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Assessing Impacts of Urban Expansion on Carbon Stock and Sequestration for Kokan Division, Maharashtra, India

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Comparative Study of Project Delivery System: Impact on Green Building Performance and Certification in Indonesia

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This study examines the effectiveness of three project delivery system (PDS) methods design-bid-build (DBB), design-build (DB), and construction management (CM) in managing green projects in Indonesia, with a particular focus on achieving green building certification performance under Indonesia's Green Building (Bangunan Gedung Hijau/BGH) rating system. The BGH system consists of three certification levels: BGH Pratama (basic level, 56% implementation of green project requirements), BGH Madya (intermediate level, 86% implementation), and BGH Utama (highest level, 100% implementation). Data collection was conducted through a survey of 109 respondents consisting of project stakeholders in five major cities in Indonesia, with a composition of 39% DB, 33% CM, and 28% DBB. Analysis using Multivariate Analysis of Variance (MANOVA) shows that each PDS method has distinct characteristics and advantages in achieving different BGH certification targets. The DB method shows advantages in achieving the highest certification level (BGH Utama – 100% implementation of green project requirements) and the intermediate level (BGH Madya – 86% implementation), but is less than optimal for the basic level (BGH Pratama). In contrast, CM performs best in achieving BGH Pratama, although relatively lower for BGH Utama. DBB shows moderate consistency at all BGH levels. Important findings indicate that the optimal implementation achieved in the field only reaches 86%, regardless of the PDS method used. The results of this study indicate that the selection of PDS methods for green building projects should be tailored to the targeted BGH certification level: DB is more suitable for projects with high certification targets, CM for projects with basic certification targets, while DBB offers a more balanced approach for all certification levels.

Keywords: project delivery system, design-bid-build, design-build, construction management, project performance.

Introduction

The success of a project is inseparable from the selection of its procurement method, also called the project delivery system (PDS), which is a comprehensive process including planning, design, and construction required to implement and complete building facilities or other types of projects. Choosing a PDS method is one of the fundamental decisions owners make when developing their acquisition strategy. Determining the PDS method is one of the most critical decisions made by every owner who starts a construction project. Choosing the best method for each project must begin with understanding the options available (DBIA, 2015). The character of green projects is more complex than that of conventional projects, making the selection of PDS for each project significant in building communication, coordination, and contract issues between owners, contractors, and designers. With the increasing number of green design projects, understanding the relationship between PDS and green design is paramount in project and contract management.

In Indonesia and many developing countries, the majority of construction projects in the last ten years have been implemented according to conventional methods and traditional norms, where short-term solutions are preferred over long-term ones, with materials, technical solutions, and managerial approaches that can rarely be classified as innovative green technologies in their implementation (Demaid and Quintas, 2006) and (Gluch et al., 2009). PDS methods, namely design-bid-build (DBB), design-build (DB), and construction management (CM), are commonly adopted for conventional construction projects, and each method has its pros and cons. To successfully realize green construction, specific modifications to traditional project management processes and practices are required (Robichaud and Anantatmula, 2011). For example, the design process significantly impacts cost; the specific design factors mentioned above must be considered early in the design stage, affecting the PDS method. Different PDS methods, such as the most commonly used DBB and the increasingly popular DB model, should be considered first for green buildings (CMAA, 2012). Empirical studies have also been conducted to compare the performance of each of these PDS methods. One study showed that 75% of green building construction projects used DB (Molenaar et al., 2010). In addition, DB and CM have a better chance of providing high-level integration by facilitating contractor involvement early in the project (Mollaoglu-Korkmaz et al., 2013). Quantitative analysis by (Gultekin et al., 2013) revealed that DB drives higher green-level achievement in sustainable building projects compared to CM and DBB, mainly if the teams are located separately, DB facilitates timely team coordination and problem-solving, and in an environment where teams can interact effectively, decision making can be much faster (Miller et al., 2009). Based on the studies above, the three PDS methods can be used in green project management with different achievements in some research results regarding performance achievement.

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Previous studies have investigated the project performance achievement of various PDS methods. Cost, time, and quality performance in the green building PDS process raise greater sensitivity to the inherent nature of green buildings. If poor quality performance occurs at the design stage, it will result in changes at the construction stage and will impact the productivity of construction staff because the overall progress is reduced (Raouf and Al-Ghamdi, 2019). Research by Zhu et al. (2020) shows differences in cost and time performance achievements but produces the same quality performance across different PDS methods. Demkin (2018) stated that construction cost, schedule, quality, risk, and owner capability influence the choice of PDS methods. However, how these factors lead to choosing a particular delivery method is not clearly explained.

Beyond conventional project performance metrics (cost, time, quality), green project management that applies green construction indicators in its implementation has sustainability goals. According to National Academies of Sciences, Engineering, and Medicine (2009), sustainable construction is becoming more common and may be mandatory in assessing sustainability or green project performance. Thus, it is essential to measure the ability of the PDS method by including green building performance assessments according to the owner's needs. Public institutions often use the Leadership in Energy and Environmental Design (LEED) certification from the Green Building Association USA to articulate their desire to design and build energy-efficient and environmentally responsible projects (National Academies of Sciences, Engineering, and Medicine, 2009). The PDS method in green project management must ensure that the final product is consistent with the design. It is essential for green construction, where various specifications must be met before it can be certified as a green building. During the procurement of green building construction, special attention must be paid to green requirements, which are usually found in the specifications: contract documents (Glavinich, 2008). These requirements are to determine and ensure they meet the minimum environmental sustainability standards.

