19[th] WORLD CONFERENCE OF THE ASSOCIATED RESEARCH CENTRES FOR THE URBAN UNDERGROUND SPACE
Belgrade, Serbia, November 4-7, 2025.

ACUUS BELGRADE 2025

Paper No: 6.4.157
DOI: 10.46793/ACUUS2025.6.4.157

ANALYZING CONTRACTUAL PRACTICES IN MAJOR UNDERGROUND INFRASTRUCTURE PROJECTS

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Abstract: The underground space presents significant opportunities for infrastructure development. The infrastructure industry (architecture, engineering, construction, and operation) has historically struggled with poor project performance caused by complexity, fragmentation, and low digitalization. Underground projects face additional challenges due to the uncertainty of unknown subsurface conditions. The continued increase in materials and energy costs, inflation, and the COVID-19 pandemic are just a few of the unforeseen factors exacerbating this situation. Based on case studies, this analysis examines current contracting practices in major underground infrastructure projects, investigating their characteristics and their impact on conflicts, disputes, and claims. These factors in major projects often result in the use of multi-party contracts and complex contractual arrangements. Traditional contracting practices have primarily focused on risk allocation, commonly leading to disputes and inefficiencies that result in further delays and financial burdens in the project. Recent advances in contract management encourage integrated and collaborative approaches, while the adaptation of digital tools generates blockchain-based smart legal contracts to enhance automation, transparency, and sustainability. This shift in contractual practices influences performance optimization as well as dispute mitigation. Finally, key lessons are derived from their implementation.

Keywords: Underground infrastructure, smart contracts, claims, digitalization, sustainability

1. INTRODUCTION

The construction sector is a pillar of economic growth, making significant contributions to both the financial and infrastructure development of countries worldwide. It is mentioned that the share of this industry in terms of gross domestic product (GDP) is almost 10% for developed countries, and could be even higher in developing countries [1]. However, this sector faces significant challenges and is widely regarded as having one of the highest-risk profiles among industries worldwide, due to the inherent uncertainties and the unpredictable environmental factors that can disrupt successful project execution [2], [3]. The dynamic and complex environment, consisting of interactions and frictions among stakeholders and fragmented project delivery, adds to this characterization. These risks manifest as cost overruns, delays, and quality issues, which collectively undermine project success and its economic benefits. It has been observed that allocating these risks to project parties often results in claims being integrated into the contractual framework. Claims and disputes in construction projects and the cost associated with these adversarial relationships can reach up to €3,5-€10,5 billion per year [4], [5].

The excess urbanization and increasing demand for resilient infrastructure have driven the development of underground projects ranging from tunnels, subways, and underground utilities to subterranean corridors. Underground projects offer a solution to space constraints and environmental concerns, but introduce additional project management challenges [6]. The subsurface environment is characterized by incomplete geological data, unpredictable soil and groundwater conditions, and safety hazards, which increase technical complexity and risk.

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Choosing the appropriate project delivery method and contracting approach is critical to managing risks and achieving project objectives. The project delivery method (PDM) defines the overall process and relationships among the parties involved in a project [7]. Contracting methods (CM) focus on the legal and financial mechanisms that govern compensation and risk sharing. Meanwhile, technological advancements have influenced contracting methods as well, introducing smart contracts. Smart contracts are self-executing agreements where terms are encoded into blockchain-based code, automating enforcement and payments when predefined conditions are met [8], [9]. Project delivery methods and contracting methods are two distinct topics. However, the two are often discussed together, sometimes even interchangeably, because the chosen project delivery method typically dictates the types of contracts used and shapes the contractual relationships on a project. As a result, both are frequently grouped under the broader term contractual practices or contracts, reflecting their combined influence on project risk, collaboration, and performance [10].

