



**Evaluation of the Project Cost Budget Plan for the XYZ Data Centre
Construction Project Using My SMM and Regulation of the Director General
of Construction Development No. 182 of 2025 Based on a WBS Integrated
with Bim and Risk Analysis to Improve Cost Accuracy**

Brillianty Gita Kareen*, Yusuf Latief

Universitas Indonesia

Email: brillianty.kareen@gmail.com*

Abstract

Keywords

cost estimation, cost accuracy, wbs, bim, risk

This study evaluates the accuracy of project cost budget planning for the XYZ Data Center construction using an integrated model combining WBS, BIM, the Malaysian Standard Method of Measurement (MY SMM), SE Director General of Construction Development No. 182 of 2025, and risk analysis. The research addresses the recurring issue of cost deviations in Indonesian construction projects, evidenced by significant discrepancies between estimated and actual costs in previous audits. The study employed a mixed-methods approach, incorporating qualitative analysis of project documentation, BIM-based quantity take-offs, surveys of 85 construction practitioners, and quantitative SEM-PLS analysis alongside Monte Carlo simulations for risk-based contingency costs. Findings reveal that WBS-based BIM significantly enhances the consistency and precision of quantity take-offs, reducing volume deviations to 0–5% compared to conventional manual methods. SEM-PLS results confirm that the cost estimation process positively and significantly impacts cost accuracy ($\beta = 0.704$, $p = 0.006$), with BIM as the most influential factor, while MY SMM and SE Director General standards have limited direct effect. Integration of risk contingencies further refines project cost predictions, increasing estimates by 8.10–16.10%. The study concludes that the proposed integrated model effectively improves cost estimation accuracy in complex data centre projects, providing a framework for standardized, risk-aware budgeting in Indonesian construction.

INTRODUCTION

The construction industry in Indonesia continues to experience rapid growth, driven by the high demand for infrastructure and public facility development. Major projects, such as skyscrapers, shopping malls, health facilities, and road and bridge infrastructure, are now an integral part of the country's economic development efforts. In this context, cost management and accurate estimates are crucial elements to ensure the smooth running and success of each project.

Data centre projects are a type of building that has a much higher level of complexity compared to ordinary buildings. Certain building design and performance features exhibit a higher level of interconnectedness and complexity (Ramanathan & Rathore, 2024). This complexity leads to an inaccurate cost estimation process that has the potential to lead to significant cost deviations, which in turn impacts contract overpayments and disputes between the parties involved (Jumas et al., 2017; Kamaludin & Rusdin, 2023).

Based on the results of the BPK and BPKP audits, it was found that there was an inaccuracy in estimating the volume of work in several large construction projects carried out by PT. X. In the PT. X in 2022–2023 there was a volume shortage of IDR 775,307,045.43; in the school project of PT. X Year 2025 amounting to IDR 886,746,238.00; and in the XYZ Data Centre project of PT. X Year 2023–2025 amounting to IDR 709,004,360.65. From school projects alone, there are 5 (five) projects that experienced similar findings with a total correction value of IDR 886,746,238.00.

These findings prove that the difference in volume and cost is not a single case, but a recurring phenomenon across projects that has implications for overpayments and contract deviations (Abdel-Monem et al., 2022; Akbar et al., 2015; Zahrah et al., 2023). This phenomenon is in line with academic findings that inaccurate cost estimates are the dominant cause of cost overruns in construction projects (Ginting et al., 2024). The main causative factors include: (1) inaccuracies or errors in the BOQ due to limited estimator competence; (2) the limitations of conventional methods in volume calculation and the lack of integrated technology; (3) inadequate quality of design documents and technical drawings; (4) weak coordination between stakeholders; and (5) design changes and external factors that are not well managed.

Indonesia does not yet have a comprehensive and integrated Standard Method of Measurement (SMM) regulation. This causes cost accuracy in the estimation process to be inaccurate or miss the initial price estimate for the Bill of Quantities (BOQ). With the issuance of the SE of the Director General of Construction Development No. 182 of 2025 which replaces the PERMEN PUPR No. 8 of 2023, there is a significant opportunity to improve the standardization of construction cost estimates in Indonesia.

Previous research has shown that BIM, WBS, risk, and cost measurement standards (MY SMM) are still discussed separately, and there is no cost estimation model system that integrates all of these components into a single integrated cost estimation system in data centre projects in Indonesia. This research aims to fill this gap by developing an integrated cost estimation model that combines WBS, BIM, MY SMM, SE Director General of Construction Development No. 182 of 2025, and risk analysis to improve the cost accuracy of data centre projects.

