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Research Article

BIM in PPP projects comprehensive performance evaluation framework: A literature-based analysis

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ABSTRACT

The release of greenhouse gases and climate change are mostly caused by internal combustion engine emissions from combustion fossil fuels, especially those from gasoline engines. Ethanol can be been recognized as an alternative fuel to gasoline that may also help to reduce pollution. In this paper, the various ethanol-premium gasoline blends with partial additions of paraffin such as n-pentane, hexane, etc. were evaluated for engine performance, combustion, and emission characteristics. CO emissions are reduced by 12 and 15% respectively when hexane and pentane are blended with premium gasoline and ethanol blends. PG40E10P fuel blend had the lowest emissions amongst all fuel blend used in spark ignition engine. Hydrocarbons have been seen to diminish with the addition of hexane and pentane. Partial addition of paraffin assisted complete combustion of fuel therby reducing hydrocarbon emissions by 25%. PG60E10P fuel blend found to have least HC emission amongst all fuel blends. In addition, the cylinder pressure dropped when ethanol was added. The maximum braking thermal efficiency was determined to be PG10P as compared to PG . Paraffin blends helped in complete combustion of fuel and hence BTE improved slightly by 7% as compared with PG. A partial addition of paraffin to gasoline was shown to reduce CO emissions by 10% as compared with PG. The nitrogen oxides (NO_x) was found to decrease by 25% for PG40EP as compared to PG.

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INTRODUCTION

Public-Private Collaboration (PPC) initiatives exhibit inherent complexity in their operational execution, requiring interdisciplinary integration across domains such as legal frameworks, financial systems, technical infrastructure, and organizational governance [1]. These ventures engage a diverse consortium of public and private entities with divergent priorities, necessitating robust performance oversight mechanisms to achieve optimal resource allocation benchmarks (commonly termed Value for Money) during project implementation phases [2]. The

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significance of addressing operational deficiencies is exemplified by empirical evidence indicating that 60-90% of construction modification requests stem from insufficient design specifications during planning stages [3].

Value for Money analysis functions as a critical evaluative paradigm in PPC feasibility assessments, serving as a foundational metric for procurement justification. Nevertheless, current methodologies for monitoring project efficacy remain deficient in two key aspects: the implementation of automated frameworks for real-time evaluation and the establishment of systematic data integration protocols between stakeholders [4].

Projects using the PPP procurement method are expanding globally. PPP is typically distinguished by complexity and lengthy operation, construction, and maintenance periods [5]. PPP projects involve numerous stakeholders and contracts of varying lengths, raising issues with dealing with and integrating information [6]. Multiple public infrastructure projects run using the PPP procurement method frequently ensure VfM. Nevertheless, additional problems might arise, like cost and time overruns [7]. Many PPP projects require more accurate performance evaluation [8]. The successful completion of PPP projects depends on effective performance measurement and assessment because the typical post-evaluation primarily considers cost and schedule, ignoring other factors contributing to a project's success [7].

Building Information Modeling (BIM) is viewed as a tool for enhancing integration and cooperation in PPP projects [6]. BIM adoption has made architecture, Engineering, and Construction (AEC) projects more effective and high-quality [9]. Effectively utilizing BIM for PPP project performance evaluation is relatively challenging due to the complexity of PPP projects and information integration across the project lifecycle [8]. BIM implementation for PPP performance management aids in providing direction to stakeholders and enhancing productivity [2]. Throughout the project life cycle, BIM may also give a digital presentation of the characteristics of the asset [7]. However, due to increased information sharing, BIM can expose consumers to significant danger, such as the risk of Intellectual property rights issues, liability issues, change of BIM policies, or even short-term risks such as time-consuming to be proficient and increased short-term workload [6].

Achieving VfM in PPP initiatives requires effective Performance Management (PM) [2]. Cost overruns, schedule delays, and poor quality are common problems with urban rail transportation PPP projects. The inability of projects to execute well is a crucial problem that must be resolved [10]. By combining Web and Cloud technology, BIM can also aid performance monitoring and payments based on performance [2]. The performance evaluation of buildings' sustainability-related factors requires further analysis [11]. In plenty of PPP projects, accurate performance evaluation must be enhanced [8].