The Leadership in Energy and Environmental Design (LEED) rating system developed by the US Green Building Council (USBGC) in 1998 is a rating tool to evaluate sustainability performance through green building certification from both design and construction perspectives (Molenaar et al., 2010). Integrated design is a crucial component to effectively delivering LEED-rated buildings (Yudelson, 2010), and Korkmaz et al. (2010) communicates sustainable goals with DB methods in the public sector, most often achieved through a set LEED certification level that usually does not include specific LEED points to be achieved (Koch et al., 2010b). While integrated PDS methods are inherently more capable of facilitating integrated design, little research is measuring the trend of PDS methods in the green building sector. A recent study of 230 LEED-rated projects found that integrated delivery methods, such as DB and CM, were used in 75 percent of projects seeking LEED certification (Koch et al., 2010a). However, the study could not determine the certification rating achieved using both methods.

Although various studies on the effectiveness of the PDS method in green construction projects have been conducted in developed countries, there is a significant gap in understanding its application in the Indonesian context. Studies by Molenaar et al. (2010) and Mollaoglu et al. (2013) showed the superiority of the DB and CM methods in the United States, but these findings need to be reviewed in the Indonesian context which has different characteristics. Indonesia faces unique challenges such as limited green-certified contractors (Thohirin et al., 2024), lack of integration of sustainable construction supply chains (Abduh et al., 2012), and significant differences in project management practices (Toor and Ogunlana, 2008). The construction procurement system in Indonesia also has its own characteristics, with a dominance of government projects and strict regulations (Larasati and Watanabe, 2012). In addition, Molenaar et al. (2010) found that even in developed countries, 35% of projects did not specify the desired green certification level, and 77% did not specify specific points in the green criteria, indicating potentially greater challenges in the Indonesian context. With the enactment of the The Ministry of Public Works and Public Housing, in Indonesian: Kementerian Pekerjaan Umum dan Perumahan Rakyat, abbreviated as PUPR. Regulation No. 21 of 2021 concerning the Assessment of Green Building Performance (BGH), the Indonesian construction industry faces new demands to integrate sustainable practices into the construction process (Wirahadikusumah and Ario, 2015). This study fills this gap by analyzing the effectiveness of three PDS methods in the specific context of Indonesia, taking into account the characteristics of the local labor market, construction industry capacity, and the existing regulatory framework. This study makes a unique contribution by providing empirical evidence on how Indonesian contextual factors influence the performance of different PDS methods in achieving green building certification.

In Indonesia, the assessment of green building performance has been strengthened by the Regulation of the Minister of PUPR No. 21 of 2021 concerning the assessment of green building (GB) performance stipulated on 31 March 2021 and came into effect on 1 April 2021. Chapter II, article 2 of the PUPR regulation states that the order for fulfilling GB performance technical standards consists of new buildings in the mandatory and recommended categories and old buildings in the mandatory and recommended categories. The GB performance assessment of new buildings occurs during the technical planning, construction, utilization, and demolition stages. This performance assessment is in the form of ranking and certification of green buildings based on the GB performance order consisting of GB Primary, GB Middle, and GB Main.

Given these research gaps and the unique characteristics of the Indonesian construction industry, this study fills the gap by analyzing the effectiveness of three PDS methods in the specific context of Indonesia, taking into account the characteristics of the local labor market, construction industry capacity, and the existing regulatory framework. This study makes a unique contribution by providing empirical evidence on how Indonesian contextual factors influence the performance of different PDS methods in achieving green building certification. Specifically, this study compares three PDS methods DBB, DB, and CM to evaluate the delivery system of sustainable high-performance buildings in Indonesia. This study extends previous research by incorporating green building certification achievement as an additional performance variable alongside conventional metrics of cost, time, quality, and occupational health and safety (OHS). Quality performance as a metric for the delivery system has also not been addressed as comprehensively as time and cost metrics, and there is no conclusion supported by scientific rigor about which system provides quality more effectively, especially related to the concept of green construction.

The implications of this study are expected to help project managers and decision-makers in the construction industry determine the most appropriate PDS method for green construction projects. The findings of the study can encourage adjustments to project management practices to optimize performance in the context of sustainable construction. The study results are also expected to be input for policymakers in developing regulations or standards for implementing green construction projects in Indonesia. By helping to optimize the selection of PDS methods for green projects, this study indirectly contributes to efforts to minimize the environmental impact of the construction industry.

Methods

This study's treatment categories (explanatory variables) are three PDS methods (DBB, DB, and CM). In construction project management, it is important to distinguish between CM and construction manager at risk (CMAR) because both have different characteristics and responsibilities. According to the American Institute of Architects (AIA, 2007), CM acts as an agent and advisor to the project owner, while CMAR has a broader role and responsibilities. The Construction Management Association of America (CMAA, 2012) emphasizes that in the traditional CM model, the construction manager acts purely as a consultant who provides management expertise without taking on construction risks or providing maximum price guarantees. The fundamental differences between the two models are further explained by (National Academies of Sciences, Engineering, and Medicine, 2009), wherein CMAR, the construction manager, initially acts as a consultant during the pre-construction phase but then transforms into a general contractor when construction begins, including providing Guaranteed Maximum Price (GMP) and taking on construction risks. Design-Build Institute of America (DBIA, 2015) explains that in the traditional CM model, the project owner still signs a direct contract with the contractor, while the construction manager focuses on coordination, supervision, and project management. In the context of this study, the term CM refers to the traditional CM model as an agent, not CMAR. Understanding this difference is important to interpret the study results and their implications for green construction project management practices in Indonesia. CMAR involves different levels of responsibility and risk, affecting the approach to implementing green construction practices and achieving BGH certification targets.

