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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

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ABSTRACT

Green retrofitting aims to guide buildings toward sustainable practices, reducing carbon emissions associated with building operations and construction. This study explores the application of Building Information Modeling (BIM) 5D Quantity Take-Off (QTO) to existing high-rise buildings, focusing on components that enhance the performance of environmentally friendly structures and project management. This research identifies the factors influencing the cost estimation process and examines the risks across various phases, activities, outputs, and utilization of BIM 5D in cost estimation. The study highlights the most influential factors in implementing green retrofitting for high-rise buildings using structured interviews, questionnaires, and expert validation. The analysis demonstrates that BIM 5D QTO significantly impacts the risk associated with cost estimation in green retrofitting processes. The study ranks the criteria based on respondent feedback by employing Relative Importance Index (RII) analysis. The statistical analysis identifies key factors affecting the risk of cost estimation in BIM QTO for green retrofitting of high-rise buildings. These factors include evaluating specifications, defining acceptance criteria, decomposing the high-level Work Breakdown Structure (WBS), inputting sizes and specifications of each work component into the 3D model, integrating scheduling into the 3D model, and establishing a BIM Execution Plan.

Keywords: Green retrofitting; Cost estimation process; BIM 5D-QTO; High rise buildings; Relative importance index

1. INTRODUCTION

By 2040, it is projected that two-thirds of the world's buildings will be existing structures, continuing to generate significant carbon emissions. A substantial goal has been set to reduce the carbon emissions of 20% of these existing buildings by 2030, which is critical for achieving Net Zero Energy (NZE) status by 2050 (IEA, 2022). The construction sector currently contributes to 40% of the annual global carbon emissions, as depicted in Figure 1. Building operations account for 27% of these total annual global carbon emissions, while emissions from building construction materials and processes contribute an additional 13% annually (Why The Built Environment?, 2022).

Failure to address these issues could hinder the primary targets of The Paris Agreement (Why The Built Environment?, 2022). Globally, buildings consume 40% of energy, 20% of water, 40% of natural resources, and produce one-third of greenhouse gas emissions, according to the United Nations Environment Program. To mitigate this impact, it is imperative for all building-related

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activities to prioritize environmental considerations, such as green renovations, as recommended by the International Energy Agency (2022).

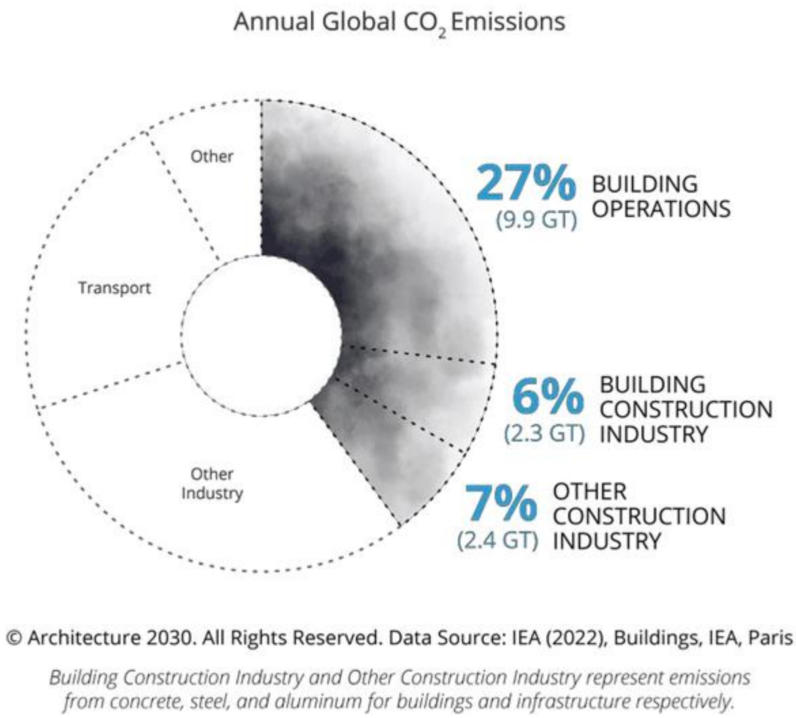

Figure 1 Annual Carbon Emissions
(source: architecture2030.org, 2022)

Green Retrofit, or custom construction, emerges as a highly profitable strategy for reducing carbon emissions in the construction sector. This approach costs only 30% to 50% compared to demolishing existing buildings and constructing new ones, and it is 20% less expensive than building structures that meet green building standards on vacant land.

In addition to using the Work Breakdown Structure (WBS) for building construction work, advanced technology is needed to facilitate effective and efficient building planning. With current technological advancements, the goal is to minimize errors in cost estimation calculations, especially in the construction industry. Most construction companies in Indonesia still rely on conventional applications such as AutoCAD for design, Structure Analysis Program (SAP) for structural calculations, Microsoft Project for scheduling, and Microsoft Excel for cost and volume calculations, which are often done separately (Kamil, 2019). Using fragmented conventional applications frequently leads to construction waste and information delays, resulting in cost and time inefficiencies.

Advancements in information technology, such as big data and cloud technology, enable Building Information Modeling (BIM) to integrate all construction project data, facilitating visualization and management throughout the project lifecycle. BIM 5D can auto-extract and associate with assembly items, ensuring that data is always updated.

