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Implementation of BIM 4D and 5D Integration for Modelling and Visualization in the Spillway Crest Structure Planning on the Cijurey Dam Package 3, Bogor Regency

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ABSTRACT
Large-scale dam construction in Indonesia faces significant challenges in design coordination, scheduling, and cost control, particularly for complex structures like the spillway crest. This study analyzes the implementation of Building Information Modelling (BIM) 3D–5D in the Cijurey Dam spillway crest project using a qualitative-descriptive approach based on interviews, document analysis, and field observation. The 3D model was developed with Autodesk Revit, integrated with 4D scheduling in MS Project, and 5D cost data from the Bill of Quantities through Navisworks. The quantitative results indicate that BIM 4D–5D improved calculation accuracy and cost reliability, with absolute deviations in volumetric quantities ranging from 10.4% to 15.25% (average 14.67%), and a total cost difference of IDR 221,962,356 compared to the DED baseline. All deviations remain below the conservative 20% threshold, confirming that BIM-generated quantities provide reliable estimates for structural planning and realistic budgeting. The integration of Navisworks enhanced visualization, early detection of discrepancies, and multidisciplinary coordination, highlighting BIM 4D–5D's effectiveness in supporting accurate quantity and cost estimation, minimizing financial risk, and enabling informed decision-making in complex dam projects.

ABSTRAK
Konstruksi bendungan berskala besar di Indonesia menghadapi tantangan signifikan dalam koordinasi desain, penjadwalan, dan pengendalian biaya, terutama pada struktur kompleks seperti puncak spillway. *Penelitian ini menganalisis implementasi* Building Information Modelling (BIM) 3D–5D *pada proyek puncak* spillway *Bendungan Cijurey menggunakan pendekatan kualitatif-deskriptif berbasis wawancara, analisis dokumen, dan observasi lapangan. Model* 3D *dikembangkan menggunakan Autodesk Revit, diintegrasikan dengan penjadwalan* 4D *melalui MS Project, dan data biaya* 5D *dari* Bill of Quantities *melalui Navisworks. Hasil kuantitatif menunjukkan bahwa* BIM 4D–5D *meningkatkan akurasi perhitungan dan keandalan biaya, dengan deviasi absolut volume berkisar antara* 10,4% *hingga* 15,25% *(rata-rata* 14,67%*), serta selisih total biaya sebesar* IDR 221.962.356 *dibandingkan perhitungan berbasis* DED. *Seluruh deviasi berada di bawah ambang konservatif* 20%*, menegaskan bahwa volume yang dihasilkan BIM memberikan estimasi yang andal untuk perencanaan struktur dan penganggaran realistis. Integrasi Navisworks mendukung visualisasi, deteksi awal ketidaksesuaian, dan koordinasi multidisiplin, sehingga menegaskan efektivitas* BIM 4D–5D *dalam mendukung estimasi kuantitas dan biaya yang akurat, meminimalkan risiko finansial, serta memperkuat pengambilan keputusan pada tahap perencanaan proyek bendungan yang kompleks.*

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INTRODUCTION

Managing large-scale infrastructure projects often involves complex designs, schedule risks, and cost uncertainties. To overcome these challenges, Building Information Modelling (BIM) has been introduced as a digital platform that integrates design, scheduling, and cost estimation. Unlike conventional methods, BIM supports multidimensional mvodelling (3D, 4D, and 5D), enabling improved visualization, coordination, and project monitoring.

In Indonesia, the Ministry of Public Works and Housing (PUPR) mandates BIM for projects above 100 billion rupiah, especially National Strategic Projects, to accelerate digital transformation in infrastructure. In practice, however, BIM use is often limited to 3D modelling, while 4D–5D integration remains underutilized due to technical and managerial barriers. Anugrah Putra and Suroso (2025) showed that 4D–5D BIM improved quality and scheduling in toll road projects, yet such practices remain rare in hydraulic infrastructure.

Similarly, Yoga Dwi Putra (2024) and Kusumaningroem (2023) demonstrated that 5D BIM enhances the accuracy of quantity take-off and cost estimation compared to manual methods, but their focus was limited to building and road projects. Internationally, Wangchuk et al. (2024) reviewed BIM applications in hydropower infrastructure and highlighted gaps in lifecycle integration, while Schettini (2023) documented a dam project in Brazil where BIM was combined with hydraulic modelling to optimize spillway design.

These findings indicate that, both globally and locally, the adoption of BIM beyond 3D in hydraulic projects remains fragmented and underdeveloped. This research gap becomes particularly relevant in the context of dam construction in Indonesia. The Cijurey Dam in Bogor, West Java, serves multiple functions such as irrigation, flood control, and regional water supply and is categorized as a National Strategic Project. Within this project, the spillway crest is a critical structure requiring precise modelling and synchronization of design, schedule, and cost. Frequent design revisions in hydraulic works often disrupt alignment between 3D models, time planning, and budgeting, creating inefficiencies.

Therefore, this study aims not only to support construction activities through BIM implementation but also to propose a structured workflow for design revisions to accelerate and simplify processes in the Cijurey Dam Package 3 project. In line with this, the study also assesses the effectiveness of BIM by identifying deviations in structural and material quantities and the associated costs generated through the 4D–5D BIM simulations compared to the actual project data recorded on-site. The deviation assessment in this research does not rely on comparisons with conventional methods, but rather on internal project data, where the BIM-derived baseline is compared to field records collected during the same period. This conceptual approach allows the study to determine how BIM supports cost control and provides insights for optimizing future BIM workflows.
Catatan: Gambar yang diupload harus terlihat jelas, tidak blur (High Definition).

METHODS

This study uses a qualitative–descriptive approach with digital modelling and simulation to integrate design, schedule, and cost data into BIM 4D and 5D. The BIM model was developed up to LOD 300, where elements have accurate geometry and dimensions suitable for quantity and cost estimation, but exclude construction-level details such as connections, minor embedded components, or clash detection. Literature reports that LOD 300 models typically show quantity deviations of 10–25% depending on project complexity and model completeness. To remain conservative yet reasonable, this study adopts a deviation tolerance of ≤20% for evaluating data consistency. The workflow (Figures 1–2) progresses from literature review and problem identification to modelling, simulation, and validation, forming a basis for assessing BIM effectiveness in planning, scheduling, and cost control of complex hydraulic structures.

