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Advancing Airport Project Delivery: A Comparison Of Design-Build And Traditional Methods In Terms Of Schedule And Cost Performance

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Abstract: Current airport infrastructure is in a state of decline, with reports scoring it at an underperforming classification of D+. To address this issue, significant improvement and advancement of the infrastructure is needed. With backing on an authoritative level, the nation can expect an increase in the number of improvement projects. Airport stakeholders have long been accustomed to delivering their projects using traditional methods, such as design–bid–build (DBB). Design–build (DB) is an alternative delivery method that has added benefits for project metrics, such as schedule and cost performance. There is a lack of research evaluating DB within the context of airport projects. This study fills this knowledge gap. The goal of this research is to provide an improved understanding of DB with respect to DBB on fundamental key risks that impact schedule and cost performance in airport projects. This goal is achieved by a multistep interdependent methodology comprised of: (1) collecting and assessing data on 34 risk factors, (2) calculating the risk ratings of each factor, and (3) statistically analyzing the risks for their actual effect, as well as how they are perceived by between different stakeholder groups. The results show that the traditional DBB delivery method results in greater risks for most risk factors than does DB. Furthermore, contractors perceived DBB more negatively than DB. The top significant risk in DBB is the low level of team collaboration. Conversely, while statistically insignificant, unclarity or incompleteness in project scope was the most critical risk factor in affecting DB. To this end, DB implementation has promise for handling many risks better than DBB, and greater integration of DB should be prioritized in future airport projects to reap those added benefits. Ultimately, this research contributes to the body of knowledge by providing insight for airport stakeholders on the crucial risk factors that must be considered in project delivery. **DOI: 10.1061/JMENEA.MEENG-5490.**

Introduction

The aviation sector in the US is lagging behind the average performance of the country's overall infrastructure. According to the ASCE 2021 report card (ASCE 2021), the nation's airport infrastructure received a grade of D+, far below the acceptable standards required. Many airports, as well as their associated infrastructures, require modernization and upgrades to meet the increasing demand for air travel, as shown by the fact that that none of the top 25 airports worldwide are located in the US, as some rankings report (White House 2021). In the last few years, as the demand for air travel has increased by 24%, the time delays at airports have also increased by a staggering 45% (BTS 2019b, a). There is a dire need to update the deteriorating airport infrastructure to support these demands effectively. US governmental bodies have recognized this, and have called for investments to substantially improve the nation's airport infrastructure (White House 2021).

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By investing in the modernization and upgrade of the US airport infrastructure, we can expect an increase in major projects related to terminal facilities, airfields, and other capacity-related work (ACINA 2019; NPIAS 2019). However, such projects often face challenges related to cost and schedule performance. Funding shortages, regulatory hurdles, lack of coordination among stakeholders, and many other factors can all impact airport projects and cause delays and cost overruns. In addition, such projects are traditionally delivered using outdated project delivery methods (PDMs) such as design–bid-build (DBB) (MoDOT 2020). DBB provides limited contractor input, especially in phases preceding construction, greater disputes due to design errors, resulting in increased cost and delays, decreased performance due to process fragmentation, lack of collaboration and communication, and ineffective shift of risk (Tran and Molenaar 2014; Pishdad-Bozorgi and de la Garza 2012; Papajohn et al. 2020; Nikou Goftar et al. 2014; Bypaneni and Tran 2018; Alleman and Tran 2020). Accordingly, the use of PDMs becomes vital to support efficient and effective construction that will result in improved cost and schedule performance, and overall project success.

Design–build (DB) is an effective alternative PDM for infrastructure projects because it can provide fast-tracked delivery through better cost control and time efficiency techniques. This is in part due to having a design–builder with a single point of responsibility towards the client in both the design and the construction of the project (Abou Chakra and Ashi 2019; Ramsey et al. 2016; Beard et al. 2001; Gransberg et al. 2006; Loulakis et al. 2015). Adopting this system can greatly streamline the delivery process and reduce the risk of disputes and therefore delays (Ramsey et al. 2016). Previous research assessed DB from cost and schedule perspectives. Shrestha et al. (2012) found that the delivery speed in large highway projects is four times faster in DB than in DBB. Hale et al. (2009) concluded that the unit cost of DB was 3.4% lower than that of DBB.

However, no one has studied DB implementation in airport projects. This is important, as DB is particularly well-suited for airport construction projects. Specifically, it can provide the following to airport projects:

- Greater collaboration and coordination between the design and construction teams to quickly identify and address potential issues, which tend to be very complex because they involve many different stakeholders and intricate systems, components, and facilities.
- Greater flexibility and adaptability to react efficiently in addressing unique site conditions, such as challenging topography or proximity to existing airport infrastructure.
- Improved seamless integration of complex systems, such as air traffic control and security, because the design and construction teams can both influence the delivery of projects effectively.
- Minimization of project schedules by concurrently completing the design and construction of a project so as to minimize disruptions to airport operations and flights.

Despite these advantages, there is a clear lack of studies of airport projects from the perspective of DB, and in particular cost and schedule performance. Khalef and El-adaway (2023) noted that the airport sector has the least number of DB-related studies of all construction sectors. Thus, this research aims to fill this gap in the literature by providing holistic insight into the increased value that DB provides over traditional delivery methods. Ultimately, this research promotes better risk management implementation and supports overall project success in modern airport projects.

Goal and Objectives

The goal of this paper is to provide an improved understanding of DB with respect to DBB on associated fundamental key risks that impact schedule and cost performance in airport projects. To this end, objectives of this research include (1) quantifying risk factors within the context of airport projects, (2) identifying those risk factors that affect cost and schedule performance, and (3) holistically providing a greater understanding of how these risks are perceived by different stakeholders. Furthermore, in-depth discussions are provided regarding the effect of those risks on airport projects.

Background Information

Currently and traditionally, airport projects are delivered using techniques such as DBB (MoDOT 2020). This is a common phenomenon not just in the airport sector, but also in various other infrastructure sectors that are reluctant to adopt modern delivery techniques such as DB (Shrestha and Batista 2020; Hashem 2014; Bo and Chan 2012). In a conversation with a lead director of airport planning and development works, a surveyed anonymous expert (involved in directing the findings of this research), despite the many benefits that airport projects could reap from DB implementation, airport stakeholders are "accustomed" to traditional practices (DBB) as "this is just how we always did it." Resistance to change has always been a trait of the construction industry (Davis 2004), and airport projects are no different in this regard (MoDOT 2020). Historically, this resistance was also on an authoritative level, from two ends (Gad et al. 2019). From one end, there was an abundance of public projects, including airport projects, that limited DB implementation due to the requirement to award projects to the lowest responsible bidder. On the other end, the Brooks Act of 1972 (40 U.S.C. 1101) requires design procurement for federally funded projects to be based on the qualification of architects and engineers, rather than price. For these reasons, public projects, and particularly airport projects, have been limited to the traditional DBB form of project delivery. Recently, there have been efforts made to adopt DB as a PDM in infrastructure projects. In 1996, Congress passed the Clinger-Cohen Act (40 U.S.C. 1401) that permitted the adoption of DB for projects that are under the Federal Acquisition Reform Act (Loulakis 2003; Touran et al. 2009; USDOD 1996). Consequently, the Federal Aviation Administration (FAA) permitted the use of DB as an acceptable PDM in airport projects (FAA 2005), as seen in its Advisory Circular (AC) 150/5100-14D updated stipulations. Even with all these strides, the traditional form of delivery remains the dominant technique in airport projects.

The current state of airport construction suffers from a certain lack of initiative to innovate, as the sense of familiarity with traditional methods trumps the potential of modern and more effective methods that have not yet been implemented. Past airport-related research does not help in that regard, either. In fact, in DB-related research, the airport sector is the most understudied of all construction sectors, totaling about 5% of the entire body of DB knowledge (Khalef and El-adaway 2023). Thus, there is a clear benefit to all stakeholders, including researchers, to show the benefits, or lack therein, of implementing DB in airport projects. DB has realized many schedule and cost performance advantages in several industries or sectors including general, transportation, water/wastewater, military, and others (Shrestha et al. 2012; Park et al. 2015; Feghaly et al. 2020; Hale et al. 2009). In addition, recent and extensive DB assessments have also compared DB to DBB in different construction sectors.

Tran et al. (2018) compared the cost and schedule growth of DBB and DB highway projects built by the Florida DOT through five categories: miscellaneous construction, intelligent transportation systems, resurfacing/restoration/rehabilitation, reconstruction, and new construction projects. Abou Chakra and Ashi (2019) performed a comparative analysis that assessed DBB and DB residential projects in Lebanon across safety, risk, communication, quality, time, and cost performance metrics. Nguyen et al. (2021) analyzed the impact of project size on construction intensity and schedule/cost growth in DBB and DB highway projects in department of transportation (DOT) projects. Kalsaas et al. (2018) studied the differences between DBB and DB contracts in roadway projects from aspects related to quality and customer value, construction cost and time, and constructability. Similarly, Järvenpää et al. (2019) researched how typical road projects (and, specifically, their clients) transitioned from DBB to DB from the perspective of organizational change. Salla (2020) investigated the perception of construction professionals of the performance quality of DBB and DB general construction projects. AL-Smadi et al. (2021) cross-examined DBB and DB Jordanian construction projects through different local constraints such as political and economic conditions. Wubbels (2021) provided an increased cost performance understanding by comparing DBB and DB projects in the Netherlands. Oyelami and Shittu (2019) assessed and strategized risk management procedures by contrasting the DBB and DB delivery methods in Nigerian projects. Moon et al. (2020) conducted a comparative analysis on cost performance metrics in DBB and DB building and civil projects in South Korea.