Despite the critical role of contracts in underground infrastructure projects, comprehensive analyses of contractual practices remain limited. Most literature focuses on individual contract types or project delivery methods without integrating their combined impact on project performance, dispute resolution, and innovation adoption, particularly in the context of underground projects. Furthermore, emerging technologies such as blockchain-based smart contracts have not been extensively studied in this context. The evaluation of contractual practices used in an underground project is multifactorial. This paper makes a contribution to underground space knowledge by integrating an assessment of traditional and emerging project delivery methods with digital innovations such as blockchain-enabled smart contracts through assessesing the contractual practices and their use in underground projects, evaluating and addressing their impact on project delivery success by analysing contractual practices in major underground projects through case studies, aiming to underscore the next steps required to improve their successful completion. The most used contractual practices in underground projects, along with alternative project delivery methods, were analysed using indicative use cases to showcase their efficiency. By evaluating the PDMs and the use cases, it was confirmed that major underground infrastructure projects face unique risks that traditional contracting methods struggle to manage effectively. Integrated and collaborative contractual practices offer improved performance in terms of dispute mitigation, cost control, and schedule adherence.

2. ANALYSIS OF CONTRACTUAL PRACTICES

2.1. Background

Selecting an appropriate project delivery method is an important decision that influences the relationships, risk allocation, and overall success of any construction project [10]. Over the years, the construction industry has relied on a variety of delivery methods and contracts, each offering distinct advantages and challenges. The most popular PDMs in underground construction are Design-Bid-Build (DBB) in which project development occurs through the sequential steps of design, procurement and construction and Design-Build (DB) in which a joint venture of a general contractor and an architectural/engineering firm will be in charge of the design and construction of the project. Emerging PDMs with potential in underground construction are Construction Manager at Risk (CMAR), in which the construction manager, in addition to offering preconstruction services during the design phase, serves as the general contractor overseeing the overall construction, and Integrated Project Delivery (IPD) [5], [11]. Additionally, some of the most frequently used CMs are also mentioned. The lump sum, in which the price for the whole work is proposed, cost-plus, guaranteed maximum price (GMP), in which the bidder is held accountable beyond the guaranteed price, and unit price contracts, which are a compensation method based on the actual amount of work performed [7], [12].