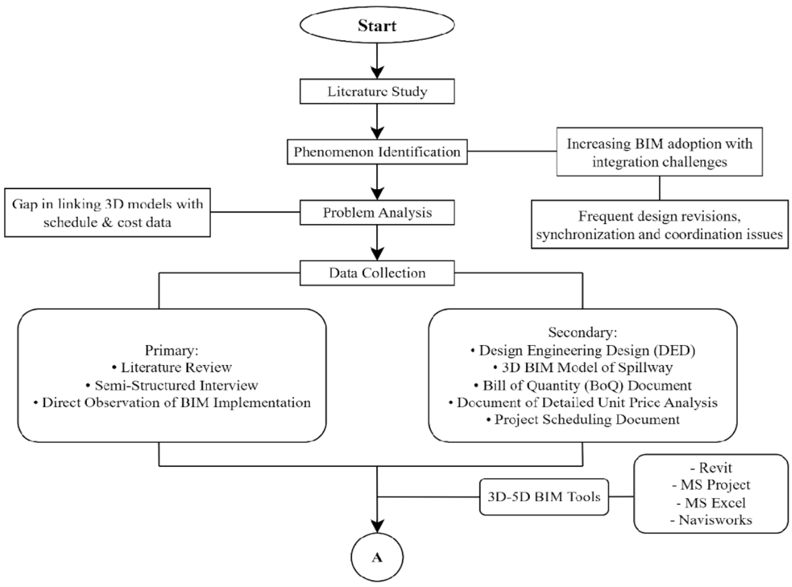

Figure 1. Research Flowchart

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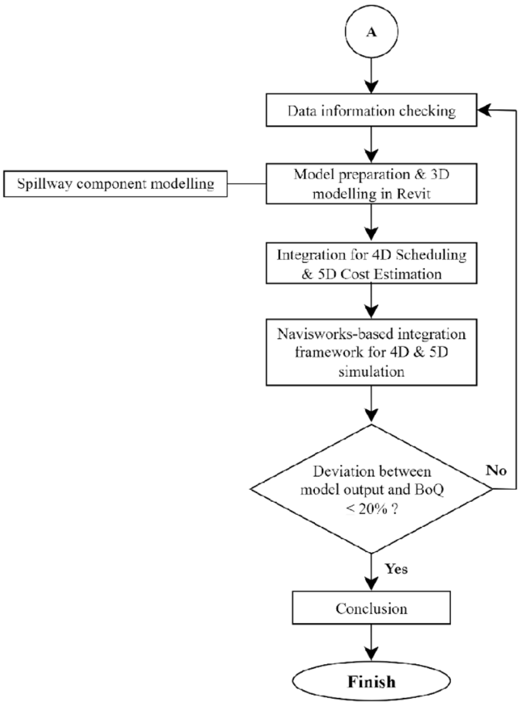

Figure 2. Research Flowchart (Continued 2)

RESULTS AND DISCUSSIONS

The findings of this study, drawn from interviews, field observations, and project documentation, focus on BIM application in constructing the spillway crest structure. As summarized in Table 1, the workflow linked 3D modelling with 4D scheduling and 5D cost estimation, allowing design data to directly inform construction planning. This integration improved visualization and coordination among stakeholders, despite challenges in software interoperability, data consistency, and cross-disciplinary communication. Overall, BIM proved valuable for monitoring time and cost, providing greater transparency and accuracy than conventional methods, while highlighting both its potential and current limitations in large-scale dam projects.

Table 1. Matrix of BIM 3D–5D Integration in the Cijurey Dam Project Package 3

Stage	Workflow & Tools	Key Challenges	Effectiveness & Evidence
3D Modelling	Model crest, segment blocks, apply revision *(Tools: Revit)*	Field–plan mismatches, construction adjustments	Improved coordination fewer design errors
4D Scheduling	Link model with schedule, visualize sequence. *(Tools: Navisworks + MS Project)*	Sequence mismatch, late updates	Clear progress tracking, early delay detection
5D Cost Simulation	Integrate BOQ, cost mapping. *(Tools: Navisworks + MS project)*	Low-cost detail, early-phase mapping gaps	Improved budget tracking; reduced estimate gaps

Analysis of BIM 3D-5D Implementation Stages and Integration

This section analyzes the BIM implementation across 3D, 4D, and 5D dimensions, highlighting each stage's contribution to project workflow and their systematic integration. Autodesk Revit was used for digital modelling, Microsoft Project and Excel supported scheduling, and Navisworks enabled integration and simulation. This combination allowed assessment of both the model's geometric and technical accuracy and the managerial benefits in planning and controlling the spillway crest construction. As shown in Figure 3, the BIM workflow incorporated a feedback loop, where revisions in quantities or design stages were updated in Revit and reprocessed for scheduling and cost estimation. This iterative integration ensures continuous alignment of design and management data, enhancing coordination and providing a solid foundation for subsequent project phases.