It can be seen that none of the foregoing research addressed the airport sector, especially from a schedule and cost perspective. Accordingly, there is a clear gap in the literature. And thus comes the motivation for this research in quantifiably understanding how DB impacts the schedule and cost performance of airport projects, in comparison to traditional delivery methods such as DBB. The aim of this research is to advance the lagging airport sector with added knowledge and guidelines for better managing their projects using effective delivery methods such as DB. Through the findings

of this research, airport stakeholders will have a good holistic understanding of the risks and rewards of DB implementation compared to traditional delivery. Overall, this research will be of interest to airport and DB-related stakeholders, and researchers.

Methodology

The authors of this research employed an interdependent multistep methodology, constituting of the following three steps: (1) collection and assessment of data, (2) calculating the risk ratings, and (3) analyzing the data. Fig. 1 illustrates those steps. Subsequent sections shall provide more information on the specifics of each step.

Step 1: Collection and Assessment of Data

Survey Development

This research used Qualtrics, an online survey distribution platform, to collect the data needed regarding the risk factors affecting DB airport project delivery in terms of cost and schedule. Khalef and El-adaway (2023) performed a systematic literature review and identified a comprehensive set of 34 factors that affect DB projects. This study adopted those factors to assess them against their risk effect on DB versus DBB delivery in airport projects. While the latter delivery methods are different, utilizing a consistent set of DB factors across both PDMs facilitates determining whether DB can offer more benefits than DBB in terms of cost and schedule performance. Much previous research used consistent key points to compare DB and DBB (Shrestha and Fernane 2017; Nikou Goftar et al. 2014; Tran et al. 2018; Minchin et al. 2013). A complete list and description of those factors can be found in Table 1, and is based on the research conducted by Khalef and El-adaway (2023), whose risk perspectives are set forth in Table 2.

In the developed survey, respondents were asked to rate 34 risk factors. Each of those factors was quantified against three main attributes: (1) their likelihood of occurring in projects with DB versus DBB implementation, (2) their impact on schedule, and (3) their impact on cost. Because this research assesses one PDM against

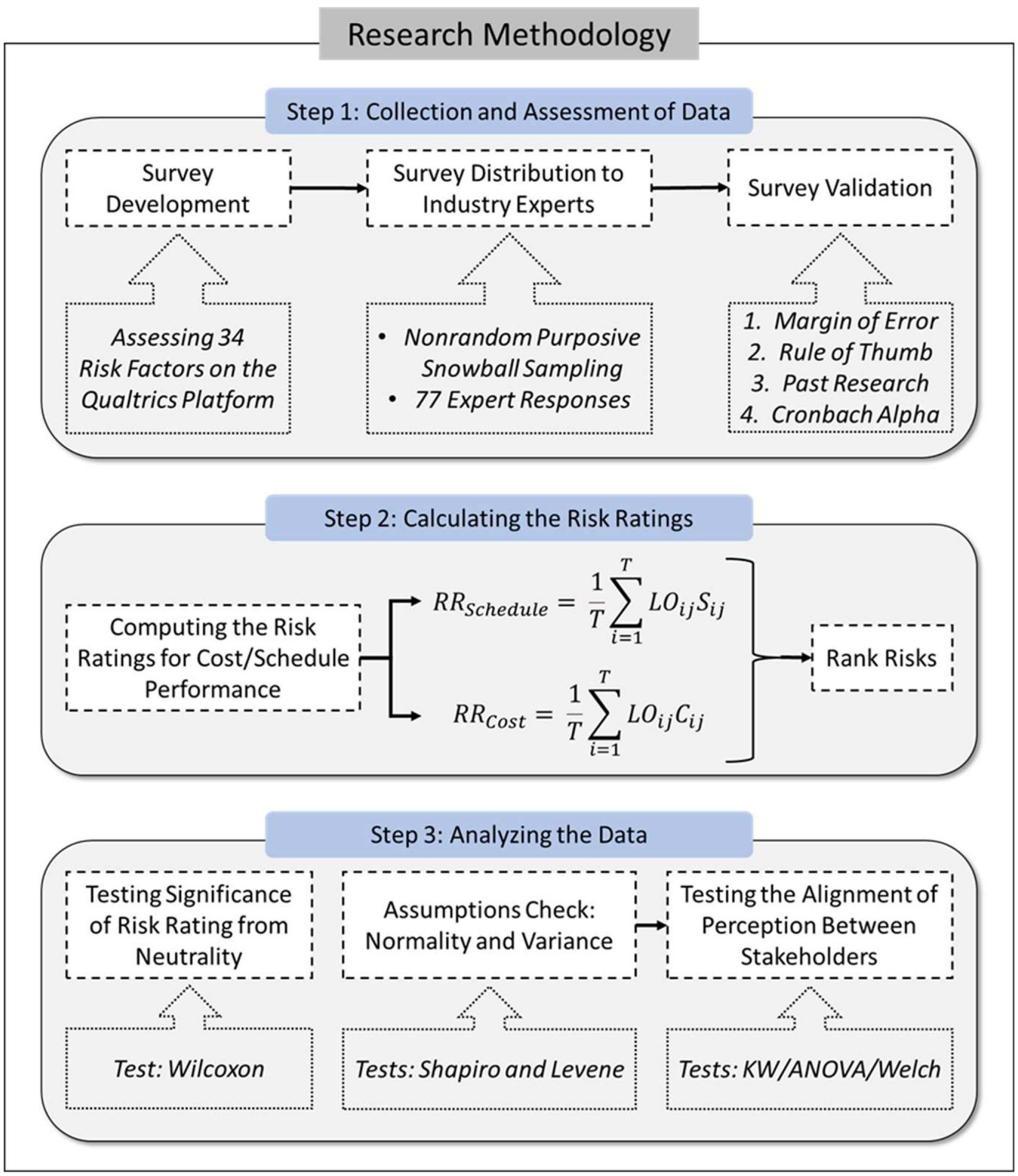

Fig. 1. Overall research methodology.

Table 1. Risk factors

Factor number	Factor title
F1	Increased Project Complexity
F2	Unclarity or Incompleteness in Project Scope
F3	Difficulty in Assessing Site Condition and Attributes
F4	Increased Project Cost
F5	Project Financials/Fundings Hardships
F6	Inaccurate Predictability of Project Cost
F7	Inaccurate Predictability of Project Schedule
F8	Inability of Fast-Tracked Delivery
F9	Ineffective Change Management
F10	Ineffective Dispute Resolution and Claims Management
F11	Ineffective Safety Management
F12	Ineffective Risk Management
F13	Ineffective Quality Management
F14	Ineffective Sustainability Management
F15	Improper Implementation or Lack of use of Value Engineering
F16	Inappropriate Contractor Selection Method
F17	Inappropriate Pricing Agreement Method
F18	Improper Implementation or Lack of use of Innovative Construction Methods
F19	Lack of Contractor Incentives
F20	Low level of Team Collaboration
F21	Poor Team Culture
F22	Ineffective or Inappropriate Organizational Structure
F23	Low Stakeholder Experience
F24	Poor Stakeholder Relationships
F25	Low Owner Satisfaction
F26	Low Owner Involvement
F27	Lack of In-house Capacity
F28	Lack of Regular Meetings
F29	Lack of Project Monitoring
F30	Ineffective Project Documentation
F31	Lack in Use of Constructability Reviews
F32	Regulatory Restrictions
F33	Negatively Influencing Market Conditions
F34	Negative Impact on Neighboring Area

Source: Adapted from Khalef and El-adaway (2023).

another, a seven-point Likert scale is most appropriate to ensure reliability and robustness (Emerson 2017; Chyung et al. 2017). A seven-point Likert scale is considered to be more reliable than systems that offer fewer choices (Alwin and Krosnick 1991). Because this research targets industry experts as respondents, a seven-point scale is preferred over a five-point scale (Weijters et al. 2010). Table 2 describes each point on the scale, as inspired by Abdul Nabi and El-adaway (2021). The survey also collected data regarding each respondent's career level, experience, and stakeholder group.

Survey Distribution

The electronic survey was distributed to experts who have worked in the fields of DB, airport construction, and related infrastructure projects. Respondents were part of a wide range of stakeholder groups including consultants, contractors, subcontractors, and owners. Their career levels included engineering, management, and upper administration positions. The authors distributed the survey by email over a period of about eight months, and survey respondents were selected nonrandomly based on purposive and snowballing sampling methods (Biernacki and Waldorf 1981; El-adaway et al. 2022). By this method, survey respondents were selected based on their relevance to and expertise in the researched subject (Creswell et al. 2011). Because the population size was unknown, a computed margin of error was utilized to determine the sample size needed (Bhardwaj 2019; Islam 2018). The adequacy of the sample size shall be discussed in the "Survey Validation" subsection of the "Methodology" section, and additional information concerning the respondents' profiles is provided in the subsequent Results and Analysis section. While 80 responses were received, three responses were incomplete; thus, 77 responses were used for analysis. As previously mentioned, these experts were selected on basis of nonrandomly purposive snowballing sampling techniques. Fig. 2 summarizes the survey distribution and data collection process. The directories of the Design–Build Institute of America (DBIA) and the Associated General Contractors of America (AGC) were consulted to aid in determining the snowballed sample size, as these directories were used in previous related research (Hyun Lee et al. 2020;