Analysis using Multivariate Analysis of Variance (MANOVA) was chosen due to several methodological considerations. First, this study has multiple dependent variables that are correlated with each other (cost performance, time, quality, Occupational Health and Safety (OHS), and green building performance) where MANOVA can handle the intercorrelation between dependent variables and reduce the risk of Type I error that may occur if multiple ANOVA tests are conducted separately (Hair et al., 2019). Second, MANOVA allows simultaneous analysis of the effects of PDS methods on all performance variables, providing a more comprehensive understanding of how each method simultaneously affects different aspects of project performance (McNabb, 2018). Compared with alternatives such as separate multiple ANOVA tests, MANOVA is more appropriate because it can detect differences between groups that may not be identified when variables are analyzed individually (Johnson and Wichern, 2002). Multivariate regression was also considered but was less appropriate because the study focused on comparing performance differences across PDS methods, not predicting the value of the dependent variable. In addition, MANOVA can accommodate the categorical nature of the independent variables (PDS type) better than regression (Rencher, 2002).

Research variables

The variables analyzed include (1) Independent variables, type of PDS, in the form of manifest variables with categorical data (1 = DBB, 2 = DB, and 3 = CM), and (2) Dependent variables: six main variables consisting of several factors for each main variable, namely (i) cost performance, (ii) time performance, (iii) quality performance, (iv) HSE performance and (v) green building performance. Before the MANOVA analysis, assumption tests included multivariate normality, homogeneity of the variance-covariance matrix, and linearity of the relationship between dependent variables (Huberty and Olejnik, 2006).

Population and sample

The unit of analysis in this study is the project delivery system implementation, while the unit of observation is individual project stakeholders who have experience in managing green projects. Data were collected from project stakeholders including supervisory consultants, construction management, consultants, and contractors who have implemented green building projects using DBB, DB, or CM methods. Therefore, the sample unit in this study is the project stakeholders. From the predetermined sample units, it can be determined that the population of this study is the construction service industry players, specially building construction projects in Indonesia, particularly cities that have implemented green construction-based building construction. The construction service industry, in this case, is the supervisory consultant, MK consultant, and contractor as a construction service provider. The characteristics of the population used are infinite populations because the individuals who are the research objects in this study do not know the total number of stakeholders who have experience in managing green projects in Indonesia that apply the DBB, DB, and CM methods.

The sampling technique used is the nonprobability sampling technique, namely purposive sampling, which is a sample determination technique with specific considerations or people who are experts in the field to be studied. The respondents selected are project stakeholders in the organizational structure of supervisory consultants or MK consultants with the positions of team leader, supervising engineer, and construction management (MK) and contractors with the positions of vice president manager, project manager, site manager, and site engineer with the consideration that this position can assess project performance as a whole. These respondents represent the research study areas in 5 cities in Indonesia (DKI Jakarta, Bandung, Semarang, Surabaya, and Denpasar) who have experience and manage green building projects for at least one project.

This study's sample size determination follows several rule-of-thumb criteria for MANOVA analysis. According to Hair et al. (2019), for MANOVA with three groups (DBB, DB, CM), the recommended minimum sample size is 20 observations per group to ensure adequate statistical power. In addition, McNabb (2018) suggests that for multivariate analysis, the sample size should be greater than 20 times the number of independent variables (in this case, 20 × 1 = 20) and at least 5 times the number of dependent variables (in this case 5 × 5 = 25). More specifically for MANOVA, Stevens (2009) recommends a minimum sample size of 15–20 observations per dependent variable to achieve a statistical power of 0.80 with an alpha of 0.05. With five dependent variables in this study (cost performance, time, quality, HSE, and green building performance), the minimum sample size required is 75–100 respondents. Based on these criteria, this study collected data from 109 respondents (39% DB, 33% CM, and 28% DBB), which exceeded the recommended minimum sample size and met the requirements. The questionnaire was distributed in February – July 2024.

Statistics and data analysis

This study uses MANOVA to test the performance differences between three PDS methods – DBB, DB, and Construction Management (CM). Before conducting the main analysis, several MANOVA assumptions will be tested to ensure the suitability of using this method. The first assumption test is multivariate normality, which will be carried out using the Kolmogorov-Smirnov Test. This test evaluates whether the data from the five dependent variables (cost performance, time, quality, OHS, and green building performance) follow a multivariate normal distribution. The null hypothesis states that the data is usually distributed, while the alternative hypothesis states otherwise, with the rejection criterion at a significance value of less than 0.05. The second assumption to be tested is the homogeneity of the variance-covariance matrix. This test is important to ensure equality of variability between PDS groups, with the criterion of a significance value greater than 0.05 to meet the assumption of homogeneity. In addition, the assumption of independence of observations will be ensured through a research design where each respondent only assesses one PDS method. MANOVA analysis will be conducted using four test statistics – Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root – with a significance level of 0.05. If significant differences are found, post-hoc analysis will be conducted to identify specific differences between PDS methods and effect size calculations to assess the practical magnitude of the differences found. Descriptive analysis will present the means and standard deviations for each dependent variable using the PDS method, and performance profiles will be visualized through graphs and plots. Hypothesis testing will evaluate whether there are differences in performance between PDS methods, with the criterion for rejecting the null hypothesis at a significance value of less than 0.05.

