of the worst. These are determined from the weighted normalized decision matrix: $A^*=\{\max_i v_{ij} \mid j \in J\}$, $A^-=\{\min_i v_{ij} \mid j \in J\}$ where J is the set of benefit criteria and J′ is the set of cost criteria. Distances from each alternative to the A* and A- are then calculated using the Euclidean distance formula, providing a basis for comparison:

$$D_i^* = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2}, \quad D_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2},$$

The final step in the TOPSIS process is to calculate the relative closeness of each alternative to the ideal solution, which determines the rank of each PDS:

$$RC_i = \frac{D_i^-}{D_i^* - D_i^-}$$

where RC_i is the relative closeness to the ideal solution. The alternatives are then ranked based on these values, with higher scores indicating better performance.

4.6.2 Application in Research:

For this study, inputs for the TOPSIS matrix were gathered through Key Informant Interviews (KIIs) with 14 experts in the fields of construction management and sustainable development. These experts provided valuable insights to quantify the

performance of each Project Delivery System (PDS) relative to the criteria established for SDG alignment.

To ensure a robust and systematic evaluation, 14 individual TOPSIS decision matrices were initially developed, one for each expert based on their responses. These individual matrices were then consolidated into a single aggregated decision matrix using the weighted arithmetic mean method. The weights assigned to each expert's input were determined through a prior question in the Google form, which assessed their level of knowledge about each PDS. Experts who rated their knowledge as 1 (no knowledge) or 2 (low knowledge) had their responses related to those specific PDS excluded from the analysis. For experts who rated their knowledge as 3, 4, or 5, their responses were included, with weights assigned proportionally to their level of expertise (e.g., higher scores carried greater weight).

Once the consolidated decision matrix was established, the weights derived from the AHP calculations were applied to reflect the relative importance of each criterion. The resulting decision matrix, shown in the table below, integrates both the expert judgments and the criteria weights, providing a robust foundation for the TOPSIS analysis.

The methodical application of the TOPSIS framework, combined with this systematic and rigorous data collection approach, ensures that the evaluations are both empirical and reflective of a consensus-driven methodology. This comprehensive process offers a well-rounded assessment of each PDS's potential to align with and advance the Sustainable Development Goals effectively.

Table 4.3 TOPSIS Matrix

TOPSIS Decision Matrix																
Criteria	1.1	1.2	1.3	1.4	2.1	2.2	2.3	3.1	3.2	3.3	4.1	4.2	4.3	5.1	5.2	5.3
Weight	0.06	0.06	0.06	0.06	0.04	0.04	0.04	0.09	0.09	0.09	0.04	0.04	0.04	0.07	0.07	0.07
DBB	3.6	3.0	3.2	2.9	3.1	3.4	3.0	3.1	3.5	3.1	2.7	3.0	3.6	2.8	3.0	3.4
DB	4.0	3.8	3.6	3.3	3.5	3.7	3.1	3.2	2.9	3.2	3.6	3.6	3.7	3.2	3.3	3.5
CMR	3.6	4.0	3.6	3.6	3.8	3.8	4.3	3.8	3.1	3.6	4.1	3.6	3.8	3.4	3.3	3.8
IPD	4.4	4.5	4.5	3.8	4.4	4.0	4.2	4.5	4.1	4.1	4.5	4.1	4.2	4.1	4.1	4.3

5
RESULTS

5.1 Introduction

This chapter presents the outcomes of the TOPSIS analysis, evaluating the performance of four Project Delivery Systems (PDS) – Design-Bid-Build (DBB), Design-Build (DB), Construction Manager-at-Risk (CMR), and Integrated Project Delivery (IPD) – in contributing to the Sustainable Development Goals (SDGs). The results provide a comparative ranking of these systems based on their alignment with sustainability criteria, offering insights into their relative strengths and weaknesses.

5.2 TOPSIS Analysis Outcomes

5.2.1 Ranking of Project Delivery Systems

The TOPSIS analysis ranked the PDS alternatives as follows:

1. **Integrated Project Delivery (IPD)** – 1st place with a relative closeness score (Ci) of 0.52.
2. **Construction Manager-at-Risk (CMR)** – 2nd place with a Ci of 0.25.
3. **Design-Build (DB)** – 3rd place with a Ci of 0.14.
4. **Design-Bid-Build (DBB)** – 4th place with a Ci of 0.08.

This ranking indicates that IPD, characterized by its collaborative and integrated approach, is most aligned with sustainability criteria, while DBB, a traditional method, exhibits the least alignment.

5.2.2 Relative Closeness to Ideal and Negative-Ideal Solutions

The TOPSIS methodology evaluates each alternative based on its Euclidean distance from the Positive Ideal Solution (Si+) and the Negative Ideal Solution (Si−):

- **IPD** has the shortest distance from the ideal solution (Si+ = 0.0007) and the farthest from the negative ideal solution (Si− = 0.0424), confirming its strong performance.
- **DBB** has the farthest distance from the ideal solution (Si+ = 0.040) and the closest to the negative ideal solution (Si− = 0.0007), reflecting its weaker performance.