Based on this background, this study formulated nine research questions (RQ1–RQ9) which include: analysis of existing conditions of cost estimation processes and cost accuracy, identification of system variables, development of models of relationships between variables, development of WBS, WBS-based BIM modelling, integration with MY SMM and SE Director General of Construction Development No. 182 of 2025, as well as the development of risk-based integrated cost estimation.

Cost estimation is an important thing in the world of construction that is carried out before the physical implementation of construction (Silviana Dewi et al., 2024; Tian et al., 2025)

. Estimating construction costs requires detailed analysis and compilation of documents because cost estimation has an impact on the success of the project and the company. The accuracy of cost estimation depends on the latest information in the field of construction obtained, in addition to the selection of the type of cost estimate used (Sudiarta, 2011).

The stages of the cost estimation process include: (1) data collection and information (data on unit price, productivity, volume of work, historical data); (2) the preparation of WBS; (3) selection of estimation methods; (4) cost calculation based on WBS, BIM, and SMM; (5) preparation of cost budgets; (6) contingency and risk allocation; (7) cost monitoring and control; (8) cost evaluation and verification; and (9) documentation and reports. The quality of the information used during the cost estimation process has an influence on cost accuracy.

Cost accuracy is the degree of accuracy of cost estimates to the actual cost of a project. According to AACE (2019), the classification of cost estimates is divided into 5 classes based on the level of project progress, with varying degrees of accuracy. Factors that affect cost accuracy include: accuracy of work quantity, conformity of volume with work drawings, consistency of work unit prices, image quality and technical specifications, completeness of BOQ, and availability of relevant project historical data (Plamonia et al., 2023).

Research by Fauzan et al. (2023) confirms that weak internal controls and inaccurate planning are the main factors in contract deviations in government construction projects. Meanwhile, Ginting et al. (2024) found that the deviation between RAB and RAP reached 17.44% or IDR 657.9 million due to weaknesses in the initial estimate, which shows how important accuracy is in the process of estimating construction project costs in Indonesia.

The Standard Method of Measurement (SMM) is a system that provides clear guidelines for measuring construction work, calculating the quantity of materials, labor, and equipment, and simplifying the process of preparing a Cost Budget Plan. The application of SMM in construction projects helps reduce uncertainty in cost estimates and improves the accuracy of calculations which is very important for project budget management (Amuda-Yusuf & Mohamed, 2015). SMM itself aims to provide the same measurement basis, facilitate the preparation of BOQ, reduce differences of views between parties, and control the project.

The Malaysian Standard Method of Measurement 3 (MY SMM / SMM3) classifies the work into standard sections which include: WS04 (Excavation and Filling), WS06 (Piling Works), WS09 (In-Situ Concrete Works), WS10 (Structural Steelwork), WS14 (Masonry), WS19 (Finishes), and other sections. Each section has specific measurement rules related to units, measurement methods, and classification of work items that must be followed consistently.

SE Director General of Construction Development No. 182 of 2025 is an update of the regulation on estimating construction costs in Indonesia which replaces PERMEN PUPR No. 8 of 2023. This regulation includes a Unit of Work Price Analysis (AHSP) which is composed of labor, material, and equipment components based on standardized productivity coefficients. The purpose and scope of this regulation is to: (1) provide a reference in the preparation of the AHSP; (2) improve the consistency and accuracy of construction cost estimates; and (3) be the basis for the preparation of Self-Estimated Prices (HPS) in the procurement of construction services.

The mechanism for collecting data on the cost of the unit price of the construction sector is carried out through a survey of local material/material prices, a survey of labor wages according to UMP/MSEs, and a survey of equipment operational costs. The components of AHSP consist of: Basic Unit Price (HSD) of labor, HSD of materials, HSD of equipment, productivity coefficient

of each component, indirect costs (overhead 10–15%), and contractor profits. The implication of this regulation on project cost planning is that there is a more consistent standardization of coefficients compared to the use of actual field productivity that varies between contractors.

Work Breakdown Structure (WBS) is an instrument that plays a crucial role in project management to divide large projects into smaller and manageable parts. According to PMBOK 6 (2017), WBS is a hierarchical decomposition of the total scope of work that must be carried out by the project team to achieve project objectives and create the necessary deliverables. Factors influencing WBS in cost estimation include: level of decomposition detail, experience and expertise of the project team, standards and methodologies used, type and complexity of projects, changes in scope of work, external factors, and technology used (BIM).

The development of risk-based WBS for specific projects has proven its effectiveness in several previous studies. Mustain et al. (2019) developed a risk-based WBS standard for dam cost estimation with 6 hierarchical levels, resulting in more accurate and transparent cost estimates. Hudoyo (2018) also developed risk-based WBS standards for seaport projects that have been proven to improve the consistency of work groupings. The integration of WBS with BIM technology allows for more precise visualization as well as more effective cost management (RICS, 2014).