However, data indicates numerous challenges in making decisions regarding green retrofit projects, with inaccurate cost estimates being a significant issue. Inaccurate cost estimates often lead to budget overruns during project execution. BIM can address this challenge by providing essential information to facilitate the quantity take-off process in cost estimation (Mahadevi et al., 2018).

The cost estimation process for a green retrofit project, from planning to implementation, utilizes BIM to generate comprehensive project cost estimates. By integrating the WBS for green retrofitting with BIM during the cost estimation phase, it is anticipated that the estimation outcomes will be more accurate. Using BIM in cost estimation can mitigate the risk of incomplete cost calculations for project components, as it provides fundamental information necessary for obtaining accurate estimates (Mahadevi et al., 2018), enhancing the completeness of the information. Furthermore, BIM can minimize the risk of duplicate cost calculations by providing a clearer breakdown of cost components.

Figure 2 illustrates BIM modeling for the Quantity Take-Off (QTO) process. The building design is created in 3D, and detailed building information is provided for the QTO process. Every change and data update is entered into the 3D model, ensuring the QTO process reflects current information. This means that with BIM 5D, the calculation of building volume will be more accurate than with conventional methods.

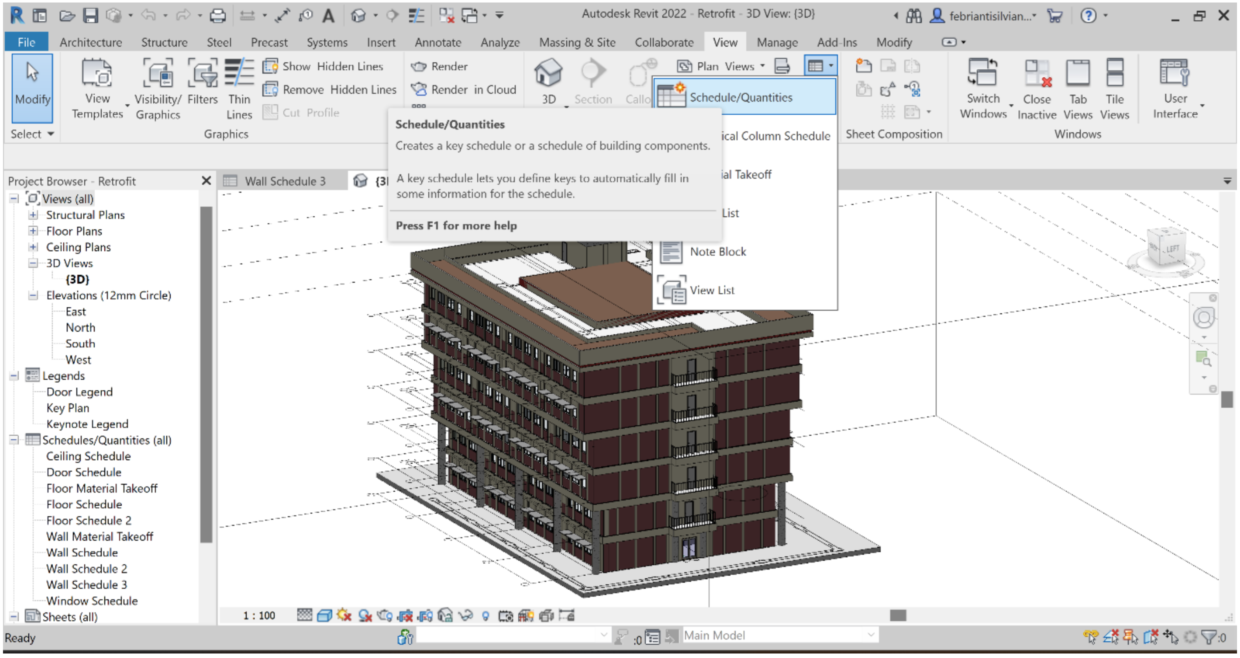

Figure 2 BIM Modelling for QTO Process

This study contributes to green retrofitting for high-rise buildings by identifying factors influencing cost estimation. It also examines the associated risks across various phases, activities, outputs, and risks in utilizing BIM 5D and the cost estimation process. The figure 3 illustrates how to calculate wall-building elements using Revit for the research object. Implementing BIM 5D ensures that the QTO process is streamlined, eliminating any repetition or overlap in the volume calculation of each detailed element.

