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Exploring BIM Based Automated Quantity Take Off for Contractors in Bridge Structural Models

Vendie Abma[1✉], **Tri Nugroho Sulistyantoro**[2], **Fitri Nugraheni**[3]

[1, 2, 3] Department of Civil Engeneering, Universitas Islam Indonesia, Yogyakarta, Indonesia

✉ **Corresponding Author :** Vendie Abma (e-mail: vendie.abma@uii.ac.id)

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ABSTRACT

The implementation of Building Information Modelling (BIM) in Indonesia's construction industry has grown steadily, but it mainly focuses on the planning stage. One important function of BIM, automated quantity take-off (QTO), has great potential benefits for contractors during the construction phase. However, its use often faces challenges due to poor model quality. This study explores the implementation of BIM-based automated QTO in a bridge construction project to support digital construction practices from a contractor's viewpoint. A structured modeling approach that follows Level of Development (LOD) 350 was used to improve model quality, ensure data consistency, and allow reliable quantity extraction and shop drawing generation within the BIM environment. The QTO results for the concrete and reinforcement materials in this analysis showed a total concrete volume of 2,075.30 m^3, and the reinforcement volume was 381,548.21 kg. The findings also highlight the need to align modeling practices with the requirements of the construction phase to fully take advantage of BIM. Overall, BIM-based automated QTO can enhance construction performance, reduce material waste, and improve contractor decision-making, providing evidence to support broader industry adoption and informing future guidelines and policy initiatives for digital construction in Indonesia.

INTRODUCTION

Digital transformation in the construction industry has been rapidly progressing, and is a key agenda in various countries, including Indonesia. The Indonesian government has provided support through legal and regulatory frameworks such as Law No. 6 of 2023 and the Ministry of Public Works and Housing Regulation No. 22/PRT/M/2018 for public building development. These frameworks mandate the implementation of Building Information Modelling (BIM). The regulations encourage the use of BIM as part of digital construction and have resulted in the development of national standards, such as the SKKNI BIM, wich aims to align Indonesian construction industry practices with global technological developments (Abma et al., 2025). In this context, BIM is seen as key technology to support the transition to Construction 4.0 and the implementation of lean construction principles that emphasize value enhancement and waste reduction (Eldeep et al., 2022; Liu et al., 2024).

BIM has become widely recognized as an approach that enables the integration into a single digital model of geometric and non-geometric data used throughout the construction project life cycle. BIM models support various project stages, from planning, design, procurement, construction, to the operation and maintenance of infrastructure (G. Chen et al., 2025; Wang et al., 2024). Numerous studies have shown thet BIM can improve coordination between stakeholders, enhance project visualitation, and reduce design errors and rework (Atmajaya & Abma, 2025). Although BIM adoption in Indonesia has increased, its use varies throughout the project lifecycle. Most BIM implementations concentrate on the planning and design phases. However, its use during the construction phase, especially from the contractor's perspective, is still limited (Abma et al., 2024, 2025; Gustian et al., 2022).

For contractors, the construction phase is important because it affects costs, time, and resource management. One BIM function that can significantly help contractors is automating QTO. QTO involves calculating the amounts of materials and construction parts needed for cost estimation, procurement, scheduling, and project control. Traditionally, QTO is done manually using 2D drawings, either printed or in PDF format. This method takes a lot of time and often leads to calculation mistakes and data inconsistencies (PUPR, 2018; Soon et al., 2024). The implementation of BIM can automate the QTO process by extracting quantity data information directly from the 3D model. This approach allows for real-time quantity updates when design changes happen, which improves the reliability and efficiency of the estimating process (Ferial et al., 2022; Meléndez et al., 2024). With BIM-based QTO, contractors can obtain more accurate and consistent quantity information, which is essential for decision-making during construction. However, the accuracy of automated QTO depends heavily on the quality of the level BIM development model (Yin & Mei, 2023).

Several recent studies have demonstrated the potential of BIM-based QTO and shown its benefits in improving the efficiency and accuracy of quantity calculation (B. Chen et al., 2022; Fürstenberg et al., 2024). However, most of these studies were done under relatively ideal conditions and focused on the design or planning phase. In actual construction practice, especially during the construction phase by contractors still face various barriers and many challenges during in implementating BIM-based QTO. These barriers include low model quality, insufficient Level of Development (LOD), inconsistent modelling practices across disciplines, and limited data interoperability (Ashurmamadova & Rexhepi, 2024; Li, 2021). Furthermore, BIM models used in projects are often created by designers who do not fully consider the needs of contractors, requiring recheck and adjust the models before the data can be reliably used for QTO during the construction phase (Kiet et al., 2023; Richintya et al., 2024). Despite the increasing research on BIM-based QTO, there are still few empirical studies that focus on the contractor’s view during the construction phase. This gap is particularly evident in bridge construction projects, which involve complex geometries and reinforcement detailing that require high accuracy in quantity take-off. This problem is even more important in infrastructure projects, such as bridge projects. Bridge projects are dominated by high-volume structural elements, especially concrete and reinforcement, which require precise QTO accuracy. Small mistakes in quantity calculations can greatly affect costs, material procurement, and construction schedules. Therefore, contractors need QTO methods that are accurate, reliable, and practical for the construction phase (Pratama et al., 2025; Wibowo et al., 2025). However, there are still few studies that specifically look into the use of BIM automatic QTO for bridge structural models from a contractor's viewpoint.

