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Data-Driven Analysis of Progressive Design Build in Water and Wastewater Infrastructure Projects

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Abstract: The United States has invested heavily in water and wastewater infrastructure projects to address growing demand and aging systems. To ensure the effective delivery of these projects, agencies are shifting toward alternative delivery methods such as progressive design build (PDB), which has demonstrated accelerated schedule and enhanced cost performance across the literature as well as multiple projects compared to traditional DB. This has raised a need for evaluating PDB's state of adoption and performance in the water and wastewater sector. To this end, the authors: (1) conducted descriptive and statistical analyses of the 21 PDB water and wastewater projects available on the Design-Build Institute of America database evaluating their characteristics and performance metrics; (2) investigated the frequency of materialized risks impacting schedule and cost in these projects; and finally (3) identified the key adoption drivers and challenges for PDB in the water and wastewater sector by triangulating findings from the studied narratives with a literature and practice review. Results revealed that 71% and 57% of the investigated projects were completed on or before the contracted schedules and costs, respectively. From the studied project narratives, owner-led changes and COVID-19 impacts were the most frequently encountered risks. Also, it was shown that project planning and risk management drivers were the most influential causes for PDB adoption, whereas legal and contractual restrictions as well as the owner's mindset and culture-related concerns were the most pressing challenges. This study contributes to the body of knowledge by delivering managerial insights through an aggregated snapshot of PDB implementation in the water and wastewater sector. Ultimately, the provided managerial insights can assist stakeholders in making better-informed decisions by weighing the advantages and challenges of PDB identified in this research against more traditional delivery approaches. **DOI:** **10.1061/JCEMD4.COENG-13824.**

Author keywords: Progressive design build (PDB); Water and wastewater infrastructure; Alternative project delivery.

Introduction

Water infrastructure including both drinking and wastewater utilities plays a crucial role in ensuring nations' security, safeguarding public health, and carrying significant social and economic implications. In the United States, water infrastructure has long been acknowledged to be aging and underperforming (ASCE 2021). According to the 2021 ASCE infrastructure report card, which graded drinking water and wastewater infrastructure at C− and D+, respectively, a water main breaks each couple of minutes, with an estimated 6 billion gallons of treated water leaking daily in the United States. Moreover, around 15% of the wastewater treatment plants have reached or surpassed their design capacities, and nearly 16,000 plants are operating at an average of 81% (ASCE 2021). To address the growing demand, coupled with the fact that most of the water and wastewater systems were constructed in the 1970s and 1980s and are reaching the end of their lifespans, the Bipartisan Infrastructure Law signed in November 2021 assigned more than $50 billion to improvement projects of the US water and wastewater infrastructure (US EPA 2021). In addition, the American Jobs Plan issued in 2021 introduced key legislations such as S. 914 (Drinking Water and Wastewater Infrastructure Act of 2021) and H.R. 1915 (Water Quality Protection and Job Creation Act of 2021) which allocate significant investments to water and wastewater infrastructure improvement projects.

In recent years, water and wastewater infrastructure projects have seen a shift from traditional design-bid-build (DBB) project delivery approaches to alternative methods like Design Build (DB) and Construction Manager at Risk (CMAR) (Feghaly et al. 2020). These alternative delivery methods offer potential advantages in terms of cost, schedule, quality, and fostering a collaborative environment (Feghaly et al. 2020; HM Government 2022). Several studies have emphasized the superiority of the DB delivery method in water and wastewater infrastructure projects (Gransberg et al. 2006; Gaikwad et al. 2021; Feghaly et al. 2019). Compared to traditional DBB methods, DB provides enhanced cost and schedule performance (Hale et al. 2009; Hoseingholi and Parchami Jalal 2017; Molenaar and Franz 2018). However, one of the challenges of DB is accurate project cost estimation, as the project scope and requirements are not fully defined during procurement (Tehran et al. 2009). Estimation becomes particularly difficult for design builders at lower levels of design development and scope definition (Hoseingholi and Parchami Jalal 2017). Additionally, owners face the risk of setting a price before confirming the alignment of the

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proposed design and cost proposals with their program and operation requirements (CPARB 2017). Furthermore, owners relinquish much of their design control once a design builder is hired and the contract is initiated (ABA 2019; CPARB 2017).

More recently, PDB has emerged as a variant of DB, gaining momentum in the buildings, airports, and water and wastewater sectors, by allowing for significant owner input during design and scope development, enhancing early cost certainty, while maintaining the single DB firm's contract (Alleman and Tran 2020). As such, agencies tend to select PDB for their projects owing to its streamlined procurement process that encourages competition and innovation while enabling owners to retain substantial input on design development decisions (Gransberg and Molenaar 2019). In addition to agencies and owners, according to the 2022 ACEC DB State of Practice report, engineering firms also demonstrate an increased preference toward PDB over the traditional DB (ACEC 2022). Furthermore, previous studies investigating the performance of recently completed PDB projects across multiple project sectors have reported its superiority over the traditional DB in terms of accelerated schedule and reduced costs (Adamtey 2020; Alameri and Esmaeili 2021; Liang et al. 2020).

As for the water and wastewater sector, the Water Design-Build Council (WDBC) has stated in their 2018 annual report that owners of water and wastewater projects are demonstrating a rapidly increasing preference for PDB, affirming that PDB has been emerging as the leading collaborative method for water and wastewater since 2015 to date. The primary reasons for the reported preferences and trends included the increased owners' involvement in the design, logistics, and construction decisions, as well as their influence over equipment selection, hence safeguarding future utility operation and maintenance practices and budgets (WDBC 2019). Other reasons included the streamlining of permitting and commissioning activities, which are two unique aspects of water and wastewater projects (WDBC 2019). According to Shorney-Darby (2012), the latter was also endorsed by the American Water Works Association, which stated that PDB is best suited for projects with specific performance and regulatory requirements (e.g., specific treatment processes, quality, or flow requirements, as well as operational reliability measures). Given its highlighted advantages, it is important to note that recent legislative revisions—such as the California Senate Bill 991 which took effect in January 2023—promote the use of PDB by water and wastewater agencies to ensure more efficient and cost-effective project delivery (WCDA 2023).

Even with these benefits and its increasing adoption rate across project sectors, PDB literature is rather scarce, with only a handful of studies since 2018. Notable previous PDB-related studies have investigated its application in specific sectors using project case studies in different infrastructure sectors such as airports (Gad et al. 2019), highways (Alleman and Tran 2021), water and wastewater (Rankin et al. 2017; Kora et al. 2017; Keddy et al. 2022), and building projects (Shang and Migliaccio 2019, 2020). Other research efforts have studied the performance of PDB compared to traditional DB (Adamtey 2020) and construction manager/general contractor (CM/GC) delivery methods (Gransberg and Molenaar 2019). Despite the valuable contributions of previous research investigating the implementation of PDB; such efforts were: (1) limited to investigating the implementation of PDB drawing on conclusions from a single or two case studies at most in a specific sector (Gad et al. 2019; Alleman and Tran 2021; Rankin et al. 2017; Kora et al. 2017; Keddy et al. 2022; Shang and Migliaccio 2019, 2020), or (2) analyzed PDB datasets of generic project types and did not particularly focus on specified critical sectors like water and wastewater infrastructure (Adamtey 2020; Liang et al. 2020; Alameri and Esmaeili 2021, 2022).

As PDB continues to grow simultaneously with infrastructure investment in the water and wastewater sectors, it has become necessary to provide an in-depth analysis of the extent of its adoption across projects, evaluating its actual performance and risks, in addition to understanding the main drivers and challenges specific to this relatively new method. To this end, this research aims to fill both aforementioned knowledge gaps by providing specific in-depth analysis of the state of adoption of PDB in the water and wastewater infrastructure sector using multiple case studies and harnessing data from all the published project records on the database maintained by the Design-Build Institute of America (DBIA).

The remainder of this paper is organized as follows: In the second section, the research goal and its associated objectives are listed. In the third section, a background information section provides an overview of alternative delivery methods, the evolution of PDB, and its relevance to the water and wastewater infrastructure sector; also a summary of previous studies investigating the performance of delivery methods is provided. In the fourth section, the research methods adopted in this paper are listed and discussed. In the fifth section, the results of the studied PDB projects in terms of descriptive and statistical analyses of performance metrics are summarized. In addition, the results of the content analysis of materialized risks faced by the studied projects, as well as their PDB-associated adoption drivers and challenges are analyzed and discussed. This is followed by a discussion of the research contributions. conclusions, limitations, and future work in the final section.

Goal and Objectives

The goal of this paper is to analyze and evaluate the state of adoption of PDB in the water and wastewater sector. As such, the detailed objectives of this article are as follows: (1) explore the extent of PDB adoption in the water and wastewater sector in terms of projects completed per year; geographical distribution; procurement mechanisms, structural arrangements, payment mechanisms, design builder selection criteria, as well as schedule and cost performances; (2) investigate the frequency of materialized risks impacting schedule and cost performance of actual PDB projects; and finally (3) identify key adoption drivers and challenges associated with PDB implementation in the water and wastewater sector.

