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Article

Increasing the cost accuracy of implementing green retrofitting in high-rise office buildings

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Abstract: Implementing green retrofitting can save 50–90% of energy use in buildings built worldwide. Government policies in several developed countries have begun to increase the implementation of green retrofitting buildings in those countries, which must rise by up to 2.5% of the lifespan of buildings by 2030. By 2050, it is hoped that more than 85% of all buildings will have been retrofitted. The high costs of implementing green retrofitting amounting to 20% of the total initial construction costs, as well as the uncertainty of costs due to cost overruns are one of the main problems in achieving the implementation target in 2050. Therefore, increasing the accuracy of the costs of implementing green retrofitting is the best solution to overcome this. This research is limited to analyzing the factors that influence increasing the accuracy of green retrofitting costs based on WBS, BIM, and Information Systems. The results show that there are 10 factors affecting the cost accuracy of retrofitting or customizing high-rise office buildings, namely Energy Use Efficiency, Water Use Efficiency, Use of Environmentally Friendly Materials, Maintenance of Green Building Performance during the Use Period, Initial Survey, Project Information Documents, Cost Estimation Process, Resources, Legal, and Quantity Extraction applied. These factors are shown to increase the accuracy of green retrofitting costs.

Keywords: green retrofitting; high rise office buildings; cost accuracy; critical success factors; SEM-PLS

1. Introduction

Climate change is a threat and crisis that is engulfing the world today, therefore the target towards Net Zero Emission (NZE) by 2060 should be an obligation of all countries (Husin et al., 2023). The process of implementing the green retrofitting concept requires a cost of 10.77% of the total new construction costs (Xie and Gou, 2017). The GB concept has several advantages related to the economy, society, and environment that make buildings have the concept of sustainable resource conservation (energy, water, land, and nature), resource efficiency (groundwater energy and materials), and public facilities on transportation and employment (Husin and Priyawan, 2023). In the absence of incentives, streamlining the costs of implementing green retrofitting is an attraction for owners.

Implementing green retrofitting can of course experience problems with occupant comfort, expensive investment costs, and difficulties in licensing. If the target retrofit rate of at least 2.5% per year in 2030 is not achieved, it will fail in all buildings to retrofit in 2050. Besides, the setback in implementing retrofit based on the NZE target can increase demand for space heating by 25% and demand for space cooling by more than 20% resulting in an increase in electricity by 20% by 2050 (Birol, 2021). **Figure 1** shows the NZE Scenario, despite the projected growth in service demand, direct CO emissions from the buildings sector decline by 45% by 2030 and more than 98% by 2050 (Birol, 2022).

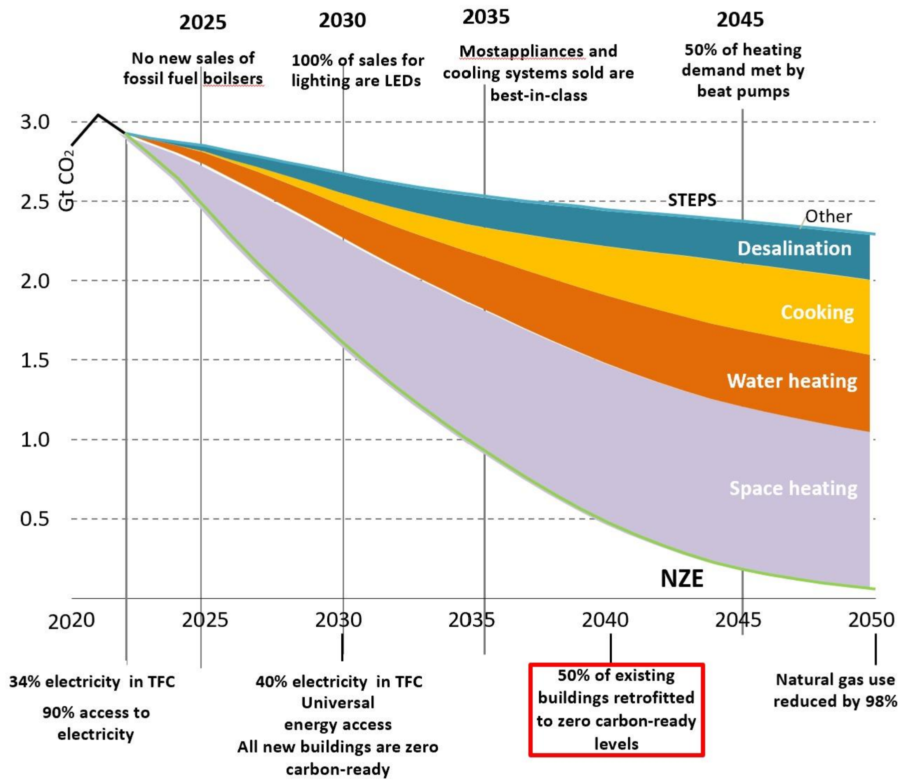


Figure 1. Emissions reductions and key milestones in the buildings sector in the NZE Scenario relative to the STEPS, 2020–2050 (Birol, 2022).