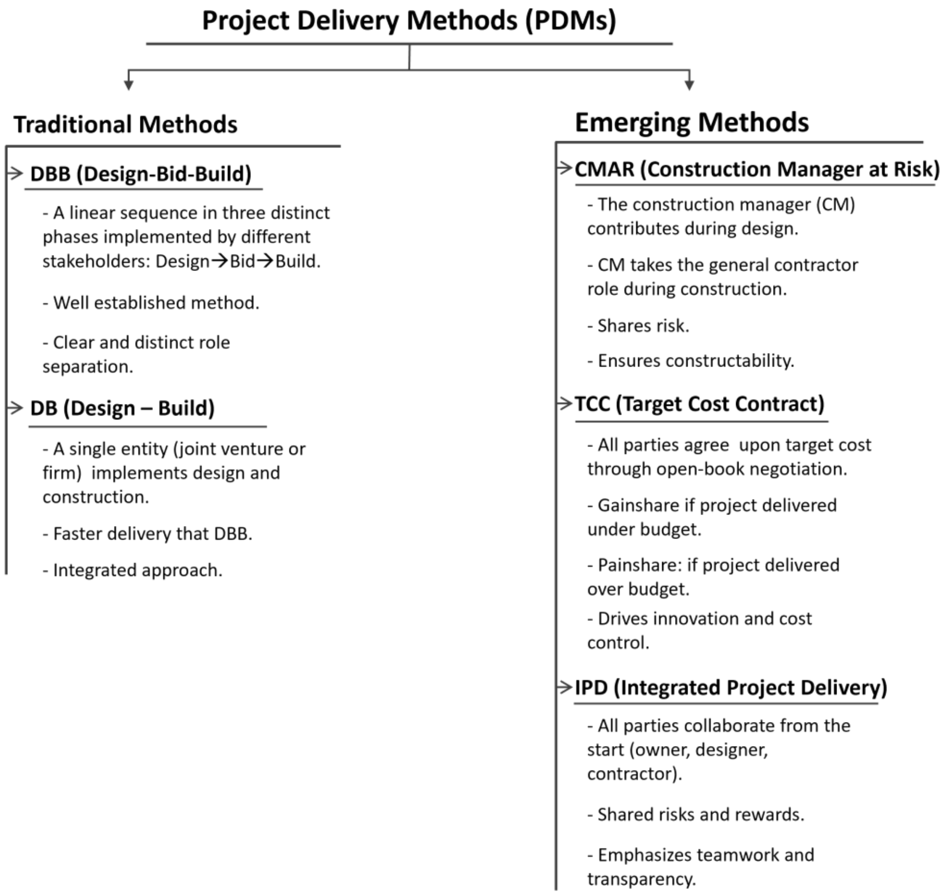

Figure 1. *Project Delivery Methods (PDMs) overview*

Gaining a solid understanding of the theoretical background behind these approaches is essential for making informed decisions and optimizing project outcomes. In the context of underground projects, where risks and uncertainties are often heightened, the most commonly utilized contractual practices include |DBB, DB, CMAR, Target Cost Contracts (TCC), and IPD are analyzed.

2.1.1. Design-Bid-Build (DBB)

The **Design-Bid-Build** method has long been the most traditional and widely practiced project delivery method, especially throughout the late 20th century [6], [13], [14]. In DBB, the owner separately contracts with the designer and the contractor, with the designer preparing construction documents and bid packages for competitive bidding. While this structure provides clear separation of responsibilities, it often leads to poor communication and limited knowledge sharing between designers and contractors, as each party operates independently and tends to prioritize shifting risk and maximizing their profit [4], [15]. Managing changes is particularly challenging in DBB due to fragmented negotiations and a lack of collaboration, frequently resulting in claims and disputes [4]. The conflicts in DBB, compared to alternative delivery methods, have been well documented [16]. As projects grew in complexity and cost during the late 1970s, these disadvantages dictated the development and adoption of alternative project delivery methods that better address the limitations of the traditional DBB approach [6]. In DBB, the owner typically uses a lump sum contract type and contracts separately with designers and contractors, which is best suited for projects with a well-defined scope. This oldest and most common method that separates design and construction phases with fixed-price contracts while providing cost certainty for owners, often resulting in rival relationships and claims due to unforeseen subsurface conditions [12].

2.1.2. Design-Build (DB)

The **Design-Build** is one of the most widely adopted project delivery methods. Unlike Design-Bid-Build (DBB), where interaction between designers and contractors is limited to the beginning or end of construction, DB fosters continuous collaboration as design and construction services are consolidated under a single entity, either a joint venture, an in-house team, or a partnership, providing the owner with a single point of communication [13]. This integration addresses many of the shortcomings of DBB, such as ineffective design, errors, change orders, and disputes, which often lead to increased costs and project delays. The popularity of DB surged in the late 1980s and early 1990s, and it currently accounts for over 40% of non-residential project deliveries [4].

In the DB process, owners typically issue a request for proposal outlining design parameters, after which DB teams develop conceptual designs and proposals, including schedules and cost estimates, for owner evaluation [4]. Construction often begins before design completion, enabling significant schedule reductions compared to DBB. Studies indicate that contractors, clients, and architects largely agree that DB offers schedule advantages and higher owner satisfaction with design quality. Common disputes in DB projects typically involve conflicting employer requirements, contractor obligations regarding designs and/or design changes, valuation of design variations, and additional work not specified in contracts. In literature, it is indicated that DB projects generally have better time performance than cost performance over the DBB, however, the cost benefits of DB over DBB remain debated among researchers, with some studies finding no significant advantage [6], [17], [18], [19]. In DB design and construction are integrated under a single contract, often leading to faster project delivery, but sometimes with a less clearly defined initial scope [17].

2.1.3. Construction Manager at Risk (CMAR)

Construction Manager at Risk (CMAR), also known as Construction Manager/General Contractor (CM/GC), is a project delivery method that integrates the contractor into the project team early in the design phase, allowing for essential input on constructability, cost, and scheduling before construction begins [20], [21]. In this approach, the owner holds separate contracts with the designer and the construction manager, who is selected based on qualifications or best value, not just lowest price. The process typically begins with a preconstruction services agreement, during which the CMAR collaborates with the designer and owner to review design documents, identify risks, and provide cost estimates. Once the design reaches a certain level of completion, CMAR and the owner negotiate a Guaranteed Maximum Price (GMP) for construction [20], [21]. The CMAR influences design decisions early, leading to improved constructability and quality, as well as enhanced cost and schedule certainty. The method enables fast-tracking, as construction can begin before design is fully complete, and allows for early bidding of work packages, which can mitigate price uncertainty and accelerate delivery. However, managing two separate contracts (designer and CMAR) can add complexity and requires careful coordination to avoid conflicting agendas and ensure collaboration [20], [21]. The actual project cost is not known until the GMP is set, and there can be ambiguity regarding the extent of the CMAR’s responsibility for design errors or omissions. CMAR is most commonly used for complex, high-risk projects where early contractor involvement can add significant value [20], [21].