Table 2. Description of scale use in the survey

Scale category	Likelihood of occurrence	Impact on schedule (duration) and cost
1	Extremely Likely to occur in DBB relative to DB. It is expected or almost certain to occur in most circumstances in DBB relative to DB. The risk factor is >80% more likely to occur in DBB relative to DB.	Extremely High Impact in DBB relative to DB. Extreme and stops achievement of functional goals in DBB relative to DB. The risk factor is associated with a >50% increase of duration/cost in DBB relative to DB.
2	Likely to Occur in DBB relative to DB. It is likely to occur in most circumstances in DBB relative to DB. The risk factor is 40%–80% more likely to occur in DBB relative to DB.	High Impact in DBB relative to DB. Necessitates significant adjustment to the overall function in DBB relative to DB. The risk factor is associated with a 10%–40% increase of duration/cost in DBB relative to DB.
3	More or Less Likely to occur in DBB relative to DB. It is more or less likely to occur in most circumstances in DBB relative to DB. The risk factor is 10%–40% more likely to occur in DBB relative to DB.	Relatively Minor Impact in DBB relative to DB. Negligible/minor threat to an element of the function in DBB relative to DB. The risk factor is associated with a <10% increase in duration/cost in DBB relative to DB.
4 (Midpoint)	Neutral. Likelihood of occurrence of the risk factor is the same in DB and DBB.	Neutral. Duration/cost is the same in DB and DBB.
5	More or Less Likely to occur in DB relative to DBB in most circumstances. Specifically, the risk factor is 10%–40% more likely to occur in DB relative to DBB.	Relatively Minor Impact in DB relative to DBB. Negligible/minor threat to an element of the function in DB relative to DBB. The risk factor is associated with a <10% increase in duration/cost in DB relative to DBB.
6	Likely to occur in DB relative to DBB. It is likely to occur in most circumstances in DB relative to DBB. The risk factor is 40%–80% more likely to occur in DB relative to DBB.	High Impact in DB relative to DBB. Necessitates significant adjustment to the overall function in DB relative to DBB. The risk factor is associated with a 10%–40% increase in duration/cost in DB relative to DBB.
7	Extremely Likely to occur in DB relative to DBB in most circumstances. The risk factor is >80% more likely to occur in DB relative to DBB.	Extremely High Impact in DB relative to DBB. Extreme and stops achievement of functional goals in DB relative to DBB. The risk factor is associated with a >50% increase in duration/cost in DB relative to DBB.

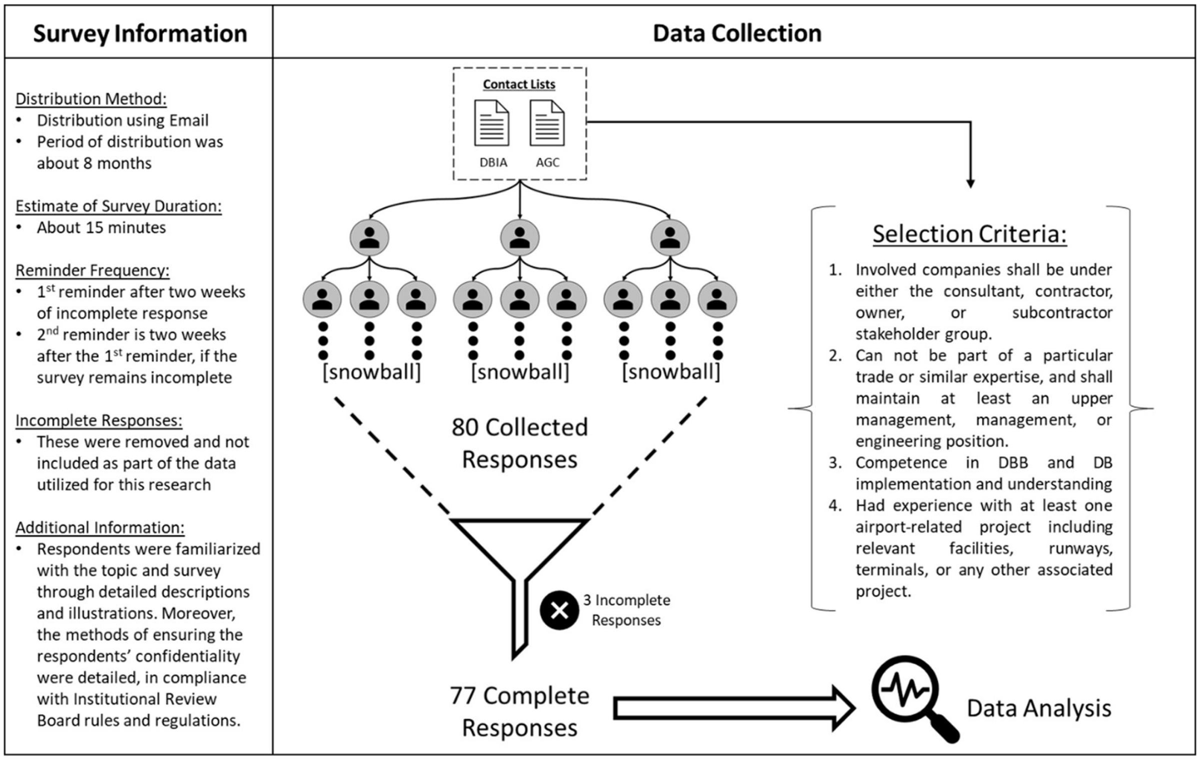

Fig. 2. Survey information and data collection procedure.

Tymvios et al. 2012). The selection criteria listed in Fig. 2 was conducted to ensure a relevant and consistent expertise level. Specifically, the authors ensured that the respondents were competent in DBB and DB implementation and had experience with at least one related project in the field of airport construction. The overall level of expertise of the respondents is supported through past research in the "Survey Respondents" subsection of the "Results and Analysis" section. It is critical to note that respondents were familiarized with the research topic and survey conducted through detailed descriptions and illustrations. Reminders were also sent to those respondents who failed to complete the survey. This was performed in two cycles: In the first cycle respondents were reminded two weeks after their last activity. In the second cycle, those respondents who still failed to complete the survey were sent another reminder two weeks after the first reminder. Respondents could also elect to opt-out from reminders.

Survey Validation

The authors conducted a sufficiency test on the survey data to determine whether it had a sample size adequate to ensure representativeness. This was based on a commonly employed statistical method, such as that established by Cochran (1977), which was used by various other studies related to construction (Pereira et al. 2018; Srour et al. 2017). To this end, Eq. (1) computes the minimum number of survey respondents required to obtain meaningful conclusions and valid findings. The computed minimum value was then compared to the total number of survey respondents collected for this study (77 datapoints or respondents)

$$n = \frac{t^2 s^2}{e^2} \tag{1}$$

where n = the minimum required number of survey respondents; s = the estimated variance deviation expected from the adopted scale point system used, which is the fraction of the range of the scale, inclusive of all values, to the number of standard deviations that encompass almost all possible values within the range; t = Z-statistic at 95% confidence; and e = scale points (7) multiplied by the acceptable error margin.

In adopting this technique, t had a value of 1.96 because the authors utilized the commonly-used 95% confidence level that corresponds to $\alpha = 0.05$ (Kamali and Hewage 2017). With that error margin selected, e therefore had a value of 0.35 (7×0.05). Moreover, because this study adopts a 7-point Likert scale, the s value becomes either 7/6 or 7/8; 7/6 was used to be more conservative. As a result, the minimum number of survey respondents should be no less than about 43. As this study used 77 responses, the number of responses was sufficient to ensure valid findings and meaningful conclusions. To this end, in fixing all the aforementioned values of the variance deviation (7/6) and confidence interval (1.96), Eq. (1) also shows that the sample size of 77 respondents has a margin of error of about 3.7%, which is considered adequate. In fact, a margin of error of up to 5% is often desirable for determining sample size adequacy (Ziafati Bafarasat 2021). The sample size utilized for this study also passes the general rule of thumb often employed in determining appropriate sample sizes, which is a minimum of 10 observations per variable (Rivers 2021; Moshagen and Musch 2014; Jackson 2007). [Other analytical studies suggest a minimum of five observations per parameter (Chen et al. 2014; Galpin and Held 2002; Zhu et al. 2006)]. Because this survey collected 7-likert scale data (seven variables) through three different sections of the survey (assessing the likelihood of occurrence, impact on schedule, and impact on cost), then a total of 70 (7 multiplied by 10) or 35 (7 multiplied by 5) datapoints or respondents should be considered as an appropriate sample size for each of those aforementioned sections. This study fulfills this requirement because it has 77 datapoints. This amount of data is aligned with similar studies in different construction sectors. Assaad et al. (2020) utilized 63 survey datapoints to assess project performance in the construction industry. Hasanzadeh et al. (2018) investigated project performance metrics in public

highway projects using 56 datapoints. Elsayegh and El-adaway (2022) employed 46 respondents to evaluate the implementation of collaborative planning practices in construction. Subramanya et al. (2022) used 53 datapoints to study the operational challenges of material delivery in highway construction projects. Kermanshachi and Pamidimukkala (2023) examined key indicators that affect schedule performance in heavy industrial projects using 44 collected datapoints. Accordingly, it can be seen that the number of datapoints is adequate to three ends: (1) having a desirable margin of error value, (2) satisfying the research-adopted general rule of thumb regarding appropriate sample sizes, and (3) aligning with previous research within the construction industry.

The authors also verified the internal consistency of the collected data. This was done by computing Cronbach's alpha, which is a technique that is used to evaluate the reliability of determinants retrieved from multipoint or dichotomous scales (Santos 1999). Cronbach alpha values of 0.75 or greater show valid and reliable surveys (Christmann and Van Aelst 2006). Generally, high values of Cronbach's alpha show that all survey respondents have an equal understanding of the survey questions. Within the context of this study, the Cronbach alpha value was computed for the data related to the likelihood of occurrence, impact on schedule, and impact on cost. Respectively, the computed values were approximately 0.9434, 0.9626, and 0.9595. Accordingly, because they are all greater than 0.75, the survey questionnaires can be considered valid and reliable.