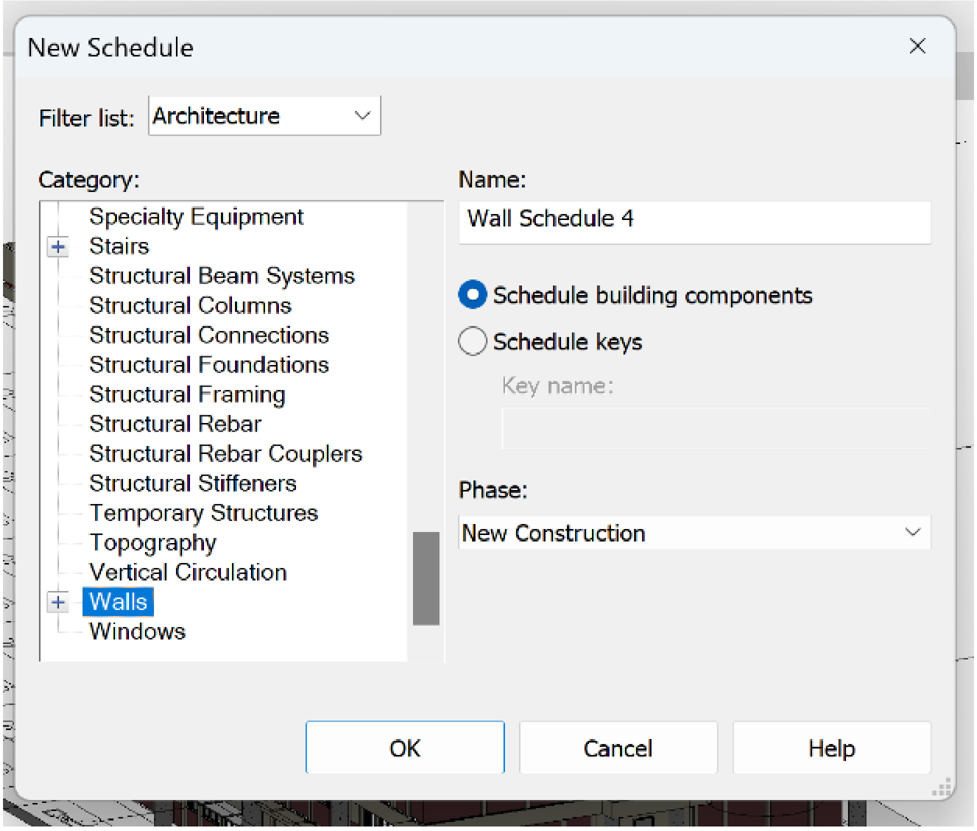

Figure 3 QTO Calculation Process in BIM 5D

Cost factors are integral to the completion of a green retrofitting project. Therefore, during the initial planning phase, it is crucial to account for factors influencing costs to mitigate or minimize potential risks, particularly errors or failures in volume and cost calculations. It is essential to develop mitigation methods and strategies to address these challenges. By doing so, stakeholders can proactively consider these factors at the outset, enhancing the likelihood of project success. According to Mohammadi et al. (2018), the construction sector is characterized by unique, dynamic, and complex characteristics, leading to a higher risk level than other sectors. Construction projects also absorb significant resources, involving many parties in the work. Carelessness in calculating cost estimates during the planning phase can cause substantial losses to various stakeholders.

Despite its benefits, the application of BIM 5D technology in Indonesia is not yet optimal due to risks that hinder the cost estimation process using BIM 5D. Therefore, to ensure that the cost estimation process in green retrofitting high-rise buildings meets the desired goals, it is necessary to identify the factors that give rise to these risks from the beginning.

Previous studies have extensively investigated the factors crucial for calculating quantity and pricing, identifying them as key determinants of project success. Some studies have ranked these factors based on their impact on project performance, while others have proposed mitigation methods for these factors in the QTO estimation and calculation process. However, studies focusing on factors related to the estimation process and BIM 5D QTO in green retrofitting projects are lacking despite widespread implementation in new green building projects. Therefore, this research aims to identify the most dominant factors influencing the risk in the cost estimation process and the implementation of BIM 5D for green retrofitting of high-rise office buildings.

2. LITERATURE STUDY

2.1. Green Cost Estimation Process for Retrofitting High-rise Office Buildings

The cost estimation process entails the systematic steps to estimate the costs required to execute a project, product, or service. Peurifoy et al. (2014) state that a robust cost estimation process is essential for generating accurate cost estimates. While the estimation process is not entirely automated, BIM-based QTO can furnish all the requisite data for creating cost estimates and bills of quantities. However, it remains imperative to assess whether the data extracted from the model accurately reflects the actual building (Monteiro & Poças Martins, 2013).

Cost estimates and budgeting are closely intertwined, each influencing the other. Careful and precise cost estimates are crucial, as they inform comprehensive budgeting, enabling the anticipation of all project costs. In contrast, inaccurate cost estimates can lead to unrealistic budgeting, resulting in financial challenges during project implementation.

2.2. BIM-based Quantity Take-Off

BIM is a comprehensive system, management approach, method, or sequence utilized in project implementation. It integrates relevant information from all aspects of a building, which is then projected into a three-dimensional model (Wong et al., 2010). BIM entails the creation of a 3D digital model (virtual building) containing all pertinent building information. This model is a tool for planning, designing, executing construction, and maintaining buildings and their infrastructure for all project stakeholders.

Before providing cost estimates or commencing a project, estimators require detailed knowledge of the types and quantities of materials needed for completion. This process ensures accurate cost estimates and material requirements while also offering insights into labor costs associated with installation or execution. This crucial process is known as Quantity Take-Off (QTO), which forms an integral part of the estimation process (Husin et al., 2020).

Historically, manual QTO involved reading scale drawings and persisted as the primary method for volume calculations until the early 1980s. Subsequently, in the mid-1980s, new quantity take-off software emerged. Further advancements occurred in the early 1990s with the adoption of 3D drawings, now recognized as BIM 5D QTO (Choi et al., 2015).

Research by Eastman et al. (2011) indicates that the cost estimation process using BIM 5D is easier and more accurate than traditional paper-based estimation processes because BIM 5D will auto-extract, associate with assembly items, and is always updated (see figure 4).