2.1.4. Target Cost Contract (TCC)

A **Target Cost Contract (TCC)** is a collaborative construction contract where the client and contractor agree in advance on a target cost, an estimate of the expected project expenses, typically determined through open-book negotiation and joint risk assessment. Target cost contracts share both savings and overruns between the parties according to a pre-agreed formula. If the actual project cost comes in below the target, both parties split the savings (gainshare), on the other hand, if costs exceed the target, both share the overrun (pain share) [22]. This arrangement encourages the contractor to control costs as well as teamwork, as both sides benefit from efficiency and innovation, and both are motivated to avoid overruns. Target cost contracts are especially useful for complex or high-risk projects, such as underground infrastructure, where exact costs are difficult to predict, and collaboration is essential for managing uncertainty and achieving value for money. Challenges can include complexity in setting a realistic target cost, the need for robust contract administration, and potential disputes if the scope or risk allocation is unclear [23].

2.1.5. Integrated Project Delivery (IPD)

Integrated Project Delivery (IPD) is a collaborative project delivery method that brings together the owner, designer, and contractor under a multiparty agreement, fostering open communication, joint risk/reward sharing, and early involvement of all key stakeholders [24]. Unlike traditional methods such as DBB, where roles are fragmented and adversarial relationships are common, IPD encourages a team-oriented approach, aligning all parties toward common project goals. Standard contract forms for IPD, such as the American Institute of Architects’(AIA) Integrated Form of Agreement (IFOA) and ConsensusDOCS, are designed to formalize these collaborative relationships and risk-sharing mechanisms. Survey results from industry practitioners indicate that while IPD is not yet widely adopted, it is more frequently used in large, complex projects, particularly in healthcare and technically challenging environments, where collaboration and flexibility are essential [25], [26].

2.1.6. FIDIC and Underground Project Contracts

Internationally, several legal frameworks influence construction contract management. The FIDIC (Fédération Internationale des Ingénieurs-Conseils) contract conditions provide standardized contractual terms widely used in global construction projects to ensure consistency in contract administration. FIDIC has issued a suite of contracts through the books covering topics related to jobs and authority, work conditions, delays brought about by specialists, as well as methodology for dispute settlement, liability, and risk-related issues [27]. One of the most significant advancements in underground infrastructure contracting is the introduction of the ITA/FIDIC Emerald Book, a specialized standard contract designed to address the unique risks of subsurface construction. Unlike previous practices that unfairly placed all ground condition risks on contractors, often resulting in disputes, cost overruns, and bankruptcies, the Emerald Book establishes a more balanced framework for risk allocation. Central to this approach is the use of a Geotechnical Baseline Report (GBR), which clearly defines the allocation of ground risk between the employer and the contractor. This allows for contract adjustments if actual ground conditions differ from those anticipated, ensuring contractors are compensated for unforeseen conditions while still holding them accountable for performance under expected circumstances. The Emerald Book also introduces mechanisms for time and remuneration adjustments, prioritizes factual ground data over legal manoeuvring, and emphasizes the engineer's neutral and fair role in contract administration [28].

3. CONTRACTUAL PRACTICES CASE STUDIES

Construction industry practices differ significantly across countries due to variations in culture, legal systems, and construction techniques. Despite these differences, certain challenges, such as effective project planning and control, are common worldwide, regardless of geographic location [2]. The case studies selected for this analysis represent a diverse range of underground infrastructure projects across different geographies and scales. They were chosen based on their relevance to tunnelling and underground construction, the variety of contractual and project delivery methods employed, and the availability of detailed information about their contractual frameworks and project outcomes. The cases demonstrate both traditional and innovative contractual practices.

