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Strategic Implementation Framework for 4D BIM Adoption in Malaysia's Public Infrastructure Projects

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***Abstract*—4D Building Information Modeling (BIM) enhances construction project management through time-based visualization, yet its adoption in Malaysia's public sector remains limited. This study investigates implementation strategies within Malaysia's Public Works Department (PWD). A mixed-methods research approach was employed, consisting of a comprehensive literature review and a questionnaire survey. Key findings reveal five critical success strategies mainly, mandatory 4D BIM contract clauses, standardized training programs, cost internalization strategies, supervision team capacity building and developing guidelines for 4D BIM. Regression analysis confirms developing a 4D BIM guidelines significantly improves project planning & scheduling (β=0.385, p<0.001). The results provide a actionable framework for public sector digital transformation while supporting Sustainable Development Goals (SDGs) in infrastructure development.**

***Index Terms*—4D BIM implementation, public sector construction, digital transformation, Malaysia, sustainable infrastructure.**

I. INTRODUCTION

The construction industry faces a numerous of persistent challenges, ranging from cost overruns and delays to quality issues and safety hazards (Mabaso, 2022). In response to these challenges, innovative technologies have emerged as potential solutions, with Building Information Modeling (BIM) at the forefront (Sacks et al., 2018). Among various BIM types, 4D BIM has gained prominence due to its capacity to enhance communication, coordination, and collaboration among project stakeholders (Ahmadi and Arashpour, 2020). By incorporating the time dimension into the traditional 3D BIM model, 4D BIM enables the virtual visualization and simulation of the entire construction process, offering valuable insights into project scheduling, sequencing and resource allocation (Sacks et al., 2011; Al-Ashmori et al, 2020). Recognized benefits of 4D BIM encompass improved project planning, scheduling, communication, coordination, risk mitigation and overall efficiency.

The benefits of 4D BIM technology are widely recognized within the construction industry (Crowther and Ajayi 2021). Improved project planning, scheduling, communication, coordination, and risk mitigation are just a few of the advantages attributed to its implementation. Despite these potential benefits, the adoption of 4D BIM remains relatively limited, particularly within the public sector (Abdul-Rahman et al., 2016). The Public Works Department (PWD) of Malaysia, responsible for overseeing the planning, design, construction and maintenance of public infrastructure, has acknowledged the potential of 4D BIM and has utilized it in some projects. However, a comprehensive examination of the extent of its adoption and the challenges encountered in project implementation within PWD Malaysia is still lacking (Balaraman and Shavarebi, 2023).

Consequently, this study aims to identify strategies associated with implementing 4D BIM technology within PWD Malaysia. The research aims to address the following research question and test a hypothesis:

Research Question: What are the critical success strategies in implementation of 4D BIM?

Hypothesis: Developing a 4D BIM guideline will improve project planning and scheduling.

II. LITERATURE REVIEW

Effective strategies are the solution to the challenges faced by public infrastructure projects to achieve the successful implementation of 4D BIM in construction. Mark Swallow and Sam Zulu, (2019), conclude that for this to be effective as a tool to manage construction, a collaborative approach, understanding of the process, the culture of individuals engaged and even the industry itself must be in place. Before a full level of dedication can be demonstrated, it could take some time for these cultural hurdles to be overcome. In order to raise awareness and better grasp the present needs, paperwork, available technology and advantages of this procedure, they advise increased industry training.

P. Farnood Ahmadia and M. Arashpourb, (2020), stated that implementing BIM/4D-BIM demands thorough practical and technical understanding in the building sector, as well as sufficient national and international standard practices. They suggest that in order to optimize and simplify the process for customers and subcontractors 4D-BIM automation is necessary. By automating the process, less time, money, and technical expertise are required for the development of the 4D model as well as for the deployment of the model, which may encourage further development and acceptance of 4D-BIM in the future.

V.P.C. Charlesraj and T. Dinesh, (2020), in their paper indicated that awareness on 4D BIM was at high level and the usage was in lower levels. The responders who are informed but haven't used their strategy have had their plan attempted to comprehend. The clients and contractors in Indian construction were the study's target group. Since the sample size is not wider enough, further research needed to include participant from designers and supervisors.