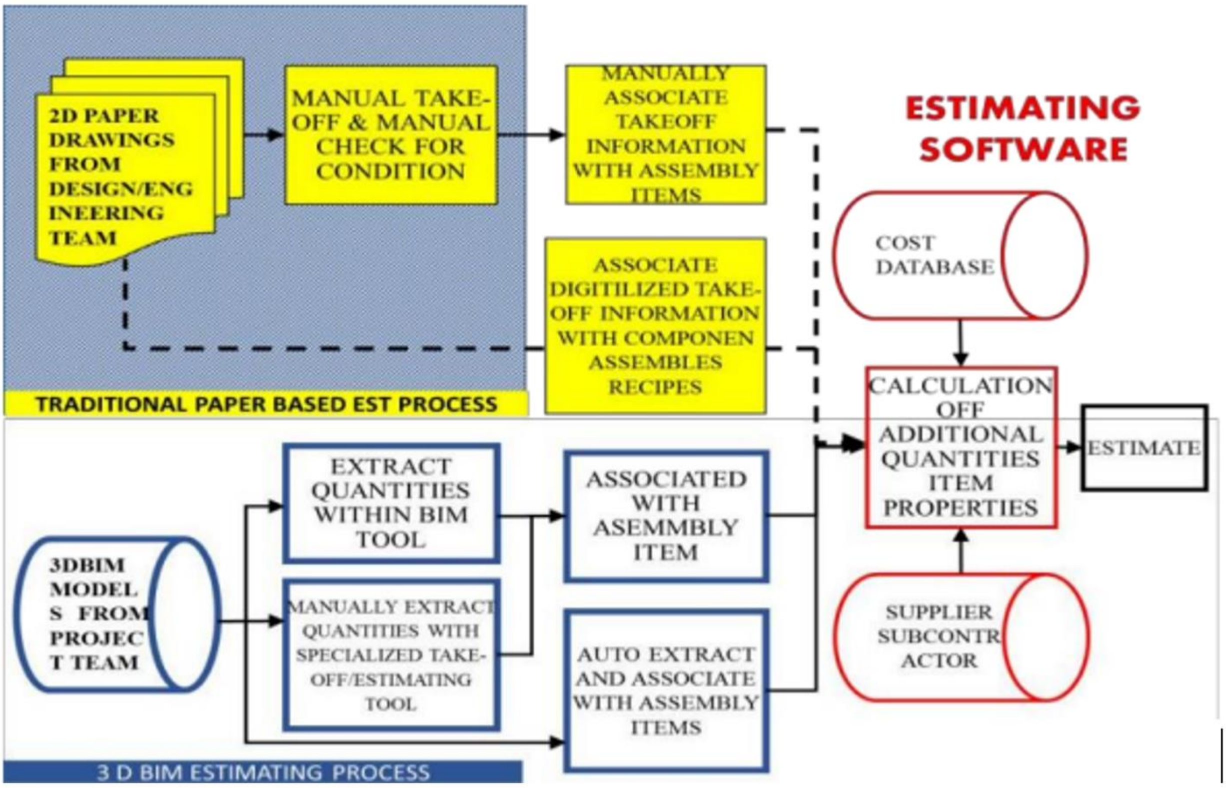

Figure 4 Diagram Comparison of Process between BIM-based QTO and Paper-Based Version (source: Eastman et al., 2011)

2.3. Relative Importance Index

Relative Importance Index (RII) analysis allows for identifying the most significant criteria based on respondents' responses. It is a suitable tool for prioritizing indicators assessed on a Likert-type scale (Rooshdia et al., 2018). The contribution of each factor to the overall delay is examined, and the ranking of attributes in terms of their perceived criticality by respondents is conducted using the Relative Importance Index, calculated through a specific equation (Gunduz et al., 2013). This analytical approach will utilize questionnaires' data, revealing significant factors. The Relative Importance Index will then rank these factors based on their influence as indicated by scores provided by respondents in the questionnaire.

The RII method serves as a means to analyze the most influential factors within the scope of the research. This analytical method involves statistical computations using questionnaire results as input, which are subsequently processed to identify significant factors. The Relative Importance Index determines the most significant factors through a ranking system based on the weighting of scores provided by respondents upon questionnaire completion. Previous research has employed the RII method to ascertain significant factors through computational equations.

3. METHODS

This research employed the quantitative method to determine the causal relationship between independent and dependent variables to obtain its objective. In this approach, all variables influencing the outcome must be controlled except for the predetermined independent variable. The relationship between these variables can be represented as an operational research model, as illustrated in Figure 5..

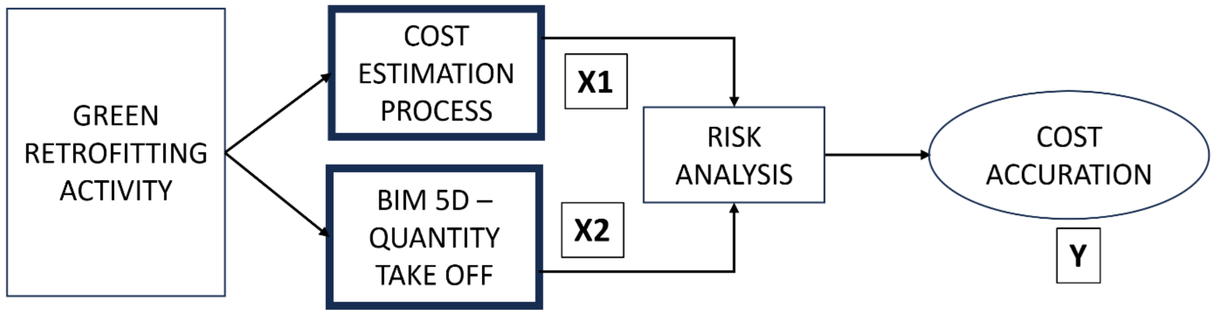

Figure 5 Conceptual Research Model

The methods and techniques used for data collection and analysis in this research are outlined in the accompanying flowchart, depicting the research process employed in this study, which includes literature review, expert validation, identification of process estimation, questionnaire survey, and RII ranking. Additionally, it illustrates the relationship between risk, BIM 5D QTO, and the cost estimation process, highlighting their influence on cost accuracy.