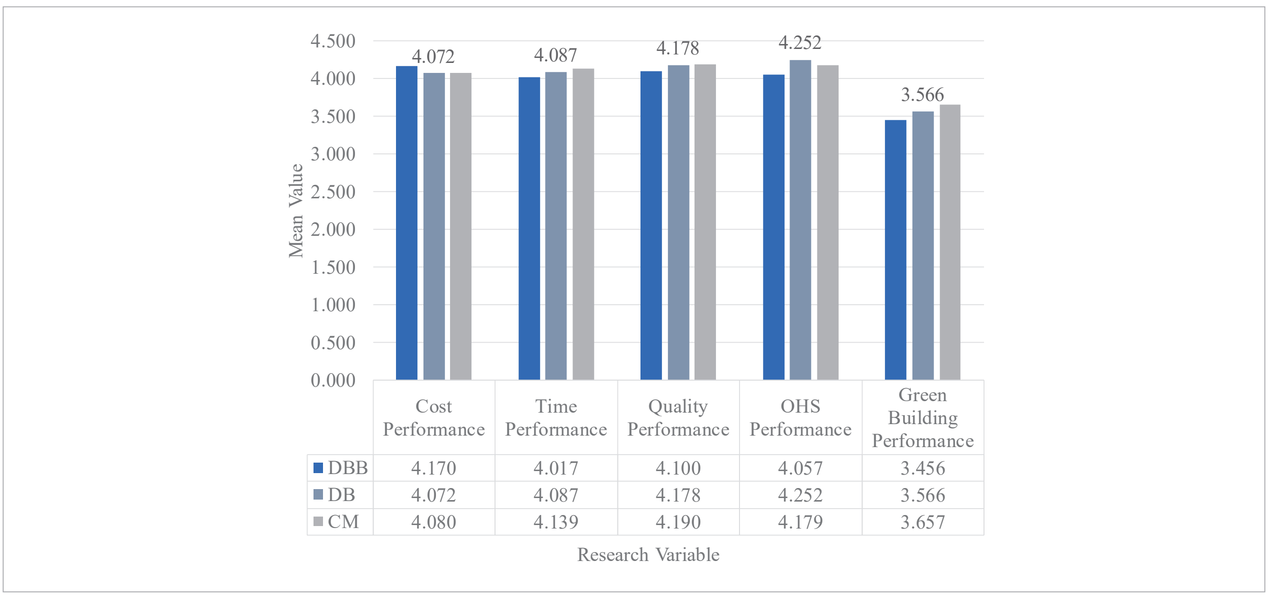
Multivariate rest

Testing is done with the average value of all tested variables and the average value of each tested variable. In the first test, the data used is the average value data of all variables, namely the average value of the cost performance variable, time performance, quality performance, OHS performance, and GB performance, which are analyzed simultaneously. The analysis determines how the three PDS methods compare to the tested variables. In the second test, the data used is the average value data of each variable, namely the average value of the cost performance variable, time performance, quality performance, OHS performance, and GB performance, which are analyzed separately. The analysis determines how the three PDS methods compare to the tested variables. This can be seen from the mean value obtained from each research variable.

Results and Discussion

To be able to see a comparison of the three methods above, the following graph shows the deviation of the mean value from the selection of the use of the three methods, which is relatively tiny (< 0.200), but from the three values, it can be seen which method is more appropriate to choose compared to other methods related to its relationship with each variable tested.

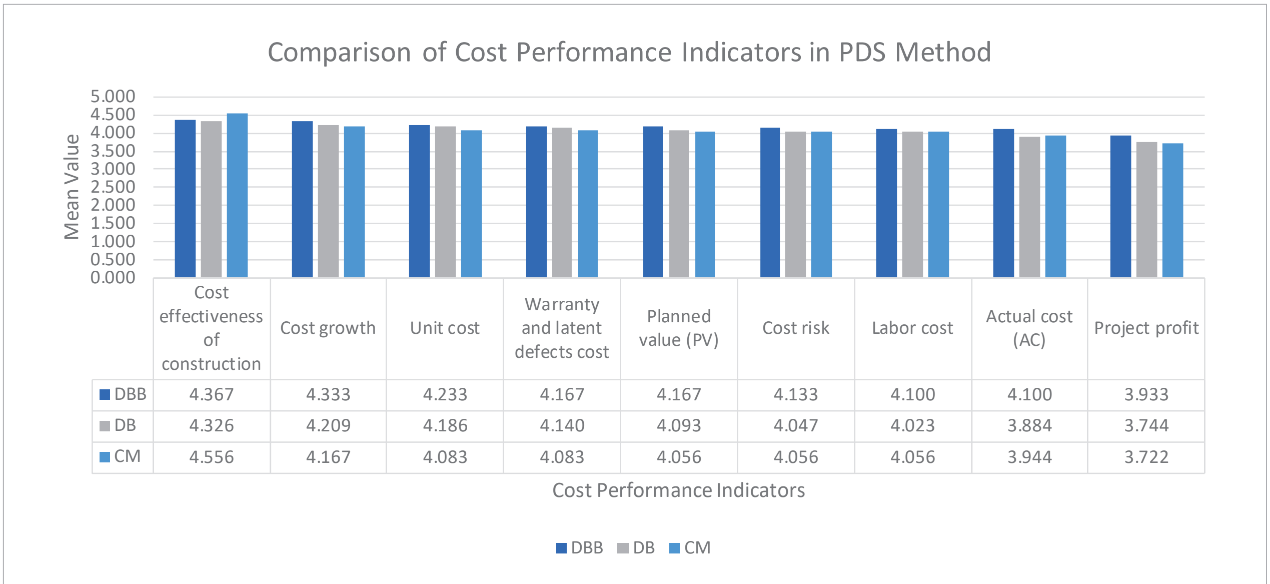
Fig. 1. *Comparison chart of mean project delivery system (PDS) values*