3.1.1. Toronto-York Spadina Subway Extension (TYSSE)

The Toronto-York Spadina Subway Extension (TYSSE) project is an expansion of Toronto's subway system, extending Line 1 by 8,6km and adding six new stations from Downsview to Vaughan. Delivered using the DBB method, the project was managed by the Toronto Transit Commission (TTC), which oversaw the design process and then awarded multiple construction contracts through competitive bidding to private contractors [29], [30], [31]. This approach allowed the TTC to maintain control over design standards and integration with the existing network, but also meant that contractors had no input into the design and were responsible for building exactly to the provided specifications [29], [30], [31].

The TYSSE project faced a series of significant challenges that affected its timeline, budget, and overall execution. From the outset, the project suffered an 18-month delay, with the opening date pushed back multiple times and completion not achieved until late 2017 [29], [32]. Additionally, cost overruns were significant, as the budget increased from an initial estimate of €2,27 billion to nearly €2.8 billion, driven by delays, scope changes, and unforeseen construction complexities. Contractor performance issues that led to safety issues were one of the factors of the project delays. Utility relocation also proved to be more complex and time-consuming than anticipated, causing up to 11 months of extra delay in some areas [30]. Additionally, frequent changes to station designs and project scope were not factored into the original schedule or budget, compounding both delays and cost increases. These factors were related to contractor claims. While some of these claims were acknowledged by the TTC as having merit and were billed for payment, others were expected to be contested through litigation. By early 2016, the TTC disclosed that up to €350 million would be required to address contractor claims. Persistent challenges ultimately led to a complete reset of the project, including the dismissal of two managers and the appointment of a new design team to restore control over costs and scheduling [29], [32], [33].

3.1.2. Doha Metro Gold Line project

The Doha Metro Gold Line project in Qatar was delivered using a Design-Build project delivery method. Qatar Rail awarded a single, large-scale contract to a joint venture consortium, comprising Aktor, Larsen & Toubro, Yapi Merkezi, STFA, and Al Jaber Engineering, to both design and construct the underground Gold Line, including its tunnels and stations [34], [35]. Under this approach, the consortium was responsible for the full scope of design, engineering, and construction works, integrating all phases under one contract to streamline coordination, accelerate delivery, and manage risks more effectively. The contract covered the design and construction of approximately 16 km of twin tunnels, 10 underground stations, and associated infrastructure, with the project running from 2014 to 2017 [35]. This method was chosen to meet tight timelines and complex technical requirements, enabling the contractor to optimize construction solutions and adapt to project challenges as they arose [34], [35], [36]. Nonetheless, the Doha Metro Gold Line project experienced significant time and cost overruns during its execution. Initially scheduled for completion between 2014 and 2017, phase I faced delays that pushed the opening to 2019 [37], [38]. These delays were attributed to design changes, the 2017 Gulf blockade, which disrupted material supply chains and labour logistics, and contractor disputes over scope adjustments and compensation claims [37]. In terms of cost, the broader Doha Metro project, initially estimated at €14,43 billion, saw substantial escalation, with the Gold Line contributing significantly to overruns [37], [39].

The project faced major arbitration and financial disputes alongside significant technical challenges. In 2017, a consortium including OHLA filed a €400 million arbitration claim against Qatar Rail following contract termination for work on key stations. The International Chamber of Commerce (ICC) ruled in 2025, awarding €315 million in compensation, with OHLA receiving €95 million [40]. This dispute centred on whether the contract should have been terminated or renegotiated, with the consortium arguing for negotiation or formal arbitration. Additionally, the project encountered unforeseen ground conditions, such as karstic limestone and aggressive groundwater, which required extra ground stabilization. Contractors claimed these were differing site conditions, leading to further claims for time extensions and cost adjustments [35], [41].

3.1.3. City of Atlanta Water Supply Program

The City of Atlanta Water Supply Program is an infrastructure initiative designed to secure Atlanta's drinking water supply for the next century. The project included converting a 120m deep quarry into a 9 million cubic meter raw water storage facility, constructing 8km of 3.8m diameter tunnel through hard bedrock, and building new pump stations to connect the quarry to the Chattahoochee and Hemphill Water Treatment Plants. The project construction started in 2015 and was delivered as initially projected in 2020 [42]. The City of Atlanta selected the CMAR delivery method for this €280 million project due to its scale, complexity, and the need for cost and schedule certainty. Under CMAR, the construction manager, PC Construction and H.J. Russell JV, was engaged early to provide preconstruction services, value engineering, and risk management, and then assumed construction risk under a GMP. This approach fostered collaboration, expedited construction, and allowed for flexibility in addressing unforeseen challenges [42], [43].