Implementing PPP Projects requires high practical performance evaluation and measurement [7][8]. Traditional post-evaluations focus only on budgets and established timelines. BIM provides a digital representation of the characteristics of the projects. However, BIM also empowers critical decision-makers to make informed decisions throughout the project lifecycle, enabling coordination and integration [7]. That is why a life-cycle performance measurement conceptual framework can aid in establishing resilience [12]. A different approach dealt with the relationship between BIM PPP projects' performance and contractual flexibility throughout the construction phase of projects, where they found that content and executing flexibility significantly impact performance [13]. Furthermore, IFC extension and enhanced matter-element method to accurately evaluate PPP project performance [8]. Combining empirical and experimental studies with semi-structured interviews will construct a BIM-based performance management system (BPMS) using web and cloud technologies [2]. Two research studies studied the cost performance of rail infrastructure. BIM improved overall visualization, which led to selecting the optimal route for the LRT system in one research study [11]. And improved the cost confidence analysis during construction [14]. Scholars have developed analytical frameworks to measure the composite behavioral dimensions observed during Building Information Modeling (BIM) integration in construction initiatives, focusing on post-implementation lifecycle stages. These methodologies synthesize stakeholder adaptation patterns with heterogeneous environmental variables, systematically correlating user engagement metrics (e.g., compliance, resistance, or innovation) with organizational and technical ecosystem conditions [15]. Furthermore, another study suggests that introducing BIM technology can help improve the level of information exchange, which is a key to project success [16]. Another study investigated the role of stakeholder management in moderating the relationship between BIM implementation and project performance. Effective stakeholder dynamics and stakeholder engagement or empowerment have a substantial role in BIM implementation and project performance [17]. Empirical analyses identify four primary operational deficiencies contributing to performance degradation in healthcare infrastructure development: requirement volatility during implementation phases, deficient adaptive capacity toward emergent risks and unpredictable variables, suboptimal governance frameworks in oversight mechanisms, and cognitive predisposition toward favorable outcome projections. These interrelated factors demonstrably compromise project viability and operational outcomes in hospital construction initiatives. If BIM is not deployed, projects have higher possibilities of project costs [18]. However, a cloud-based BIM and information exchange can measure the life cycle of PPP procurement building performance [19]. Nonetheless, Big Data analysis combined with Oracle and BIM models with Primavera software was studied to predict the completion risk in PPP projects [20].

Literature Review

The World Bank [21] defined PPP as a governmental tool or a service to purchase and install public services or infrastructures using the expertise of the private sector. Typically, this tool is used when the government needs more knowledge or more efficient services or goods. Partnerships with the private sector can help stimulate newer, better, or more efficient solutions. In their research, [22] elaborated that PPP models can facilitate and maintain public health and trade. Public services are the primary beneficiaries of the PPP model, including water and sewage treatment, energy, transportation, communication and technology, logistics, and fiscal services.

Furthermore, PPP is one constructive way many countries use for further development. However, the PPP procurement method must solve various challenges, such as organizational cultures and goals between partners, Poor Institutional environment and support, and weak political and legal framework [23]. From a different perspective, [22] argues that PPPs stimulate investment in many fields, especially in infrastructure development, which creates more opportunities and economic growth in many cases. However, challenges and risks can hinder progress in PPP projects. PPP construction practices emphasize the private sector's crucial role and modern sustainability methods while underscoring the need to address fiscal concerns to ensure successful PPP projects [24].

PPP advantages like private sector expertise and budgetary certainty are praised. Yet, challenges like contract renegotiations and delays underscore the necessity for robust systematic performance evaluation methods and understanding critical success factors [25]. Effective performance monitoring and assessment is essential for effectively executing PPP projects [7][8]. Nevertheless, standard ex-post evaluation focuses solely on the budget and planned schedule. Building Information Modelling (BIM) may facilitate coordination and integration by providing a digital representation of an asset's physical and functional qualities and allowing key decision-makers to make informed decisions throughout the life cycle of a project [7]. This is why a conceptual framework for measuring life-cycle performance may assist in assuring resilience [12]. Several studies integrate BIM to address challenges in different aspects of PPP projects. The study by [26] Integrates BIM and integrated project delivery (IPD) to characteristic town development, emphasizing the need for efficient collaborative management amidst information asymmetry.