Background Information

Alternative Project Delivery Methods and the Evolution of PDB in the Water and Wastewater Infrastructure Sector

Project delivery methods are defined as the overall management processes used to deliver a facility throughout its concept design to project completion, and it is characterized by features such as the engagement timing of key stakeholders, their assigned roles and responsibilities, as well as the level of scope development and design completion at the time of their involvement (El Asmar et al. 2013). DBB is often regarded as the industry's most conventional, well-established, and widely used project delivery method (Touran et al. 2009). As inferred from its title, DBB is a linear process that starts with the design phase and only involves the contractor after design completion, usually using a lowest-bid selection process (Feghaly et al. 2020). The main shortcoming with DBB projects is the lack of input from contractors in the design phase, which results in problematic consequences in the construction phase where any design changes are handled via change orders, potentially impacting cost and schedule performance (Ibrahim et al. 2020). Similar to DBB, CMAR also incorporates two separate contracts for design and construction services. However, unlike DBB, CMAR firms are engaged early in the project to provide constructability reviews and preconstruction insight; furthermore, they are selected based on qualifications (Alleman and Tran 2020). Unlike DBB and CMAR, DB is characterized by a singular contract with a DB firm that is the sole point of responsibility for design and construction services (Rahmani et al. 2017). DB firms are usually procured on a best-value selection basis where both technical qualifications and price proposals are taken into consideration (Chen et al. 2016). Despite its advantages, DB has been associated with disadvantages such as bid dispersion and cost estimation inaccuracies due to the lower levels of scope definition and design requirements at the time of procurement (Gaikwad et al. 2021). Furthermore, owners of DB projects reported that their loss of design control is one of the major shortcomings of DB where they risk setting a price before the alignment of the proposed design and cost proposals with their program and operation requirements (Hoseingholi and Parchami Jalal 2017; CPARB 2017). Additionally, the American Council of Engineering Companies ACEC (2022) report on DB state of practice revealed that increased project claims, disputes, and litigations stemming from inequities in DB risk allocation practices will eventually overshadow the early DB project success stories (ACEC 2022). These concerns were also reported by the American Bar Association (ABA 2019) that stated the risk allocation inequities in DB contracts were a result of short-term thinking and would ultimately steer contractors away from alternative delivery project markets in the long term (ABA 2019).

Aiming to address DB's shortcomings and curtail its customary risks, PDB has emerged as an evolution of both DB and CM/GC (Alleman and Tran 2020). According to the DBIA, PDB projects undergo either a qualification-based or a based-value selection process to hire the DB firm, followed by a process where the owner "progresses" the scope of work, design, and preconstruction activities collaboratively with the design builder to the point where schedule and cost estimations can be developed, prior to entering into a contract for final design and construction services (Alleman and Tran 2021; DBIA 2018). PDB projects have the following prominent features: (1) early engagement of the DB firm, in some cases before any design development, (2) the DB firm selection is predominantly selected on a qualification basis, and their final price and schedule are not included as a factor for the selection criteria, and (3) the DB firm delivers the project on a two-phase basis, the first including the budget level for the preconstruction services and price negotiation for the second phase, which includes the final design, construction, and commissioning (DBIA 2018). According to the Construction Playbook, a collaborative environment with early contractor engagement is a critical factor in attaining timely and cost-effective delivery (HM Government 2022). Given that PDB allows owners to collaboratively control the design process until the final guaranteed maximum price (GMP) or lump sum price has been set (WCDA 2021). Fig. 1 illustrates the flow of the PDB processes and phases. Another advantage of PDB is the use of open-book estimation in the preconstruction phase, as it assists owners in making more informed decisions on the overall design, scope, cost, schedule, and quality of the project (Gransberg and Molenaar 2019). PDB preconstruction phases usually end by setting the GMP; however, in case an agreement is not reached, an off-ramp option is available where the owner can end the contract and proceed with the construction phase using the services of another contractor (Adamtey 2020).

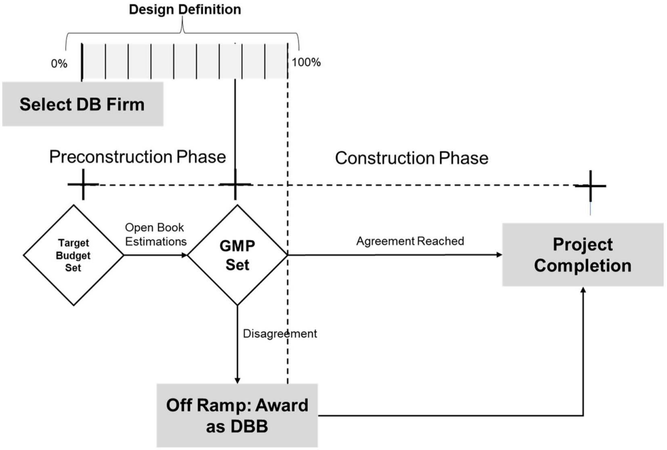


Fig. 1. PDB processes and phases.

Conventionally, water and wastewater projects have been delivered using the traditional DBB method; however, due to changes in procurement legislations and the enhanced performance of alternative project delivery methods, project owners have been leaning toward other methods, such as DB and CM/GC (Shane et al. 2013; El Asmar et al. 2013). This shift toward alternative delivery methods has resulted in multiple research efforts investigating the performance of alternative project delivery in the water and wastewater sector. For example, Shane et al. (2013) analyzed the cost and schedule performance of DB projects as compared to the traditional DBB using data from 31 DB and 69 DBB water and wastewater projects, indicating the superiority of DB in terms of both metrics. In the same context, El Asmar et al. (2013) compared the performance of 34 DB, DBB, as well as CMAR projects in terms of cost growth as well as project speed and concluded that alternative delivery methods are demonstrating improved performance. More recently, Feghaly et al. (2020) investigated implementation practices of CMAR and DB in water infrastructure projects and revealed that GMP was the most preferred compensation form, qualifications-based selection was the most favored procurement method, stakeholders were least comfortable with CMAR, and DB had the lowest owner design involvement. Notwithstanding these valuable contributions to the water and wastewater project delivery research, none of these previously mentioned studies examined the implementation and the performance of PDB using sector-specific project datasets.

Previous Research on Project Delivery System Performance

Apart from the water and wastewater sector, plenty of research endeavors have studied and compared the performance of various forms of project delivery, procurement methods, and payment mechanisms across multiple sectors in the construction industry. Table 1 summarizes these valuable efforts, highlighting the number of projects in the sample size, the construction sectors investigated, studied delivery methods, and major findings. The summarized studies in Table 1 shed light on the gap highlighted in this study, which is the lack of research investigating the adoption and performance of PDB across projects in the water and wastewater sector.

Table 1. Findings of previous studies on the performance of project delivery methods

Study	Sample size	Construction sector	Major findings	Delivery/procurement methods
Songer and Molenaar (1996)	108 DB projects	Industrial, highway, and buildings	The top factors for selecting DB are decreased cost and shortened project duration.	DBB-DB
Konchar and Sanvido (1998)	351 projects (155 DB + 116 DBB)	Industrial and buildings	Cost and schedule growth are less in DB with 5.2% and 11.4% respectively.	DBB-DB
Molenaar et al. (1999)	104 DB projects	Industrial, highway, and buildings	DB will continue to grow in the public sector with more agencies adopting the method.	DBB-DB
Ibbs et al. (2003)	54 projects (24 DB + 30 DBB)	—	DB does not outperform DBB in terms of cost growth and productivity.	DBB-DB-others
El Wardani et al. (2006)	76 DB projects	Industrial and buildings	QBS results in the lowest cost growth. BV has the least schedule growth.	QBS-BVS-sole source-low bid
Hale et al. (2009)	77 Projects (38 DB + 39 DBB)	Buildings (US Navy)	Schedule growth is 5.2% higher in DB projects.	DBB-DB
Bogus et al. (2010)	100 Projects (31 DB + 69 DBB)	Water and wastewater	DB projects had a shorter design and construction duration than DBB projects, as well as smaller schedule growth.	DBB-DB
Bogus et al. (2013)	31 DB projects	Water and wastewater	Procurement duration has little effect on schedule and cost performance.	DB
Shane et al. (2013)	100 Projects (31 DB + 69 DBB)	Municipal water and wastewater sector	Schedule growth for DB projects was half that of the DBB project. DB projects finished at or below budget.	DBB-DB
Chen et al. (2016)	418 DB projects	Buildings, infrastructure, and industrial projects	More than 50% of DB projects are over budget. QBS outperforms BV in terms of schedule.	QBS-BVS-sole source-low bid-fixed budget
Tran et al. (2018)	139 pairs of DB and DBB projects	Transportation projects	DB projects perform better in terms of schedule and cost performance for resurfacing, restoration, and rehabilitation projects as well as miscellaneous construction such as sidewalks, bike lanes, and landscaping.	DBB-DB
Asmar and Ariaratnam (2018)	34 projects (10 DB + 12 DBB + 12 CMAR)	Water and wastewater	Project performance under CMAR and DB improved when compared to DBB.	DBB-DB-CMAR
Franz et al. (2020)	212 projects (81 DB + 73 DBB + 78 CMAR)	Buildings	DB projects are delivered faster and with lower cost and schedule growth.	DBB-DB-CMAR
Liang et al. (2020)	167 DB projects	Industrial, buildings, and transportation	PDB is associated with the best cost performance.	QBS-BVS-PDB-sole source-lowest bid
Adamtey (2020)	163 projects (91 DB + 72 PDB)	Industrial, commercial, civil, water, and healthcare	80% of the PDB projects were completed either on or ahead of schedule.	DB-PDB
Feghaly et al. (2020)	75 projects (23 DB + 25 DBB + 27 CMAR)	Water and wastewater	An expedited schedule is the highest driver for alternative project delivery methods (APDM). QBS is the preferred procurement method and GMP is the preferred payment mechanism.	DBB-DB-CMAR
Ibrahim et al. (2020)	Survey respondents from 109 projects [DBB + DB + CMAR + integrated project delivery (IPD)]	—	IPD outperformed DBB in 11 metrics, while it outperformed CM and DB in two metrics each. DB outperformed DBB in seven metrics, and CM outperformed DBB in five metrics.	DBB-DB-CMAR-IPD

Note: BVS: best-value selection; and QBS: qualifications-based selection.