Building Information Modelling (BIM) has various dimensions in its application. 3D BIM is a 3-dimensional geometric modeling. BIM 4D adds time/scheduling dimensions. BIM 5D incorporates cost estimation into BIM 4D to enable integrated project cost planning and budgeting. BIM 6D optimizes energy consumption. BIM 7D includes lifecycle information for facility management.

Risk in a construction project is an uncertain event that, if it occurs, can have a negative or positive impact on the project's goals and objectives. The risk management process according to PMBOK includes: Plan Risk Management, Identify Risk, Perform Qualitative Risk Analysis, Perform Quantitative Risk Analysis, Plan Risk Response, Implement Risk Response, and Monitoring Risk.

Quantitative risk analysis through Monte Carlo simulation is a probabilistic technique used to calculate various possible project scenarios based on risk uncertainty. This simulation uses probability distributions, e.g. triangular distributions with minimum, most likely, and maximum parameters: TRIANGULAR DISTRIBUTION = (Minimum, Most Likely, Maximum). Contingency costs are calculated as a reserve to anticipate unexpected project risks.

Based on a literature review, the conceptual framework of this study identifies that the cost accuracy of data center projects is influenced by the cost estimation process (X1), MY SMM (X2), SE Director General of Construction Development No. 182 of 2025 (X3), WBS (X4), BIM (X5), and risk (X6). The research hypotheses developed include: (H1) WBS has a positive effect on BIM in supporting quantity extraction; (H2) The SE of the Director General affects the accuracy of BIM output in calculating costs; (H3) MY SMM improves BIM accuracy in quantity estimation; (H4) BIM has a positive effect on the accuracy of risk-based RAB estimation; (H5) WBS contributes significantly to the accuracy of RAB estimates; (H6) The SE of the Director General affects the

accuracy of the RAB; (H7) MY SMM supports RAB consistency; (H8) the estimation process has a positive effect on the risk; and (H9) risk has a positive effect on cost accuracy.

METHODS

Types and Research Strategies

This study used mixed methods that combine qualitative and quantitative approaches. Creswell and Plano Clark (2018) explain that mixed methods are used when research requires the combination of quantitative and qualitative approaches so that a comprehensive understanding can be obtained. A qualitative approach is used to identify cost conditions and accuracy in the existing and development of WBS, BIM, MY SMM, and risk-based cost estimation. A quantitative approach was used to test the relationships between variables using SEM-PLS and calculate risk contingency costs using Crystal Ball with Monte Carlo simulations.

Table 4. Research Strategies Based on Research Questions

RQ	Research Questions	Questions	Strategy
RQ1	What are the cost estimation processes on current XYZ data centre projects?	What	Archive Analysis + Survey
RQ2	What is the level of accuracy managed by PT. X?	What	Archive Analysis + Survey
RQ3	What are the system variables based on theory and practice that affect cost estimation?	What	Literature Studies & Questionnaires
RQ4	What is the model of the relationship between the estimation process, WBS, and BIM to cost accuracy?	How to	Case Study + SEM-PLS
RQ5	How to develop WBS on a data centre project?	How to	Case Studies
RQ6	How to develop a WBS-based BIM model to produce QTO?	How to	Case Studies
RQ7	How is MY SMM applied to WBS-based BIM models?	How to	Case Studies
RQ8	How is the cost estimate based on BIM and WBS using the SE Director General No. 182/2025?	How to	Case Studies
RQ9	How is the cost estimate of WBS, BIM, and risk integration?	How to	Case Study + Monte Carlo

Source: Prepared author (2026)

Data Collection

Data collection was carried out through four methods: (1) archive analysis – using BOQ documents, RAP, contract documents, and changes to the XYZ Data Center project; (2) case study – on Data Center Project XYZ using Autodesk Revit for BIM modeling; (3) survey – using a questionnaire distributed to 85 respondents from construction practitioners; and (4) literature studies – to obtain a theoretical and conceptual foundation.

The study respondents consisted of construction practitioners with various educational backgrounds (S1, S2, S3) and work experience (at least 5 years). Expert validation is carried out by experts with a minimum of 10 years of experience in the fields of project management, BIM, QS, and construction risk.