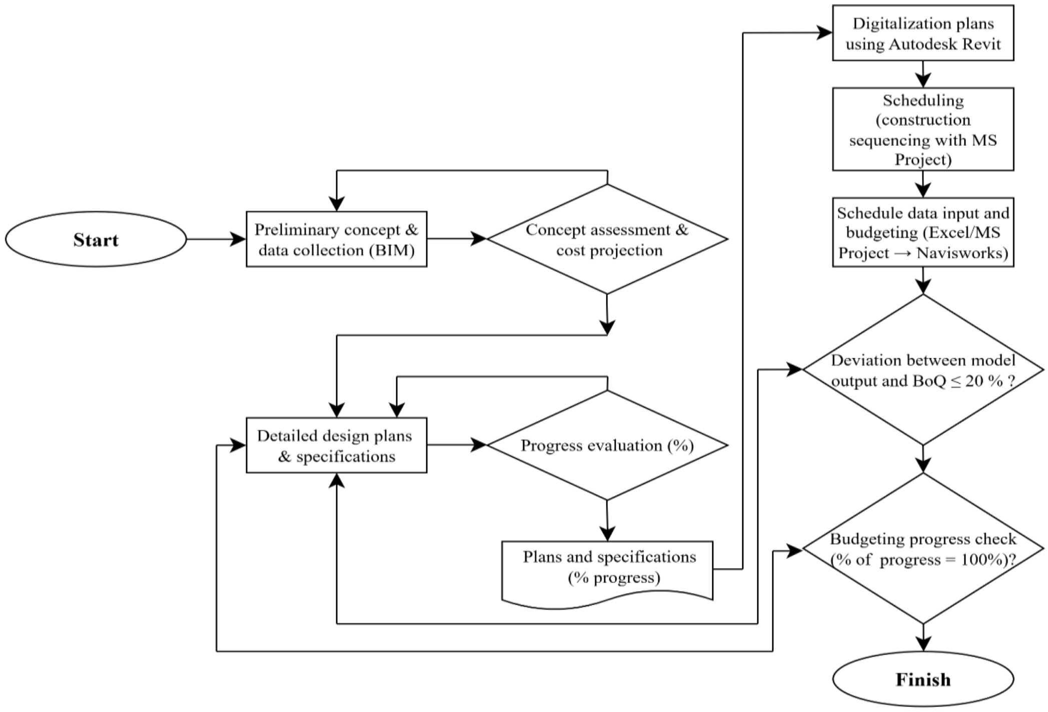

Figure 3. BIM 3D–5D integration workflow

The interconnected workflow illustrated above demonstrates the cyclical and adaptive nature of BIM, where data is continuously refined to align design, scheduling, and cost estimation. While this diagram shows the overall process, a deeper understanding can be gained by examining how each dimension (3D, 4D, and 5D) contributed to the project. The following subsections elaborate on the role of each stage, highlighting not only their technical outputs but also the managerial value they provided in the context of spillway crest construction.

- 3D - Autodesk Revit (Model Development and Structuring)
  The 3D modelling stage provided the backbone of the entire workflow by translating conventional drawings into a parametric digital model. The primary objective was to create a segmented and data-rich representation of the spillway crest that could later serve as the foundation for scheduling and cost analysis. The steps included:
  1. Project setup
     Initiated a new file with the Structural Template (RC standards aligned), while establishing levels, grid lines, and STA markers (STA 0+125–0+175) as key control references.

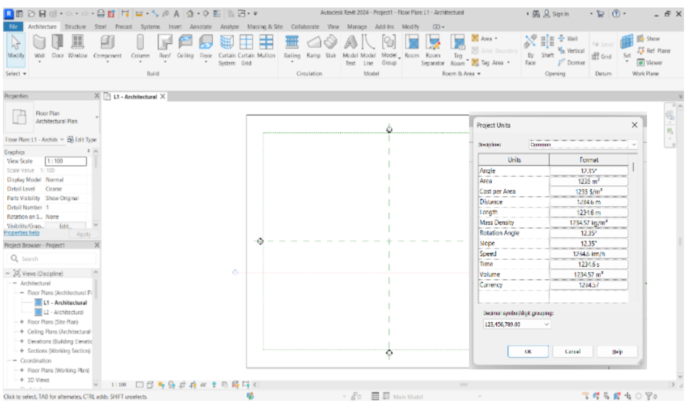

Figure 4. Setting-up levels, grid lines, and STA references

2. Segmentation reflecting site execution
   Divided the crest into six blocks, with each block further segmented into approximately twelve vertical pours (casting stages).
3. Geometry authoring
   Modelled crest segments using Model In-Place or Component Family, applying the Swept Blend function to represent varying cross-sections. All editing was consistently performed in 2D floor plans to maintain alignment with STA and elevation controls.

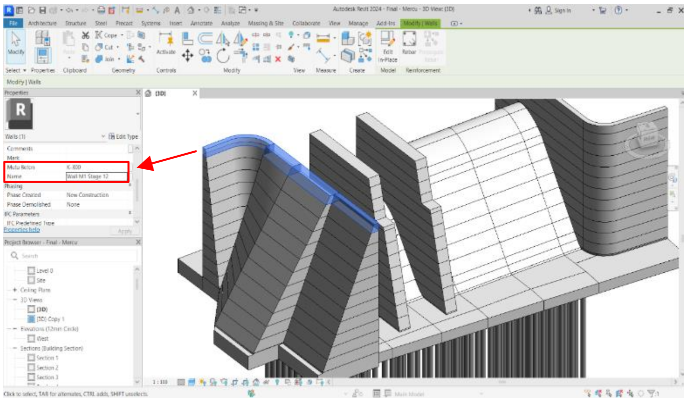

Figure 5. Generating quantity take-off (QTO) schedules

4. Classification & materials
   Assigned categories (Walls/Floors) and designated material properties such as Concrete – Cast in Situ, with construction functions attached.
5. Quantity structuring (QTO)
   Generated Schedule/Quantities by block and stage, including element ID (e.g., Mercu M2 Stage 6), volume (m^3), material, and concrete class.

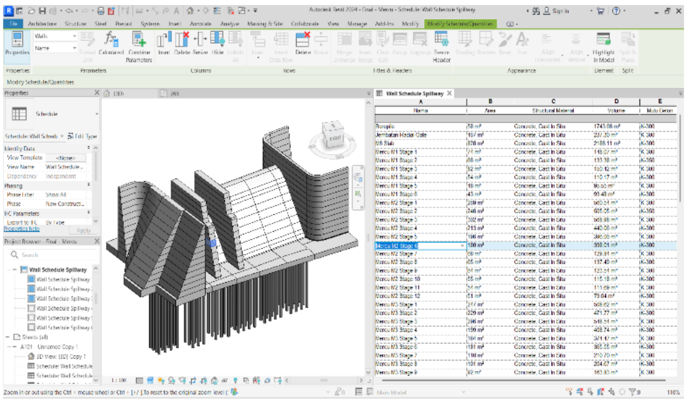

Figure 6. Creating QTO schedules for structure elements

6. Immediate outputs
   Produced a parametric 3D model segmented per block and casting stage, complete with accurate volume data and spatial referencing, establishing the data backbone for 4D and 5D integration.

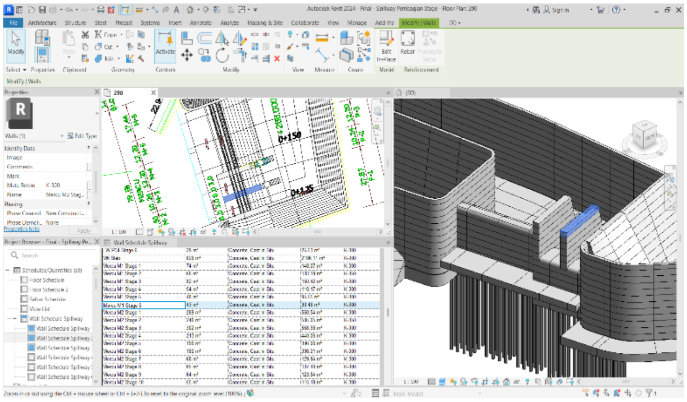

Figure 7. 3D crest model with pouring stages and STA references in Autodesk Revit

- 4D Time Integration (MS Project + Navisworks)
  The 4D stage focused on linking the validated 3D model with construction scheduling to produce a time-phased simulation of progress. This dimension was intended to enhance visibility of work sequences and support proactive management of delays and resources. The steps were:
  1. Schedule authoring in MS Project
     Defined task lists per block–stage with durations, start/finish dates, and interdependencies, then exported to .XML format.