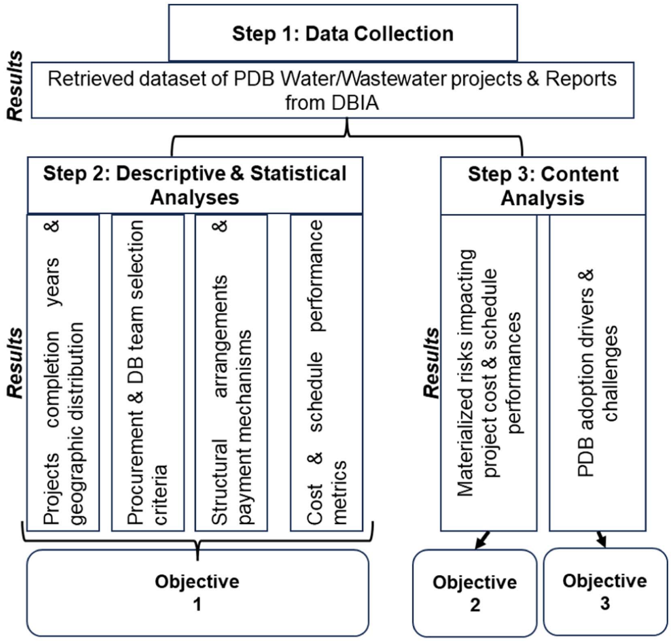


Fig. 2. Research design and flow.

Research Methods

To achieve the previously defined goal and objectives of this research, the authors implemented the following multistep research design: (1) Data Collection; (2) Descriptive and Statistical Analyses, and finally; (3) Content Analysis. Fig. 2 summarizes the adopted methodological steps, their results, and associated research objectives. The following paragraphs elaborate on each of the previously stated methodological steps.

Data Collection

To derive project-driven insights concerning PDB adoption and performance in the water and wastewater sector, the authors extracted all PDB water and wastewater project records available on the projects database maintained by the DBIA that is publicly available at projects.dbia.org. The DBIA database provides accessible records of all types of DB projects—including PDB projects—that have been completed using the organization's guidelines and best practices. The database can be searched by project type, sector, and location, and includes information such as project details, nature of the design builder entity, procurement method, as well as the selected payment mechanism for the project. Furthermore, the database has records for the contracted and actual project costs and schedules. In addition to the previously mentioned numerical data, narratives for each project record are presented which include a project description and whether unusual challenges, unforeseen conditions, or owner-directed changes have been encountered in the project. Also, projects completed after the year 2018 had full project reports, with further elaboration on each project along with additional features such as lifecycle costs, project certifications, impact on the community, as well as detailed weights of the evaluation criteria used for the selection of DB team. To this end, and to achieve the objectives of this paper, the authors filtered the extracted water and wastewater project records delivered using PDB to be employed in the conducted descriptive, statistical, and content analyses.

Descriptive and Statistical Analyses

To achieve the first objective of this paper, the authors provided a descriptive analysis of the retrieved set of PDB water and wastewater projects from the DBIA database by providing summary statistics of the projects in terms of completion years, geographic distribution, procurement and design builder selection criteria, structural arrangements, and payment mechanisms.

Prior to embarking on the statistical analysis of PDB cost and schedule performance, three well-established project performance metrics were calculated from the data available in the retrieved dataset. These performance metrics are (1) project cost growth ratio: the percentage difference between the project's actual cost and the contracted award amount, (2) project schedule growth ratio: the percentage difference between the actual project duration and its' contracted duration, and (3) construction intensity: the ratio between the projects' actual final cost and its actual duration, indicating construction pace. There has been a growing consensus on such performance metrics and their definitions, which have been used in previous studies comparing the performance of delivery methods in several sectors (Chen et al. 2016; Adamtey 2020; Franz et al. 2022; Tran et al. 2018). Eqs. (1)–(3) show the formulas to calculate each of these three metrics. It is worth noting that despite that all the studied projects are classified as water and wastewater infrastructure projects, performance metrics such as the normalized absolute unit costs and durations could not be applied in this paper due to the relative variations in the scopes of the studied projects, which included new construction, as well as upgrades and improvements of existing facilities

$$\text{Schedule Growth Ratio}\,(\%) = \frac{\text{Actual Project Duration–Contracted Project Duration}}{\text{Contracted Project Duration}} \times 100\% \tag{1}$$

$$\text{Cost Growth Ratio}\,(\%) = \frac{\text{Actual Project Cost–Contracted Project Cost}}{\text{Contracted Project Cost}} \times 100\% \tag{2}$$

$$\text{Construction Intensity}\left(\frac{\$}{\text{day}}\right) = \frac{\text{Actual Project Cost}}{\text{Actual Project Duration}} \tag{3}$$

After calculating the project performance metrics for all the retrieved PDB records, statistical methods such as descriptive statistics and boxplots (which visually represent data distribution, displaying the minimum, 25% quartile, median, 75% quartile, and maximum of each data set) were used to provide insights on the distribution of the data. Owing to the relatively small sample size, Shapiro–Wilk normality tests were conducted for each metric to test whether the data are normally distributed and accordingly determine whether the mean or median is more representative of the central tendencies in the dataset (Jato-Espino et al. 2017). If the data is normally distributed, the mean and median should be similar and can be used interchangeably (Christianson et al. 2016). Otherwise, if the data is not normally distributed, the median may be considered a more representative measure of central tendency; since it is less affected by skewed data and outliers (Jato-Espino et al. 2017; Christianson et al. 2016). Shapiro–Wilk test uses a null hypothesis of the data being normally distributed (Solomon et al. 2021). As such, if the p-value of the results is less than 0.05, then the null hypothesis is rejected, and it is assumed that the data is nonnormally distributed (Ibrahim et al. 2020).

Content Analysis

To achieve the second and third objectives of this study (i.e., frequency analysis of risks impacting schedule and cost performance of actual PDB projects, in addition to the identification of key drivers and challenges associated with PDB implementation in the water and wastewater sector), multiple content analyses of the retrieved PDB project records were conducted. Content analysis is a systematic, repeatable technique for reducing large amounts of text to fewer content categories based on clear coding principles (Krippendorff 2018). Thus, such an approach was deemed appropriate for providing data-driven insights from the analyzed project records by identifying: (1) the encountered materialized risks in the studied projects and (2) the drivers and challenges affiliated with the PDB delivery method in the water and wastewater sector. Content analysis techniques are usually categorized into three distinct approaches: inductive; deductive; and hybrid content analysis. In an inductive content analysis process, coding categories are generated directly from the studied text data (Hsieh and Shannon 2005). On the other hand, for deductive content analysis, researchers adopt a preset coding scheme based on prior existing theory or literature and apply such coding schemes to quantify and present the frequencies of such codes in tables (Spearing et al. 2022; Krippendorff 2018). Finally, the third approach is a hybrid analysis which is a combination of both inductive and deductive techniques. In other words, researchers applying this technique start by adopting a deductively predefined conceptual coding framework yet continue to inductively derive new codes or themes that emerge from the analyzed data (Spearing et al. 2022; Burla et al. 2008).

Each content analysis method has its advantages depending on the research goals and objectives. Inductive content analysis allows for open exploration and discovery of patterns and themes within the data, which is particularly useful when the research aims to generate new insights or explore uncharted territories (Spearing et al. 2022). Hybrid content analysis, combining the strengths of both inductive and deductive approaches, provides a balance between flexibility and guidance, enabling researchers to apply existing theories or concepts while remaining open to emergent patterns.

In addition to content analysis, several other methods can be considered for this study, including quantitative data analysis, survey research, and comparative analysis. However, it is important to highlight that content analysis was chosen as the most relevant method for this study due to the limited number of available PDB projects in the water and wastewater sector. With a smaller sample size of PDB projects, it becomes challenging to conduct comprehensive quantitative analyses or comparative studies. Content analysis allows for a thorough examination of the available textual data, such as project narratives and reports, to derive meaningful insights specific to PDB projects (Krippendorff 2018). By focusing on the qualitative aspects and in-depth exploration of the available data, the content analysis provides a valuable approach to understanding the unique characteristics, adoption drivers, and challenges of these limited PDB projects. It allows for a detailed examination of project narratives and documentation to uncover patterns, themes, and key findings, thereby contributing to a deeper understanding of PDB projects in the water and wastewater sector.

To this end, both inductive and hybrid content analysis techniques were followed to achieve the second and third research objectives, respectively. First, for the second objective, an inductive content analysis technique was applied to the retrieved PDB project narratives and reports to directly extract and quantify the frequency of materialized risks impacting the cost or schedule performance of such projects. As for the third objective of the study, project narratives were reviewed to extract and quantify the frequency of the highlighted drivers for PDB selection and any mentioned challenges concerning its implementation. Accordingly, the authors initially adopted a predefined set of PDB drivers and challenges derived from the study by Alleman and Tran (2020) that provided a list of challenges for implementing PDB in highway construction projects, and inductively added emerging codes generated from the studied project records.

To minimize subjectivity and biases, coding consistency and validation techniques using multiple coders were applied. In this study, two of the authors performed the manual content analysis processes to mitigate any biases that may arise from a single judgment of one coder. More specifically, the second author independently repeated the coding process completed by the first author, verifying that similar fundamental categories have emerged and agreeing on revisions in case of discrepancies. This is similar to the coding validation and consistency approach referred to by Spearing et al. (2022), Neuendorf (2002), and Krippendorff (2018), which was also implemented by Mutikanga et al. (2022).

To further examine the validity and credibility of the outcomes, findings from the previous step were triangulated with additional PDB-related publications including peer-reviewed literature as well as published industry best practices and guidelines. In the construction management domain, Love et al. (2002) and Mathison (1988) have affirmed triangulation's superiority and effectiveness. This approach has been applied in multiple relevant research endeavors (Alleman et al. 2017; Alleman and Tran 2020; Mutikanga et al. 2022). In the context of this article, identified drivers and challenges were triangulated with peer-reviewed literature indexed on the Scopus database as well as published industry best practices and guidelines related to PDB from the DBIA as well as the Water Collaborative Delivery Association (WCDA). Peer-reviewed publications were extracted from the Scopus database using the following keyword search: ("Progressive Design-Build" OR "Progressive Design-Build").