Step 2: Calculating the Risk Ratings

After distributing, collecting, and validating the data, the authors then computed the risk rating or criticality for each factor affecting the delivery of DB and DBB airport projects. As mentioned previously, this is done from two dimensions or perspectives: schedule and cost. The risk rating is calculated by multiplying the likelihood of occurrence by the impact on schedule and cost. This provides two risk ratings for each factor: schedule performance, and cost performance. Risk rating is a common practice in construction risk management for evaluating, prioritizing, and managing project risks. The goal of risk analysis, according to Marle and Vidal (2016), is to prioritize risks based on their criticality, which is calculated by multiplying impact and probability. Many construction-related studies have established guidelines for quantifying risk ratings using the discussed method (Russell et al. 2013; Haider et al. 2016; Castro-Nova et al. 2018). Eqs. (2) and (3) were used to calculate the average schedule and cost risk ratings for each of the 34 factors. Each risk rating supplies a consolidated detail of the overall perception of the industry experts surveyed

$$RR_{\text{Schedule}} = \frac{1}{T}\sum_{i=1}^{T} LO_{ij}S_{ij} \quad (2)$$

$$RR_{\text{Cost}} = \frac{1}{T}\sum_{i=1}^{T} LO_{ij}C_{ij} \quad (3)$$

where R_{Schedule} refers to the risk rating with respect to schedule; R_{Cost} refer to the risk rating with respect to cost; T refers to the total number of surveyed respondents; LO_{ij} refers to the likelihood of occurrence of factor i as inputted by respondent j; S_{ij} refers to the impact of factor i on the schedule as inputted by respondent j; and C_{ij} refers to the impact of factor i on the cost as inputted by respondent j.

The likelihood of occurrence and impact on schedule/cost values range from 1 to 7 (Table 2). This means that the risk rating will range from 1 to 49, with 16 as the neutral point (4×4); i.e., the point at which there is no clear advantage of DB over DBB. This is further explained in Fig. 3. Values less than 16 pose a greater risk in DBB than in DB, and risk ratings greater than 16 are riskier in DB than in DBB. This risk rating technique ranks the risky factors in each delivery method. To this end, improved guidelines and recommendations can be provided to airport-related projects on whether there is a clear advantage to employing DB over the traditional DBB.

Step 3: Analyzing the Data

After collecting the needed data, the authors conducted statistical tests to investigate the differences in perception between different stakeholder groups (consultants, contractors, subcontractors, and owners) regarding the criticality of each risk factor to schedule and cost performance. The overall procedure is shown in Fig. 4. First, the assumption of normality is checked using the Shapiro test. If the test fails and the data is deemed not normal, then a nonparametric Kruskal-Wallis (KW) test is performed to test the statistical difference between different groups (Xiong et al. 2019). However, if the Shapiro test is passed and the data is deemed normal, then Levene's test is used to check whether the variance among the data is equal (Hale et al. 2009). A one-way ANOVA test is performed if the variances are equal, and the Welch test is conducted if the variances are not equal (Forcada et al. 2017). These tests determine whether there is a statistical difference between different groups. This approach has been adopted by many impactful studies within the realm of construction management research (Sankarak et al. 2018; Abdul Nabi and El-adaway 2021; Fathi and Shrestha 2022).

The authors also conducted the Wilcoxon test, a nonparametric technique, to test the significance of risk ratings differing from neutrality (risk rating value of 16). This provides the additional ability to discern truly significant factors that provide added benefits in one PDM over another, from schedule and cost perspectives. Finally, risk factors were analyzed by their ranking and effect across schedule and cost criticality.

Likelihood of	Impact on Schedule/Cost						
Occurrence	1	2	3	4	5	6	7
1	1	2	3	4	5	6	7
2	2	4	6	8	10	12	14
3	3	6	9	12	15	18	21
4	4	8	12	16	20	24	28
5	5	10	15	20	25	30	35
6	6	12	18	24	30	36	42
7	7	14	21	28	35	42	49

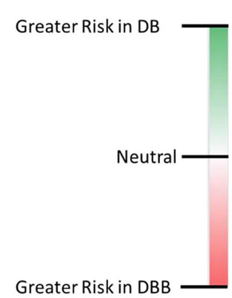

Fig. 3. Illustrative explanation of risk rating.

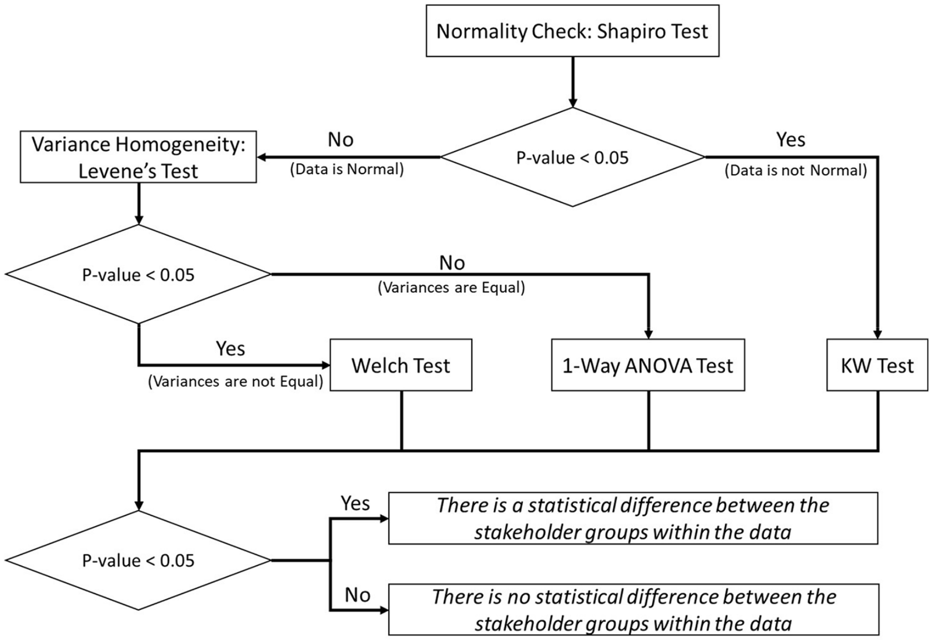

Fig. 4. Procedure of testing the statistical difference of different stakeholder groups.

Coding Environment

The data was cleaned and assessed, and risk ratings were calculated for further evaluations through Python, a programming language that is easy to use and has clear linguistic and dynamic semantics (Ahmed et al. 2021; Khalef and El-adaway 2021). Python was run in a virtual environment called Project Jupyter, where the authors utilized popular open source libraries/packages such as Pandas, Numpy, Scipy, Pingouin, and Matplotlib to aid in the manipulation of data, computation, statistical tests, and data visualizations.

Results and Analysis

Survey Respondents

As previously mentioned, the developed Qualtrics survey collected 77 responses from industry experts in various stakeholder groups (38.96% consultants, 33.77% contractors, 16.88% owners, and 10.39% subcontractors). These experts were involved in upper administration (51.95%), management (36.36%), and engineering (11.69%). Experts had an average experience of 26.3 years in construction, and about 94% had at least 10 years of construction experience. The experts also had an average experience of 15 years in DB construction, and 12.3 years in airport construction. Specifically, 74% of the respondents had more than 10 years of experience in DB construction, and 52% had more than 10 years of experience in airport construction. These values are in line with previously conducted research in various construction fields. Panagoulia and Rakha (2023) distributed a survey to assess the data reliability of building information modeling (BIM) in construction, and about 38% of the respondents had more than 10 years of experience in BIM in construction. Shrestha and Neupane (2020) assessed geotechnical-related impacts affecting bridge construction projects using survey data, and 47% of the respondents had more than 10 years of experience in bridge construction. Elsayegh and El-adaway (2022) conducted a survey on collaborative planning in construction, and about 54% of the respondents had more than 10 years of experience in collaborative planning. Khalafallah et al. (2019) distributed a survey to validate and assess the impacts of different safety-related indicators, and 39% of the respondents had more than 10 years of related construction experience. Islam et al. (2019) examined facility management (FM) cost factors in construction projects, and about 55% of the respondents had more than 10 years of FM experience. Shrestha et al. (2018) employed a survey-driven study that examined Chinese Public Private Partnership (PPP) water construction projects, and 22% of the respondents had more than 10 years of experience. Hasanzadeh et al. (2019) explored the effects of personality dimensions on residential and commercial construction projects regarding selective attention of workers susceptible to fall hazards, and 38.7% of the respondents had more than 10 years of experience in the field. Table 3 provides descriptive statistics of the survey respondents herein. The collected data

Table 3. Survey respondents descriptive statistics

Criteria	Subcriteria	Count	Mean
Stakeholder group	Consultants	30	—
	Contractors	26	
	Owners	13	
	Subcontractors	8	
Position	Upper management	40	—
	Management	28	
	Engineering	9	
Construction	<5	3	26.30
	5–10	2	
	10–20	14	
	>20	58	
DB construction	<5	10	15.00
	5–10	10	
	10–20	31	
	>20	26	
Airport construction	<5	22	12.30
	5–10	15	
	10–20	18	
	>20	22	

points passed the tests of meeting (1) the minimum number of respondents needed to ensure meaningful conclusions and valid findings; and (2) the acceptable thresholds of Cronbach alpha values to maintain internal consistency and overall reliability. The Methodology section provides additional details regarding this subject.