Based on these conditions, this study addresses this gap by exploring the application of BIM-based automatic QTO for a bridge structural model from the contractor’s viewpoint. Therefore, this study aims to explore the implementation of BIM-based automated QTO during the construction phase from a contractor's perspective, using a bridge structural model as a case study. The study focuses on how BIM modeling practices can meet the need for automatic QTO on essential structural elements, such as concrete and reinforcement using BIM model developed to LOD 350. The main contribution of this study is presenting a practical and easy-to-apply method for contractors to enhance the reliability of BIM-based QTO in real-world construction site conditions. The study is expected to provide a useful reference for contractors to use BIM more effectively, improve data accuracy, reduce waste, and support decision-making during construction, while also supporting wider and more sustainable BIM implementation in infrastructure projects in Indonesia.

RESEARH METHODS

This study adopts a case study approach to explore the implementation of BIM-based automated quantity take-off in a bridge construction project located on the Plajan, Baron, Tepus road in Yogyakarta, Indonesia. The analysis highlights how the contractor used BIM during the construction phase, focusing on quantity extraction for concrete and reinforcement work.

BIM Modeling and Data Preparation

A three-dimensional (3D) structural model of the bridge was developed using Autodesk Revit based on approved construction drawings (2D). The model was developed to LOD 350 to ensure sufficient geometric and informational detail for automated quantity extraction, particularly for concrete elements and reinforcement bars. In the conventional approach, contractors often rely on printed drawings or PDFs and must engage subcontractors for manual quantity verification (Soon et al., 2024)). In contrast, BIM enables more accurate QTO directly from the 3D model, enhancing reliability and efficiency (Elyano & Yuliastuti, 2021; Ferial et al., 2022). The level of detail in the model significantly impacts the accuracy of automatic QTO, making it essential to establish high-quality modelling practices early in the process (Yin & Mei, 2023).

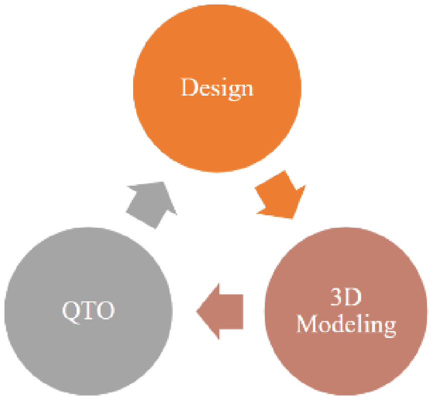

Figure 1. A scheme of QTO processes (Yin & Mei, 2023)

The schematic above (see Figure 1), shows the involvement and important role of design and 3D modeling in the QTO process (Yin & Mei, 2023). QTO automation reduces manual tasks, but it only works well if the model considers the needs of the construction phase (Cepni & Akcamete, 2021; Putra et al., 2022). Additionally, data interoperability is necessary for better accuracy (Meisaroh & Husin, 2021). Several steps in this study's methodology aimed to improve the accuracy of QTO results, including:

1. Developing strong coordination and communication with project team member,
2. Modifying and developing BIM models from the design phase to the construction phase (LOD 350),
3. Verifying BIM models before the QTO process

After implementing the QTO automation process, we looked more closely at the contractor and subcontractor's needs for using BIM during the implementation phase. This research focuses on concrete and reinforcing steel work on bridge structures. The QTO automation plan used refers to the QTO process from earlier research (Vassen, 2021).

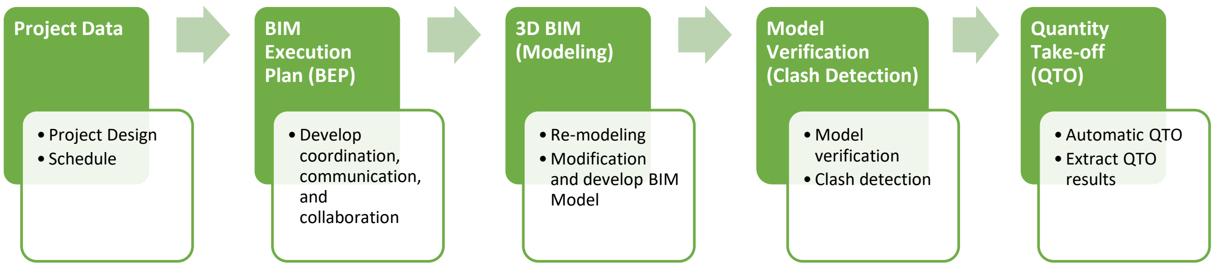

Figure 2. Workflow of QTO.

Based on Figure 2 above on the QTO process, the automatic QTO process was conducted directly within the BIM environment by extracting volume and weight data for structural elements. Concrete quantities were obtained in cubic meters (m^3), while reinforcement quantities were calculated in kilograms (kg). The extracted quantities were exported into spreadsheet format for analysis.