The previously summarized descriptive and statistical data analysis and visualization were conducted using Python 3.9, which is a high-level, general-purpose programming language (Van Rossum and Drake 1995; Hunter 2007). Whereas NVivo 12 software, which is a qualitative data handling software (Leech and Onwuegbuzie 2011), was used to assist with the data organization, management, and coordination of the manual content analysis performed by the authors.

Results, Analysis, and Discussion

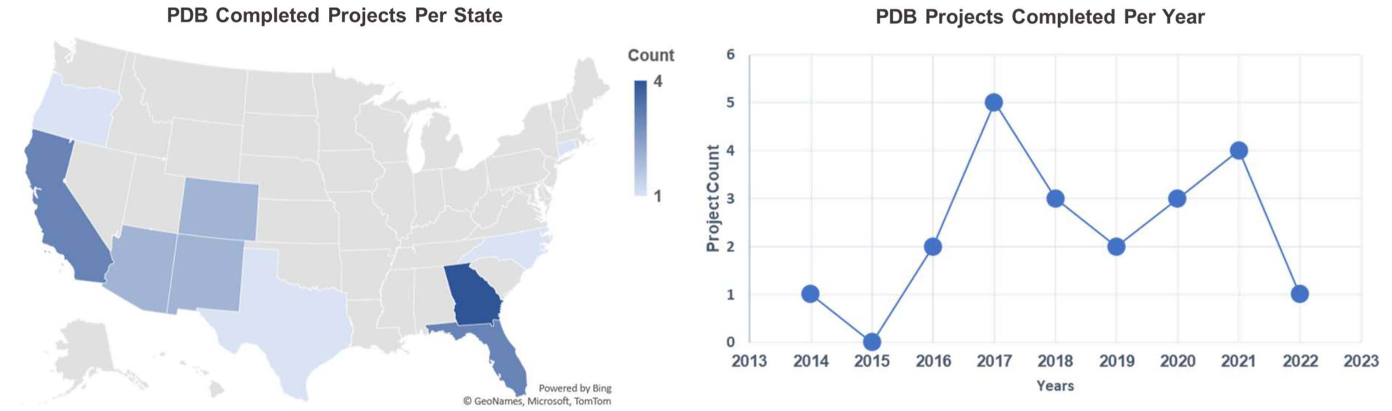
Data Collection

At the time of data collection (August 1, 2022), the DBIA dataset possessed 62 records of water and wastewater projects delivered using different variations of DB contracts. After manual data cleaning, and removal of duplicate projects as well as projects with missing cost and schedule data due to confidentiality, 21 PDB project records shown in Table 2 were considered in this study. Projects were completed between the years 2014 and 2022, with a cumulative total worth of more than $1.2 billion. Further details on the collected projects, including the DBIA reports URLs which provide further details on the assigned Design Build teams among other relevant project information, are furnished in Table S1 of the

Table 2. PDB projects dataset

ID	Project title	Location	Year	PM	SA	CD	AD	CC	AC
P1	Cogeneration Facility at the San José-Santa Clara Regional Wastewater Facility	California	2017	CPGMP	Integrated Design-Build Firm	1,694	1,694	$95.30	$98.50
P2	Cutter Lateral Reach 21 Water Treatment Plant and Associated Items, Navajo Gallup Water Supply Project (NGWSP)	New Mexico	2014	LS	Integrated Design-Build Firm	1,672	1,672	$68.80	$70.70
P3	Tanner's Bridge Road Water Pollution Control Plant	Georgia	2017	CPGMP	Contractor Led	841	886	$15.60	$15.60
P4	Eastside/Westside Sewer Interceptor Rehabilitation Design-Build Project	Georgia	2022	CPGMP	Integrated Design-Build Firm	843	863	$15.00	$15.00
P5	FY19 WM Improvements Project	Florida	2021	CPGMP	Contractor Led	1,081	864	$28.70	$29.50
P6	Goodyear Water Treatment Facility	Arizona	2017	CPGMP	Integrated Design-Build Firm	1,397	1,376	$128.90	$125.90
P7	Honey Creek Pump Station and Force Main Project	Georgia	2018	GMP	Contractor Led	439	419	$24.40	$24.40
P8	Ion Exchange Resin Plant and East Water Treatment Plant Improvements, City of Boynton Beach, FL	Florida	2019	Other	Integrated Design-Build Firm	973	973	$30.80	$25.50
P9	McAlpine Creek WWMF Design-Build Effluent Filters Upgrades and Expansion	North Carolina	2021	GMP	Integrated Design-Build Firm	581	581	$25.50	$25.30
P10	Midland Water Pollution Control Plant (WPCP) Expansion	Texas	2021	Other	Other	1,012	965	$134.00	$134.00
P11	Montevina Water Treatment Plant Improvements Project	California	2018	Other	Integrated Design-Build Firm	1,511	1,511	$47.90	$53.50
P12	Thornton Water Treatment Plant Replacement Project	Colorado	2017	CPGMP	Contractor Led	746	819	$78.50	$80.40
P13	Rockville Water Treatment Plant	Connecticut	2020	GMP	Designer (A/E) Led	692	677	$28.50	$27.20
P14	Rocky Creek WRF & Lower Poplar WRF Upgrades	Georgia	2021	GMP	Other	1,497	1,903	$33.00	$50.30
P15	The Santa Ana Wastewater Treatment Plant Membrane Bioreactor (MBR) Upgrades and Solids Handling Facilities Expansion Project	New Mexico	2016	GMP	Joint Venture	695	709	$17.30	$19.50
P16	Mel Leong Treatment Plant Upgrades Project	California	2020	CPGMP	Contractor Led	1,197	1,316	$64.90	$63.30
P17	Tres Rios Wastewater Reclamation Facility Nutrient Recovery Project	Arizona	2020	CPGMP	Integrated Design-Build Firm	774	774	$7.50	$7.40
P18	Metro Wastewater Reclamation District Northern Treatment Plant Facilities Project	Colorado	2016	GMP	Integrated Design-Build Firm	1,379	1,379	$275.80	$280.10
P19	Grants Pass Water Restoration Plant Phase 2 Upgrade Project	Oregon	2019	LS	Integrated Design-Build Firm	1,038	1,038	$25.50	$25.30
P20	Palm Beach County Water Utilities Department (PBCWUD) Optimization and Improvements Continuing Design-Build Contract 2015-2018	Florida	2018	CPGMP	Integrated Design-Build Firm	1,096	1,096	$14.30	$16.30
P21	Bush Beans Process Water Reclamation Facility	Tennessee	2017	GMP	Joint Venture	764	764	$57.20	$54.80

Note: PM: payment mechanism; SA: structural arrangement; CD: contracted duration (Days); AD: actual duration (Days); CC: contracted cost (Million USD); and AC: actual cost (Million USD).



(a)

(b)

Fig. 3. (a) Geographic distribution; and (b) actual completion years.

supplementary data. Results of the conducted descriptive, statistical, and content analyses of the extracted project records are elaborated in the following subsections.

Descriptive and Statistical Analyses

Completion Years and Geographic Distribution

Fig. 3 shows the distributions of the studied projects retrieved from the DBIA dataset in terms of their geographic location as well as their actual completion year. From the geographic distribution of the studied projects, it is observed that the state of Georgia had the overall highest number of projects, with four completed PDB water and wastewater projects. Followed by the states of California and Florida with three PDB water and wastewater projects in each state.

As for completion years, the first PDB project in the dataset dates to the year 2014. However, the number of yearly completed projects has been fluctuating since. Nevertheless, a significant increase in PDB project completion frequency can be observed in the years 2017 and 2021. Meanwhile, it should be considered that the project's dataset was retrieved in August 2022 to which the dip in the year 2022 may be attributable.

Procurement and Design Builder Selection Criteria

To get an aggregated overview of the bases of design builder selection under the studied PDB projects, the authors analyzed the previously highlighted comprehensive DBIA project reports submitted by project owners. In these documents, project owners provided detailed descriptions of the evaluation criteria used for the selection of the DB team and the weights allocated to each factor. The following seven design builder evaluation factors were prelisted by the DBIA: Price, Past Performance, Completion Schedule, Operations/Maintenance Costs, Lifecycle Costs, Technical Solution, and Image/Character of Design; however, owners are allowed to add any additional factors, and their respective weights as per their reported project. Similarly, owners can leave blank or zero the factors that were not considered in their DB team selection process. Nevertheless, these detailed reports were only available for projects completed after the year 2018. As such, the results shown in Fig. 4 were derived using 13 PDB projects that were completed after the year 2018 and had the DB team selection factors as well as their weights as publicly available data as indicated in Table S1. The resulting weights (w_i) for each selection factor (i) were determined by summing its assigned weights along each of the 13 projects (denoted as j). If a factor was not selected (meaning the owners did not consider it for selecting their design-build team), it was given a weight of zero. After the summation process, a normalized score for each factor was generated. This was achieved by dividing the sum of its raw weights (w_{ij}^{raw}) by the sum of all total weights (T_{all}). The calculation process is shown in the following Eq. (4). This process ensures a reasonable basis for comparison of the influence of each factor on the Design Build team selection process within the context of the studied projects

$$w_i = \frac{\sum_{j=1}^{13} w_{ij}^{raw}}{T_{all}} \tag{4}$$

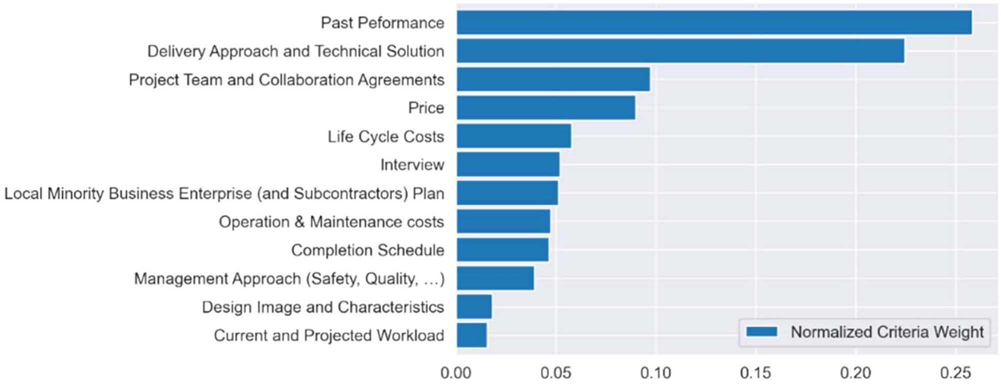


Fig. 4. Procurement and design builder selection criteria.