Schedule and Cost Risk Ratings

With verification of the validity and reliability of the survey, the authors calculated each factor's mean of the (1) likelihood of occurrence (LO), (2) relative impact on schedule (IS), and (3) relative impact on cost (IC). Consequently, using these values, the authors were able to compute the risk rating of the schedule (RR_s) and cost (RR_c) performance by following Eqs. (2) and (3), respectively. Table 4 provides the mean and standard deviation values of LO, IS, IC, RR_s, and RR_c on all 34 risk factors. Moreover, each risk rating was ranked, while taking into consideration whether the value of the risk rating was greater than 16 or not. Values that are less than 16 pose a greater risk in DBB than in DB. Similarly, risk ratings greater than 16 are riskier in DB than in DBB. Each factor was ranked twice, for schedule and cost, whereby DBB-1 is the riskiest factor in DBB relative to DB, and DB-1 is the riskiest factor in DB relative to DBB. The asterisk (placed on RR_s and RR_c ranks in Table 4) refers to factors that are insignificant in the Wilcoxon test. Insignificant factors are those that have a risk rating that is not statistically different from neutrality (value of 16) and do not identify a statistically significant benefit in one PDM over the other.

The overall results indicate that the traditional DBB delivery method contributes to greater risks over most factors than does DB. Also, factors deemed riskier in DB are statistically insignificant from neutrality (neither PDM shows a statistically clear edge over the other). Good examples include F2 (unclarity or incompleteness in project scope) from a schedule/cost perspective, as well as F17 (inappropriate pricing agreement method) and F32 (regulatory restrictions) from a cost perspective. This places DB at a clear advantage over DBB in delivering airport projects, because experts show that generally DB provides added perks and has a greater ability to avert or mitigate some significant risks.

From a schedule performance perspective, the top 10 significant risk factors that DBB suffers from, and to which DB reacts significantly better, are: (1) low level of team collaboration, (2) inability to fast-track delivery, (3) improper implementation or lack of value engineering, (4) poor team culture, (5) improper implementation or lack of innovative construction methods, (6) lack of contractor incentives, (7) project cost, (8) ineffective dispute resolution and claims management, (9) lack of constructability reviews, and (10) project financials/fundings difficulties.

From a cost performance perspective, the top 10 significant risk factors that DBB suffers from are: (1) low level of team collaboration, (2) inability to fast-track delivery, (3) improper implementation

Table 4. Quantified risks and their ranks

Factor	LO Mean	LO Std	IS Mean	IS Std	IC Mean	IC Std	RR_s Mean	RR_s Std	RR_s Rank	RR_c Mean	RR_c Std	RR_c Rank
F1	3.74	1.72	3.18	1.87	3.48	1.88	12.43	9.88	DBB-12	14.30	11.31	DBB-22[a]
F2	4.04	2.01	3.51	1.92	3.79	2.05	16.35	13.58	DB-1[a]	18.12	14.93	DB-1[a]
F3	3.83	1.59	3.49	1.65	3.68	1.70	14.90	11.13	DBB-27[a]	15.87	11.62	DBB-30[a]
F4	3.10	1.86	2.97	1.58	3.14	1.64	11.35	11.92	DBB-7	12.27	13.15	DBB-10
F5	3.40	1.46	3.19	1.41	3.42	1.36	11.97	8.50	DBB-10	12.94	9.10	DBB-13
F6	3.19	1.97	3.27	1.68	3.30	1.66	12.92	12.35	DBB-15	13.14	12.79	DBB-14
F7	3.36	1.72	3.31	1.67	3.48	1.74	13.49	12.01	DBB-20	14.25	12.41	DBB-21[a]
F8	2.61	1.77	2.86	1.77	3.12	1.68	9.94	12.08	DBB-2	10.35	11.62	DBB-2
F9	3.39	1.40	3.32	1.49	3.31	1.57	12.65	8.77	DBB-13	12.88	9.50	DBB-12
F10	3.16	1.43	3.14	1.47	3.12	1.45	11.53	9.22	DBB-8	11.43	9.11	DBB-7
F11	3.78	0.84	3.74	0.83	3.78	0.91	14.62	4.99	DBB-24	14.75	5.06	DBB-25[a]
F12	3.36	1.20	3.45	1.21	3.35	1.25	12.66	7.74	DBB-14	12.34	7.83	DBB-11
F13	3.82	1.30	3.78	1.10	3.68	1.24	15.44	7.96	DBB-30[a]	15.25	8.98	DBB-29[a]
F14	3.73	1.02	3.81	0.87	3.71	0.92	14.90	6.20	DBB-28[a]	14.62	6.38	DBB-24[a]
F15	2.92	1.60	3.10	1.41	3.00	1.61	10.65	9.74	DBB-3	10.88	11.02	DBB-3
F16	3.30	1.89	3.39	1.66	3.55	1.64	13.35	11.53	DBB-18	14.08	12.30	DBB-18[a]
F17	3.88	1.48	3.82	1.23	3.97	1.46	15.94	9.42	DBB-33[a]	17.08	11.51	DB-2[a]
F18	2.86	1.65	3.17	1.45	3.10	1.51	10.87	10.35	DBB-5	10.90	10.85	DBB-4
F19	3.01	1.51	3.29	1.38	3.23	1.38	11.34	8.67	DBB-6	11.39	9.33	DBB-5
F20	2.64	1.53	3.06	1.50	3.14	1.52	9.62	9.58	DBB-1	10.16	10.30	DBB-1
F21	3.03	1.46	3.18	1.35	3.31	1.40	10.68	7.65	DBB-4	11.40	8.77	DBB-6
F22	3.38	1.40	3.58	1.26	3.68	1.35	13.38	8.62	DBB-19	13.79	8.91	DBB-17
F23	3.44	1.44	3.61	1.28	3.69	1.33	13.88	9.69	DBB-22	14.12	9.69	DBB-19
F24	3.17	1.44	3.40	1.32	3.48	1.32	12.03	8.49	DBB-11	12.26	8.50	DBB-9
F25	3.38	1.42	3.49	1.39	3.43	1.36	13.30	9.36	DBB-17	13.19	9.55	DBB-15
F26	3.47	1.46	3.43	1.27	3.57	1.37	13.00	8.17	DBB-16	13.78	8.88	DBB-16
F27	3.69	1.45	3.87	1.40	3.91	1.40	15.87	10.93	DBB-32[a]	15.99	10.83	DBB-31[a]
F28	3.58	1.26	3.64	1.28	3.68	1.16	14.19	8.66	DBB-23	14.40	8.46	DBB-23
F29	3.70	1.27	3.70	1.16	3.70	1.19	14.70	8.33	DBB-25[a]	14.87	8.39	DBB-27[a]
F30	3.61	1.14	3.66	1.03	3.65	1.14	13.87	6.67	DBB-21	14.12	7.46	DBB-20
F31	3.09	1.44	3.32	1.40	3.18	1.44	11.69	9.05	DBB-9	11.53	9.44	DBB-8
F32	3.94	1.09	3.79	0.94	3.87	0.89	15.52	6.69	DBB-31[a]	16.01	7.27	DB-3[a]
F33	3.81	1.08	3.75	0.99	3.71	1.06	14.94	6.54	DBB-29[a]	15.09	7.48	DBB-28[a]
F34	3.73	0.87	3.84	0.73	3.87	0.68	14.70	4.66	DBB-26	14.86	4.84	DBB-26

Note: Std = standard deviation.
[a]P-value is greater than 0.05 (insignificant) in the Wilcoxon test conducted.

or lack of value engineering, (4) improper implementation or lack of innovative construction methods, (5) lack of contractor incentives, (6) poor team culture, (7) ineffective dispute resolutions and claims management, (8) lack of constructability reviews, (9) poor stakeholder relationships, and (10) increased project cost. It is important to note that the top three risks for both schedule and cost performance are the same. Improper implementation or lack of innovative construction methods, lack of contractor incentives, poor team culture, lack of constructability reviews, increased project cost, and ineffective dispute resolutions and claims management are also shared significant risks. Moreover, while statistically insignificant from neutrality, the top shared risk for both schedule and cost performance is unclarity or incompleteness in project scope. These shared risk factors shall be further examined in the Discussion section of this paper.

Stakeholder Groups' Perception Alignment

As previously mentioned in the Methodology section, four different stakeholder groups participated: consultants, contractors, subcontractors, and owners. This section examines whether the different groups were in consensus regarding the effect of each risk factor. The procedure in Fig. 3 was used to select the statistical technique utilized (KW, Welch, or a one-way ANOVA test), depending on normality and variance assumptions, and a p-value was determined. This aided in determining whether there is a statistical significance between the risk factors identified by different stakeholder groups (p-value less than 0.05). Tables 5 and 6 provide the risk factors with significant differences between groups (p-values less than 0.05) for schedule and cost performance, respectively. The rows in those tables are sorted in descending order, based on the overall risk rating of each factor studied.

About 20% of the risk factors had a lack of alignment in perceived risk effect of factors between the different stakeholder groups concerning schedule performance, and about 15% of the risk factors show this misalignment from a cost performance perspective. In order of decreasing risk rating values, the factors experiencing a lack of alignment from a schedule perspective were: (1) ineffective sustainability management, (2) low stakeholder experience, (3) low owner involvement, (4) poor stakeholder relationship, (5) lack of constructability reviews, (6) improper implementation or lack of value engineering, and (7) low level of team collaboration. From the cost perspective, and in the same order, the factors were: (1) ineffective risk management, (2) increased project complexity, (3) poor stakeholder relationships, (4) lack of constructability reviews, and (5) improper implementation or lack of value engineering. Four factors are shared in the misalignment of perception of risk rating with schedule and cost performance risk factors.