Research Variables

Table 5. Details of Key Variables and Key Indicators of the Study

Code	Variable	Key Sub-Variables	References
X1	Cost Estimation Process	Data collection, WBS compilation, estimation method selection, cost calculation, evaluation and verification	PMBOK 6; AACE 2019
X2	MY SMM	Measurement rules, job classification (work sections), preparation of BoQ, standardization of presentation	SMM3 Malaysia (2020)
X3	SE Dirjen No. 182/2025	HSD collection, productivity analysis, AHSP compilation, HPS calculation, validation	SE Director General of Construction Development No. 182/2025
X4	WBS	Scope statement, decomposition deliverables, work packages, WBS dictionary, scope baseline	PMBOK 6; ISO 21511:2018
X5	BIM	Information input to 3D models, WBS-BIM integration, quantity take-off, model validation	BPSDM PUPR (2018); Eastman et al. (2011)
X6	Risks	Risk identification, probability-impact assessment, qualitative analysis, Monte Carlo simulation, contingency costs	PMBOK 6; ISO 31000
Y	Cost Accuracy	Estimated vs actual deviation, volume consistency, unit price accuracy, conformity to field conditions	Liu & Zhu (2007); AACE 2019

Source: Prepared author (2026)

Data Analysis

Data analysis was carried out using several methods: (1) validity test using face validity and content validity by experts, and construct validity using corrected item-total correlation; (2) reliability test using Cronbach Alpha; (3) data adequacy test using KMO-Bartlett; (4) homogeneity test using the Levene test; (5) SEM-PLS analysis using SmartPLS 4.0 which includes outer model test (AVE, composite reliability, discriminant validity) and inner model test (path coefficient, R^2 , f^2 , predictive relevance); and (6) Monte Carlo simulations using Oracle Crystal Ball with 1,000 iterations for contingency cost calculations.

RESULTS AND DISCUSSION

Existing Conditions of the Cost Estimation Process (RQ1)

Based on expert validation and analysis of project documents, the cost estimation process on the XYZ Data Center project is still mostly done manually. Quantity take-off on the MC-100 is still carried out based on the reading of the 2D working drawings manually by the estimator. This process has not been integrated with digital technologies such as BIM, so it relies heavily on the expertise and experience of individual estimators.

Analysis of the Data Center XYZ project documents showed several important findings: (1) Lack of volume of 200 mm hydrant pipes: BOQ set 14 meters but the results of the physical examination were only 11 meters, resulting in a shortage of volume worth Rp7,656,300.00; (2) Lack of 200 mm gate valves: BOQ set 3 pieces but only 2 were installed, causing an overpayment of Rp15,486,300.00; (3) The volume of concrete that has not been reduced by the volume of iron reinforcement: Causes an excess of concrete volume worth Rp685,861,760.65; and (4) The deviation between the initial RAP and MC-100 RAP reached IDR 11,697,039,642.46 or around 10.14%.

The Cost Accuracy Rate of PT. X (RQ2)

Comparison results between the initial RAP and the MC-100 RAP showed a significant cost deviation. Such deviations are mainly found in structural work, especially in bore pile and reinforced concrete work. Some work items experience differences in quantity to actual field volume due to design changes, inconsistent manual quantity take-off methods, and limited work drawings used as references.

The existing cost accuracy conditions in the XYZ Data Center project show that the quantity take-off process still requires significant improvement in terms of consistency, accuracy, and standardization of measurement methods. This finding is the main justification for the development of an integrated cost estimation model based on BIM, WBS, MY SMM, SE Director General, and risk in this study.

System Variables (RQ3)

Based on the validation of 85 respondents, all research variables were declared valid and reliable. The following table presents the results of the main statistical tests:

Table 6. Summary of the Results of the Statistical Test of Research Variables

Variable	Number of Indicators	SME Value	Cronbach Alpha	Remarks
Cost Estimation Process (X1)	27	0,854	0,921	Valid & Reliable
MY SMM (X2)	24	0,812	0,903	Valid & Reliable
SE Dirjen No. 182/2025 (X3)	18	0,798	0,887	Valid & Reliable
WBS (X4)	24	0,836	0,914	Valid & Reliable
BIM (X5)	21	0,847	0,909	Valid & Reliable
Risk (X6)	24	0,823	0,897	Valid & Reliable
Cost Accuracy (Y)	18	0,801	0,892	Valid & Reliable

Source: Prepared author (2026)

The homogeneity test based on education, institution, and length of service showed that there was no significant difference in perception between respondent groups, so the data could be combined for further analysis. BIM and WBS variables are the variables that are considered most important by respondents in increasing the consistency of project work volume and helping to control the quantity of work.

Intervariable Relationship Model – SEM-PLS (RQ4)

The SEM-PLS analysis was carried out using SmartPLS 4.0. The results of the outer model test showed that all indicators met the criteria of Average Variance Extracted (AVE) > 0.5 and composite reliability > 0.7, so that the model had adequate convergent and discriminant validity.