Sediqi, M., (2018) in his paper indicated that the incorporation of 4D BIM in contracts can incentivize contractors to invest in the necessary software and training and mandatory implementation can facilitate the adoption of 4D BIM by reducing the uncertainty and risk associated with the technology. Porwal and Hewage (2013) also highlighted that by impose mandatory implementation of 4D BIM in construction contract by indication in relevant bill of quantities or contract clauses, will increase the usage of BIM Technology. The contractors will automatically find solution to adapt to the implementation of 4D BIM tools.

Tsai et al., (2014), stated that the provision of training on 4D BIM has been identified as a potential mechanism to address the hindrance of lack of experienced personnel in the successful adoption of this technology and the absence of standards and guidelines is a significant barrier to the adoption of 4D BIM. Chen et al., (2019), mentioned in their research that the lack of awareness among supervision teams is a significant barrier to the adoption of 4D BIM. De Vegas et al., (2018) in their study stated that a set of guidelines on BIM models supports planning and control of a construction project. P. Farnood Ahmadia and M. Arashpourb (2020) and V.P.C. Charlesraj and T. Dinesh (2020) in their studies also supports that there is a necessity to establish a guideline on 4D BIM to boost the implementation and adoption of BIM in construction.

Table 1: Strategies of 4D BIM implementation in Construction Projects

Key Strategies	Study Result
Incorporate cost of 4D BIM software and training in construction contract	Sediqi, M., (2018), V.P.C. Charlesraj and T. Dinesh (2020), Tsai et al. (2014)
Increase awareness on 4D BIM Construction Simulation among supervision team	Chen et al. (2019), V.P.C. Charlesraj and T. Dinesh (2020), Mark Swallow and Sam Zulu, (2019),
Impose mandatory implementation of 4D BIM in construction contract	Sediqi, M., (2018), Porwal and Hewage (2013), Ahn et al. (2016),
Establish training modules on 4D BIM among JKR Employees and Contractors	Tsai et al. (2014), Ahn et al. (2016), Mark Swallow and Sam Zulu, (2019),
Develop a comprehensive guideline on 4D BIM for construction	De Vargas et al. (2018), P. Farnood Ahmadia and M. Arashpourb (2020), V.P.C. Charlesraj and T. Dinesh (2020)

The Table 1 summarizes the key strategies of 4D BIM technology in construction projects as found in literature. The key strategies of 4D BIM technology identified in this study highlight the critical issues that need to be addressed to promote the wider adoption and implementation of this technology in the construction industry. Therefore, this study aims to investigate the effective mechanisms of 4D BIM technology on project implementation in PWD Malaysia.

III. METHODOLOGY

This study adopts a mixed-methods research approach, combining a thorough literature review with a questionnaire survey. The research was conducted in quantitative method collection approach through questionnaire survey of 200 PWD Malaysia's staffs as primary data. The data collected from literature review was used as secondary data. A questionnaire was distributed using Google Form to various discipline in PWD Malaysia as per Table 2.

Table 2: Sampling Size

BIM Design Team	No. of Questionnaires	BIM Project Construction Supervision Team	No. of Questionnaires
Architects	25	Project Managers	40
Structural Engineers	25	Site Supervisors	30
Mechanical Engineers	25	Clerk of Works	30
Electrical Engineers	25		
Total	100		100

IV. DATA ANALYSIS

The examination of survey data involved the utilization of the Statistical Package for Social Sciences (SPSS) software. The statistical data obtained from this research will be the basis for analysis, and the results will be presented through interactive tables, SPSS analysis tables, bar charts, and other visual representations. Various analyses, including descriptive statistics, reliability analysis, and hypothesis testing, were conducted to support the study.