From Fig. 4, it can be observed that the selection criteria with the highest normalized weight for PDB projects were "Past performance" followed by "Delivery approach and technical solution." Notably, the 13 projects under analysis predominantly encompass complex upgrades, rehabilitations, and replacements of water treatment facilities and plants. These undertakings inherently introduce a layer of complexity, demanding a meticulous evaluation of design builder selection criteria beyond conventional cost parameters. Consequently, PDB projects displayed relatively lower weights for price and completion schedule factors, stemming from the inherent challenge of defining scope during procurement, especially in comparison to traditional DB projects. Nevertheless, PDB projects had placed weights on long-term performance metrics such as the expected life cycle costs as well as operation and maintenance costs. This strategic weighting underscores a notable advantage of PDB in the water and wastewater domain, facilitating enhanced long-range planning capabilities (Anderson 2022). It was also observed that some of the studied PDB projects had accounted for factors such as the subcontractor selection plan as well as the engagement of local or minority-owned business enterprises in the project. In addition to that, multiple PDB projects assigned a weight for the design builder's performance in an interview process. Other factors taken into consideration with relatively minor weights were the design builder's management approach, current and projected workloads as well as design image and characteristics. It is noteworthy to mention that the DBIA database and project report submission guidelines do not provide explicit definitions for the predefined set of criteria. As a result, project owners submitting such reports may have applied their own interpretations or relied on industry best practices to establish meaningful definitions for the criteria under consideration.

Structural Arrangements and Payment Mechanisms

Fig. 5 is a bar chart demonstrating the prevalence of different payment mechanisms and structural arrangements in the investigated PDB water and wastewater projects. In terms of structural arrangements, PDB projects were mostly dominated by integrated Design Build firm arrangements (11 out of 21), followed by contractor-led projects. Projects with joint venture (JV) agreements were relatively less frequent than both former arrangements. On the other hand, designer-led projects were the least common structure, with only a single project. As for payment mechanisms, PDB projects mostly applied CPGMP, followed by GMP mechanisms. On the other hand, lump sum (LS) payment mechanisms were only adopted in two PDB projects. Also, a considerable portion of the studied projects had customized structural arrangements and payment mechanisms developed on a bespoke basis.

Cost and Schedule Performance Metrics

The following paragraphs summarize the results of the statistical analyses including projects contracted as well as the actual durations, and costs, in addition to the calculated values for the following schedule and cost performance metrics: project schedule growth, project cost growth, and construction intensity. Such values were derived from the previously defined Eqs. (1)–(3), respectively. Also, results of the Shapiro–Wilk statistical investigations to test whether the dataset is normally distributed are summarized and presented.

Fig. 6 demonstrates the statistical distribution of the contracted and actual projects' costs in \$100 million, as well as their duration in days, highlighting their means and medians. From Fig. 6, it can be observed that the analyzed project durations range mostly between 500 and 1,500 days, with a seemingly normal distribution. On the other hand, the studied project costs histograms were skewed to the right with most project costs falling in the interval below \$100 million. Further elaboration on the statistical distributions of performance metrics is furnished in the boxplots shown in Fig. 7. The boxplots highlighted the existence of outliers beyond the boundaries of the interquartile range for the three-performance metrics; nevertheless, these were kept for analysis purposes as they were retrieved from actual project data. The boxplot results demonstrate that the 50% percentile of both the schedule and cost growth ratios were zero: indicating efficient performance on both fronts. Nevertheless, variances were more apparent on the cost growth ratio metric. On the other hand, the construction intensity metric spanned over a relatively wider range, with a 50% percentile of 40,177.25 \$/day. Further analysis of the results is provided in Table 3, which presents the summary statistics of the studied performance metrics.

As previously mentioned in the Research Methods Section, Shapiro–Wilk normality tests were conducted to determine which statistical measure (mean or median) would better depict the center of the distributions in the dataset. Results of the Shapiro–Wilk normality tests revealed that only the contracted and actual durations in the projects' dataset were normally distributed ($p>0.05$), whereas all other variables were not. Hence, except for the contracted and actual durations, the medians of the studied variables would be considered more representative measures of central tendency. Results of the summary statistics of the studied performance metrics are summarized in Table 3. Furthermore, individual results of the scheduled growth and cost growth ratios for each project are presented in Table 4.

The results depicted in Tables 3 and 4 provide further details on the histograms and boxplots represented in Figs. 6 and 7, respectively. With an average actual duration of 1,061 days, the mean duration of the studied projects was 17 days longer than the contracted duration of 1,044 days. This suggests that the projects

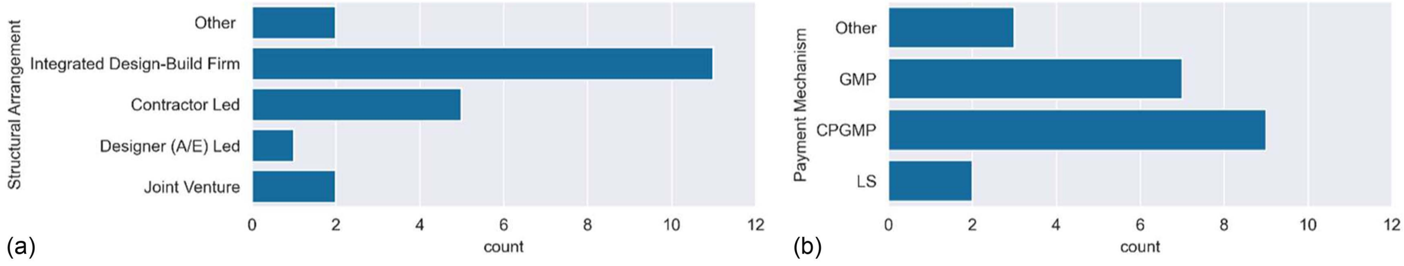
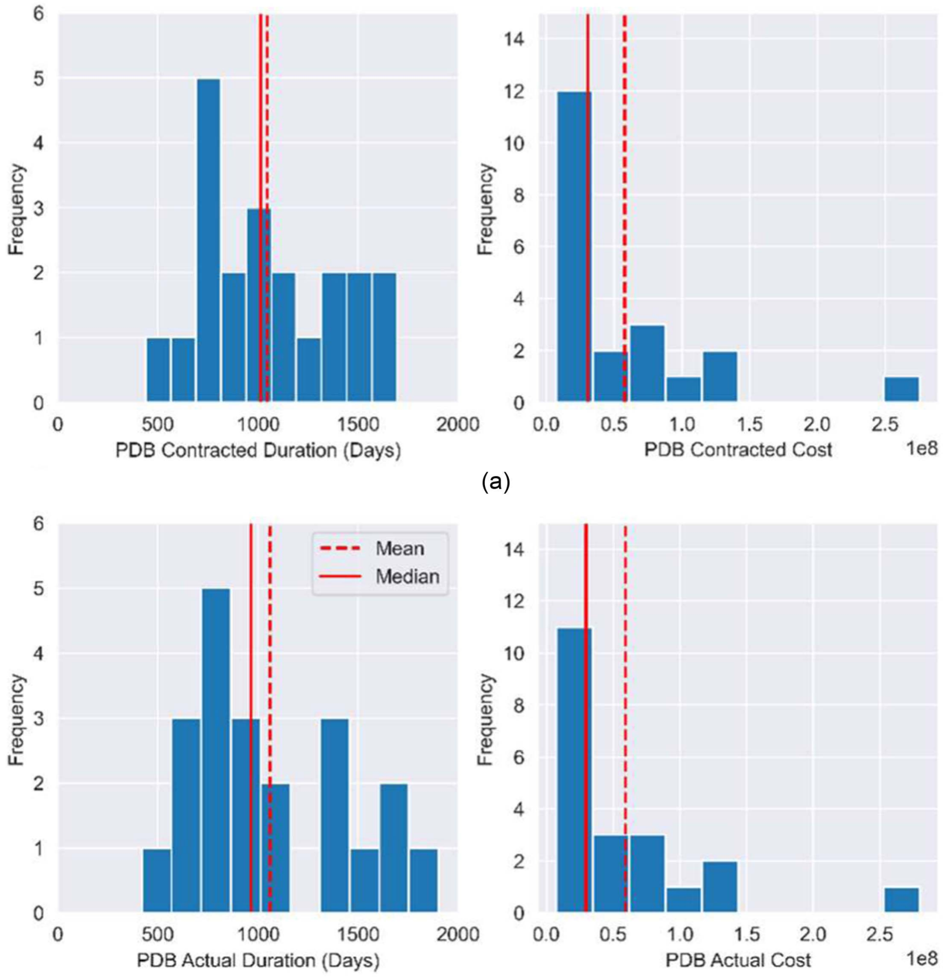


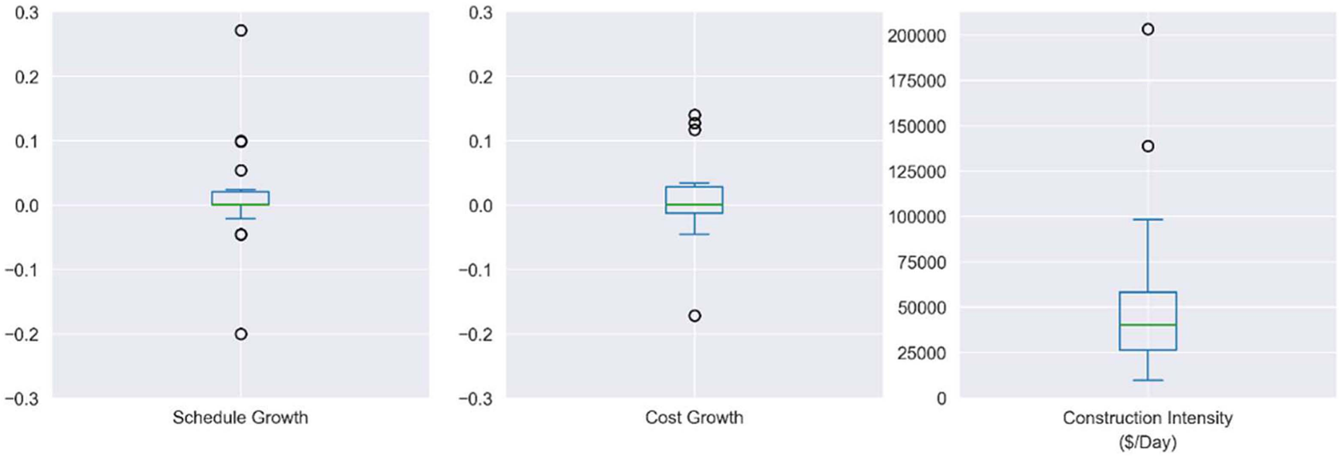
Fig. 5. (a) Structural arrangements; and (b) payment mechanisms.