Moreover, three of the top 10 schedule performance risks (refer to the previous section) are also in disagreement of perception between the different stakeholder groups: lack of constructability reviews, improper implementation or lack of value engineering, and low level of team collaboration. On the cost performance side, a similar trend is seen, with three of the top 10 cost performance risks in disagreement of perception. Across both schedule and cost values, the general trend is that the contractor risk rating values are the lowest among all groups. Accordingly, it could be hypothesized that the contractors could better see the shortcomings of implementing DBB relative to DB than could the other parties surveyed.

Beyond the quantified risk ratings, there are some other notable rankings. While the low level of team collaboration (F20) is ranked by most parties as a higher risk in DBB, the subcontractors generally perceive it as a lower-ranked risk. This may be because a subcontractor is usually a terminal-end party to the project (from an organizational structure point of view), performing a small portion of work that is within its special expertise. For this reason, there is less dependence on multiple parties and, therefore, decreased reliance on collaboration. Conversely, the subcontractor ranks poor stakeholder relationships (F24) as a greater risk. This may be because subcontractors are pressured to have good relations with the client, as they are a prominent determinant for contract award (Grimshaw et al. 2019).

Discussion

The subsequent subsections provide additional discussions about the top shared significant risk factors. These include risk factors

Table 5. Risk factors with a lack of alignment with stakeholder groups in schedule performance

Factor	Risk rating (rank of subgroups)					Shapiro[a] <0.05 (Y/N)	Levene[a] <0.05 (Y/N)	Test conducted	P-Value
	Overall	Consultants	Contractors	Owners	Subcontractors				
F14	14.90	16.00 (DBB-25/DB-10)	13.15 (DBB-6)	16.23 (DB-11)	14.25 (DBB-19)	Y	—	KW	0.0403
F23	13.88	17.40 (DB-2)	10.27 (DBB-15)	13.15 (DBB-10)	13.62 (DBB-16)	Y	—	KW	0.0115
F26	13.00	16.67 (DB-7)	10.15 (DBB-13)	11.23 (DBB-1)	11.38 (DBB-7)	N	N	ANOVA	0.0147
F24	12.03	15.67 (DBB-23)	7.85 (DBB-6)	13.46 (DBB-12)	9.62 (DBB-3)	N	N	ANOVA	0.0035
F31	11.69	12.77 (DBB-9)	7.50 (DBB-4)	13.92 (DBB-16)	17.62 (DB-3)	N	N	ANOVA	0.0139
F15	10.65	10.30 (DBB-2)	7.12 (DBB-3)	15.85 (DBB-22)	15.00 (DBB-23)	N	N	ANOVA	0.0293
F20	9.62	10.20 (DBB-1)	5.96 (DBB-1)	12.00 (DBB-3)	15.50 (DBB-24)	N	N	ANOVA	0.0488

[a]P-value in the aforementioned test.

Table 6. Risk factors with a lack of alignment with stakeholder groups in cost performance

Factor	Risk rating (rank of subgroups)					Shapiro[a] <0.05 (Y/N)	Levene[a] <0.05 (Y/N)	Test conducted	P-value
	Overall	Consultants	Contractors	Owners	Subcontractors				
F14	14.62	15.83 (DBB-23)	12.54 (DBB-26)	16.23 (DB-10)	14.25 (DBB-18)	Y	—	KW	0.0364
F1	14.30	17.97 (DB-3)	11.12 (DBB-16)	15.85 (DBB-22)	8.38 (DBB-1)	N	Y	Welch	0.0449
F24	12.26	15.27 (DBB-16)	8.65 (DBB-7)	13.92 (DBB-14)	10.00 (DBB-3)	N	N	ANOVA	0.0204
F31	11.53	12.83 (DBB-8)	7.08 (DBB-3)	13.69 (DBB-13)	17.62 (DB-4)	N	N	ANOVA	0.0130
F15	10.88	10.80 (DBB-1)	6.81 (DBB-2)	16.62 (DB-8)	15.12 (DBB-20)	N	N	ANOVA	0.0374

[a]P-value in the aforementioned test.

F20, F8, F15, F18, F19, F21, F31, F4, and F10. The risk considerations for DB airport delivery are also discussed.

Team Collaboration

Airport projects can be complex and involve many stakeholders, including airport authorities, airlines, government agencies, and contractors. As indicated in Table 4, industry experts show that F20 (low level of team collaboration) provides the highest overall risk rating (in both schedule and cost) when delivering airport projects using DBB instead of DB. Furthermore, there is a perceived misalignment between different stakeholders, where the contractor, much more so than other parties, perceives low team collaboration to much more severely affect schedule performance. This may be because contractors are responsible for the execution of the project, and delays arising from poor collaboration can have a significant impact on their ability to meet project deadlines (Melaku Belay et al. 2021). Accordingly, collaboration among team members is essential not only to ensure that the project is completed on time, but also within budget and to the required standards. Airport standards/regulations can vary depending on the location of the airport and the specific requirements of the project. For example, airport projects must adhere to strict safety regulations to ensure the safety of passengers, employees, and the general public (Davies et al. 2009b). This can include building codes, fire safety regulations, and emergency response requirements that conform to the applicable laws and codes on a federal, state, and local level. Project safety should also extend to national security issues, because airports are critical infrastructure and are vulnerable to terrorism and other security threats. This can involve designing secure areas, implementing access control systems, and complying with security regulations set by government agencies (Khalafallah and El-Rayes 2008). Airport projects may also be subject to environmental regulations, such as those related to air quality, water quality, and noise. These environmental regulations include the Clean Water Act (CWA), the Clean Air Act (CAA), the National Environmental Policy Act (NEPA), and the Airport Noise and Capacity Act (ANCA) (Luther 2007; EPA 2023a, b; BOEM 2023; Congressional Research Service 2021). These regulations can be complex, particularly for the contractor, who perceives the most risk (Table 5) trying to meet project deadlines through miniscule and informal guided involvement emanating from DBB's organizational structure (Salcedo Rahola and Straub 2014). Therefore, close collaboration among team members in airport projects is necessary to ensure compliance on a design as well as on a construction level. This can be better implemented in DB projects, because in DBB projects the design and construction phases are performed by separate parties, leading to a lack of collaboration. With DB implementation, the design and construction phases are completed by the same team, allowing for increased collaboration and teamwork (Gad et al. 2019).

Fast-Tracked Delivery

F8 (inability of fast-tracked delivery) is ranked as the second riskiest aspect in terms of schedule and cost performance in DBB airport projects (Table 4). There is a consensus among consultants, contractors, subcontractors, and owners regarding the negative effects that F8 can have on DBB airport projects. There are many reasons why the ability to fast-tracking airport projects is essential beyond completing construction in a shorter time frame than normally required. First, demand for air travel is constantly increasing (Sgouridis et al. 2011), which means that airports need to expand and improve their facilities to meet this demand in a timely manner. Airports are important economic drivers for the regions they serve, and delays in their construction can have a negative nationwide impact, including decreased accessibility to the region as well as reduced economic activity (Cohen and Coughlin 2003). Thus, it is essential to avoid those delays through greater ability to fast-track projects, especially by increased coordination between different airport stakeholders, such as airlines, airport operators, government agencies, local communities, and many more. A good example of an airport project that could have greatly benefited from improved and effective fast-track delivery is the Heathrow International Airport expansion project, which is expected to experience ongoing delays up to 2030. The delays have had a significant economic impact on the region, as the airport is a major economic driver and employer in the area. Some estimate that the delays will cost the UK government £30 billion by the end of 2030, while others estimate the delays cost as much as £6 million a day (Bowler 2016). There are many other examples, including similar construction projects at LaGuardia Airport and Chennai Airport (Sekar 2022; Tangel 2015). Fast-tracking airport projects using DB can help to minimize the negative impacts of construction by allowing the economic benefits of the project to be realized more quickly, reducing disruption to the local community and economy, and improving the efficiency of the construction process. This can reduce costs and minimize delays, while providing a more streamlined and focused approach.

Value Engineering

Airport projects need to be designed and constructed efficiently to control costs and meet budget constraints, while still delivering a high-quality facility that meets the needs of the airport operator and its users. Effective value engineering can help to achieve these goals by identifying opportunities to reduce costs and improve the value of the project. However, the typical DBB delivery in airport projects hinders the value engineering process. In fact, F15 (improper implementation or lack of use of value engineering) is the third highest risk, in terms of schedule and cost performance, in airport projects delivered by DBB (Table 4). This is because in DBB value engineering is typically carried out by the design team with no involvement by other stakeholders, such as the contractor (Ganiyu et al. 2015). The bid-winning contractor is then responsible for delivering the project according to those design documents, with no ability to provide realistic input into the design to achieve more efficient solutions, including more cost-effective materials or methods, optimizing the sequence of construction activities, and identifying ways to reduce waste or inefficiencies. It can be reasoned that, due to this fact, and because the contractor typically hands over the project as the final party, there is an evident lack of alignment in perception between the contractor and other stakeholders (Tables 5 and 6). This conclusion can be further supported by the fact that contractors have a more hands-on approach to the project, which allows them to better identify potential areas of waste or inefficiency that directly affects their schedule and cost performance goals or targets (Heralova 2016). In DB projects, the design and construction teams work collaboratively throughout the design and construction process. This allows for a more seamless integration of value engineering into the project, as the design and construction teams can identify opportunities for cost savings and optimization as they arise throughout the entire project lifecycle.