Ease of implementing green retrofitting or customization can be achieved through the development of a Work Breakdown Structure (WBS) where the development of WBS is a general work framework—work implementation, which is useful for completing work, basic planning, and clarifying reporting and accountability procedures (Handayaniputri et al., 2019).

This study aimed to analyze the affecting factors of increasing the cost accuracy of green retrofitting high-rise office buildings based on WBS, Risks, BIM-5D, Information Systems, and Cost Estimation with a structural correlation model using Structural Equation Modeling–Partial Least Square (SEM-PLS) 4.

1.1. Green retrofitting in high-rise office buildings

Buildings that have been built need to obtain green building certification through green retrofitting or customization. Retrofitting is an effort to adjust the performance of buildings that have been utilized to meet the requirements for Green Buildings (BGH) (The Ministry of PUPR-RI, 2021). The number of buildings continues to increase so the implementation of retrofitting is starting to be reviewed to move towards sustainable development (Castro et al., 2019). The application of GB principles following the function and classification in every stage of its Implementation is expected to reduce greenhouse gas emissions (Husin et al., 2023). Carrying out retrofitting of buildings on a large scale is being considered by governments throughout the world (Pasichnyi et al., 2019).

1.2. Work breakdown structure (WBS)

Successful project management depends on careful planning, which starts with defining project objectives with sufficiently detailed information through creating a WBS. According to the statement in the Project Management Body of Knowledge (PMBOK) 6th edition, project management, including project scope management, is a process needed to ensure the project covers all the work required to meet the project objectives (Project Management Institute, 2017). Project scope management is primarily concerned with defining and controlling what is and is not included in the project work. According to the PMBOK 6th edition, a WBS is a hierarchy of project scope that must be considered by project team members to achieve project objectives and project deliverable requirements. The PMBOK also explains that the development of a WBS is a process that breaks down project deliverables and project work into the smallest parts with more manageable components.

A Work Breakdown Structure (WBS) can provide a basis for defining project-related activities. Besides, A WBS can be used as a framework for managing work until completion (Marchewka, 2015). In preparing a WBS, the principles used are the same as preparing a job decomposition into more detailed jobs expressed in the form of a tree diagram or hierarchy that is tiered according to job levels. The decomposition is carried out by numbering each job according to its level (Leni et al., 2017). A WBS is used to break down each work process into more detail. This is intended so that the project planning process has a better level. A WBS is very important in project planning. With WBS, the project team members will write down the project stages in detail.

1.3. Risks analysis

The risk is a combination of the likelihood of an event and its consequences. In other words, risk can be defined as a quantifiable uncertainty that can cause harm or loss (IRM, 2002). Uncertainty about future conditions that affect investment is the risk of not meeting expectations and insufficient economic return or even the occurrence of economic losses—risk levels are a function of the relative uncertainty of the important variables of the project (Hudoyo et al., 2019). A risk has a cause and if it occurs, it will have an impact on the cost, schedule, and quality of the project (Fan et al., 2022).

The weight of project risks depends on the stages throughout the project cycle, where the potential for risks to occur at the project planning and project conceptual stages is very high—but is low (decreases) at the implementation and termination stages. In the process of identifying risks according to their sources and impacts, risks can be divided into controllable and uncontrollable risks. Controllable risks are risks that are taken as a decision and the results are partly controllable. In its implementation, there are risks originating from work activities, this can be in the form of work sequences that have not been planned in the WBS and are not risk-based, as well as errors in carrying out these work activities.

1.4. Building information modeling (BIM) 5D

Several determinants of a control system, including a clearly defined change processing method, clear instructions regarding the scope of change, timely performance of work changing, and prompt payment for work undergoing change can be achieved by implementing BIM-5D which is a 3D model with Quantity Take Off (QTO) data associated with it (Husin et al., 2020). The application of BIM-5D technology can reduce the time for Quantity Take-off calculations and the estimation process from weeks to minutes, increase accuracy, minimize the incidence of disputes due to data ambiguity from CAD, and provide ample time for cost consultants to carry out value improvements.