Data Validation

To validate the reliability of the BIM-based QTO results, the extracted quantities were reviewed and confirmed with the project manager. Although the project's official Bill of Quantities (BoQ) was prepared using conventional methods, the detailed data could not be disclosed due to confidentiality constraints. Therefore, validation focused on qualitative consistency and practical applicability rather than direct numerical comparison. Then the discussion continued on the exploration of automatic QTO and the application of BIM for contractors based on the results of case studies and literature studies. The results of this study are designed to provide a more detailed picture, sharpen knowledge, and explore more the important role of BIM implementation at the construction phase.

RESULTS AND DISCUSSION

Due to limited available project data, the analysis began by processing the accessible source information. Although the project originally utilized BIM-based modeling, access to the native BIM model data was restricted and could not be disclosed for the purposes of this study. The primary data obtained consisted of Detailed Engineering Design (DED) drawings in PDF format (2D drawings).

Re-Modeling (BIM 3D)

The initial phase of this study involved reconstructing the bridge design through remodeling. The remodeling was based on 2D project data drawings (DED) and modeled in 3D using Autodesk Revit software. The model was developed to LOD 350 to ensure adequate geometric and informational detail. Figure 3 presents an example of the Detailed Engineering Design (DED) drawing from the available project documentation. Based on the project's DED data, 3D BIM re-modeling was then performed.

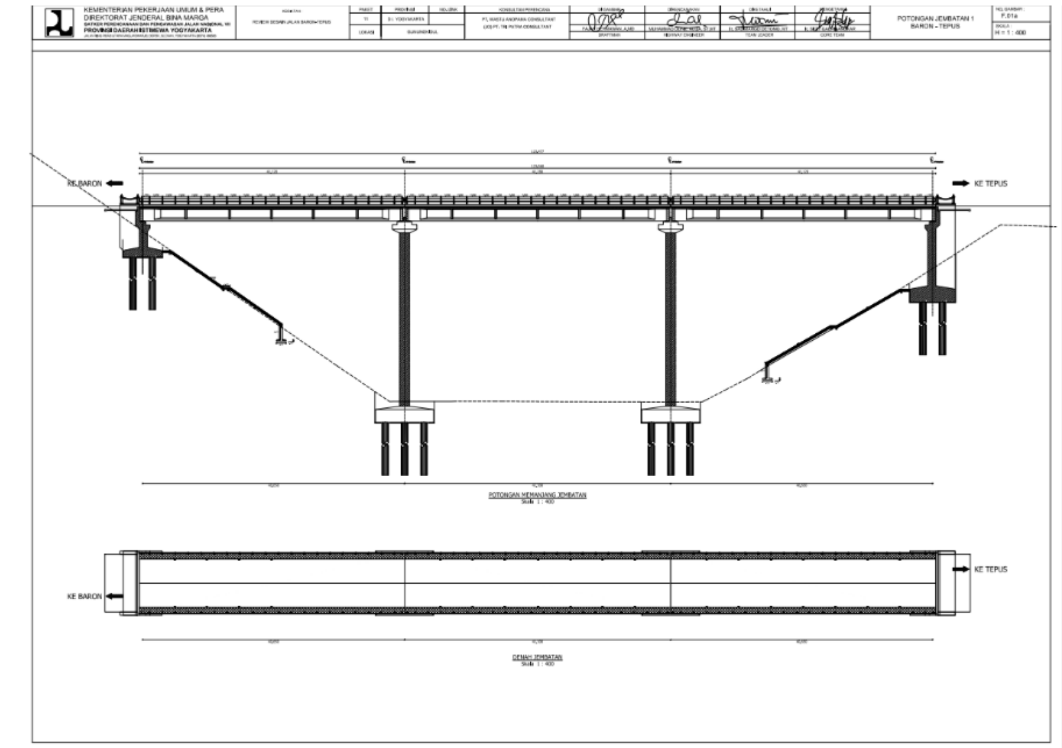

Figure 3. Drawing engineering detail of project.

At this stage, effective communication, coordination, and collaboration are established as a prerequisite for initiating the re-modelling process. These processes are closely aligned with the development of the BIM Execution Plan (BEP) during the planning phase. The BEP serves as a foundational document to ensure a shared understanding among stakeholders regarding BIM implementation, providing a standardized reference to guide project execution. Functions of BEP as a mutually agreed baseline that outlines key aspects such as BIM representation standards, required LOD, protocols and procedures, and the technical infrastructure including the software to be used.

The bridge structure was re-modeled in BIM 3D with Revit software using concrete as the primary material, with detailed reinforcement elements developed in LOD 350. Figure 4 and Figure 5 illustrate the resulting BIM-based structural models developed in this study.