The project faced significant technical and logistical challenges, including mining through hard gneiss bedrock, constructing eleven deep shafts, and managing complex connections to existing infrastructure while prioritizing safety and minimizing community disruption [43]. During construction, an unexpected zone of contaminated groundwater was encountered, necessitating slowed tunnel-boring operations and additional safety protocols. The final commissioning phase coincided with the COVID-19 pandemic, requiring adaptations such as masking, social distancing, and remote coordination for pump installations [43]. Despite these hurdles, the CMAR delivery method fostered collaboration and transparent risk-sharing, avoiding major disputes or litigation and enabling constructive resolution of issues. The project was completed on time and €4,37 million under budget, demonstrating resilience against pandemic-related and technical challenges [42].

3.1.4. Tsim Sha Tsui (TST) Underground Railway Station Modification and Extension Works

The Tsim Sha Tsui (TST) Underground Railway Station Modification and Extension Works was a critical infrastructure project in Hong Kong aimed at enhancing connectivity between the Mass Transit Railway Corporation (MTRCL) Tsim Sha Tsui Station and the Kowloon-Canton Railway Corporation (KCRC) East Tsim Sha Tsui Station under a TCC framework. Key objectives included relieving passenger congestion, improving accessibility, and integrating pedestrian subways in one of Hong Kong's busiest districts. The project involved deep excavation beneath Nathan Road, construction of a 160m subway extension, and modifications to the existing station structure while maintaining uninterrupted railway operations. Completed in September 2005, the project was delivered seven months early and 5% under budget, achieving significant time and cost savings [23], [44], [45]. Management challenges included initial resistance to the TCC model and the need to modify existing contracts due to the lack of a standard TCC template, raising liability concerns [23].

The project encountered several key issues, disputes, and claims. Excavation close to operational tunnels required precise ground stabilization. The presence of contaminated groundwater and unstable geology led to delays and the need for additional safety protocols. These unforeseen ground conditions were addressed through joint risk assessments and contingency funds within the TCC framework, helping to mitigate disputes [46]. Disagreements also arose over whether certain design changes, such as station layout adjustments and utility relocations, constituted target cost variations or design developments. These were resolved through adjudication meetings involving the client, contractor, and a partnering facilitator, avoiding litigation.

4. INSIGHTS FROM CASE STUDIES

To enable a critical assessment, the case studies were evaluated against four performance criteria: (i) cost performance, (ii) schedule performance, and (iii) dispute incidence.

The rigid separation of design and construction phases under DBB led to fragmented communication and inflexibility. Contractors had no input during design, resulting in impractical specifications and costly rework [30]. The TYSSE project underscores the challenges of using DBB for large, complex underground infrastructure. While DBB provided design control, its inflexibility in managing risks, scope changes, and contractor input led to significant delays, cost overruns, and disputes. The TTC bore most risks for unforeseen conditions leading to adversarial claims. DBB's fixed-price contracts urged contractors to submit claims rather than collaborate on solutions. On the other hand, the DB method utilisation in the Doha Metro Gold Line enabled integrated design-construction workflows and accelerated tunnelling rigid risk allocation for subsurface uncertainties, while design changes led to disputes, highlighting the need for adaptive contracting, robust geotechnical planning, and collaborative risk-sharing to balance efficiency with resilience.

The City of Atlanta Water Supply Program shows the effectiveness of CMAR in complex, high-risk infrastructure. By integrating the construction manager early, sharing risks transparently, and maintaining collaborative governance, the project achieved exceptional outcomes despite geological and external challenges. The GMP model led the CMAR to control costs while allowing flexibility for unforeseen conditions. Unlike traditional delivery methods, the collaborative CMAR approach avoided litigation and adversarial claims, resolving issues through joint decision-making.