The BIM dimension that is expected to be a solution for developing a change control system is BIM-5D. The BIM-5D dimension consists of real-time concept modeling and cost planning, quantity extraction, trade verification from manufacturing models, value engineering, and pre-fabrication solutions (Husin et al., 2020).

1.5. Estimation process

Cost estimates are predictions and are subject to uncertainty. Therefore, it is important to update and monitor cost estimates during project implementation, and also adopt a flexible approach in dealing with changes and risks that may occur (Persons, 2020).

The cost estimation process is the steps taken to estimate the amount of costs required to carry out a project, product, or service. (Persons, 2020). A good cost estimation process will produce accurate cost estimates. The estimation process that needs to be carried out, includes reviewing the project scope; carrying out Quantity Take Off; obtaining supplier offers, material prices, worker prices, worker wages, equipment prices, and contractor offers; calculating tax, bonds, insurance & overhead costs, contingency & mark up, and profit (Persons, 2020).

1.6. Information systems

An information system is a set of interconnected components that collect, process, store, and distribute information to support decision-making and control within an organization. Information systems contain important information related to parties, places, and things within the organization or the surrounding environment (Laudon and Laudon, 2014). Information systems are a combination of software, hardware, telecommunications networks, and brain-ware that are developed to collect, create, and distribute data and information that are useful in an organizational context (Jessup and Valacich, 2003). The information system used is a web-based information system.

WBS-based Information Systems can improve building maintenance and upkeep performance through the integration of work scope management and maintenance schedules (Watchson and Latief, 2019). The role of information systems in the maintenance performance of high-rise buildings is very important for cross-checking or re-checking information and the real conditions of high-rise building maintenance and maintenance performance with all its indicators (Wardahni, 2019).

1.7. Web

The Web, or World Wide Web (W3), is essentially an Internet server system that supports specially formatted documents. The documents are formatted in a markup language called HTML (Hyper Text Markup Language) that supports links to other documents, as well as graphic, audio, and video files.

Applications that appear on intranets and extranets using web technology can be called web-based information systems (Wardahni, 2019). Several synonyms refer to web-based information systems such as web applications, web-based applications, web-based systems, web internet applications, and rich internet applications (Rossi et al., 2008). However, there are differences between web-based information systems and standard web applications or pages. The difference lies in the nature and type of information created for users. Standard web applications are uni-directional in terms of providing information to users. For example, a user requests a catalog or directory-based site by following a hypertext link. Meanwhile, web-based information systems can be interpreted as applications that not only disseminate information but also proactively interact with users to help them with their work (Takahashi and Liang, 1997). Therefore, the information presented to users is bi-directional.

A good website must provide convenience for its users so it can provide user satisfaction. WEB design: must be attractive, suit the purpose of the web, have clear content (content is not confusing), have clear navigation, and have simple procedures (Rossi et al., 2008). Content: it is hoped that it will be able to bring the reader to enjoy the writing that has been written. For this reason, forum facilities, surveys, or other interesting things can be provided. Online Promotion: the key for a website to be widely known and visited by internet users (Rossi et al., 2008).

1.8. Cost accuracy

Cost accuracy in the cost estimation process refers to the extent to which the estimated or projected costs correspond to the actual costs that will be incurred during project implementation. The level of cost accuracy is generally expressed in certain percentages or categories—the more detailed information on a project is obtained during the estimation, the more accurate the cost estimation results will be. In the conceptual stage estimation process, cost accuracy is assumed to be +/− 30% (Ballard and Pennanen, 2013).

There are 5 factors affecting the accuracy of cost estimates, namely, Quality of scope, Quality of information, Level of uncertainty, Estimator performance, and Estimation procedures (Serpell, 2005). Factors that can increase cost accuracy are obtained from literature studies, FGDs, and expert validation.

2. Research methodology

The researchers analyzed and determined the sample size required to fill the SEM-PLS model using SEM PLS version 4.0 software. The researchers prepared a research flowchart at each stage to obtain statistical analysis and case study research stages.

Data collection was carried out using a questionnaire filled in by experts in their respective fields such as green building experts, risk management experts, project managers, contractors who use BIM and the web, and academics. Questionnaires were distributed and 118 respondents were successful in responding. Data were analyzed and measured using a Likert scale, ranging from a score of 1 strongly disagree to a score of 6 strongly agree.