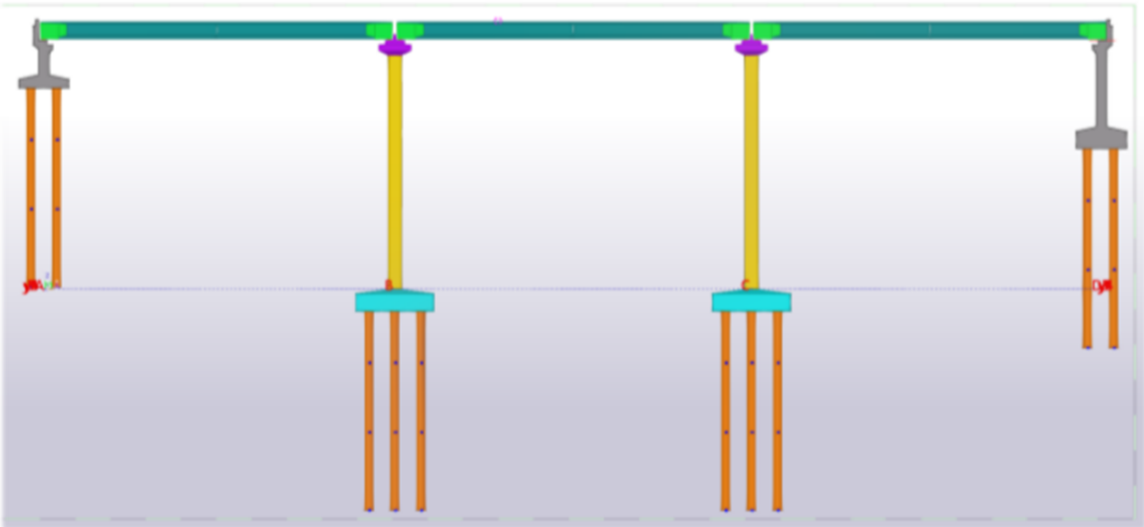

Figure 4. View 3D Model of concrete.

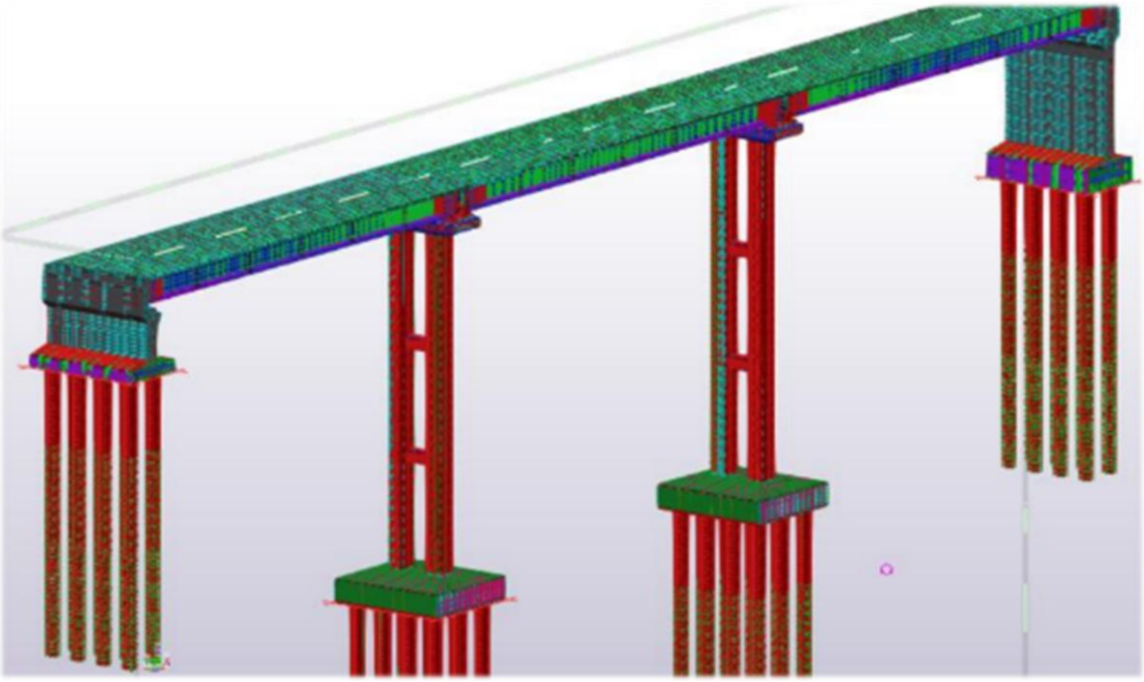

Figure 5. View 3D Model of reinforcement.

Model Verification

The verification stage in this study refers to the model checking process conducted prior to advancing to subsequent BIM processes. This verification ensures that the model is valid, consistent, and free from critical issues that may impact downstream applications. The process consists of three main components: element control, detection of overlaps and duplicates, and clash coordination.

1. Element Control
   This step involves verifying individual model elements in terms of orientation, placement, alignment with the grid system, and conformity to level references. In particular, the spatial relationship between models is examined-ensuring alignment from the defined starting point and confirming that all elements follow a consistent axis or straight path.

2. Overlap and Duplicate Checking
   At this stage, the model is evaluated to identify overlapping or duplicate components that may result in design conflicts. Automated interference checks are utilized, particularly for structural elements such as concrete and reinforcement.