Finally, the Tsim Sha Tsui case demonstrates that target cost contracting, when implemented with open-book transparency and equitable risk sharing, can deliver superior performance in underground infrastructure projects. This approach aligns stakeholder interests, fosters innovation, and provides measurable benefits in cost, time, and dispute reduction. The absence of a standard TCC contract template necessitated customization, highlighting the need for flexible contractual frameworks.

Table 1. *Case studies overview.*

Project	**TYSSE (Toronto)** 	**Doha Metro Gold Line** 	**Atlanta Water Supply Program** 	**TST Station (Hong Kong)** 
PDM	DBB	DB	CMAR	TCC
Key Characteristics	- 8.6 km subway extension with 6 new stations. - Urban setting. - Utility relocation required. - Strict design	- 16 km twin tunnels & 10 stations. - Major consortium. - Encountered karstic limestone, aggressive groundwater. - Impacted by regional political disruption.	- 120m deep quarry conversion. - 8 km tunnel through hard bedrock. - Critical municipal water infrastructure.	- Subway station modification under Nathan Road. - Deep excavation near operating tunnels and dense urban zone.
Delays	18+ months	Approximately 2 years.	Completed on time.	Delivered 7 months early.
Cost Overruns	Overbudget	Overbudget	Underbudget	Underbudget
Claims/Disputes	Extensive contractor claims and legal disputes	Major arbitration and claims.	No major disputes, collaborative issue resolution.	Minor claims resolved via adjudication, no litigation required.

This multi-criteria assessment highlights that DBB and DB methods tend to score poorly on dispute incidence and collaboration, while CMAR and TCC demonstrate stronger performance in risk sharing and dispute avoidance.

5. RESULTS

The case studies analyzed indicate that CMAR and TCC perform better than the more traditional DBB and DB practices. However, the CMAR and TCC methods are mainly used in smaller and limited infrastructure projects. For instance, the implementation of TCC in bigger-scale projects, such as the Thames Tideway Tunnel in London, shows cost and time overruns as well [47]. Nonetheless, early contractor involvement in design can mitigate constructability issues, especially considering the disputes and claims that may arise. Future projects could benefit from hybrid models that integrate contractor expertise early and share risks equitably.

Additionally, the digitalization of construction contract management, driven by blockchain and automation technologies, is revolutionizing traditional processes. Blockchain-powered smart contracts enhance transparency, efficiency, and security by creating abiding, tamper-proof records that enable real-time verification of contract terms, payment tracking, and enforcement of compliance. Automation allows smart contracts to self-execute predefined actions, such as releasing payments upon milestone completion, without manual intervention, reducing delays and administrative overhead. These innovations lead to cost savings, faster dispute resolution, and reduced fraud risks. Linking the applicability of blockchain and smart contracts to the case studies, the TYSSE project, automated milestone payments encoded in smart contracts could have reduced prolonged disputes over contractor claims. For the Doha Metro, transparent recording of scope changes on a blockchain ledger would have provided auditable evidence to support renegotiation, reducing arbitration costs. In the Atlanta Water Supply Program, smart contracts could complement the GMP framework by automatically reconciling cost adjustments with real-time construction data. Finally, in the Tsim Sha Tsui project, joint risk registers and gain-share/pain-share mechanisms could be operationalized through blockchain to ensure transparent calculation and distribution of risk outcomes

However, challenges remain, including the lack of legal recognition in many jurisdictions, potential coding errors in smart contracts, and the need to integrate these technologies within the existing regulatory frameworks [48], [49]. Even though smart contracts have promising benefits for construction projects, as they are capable of automating transaction protocols to achieve contractual conditions such as interim payments, liens, and confidentiality, while minimizing the need for trusted intermediaries, construction companies should modify the processes arising from smart contract implementation, which employees often resist. Except for employees, many companies believe that by utilizing smart contracts, they will lose their bargaining power, making the level of implementation of smart contracts not reach the desired level [50]. The inflexible nature of smart contracts, the shortage of professionals with both technical and legal expertise, and ongoing cybersecurity concerns are other factors that currently hinder companies from fully trusting and adopting smart contracts in construction, especially in underground projects [51], [52].