Figure 2 explains the flowchart process to obtain statistical results with SEM-PLS by output obtaining key success factors that are involved in the application of green retrofitting in High Rise Office Building.

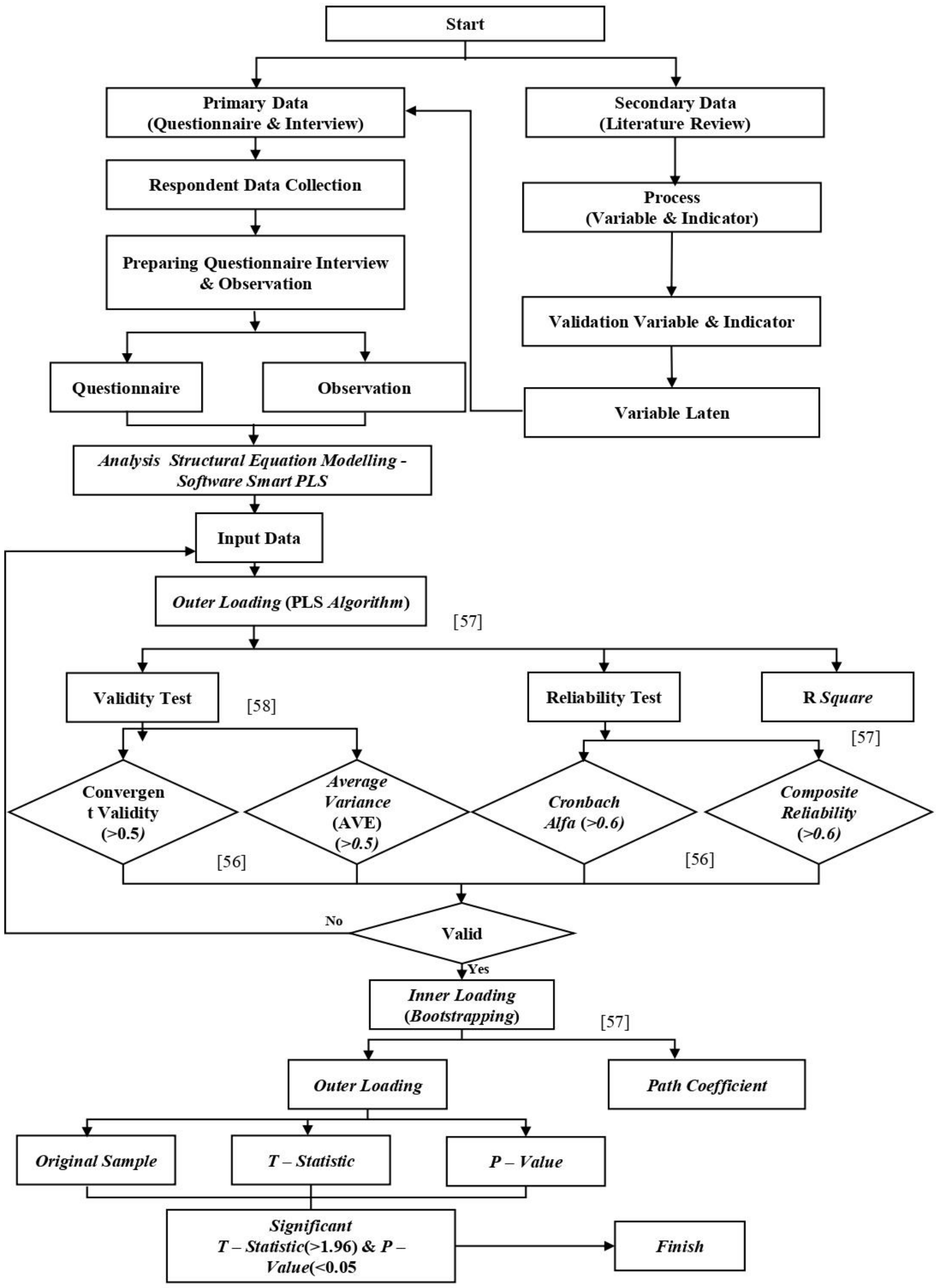


Figure 2. Data processing diagram with SEM-PLS. (Husin et al., 2023).

2.1. Conceptual model

The conceptual framework for the representation of this study is the Relationship

Model between Variables in the Relationship of Green Retrofitting, WBS, Risk (Wardahni, 2019), Cost Estimation, and BIM-5D of High-rise Office Buildings and the Level of Cost Accuracy, based on the following chart in **Figure 3**.