3. Clash Coordination
   Clash coordination aims to detect and resolve conflicts between interdisciplinary elements, such as between structural components and others component systems. However, this study focuses exclusively on structural elements; thus, interdisciplinary clash detection was not conducted as part of the analysis.

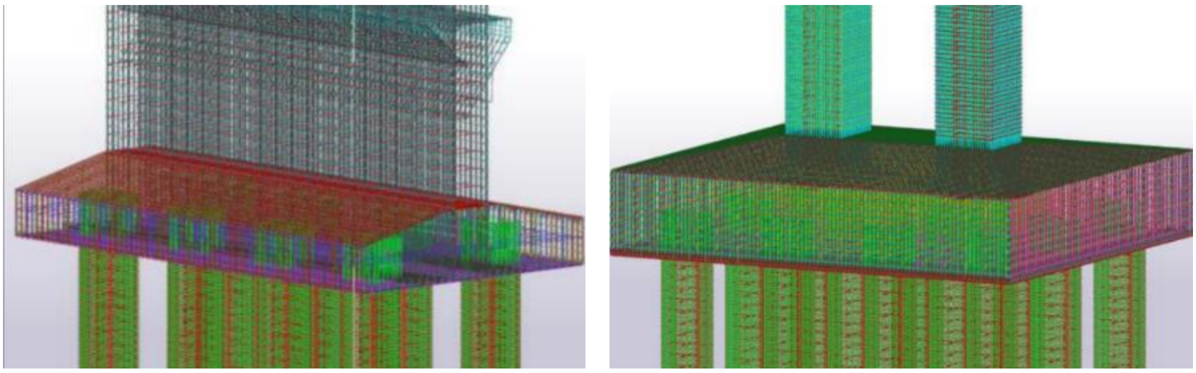

Figure 6. View 3D Model of detail reinforcement.

Figure 6 presents a verified model that has undergone element validation, overlap and duplication checks, as well as clash coordination. The model has achieved the required LOD 350 and is deemed suitable for progression to the next phase of the BIM workflow.

Quantity Take-Off

This stage is conducted after the model has been validated and confirmed to comply with the protocols and procedures outlined in the BIM Execution Plan (BEP). The automatic QTO results obtained from the BIM model are summarized in Table 1 *provides a summary of the extracted quantities.*

Table 1. Total QTO Results on Concrete and Reinforcement Materials.

No	Item	Sat	Volume
1	Concrete	m^3	2075,30
2	Reinforcement	kg	381.548,21

The total concrete volume calculated from the BIM model is 2075.30 m^3, while the total reinforcement quantity is 381,548.21 kg. These quantities represent the structural elements modeled at LOD 350, including piers, beams, and deck components. More detailed QTO can be generated at the element level, depending on the modeling's LOD 350. Table 2 presents the QTO results categorized by individual model elements.

Table 2. QTO Results based on model elements.

No	Item		Sat	Volume
1.	Abutment	Concrete	m^3	215.64
		Reinforcement	kg	19.403,53
	Bore pile	Concrete	m3	288,32
		Reinforcement	kg	48.426,08
	Footing	Concrete	m3	207,50
		Reinforcement	kg	1.2811,61
2.	Pier Head	Concrete	m3	95,22
		Reinforcement	kg	14.950,12
	Pier	Concrete	m3	280,27
		Reinforcement	kg	125.867,76
	Pile Cap	Concrete	m3	402,90
		Reinforcement	kg	38.272,58
	Bore Pile	Concrete	m3	432,48
		Reinforcement	kg	72.639,12
	Floor	Concrete	m3	155,94
		Reinforcement	kg	49.177,41

The material volume takeoff results were then verified against project data. Based on the verification and interviews with the contractor, the volume takeoff results were consistent and provided more detailed results. This demonstrates that the automated BIM-based QTO system significantly supports construction phase activities by accelerating quantity calculations and improving accuracy. From the contractor's perspective, this capability improves material planning, procurement scheduling, and cost control, particularly on bridge projects where quantity complexity is high. This finding aligns with previous research showing that a BIM-based automated QTO significantly supports construction-phase activities by accelerating quantity calculation and improving accuracy (Meléndez et al., 2024). From the contractor's perspective, discussions with the project manager and estimator confirmed that this capability can improve material planning, procurement scheduling, and cost control, particularly on bridge projects with high quantity complexity. In addition, the BIM method provides higher precision and reduces the potential for material waste, as well as supporting more efficient budgeting (Wibowo et al., 2025). However, achieving reliable outcomes requires well-developed BIM models with a LOD of at least 350 to meet detailed construction execution standards. Despite its advantages, several challenges remain. These explorations are consistent with previous studies, which highlight that:

1 Achieving a high level of detail and accuracy in modeling requires substantial experience (Atmajaya & Abma, 2025; Fürstenberg et al., 2024; Nafiyah & Martina, 2022);
2 Automated QTO is constrained by interoperability issues across software platforms (Saavedra et al., 2025; Yin & Mei, 2023); and
3 Some system features remain unusable due to incomplete or missing element properties (Ferial et al., 2022; Meléndez et al., 2024).