Value engineering is most effective if utilized from an early point in the project (Rad and Yamini 2016). DB permits this, and permits early involvement of the contractor (Gransberg and Shane 2010). Inevitably, this helps identify opportunities for cost savings and optimization early in the process that will reduce the risk of cost overruns or delays later in the project. One example of the

successful use of value engineering in an airport project is the San Francisco International Airport long-term parking garage project, which was delivered using DB (Airport Improvement 2019). The DB team needed to make significant changes to the design during the design phase, due to a major conflict with the utility infrastructure. Value engineering was implemented to maintain the schedule by starting construction of the foundation while working on the redesign of the superstructure. As a result, the team identified opportunities to optimize the design of the project and reduce costs, to deliver it on time and within budget while meeting the needs of the airport and its users. Ultimately, effective value engineering can be a valuable tool for airport projects, particularly in DB delivery, as it allows the design and construction teams to work collaboratively in an efficient manner.

Innovative Construction Methods

The construction of runways, terminals, hangars, and other airport-related facilities can be logistically and technically challenging (Edwards 2004). Thus, airport projects often require innovative construction methods, through specialized equipment, materials, or techniques, to meet the unique challenges and constraints of the industry. The improper implementation or lack of use of innovative construction methods (F18) can cause detrimental effects on schedule and cost performance, according to all the surveyed groups. From a scheduling perspective, it ranks fifth among risks in delivering airport projects using DBB versus DB, and from a cost perspective it ranks fourth. It may be hypothesized that the effect is greater in terms of cost because improper implementation or lack of use of innovative construction methods can lead to increased costs for materials and labor and cost overruns. While it can also affect scheduling, it may not have an equal impact on the overall timeline for completion of the project. The expansion of Terminal 5 at Heathrow International Airport is a good example of an airport project that used innovative construction methods. They adopted the innovative continuous improvement project process (CIPP), which involves a set of repeatable processes such as standardized design and modular systems (Davies et al. 2009a). The project team used prefabricated steel structures to aid in reducing construction time and improving quality control. By doing this, they were also able to greatly reduce waste and minimize the impact of construction on the surrounding area (Almashaqbeh and El-Rayes 2021).

DB provides flexibility and collaboration, which can encourage the use of innovative construction methods in airport projects. The DB team can propose solutions that may not have been considered, such as prefabricated components, modular construction techniques, and sustainable materials and technologies. This can reduce costs, improve efficiency, and enhance the overall quality and sustainability of the project.

Contractor Incentives

By offering incentives to contractors for meeting certain performance targets, airport projects can encourage contractors to deliver work of a higher quality. Accordingly, a lack of contractor incentives (F19) can negatively affect airport project delivery. Table 4 indicates F19 as the sixth and fifth highest risks from a schedule and cost perspective, respectively. This is agreed upon by all stakeholders: consultants, contractors, owners, and subcontractors. Eriksson et al. (2019) concluded that infrastructure projects benefit from contractor incentives in the form of: (1) project quality, which reduces maintenance costs, (2) efficiencies that can reduce the duration of a project and minimize disruption to airport operations, and (3) cost savings. By offering incentives, airport stakeholders can build positive relationships with contractors and foster a sense of partnership and improved airport reputation. This can lead to increased cooperation and a more collaborative work environment in current and future endeavors. DBB environments are not the best medium for incentivized work, because the design and construction teams might not be well-aligned (Baiden et al. 2006). Because DB teams integrate the design and construction teams, the result is that the teams are more aligned and have greater control over the process (Lee et al. 2020). This can make it easier to implement incentives that are aligned with the overall goals of the project, as the design–builder has a more holistic view of the project and can better understand the motivations and incentives of all parties involved. Additionally, DB projects often involve a certain degree of innovation and design–assist, in which the contractors are encouraged to provide input and suggestions during the design phase. Incentives can be used to encourage contractors to contribute their expertise and ideas, which can lead to more efficient and cost-effective solutions. In fact, government officials realized the benefits of incentivizing contractors and passed the Expedited Delivery of Airport Infrastructure Act of 2021 (White House 2022). This act provides incentive payments for early completion of Airport Improvement Program (AIP) projects, and it includes work related to the planning, development, and execution of airport infrastructure projects.

Team Culture

Improving team culture can have several beneficial effects on airport projects. Research suggests that teams with a positive culture are more likely to exhibit improved communication and collaboration, leading to more efficient and effective project completion (Schöttle and Gehbauer 2012). A strong team culture can also reduce conflict and increase morale, leading to higher productivity and a better overall work environment (Vaux and Kirk 2018). Furthermore, a positive team culture can help to attract and retain top talent, which can be especially important for complex and challenging projects like airport construction. Improving team culture can lead to increased safety on the job site, higher customer satisfaction, better project management, greater innovation, and higher quality work. All of these factors contribute to the overall success of airport projects.

There are a number of laws and regulations that can help to create a positive work environment, which can in turn foster a good team culture. These include the Occupational Safety and Health Act (OSHA 2023), Fair Labor Standards Act [FLSA (DOL 2023)], National Labor Relations Act [NLRA (NLRB 2023)], and American with Disabilities Act (ADA 2023), as well as relevant state and local codes. While these laws and regulations do not specifically address team culture, they provide a foundation for a positive work environment that can help to nurture a good team culture. And, as agreed by different stakeholders, failure to do so can impose added risks on airport projects, especially those delivered using DBB. Table 4 labels poor team culture (F21) as the fourth highest risk for schedule performance and sixth for cost performance in DBB airport projects. This shows how DB performs better in promoting an improved team culture among stakeholders. In addition, on a project level, and unlike DBB implementation, DB has a greater potential to create a single point of responsibility for both the design and construction processes (Chesworth 2011). This fosters a positive team culture with an increased sense of ownership and accountability.

Constructability Reviews

Constructability reviews are also a critical process for improving the efficiency and effectiveness of airport construction projects. Early use of constructability reviews is optimal, and maximizes benefits

throughout the entire project. By this process, issues with the design or construction processes can be identified early, allowing timely adjustments to be made. Stamatiadis et al. (2014) showed that delayed utilization of constructability reviews can affect project cost by at least 10.5%. Doritis (2019) provided a case study of an airport project utilizing ineffective late constructability reviews. The results were so catastrophic that the project was canceled, as it would have cost hundreds of millions to a billion dollars just to mitigate the issues at hand. Because airport projects are very complex, early constructability reviews are essential to the overall project success. DB is a much more effective solution for early constructability reviews than is DBBy. This is because the design–builder is often involved early in providing constructability input (Gransberg 2013). Effective constructability reviews not only show improved mitigation of design issues that can affect project cost, but the increased early involvement can also expedite delivery with more effective designs. Table 4 highlights F31 (lack of constructability reviews) as the ninth and eighth risk for schedule and cost performance, respectively. However, similar to other risk factors, there seems to be a misalignment in risk effect perception, where the contractor perceives a higher risk in that risk factor in DBB implementation than in DB delivery. Contractors often have a greater understanding of the hands-on construction techniques and processes. Thus, the misalignment can be because the lack of constructability reviews can result in a project that does not met the client's expectations, leading to costly legal claims against the contractor. Contractors can also face added challenges managing subcontractors if constructability issues emerge from design documents that are missing, incomplete, clashing, or impractical.

Project Cost

Airport projects can be quite economically costly (Khalef and Eladaway 2022). High project costs can pose many risks to both the contractor and the owner. For the contractor, a high initial price may make the project less financially viable, as it may result in lower profits or even a loss. It can also introduce additional risks by making it more difficult for the contractor to secure financing for the project, as lenders may be less willing to provide funding for a project that is not expected to be profitable (Eyiah 2001). A high initial price can also impact the owner's return on investment (ROI) for the project. If the cost exceeds the budget, the owner may not recoup its investment as quickly as expected, or may not see any ROI at all. This is a high risk in high-profile projects such as airport projects. Other good examples are projects from the Olympics or World Cup, as they can be risky for contractors and owners due to their scale and complexity, in terms of scope and cost. These projects have been notoriously risky for both the contractor and the owner. From the owner's side, the costs of building and maintaining the necessary facilities is very high; it is yet to be seen whether Japan will ever recoup the money expended on the 2020 Olympics (Müller et al. 2022; Demsas 2021). On the contractor's side, because time is typically of the essence, expediting projects becomes the utmost priority. However, with this level of stakes, safety procedures may be compromised, as seen in the 2022 Qatar World Cup, where between 400 and 500 workers died building the required infrastructure needed to support the event (Mngqosini 2022). To mitigate these and other risks emanating from high project costs, the contractor and the owner can work together to identify ways to reduce costs and improve efficiency, instead of compromising on safety for the gain of increased productivity and decreased costs. This might involve negotiating with suppliers to secure lower prices, streamlining the design and construction process, or finding ways to reduce waste and improve productivity. By working together to control costs, the contractor and the owner can help to ensure that the project is successful and delivers the desired ROI.

As shown in Table 4, increased project cost (F4) ranks seventh in terms of risk to schedule metrics in airport DBB project delivery, and tenth for cost metrics. These ranks are in alignment among the various stakeholder groups. A delivery system that mitigates this risk is progressive DB, which has shown success with airport projects (Gad et al. 2019). This system awards the project to the design–builder while they are estimating and designing the project (Gransberg and Molenaar 2019). In this way, they are able to better understand the project risks, and provide an improved estimate with confidence of delivery on or under budget. Progressive DB can be a more effective way to manage project costs, as it allows for more collaboration and flexibility throughout the process, unlike traditional DBB. These benefits can help ensure that the final project cost is as close as possible to the original budget.