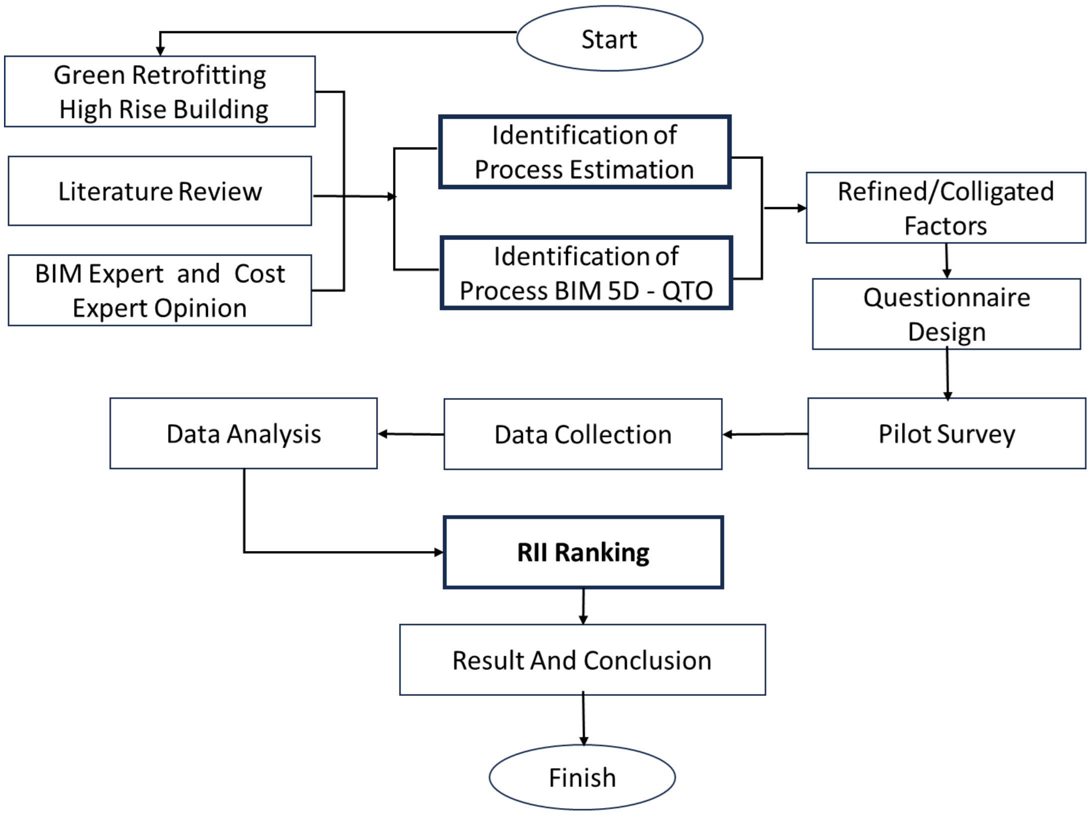

Figure 6 Research Flow Chart

Figure 6 explains that the stages of this research stage begins with identifying each process in cost estimation and BIM 5D. This identification results in key factors in the cost estimation process and BIM 5D. The key factors identified from the literature review were then validated by experts through questionnaires, seeking their responses or suggestions for improvement regarding each application of the BIM 5D process in the cost estimation phase of green retrofitting planning.

The expert responses were analyzed using the Delphi Method to validate the cost estimation process and BIM 5D for the green retrofitting planning stage. Following this, content and construct validation is conducted with respondents representing the construction and green retrofitting fields through additional questionnaires. The data obtained from respondents are analyzed and calculated using RII to identify the most dominant factors influencing the risk in the cost estimation process and the implementation of BIM 5D in the green retrofitting of high-rise office buildings.

3.1. Data Collection and Analysis Approach

To validate the factors influencing cost estimation and BIM 5D implementation, opinions were solicited from nine experts, each proficient in their respective fields. A pilot survey was conducted by disseminating questionnaires to civil engineers via Google Forms and manual distribution. The selected civil engineers constituted the population for this survey.

Table 1 Number of Experts

Expert	Number of Experts	Experience (years)
Project Director	1	16
Construction Manager	2	17
Quantity Surveyor	1	5
Building Expert	1	14
BIM Engineer	2	10
Total	9	

The expert validation process involved a pilot survey of nine expert judgments representing the construction management and green retrofitting sectors. Subsequently, the final questionnaire was distributed to 40 respondents, selected through a random sampling method from a pool of 50 potential respondents (see table 1). These respondents comprised clients/project owners, contractors, consultants, and others. Of these, 57% represented contractors, 39.9% represented consultants, and 3.1% were other respondents, including retired civil engineers or those in different occupations. The respondent population included individuals from the construction and green building fields, ranging from top management positions to engineers, as shown in the table 2.