Further exploration reveals that, with adequately developed LOD 350 models, contractors and subcontractors can execute construction activities including material procurement, more efficiently and with greater precision. A well-structured BIM model not only enables the creation of detailed volume data but also supports the automatic generation of detailed DED's and fabrication shop drawings through extraction from BIM 3D, as illustrated in Figure 7 and Figure 8.

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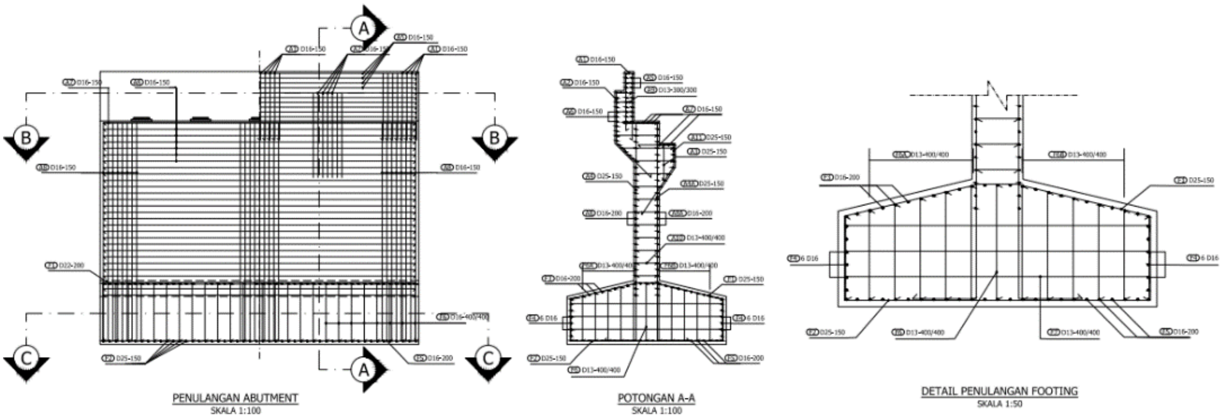

Figure 7. 2D DED drawing of reinforcement details extracted from the 3D BIM.

PENULANGAN ABUTMENT A2																
NO.	DIA.(mm)	TYPE	BENDING DIMENSION (cm)									TOTAL LENGTH (cm)	UNIT WEIGHT (kg/m)	NUMBER	WEIGHT (kg)	REMARKS
			a	b	c	d	e	f	g	h	i					
1	D 16	A1	10	244	25	264	10					553	1.578	67	584.66478	
2	D 16	A2	10	150	209	55	10					434	1.578	67	458.85084	
3	D 16	A3	10	180	10							200	1.578	67	211.452	
4	D 25	A4	10	100	1040	115	10					1275	3.853	67	3291.42525	
5	D 25	A4A	10	100	1040	145	10					1305	3.853	67	3368.87055	
6	D 16	A5	10	990	10							1010	1.578	32	510.0096	
7	D 16	A6	10	990	10							1010	1.578	17	270.9426	
8	D 16	A7	10	990	10							1010	1.578	16	255.0048	
9	D 16	A8	10	990	10							1010	1.578	47	749.0766	
10	D 16	A8A	10	990	10							1010	1.578	52	828.7656	
11	D 13	A9	10	25	10							45	1.042	204	95.6556	
12	D 13	A10	10	115	10							135	1.042	528	848.3376	
13	D 16	A11	10	180	40	180	10					420	1.578	67	444.0492	
														D 13	943.9932	
														D 16	4312.81602	
														D 25	3878.88015	
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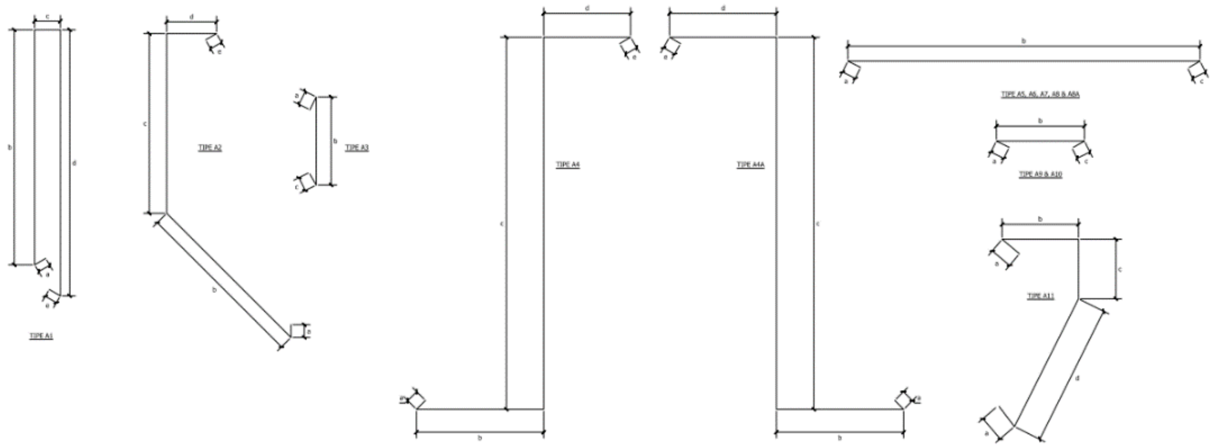

Figure 8. Detailed of bar bending schedule.