Indicator variables are a categorical analysis in which factor variables must be converted into a set of indicator variables. Once the WBS standard is achieved, the next step is to identify risks affecting the level of cost accuracy of green retrofitting high-rise office buildings based on BIM-5D. Research variables are shown in **Figure 3**. The Conceptual Model uses WBS, Risk, Cost Estimation, BIM-5D, and the Information System to increase cost accuracy.

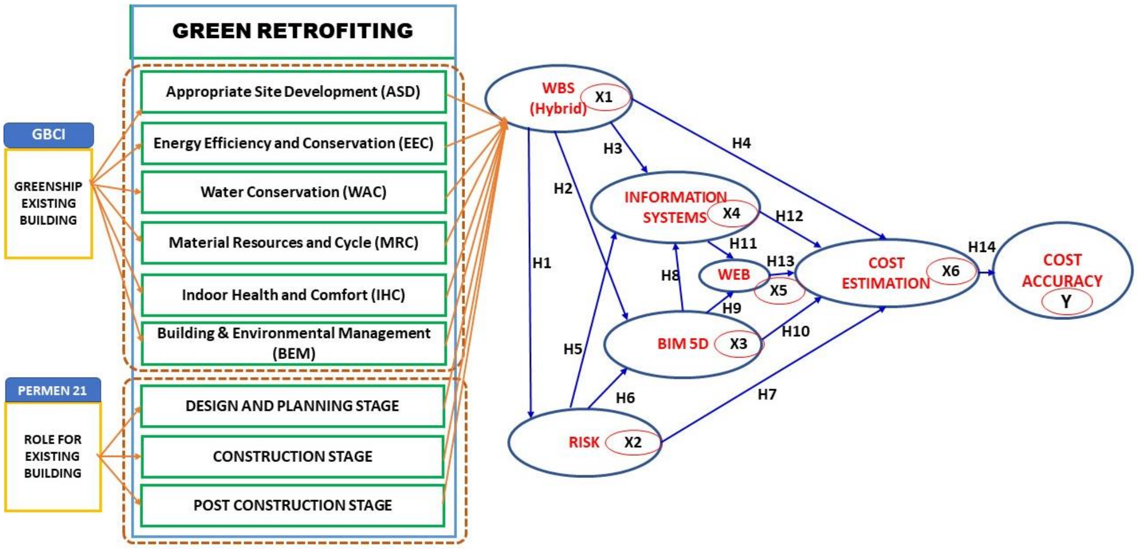


Figure 3. Conceptual models.

Source: Processed by the Authors.

2.2. Relationships between variables and research hypotheses

This study is quantitative to show the relationship between variables.

Based on the explanation of quantitative research methods, the causal relationship phenomenon which shows the existence of independent and dependent variables can be explained that the independent variables consisted of WBS Integration (X1), Risks (X2), BIM-5D QTO (X3), Information Systems (X4), Web (X5), Cost Estimation (X6), while the dependent variable consisted of Cost Accuracy (Y).

The hypothesis formed from the Inter-Variable Relationships conceptual model is and can be seen as the relationship between the variables as shown in **Figure 3**. Through the analysis of t-statistic values (significance values) in SEM-PLS, the hypothesis will be proven as follows: H1: The Effect of WBS Integration on Risk Levels, H2: The Effect of WBS Integration on BIM-5D QTO, H3: The Effect of WBS Integration on Information Systems, H4: The Effect of WBS Integration on Cost Estimation, H5: The Effect of Risk Levels on Information Systems, H6: The Effect of Risk Levels on 5D BIM QTO, H7: The Effect of Risk Levels on Cost Estimation, H8: The Effect of BIM-5D QTO on Information Systems, H9: The Effect of BIM-5D QTO on Web, H10: The Effect of BIM-5D QTO on Cost Estimation, H11: The Effect of Information Systems on WEB, H12: The Effect of Information System on Cost

Estimation, H13: The Effect of WEB on Cost Estimation, H14: The Effect of Cost Estimation on Cost Accuracy.

3. Results and discussion

SEM-PLS is an excellent research tool for advancing and developing theory. There are three simultaneous activities in SEM, namely confirming the validity and reliability, testing the correlation model between variables (path analysis), and obtaining an appropriate prediction model. Second-order confirmatory factor analysis is a type of two-level SEM measurement model that describes how first-level latent variables act as indicators of second-level latent variables (Hair et al., 2021).

A total of 120 research questionnaires were disseminated, meeting the minimum requirement of 110 respondents for statistical analysis Respondent data includes information collected from these participants shown in **Figure 4**.