5.3 Performance by Individual Criteria

The following analysis provides detailed insights into the performance of each PDS against the criteria:

5.3.1 Environmental Impact (EI)

- IPD excelled across all environmental sub-criteria (e.g., energy efficiency and carbon emissions), achieving the highest normalized scores (e.g., 0.0364 for energy efficiency).
- DBB lagged in this category, reflecting limited integration of sustainability practices in traditional project delivery.

5.3.2 Economic Factors (EF)

- CMR showed superior performance in cost efficiency and risk management (e.g., 0.0245 for risk management), indicating its suitability for projects with strict financial constraints.
- DBB and DB demonstrated moderate performance, with DB slightly outperforming DBB in project timeliness.

5.3.3 Social Impact (SI)

- IPD dominated this category, particularly in stakeholder collaboration and community impact, due to its emphasis on shared goals and early stakeholder involvement.

- DBB scored the lowest, hindered by its adversarial approach and lack of collaboration.

5.3.4 Process Efficiency and Innovation (PEI)

- IPD led in flexibility, adaptability, and technology integration, reflecting its ability to incorporate innovative solutions.
- CMR performed moderately, while DBB again scored the lowest.

5.3.5 Sustainability and Long-term Impact (SLI)

- IPD and CMR both scored highly, with IPD leading in lifecycle costing and resilience.
- DB performed moderately, and DBB lagged significantly in long-term sustainability metrics.

5.4 Summary

The results reveal that Integrated Project Delivery (IPD) is the most effective PDS for aligning with the Sustainable Development Goals, driven by its collaborative, flexible, and innovative approach. Conversely, Design-Bid-Build (DBB) struggles to meet sustainability requirements due to its segmented and traditional structure. These findings set the stage for further discussion on their implications for the construction industry and policymaking.

6
DISCUSSION

6.1 Interpretation of Results in Relation to Research Questions

The primary research question of this study was to determine which Project Delivery System (PDS) is most effective in achieving the Sustainable Development Goals (SDGs) within the construction industry. The results from the TOPSIS analysis clearly indicated that Integrated Project Delivery (IPD) ranked highest among the four PDS options, followed by Construction Manager-at-Risk (CMR), Design-Build (DB), and Design-Bid-Build (DBB).

The findings support the hypothesis that IPD and DB are more conducive to achieving SDGs than the traditional DBB method. IPD's top ranking can be attributed to its collaborative nature, which fosters stakeholder engagement, enhances innovation, and integrates sustainability from project inception to completion. This supports the assertion that integrated approaches like IPD are better suited for complex sustainability challenges, as they enable continuous feedback and adaptive management, critical for addressing environmental and social criteria linked to the SDGs.

In contrast, DBB's last-place ranking reinforces its limitations in fostering sustainable practices. The segmented nature of DBB, characterized by separate contracts for design and construction, leads to adversarial relationships and limited early-stage collaboration, hindering its ability to integrate sustainability effectively.

The analysis of individual criteria revealed that IPD consistently outperformed other systems in areas such as energy efficiency, stakeholder collaboration, and lifecycle costing. This aligns with the understanding that early and integrated stakeholder involvement—hallmarks of IPD—are crucial for embedding

sustainability into construction projects. Conversely, DBB's lower scores across environmental, economic, and social criteria highlight its inadequacies in meeting modern sustainability demands.

6.2 Implications for the Construction Industry and Policy

The findings of this study have significant implications for the construction industry and policymakers aiming to advance sustainable development:

1. **Encouraging Adoption of Integrated Systems**: The superior performance of IPD suggests a need for broader adoption of integrated and collaborative PDS in the construction industry. Policymakers should consider incentivizing IPD adoption through policy measures, subsidies, or regulatory frameworks that promote integrated project delivery as a standard practice for public and private projects.
2. **Reevaluating Traditional Methods**: Given the limitations of DBB in supporting sustainability, industry stakeholders must critically assess the use of traditional delivery systems. Transitioning from DBB to more integrated methods like DB or CMR could enhance project outcomes, especially in sustainability-focused projects.
3. **Training and Capacity Building**: To maximize the benefits of integrated systems, there is a need for targeted training programs that equip construction professionals with the skills to manage collaborative and sustainable projects. Educational institutions and industry bodies should collaborate to integrate IPD principles into construction management curricula.
4. **Supporting Innovation and Technology Integration**: The effectiveness of IPD in leveraging technology for sustainable outcomes underscores the importance of digital transformation in construction. Policymakers should support research and development initiatives that promote innovative tools like Building Information Modeling (BIM) and sustainability rating systems (e.g., LEED).