	Method	Advantages	Disadvantages	Challenges	Potential
Lower project delivery efficiency potential.	**DBB**	Clear design control, competitive bidding	Inflexible, adversarial claims, poor collaboration.	Scope changes, fragmented roles.	Suitable for simple projects; improved with early contractor input.
	DB	Fast delivery, single accountability	Limited owner control, rigid risk allocation.	Adapting to changes, underground uncertainties.	Works well with adaptive risk-sharing & geotech planning.
	Smart Contracts	Automated, transparent, tamper-proof.	Legal uncertainty, rigidity, resistance to change.	Cybersecurity, tech-legal integration.	Enables efficient, real-time project execution.
	IPD	Full team integration, shared rewards, low conflict	High coordination, limited familiarity.	Legal fit, stakeholder alignment.	High potential for complex, collaborative projects.
	TCC	Shared incentives, cost transparency, innovation-driven	Complex setup, non-standardized, cost disputes.	Realistic target setting, clear scope control.	Great for uncertain, high-risk projects.
Higher project delivery efficiency potential.	**CMAR**	Early contractor input, collaborative risk sharing, GMP control	Complex to scale, trust-dependent.	Managing GMP, governance setup.	High potential for complex, high-risk projects.

Figure 2. *PDMs potential in project delivery efficiency in future projects.*

6. DISCUSSION & CONCLUSION

The construction law is of great importance in governing contracts, trying to ensure that all involved parties will adhere to their obligations. However, the construction contracts are inherently complex due to the involvement of multiple stakeholders. In the case of underground constructions, the nature of such projects and the unpredictable conditions that may arise increase the difficulty of delivering such a project successfully, with delays and cost overruns becoming a universal phenomenon in such projects [48], [53]. The evolution of contractual practices in underground infrastructure projects reflects the sector's response to complexity and risk. Traditional risk-transfer contracts, while providing clarity, often foster adversarial relationships that worsen delays and cost overruns. Integrated and collaborative contracts, such as CMAR, TCC, and IPD, align stakeholder motives and promote transparency, which is essential for projects with high uncertainty like tunnelling, while simultaneously sharing the risks in a way that may improve the project delivery.

Additionally, digital innovations, particularly blockchain-enabled smart contracts, represent a promising option by automating contract execution of pre-defined actions and providing abiding records without manual intervention, reducing delays and administrative overhead. On the other hand, the limitations across jurisdictions, as underground projects are governed by diverse legal traditions, procurement laws, and regulatory frameworks, their inflexibility, the cybersecurity issues, and the lack of experts who can deal with both technical and law expertise are some of the most critical smart contract drawbacks. However, smart contracts are still developing, and there are several issues to be addressed. The input of construction companies in the process of refining these models and overcoming barriers to technology adoption would be beneficial for all parties, as smart contracts could better adapt to their requirements and needs. Owners and project managers must carefully select delivery and contracting methods that balance flexibility, risk sharing, and control, tailored to project complexity and stakeholder capabilities, taking into account that early engagement of contractors and designers is critical for optimizing outcomes in underground projects. Even though the use case analysis is critical, this paper aims to highlight the development of contractual practices required to improve underground projects' successful completion.

The conservative nature of construction companies and their hesitation and scepticism in adopting new methods in delivering infrastructure projects is one of the major factors of continued project failures, time delays, and financial loss that have characterised the sector. The impact of contractual practices extends beyond owners and contractors to a wider network of stakeholders, such as public authorities, consultants, regulators, and policy makers, considering that the project's cost and risk exposure are reshaped, and industry norms need to be re-evaluated and reformed accordingly. Future research must focus on how alternative contractual practices would affect the issues faced in underground projects. Specifically, how traditional methods could be combined with alternative methods, so that it could be more appealing for companies to adopt, combined with strategy analysis for overcoming resistance to new practices. Building on this study, further analysis may include developing hybrid models that combine traditional frameworks with collaborative features such as shared risk pools or early contractor involvement, promoting regulatory harmonization by updating national procurement guidelines and international standards to recognize digital contracting mechanisms, and institutionalizing dispute avoidance mechanisms supported by digital platforms to minimize litigation. However, the limitations in data availability and transparency, as well as detailed information on the projects' contract conditions, strongly determine the results of such analyses.

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