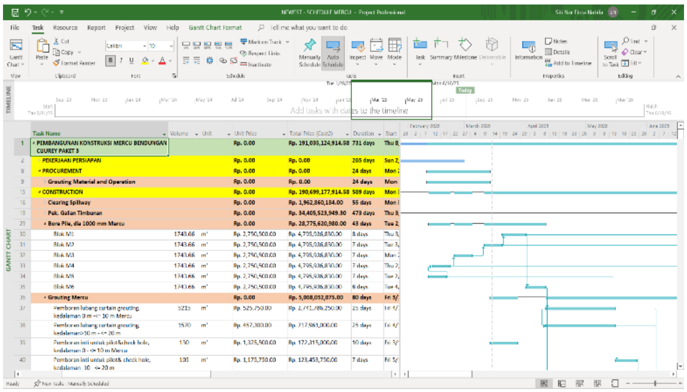

Figure 8. Gantt chart of construction schedule in MS Project

  2. Model–schedule integration
     Imported the segmented Revit model (.NWC) into Navisworks, then mapped MSP tasks to model elements using the TimeLiner tool with "Task Type = Construct".

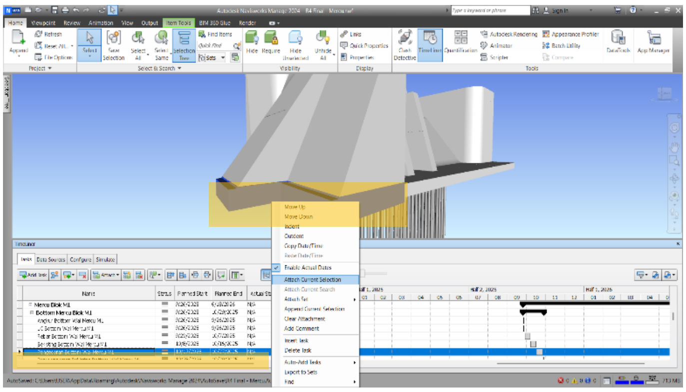

Figure 9. Linking model elements with schedule tasks in Navisworks TimeLiner

3. Simulation setup & verification
   Verified task-element links, adjusted project start dates, dependencies, and visual settings (colours, transparencies, annotations).

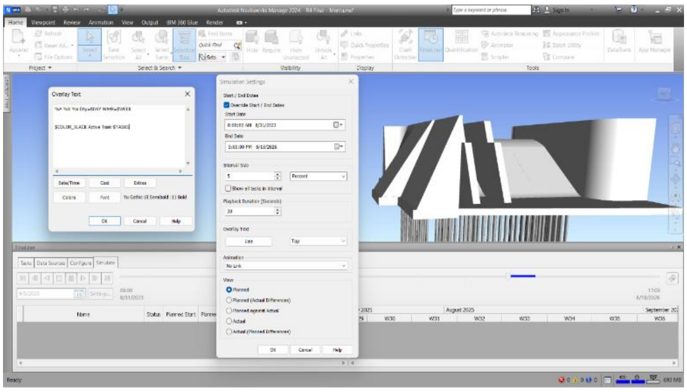

Figure 10. Visual setting for 4D rendering in Naviswokrs

4. Execution & capture
   Ran 4D simulations to visualize work progression, captured snapshots/video outputs for each casting stage, and confirmed completeness of the staged sequence.

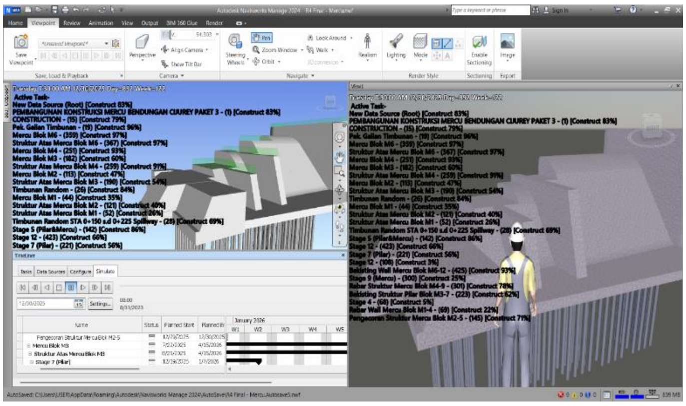

Figure 11. 4D Simulation result in Navisworks

- 5D Cost Integration (Excel + MS Project + Navisworks)
  The final dimension introduced financial data, allowing the simulation of cost flows alongside the construction timeline. This step was crucial for achieving transparency and dynamic control over project expenditures. The process involved:
  1. Quantity extraction
     Exported Revit QTO into Excel containing element names, stages, volumes (m^3), and materials.

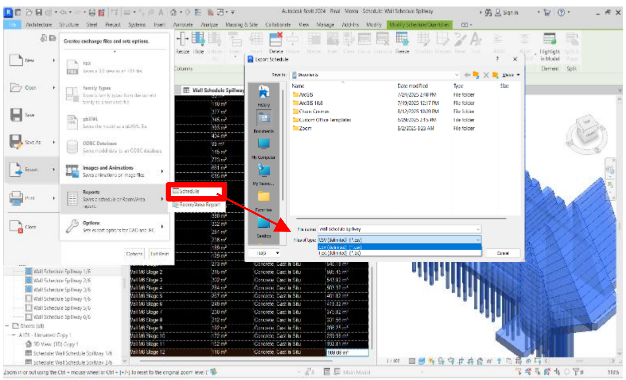

Figure 12. QTO data exported from Revit to Microsoft Excel

2. Unit rates & task costing
   Applied *Analisa Harga Satuan* (AHS) unit prices in Excel, then used MS Project custom fields to compute costs per block–stage automatically (Total Cost = Volume × Unit Price).