6.3 Comparison with Literature and Validation of Findings

The findings of this study are consistent with existing literature that emphasizes the effectiveness of integrated delivery systems in achieving sustainable construction outcomes. Previous research by Franz et al. (2020)[35] demonstrated the positive impact of team integration on project delivery performance, corroborating the high ranking of IPD in this study.

Studies by Gunhan (2019) [22] and Ahmed and El-Sayegh (2024) [18] have highlighted the limited capacity of DBB to address sustainability challenges, aligning with this study's findings. The results also support Mollaoglu-Korkmaz et al. (2013) [77], who found that DB and CMR enhance project performance through early contractor involvement and risk-sharing mechanisms.

The use of the TOPSIS method, supported by AHP for criteria weighting, provides a robust and systematic approach for evaluating PDS. The validation of results through expert feedback ensures that the findings are grounded in industry realities, further reinforcing the study's credibility.

6.4 Limitations of the Study

This study has certain limitations that should be considered. It evaluated Project Delivery Systems (PDS) based on their inherent concepts and characteristics, regardless of project size, type, or complexity. While this approach provides a generalized understanding of PDS alignment with Sustainable Development Goals (SDGs), it does not account for variations in performance that may arise in specific project contexts. Future studies could build on this methodology by focusing on particular types or sizes of construction projects to provide more tailored insights. Additionally, the criteria selected, though aligned with SDGs, may not fully capture all sustainability aspects relevant to diverse construction scenarios. Expanding the criteria or customizing them to specific project contexts could enhance the depth and applicability of findings. Finally, while the reliance on expert judgment through AHP and TOPSIS ensures industry relevance, integrating quantitative performance data in future research would provide a more objective evaluation of PDS effectiveness.

7
CONCLUSION

7.1 Summary of Findings

This study set out to evaluate the effectiveness of various Project Delivery Systems (PDS) in promoting sustainability within the construction industry, as aligned with the Sustainable Development Goals (SDGs). Utilizing the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) alongside the Analytic Hierarchy Process (AHP) for criteria weighting, the research systematically compared four predominant systems: Design-Bid-Build (DBB), Design-Build (DB), Construction Manager-at-Risk (CMR), and Integrated Project Delivery (IPD). The findings clearly demonstrate that IPD significantly outperforms other systems in aligning with sustainability objectives due to its inherent collaborative nature and integration across project phases. Conversely, the traditional DBB approach lagged in performance, primarily due to its segmented process and limited stakeholder collaboration.

The study makes substantial contributions to the understanding of how project delivery methods impact the achievement of SDGs within the construction sector. It provides a quantitative framework that stakeholders can use to evaluate and select PDS based on sustainability performance. The insights generated from this research help fill gaps in literature, particularly around the quantitative evaluation of PDS in relation to SDGs, offering a new perspective on project management in the construction industry.

7.2 Recommendations for Industry Stakeholders

Based on the study's outcomes, the following actionable recommendations are proposed:

- **Adoption of Integrated Systems:** Organizations should prioritize the adoption of IPD and similar integrated delivery methods for projects with a strong sustainability mandate.
- **Incorporation of Sustainability Criteria:** Decision-makers should incorporate explicit sustainability criteria into the PDS selection process to ensure that project goals align with SDG targets.
- **Decision-Making Tools:** The construction industry should leverage decision-making tools like TOPSIS to enhance the objectivity and effectiveness of PDS selection, particularly for large-scale or high-impact projects.

7.3 Recommendations for Future Research

The research opens several pathways for further investigation:

- **Project-Specific Analysis:** Future studies could apply the TOPSIS framework to specific types of construction projects, such as residential or infrastructure, to ascertain the best PDS for different project demands.
- **Extended Criteria Set:** Including additional sustainability-related criteria, such as socio-economic impacts or regional considerations, could provide more comprehensive insights into PDS performance.
- **Real-World Data Integration:** Incorporating empirical data from completed projects could help validate the theoretical findings from this study and refine the decision-making framework.

7.4 Final Remarks

The urgency of embedding sustainability into construction practices cannot be overstated, given the industry's significant impact on environmental and social outcomes. As this study shows, the choice of PDS can profoundly influence the ability of construction projects to meet global sustainability goals. Therefore, moving towards more integrated, collaborative, and technologically enabled project

delivery methods is not merely beneficial but essential. This transition will support the construction industry's pivotal role in realizing the ambitious 2030 Agenda for Sustainable Development.

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PUBLICATIONS FROM THE THESIS

Conference Papers

1. Mulham MASRI, and Aslı Pelin GÜRGÜN, “Comparative Analysis of Construction Project Delivery Systems in Achieving Sustainable Development Goals” ORAL SUMMARY PRESENTATION, presented at the 6th International IDU Engineering Symposium (IES’24), November 28-29, 2024. Izmir, Turkey.