From the Figure 7 and Figure 8 demonstrate that models developed to LOD 350 enable contractors to automatically generate detailed and accurate 2D drawings and detail volume calculations directly from the 3D model. Based on this exploration, the primary challenge lies in facilitating contractors and subcontractors to adopt BIM methodologies effectively. From a contractor's perspective, BIM implementation at this level offers significant advantages, including:

1 Access to highly detailed and well-visualized reference images and models through integrated 3D and 2D representations,
2 Simplified and accelerated volume calculations, enhancing the efficiency and accuracy of material procurement,
3 The ability to extract shop drawings and bar bending schedules from 3D models with embedded volume data, which supports precise construction execution and reduces material waste.

These findings provide a critical foundation for advancing BIM implementation and automated QTO in construction, particularly during the execution phase by contractors. The results demonstrate that BIM-based automatic QTO offers significant advantages for contractors, particularly in bridge construction projects where quantity complexity is high. The use of a detailed BIM model enables faster quantity extraction and reduces dependency on manual calculations, which are susceptible to human error.

However, the findings also reveal that achieving reliable automated QTO outcomes requires BIM models developed at a sufficiently high level of detail. The requirement for LOD 350 increases initial modelling effort and demands skilled BIM personnel, which may present barriers for small and medium contractors. The study confirms that BIM-based QTO should be viewed not only as a technological tool but as part of a broader digital workflow transformation within contractor organizations.

CONCLUSION

This study explored the implementation of BIM-based automatic Quantity Take-Off for a bridge structural model from a contractor's perspective. The QTO results for the concrete and reinforcement materials in this study indicated a total concrete volume of 2.075,30 m^3, and reinforcement volume of 381.548,21 kg. The findings demonstrate that BIM models developed at LOD 350 enable accurate and transparent quantity extraction for concrete and reinforcement works, supporting construction-phase decision-making and reducing reliance on manual calculations. Despite these benefits, this study highlights challenges associated with developing detailed modeling efforts and data consistency. As the findings are based on a single case study, future research should extend the analysis to multiple infrastructure projects and incorporate quantitative comparisons of time efficiency and cost accuracy. Nevertheless, this study provides practical insights for contractors considering the adoption of BIM-based QTO as part of digital construction practices..

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REFERENCES

Abma, V., Farhana, A., & Rachmawati, S. (2024). Cash flow simulation planning based on building information modeling for construction projects. *AIP Conference Proceedings*, *3114*(1). https://doi.org/10.1063/5.0202242

Abma, V., Nastiti, A. R., & Ramadhani, F. (2025). Barriers to implementing Common Data Environment (CDE) in the construction phase of BIM-based projects. *Teknisia*, *29*(2), 94–102. https://doi.org/10.20885/teknisia.vol29.iss2.art3

Ashurmamadova, S., & Rexhepi, G. (2024). *Building A Sustainable Future: Adoption, Barriers, And Pathways To Progress In Sustainability-Case Of Sustainable Construction*. https://doi.org/10.13140/RG.2.2.33469.06889

Atmajaya, W., & Abma, V. (2025). *Eksplorasi quantity take off (QTO) dan dampak terhadap biaya berbasis 5D BIM* (Vol. 4, Issue 23).

Cepni, Y., & Akcamete, A. (2021). Enhancing BIM-Based QTO Using Visual Programing. *Proceedings of the 2021 European Conference on Computing in Construction*, *2*, 229–236. https://doi.org/10.35490/ec3.2021.164

Chen, B., Jiang, S., Qi, L., Su, Y., Mao, Y., Wang, M., & Cha, H. S. (2022). Design and Implementation of Quantity Calculation Method Based on BIM Data. *Sustainability (Switzerland)*, *14*(13). https://doi.org/10.3390/su14137797

Chen, G., Feng, Q., Jiang, C., Zhang, S., & Li, Q. (2025). Towards Digital Transformation in the Construction Industry: A Selection Framework of Building Information Modeling Lifecycle Service Providers (BLSPs). *Systems*, *13*(9). https://doi.org/10.3390/systems13090816

Eldeep, A. M., Farag, M. A. M., & Abd El-hafez, L. M. (2022). Using BIM as a lean management tool in construction processes – A case study: Using BIM as a lean management tool. *Ain Shams Engineering Journal*, *13*(2), 101556. https://doi.org/10.1016/j.asej.2021.07.009

Elyano, M. R., & Yuliastuti. (2021). Analysis of clash detection and quantity take-off using BIM for warehouse construction. *IOP Conference Series: Earth and Environmental Science*, *794*(1). https://doi.org/10.1088/1755-1315/794/1/012012

Ferial, R., Hidayat, B., Pesela, R. C., & Daoed, D. (2022). Quantity take-off berbasis building information modeling (bim) studi kasus: gedung bappeda padang. *Jurnal Rekayasa Sipil (JRS-Unand)*, *17*(3), 228. https://doi.org/10.25077/jrs.17.3.228-238.2021