Recent scholarly investigations have examined the interplay between adaptive contractual frameworks and performance outcomes in Building Information Modeling (BIM)-integrated public-private infrastructure collaborations, particularly during developmental phases. Empirical findings reveal that both structural adaptability (in contractual provisions) and procedural dynamism (in implementation protocols) exert statistically significant positive effects on project efficacy in BIM-enhanced PPC ventures during construction cycles [13]. Concurrently, advancements in performance assessment methodologies have emerged, including the development of Industry Foundation Classes (IFC)-based data schemas and refined matter-element analytic systems, which enable precise, multidimensional evaluation of collaborative infrastructure initiatives [8].

A critical operational challenge in PPC frameworks remains the exposure to exogenous regulatory volatility, encompassing legislative amendments, policy shifts, or fiscal governance revisions. Such exogenous variables introduce substantial risks to project viability, as evidenced by documented correlations between abrupt regulatory changes and diminished performance metrics in areas such as compliance adherence and fiscal predictability [27][28]. This explains why a conceptual comprehensive framework measuring life-cycle performance may assist in project resilience [12].

A different technique was used in other studies, which included empirical and experimental research. Semi-structured interviews were the beginning point for these studies, and Web and cloud technologies were added to create the BIM Based Performance Management System (BPMS) [2]. Choosing and ranking 63 stage-based performance indicators (KPIs) for Build-Operate-Transfer (BOT) projects is an alternative strategy. An integrated project delivery system with BIM implementation might be employed throughout the BOT project's lifecycle. To fulfill project needs for sharing and emerging information [29].

Importance of the Study

This study highlights the essential importance of establishing a standardized performance evaluation system for PPP projects in the context of adopting BIM technology. Despite the acknowledged possibility of BIM to address PPP project challenges, a notable gap exists in the need for standardized comprehensive KPIs. The research analyzes 26 articles, extracting and categorizing KPIs into a comprehensive framework. This standardized evaluation system, encompassing Productivity KPIs (economy, environmental, social) and tool framework KPIs (People, process, technology), departs from traditional time and cost evaluation methods.

Research Methods and Data Collection

This research utilized a systematic approach to identify and analyze suitable literature on the intersection of BIM and PPP projects. The search used a comprehensive set of keywords: BIM, PPP, evaluation, assessment, sustainability, management, political, KPI, KPIs, measuring, and impact. This expansive keyword strategy aimed to ensure a holistic exploration of the topic. The search yielded articles discussing BIM and PPP projects, from which all relevant KPIs were meticulously extracted. Afterward, these KPIs were compiled and organized in an Excel file to facilitate systematic analysis. Essential KPIs, identified as those appearing in the literature more than once, were discerned and retained,