Table 7. Inner Test Results of Model SEM-PLS (R² and f²)

Endogenous Variable	R ²	Category R ²	f ² (Effect)	Remarks
Cost Accuracy (Y)	0,612	Substantial	–	62.1% of Y variance is explained by variable X
BIM (X5)	0,589	Substantial	–	58.9% of BIM variance is explained by X2, X3, X4
Estimating Process (X1)	0,708	Substantial	–	70.8% of X1 variances are explained by BIM (X5)
Risk (X6)	0,243	Moderate	–	24.3% of X6 variances are described by X1

Source: Prepared author (2026)

Table 8. SEM-PLS (Path Coefficients) Bootstrapping Test Results

Variable Relationships	Path Coefficient (β)	T-Statistic	P-Value	H Decision
Process Estimation (X1) → Cost Accuracy (Y)	0,628	2,748	0,006	H1 Accepted
WBS (X4) → BIM (X5)	0,580	4,312	0,000	H3 Accepted
MY SMM (X2) → BIM (X5)	0,191	1,876	0,061	H Not Significant
SE Director General (X3) → BIM (X5)	0,256	2,103	0,036	H Accepted
BIM (X5) → Process Estimation (X1)	0,841	12,034	0,000	H4 Accepted
Estimation Process (X1) → Risk (X6)	0,493	3,821	0,000	H8 Accepted
Risk (X6) → Cost Accuracy (Y)	0,256	1,982	0,048	H9 Accepted
MY SMM (X2) → Cost Accuracy (Y)	-0,131	0,893	0,372	H7 Insignificant
SE Director General (X3) → Cost Accuracy (Y)	-0,065	0,521	0,602	H6 Not Significant

Source: Prepared author (2026)

The resulting structural equation: (1) Cost accuracy (Y) = 0.628 X1 – 0.131 X2 – 0.065 X3 + 0.256 X6; (2) BIM (X5) = 0.191 X2 + 0.256 X3 + 0.58 X4; (3) Cost Estimation Process (X1) = 0.841 X5; (4) Risk (X6) = 0.493 X1. These findings indicate that measurement standards (MY SMM) and cost standards (SE Dirjen) do not directly improve the accuracy of projects, in line with PMI (2017) which states that the quality of the cost estimation process is the main factor in producing accurate cost estimates.

Development of WBS Data Center Project (RQ5)

The WBS of the XYZ Data Center project is developed up to level 6 (detailed activities) covering the entire structural and architectural work. The results of WBS development resulted in 198 systematically classified work activities. The WBS hierarchy includes: Level 1 (XYZ Data Center Projects), Level 2 (Structural Works/Architectural Work), Level 3 (Main groups: Foundation Structures, Lower Structures, Upper Structures, Miscellaneous Structures/Ground Floors, Mezzanine Floors, Roof Floors, Facades), Level 4 (Sub-groups of work), Level 5 (Work components), Level 6 (Detailed activities with unique WBS codes).

Some of the architectural works in the WBS that have been developed include: flooring work (ceramics, homogenous tiles, floor hardener, waterproofing), wall work (light masonry, plaster, cement, ceramic tiles, interior/exterior paint, temporary partitions), ceiling work (gypsum, calcium board, aluminum ceiling, acoustics), door and window work (glass doors, iron doors,

aluminum doors, aluminum windows), façade works (curtain walls, aluminum composite panels, galvanized louvre wall), and roofing work. The integration of WBS code into the BIM model allows each element of the job to be uniquely identified.

WBS-Based BIM Development (RQ6)

The WBS-based BIM model was developed using Autodesk Revit by integrating WBS code on each element of the 3D model. WBS parameters are created as project parameters in Revit, and then encoded on each element of the model consistently. After the modeling is complete, quantity take-off is done using the Schedule/Quantity feature in Revit which extracts volumes automatically based on the grouping of WBS codes.

Table 9. Comparison of BIM vs Conventional Method QTO Results on Main Work

Yes	Job Items	Units	QTO Manual (MC-100)	QTO BIM	Deviation (%)
1	Drilling Pile Ø1000 mm	m	8.288	7.972	-4%
2	Concrete bore pile casting Ø1000 mm	m ³	5.641	5.409	-4%
3	Concrete fc'40 MPa – Pilecap	m ³	682	650	-5%
4	Ironing – Pilecap	kg	74.590	72.252	-3%
5	Excavation – Pilecap	m ³	3.124	2.987	-4%
6	Concrete fc'40 MPa – Pedestal Column	m ³	13,94	13,86	-1%
7	SC1 steel column WF-588x300	kg	57.229	57.145	0%
8	Floor slab – Concrete fc'35 MPa	m ³	417,65	401,48	-4%
9	Floor plates – Ironing	kg	287.737	274.785	-5%
10	W1 Wall Concrete – Lower Roof Floor	m ³	48,58	46,45	-5%
11	SB3 WF-200x200 steel beam (Roof Floor)	kg	35.479	35.214	-1%
12	Lower roof floor slab – Boundek formwork	m ²	4.018	4.024	0%

Source: Prepared author (2026)

The results of BIM extraction show good consistency with conventional methods, with deviations generally ranging from 0% to -5% for concrete and ironing work. The difference in volume occurs because the results of BIM extraction are calculated directly based on the 3D model

elements so that they are more precise, while the manual method still relies on the reading of 2D images which are prone to misinterpretation and human error.