Fürstenberg, D., Hjelseth, E., Klakegg, O. J., Lohne, J., & Lædre, O. (2024). Automated quantity take-off in a Norwegian road project. *Scientific Reports*, *14*(1). https://doi.org/10.1038/s41598-023-50486-6

Gustian, E., Milyardi, R., & Lesmana, C. (2022). Analysis of Benefits and Barriers Factors in the Implementation of Building Information Modeling (BIM) in Building Construction for Contractor. *Jurnal Teknik Sipil Dan Perencanaan*, *24*(2), 158–167. https://doi.org/10.15294/jtsp.v24i2.37026

Kiet, T. T., Kha, T. T., & Thuan, T. C. (2023). Analyzing problematic issues of building information modeling (BIM) implementation by contractors. *IOP Conference Series: Earth and Environmental Science*, *1226*(1). https://doi.org/10.1088/1755-1315/1226/1/012002

Li, P. (2021). Research on the application of BIM technology in bridge design. *Journal of Physics: Conference Series*, *2023*(1). https://doi.org/10.1088/1742-6596/2023/1/012002

Liu, G., Ma, Z., Li, J., Li, S., Zhou, X., & Song, Y. (2024). Framework of Digital Lean Construction and Implementation of Its Management Platform for the Construction Phase. *Journal of Construction Engineering and Management*, *150*(6). https://doi.org/10.1061/jcemd4.coeng-14164

Meisaroh, M., & Husin, A. E. (2021). *Analysis of Key Success Factors Using RII Method on The Implementation Building Information Modeling (BIM)-Based Quantity Take-Off to Improve Cost Performance Hospital Structure*. www.solidstatetechnology.us

Meléndez, W., Saavedra, R., & Garcés, G. (2024). Quantity take-off in rough construction of high-rise buildings based on cad and bim methodologies: A case study. *Annual Conference of the International Group for Lean Construction, IGLC*, *32*, 793–806. https://doi.org/10.24928/2024/0236

Nafiyah, R., & Martina, N. (2022). Analisis quantity takeoff pada pekerjaan struktur bawah jembatan. In *Construction and Material Journal*. http://jurnal.pnj.ac.id/index.php/cmj

Pratama, H., Aminullah, A., & Handayani, T. N. (2025). Implementation of Building Information Modeling (BIM) for Bridge Abutment Cost Estimation Considering QTO Validity. *Eduvest-Journal of Universal Studies*, *5*(5), 4870–4885. http://eduvest.greenvest.co.id

PUPR. (2018). *Modul_5- Pemodelan 3D-7D simulasi dan LOD*.

Putra, A. A. P., Oei, N. I. W., Hermawan, & Hasiholan, B. (2022). Comparative Study in Bill of Quantity Estimates on Reinforcement Works of Pile Cap, Single Pier and Double Pier of Flyover between Conventional Methods and BIM (Building Information Modelling). *IOP Conference Series: Earth and Environmental Science*, *1065*(1). https://doi.org/10.1088/1755-1315/1065/1/012041

Richintya, A., Suharyanto, A., & Rachmansyah, A. (2024). Readiness of contractor companies to implementation building information modelling in East Java Province. *AIP Conference Proceedings*, *3043*(1). https://doi.org/10.1063/5.0207333

Saavedra, R., Meléndez, W., & Garcés, G. (2025). Comparative analysis of quantity take-off in concrete, steel bars and formwork in apartment buildings based on cad and bim methodologies. *Journal of Information Technology in Construction*, *30*, 159–184. https://doi.org/10.36680/j.itcon.2025.008

Soon, L. T., Wong, L. S., Kamarazaly, M. A., Saar, C. C., & Ilmi, H. S. (2024). Comparison of bim-based quantities take-off in quantity surveying profession. *Journal of the Malaysian Institute of Planners*, *22*(3), 150–164. https://doi.org/https://doi.org/10.21837/pm.v22i32.1499

Vassen, S. A. (2021). Impact of BIM-based Quantity Take off for Accuracy of Cost Estimation. *International Journal of Construction Engineering and Management*, *10*(3), 55–69. https://doi.org/10.5923/j.ijcem.20211003.01

Wang, K., Guo, F., Zhang, C., & Schaefer, D. (2024). From Industry 4.0 to Construction 4.0: barriers to the digital transformation of engineering and construction sectors. *Engineering, Construction and Architectural Management*, *31*(1), 136–158. https://doi.org/10.1108/ECAM-05-2022-0383

Wibowo, R. A., Dwiyana, P. A., & Susanti, J. E. (2025). Comparative Analysis of Concrete QTO Using BIM and Conventional on XYZ Project. *G-Tech: Jurnal Teknologi Terapan*, *9*(4), 2141–2150. https://doi.org/10.70609/g-tech.v9i4.8075

Yin, L. K., & Mei, L. K. (2023). Building Information Modeling-Based Approach for Automatic Quantity Take-off and Cost Estimation.pdf. *International Journal of Civil and Environmental Engineering*, *2*(17), 80–97. https://doi.org/https://doi.org/10.48084/etasr.9890