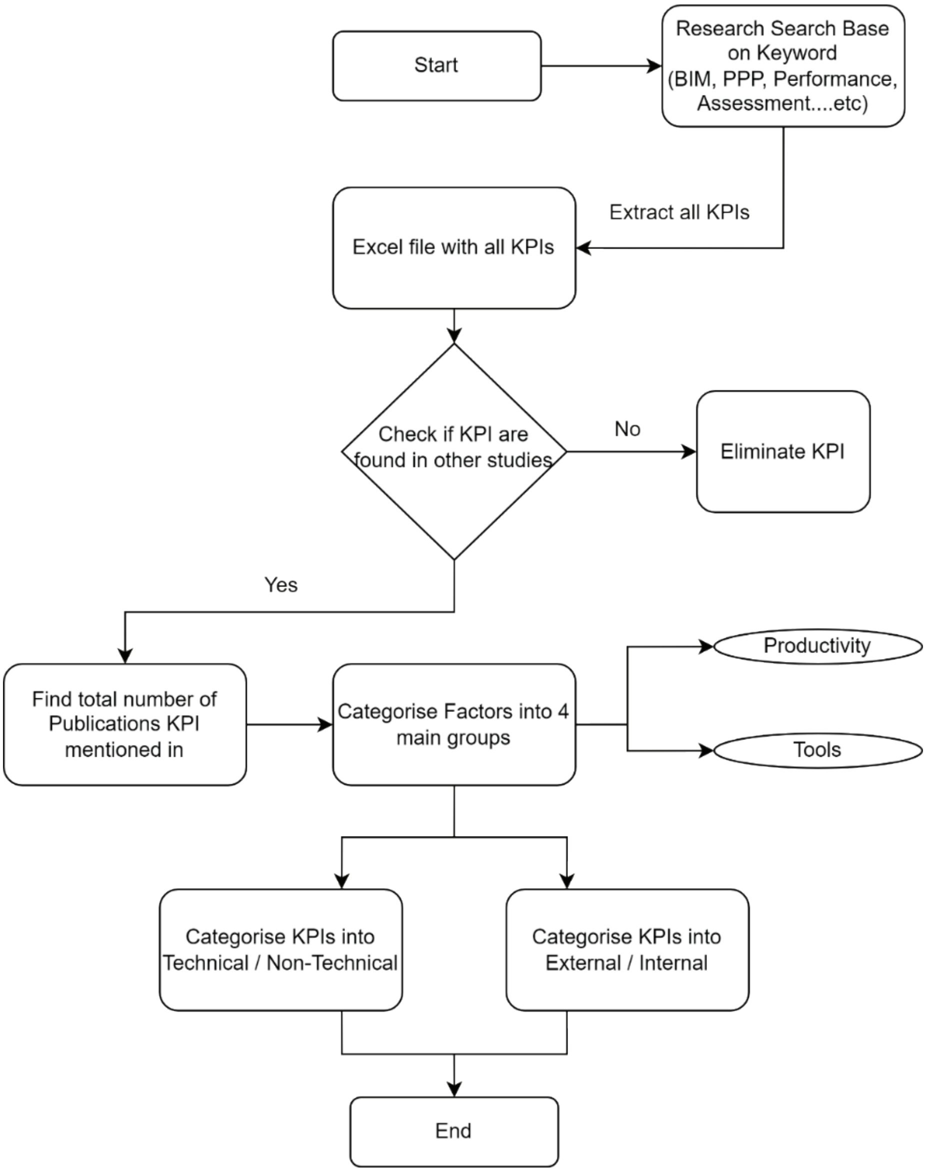

Figure 1. Flow diagram of selection of BIM KPIs for PPP performance evaluation.

while those found only once were excluded. The remaining essential KPIs were then categorized into two overarching frameworks: Productivity and Tools. Within Productivity, KPIs were further classified into environment, economy, and social categories. The Tools framework encompassed three key subcategories: People, Process, and Technology. Additionally, a categorization based on technical and non-technical aspects and internal and external considerations was implemented. The study analyzed twenty-six publications, culminating in identifying and categorizing thirty-nine essential KPIs, providing a comprehensive foundation for evaluating the impact of BIM on PPP projects. Figure 1 provides the flow diagram of selecting BIM KPIs for PPP performance evaluation.

FINDINGS CONCLUSION: PERFORMANCE EVALUATION FOR PPPS

Tools Framework Key Performance Indicators

High-level Performance Management is critical for successful PPP projects [8]. Performance management for PPP projects is essential to stakeholders' interests and improving economic, environmental, and social sustainability [5]. BIM is widely used in many construction fields. As a technology, BIM can boost productivity, collaboration, and overall efficiency [30]. BIM Partnering is suggested to provide the best value for public procurement framework projects [31].

Table 1 presents the comprehensive analysis of the Tools Framework KPIs assessing the evaluation of PPP projects when integrating BIM through the lenses of people, processes, and technology. The carefully selected 18 KPIs from

Table 1. Tools framework key performance indicators (KPIs)

Category		Indicator	Publication
Tools Framework	People	Effective Safety Management: no. of security incidents	[2][7][8][10][29][32][33][34]
		Change management - resistance to change	[6][9][35]
		Information and knowledge sharing	[2][9][33]
		Requirements of Stakeholders/Goals	[32][34]
	Process	Risk allocation	[6][7][29][36][37][38]
		procedures for settling claims and disputes	[7][13][28][34][36]
		Detail and transparent level of tendering procedure	[7][29][31][32]
		procedures for change	[13][34][35]
		Appropriateness of hand-over scope and procedures	[2][7]
		Concessionaire selection criteria	[7][32]
		Clash Detection	[30][33]
		Transferring risk to the private sector	[29][39]
		Appropriateness of final negotiation framework	[7][29]
		Effectiveness of risk management	[8][29]
		Life-cycle management ability	[36][40]
		SMART objectives	[11][36]
	Tech	Document management	[11][30][31][41]
		Updated Timeline	[2][8]