BIM-WBS Integration with MY SMM (RQ7)

The application of MY SMM to the WBS-based BIM model is carried out by adjusting BIM parameters to the measurement, unit, and classification rules of SMM3 work items. Each element of the BIM model is given additional attributes in the form of information on the SMM measurement method (type of work, unit of measurement: m, m², m³, kg, nr, item), the classification of elements according to the SMM3 Work Section, and the reference of the SMM3 page.

Table 10. Mapping of Existing Unit and MY SMM Parameters on Selected Items

Yes	Job Items	Existing Units	SMM3 Unit	SMM3 References	Notes
1	Bore hole pile Ø1000 mm	m'	m	WS06 Piling Works, pp.136–156	Boring measured linear depth (m)
2	Excavation pile Ø1000 mm	m ³	m ³	WS04 Excavation, pp.116–128	Consistent
3	In-situ concrete – Pilecap	m ³	m ³	WS09 Concrete Works, pp.171–180	Consistent
4	Ironing bore pile Ø1000 mm	kg	kg	WS09 Concrete Works, pp.171–180	Consistent
5	Cutting of the pole head Ø1000 mm	NR	NR	WS06 Piling Works, pp.136–156	Consistent
6	Anti-termite data center building	m ²	Item	WS04 Sundries	Different – SMM as an item
7	Non-shrink grouting thickness 50 mm	m ³	m ²	WS09	Different – SMM based on area area
8	Chemical anchor bore pile	bh	m ³	WS09 Concrete Works	Different – SMM as concrete volume

Source: Prepared author (2026)

The results showed that there was no significant difference in total volume between the existing method and MY SMM. The differences that exist are more about the differences in the perception of measurement and classification of work items – the way of grouping work,

measurement methods, and units of work items. The use of MY SMM is more effective as a standardization of measurement methods and grouping of work items rather than producing large changes in the volume of work, thus reducing differences in interpretation between stakeholders.

Integration of BIM-WBS with SE Director General (RQ8)

The preparation of AHSP based on the SE of the Director General of Construction Development No. 182 of 2025 is carried out systematically through: (1) determination of labor coefficient using the formula: $K_{TK} = (\text{Number of Labor} \times \text{Duration}) / \text{Volume}$; (2) determination of material coefficient using the formula: $K_{Mat} = \text{Material Requirement} / \text{Volume}$; and (3) determination of the coefficient of the equipment using the formula: $K_{Alat} = \text{Duration of Use of the Tool} / \text{Volume}$. HSD was obtained from the Karawang market price survey according to the actual conditions of the project.

For example, for bore pile ironing work: if 4 workers can complete 120 kg of ironing per day, then the labor coefficient = $(4 \times 1) / 120 = 0.033 \text{ OH/kg}$. The unit price of fc'40 MPa concrete of the lower structure based on the SE of the Director General is IDR 1,308,830.24/m³ compared to the project price of IDR 1,209,894.00/m³. This difference is due to the use of HSD based on actual market prices that already take into account increases in the prices of materials, labor, and equipment. On the other hand, WF steel construction work showed that the project unit price (Rp31,507.00/kg) was higher than the SE Director General (Rp26,627.55/kg) due to the overhead and contractor margin factors.

Risk-Based Integrated Cost Estimation (RQ9)

The risk analysis was conducted using the Probability-Impact Matrix based on PMBOK involving five experts with 14–19 years of experience. Of the 198 structural and architectural work activities analyzed, there were six activities with the HIGH category (> score 0.15), four activities with the MODERATE category (score 0.10–0.15), and the rest with the LOW category (< score 0.10).

Table 11. Results of the Dominant Risk Assessment of the XYZ Data Center Project

Yes	WBS Code	Job Activities	Key Risks	Average Score	Categories
1	X.1.1.1	Bored Pile Ø1000 & Ø600 mm	Difference in soil conditions/actual depth	0,328	HIGH
2	X.1.1.2	Drilling Pile Ø1000 & Ø600 mm	Drilling productivity decreases	0,292	HIGH
3	X.1.1.3	Concrete Casting Pile Ø1000 & Ø600 mm	Deviation of concrete and waste volume	0,260	HIGH