There is no single method that consistently excels in all variables. DBB excels in achieving cost performance. These results align with research (Minchin et al., 2013; Carpenter and Bausman, 2016), which states that projects with the DBB method perform better in costs and are significantly superior in all cost metrics. CM tends to have high scores in many variables, especially time, quality, and GB performance. (Bilbo et al., 2015) CM is more effective in controlling project schedules, while (Carpenter and Bausman, 2016) stated that CM produces higher product and service quality levels. This result differs from the previous study (Shrestha and Fernane, 2017), which showed that DB is significantly superior in terms of schedule growth and cost growth. During the results of this study, DB showed superiority in OHS performance. The difference in values between methods is generally tiny, indicating relatively balanced performance. Projects that implement green construction in the field, from the results of this study, said that the DBB method is more appropriate than the DB and CM methods. Meanwhile, when associated with project performance, the DBB method is the most appropriate for producing optimum cost performance but less appropriate for achieving GB performance. The DBB method, when compared with the DB and CM methods, is most appropriate for selecting the cost performance target but less appropriate for achieving OHS performance targets, time performance, quality performance, and GB performance. Meanwhile, when associated with project performance, the DB method is more appropriate for achieving OHS performance than quality performance but less appropriate for achieving GB performance. Compared with the DBB and CM methods, the DB method is most appropriate for selecting the OHS performance target but less appropriate for achieving cost performance targets. Furthermore, when associated with project performance, the CM method is most appropriate for achieving quality performance but less appropriate for achieving GB performance. Compared with the DBB and DB methods, the CM method is most suitable for achieving quality, time, and GB performance targets. However, it is less suitable for achieving cost performance.

In *Fig. 2*, we can compare the three PDS methods against the cost performance indicators that are priorities to be achieved in green project development. The *building cost-effectiveness* indicator is an indicator for assessing the cost performance of using these three PDS methods in green projects. However, from the mean value of this indicator in the three PDS methods, *building cost-effectiveness* is the highest indicator assessed as the achievement of cost performance in the CM method compared to the DBB and DB methods. The *project profit* indicator is the last ranked cost performance assessment indicator in the DBB method. However, the *project profit* indicator is ranked 4th and

Fig. 2. *Comparison of cost performance indicators in the use of the PDS method*

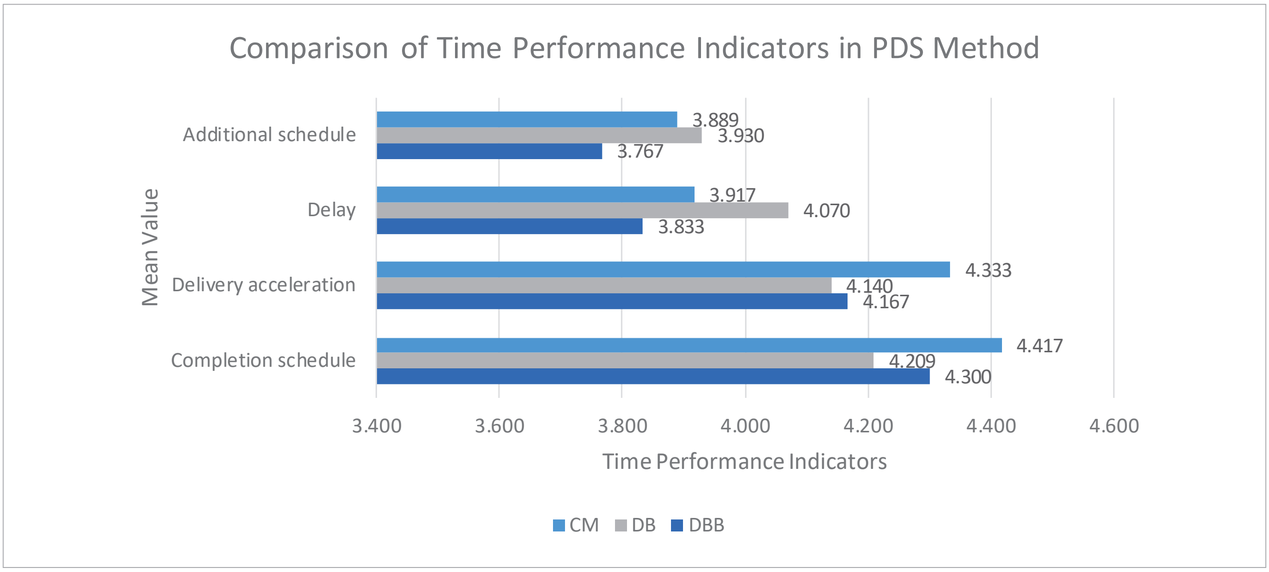


	Cost effectiveness of construction	Cost growth	Unit cost	Warranty and latent defects cost	Planned value (PV)	Cost risk	Labor cost	Actual cost (AC)	Project profit
DBB	4.367	4.333	4.233	4.167	4.167	4.133	4.100	4.100	3.933
DB	4.326	4.209	4.186	4.140	4.093	4.047	4.023	3.884	3.744
CM	4.556	4.167	4.083	4.083	4.056	4.056	4.056	3.944	3.722