(a)

(b)

Fig. 6. Project durations and costs: (a) contracted; and (b) actual.



(a) (b) (c)

Fig. 7. Project performance metrics boxplots: (a) schedule growth; (b) cost growth; and (c) construction intensity.

experienced some minor level of schedule growth. On the other hand, results of the actual and contracted project costs demonstrated that the median of actual costs was $1,273,184 less than those contracted. As for the construction intensity ratios, both the means and medians of the studied projects were relatively high, and this can be attributed to multiple factors including fast project pace or increased project complexity. As for the schedule and cost growth ratios, in addition to the values represented in the summary

Table 3. Project performance summary statistics

PDB project metrics	Summary statistics Mean	 Median	 Standard deviation
Contracted duration (Days)	1,044	1,012	364
Actual duration (Days)	1,061	965	401
Contracted cost ($)	57,970,789	30,800,000	61,816,630
Actual dost ($)	59,168,569	29,526,816	62,297,600
Schedule growth ratio	1.13%	0.00%	0.083%
Cost growth ratio	3.35%	0.00%	0.130%
Construction intensity ($/day)	53,684	40,177	46,708

Table 4. Individual projects schedule and cost growth ratios

Project #	Schedule growth (%)	Cost growth (%)
P1	0.00	0.03
P2	0.00	0.03
P3	0.05	0.00
P4	0.02	0.00
P5	−0.20	0.03
P6	−0.02	−0.02
P7	−0.05	0.00
P8	0.00	−0.17
P9	0.00	−0.01
P10	−0.05	0.00
P11	0.00	0.12
P12	0.10	0.02
P13	−0.02	−0.05
P14	0.27	0.53
P15	0.02	0.13
P16	0.10	−0.02
P17	0.00	−0.01
P18	0.00	0.02
P19	0.00	−0.01
P20	0.00	0.14
P21	0.00	−0.04

statistics Table 3, where both metrics had a median of 0.00%, Table 4 shows that 71% (15 out of 21) of the studied projects were completed on or before the contracted schedule. Whereas 57% (12 out of 21) of the studied projects were completed at or below the contracted cost.

In fact, the study results align with those of prior studies investigating PDB performance and comparing it to other delivery methods such as DB in different sectors. For example, both Adamtey (2020) and Alameri and Esmaeili (2021) reported that PDB had significantly better schedule performance, which aligns with the statistical summaries for schedule growth ratios. Moreover, in terms of cost performance, Liang et al. (2020), Adamtey (2020), as well as Alameri and Esmaeili (2021) concluded that PDB surpasses traditional DB in terms of cost performance, which can also be observed in the 0.0% median of cost growth ratios of the studied water and wastewater projects. Despite the lack of published research highlighting performance metrics of PDB using water and wastewater-specific project datasets, prior research and reports featuring single water and wastewater project case studies have also reported PDB's eminence in terms of accelerated schedules and cost certainty (Page 2021; Anderson 2022; Rankin et al. 2017; Kora et al. 2017; Keddy et al. 2022). This convergence in research further solidifies the merits of PDB and strengthens the case for its adoption in the industry. While the findings from the literature and the analyzed projects in this study are promising in relation to PDB outperforming DB, they still need to be further vetted in future research efforts using normalized data across different projects and sectors. This is because project performance is typically influenced by other project-related factors that may impact delivery system performance analysis (Moon et al. 2023; Franz et al. 2022). The upcoming content analysis section provides more in-depth insights into the factors impacting the actual performances of the studied PDB water and wastewater projects.

Content Analysis and Triangulation Results

This section summarizes the results of the inductive and hybrid content analyses of the studied 21 PDB project records. First, the results of materialized risks impacting the actual cost and schedule performances of the studied 21 PDB projects are compiled in the form of a frequency matrix. Second, results of the extracted PDB adoption drivers and challenges are presented and triangulated with findings from nine PDB-focused peer-reviewed academic articles, in addition to four published industry best practices and guidelines related to PDB from the DBIA as well as the WCDA.

Materialized Risks Impacting Cost and Schedule Performance

As explained earlier, PDB project delivery ensures early involvement of the design builder who shall work collaboratively with the owner to identify and mitigate risks earlier in the design phase. Despite all that, risks and unforeseen conditions may be encountered during construction and project implementation. To build on the findings of the previous subsection on PDB project performance in terms of schedule and cost, this subsection elaborates on the results of a deeper examination of the major risks impacting the schedule and cost of the investigated water and wastewater PDB projects. To this end, the authors reviewed and analyzed the narratives of the 21 PDB projects considered in this study to present the risks impacting project schedule (RS) and cost (RC). The occurrence of these risks in the 21 projects is shown in Table 5. The following paragraphs elaborate on the most frequently encountered materialized risks in the studied projects.

As can be seen in Table 5, the most frequent materialized risks and issues were related to owner-led changes, the impact of COVID-19, unforeseen site conditions, and adverse weather. Owner-led changes can be attributed to many factors in the context of PDB. First and foremost, the lack of definition in PDB projects requires substantial inputs from the owner for requirements and scope definition. Consequently, this input may result in an increased number of changes led by the owner. It was also observed that some of the studied PDB projects that had experienced schedule and cost growth due to owner-led changes were featured as DBIA Merit and Excellence award-winning projects on the database. In fact, this aligns with the findings of ACEC (2022), which concluded that owner-led changes as well as unforeseen site

Table 5. Materialized risks in the studied projects

Risk factors		Projects																				
		P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21
RS1	Delay due to COVID-19	x	x	—	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RS2	Delay due to owner-led change	x	—	x	—	—	—	—	—	x	—	—	—	—	—	—	—	x	x	—	—	—
RS3	Authorities permitting approval taking longer than expected	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RS4	Delay in the delivery of items	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—	—	x	—	—	—	—
RS5	Delay of utility supply to the site (water and power)	—	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RS6	Extreme weather and force majeure	—	—	—	x	—	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—	—
RS7	Interface with other projects in the vicinity	—	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RS8	Underperformed subcontractor	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—	—	—	—	—	—	—
RC1	Additional costs due to COVID-19	x	x	—	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RC2	Additional cost due to Owner-led change	x	x	x	x	x	x	—	—	—	—	—	x	x	x	x	—	—	—	x	x	—
RC3	Change in tax law (opportunity)	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—	—
RC4	The gap between available funds and project cost	—	—	—	—	—	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RC5	Hauling water to the construction site	—	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RC6	Unforeseen site conditions	—	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	x	—	—	—	—

conditions were attributed as root causes for schedule and cost growths, even for best-performing case studies. Nevertheless, the nature of the PDB approach effectively minimizes the impacts of owner-led changes compared to other delivery methods given that it enables owners to sufficiently develop their requirements in the preliminary design phase without resulting in rework in construction (Liang et al. 2020). Regarding the studied projects, owner-led changes had an impact on both project schedule and cost. However, the reported project narratives indicated that owner-led changes had a higher impact on project costs as compared to schedule overruns. Out of the studied 21 PDB projects, 12 projects reported owner-led change as the reason for cost growth, while five projects reported the same for schedule delays.

The emergence of COVID-19 as a major cause of schedule delay and cost increase was justifiable due to the timeframes of the studied projects shown in Fig. 3. Similar to COVID-19-induced project cost and schedule overruns, material shortages and supply chain disruptions attributed to the pandemic were also reflected in the performance of some of the studied PDB projects. However, these were less frequent. Other materialized risks in the studied water and wastewater PDB projects included unforeseen site conditions, problems in getting access to utilities on-site, funding and permitting obstacles that are prevalent in water and wastewater projects, in addition to issues with the subcontractor's performance.

PDB Adoption Drivers and Challenges

This subsection illustrates the 25 adoption drivers and 12 challenges extracted from the studied projects and publications. Drivers, challenges, and their grouped categories were first derived from Alleman and Tran (2021), who provided a thorough analysis of PDB in highway construction projects using insights from the literature, interviews with industry practitioners, as well as two case study projects. Furthermore, additional factors and categories were included by thematic relevance as part of the previously explained hybrid content analysis approach. Table 6 shows the frequency of the identified drivers in each of the reviewed document types, whereas Table 7 demonstrates the resulting frequency after grouping the identified drivers into categories based on their nature and characteristics. Similarly, Tables 8 and 9 list the frequency of the identified adoption challenges and their categories, respectively.