Yes	WBS Code	Job Activities	Key Risks	Average Score	Categories
4	X.1.2.1.5	Concrete fc'40 MPa – Pilecap	Deviation of concrete and waste volume during casting	0,236	HIGH
5	X.1.2.1.6	Ironing – Pilecap	Changes in bending schedule or waste ironing	0,180	HIGH
6	X.1.2.2.5	Concrete fc'40 MPa – Tie Beam	Deviation of concrete and waste volume	0,176	HIGH
7	X.1.2.2.6	Iron – Tie Beam	Changes in bending schedule or waste ironing	0,162	HIGH
8	X.1.3.2.1	Steel Column Installation	Fault erection/alignment of steel column	0,120	MODERATE
9	X.1.3.4.2	Concrete fc'35 MPa – Slab	Deviation of concrete and waste volume	0,128	MODERATE
10	X.1.3.4.3	Multiply Formwork – Plate	Formwork damage/rework	0,124	MODERATE
11	X.1.3.5.1	Steel Beam Installation	Delay in fabrication/erection of steel beams	0,104	MODERATE

Source: Prepared author (2026)

The Monte Carlo simulation was conducted using a Crystal Ball with 1,000 iterations of HIGH and MODERATE risk activities. Triangular distributions are used with a minimum limit (-3% of the AHSP value), most likely (AHSP value), and maximum (+7% of the AHSP value). The distribution input is entered as a Define Assumption on each high-risk work item, and the total project cost output is set as a Define Forecast. The simulation results in a cumulative frequency distribution and curve that illustrates the range of possible project costs.

Table 12. Comparison of Data Center Project Cost Estimate Results XYZ

Yes	Estimation Method	Estimated Value (Rp)	Deviation vs Existing	Remarks
1	Existing Method (MC-100 + RAP Contractor)	127.111.549.720,46	Baseline (0%)	Conventional manual method

Yes	Estimation Method	Estimated Value (Rp)	Deviation vs Existing	Remarks
2	QTO BIM + Existing Unit Price	118.457.380.683,55	-6,81%	More accurate volume, same price
3	QTO BIM + MY SMM + SE Director General No. 182/2025	136.817.456.615,97	+7,64%	National coefficient standards
4	QTO BIM + SMM + SE Director General + Contingency P50	137.404.694.965,42	+8,10%	Contingency: IDR 587,238,349.45 (0.429%)
5	QTO BIM + SMM + SE Director General + Contingency P60	137.526.110.058,91	+16,10%	Contingency: IDR 708,653,442.94 (0.518%)

Source: Prepared author (2026)

The difference in estimation values between the existing method and the WBS-based BIM method and the SE Director General is more influenced by the difference in the quantity take-off method, the level of detail in the work grouping, and the productivity approach used. The Director General's SE method uses coefficients and productivity of national standards that are more standardized and conservative, so that cost estimates tend to produce higher but more measurable values. This finding is in line with Wahyuningsih et al. (2024) who showed that differences in AHSP regulations can produce different cost estimation values even though the calculated work objects are the same.

Risk integration through contingency costs caused the estimated value of project costs to increase from a deviation of 7.64% to 8.10% (P50 scenario) and 16.10% (P60 scenario). This is in line with Elshaer (2022) who stated that the integration of risk in cost estimation can help improve project cost estimates through the preparation of contingency costs based on project risk levels. Data center projects have a high level of complexity and uncertainty, so contingency costs are an important component in project cost control.

CONCLUSION

This research produced an integrated cost estimation model for data center projects that combines WBS (6 levels, 198 activities), Autodesk Revit-based BIM, MY SMM, SE Director General of Construction Development No. 182 of 2025, and Monte Carlo risk analysis. The use of WBS-based BIM significantly improves the consistency and accuracy of quantity take-off with a deviation in the volume of work of the main structure in the range of 0% to -5% compared to the manual method. The SEM-PLS analysis proves that the cost estimation process has a positive and significant effect on cost accuracy ($\beta = 0.704$; p-value = 0.006), with BIM as the most dominant variable ($\beta = 0.841$) because of its ability to improve the quality of quantity take-off, while MY SMM and SE Director General have no significant direct effect on cost accuracy. The

implementation of the SE of the Director General of Construction Development No. 182 of 2025 resulted in an estimated cost 7.64% higher than the existing method due to the use of a more standardized national productivity coefficient, and after the integration of risk contingency costs (Monte Carlo), the estimated value increased to 8.10% (P50: Rp587.2 million, 0.429%) to 16.10% (P60: Rp708.7 million, 0.518%) of the existing value. Further research is recommended to develop a more in-depth analysis of labor productivity and work execution methods, expand a more diverse sample of projects to include other types of buildings, and integrate models on MEP work that have higher complexity in data center projects.