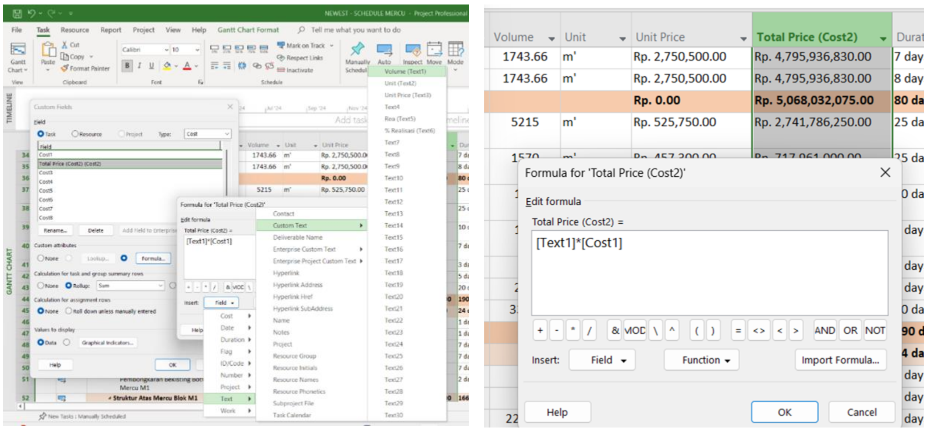

Figure 13. Applying total cost based on AHS data in MS Project

3. Cost-time integration in Navisworks
   Re-imported the cost-loaded MSP XML into Navisworks TimeLiner, maintaining task–model mapping.
4. Simulation & visualization
   Ran 5D simulations with overlay texts (e.g., Date, Week, Total Cost, Active Tasks), enabling parallel visualization of time and expenditure.
5. Change management (feedback loop)
   Ensured that design or quantity revisions in Revit were re-exported to Excel/MS Project and updated in Navisworks, maintaining alignment between model, schedule, and cost.

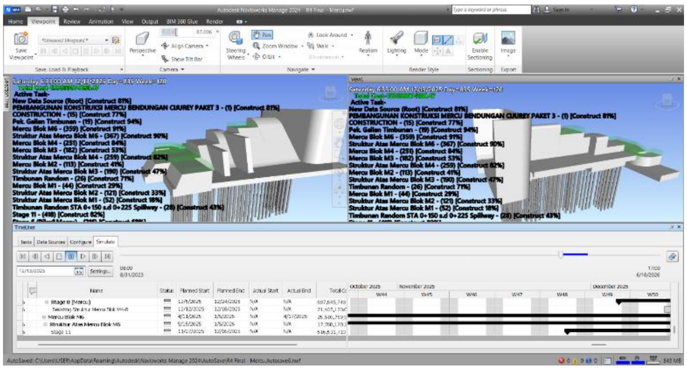

Figure 14. 5D simulation displaying dynamic project costs in Navisworks

The integration of BIM 3D, 4D, and 5D provided comprehensive insights, enabling accurate design coordination, realistic scheduling, and reliable cost estimation. The workflow also demonstrated BIM's role as a collaborative framework linking technical modelling with managerial decision-making, supporting effective project monitoring and ensuring alignment between digital simulations and field implementation.

Table 2. Integrated Analysis of BIM 3D, 4D, and 5D Workflow

BIM Dimension	Input Data	Software/Tool	Output	Integration Result
3D (Modelling)	Design drawings, structural details	Revit	3D structural model of crest	Base model for scheduling and cost
4D (Scheduling)	Activity list, duration	MS Project + Navisworks	Linked 3D model with time simulation	Visualization of construction sequence
5D (Costing)	Unit prices, volume	Excel + MS Project + Navisworks	Cost-loaded simulation	Integration of time & cost for monitoring

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Effectiveness of 4D–5D BIM Integration in Cost and Schedule Management

Effective project management relies on integrating design, schedule, and cost information to ensure accurate planning and control. Integrating 4D–5D BIM helps mitigate these issues, enabling more accurate calculation of structural and material quantities and providing a reliable basis for anticipating and reducing potential project losses. Insights are drawn from project documentation, modelling outputs, and field observations, providing a comprehensive assessment of BIM's impact on project efficiency. Observations in Microsoft Project revealed challenges such as circular and redundant dependencies, highlighting risks in conventional scheduling. The following sections detail these issues, emphasizing their potential impact on project coordination and the importance of accurate calculations.

- Circular relationship
  Cyclical dependencies occurred when a sequence of tasks is linked formed closed loops (e.g., Task A → Task B → Task C → Task A). Such sequences triggered system errors and prevented the schedule from being logically completed.
- Redundant dependency
  Redundant dependencies happen when the same relationship is defined more than once between two tasks. Although it may seem harmless, Microsoft Project recognizes it as an error because it creates unnecessary duplication and potential confusion in the task network. This issue presented on Figure 15 below.

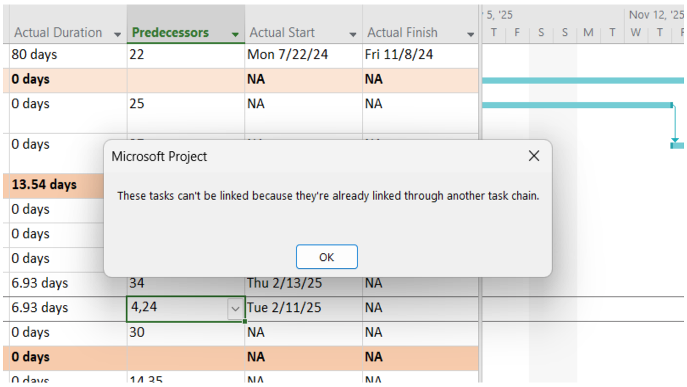

Figure 15. Error message due to redundant dependency in MS Project

- Field Mapping Error between MS Project and Navisworks
  This common problem often occurs when exported cost or schedule data fields do not match properly. This causes data to appear blank or incorrect, requiring manual correction of the mappings.
  Additionally, users frequently forget which MS Project fields are linked to Navisworks, especially with multiple similar fields like Cost1, Cost2, or Baseline Cost. This confusion can lead to missing or zero cost values in simulations, so careful attention during mapping setup is crucial. This issue is clearly demonstrated in Figure 16 and Figure 17 below.