Planning and Risk Management Drivers. The early input from the design builder firm and the owner's participation in the design process play an essential role in the unique risk management structure of PDB. From an owner's perspective, PDB retains the advantage of DB which shifts more risks toward the design builder. However, unlike traditional DB, PDB owns a unique advantage where the Spearin risks can be minimized or even eliminated if the design builder is selected to complete the entire design effort. Additionally, this approach offers a chance to actively manage those risks more equitably throughout the design process by agreeing to share those risks with the progressive design builder (Gransberg and Molenaar 2019). As can be seen in Table 6, planning and risk management drivers were the most highly cited in both projects and literature. More specifically, drivers related to enhanced cost and schedule risk management, risk control, as well as the ability to fast-track the project and achieve cost savings were highlighted by both the studied projects as well as published literature in the domains of water and wastewater (Feghaly et al. 2020), highways (Alleman and Tran 2021), airports (Gad et al. 2019), and buildings (Shang and Migliaccio 2020). Since PDB grants owners the opportunity to advance the scope and design development in collaboration with the design builder, it allows owners to influence the scope while also taking budget constraints into account. In the context of water and wastewater projects, the WCDA emphasized the superiority of PDB

Table 6. PDB adoption drivers

			Literature									Manuals & best practices				
Code	PDB drivers	21 PDB project narratives	Adamtey 2020	Adamtey and Onsarigo (2019)	Alameri and Esmaeili (2021)	Alleman and Tran (2020)	Alleman and Tran (2021)	Feghaly et al. (2021)	Gad et al. (2019)	Gransberg and Molenaar (2019)	Shang and Migliaccio (2020)	DBIA (2018)	WCDA (2019)	WCDA (2021)	ACEC (2022)	Total citations
D1	More owner involvement and control for design	4x	**x**	**x**	**x**	**x**	**x**	—	**x**	**x**	**x**	**x**	**x**	**x**	—	15
D2	Better management of project schedule and cost risks	3x	**x**	**x**	**x**	**x**	**x**	—	**x**	**x**	**x**	**x**	**x**	**x**	—	14
D3	Fostering collaboration and integrated team	8x	—	—	—	—	**x**	**x**	—	**x**	**x**	**x**	—	—	**x**	14
D4	Increased cost and/or schedule control	8x	**x**	**x**	**x**	—	**x**	—	—	—	—	**x**	—	—	—	13
D5	Innovation and creativity	7x	**x**	**x**	—	—	**x**	—	—	—	**x**	**x**	—	**x**	—	13
D6	Project fast-tracking capability	5x	—	—	**x**	—	**x**	—	**x**	**x**	—	**x**	**x**	**x**	—	12
D7	Early design builder input	2x	—	—	—	**x**	**x**	**x**	**x**	**x**	—	**x**	—	**x**	—	9
D8	Anticipated cost savings	5x	—	—	**x**	—	**x**	—	—	—	—	—	**x**	—	—	8
D9	Expedited and cheaper procurement	2x	—	—	**x**	**x**	**x**	—	—	—	—	**x**	—	**x**	—	7
D10	Clearer lines of responsibility	2x	—	—	**x**	—	—	—	—	**x**	**x**	—	**x**	**x**	—	7
D11	Off-ramp opportunity	—	**x**	**x**	—	—	**x**	—	—	**x**	—	**x**	—	**x**	—	6
D12	More owner control for the procurement process	1x	**x**	**x**	—	—	**x**	—	—	—	—	**x**	—	**x**	—	6
D13	Flexibility of PDB	2x	—	—	**x**	—	**x**	—	—	—	—	—	—	**x**	—	5
D14	Qualifications-based selection	1x	—	—	—	—	**x**	—	—	**x**	—	—	—	**x**	—	4
D15	Higher requirements of project quality	3x	—	—	—	—	—	—	—	—	—	×	—	—	—	4
D16	Transparency of the open-book process	—	**x**	**x**	—	—	—	—	—	**x**	—	—	—	**x**	—	4
D17	Supporting local community and small businesses	4x	—	—	—	—	—	—	—	—	—	—	—	—	—	4
D18	Regulatory requirements to use PDB	—	—	—	—	—	—	—	—	—	**x**	—	**x**	—	—	2
D19	Increasingly complex technical solutions	—	—	—	**x**	—	—	—	—	—	—	—	**x**	—	—	2
D20	Reduced permitting and environmental challenges	—	—	—	**x**	—	**x**	—	—	—	—	—	—	—	—	2
D21	Negotiation after the full scope is defined	—	—	—	—	—	**x**	—	—	**x**	—	—	—	—	—	2
D22	Similar successful projects	—	—	—	—	—	—	—	—	—	—	—	**x**	—	—	1
D23	Increased contractor engagement and interest	—	—	—	—	—	—	—	—	—	—	—	**x**	—	—	1
D24	Achieve fair market value	—	—	—	—	—	**xx**	—	—	—	—	—	—	—	—	1
D25	Early work packaging	—	—	—	—	—	**x**	—	—	—	—	—	—	—	—	1

Table 7. Categories of PDB adoption drivers

Category	Driver(s)	Number of citations for category
Planning & risk management drivers	D2, D4, D6, D8	48
PDB process drivers	D1, D3, D7, D12, D23	44
Procurement and stakeholders engagement drivers	D9, D14, D16, D17, D20, D24	22
Legal & contractual drivers	D10, D11, D13, D18, D21	22
Project complexity & innovation drivers	D5, D15, D19, D22	20

when the project scope is poorly defined, changes are anticipated, and the owner intends to be involved in the design process (WCDA 2021). This resolves one of the main reported disadvantages of DB projects in the water and wastewater sector, where owners' levels of design involvement and control are minimal (Feghaly et al. 2021). In addition to allowing for managing and amending the project's budget as the design progresses, PDB also allows for construction activities to be initiated prior to full design completion, thus resulting in a more efficient and condensed schedule (Page 2021). Further, PDB eliminates the need for the development of design baselines or bridging documents prior to the selection of the design builder, thus effectively reducing the project duration, and permitting early work packages to phase the work (DBIA 2018).

PDB Process Drivers. PDB process drivers revolve around the increased owner involvement as well as the early-on engagement of the design builder in both the design and construction phases, and more importantly, the enhanced collaboration between all parties. The latter was the highest reported driver in the studied PDB projects, tying with increased cost and schedule control. Hence, constructability issues and design obstacles are less likely to arise when multiple parties collaborate through a single contract, under the owner's direction, and with timely input. This driver was previously referred to by Alleman and Tran (2020) who investigated PDB in the transportation sector, where they stated that value engineering efforts are continuously provided before establishing an agreed price, and the engaged stakeholders get to select between and optimize multiple combinations of solutions for the project. This early input combined with collaborative open-book pricing bridges the understanding of project parties and steers the development of cost and schedule estimating models and parameters as the design progresses (WCDA 2021).

Procurement and Stakeholders Engagement Drivers. As previously discussed, the procurement process of the design builder in a PDB project is generally based on qualifications, delivery strategies, and limited pricing information (Fig. 4). Consequently, the procurement of a PDB team typically takes less time than a fixed-price procurement, allowing the owner to gain access to the team, commence design, and gain a better grasp of the project's cost as the design advances prior to setting price commitments. In addition, the PDB method uses open-book estimates, in which expenses must be computed in full transparency, with no hidden or inflated charges. In other words, the cost estimation procedure is documented and is accessible for the owner to examine (WCDA 2021). Lastly, one of the PDB adoption drivers was its support for the local community and small businesses, which has been emphasized in four of the studied projects' narratives, as well as the reported design builder selection criteria, yet was not mentioned in the relevant literature or best practices. Nevertheless, this qualification-based

Table 8. PDB adoption challenges

Code	PDB challenges	21 PDB project narratives	Literature								Manuals & best practices			Total number of citations
			Adamtey and Onsarigo (2019)	Adamtey (2020)	Alleman and Tran (2020)	Alleman and Tran (2021)	Feghaly et al. (2021)	Gad et al. (2019)	Gransberg and Molenaar (2019)	Shang and Migliaccio (2020)	DBIA (2018)	Shorney-Darby (2012)	CPARB (2017)	
C1	Owner's education and culture (mindset change)	1x	x	x	x	x	—	x	x	x	—	x	—	9
C2	Statutory, legal, and procurement requirements	1x	x	x	x	x	—	—	x	x	x	x	—	9
C3	Additional owner resources requirements	1x	x	x	x	x	x	—	—	—	—	—	x	7
C4	Industry resistance to change	—	x	x	x	x	—	—	—	x	x	—	—	6
C5	Price is not a selection factor	1x	x	—	x	x	—	—	—	—	x	x	—	6
C6	Difficulty in integrating the PDB team	3x	—	—	x	x	—	—	—	—	—	—	—	5
C7	Increased owner involvement requirements	1x	—	—	x	x	—	—	—	x	—	—	—	4
C8	Third-party assistance requirements	2x	—	—	x	x	—	—	—	—	—	—	—	4
C9	No contract with the designer	—	—	—	x	x	—	—	—	—	—	x	x	4
C10	Challenges with negotiations	—	—	—	x	x	—	—	—	—	—	—	—	2
C11	Concerns with off-ramp	—	—	—	—	x	—	—	—	—	x	—	—	2
C12	Awarding without full competition	—	—	—	—	—	—	—	—	—	x	—	—	1

Table 9. Categories of PDB adoption challenges

Category	Challenge(s)	Number of citations for category
Legal and contractual challenges	C2, C5, C9, C10, C11 C12	24
Owner's challenges	C1, C3, C7, C8	24
Design builder and industry challenges	C4, C6	11

procurement nature of PDB has been reported to encourage team formation and attract firms that may not otherwise pursue the project (WCDA 2021).