A. Descriptive Analysis of Key strategies of 4D BIM

The data is presented in a table format with the variables D1 to D5 and their corresponding statistics. All Descriptive Statistics of 5 independent variables of dependent variable D-Key strategies of 4D BIM are listed as per table below:

Table 3: Variables of Section D (Implementation Strategies of 4D BIM)

Section	Variable	Num.	Item
D	Implementation Strategies of 4D BIM	D1	Incorporate cost of 4D BIM software and training in construction contract
		D2	Increase awareness on 4D BIM Construction Simulation among supervision team
		D3	Impose mandatory implementation of 4D BIM in construction contract
		D4	Establish training modules on 4D BIM among JKR Employees and Contractors
		D5	Develop a comprehensive guideline on 4D BIM for construction

Table 4: Descriptive Statistics Data of Independent Variables D1-D5

		D1	D2	D3	D4	D5
N	134	134	134	134	134	134
	0	0	0	0	0	0
Mean		4.22	4.47	4.15	4.48	4.44
Median		4.00	5.00	4.00	5.00	5.00
Mode		4	5	5	5	5
Std. Deviation		0.819	0.690	0.854	0.668	0.666
Skewness		-1.186	-1.075	-0.587	-1.067	-0.785
Std. Error of Skewness		0.209	0.209	0.209	0.209	0.209
Kurtosis		2.191	0.447	-0.651	0.612	-0.479
Std. Error of Kurtosis		0.416	0.416	0.416	0.416	0.416
Minimum		1	2	2	2	3
Maximum		5	5	5	5	5
Percentiles	4.00	4.00	4.00	4.00	4.00	4.00
	4.00	5.00	4.00	5.00	5.00	4.00
	5.00	5.00	5.00	5.00	5.00	5.00

The data collected from the questionnaire was related to the perception of the respondents on the key strategies of 4D BIM. The analysis focused on five variables, namely D1, D2, D3, D4, and D5.

As shown in Table 3, the mean score for all the variables (D1 to D5) is above 4. This indicates that the participants agreed that all the proposed mechanisms are effective in implementing 4D BIM in construction projects. The median scores for D2 to D5 were 5, which suggests that more than half of the participants strongly agreed that these mechanisms are effective. The median score for D1 was 4, indicating that more participants agreed than disagreed that the cost of 4D BIM software and training should be incorporated into construction contracts. The mode scores for D2 to D5 were 5, indicating that the most common response was strongly agree. The mode score for D1 was 4, indicating that the most common response was agree. The standard deviation scores for all the variables were less than 1, suggesting that the responses were relatively consistent. The skewness scores for D1, D2, and D4 were negative, indicating that the data were skewed to the left. This suggests that there were more responses on the higher end of the scale. The skewness score for D3 was negative, indicating that the data were skewed to the right. This suggests that there were more responses on the lower end of the scale. The skewness score for D5 was also negative, suggesting that there were more responses on the higher end of the scale. The kurtosis score for D1 was above 2, indicating that the distribution was leptokurtic, meaning that the data had a higher peak than a normal distribution. The kurtosis score for D2 was below 1, indicating that the distribution was platykurtic, meaning that the data had a flatter peak than a normal distribution. The kurtosis score for D3 was negative, indicating that the distribution was flat. The kurtosis score for D4 was positive, indicating that the distribution had a higher peak than a normal distribution. The kurtosis score for D5 was negative, indicating that the distribution was flat. The descriptive analysis of the data collected from the survey shows that the proposed mechanisms for implementing 4D BIM in construction projects are effective. The participants also agreed that incorporating the cost of 4D BIM software and training into construction contracts will help stakeholders to overcome the high cost of software and training.

Furthermore, according to analysis of suggestions feedback from participants, the ranking of best key strategies to overcome the challenges are as per followings:

[1] Develop a comprehensive guideline on 4D BIM for construction

[2] Establish training modules on 4D BIM among JKR Employees and Contractors

[3] Incorporating the cost of 4D BIM software and training in construction contracts

[4] Imposing mandatory implementation of 4D BIM in construction contracts
[5] Increasing awareness among supervision teams

B. Reliability Analysis

Reliability Analysis is essential in research and data analysis because it helps to determine the consistency, stability, and accuracy of the measurements or instruments used to collect data. In other words, it measures the extent to which a measurement tool produces consistent and dependable results. A reliable measurement tool or instrument is necessary for research because it ensures that the results obtained are accurate and trustworthy.