REFERENCES

- Abdel-Monem, M., Alshaer, K. T., & El-Dash, K. (2022). Assessing risk factors affecting the accuracy of conceptual cost estimation in the Middle East. *Buildings*, *12*(7), 950. <https://doi.org/10.3390/buildings12070950>
- Akbar, A. R. N., Ali, A. S., Chuing, L. S., & Ahmad, F. (2015). Issues and challenges in the implementation of standard method of measurement in Malaysian construction industry. *Procedia - Social and Behavioral Sciences*, *170*, 37–48. <https://doi.org/10.1016/j.sbspro.2015.01.011>
- Amuda-Yusuf, G., & Adebiyi, R. T. (2019). 5-dimensional BIM and the challenges of adopting measurement standards. *Journal of Construction*, *10*(1), 45–58.
- Chan, D. W. M., Olawumi, T. O., & Ho, A. M. L. (2019). Perceived benefits of and barriers to BIM implementation in construction: The case of Hong Kong. *Journal of Building Engineering*, *25*, 100764. <https://doi.org/10.1016/j.jobe.2019.100764>
- Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers, and contractors* (2nd ed.). John Wiley & Sons.
- Fauzan, R., Hidayat, B., & Suraji, A. (2023). Contract deviation in construction projects: Analysis based on the findings of the performance audit of the Regional Inspectorate of West Sumatra Province. *Journal of Civil Engineering*, *5*, 324–333.
- Ginting, Y. B., Ginting, I. F. D. B., & Surbakti, R. (2024). Analysis of the deviation of the cost budget plan to the cost of implementing type 30/75 housing work in Medan City. In *National Conference of Social and Engineering of the Medan State Polytechnic* (pp. 1126–1133).
- Hudoyo, C. P. (2018). *Development of risk-based WBS (Work Breakdown Structure) standards to improve cost estimation planning in seaport construction projects* (Master's thesis). Universitas Indonesia.
- Jumas, D., Sesmiwati, & Tela, N. (2017). Analysis of the need for standardization of quantity measurement (standard method of measurement) in the construction industry in Indonesia. *Journal of Engineering*, *7*(2), 16–26.
- Kamaludin, T. M., & Rusdin, A. (2023). Study of contract change order (CCO) on implementation. *Journal of Applied Engineering and Technological Science*, *4*, 722–733.

- Mustain, P. N., Latief, Y., & Sagita, L. (2019). Development of standardized work breakdown structure (WBS) based on risk for cost estimate at dam project. *IOP Conference Series: Materials Science and Engineering*, 650, 012026. <https://doi.org/10.1088/1757-899X/650/1/012026>
- Ng, H. S., Ng, C. T., Noor, N. M. D., Umar, S., Ng, T. W., Koh, H. B., & Tan Ching Ling, F. (2020). BIM adoption in managing construction risks amongst Malaysian quantity surveyors: Current practice and challenges. *Journal of Quantity Surveying*, 8(1), 45–62.
- Plamonia, N., Agustin, A., & Andreas, A. (2023). Analysis of the factors determining the accuracy level of project cost estimates using the Analytical Hierarchy Process (AHP). *Architects: Journal of Sustainable Architecture and Cities*, 5(1), 54–64.
- Project Management Institute. (2017). *A guide to the project management body of knowledge (PMBOK® guide)* (6th ed.). Project Management Institute.
- Ramanathan, J. B., & Rathore, A. (2024). Identification of sources of complexity in various types of building projects in India based on design and performance features. *Buildings*, 14(8), 2331. <https://doi.org/10.3390/buildings14082331>
- Silviana Dewi, F., Latief, Y., & Kussumardianadewi, B. D. (2024). The most influential factors on the risk cost estimation process of implementing BIM 5D in quantity take-off for green retrofitting of high-rise buildings. *CSID Journal of Infrastructure Development*, 7(2), 262–277.
- Tian, X., Li, H., & Wang, Y. (2025). Quantitative risk analysis and contingency reserve estimation in construction projects. *International Journal of Project Management*, 43(2), 115–128.
- Wahyuningsih, S., Wiryasuta, I. K. H., Safitri, F. A., Ulfiyati, Y., & Sandi, E. A. (2024). Comparison of construction cost estimates using the Minister of PUPR Regulation Number 28 of 2016 and Number 8 of 2023. *PORTAL: Journal of Civil Engineering*.
- Wang, R., Salleh, H., Li, K., & Abdul-Samad, Z. (2024). A conceptual cost estimation model for building construction projects by hybrid back-propagation neural network. *Journal of Asian Architecture and Building Engineering*, 1–23. <https://doi.org/10.1080/13467581.2024.XXXXX>
- Zahrah, K., Lenggogeni, & Berliana, R. (2023). The implementation of BIM in the calculation of quantity take-off work for the structure and architecture of Pertamina's RTCT project. *Journal of Deformation*, 8(2), 178–187.