Legal and Contractual Drivers. In terms of legal and contractual relationships, PDB has clear lines of responsibility, where the design builder retains responsibility for design as it progresses till up to 60% and 90% completion prior to setting and committing to a project price. Yet, such a price, which is submitted mostly using a GMP or CPGMP basis (Fig. 5), is developed over the course of the design process through open-book cost estimates. Hence, creating the maximum potential for transparency and trust with the owner prior to submitting either a GMP or fixed-price bid. Consequently, if the owner approves the furnished price, the design builder will be given the green light to proceed with the design, permits, subcontractor, and vendor procurement, construction, commissioning, and acceptance testing. Otherwise, the off-ramp option grants the owner the authority to terminate the PDB contract if the owner and design builder cannot reach an agreement on the project's budget, timeline, or risk allocation. If project parties resort to the off-ramp option, the owner can either finalize the design and proceed with a DBB procurement, or they can negotiate with another design builder to reach a pricing agreement, depending on the laws in their state (WCDA 2021). However, the off-ramp option has been reported as both a driver and a challenge in the literature and was not referred to in the studied project narratives because it provides owners with an exit option if negotiations were unsuccessful and would be considered a failure to hire another contractor after investing time and effort with the previously selected party (Alleman and Tran 2020).

Project Complexity and Innovation Drivers. Innovation and creativity drivers were the third most reported PDB selection drivers in the studied water and wastewater project narratives. Coupled with the previously mentioned qualification-based design builder selection, PDB allows for absolute flexibility and innovation to derive project-specific solutions. As such, PDB was reported to be more well-suited to more complex projects, with more stringent technical and quality requirements, and unfamiliar scopes. This finding also aligns with the reported innovation opportunities by previous PDB studies such as Shang and Migliaccio (2020) in the building sector, as well as Adamtey (2020) who studied PDB projects in multiple sectors. Such innovation opportunities were emphasized in the studied documents and project reports and could be proxied by the implied significantly higher reported project durations and costs (Fig. 6).

Legal and Contractual Challenges. Most of the documented legal and contractual challenges related to PDB implementation were related to statutory legislations concerning qualifications-based procurement processes. Since PDB is mostly centered on qualifications-based selection procurement (Gad et al. 2019), only states that allow qualifications-based selection would allow for PDB in public projects. In fact, Alleman and Tran (2021) found that only five states allow for qualifications-based selection in public projects and hence PDB. These states are (1) Alabama, (2) Arkansas, (3) Delaware, (4) Oregon, and (5) Virginia. Nevertheless, PDB and qualifications-based selection legislation are still evolving. For instance, at the time of writing this article, the California Senate Bill No. 199 is considered the most recent PDB legislation (effective January 2023). This bill allows local agencies in the state of California to use PDB to provide for "the production, storage, supply, treatment, or distribution of any water from any source."

Another challenge is the fact that agencies in most public sector projects have been working with traditional DBB and DB with best-value selection which reveals the price component before initiating the contractual relationship with the design builder. Nevertheless, unlike qualifications-based selection for DB projects, PDB and its open-book estimation process provide owners with the confidence that they will not be overpaying for the project (Gransberg and Molenaar 2019). However, it should be taken into consideration that this challenge also correlates to difficulties that may arise due to a lack of experience in negotiations for design builder selection since price is not a selection factor. Other documented challenges included the lack of a contract with the designer entity, which is a common challenge for DB projects, together with already discussed concerns related to the off-ramp option. The discussed legal challenges are anticipated to alleviate as more state agencies modify their DB legislation to allow for PDB (Alleman and Tran 2021).

Owner's Challenges. Despite its advantages, the PDB process is a major shift from traditional DB and its best-value selection approach; thus, one of the fundamental challenges pinpointed in the studied literature is raising sufficient awareness of all project parties, education, and supporting culture. This poses an essential task due to the unique process of PDB and the absence of price-based selection. This finding aligns with the challenge that was also raised by prior studies investigating PDB in the context of highways (Alleman and Tran 2021) as well as airports (Gad et al. 2019). Since the PDB process is dependent on the owner's input, more time and effort are needed on their end to move the design forward. Additionally, PDB relies on an open-book process for developing cost and pricing during preconstruction and final price development (WCDA 2021). To realize both, more resources from the owner's side are required. Although collaborative delivery techniques are becoming increasingly popular, some owners may be hesitant to make the switch from DBB due to a lack of necessary expertise. To overcome such challenges, employing an owner advisor (OA) on board to assist with the required resources and increased involvement is essential. In fact, the WCDA has deemed the involvement of an OA a distinctive feature of PDB projects (WCDA 2021). More specifically, the WCDA (2021) pointed out that hiring an OA would provide necessary support with technical reviews, procurement assistance, and supervision (WCDA 2021).

Design Builder and Industry Challenges. Difficulty in integrating the PDB team was one of the most reported challenges in the studied water and wastewater PDB project narratives and supported by the triangulated literature in other sectors such as highways as well (Shorney-Darby 2012; Alleman and Tran 2021). In addition to that, similar to owners' uncertainty about the ability of PDB to deliver the same value as fixed price DB (FMI 2021), contractors' resistance to change and a lack of industry interest has been reported in the literature as an obstacle hindering PDB adoption in general (FMI 2021; Alleman and Tran 2020). However, these challenges can be greatly reduced by spreading awareness, and sharing knowledge, lessons learned, and best practices associated with PDB to get adequate buy-in from decision makers in the water and wastewater sector.

Research Contributions

This study adds to the body of knowledge on alternative project delivery methods as well as water and wastewater infrastructure by presenting a data-driven investigation of PDB in the water and wastewater projects by harnessing data from 21 PDB water and wastewater project records compared to just one or two case studies at most in prior important studies within the existing literature that may have studied PDB in such critical sector. Such investigation included: (1) an aggregated snapshot of the state of PBD adoption in the water and wastewater sector and its actual performance; (2) the most frequently materialized risks that have impacted cost and schedule performances of actual projects and finally; (3) compiled and triangulated a comprehensive list of key PDB adoption drivers and challenges that need to be considered for its implementation. Furthermore, this study provides practical implications to water and wastewater project stakeholders by presenting PDB—and its identified attributes—as an alternative to be considered in the delivery method selection process. In other words, the managerial insights generated from this paper can assist stakeholders in making informed decisions by weighing the advantages and challenges of PDB identified in this research against more traditional delivery approaches.

Conclusions

This research addresses the need to examine the emergence of PDB projects in the water and wastewater sector, which is anticipated to rise considering recent significant infrastructure investments and successful implementation case studies. First, the study used records from 21 PDB projects from the DBIA database to quantitatively examine the adoption of PDB and its performance in the water and wastewater sector. Second, from the retrieved records, the authors compiled the most frequent issues and materialized risks impacting the actual performance of these projects. Finally, the authors triangulated findings from the retrieved records with published PDB literature and industry best practices to present a comprehensive list of PDB adoption drivers and challenges. The study's main conclusions are as follows:

- Water and wastewater PDB projects considered in this study are spread across 11 states, with Georgia having the highest number of projects (four), followed by California and Florida (three each). Design builder selection was primarily influenced by qualifications-based criteria, with historical performance and partnership agreements carrying the most weight. PDB projects performed well, with 71% of them completed on time or ahead of schedule and 57% delivered under budget.
- The analysis of project narratives revealed that owner-led changes and the impact of COVID-19 were the primary drivers of cost and schedule overruns in PDB projects. However, the nature of PDB significantly reduced the risks associated with owner-led changes. Interestingly, some projects experiencing growth were DBIA award-winning projects that demonstrated exceptional performance.
- The compilation of adoption drivers and challenges identified common themes such as increased cost control, schedule management, and the fostering of collaboration. Challenges related to integrating the PDB project team were prevalent, while the literature emphasized owner education and statutory/legal requirements. PDB project planning and risk management were dominant adoption drivers, while legal/contractual restrictions and owner-related concerns were frequent challenges.

Considering the expected surge in water and wastewater infrastructure projects following the Bipartisan Infrastructure Law and other public investment acts, the study recommends further research to assess their impact on PDB adoption and alignment with the study's findings. Comparing the impacts of recent legislative bills that allow public agencies to adopt PDB, such as California S.B. 199 and the New York City Public Works Investment Act, would also be a valuable direction for future research. The study's findings can serve as a benchmark for water and wastewater projects, offering valuable insights for future investigations into PDB performance in other sectors. However, generalizations of these findings to other project sectors should be approached cautiously, as the role of project sectors plays a significant moderating role in studying the performance of project delivery methods.

Acknowledging certain limitations of the study, including the limited number of investigated projects and their diversity in scope within the water and wastewater infrastructure sector as well as the relatively small number of existing PDB literature for triangulation purposes, the authors propose future research directions to address these issues. First, incorporating a larger number of PDB projects spanning diverse infrastructure sectors, beyond the water and wastewater domain, stands as a promising step. This expansion would facilitate a comprehensive exploration and comparison of performances while also enabling cross-validation and enhancing the generalizability of the findings presented in this study.

Secondly, leveraging specialized scope-specific metrics tailored to each project's unique attributes can significantly enhance the practical relevance of research insights. Metrics such as cost or schedule per unit output, like per mile of road or unit length of constructed pipeline, provide a tangible means of assessing project performance that resonates more directly with industry practitioners and decision makers. Furthermore, delving into performance differences between PDB projects and alternative delivery methods across various infrastructure sectors offers an avenue to uncover valuable comparative insights. Analyzing the impact of payment mechanisms and structural arrangements on project outcomes provides an additional layer of understanding that can inform and guide effective decision-making.

Lastly, embracing predictive analysis using historical PDB project data and emerging datasets offers a proactive approach to decision-making. By harnessing advanced data analytics, researchers can anticipate challenges, optimize strategies, and contribute to more efficient project outcomes. As additional data becomes available over time, continuous refinement of predictive models can further enhance their accuracy and practical applicability. In essence, these proposed research directions go beyond the scope of this study, leading to a better grasp of project delivery dynamics and adding to the ongoing evolution of PDB delivery practices.

Data Availability Statement

All data, models, and code generated or used during the study appear in the published article.

Supplemental Materials

There are supplemental materials associated with this paper online in the ASCE Library (www.ascelibrary.org).

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