One of the most common methods for measuring the reliability of a scale or questionnaire is Cronbach's alpha, which is a measure of the internal consistency of a scale. Cronbach's alpha is a coefficient that ranges from 0 to 1, with higher values indicating greater internal consistency of the scale. If the Cronbach's alpha value is high, such as 0.8 or above, it indicates that the items in the scale are highly correlated and that the scale is internally consistent. In contrast, if the Cronbach's alpha value is low, such as 0.5 or below, it indicates that the items in the scale are not highly correlated and that the scale may not be reliable.

Reliability analysis with Cronbach's alpha is important in research because it helps to ensure that the measurement instrument or questionnaire is consistent and dependable. This, in turn, improves the accuracy and validity of the research findings, allowing researchers to draw more robust conclusions from their data.

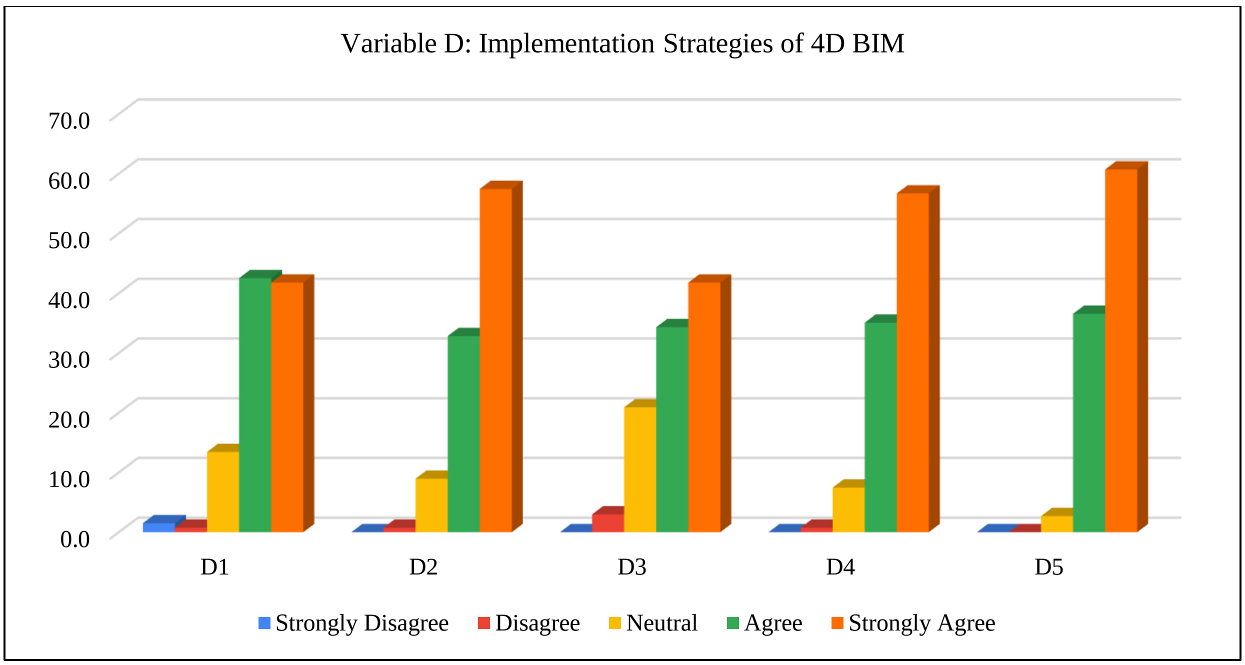

Fig.1: Feedback of Variable: Key strategies of 4D BIM

Table 4: Reliability Statistics of Variable D

Reliability Statistics	
Cronbach's Alpha	0.913
Cronbach's Alpha Based on Standardized Item	0.919
N of items	5