Table 2 Number of Respondents

Position	Number of Respondents	Percentage
Top Management	3	7.50%
Middle Management	7	17.50%
Modeler	10	25.00%
Engineer	20	50.00%
Total Respondent	40	100.00%

The majority of respondents (82.8%) were male. Among them, 58.9% were over 40 years old. Furthermore, 55.2% of respondents held a master's degree, while 42.3% held a bachelor's degree as their highest educational qualification. A significant portion of respondents (46.6%) reported having more than 20 years of work experience in civil engineering. Regarding the type of organization, 28.8% of respondents were employed in construction companies.

3.2. Data Analysis

The preparation of the questionnaire followed a thorough literature review. Components of the questionnaire, including variables, main factors, and sub-factors, were derived from literature study, considering several previous studies (Dipohusodo, 1996; Kerzner, 1995; Shen, 1997; Stockton & Wang, 2004; Kappelman et al., 2006; Kerzner, 1995; Supriyadi, 2010; Zou et al., 2007; El-Sayegh, 2008; Buranda, 2009; Santoso, 2009; Adnyana, 2017; Indriani, 2022; Akbar, 2023). The subsequent step involved compiling the findings from the literature review into a set of questions to be presented to respondents. Details regarding the sub-factors of this study are elucidated in tabular format, as shown in Table 3 and Table 4.

Table 3 Factor Variables

Main Factors and Sub-Factors (X1: Cost Estimation Process)		**Risks in The Cost Estimation Process**	
X1.1	Project Scope Statement	X.1.1.1	Errors in determining the scope of work
		X.1.1.2	Lack of communication and collaboration among stakeholders in determining the project scope
		X.1.1.3	Absence or lack of clear and structured planning processes
		X.1.1.4	Lack of monitoring and control of changes occurring in the project scope
X1.2	Baseline Scope	X.1.2.1	Inaccurate planning and scheduling resulting in rework
X1.3	WBS Documents	X.1.3.1	Errors in determining the Project WBS
		X.1.3.2	Lack of monitoring and control of changes occurring in the project WBS
X1.4	Project Scope Boundary/Exclusion (exception) Documents	X.1.4.1	Inability to establish boundaries and control over the project scope
		X.1.4.2	Overlap in the project scope occurs
X1.5	Validated DED (Project Document Update)	X.1.5.1	Discrepancies in data between updated drawing documents/Design and Engineering Drawings (DED) from the owner
		X.1.5.2	Incompleteness of drawing documents/DED obtained from the owner
X1.6	Validated Work Method Documents (Project Document Update)		Incompleteness of work method documents and items in the work method from the owner
			Lack of experience in handling similar projects
			Discrepancies in data between technical specifications and drawing documents/DED obtained from the owner
			Lack of information related to existing project utility data
			Errors in planning implementation methods
X1.7	Validated Specification and Technical Documents (Project Document Update)	X.1.7.1	Discrepancies in data between technical specifications and drawings obtained from the owner
		X.1.7.2	Incomplete contract documents, specifications, and drawings from the owner
		X.1.7.3	Lack of experience in handling similar projects
X1.8	Updated WBS Documents	X.1.8.1	Inaccuracy in creating the Work Breakdown Structure (WBS)
X1.9	Activity Resource Estimation Documents	X.1.9.1	Errors in calculating equipment requirements
		X.1.9.2	Errors in calculating material requirements
		X.1.9.3	Errors in calculating labor requirements and productivity

Main Factors and Sub-Factors (X1: Cost Estimation Process)		Risks in The Cost Estimation Process	
X1.10	Updated Price Index List Documents	X.1.10.1	Errors in calculating work item coefficient coefficients
		X.1.10.2	Discrepancies in volume stated in the Bill of Quantity (B.Q.)
		X.1.10.3	Incomplete reference data regarding equipment and labor productivity
X1.11	Budget Plan Documents (RAB)	X.1.11.1	Incomplete reference data regarding unit prices for work
		X.1.11.2	Errors determining unit prices for work
		X.1.11.3	Incomplete list of updated price indices
		X.1.11.4	Lack of data references regarding subcontractors
		X.1.11.5	Errors in calculating work volume
X1.12	Self-Estimated Proce Documents (HPS)	X.1.12.1	Less accuracy in considering the influence of fluctuations in material prices, inflation, interest rates, and exchange rates
		X.1.12.2	Inaccurate risk calculation for location and construction
		X.1.12.3	Inaccurate risk calculation for location and construction
		X.1.12.4	Errors in calculating taxes, insurance, overhead, and profit
		X.1.12.5	Errors in determining unit prices for work
		X.1.12.6	Lack of understanding of project scope by estimators
		X.1.12.7	Estimators lacking qualification
		X.1.12.8	Errors in summarizing
		X.1.12.9	Errors in linking files
		X.1.12.10	Lack of understanding of project implementation methods by estimators