sixth in the DB and CM methods. In contrast, the *cost risk* indicator is ranked last in the DB and CM methods. Meanwhile, the *cost risk* indicator in the DBB method is not the leading assessment indicator for cost performance (ranked six[th]). Research in Qatar (Venzon et al., 2019) also stated that PDS can affect cost overruns in green building projects. This study shows that PDS can affect these factors, especially concerning procurement methods and stakeholder engagement time.

For time performance, the *project completion schedule* indicator is the top-ranking indicator for assessing time performance achievement in selecting the three PDS methods. However, based on the mean value, this indicator is the highest priority in the CM method. Likewise, the second-ranking indicator, *delivery acceleration*, ranks the same in the three PDS methods. However, *delivery acceleration* is the most critical indicator in the CM method based on the mean value compared to the other two methods. The *schedule addition* indicator is the last ranking indicator (4[th]) in the DBB and CM methods, while for the DB method, the last ranking indicator is *delay*. Related research (Nikou Goftar et al., 2014) has different results, stating that DB consistently shows faster project completion times, with some studies reporting that it is 30–33% faster than DBB.

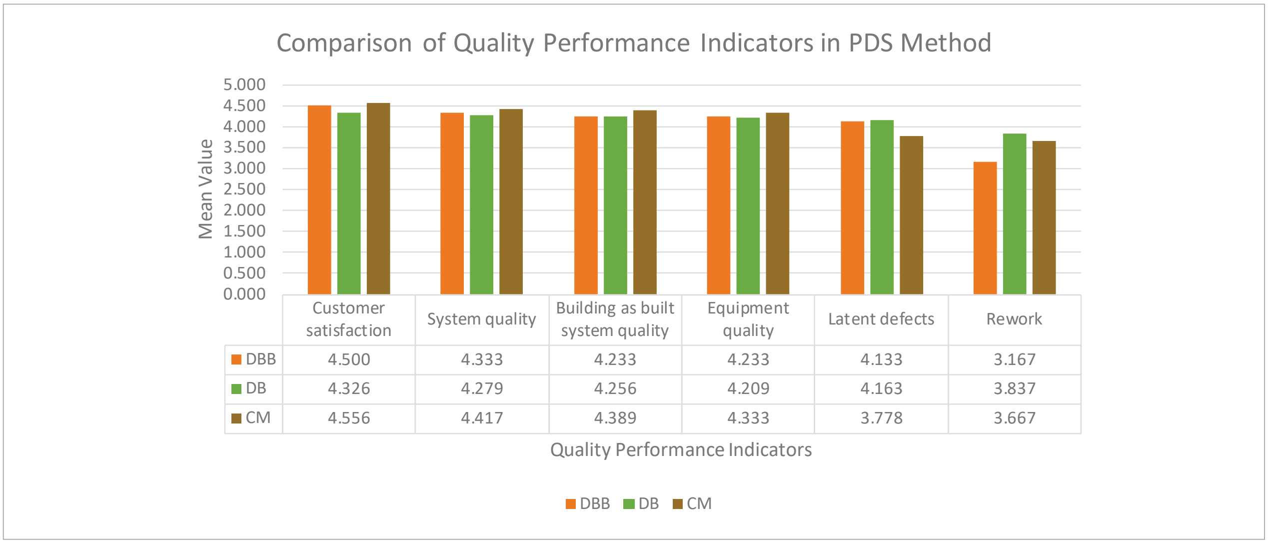
Fig. 3. *Comparison of time performance indicators in the PDS method*



A comparison of the PDS method quality performance assessment on DB and CM methods has similarities in ranking results, only differing in the last ranking. In the DB method, the *rework* indicator is ranked last (6[th]), the same as the DBB method, while in the CM method, the *latent defect* indicator is ranked last. The *customer satisfaction* indicator is the top-ranking indicator in all methods used as quality performance assessment in selecting the three PDS methods. However, research (Nikou Goftar et al., 2014) states that customer satisfaction is more influenced by the size and complexity of the project than the delivery method (PDS).