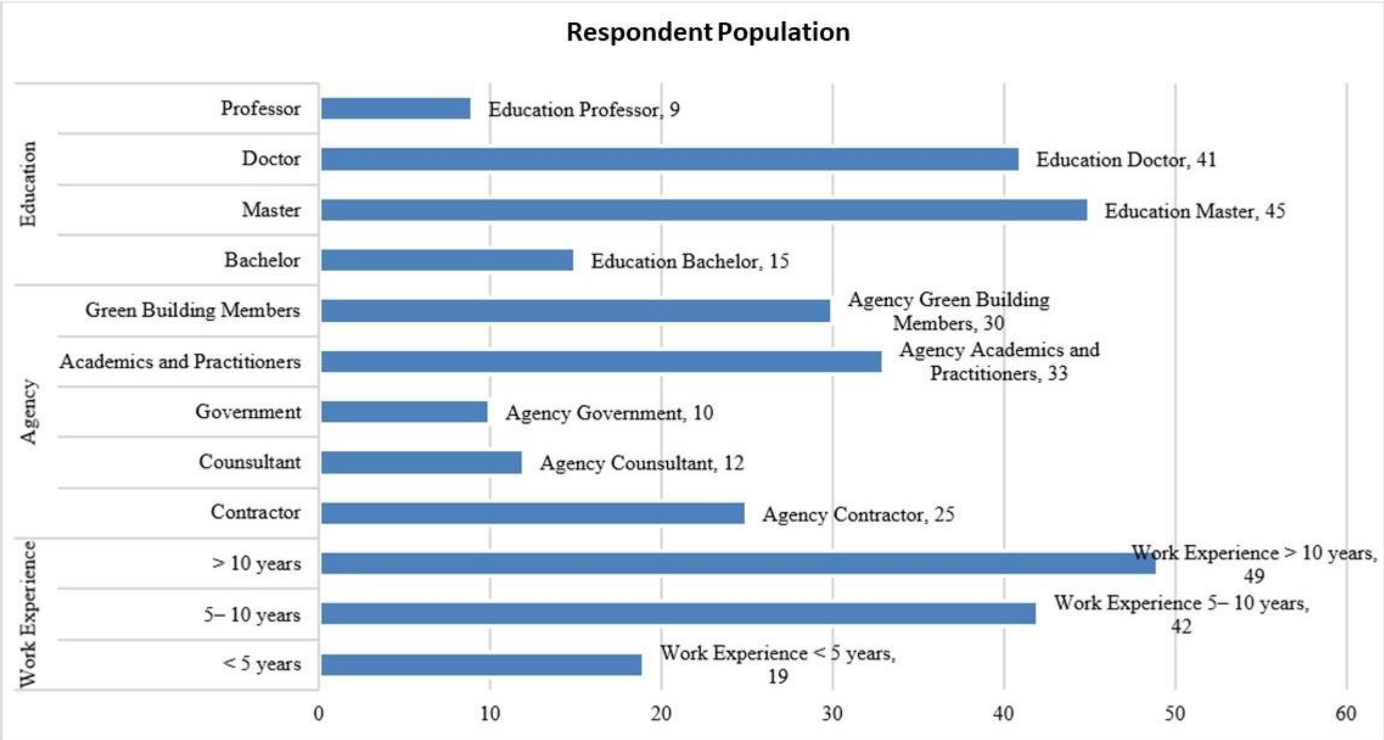


Figure 4. Respondent data.

Population data was determined based on journal literacy and expert validity to make sure that the population used was appropriate. Data were examined and grouped (categorized) based on education, position, and experience. **Table 1** explains the minimum sample size requirements that must be taken based on references by the Minimum Sample Size for the Difference Level between the Minimum Path Coefficient and 80 Power Test (Hair et al., 2021).

Table 1. The lowest sample size for the difference level between the minimum path coefficient and 80 power test (Hair et al., 2021).

$\wp$ min	**Significance level**		
	1%	5%	10%
0.05–0.1	1004	619	451
0.11–0.2	251	155	113
0.21–0.3	112	69	51
0.31–0.4	63	39	29
0.41–0.5	41	25	19

In SEM-PLS, there are three simultaneous activities, namely confirming the validity and reliability of the instrument (confirmatory factor analysis), testing the correlation model between variables (path analysis), and obtaining an appropriate prediction model (structural model and regression analysis). **Table 2** shows a list of key success factors from literature studies and expert validation. Data analysis was applied to high-rise office buildings to identify and analyze factors affecting the cost accuracy of green retrofitting based on WBS development factors, risk levels, BIM-5D, information systems, web, and cost estimation process along with sub-factors of the variables tested using SEM-PLS as shown in the following **Table 2**.