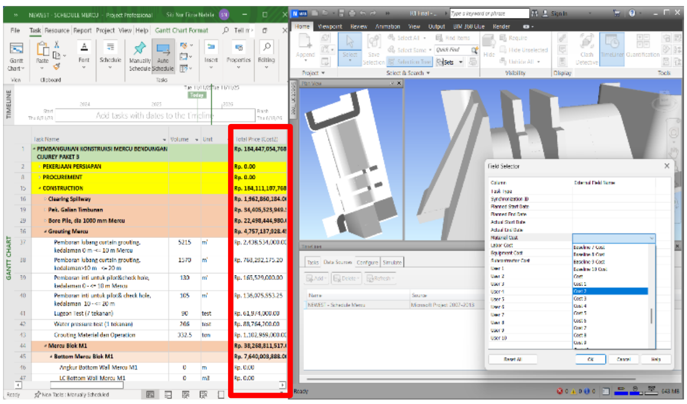

Figure 16. Field mismatch issues between MS Project and Navisworks

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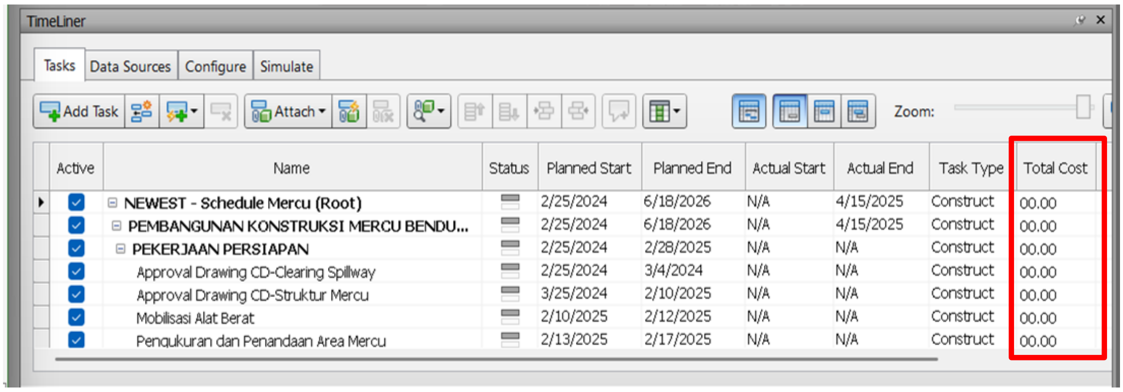

Figure 17. Field mapping mismatch between MS Project and Navisworks (Continued 2)

- Redundant dependency
  Occasionally, error notifications appear during cost calculations even when unit prices and volume data are correctly entered. This typically results from inconsistencies in resource assignments or incorrect linking between task resources and cost parameters. Such errors complicate the integration of scheduling and cost estimation and require additional verification. This issue is depicted in Figure 18.

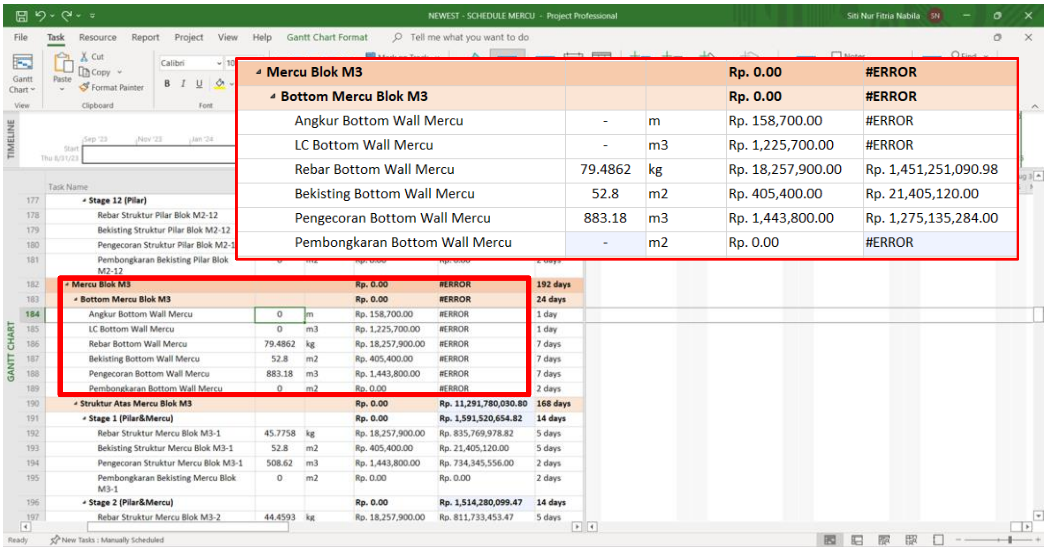

Figure 18. Cost calculation error due to field data mismatch in MS Project

While direct observation revealed some challenges, interviews with project participants were essential to provide deeper insights. Observation focused on software use and task sequencing difficulties but overlooked organizational and practical field issues. Interviews added valuable information on coordination, user experience, and institutional support. Together, these methods offer a comprehensive understanding of the challenges in BIM implementation. Interview results are summarized in Table 3.

Table 3. Interview Insights on Challenges in BIM Implementation

No	Question Parameter	Drafter 1 (N1)	Drafter 2 (N2)	BIM Engineer (N3)	Analysis Summary
1	Common technical challenges?	Frequent design changes; need full redraw	Revisions overlap; cascade effect	Frequent changes from hydraulic calculations; stakeholder misalignment	All note design changes as main challenge; revisions cascade; data and responsibility misalignment add difficulty.

2	Cause of design changes?	Site conditions differs from plan (soil, dimension)	Field mismatch; material/structure adjustments	Variations in hydraulic calculation from *Balai Hidrolika dan Geoteknik Keairan* (BHGK)	All agree field conditions differ from plan, causing redesign; BIM Engineer highlights recurring hydraulic issue.
3	Tools/software limitation?	AutoCAD only	AutoCAD, Revit, MS Excel	Full Autodesk suite	Software capability varies; limited access at drafter level reduces efficiency.
4	Coordination issues?	Coordinates only through Head of Engineering; slow loop	Same: one-route coordination to consultant	Coordinates with multiple divisions, but workload is high	Only the BIM Engineer has multi-directional communication, but this creates overload on one person.
5	Organizational support?	Manual revisions; no automation	Dependent on personal initiative	Only 1 PIC handles everything; no BIM team	Organization lacks support, standards, and team setup; too much burden on individuals.