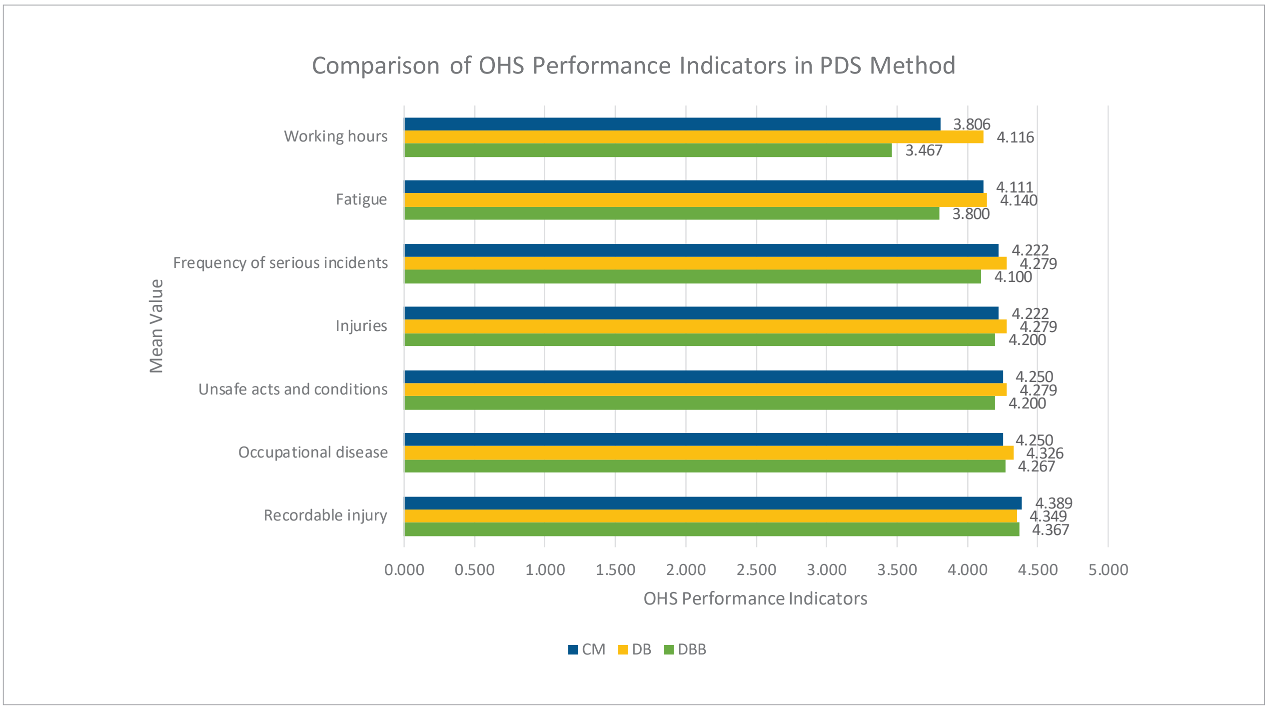
The *working hour* indicator is the last ranked indicator (7[th]) for assessing OHS performance in selecting the PDS method because the ranking results are the same. However, from the mean value of the *working hour* indicator, it is not a priority to assess OHS performance using the DBB method. At the same time, the top-ranking indicator in the DBB and DB methods is *recordable injury*. The *recordable injury* indicator has a high value in all methods, while the *working hour* indicator is consistently the indicator with the lowest value in all methods; CM has a more even distribution of values than DBB and DB. The *fatigue* indicator has a different ranking: highest in CM and lowest in DBB. The *occupational disease* indicator has varying values, highest in DBB and lowest in CM. DB tends to have more consistently high values for most indicators. The *recordable*

Fig. 4. *Comparison of quality performance indicators in the PDS method*



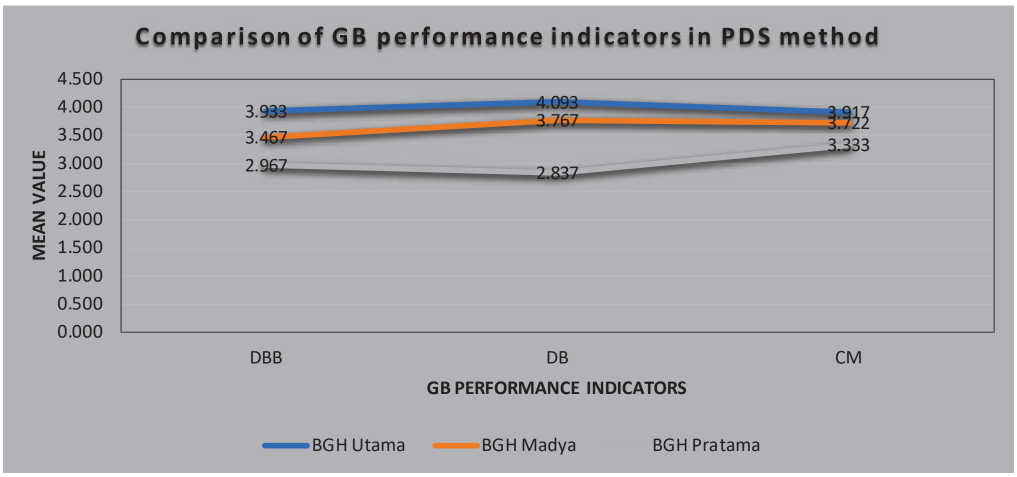
injury indicator is consistently ranked at the top for all methods. The *serious incident frequency* indicator has a relatively consistent ranking in all methods. The priority order of the indicators varies between methods, indicating different focuses in OHS management. In conclusion, each construction method (DBB, DB, CM) has a different approach to OHS aspects: DBB strongly focuses on preventing *recordable injuries* and *occupational diseases*. DB showed a more balanced performance in most indicators. CM paid particular attention to the issue of worker fatigue. Method selection should consider the project-specific OHS priorities and the relative merits of each method in the indicators considered important for worker safety and health.