Table 2. Productivity key performance indicators (KPIs)

Category		Indicator	Publication
Productivity	Environment	Water pollution and environmental indicators	[2][11][34][41][42]
		Environmental risk	[2][7][40]
		Energy efficiency (e.g., reduction of energy consumption and use of renewable energy resources)	[11][42][43]
		noise and vibration pollution	[2][10]
		Reduction of pollutant discharge	[42][43]
		Protection of landscape and historical sites	[42][43]
	Economy	Value for Money (VFM)	[2][7][10][29][32][36]
		Feasibility analysis	[7][29][31][32][36]
		Sustainable cash flow	[32][42][43]
		Economic development	[5][34]
		Financial cost	[36][40]
		Financial analysis and operations	[2][7]
	Social	Public Satisfaction	[2][7][8][29][42][43]
		market interest and opportunity	[5][29][32][38]
		End-users satisfaction	[2][7][36]
		Government satisfaction	[2][8]
		Government reputation and improvement	[5][34]
		Trust and respect	[36][43]
		Creditors' satisfaction	[7][29]
		Public interest	[36][40]
		Impact on social development	[42][43]

the literature provide a more detailed knowledge of the implications of adopting BIM. Notably, within the People subcategory, the focus on safety management, change management, information sharing, and stakeholder goals highlights the human dimensions crucial for successful PPP project implementation. The Process KPIs delve into risk allocation, claims settlement procedures, tendering transparency, and other intricate facets of project management, shedding light on the intricacies of operational processes. Furthermore, the Technology KPIs emphasize the significance of document management and timeline updates, emphasizing the role of technological tools in enhancing project efficiency. This framework emphasizes the need for a holistic approach that considers the interplay between people, processes, and technology, providing a solid platform for PPP performance management.

Productivity Key Performance Indicators

Successful PPP projects require a practical and high level of effective performance management [7][8]. Furthermore, effective PM is essential to realize the VfM in PPP projects [2]. BIM is broadly utilized in many construction fields. As a set of technologies, BIM can increase productivity and collaboration and improve overall efficiency [30]. Key performance areas (KPAs) and performance indicators for Bangladesh's PPPs are analyzed. However, relative indicators influencing the performance in developing countries still need to be addressed [36]. However, PPP transit projects still face cost and schedule overruns, poor quality, and a lack of concise and comprehensive performance evaluation systems is still a critical unsolved problem [10].

Productivity KPIs for PPP projects' performance are outlined in Table 2 for adopting BIM across three essential domains: economy, environment, and social. This comprehensive evaluation is vital for understanding the implications of integrating BIM in PPP project performance management. Drawing from various literature, the table shows 21 distinct KPIs categorized into these three primary dimensions. Notably, within the Economy subcategory, key indicators such as Value for Money (VFM) and Feasibility Analysis are crucial benchmarks for evaluating the economic impact of PPP projects. Environmental considerations, encompassing Water Pollution and Environmental Indicators of environmental Risk, illustrate the environmental implications of such projects. Furthermore, the Social KPIs, such as Protection of Landscape and Historic Sites, Public Satisfaction, Market Interest and Opportunity, and End-users' Satisfaction, underscore the societal dimensions integral to a comprehensive assessment of PPP project productivity.

RESULTS AND DISCUSSION

This study aims to enhance PPP projects' performance management by introducing a comprehensive performance evaluation system centered around Productivity and Tools Framework KPIs and explicitly focusing on the impact of the adoption of BIM. The extensive literature review establishes thirty-nine KPIs categorized into Productivity and Tools Framework, further differentiated into (Internal/External) and (Technical/Non-Technical) dimensions. Project stakeholders can evaluate PPP project performance thoroughly because of this study's systematic approach, which provides insightful information about the project's advantages and disadvantages. This work fills a gap by diverging from the conventional focus on construction time and cost, providing a holistic perspective for both public and private sectors to analyze PPP projects.