Table 4 Factor Variables for the BIM 5D-QTO Activities

Main Factors and Sub-Factors (X2: BIM 5D)		Risks in BIM 5D-QTO Activities	
X2.1	Project Scope Statement	X.2.1.1	Errors in determining the scope of work
		X.2.1.2	Lack of communication and collaboration among stakeholders in determining the project scope
		X.2.1.3	Absence or lack of clear and structured planning processes
		X.2.1.4	Lack of monitoring and control of changes occurring in the project scope
X2.2	Project Information Documents	X.2.2.1	Errors in data collection
		X.2.2.2	Inaccurate information presentation
		X.2.2.3	Incompleteness of information presentation
X2.3	BIM Execution Plan Documents	X.2.3.1	Lack of understanding of BIM needs and usage objectives in the project
		X.2.3.2	Lack of stakeholder participation in the BEP creation process
		X.2.3.3	Lack of correlation between BEP and project master plan
		X.2.3.4	Lack of resource allocation to support BEP implementation
		X.2.3.5	Failure to consider changes or revisions to the Break Even Point (BEP) that may occur during the project process
X2.4	WBS Diagram	X.2.4.1	Errors in creating the Work Breakdown Structure (WBS)
		X.2.4.2	Failure to consider or understand the project scope thoroughly
		X.2.4.3	Lack of involvement of the core project team in the creation of WBS
		X.2.4.4	Inconsistency in using WBS levels and structures
		X.2.4.5	Inaccuracy in grouping work package details

Main Factors and Sub-Factors (X2: BIM 5D)		Risks in BIM 5D-QTO Activities	
X2.5	Building Information-based 3D Models	X.2.5.1	Incompatibility of software used
		X.2.5.2	Inability to integrate data from various sources into the 3D model
		X.2.5.3	Lack of understanding regarding the methods or technologies used in creating 3D models
		X.2.5.4	Use of non-integrated BIM-based software
		X.2.5.5	Lack of coordination among project teams in 3D modeling
		X.2.5.6	Lack of skilled labor/workforce available
		X.2.5.7	Lack of attention to detail in the early stages of 3D model creation
X2.6	Standardization of Sizes and Specifications for Each Work Component	X.2.6.1	Inaccuracy when inputting dimensions and specifications from 2D drawings into the 3D model
X2.7	Determination of Prices for materials, labor, and equipment for each work component	X.2.7.1	Lack of building component and price-related data
		X.2.7.2	Disregarding differences in price or cost that may occur in different regions or markets
		X.2.7.3	Disregarding differences in specifications or quality of materials and equipment that may be used in the project
		X.2.7.4	Failure to consider risk factors or additional needs in the cost estimation process
X2.8	Specification of Materials Used	X.2.8.1	Inaccuracy in setting the materials used
X2.9	List of Project Work Schedules	Unidentified activities in the plan	
		Failure to consider risk factors or additional needs in the scheduling process, such as weather or material delivery delays	
		Errors in sequencing work activities	
		Inaccurate estimation methods for the duration of each activity	
X2.10	Integrated 3D Model with Scheduling	X.2.10.1	Inaccuracy in linking scheduling into the 3D model
X2.11	Quantities of each work component	X.2.11.1	Inaccuracy in the data input process
		X.2.11.2	High complexity of the BIM model
		X.2.11.3	Incompatibility between the BIM model and the Bill of Quantities documents
		X.2.11.4	The inability of BIM 5D teams to understand and utilize all features and potentials of the software
X2.12	List of quantity results for each work component	X.2.12.1	Changes or modifications to designs during the construction process, requiring changes to the BIM model and bill of quantity calculation
X2.13	Integrated the 3D model with scheduling and costs	X.2.13.1	Limited capabilities of BIM 5D to process non-geometric aspects of the project, such as schedules and budgets

The RII method is utilized to ascertain the significance level of each delay factor. Data collected from the questionnaires is employed to compute the Relative Importance Index, average value, and standard deviation for each project delay factor. The equation used to calculate the Relative Importance Index is as follows:

$$RII = \frac{\sum_{i=1}^{5} wx}{A \times N}$$

where,

RII = Relative Importance Index
A = 5 (Highest weight)
N = Total number of respondents
w = 1 to 5 (weight given to each factor by each respondent)
x = frequency of answer given for each factor

The weight assigned to each factor by each respondent (1 = Very low significance, 2 = Low significance, 3 = Medium significance, 4 = High significance, 5 = Very high significance) is multiplied by the frequency of answers given to each factor. The total of these values is then calculated. Subsequently, the results are divided by the product of the highest weight (5) and the total number of respondents. The ranking of delay factors is conducted using the RII. The overall rating is calculated by aggregating the responses provided by all respondents. Data analysis in the initial data collection stage involves archival analysis and preliminary validation of variables by experts. Subsequently, the data will undergo processing utilizing the RII technique.

4. RESULTS AND DISCUSSION

4.1. System Performance Benchmarks

To identify the factors influencing the implementation of BIM-Based Quantity Take-Off in high-rise office buildings, researchers utilized the RII statistical analysis method. This approach involved statistical calculations conducted on the questionnaire results, which served as input for determining the significant (influential) factors. The RII method employs a ranking system based on the weighting of values provided by respondents upon questionnaire completion to determine the most significant (influential) factors (see table 5).