In summary, observations and interviews indicate that challenges in using Microsoft Project extend beyond technical issues to include organizational and coordination problems. Technical difficulties, such as task sequencing errors and inconsistent cost data, highlight the need for accuracy, while limited awareness, insufficient resources, and weak institutional support further hinder smooth BIM integration. Addressing these challenges requires a combination of standardized technical procedures, targeted staff training, strengthened coordination structures, and active stakeholder engagement. Overcoming these obstacles is essential to ensure that BIM 4D–5D can reliably support accurate calculation of structural and material quantities, forming the basis for cost monitoring and deviation analysis presented in the following section.

Following these observations, the effectiveness of BIM 3D–5D is assessed through deviations in structural and material quantities, highlighting its role in improving calculation accuracy and reducing potential project losses. In this study, the DED-based volume serves as the reference baseline, representing the officially approved planning quantities. Deviations are calculated relative to the DED-based volumes, ensuring that the assessment of BIM-generated quantities reflects the original design data. The availability of Revit-generated volume data, as illustrated in Figure 19, supports this analysis by providing model-based quantities used as inputs for the deviation calculation.

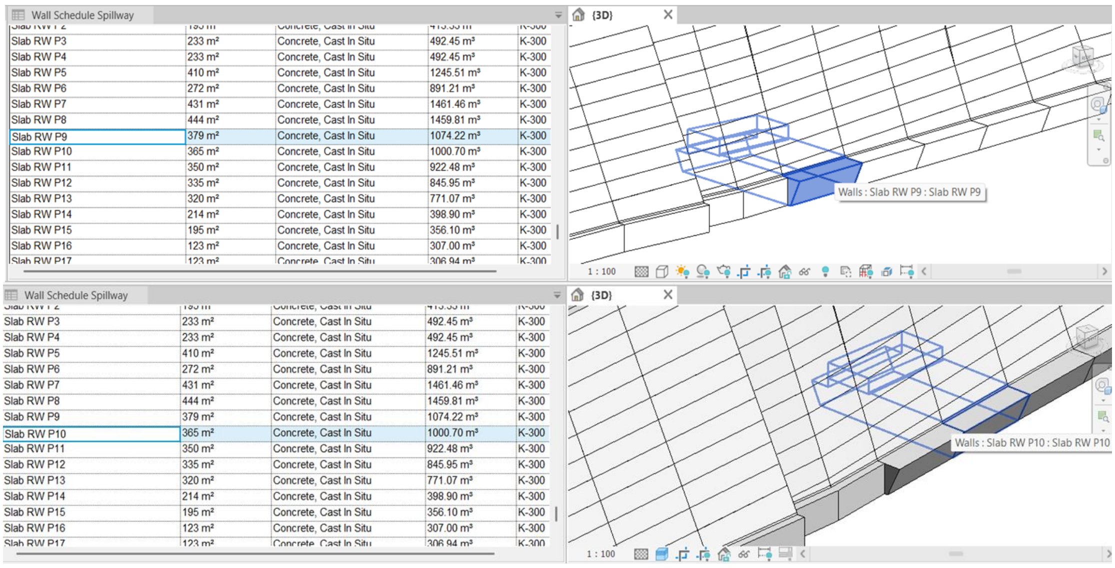

Figure 19. Quantity Outputs and 3D Visualization of Spillway Wall

Based on the Revit-generated quantities shown in Figure 19, the volumetric deviation analysis was then conducted by comparing these model-derived values with the DED-based volumes. The results of this comparison are presented in Table 4.

Table 4. Volumetric Deviation Analysis Between DED-Based and BIM-Based Quantities

Structural Element	DED-based Volume (m³)	BIM-based Volume (m³)	Difference (kg)	Accuracy (%)	Absolute Deviation (%)
	(a)	(b)	(c) = (a) – (b)	(d) = 100 – (e)	(e) = (c/a) *100
Slab Right Wall P9	923.48	1074.22	150.74	83.68	16.32
Slab Right Wall P10	868.28	1000.70	132.42	84.75	15.25
Slab Left Wall P9	1619.43	1348.92	270.51	83.3	16.7
Slab Left Wall P10	1404.28	1550.39	-146.11	89.6	10.4
	Total		**407.56**	-	-
	Average		-	**85.33**	**14.67**

Table 4 summarizes the volumetric comparison of four spillway wall elements. BIM-based volumes differ from DED references by 10–17%, with an average accuracy of 85.33% and an absolute deviation of 14.67%. These differences mainly arise from geometric assumptions: DED uses full solid volumes, while BIM excludes internal components such as reinforcement and embedded elements. Despite this, the BIM model provides reliable quantity data for 5D simulations, supporting project planning and cost estimation. After determining the deviation in volumetric quantities, the analysis was extended to evaluate the cost implications by applying the project's BOQ to both the DED-based and BIM-based volumes. The unit price of IDR 1,398,100 used in this calculation represents the BOQ cost for K-300 concrete casting along the spillway wall. Table 5 presents the resulting comparison for four major spillway structural components.

Table 5. Cost Impact Analysis Based on DED-Based and BIM-Based Quantities

Structural Element	DED-based Volume (m³)	BIM-based Volume (m³)	Cost (Rp/m³)	Total Cost DED-based (IDR)	Total Cost BIM -based (IDR)	Cost Difference (IDR)	Absolute Deviation (%)
	(a)	(b)	(c)	(d) = (a)*(c)	(e) = (b)*(c)	(f) = (d) – (e)	(g) = (f/d)*100
Slab Right Wall P9	923.48	1074.22	1,398,100.00	1,291,117,388.00	1,501,866,982.00	-Rp 210,749,594.00	16.32
Slab Right Wall P10	868.28	1000.70	1,398,100.00	1,213,942,268.00	1,399,078,670.00	-Rp 185,136,402.00	15.25
Slab Left Wall P9	1619.43	1348.92	1,398,100.00	2,264,125,083.00	1,885,925,052.00	Rp 378,200,031.00	16.7
Slab Left Wall P10	1404.28	1550.39	1,398,100.00	1,963,323,868.00	2,167,600,259.00	-Rp 204,276,391.00	10.4
	Total			**6,732,508,60700**	**6,954,470,963.00**	**-221,962,470,963.00**	
	Average						**14.67**

Table 5 presents a volumetric and cost analysis of the BIM 4D–5D model for slab components of the spillway crest. The total project cost using BIM quantities amounts to IDR 6,954,470,963. Variations in component volumes result in cost differences up to IDR 221,962,356, with absolute deviations ranging from 10.4% to 15.25% and an overall average of 14.67%. All deviations remain below the conservative 20% threshold, confirming that BIM-generated quantities provide reliable estimates for structural and material planning.