Table 2. Key success factors.

Variable	**Variable**
X.1.WBS INTEGRATION (The Ministry of PUPR-RI 2021; The Ministry of PUPR-RI, 2022; Green Building Council Indonesia, 2016) X.1.1. Planning Stage X.1.1.1 Building Orientation Performance Assessment X.1.1.2 Energy use efficiency planning X.1.1.3 Water use efficiency planning X.1.1.4 Indoor Air Quality Planning X.1.1.5 Planning for the use of environmentally friendly materials X.1.1.6 Waste management planning X.1.1.7 Wastewater management planning X.1.2. Implementation Stage X.1.2.1 Presenting the BGH work quality plan in the construction work quality plan (RMPK) X.1.2.2 Site management X.1.2.3 Energy use efficiency X.1.2.4 Water use efficiency X.1.2.5 Indoor air quality X.1.2.6 Use of environmentally friendly materials X.1.2.7 Waste management X.1.2.8 Green Construction Process documents X.1.3. Post-Implementation Stage X.1.3.1 Performance of Environmentally Friendly Building Policy SOPs X.1.3.2 Maintenance of BGH Performance during the Use Period X.1.3.3 Disassembly Procedure X.1.3.4 Environmental Site Restoration Efforts X.2. RISKS (Brokbals et al., 2019) X.2.1. Risks in Cost Estimation	X.5. WEB (Martoyo and Suprapto, 2010) X.5.1. Content X.5.1.1 Attractive web graphic display X.5.1.2 Containing the information required by users X.5.1.3 Containing files or documents required by users X.5.1.4 The information displayed is accurate and up-to-date X.5.2. Format X.5.2.1 There is space to provide information regarding the implementation of retrofitting X.5.2.2 There is space to access documents related to retrofitting X.5.2.3 There is space to upload report documents in the implementation of retrofitting X.5.2.4 There is space to exchange messages between system users X.5.3. Accuracy and speed X.5.3.1 The information presented on the web is suitable for the implementation of retrofitting X.5.3.2 Attachment of documents that can be downloaded according to the implementation of retrofitting X.5.3.3 The retrofitting documents stored in the system correspond to the uploaded documents X.5.3.4 The information presented is up-to-date X.5.3.5 There is a time limit for updating the required data X.5.3.6 Fast login and logout process X.5.3.7 Response when selecting menus on the website is fast X.5.3.8 The process of downloading and uploading documents from the web is fast X.5.4. Ease of Use X.5.4.1 The web system is easy to access X.5.4.2 The web layout is easy to understand and use X.5.4.3 The login and logout process from the web system is easy X.5.4.4 Easy to upload and download documents

Table 2. (*Continued*).