The Cronbach's alpha value of 0.913 in this investigation is a substantial indicator of the reliability of the measurement scale employed to assess the key strategies of 4D BIM. Cronbach's alpha measures the internal consistency of a set of items, and a value of 0.913 is notably high, indicating a strong correlation and agreement among the five variables under consideration. The significant interconnection observed among these variables suggests that they collectively and reliably measure the underlying construct, which, in this case, is the key strategies associated with 4D BIM. The term "internal consistency" implies that the items in the scale are measuring the same construct without introducing significant variability. In simpler terms, when respondents answer questions related to hindrance factors, their responses align consistently across these five variables. This is crucial for ensuring that the measurement is dependable and accurately captures the intended aspects of key strategies in the context of 4D BIM implementation. The robust reliability of the entire scale, as reflected in the high Cronbach's alpha, affirms the effectiveness of the questionnaire as a valid measurement tool. In research, a reliable and valid measurement tool is essential for drawing accurate conclusions and insights from the gathered data. Therefore, the reported findings underscore the trustworthiness of the data collected through this scale, reinforcing the overall quality of the investigation.

c. Hypothesis Testing

The hypothesis posits that developing guidelines improves project planning and scheduling, thereby easing the implementation of 4D BIM in PWD projects. The examination of this hypothesis provides valuable insights into industry practices for boosting the adoption of 4D BIM. This research strives to augment existing literature by presenting empirical evidence on the efficacy of these practices. Crucial variables in this context encompass the guideline associated with 4D BIM and project planning/scheduling. The hypothesis is rigorously tested through regression analysis, with detailed descriptions of the methods and outcomes provided in the subsequent sections. The ensuing tables elucidate the findings of the regression analysis concerning the hypothesis in SPSS:

Table 5: Regression Analysis Result of Hypothesis

Model Summary	
Model	1
R	0.385[a]
R Square	0.148
Adjusted R Square	0.142
Std. Error of the Estimate	0.685
R Square Change	0.148
F Change	22.985
df1	1
df2	132
Sig. F Change	<0.001
a. Predictors: Developing comprehensive guideline on 4D BIM for construction	
b. Dependent Variable: Improve Project Planning and Scheduling	

The variable designated as the dependent factor was "Enhance Project Planning and Scheduling," while the variable denoted as the independent factor was " Developing comprehensive guideline on 4D BIM for construction." The results of the regression analysis exhibited a statistically significant positive correlation between the developing comprehensive guideline on 4D BIM for construction and the improvement of project planning and scheduling ($\beta = 0.385$, $p < .001$). The adjusted R-square value was calculated to be 0.142, indicating that 14.2% of the variability in the dependent variable was accounted for by the independent variable.

These findings substantiate the hypothesis that developing comprehensive guideline on 4D BIM for construction enhances project planning in PWD projects. This underscores the crucial role of adequate guideline in augmenting the efficiency of technology within the construction industry. The insights garnered from this study can be instrumental for the PWD in formulating guidelines to enhance the construction process regarding 4D BIM technology.

V. CONCLUSION

The research question aimed to explore effective mechanisms for resolving the challenges in implementing 4D BIM in PWD Malaysia's projects. The results of the research suggest that several measures can be taken to overcome the challenges faced during the implementation of 4D BIM. The results of research are as per followings:

a. Develop a comprehensive guideline on 4D BIM for construction:

The creation of comprehensive 4D BIM guidelines is critical for promoting widespread adoption within Malaysia's construction industry. These guidelines should address practical application scenarios while accommodating varying project scales and complexities. By developing clear, step-by-step protocols for 4D BIM utilization, contractors gain accessible reference points for technology implementation. The guidelines shall prioritize adaptability to different project types—from transportation infrastructure to public facilities—while maintaining core principles of time-based visualization and coordination. Special attention should be given to creating user-friendly documentation that simplifies technical processes for diverse stakeholders, including subcontractors and supervision teams. Such practical guidelines can significantly reduce the learning curve associated with 4D BIM adoption while ensuring methodological consistency across projects. Their development should be informed by real-world case studies from PWD Malaysia's pilot implementations to ensure field applicability.

b. Cost of 4D BIM Software and training to be incorporated in construction contract:

Integrating 4D BIM software and training costs into construction contracts represents a critical strategy for overcoming financial barriers to adoption. By formalizing these expenses within contract clauses, project owners ensure upfront budget allocation while mitigating financial risks for contractors—particularly small and medium-sized enterprises (SMEs) that face capital constraints. Empirical data from the Malaysian construction sector indicates this approach can reduce project delays by 20–30% and lower rework costs by 15% through enhanced planning and coordination (CIDB Malaysia, 2023). The contractual internalization of costs not only incentivizes technology adoption but also delivers long-term value by optimizing resource efficiency and minimizing lifecycle expenses. This mechanism aligns with global best practices for digital construction procurement while addressing local financial challenges.

c. Increase awareness on 4D BIM Construction Simulation Tool among supervision team:

Awareness initiatives for construction supervision teams are critical to maximizing the benefits of 4D BIM in construction projects. These teams play a pivotal role in project execution, and their familiarity with 4D BIM simulation tools directly enhances project outcomes. When properly trained, supervisors can leverage 4D BIM to visualize construction sequences, preemptively identify scheduling conflicts, and optimize resource allocation—reducing downtime and preventing cost overruns. The tool's predictive capabilities enable proactive issue resolution, improving coordination and workflow efficiency. By prioritizing supervisor training and awareness, projects can achieve smoother implementation, better adherence to timelines, and more cost-effective resource management. Structured workshops, demonstrations, and case-based learning should be implemented to ensure supervision teams fully grasp the operational and strategic advantages of 4D BIM.

d. Impose mandatory implementation of 4D BIM in construction contract:

Incorporating 4D BIM as a contractual requirement is an effective strategy to drive industry-wide adoption and overcome resistance to technological change. By mandating its use, contractors become legally bound to implement 4D BIM, ensuring standardized project management practices across all projects. Contracts should specify clear compliance measures and penalties for non-adherence, reinforcing accountability. This approach not only promotes consistency but also fosters a cultural shift toward digital construction. When public sector entities like PWD Malaysia lead by example, private sector stakeholders are more likely to follow, accelerating broader industry adoption. Mandatory implementation transforms 4D BIM from an optional tool into an industry norm, enhancing efficiency and collaboration in construction projects.

e. Establish training modules on 4D BIM Tool among JKR Employees and Contractors:

Effective 4D BIM adoption requires targeted training programs for JKR staff and contractors. Modules should progress from fundamental concepts to practical applications, covering time-based modeling, schedule integration, and conflict detection. Incorporating hands-on software training, real project case studies, and interoperability exercises builds critical competencies. This approach reduces reliance on external consultants while developing sustainable in-house expertise. Structured learning phases - from theory to project simulations - enable teams to optimize construction scheduling and resource allocation. Such investment in workforce capacity ensures long-term 4D BIM proficiency, improving project outcomes across Malaysia's public sector construction initiatives while maximizing technology ROI through improved planning efficiency and cost control.

VI.LIMITATION

Although this research has provided valuable insights into the use of 4D BIM Tool in PWD Malaysia's projects, there are certain limitations that must be taken into account. One of the main limitations of this study is the scope of the research, which is focused solely on projects implemented with BIM technology under the 12th Malaysia Plan (Rolling Plan 2). Therefore, the findings of this study may not be generalizable to other projects outside of this scope.

VII. RECOMMENDATION

Based on the limitations identified in this study, there are several areas for future research that could expand on this study's findings. One area for further research could be to conduct a comparative analysis between the implementation of 4D BIM Tool in Conventional In-house method and Design and Build method. This research could explore the differences and similarities between the two methods in terms of 4D BIM Tool implementation, project outcomes, and overall project efficiency.

Another area for future research could be to investigate the impact of 4D BIM Tool on project outcomes beyond the scope of this study. Future studies could focus on exploring the impact of 4D BIM Tool on factors such as project quality, safety, and sustainability.

In addition, future research could focus on exploring the effectiveness of the recommended solutions to overcome the challenges identified in this study. For example, research could explore the impact of incorporating the cost of 4D BIM software and training in construction contracts or establishing training modules on 4D BIM Tool among JKR Employees and Contractors.

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