It is important to note that these deviations do not imply financial loss or inefficiency. They reflect the inherent limitations of LOD 300 modelling and the detailed representation of embedded components in BIM. All deviations remain below the conservative 20% threshold, confirming that BIM-generated quantities provide reliable estimates for structural and material planning. From a project management perspective, this analysis highlights BIM effectiveness in supporting accurate quantity and cost estimation, controlling potential under- or overestimation, and reducing the risk of unexpected project losses during execution.

Contributions of Navisworks in 4D and 5D BIM Integration

After conducting the integration process in Navisworks as explained in Chapter 4.2, this section highlights the outcomes and value derived from using Navisworks in integrating 3D models with project schedule and cost data for pre-construction planning of the spillway crest. This made 4D and 5D BIM practical, providing a clearer view of construction stages and real-time cost tracking.

- Integration of 3D Model with Project Schedule (4D BIM)
  Navisworks lets you directly link a detailed 3D model of the crest structure with the project schedule. This goes beyond traditional Gantt charts by allowing stakeholders to visually follow the construction sequence and catch any discrepancies early on. According to the BIM Engineer, combining the schedule and model helped speed up revisions and coordination significantly.

  > *"Dengan model 3D, kita bisa cek langsung jika ada ketidaksesuaian antardisiplin, sehingga proses revision bisa dilakukan dengan cepat. Dalam hal ini, Navisworks sangat membantu dalam proses rendering, kita bisa lihat urutan kerja secara visual."* – (BIM Engineer, Interview Apr 18th, 2025)

- Integration of 3D Model with Cost Data (5D BIM)
  Navisworks also links cost details to each model element, as shown in the quantification and simulation features. Every structural part, like concrete or reinforcement, is assigned unit prices and volumes, enabling real-time cost tracking. This direct connection supports early cost estimation and better budget control during pre-construction.

  > *"Setiap elemen bisa dihitung volumenya, dan otomatis anggarannya bisa kita pantau di model."* – (BIM Engineer, Interview Apr 18th, 2025)

- Enhanced Visualization and Communication, and Decision Support
  The combined visualization shows how design, schedule, and cost interact within one platform. Despite initial learning curves, simulations improved understanding, communication, and decision-making, making Navisworks a powerful collaborative tool for integrated project planning and evaluation.

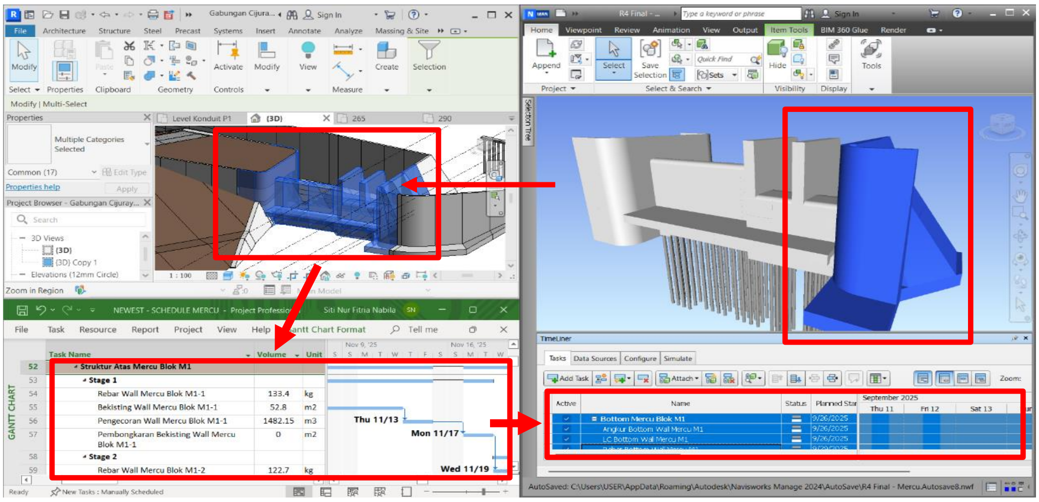

Figure 20. Combined view of Revit model, MS Project schedule, and Navisworks simulation

The integration of Navisworks in the pre-construction planning of the spillway crest project provided clear benefits across multiple aspects of BIM implementation. It links detailed 3D models with schedules and cost data, enabling 4D and 5D simulations that enhance visualization of construction sequences and budget impacts, supporting proactive management. Feedback from the BIM Engineer highlighted how this integration detects design inconsistencies early and accelerates revision processes, while 5D features allow real-time cost monitoring. Overall, Navisworks serves as both a visualization and integrative platform, connecting geometry, time, and cost data. It improves coordination, reduces risks of scheduling and cost overruns, and enhances informed decision-making prior to construction.

CONCLUSIONS

The implementation of BIM 4D–5D in the spillway crest project at Cijurey Dam demonstrated effective integration, with Navisworks linking Revit design data and cost information. This allowed stakeholders to visualize construction sequences, monitor cost impacts, and detect potential discrepancies in structural and material quantities early. While repeated design revisions still required manual updates, the workflow highlights the need for more automated processes and stronger version control in complex infrastructure projects.

Challenges identified through workflow observations and stakeholder interviews included data mapping mismatches in Navisworks, inconsistencies in cost input, limited user expertise, restricted coordination, and low BIM literacy. These findings indicate that successful BIM adoption requires not only technical accuracy but also organizational readiness, skilled human resources, and standardized protocols.

The quantitative analysis confirmed BIM's effectiveness in supporting reliable project planning. Table 5 presents volumetric and cost analyses of slab components on the spillway crest, showing **absolute deviations** ranging **from 10.4%** (Slab Left Wall P10) **to 15.25%** (Slab Right Wall P10), with an overall **average accuracy of 85.33%.** All deviations remain below the conservative 20% threshold. Total project cost based on BIM quantities was IDR 6,954,470,963, compared to the DED baseline of IDR 6,732,508,607, **resulting in a difference of IDR 221,962,356.** Although the BIM-based cost appears slightly higher, this reflects a more conservative and accurate calculation at LOD 300, focusing on capturable working volumes rather than all embedded details. This approach minimizes underestimation, ensures realistic budgeting, and anticipates potential project losses during execution.

Beyond visualization, Navisworks functioned as a decision-support tool, enhancing multidisciplinary coordination, transparency, and stakeholder confidence during pre-construction. Overall, BIM 4D–5D effectively supports accurate quantity and cost estimation, controls potential estimation errors, minimizes financial risk, and enables more informed project planning and management.

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