Fig. 5. *Comparison of OHS performance indicators in the PDS method*



Comparison of GB performance assessment on the selection of PDS usage obtained the same ranking results according to the GB performance ranking category in Indonesia, namely *Main GB* (implementation of green projects by 100%), *Middle GB* (implementation of green projects by 86%), and *Primary GB* (implementation of green projects 56%). The results of this study state that all PDS methods consider *Main GB* to be a priority to be achieved in GB performance assessment. *Main GB* has the highest consistency for all methods, followed by *Middle GB*, and the lowest is *Primary GB*. Significant Differences: DB excels in *Main GB* and *Middle GB* but is the weakest in *Primary GB*. CM has the highest value for *Primary GB* but is the lowest in *Main GB*. DBB tends to be in the middle for all categories. In conclusion, DB seems to be more effective for high-level GB projects (Main and Middle). CM is more suitable for basic-level GB projects (Primary). DBB shows fairly consistent performance at all levels of GBP. The selection of construction methods should consider the desired GB performance level for a particular project. DB may be better suited for more complex GB performance projects, while CM may be a good choice for more basic GB performance projects. DBB offers a more balanced approach across all levels of GB performance. However, the most optimum implementation that can be achieved in the field is only 86% (this result was obtained from other problem formulations in this study). Research (Molenaar et al., 2010) states that 35% of projects do not determine the desired LEED level, and 77% do not determine specific LEED points using a performance specification approach. Moreover, although project management plans are often required, most (42%) do not include sustainability-related criteria.

Fig. 6. *Comparison of GB performance indicators in the PDS method*



Although this study provides valuable insights into the effectiveness of PDS methods in green construction projects in Indonesia, several limitations must be considered. First, the geographical scope of the study is limited to five major cities (DKI Jakarta, Bandung, Semarang, Surabaya, and Denpasar), which may not fully represent conditions in medium and small cities in Indonesia that have different construction market characteristics and industrial capacities. Second, the sample size of 109 respondents, although meeting the minimum statistical requirements, is relatively small compared to the population of construction practitioners in Indonesia, which may limit the generalizability of the findings. Third, this study focuses on completed projects in 2021–2024, excluding ongoing projects or those in the planning stage, which may use newer green construction approaches and technologies. Future research can address these limitations by (1) expanding the geographical scope to medium and small cities to provide a more comprehensive understanding of PDS implementation in more diverse contexts and (2) conducting longitudinal studies to observe how the performance of various PDS methods evolves over time and with regulatory changes; (3) increasing the sample size and stratifying by project size and building type for more in-depth analysis; and (4) conduct a comparative analysis with other ASEAN countries to understand how regional factors influence the effectiveness of the PDS method in green construction. In addition, an in-depth qualitative study of the contextual factors that influence the successful implementation of the PDS method can provide a better understanding of optimizing the selection and implementation of the PDS method in green construction projects in Indonesia.

Conclusions

The study results indicate that no single PDS method consistently excels in all aspects of green project performance in Indonesia. Each method has its strengths and weaknesses. DBB shows superiority in implementing green construction and optimizing cost performance. CM tends to have high scores in various variables, especially regarding time performance, quality, and achievement of GB performance standards. Meanwhile, Design-Build (DB) shows superiority in OHS performance. Analysis of specific indicators for each performance variable provides deeper insight into the characteristics of each PDS method. Differences in values between methods are generally minor, indicating relatively balanced performance. Therefore, selecting the optimal PDS method for green building projects in Indonesia must consider various factors, including specific project priorities, desired GB performance levels, and each method's relative strengths and weaknesses in a particular project context. This study contributes to understanding the effectiveness of various PDS methods in Indonesia's sustainable development context. It can be a valuable reference for practitioners when making decisions related to green project management.

The results of this study provide a new perspective on the effectiveness of the PDS method in green projects in Indonesia, which is significantly different from the findings of studies in developed countries. Unlike the study by Nikou Goftar et al. (2014) which found that DB consistently showed faster project completion times in developed countries, this study found that CM had an advantage in time performance in Indonesia. This can be attributed to the unique characteristics of the Indonesian construction market which requires more intensive management and coordination which is the strength of the CM method. The finding that DB demonstrated superiority in achieving Main Green Building (100% implementation) and Middle Green Building (86%) supports previous research by Gultekin et al. (2013) which showed that DB drives higher green level achievement in sustainable building projects. However, a unique finding of this study is that CM performed best in achieving Primary Green Building, indicating the importance of considering the targeted certification level in selecting the PDS method.

Practically, these results suggest that the selection of PDS methods for green building projects in Indonesia should be tailored to the targeted Green Building certification level: DB is more suitable for projects with high certification targets, CM for projects with basic certification targets, while DBB offers a more balanced approach for all certification levels. This provides concrete guidance for decision makers in the Indonesian construction industry. While this study provides valuable insights, it is worth acknowledging some limitations. The geographic coverage is limited to five major cities, which may not fully represent conditions in medium and small cities in Indonesia. The sample size of 109 respondents, although meeting the minimum statistical requirements, is relatively small compared to the population of construction practitioners in Indonesia. Future studies could expand the geographic coverage to medium and small cities, conduct longitudinal studies to observe how the performance of different PDS methods evolves over time and with regulatory changes, and increase sample size and stratification by project size and building type for more in-depth analysis.

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