Table 5 RII and Ranking of Estimation Process Factors

Sub-Factors			Likert Scale					RII Component			RII Index Value	Rank
			1	2	3	4	5	E.W.	A	N	(EW/(A*N))	
X1.1 Project scope statement	X1.1.1	Describe the scope of the project			1	16	23	182	5	40	0.91	13
	X1.1.2	Describe the results of each product				16	24	184	5	40	0.92	8
	X1.1.3	Describe the acceptance criteria				12	28	188	5	40	0.94	2
	X1.1.4	Project boundary/exclusion (exception)				15	25	185	5	40	0.925	6
X1.2 Images and Specifications	X1.2.1	Review the drawings for the type of construction used				17	23	183	5	40	0.915	9

Sub-Factors			Likert Scale					RII Component			RII Index Value	Rank
			1	2	3	4	5	E.W.	A	N	(EW/(A*N))	
	X1.2.2	Review the work methods used				19	21	181	5	40	0.905	15
	X1.2.3	Evaluate specifications				11	29	189	5	40	0.945	1
X1.3 WBS	X1.3.1	Identify and analyze results and related work				18	22	182	5	40	0.91	14
	X1.3.2	Structure and organize the WBS				17	23	183	5	40	0.915	10
	X1.3.3	Decompose high-level WBS into more detailed low-level components				13	27	187	5	40	0.935	3
	X1.3.4	Compile and assign identification codes for WBS components				17	23	183	5	40	0.915	11
	X1.3.5	Verify the degree of decomposition				17	23	183	5	40	0.915	12
X1.4 Resource	X3.4.1	Identify the resource type			2	16	22	180	5	40	0.9	18
	X3.4.2	Determine resource requirements			1	12	27	186	5	40	0.93	4
X1.5 Unit price	X1.5.1	Determine the price of labor wages			1	13	26	185	5	40	0.925	7
	X1.5.2	Determine the price of materials			1	17	22	181	5	40	0.905	16
	X1.5.3	Determine the price of the equipment.			1	12	27	186	5	40	0.93	5
X1.6 Cost estimation	X1.6.1	Prepare cost estimates for procuring resources				19	21	181	5	40	0.905	17
X1.7 Offer	X1.7.1	Prepare offer documents			2	19	19	177	5	40	0.885	19

Among the seven main factors and nineteen sub-factors, an analysis was conducted to rank and identify the top five factors influencing the risk estimation process activities, as shown in Table 4. The most dominant factors in the risk of the green retrofitting cost estimation process for high-rise office buildings are as follows: Evaluating specifications (1), describing the acceptance criteria (2), decomposing high-level WBS into more detailed low-level components (3), determining resource requirements (4), determining the price of the equipment (5).

Table 6 RII and Ranking of BIM 5 QTO Factors

Main Factors (X2: BIM 5D)	Sub-Factors		Linkert Scale					RII Compenent			RII Index Value	Rank
			1	2	3	4	5	E.W.	A	N	(EW/(A*N))	
X2.1 Collecting and Inputting Building Information into a 3D Model	X2.1.1	Identify the project scope			1	16	23	182	5	40	0.91	13
	X2.1.2	Compile project information			1	15	24	183	5	40	0.915	9
	X2.1.3	Establish a BIM Execution Plan			1	14	25	184	5	40	0.92	7
	X2.1.4	Structure and organize the WBS			1	12	27	186	5	40	0.93	3
	X2.1.5	Create a 3D model			2	14	24	182	5	40	0.91	10
X2.2 Inputting Building Component Information and Prices for Cost Estimation	X2.2.1	Input the sizes and specifications of each work component into the 3D model			1	16	23	182	5	40	0.91	11
	X2.2.2	Input the price of materials, labor, and equipment for each component of the work				8	32	192	5	40	0.96	1
	X2.2.3	Present the materials that will be used			2	15	23	181	5	40	0.905	12
X2.3 Inputting Information for Time Scheduling	X2.3.1	Arrange overall project scheduling			1	14	25	184	5	40	0.92	8
	X2.3.2	Integrate scheduling into the 3D model				14	26	186	5	40	0.93	4
X2.4 Visualizing Cost Estimation with Time Scheduling	X2.4.1	Quantity Take-Off			1	11	28	187	5	40	0.935	2
	X2.4.2	Generate a Bill of Quantities				15	25	185	5	40	0.925	5
	X2.4.3	Integrate costs of 3D model elements to defined time schedules			4	11	25	181	5	40	0.905	13
					2	11	27	185	5	40	0.925	6

Among the four main factors and thirteen sub-factors, an analysis was conducted to rank and identify the top five factors influencing the risk of BIM 5D QTO activities, as shown in Table 6. The most dominant factors in the risk of implementing BIM 5D QTO in green retrofitting high-rise office buildings are as follows: Inputting the sizes and specifications of each work component into the 3D model (1), integrating scheduling into the 3D model (2), establishing a BIM execution plan (3), arranging overall project scheduling (4), processing quantity take-off (5).

This research is novel in its focus on the cost estimation process and BIM 5D in the green retrofitting of high-rise buildings, as previous studies have primarily focused on green and new buildings.

5. CONCLUSION

The influence of risk on estimating green retrofitting work and implementing BIM 5D-based Quantity Take-Off activities in high-rise office buildings has been analyzed. Statistical analysis results using the RII method revealed five highly significant factors (influential) in these two activities. Identifying these five highly influential factors will help mitigate the risks in the cost estimation process and BIM 5D implementation.

With the significant influence of these dominant factors, future retrofitting activities can be better mitigated and aligned with desired goals, benefiting stakeholders and promoting sustainability. Addressing risk factors that hinder the attainment of the desired level of cost accuracy when utilizing BIM 5D in the cost estimation process is crucial. One major contributing factor is the high complexity of the BIM model. This risk can be mitigated by providing knowledge, training, and certification to BIM users, particularly estimators and engineers, to optimize the utilization of BIM 5D for the cost estimation process.

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