Dispute Resolutions and Claims Management

The time and money spent on disputes and claims have put airport projects at significant risk. The average duration needed to resolve a dispute is between 14 and 18 months, and average cost of disputes in 2021 was 60% higher than in 2019 (Arcadis 2022). Thus, airport project managers must be proactive in identifying and managing those risks to minimize the likelihood of disputes and claims. The Berlin Brandenburg Airport project is a prime example of a project with insufficient dispute resolution and claims management procedures, which led to a larger number of disputes, significant delays, and cost overruns (Wulf 2020). These disputes concerned design defects, construction deficiencies, financial claims, and other contract-related conflicts. As a result, total costs were €8 billion, as opposed to the initial €1.7 billion budget, and the project was delayed by nine years. Airport construction project stakeholders must learn from these mistakes and implement effective procedures to reduce risk and promote sound dispute resolution and claims management. The experts agreed that these risks affect both schedule and cost performance in DBB airport projects: F10 (ineffective dispute resolution and claims management) ranks eighth for schedule metrics, and seventh for cost metrics (Table 4). Unlike traditional methods, DB provides a dispute resolution and claims management process with a single point of responsibility, which makes it easier to identify and resolve disputes and claims (Seng and Yusof 2006). Furthermore, the DB team is typically involved in the project from the outset, which allows for the early identification and resolution of issues. And in line with a previous subsection of this research, contractor incentives are an excellent means to mitigate disputes. With only one entity delivering the project, incentives in DB create an environment of shared risk and reward between just two parties: the owner and the DB team. This can help to reduce the risk of disputes and claims.

Overall Risk Considerations for DB in Airport Projects

This research has shown that, compared to DBB, DB in airport projects has great potential for improved project delivery in terms of schedule and cost performance. This is especially true in risk factors related to low level of team collaboration, inability to fast-track delivery, improper implementation or lack of use of value engineering, improper implementation or lack of use of innovative construction methods, lack of contractor incentives, poor team culture, lack of use of constructability reviews, increased project cost, and ineffective dispute resolutions and claims management. Fig. 5 provides a summary chart of the risk ratings of the significant risk factors in both schedule and cost performance; an asterisk beside a factor indicates lack of alignment in perception between

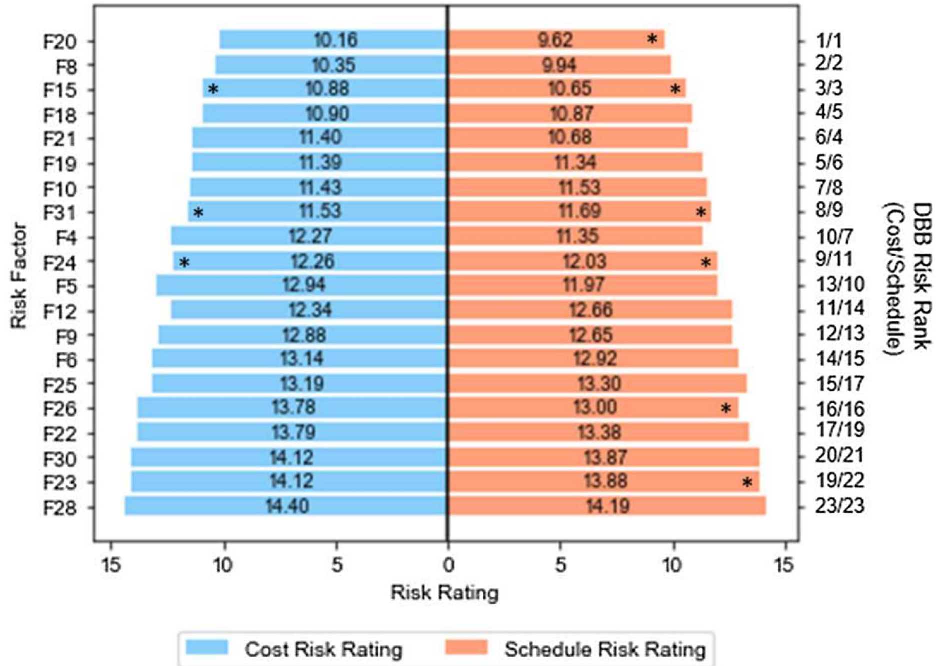

Fig. 5. Summary chart of significant risk ratings in schedule and cost performance.

stakeholders about the respective metric. The illustration shows that all the risks are prominent and significant only in DBB (because they are all under the value of 16). However, although DB responds more effectively to these risks, it has risks of its own, and while statistically insignificant to schedule and cost performance, they are worth careful consideration by airport stakeholders adopting DB. Ranked in order of highest to lowest in schedule risk ratings from Table 4, these DB considerations include: unclarity or incompleteness in project scope (F2), inappropriate pricing agreement method (F17), and regulatory restrictions (F32). F2 is the only DB risk consideration from a cost perspective. Unclarity or incompleteness in project scope or understanding in DB is critical, because it affects the quality and overall understanding of the project and its expectation to involved stakeholders (Arditi and Lee 2003). Qualitative bid selection of design–builders may result in improved understanding from the contractor's perspective (El Wardani et al. 2006). The latter can remove inefficiencies and make project understanding clearer, positively influencing the schedule and cost performance. Pricing agreements should also be taken into account for airport DB projects. These include fixed price contracting, and variants of cost-plus fee or percent (with or without a price ceiling). In many complex projects, a progressive DB system, which allows for agreement on price throughout the life of the project, can be beneficial (Gransberg and Molenaar 2019). However, if an agreement is not reached then this postponed price determination system may be inefficient in terms of schedule, and a fixed price would have been more beneficial. Lastly, regulatory restrictions can affect DB implementation in airport projects by adding complexity, documentation, approvals, and time to the process. Thus, limiting the scope of work, and increasing the risk of delays and cost overruns. These regulatory restrictions are a main barrier to DB implementation (Opfer et al. 2002), but it seems that the recent trend has been a growing DB market (Vashani et al. 2016). Airport stakeholders must consider local, state, and federal regulations when implementing and delivering DB-related projects. Various common law principles may also apply to the construction activities (Khalef et al. 2022). DB has much more promise regarding handling many risks than DBB, and greater integration of DB should be prioritized in future airport projects to reap those added benefits.

Addition to the Body of Knowledge

This paper adds to the current body of knowledge by providing data-driven insight from experienced industry experts into the crucial risk factors that must be considered in delivering DB and DBB projects in the airport industry. The study fills a gap in the literature by quantitively evaluating DB within the context of airport projects, an area that has not been researched before. Results indicate that the traditional DBB delivery method contributes to greater risks over most aspects of delivery than does DB. The findings of this study can be used by researchers and industry practitioners to further explore the benefits of DB and how it can be better and more often implemented in the airport construction industry. Additionally, the outcomes of this study can be used by airport stakeholders to better understand project risks, in order to make informed decisions about the best delivery methods for their projects.

This study provides added value to the relevant domain of knowledge through multiple facets, including: (1) providing a data-driven analysis of 34 risk factors that can be used to inform future research and industry practices, (2) highlighting the potential benefits of using DB over DBB as well as underlining the importance of PDM considerations in airport projects, (3) providing insights from the various perspectives of the involved stakeholders, (4) aiding in better identifying the points of risk that need improved risk mitigation procedures that can improve project metrics, reduce project risks, and ultimately enhance the overall functioning of airports for their end-users, and (5) serving as a foundation for other construction sectors to compare and contrast their delivery with the airport industry. Overall, the study contributes to the current body

of knowledge by providing a comprehensive evaluation of DB and DBB delivery methods in the context of airport projects.

Conclusion

This research studied 34 risk factors affecting DB implementation from the schedule and cost performance perspectives. A validated online survey was developed to collect data on the perception of the impact of those factors on schedule and cost performance. The top three significant risks in traditional DBB delivery are (1) low level of team collaboration, (2) inability to fast-track delivery, and (3) improper implementation or lack of use of value engineering. Conversely, while statistically insignificant, unclarity or incompleteness in project scope was the most critical risk factor in affecting DB. The overall risk ratings were statistically tested using tests such as KW, ANOVA, Welch, and Wilcoxon. The latter tests showed that contractors, generally and more than others, perceived DBB more negatively than DB. Discussions from previous literature as well as related projects were made to the top risk factors affecting schedule and cost performance in projects. The outcomes of this research show how DB is a more promising PDM than traditional methods for airport projects. With the industry's current reluctance to adopt more modern delivery techniques such as DB, the authors of this research hope to have provided enough evidence to influence airport stakeholders to integrate DB into their projects. Ultimately, this research contributes to the current body of knowledge by providing insight for related airport stakeholders on the crucial risk factors that must be taken into account in delivering DB and DBB.

This research was focused on the aviation sector of the construction industry through a holistic and comprehensive set of risk factors that influence project delivery. Future studies are recommended to analyze those factors in other construction sectors and draw comparisons through the differences in risk assessment. Future research can also focus on specific stakeholders, such as the owner, to analyze the effect of the level of their involvement on DB airport projects. Additionally, this study adopted a particular scale to evaluate different risk factors. Future works may elect to use a different scales that aim to assess alternative perspectives. Different scopes of analysis could also be adopted in testing statistical differences, where an analysis of the ranks (instead of a quantified risk rating) can be performed. Future researchers are also encouraged to develop new models using system dynamics or other means to further enable prospective and retrospective quantitative assessments of various project delivery parameters and performance metrics for airport projects.

Data Availability Statement

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

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