Furthermore, this article aims to flatten the path for evaluating the impact of BIM implementation in PPP projects. Even with the study's strengths, this paper does not include the process for analyzing BIM adoption using the specified KPIs. Furthermore, the selected KPIs will be utilized to evaluate BIM adoption in PPP later. Future research could also include establishing a particular country or project type for further and deeper analysis. Another aspect of future research is the role of artificial intelligence in improving and facilitating the BIM evaluation process, especially in the context of PPP projects.

CONCLUSION

This study delves into the complex landscape of PPP projects, providing a tailored lens by exploring standardized KPIs to effectively evaluate the performance of BIM adoption, especially in productivity and tools framework. The meticulous analysis of twenty-six publications identified thirty-nine essential KPIs strategically categorized into environment, economy, and social dimensions within Productivity, and it showed People, Processes, and Technology aspects within the Tools framework. This study is an essential resource for project managers and stakeholders looking for a systematic way to evaluate the performance of PPP projects adopting BIM. The study provides technical and non-technical aspects and distinguishes between internal and external considerations; this study offers a comprehensive and practical guide for navigating the different aspects of PPP projects, ultimately contributing to informed decision-making and enhanced project outcomes.

Recommendations

The research recommends two practical recommendations: first, KPIs covering productivity and tools framework and project-specific aspects should be integrated as core elements in evaluating BIM-enabled PPP projects, which will provide a holistic assessment framework. Secondly, continuous collaboration and knowledge sharing between the public and private sectors is crucial to regularly updating and improving these KPIs. This iterative approach will guarantee their relevance and effectiveness in monitoring the impact of BIM in PPP projects. Tables 3 and 4 show the KPIs subdivided into External-Internal and Technical-Nontechnical.

Table 3. Tools framework key performance indicators (KPIs)

Category / Indicator			External	Internal	Technical	Non-Technical
Tools Framework	People	effective Safety management: no. of security incidents	-	✓	✓	-
		Change management - resistance to change	-	✓	-	✓
		Information and knowledge sharing	✓	-	✓	-
		Requirements of Stakeholders/Goals	✓	-	-	✓
	Process	Risk allocation	-	✓	✓	-
		procedures for settling claims and disputes	✓	-	✓	-
		Detail and transparent level of tendering procedure	✓	-	✓	-
		procedures for change	✓	-	✓	-
		Appropriateness of hand-over scope and procedures	-	✓	-	✓
		Concessionaire selection criteria	✓	-	✓	-
		Clash Detection	-	✓	-	✓
		transferring risk to the private sector	-	✓	-	✓
		Appropriateness of final negotiation framework	-	✓	-	✓
		Effectiveness of risk management	-	✓	✓	-
		Life-cycle management ability	-	✓	✓	-
		SMART objectives	✓	-	-	✓
	Tech	Document management	✓	-	-	✓
		updated Timeline	-	✓	✓	-

Table 4. Productivity key performance indicators (KPIs)

Category / Indicator			External	Internal	Technical	Non-Technical
Productivity	Environment	Water pollution and environmental indicators	-	✓	✓	-
		Environmental risk	✓	-	✓	-
		Energy efficiency (e.g., reduction of energy consumption and use of renewable energy resources)	-	✓	✓	-
		noise and vibration pollution	-	✓	-	✓
		Reduction of pollutant discharge	-	✓	✓	-
		Protection of landscape and historical sites	✓	-	-	✓
	Economy	Value for Money (VFM)	-	✓	✓	-
		Feasibility analysis	-	✓	✓	-
		Sustainable cash flow	-	✓	-	✓
		Economic development	✓	-	-	✓
		Financial cost	-	✓	✓	-
		Financial analysis and operations	-	✓	✓	-
	Social	Public Satisfaction	✓	-	-	✓
		market interest and opportunity	✓	-	✓	-
		End-users satisfaction	-	✓	-	✓
		Government satisfaction	✓	-	-	✓
		Government reputation and improvement	✓	-	-	✓
		Trust and respect	-	✓	-	✓
		Creditors' satisfaction	-	✓	-	✓
		Public interest	✓	-	✓	-
		Impact on social development	✓	-	-	✓

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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