Variable	Variable
X.2.1.1 Initial survey	X.5.4.5 Easy to see and get the information needed
X.2.1.2 Design change	X.5.4.6 Ease of checking work status/progress
X.2.1.3 Resources	X.5.4.7 There is a guide to using or operating the web, which is easy to access
X.2.1.4 Subcontractor	X.5.4.8 Supported by navigation, as a guide for users while on the web
X.2.1.5 Cost of work change	X.5.5. Security and Privacy
X.2.1.6 Legal	X.5.5.1 Using a username and password to access the web
X.2.2. Risks in BIM	X.5.5.2 There is a login and logout process as a form of securing user access
(Zou et al., 2007; El-Sayegh, 2008; Project Management Institute, 2017; Wallace and Keil, 2004; Mitchell and Pulvino, 2001; Arshad et al., 2019; Thurairajah and Goucher, 2013; Olatunji, 2011).	X.5.5.3 Maintaining user privacy and confidentiality from irresponsible individuals
X.2.2.1 Project scope statement	X.5.5.4 The system has a strategy to handle issues related to copyright
X.2.2.2 Project information documents	X.6. COST ESTIMATION
X.2.2.3 Bim execution plan documents	(Project Management Institute 2017)
X.2.2.4 Information-based 3d model	X.6.1. Resource Planning
X.2.2.5 Standardization of the size and specifications of each work component	X.6.1.1 The structural work is broken down into several parts
X.2.2.6 Determination of prices for materials, materials, labor, and equipment for each work component	X.6.1.2 Resource requirements
X.2.2.7 List of project work schedules	X.6.1.3 Resource levels
X.2.2.8 List of quantity results for each work component	X.6.1.4 Estimated duration of activity
X.2.2.9 Integrated 3D model with costs and scheduling	X.6.1.5 Estimated publication
X.3.BIM-5D	X.6.1.6 Information History
(Halpin and Woodhead 1998)	X.6.1.7 Chart of accounts
X.3.1. Real-Time Modeling	X.6.1.8 Risks
X.3.1.1 Showing actual concept modeling	X.6.2. Cost Estimation Techniques and Process
X.3.1.2 Showing accurate cost estimates from The 3D model	X.6.2.1 Manual estimation
X.3.1.3 Reducing the risks of miscommunication	X.6.2.2 Parametric modeling
X.3.1.4 Preparing Bill Of Quantity in No Time	X.6.2.3 Bottom-up estimation
X.3.1.5 Accurately presenting the materials to be used	X.6.2.4 Computerization tools
X.3.1.6 Facilitating material selection and implementation processes	X.6.2.5 Scope statement
X.3.2. Quantity Extraction	X.6.2.6 Pictures (images) and specifications
X.3.2.1 Carrying out quantity calculations accurately	X.6.2.7 Work Description Structure (WBS)
X.3.2.2 Carrying out claim progress in a short time	X.6.2.8 Resources
X.3.2.3 Carrying out decision-making quickly	X.6.2.9 Unit price
X.3.2.4 Processing quantity take-off	X.6.3. Cost Estimate Classification
X.3.2.5 Estimating costs	X.6.3.1 Estimated class
X.3.2.6 Facilitating unique structural, architectural, and MEP components	X.6.3.2 Project definition results from maturity level
X.3.2.7 Simplifying Value Engineering Analysis	X.6.3.3 End-use
X.3.2.8 Developing visualization and extracting quantities in the value engineering process	X.6.3.4 Methodology
X.3.3. Visualization of Cost and Time Estimation	X.6.3.5 Expected accuracy range
X.3.3.1 Inputting the size and specifications of each work component into a 3D model	X.6.4. Results of Cost Estimation
X.3.3.2 Inputting prices for materials, labor, and equipment for each work component	X.6.4.1 Cost Estimation
X.3.3.3 Presenting the materials that will be used	X.6.4.2 Detailed support
X.3.3.4 Arranging overall project scheduling	X.6.4.3 Cost management plan
X.3.3.5 Linking scheduling into a 3D model	Y COST ACCURACY
X.3.3.6 Linking costs of 3D model elements to defined time schedules	(Serpell, 2005)
X.4. INFORMATION SYSTEMS	Y.1. Environmental Quality
(Lestari and Waryanto, 2012; Martoyo and Suprapto, 2010)	Y.1.1 Experience with the design/estimator team
X.4.1. Content	Y.1.2 Consistency (owner commitment) and scope stability with project requirements
X.4.1.1 Application method	Y.1.3 Project technology
X.4.1.2 Program testing	Y.1.4 Project complexity
X.4.1.3 Media product information	Y.2. Information Quality
X.4.2. Format	Y.2.1 Ease of application and reliability of information history
X.4.2.1 System design	Y.2.2 Availability and reality of the latest information
X.4.2.2 The way to organize information	Y.3 Level of Uncertainty
X.4.2.3 The way data are stored	Y.3.1 Changes in Market Conditions
	Y.3.2 Major Changes in Escalation Rates—and
	Y.3.3 Changes in Labor Productivity, Project Complexity, and Project Technology
	Y.4. Estimator Performance
	Y.4.1 Experience of the estimator in the field and in estimating
	Y.4.2 Efforts applied by the estimator
	Y.4.3 Perceived importance of estimates
	Y.4.4 Self-confidence and healthy thinking

Table 2. (*Continued*).

Variable	Variable
X.4.3. Usability X.4.3.1 Ease to learn X.4.3.2 Minimize errors X.4.3.3 Practice testing of applications X.4.4. Utility X.4.4.1 System automation X.4.4.2 Productivity use of technology X.4.4.3 Information exchange systems (email) X.4.5. Security and Privacy X.4.5.1 Data access systems X.4.5.2 Data protection X.4.5.3 Regulation and Technology	Y.5. Quality of Estimation Procedures Y.5.1 Technology used Y.5.2 Time availability

3.1. Measurement Model Evaluation (Outer Loading—PLS algorithm)

The initial stage of SEM-PLS analysis was to create a structural model. The structural model is shown in the following **Figure 5**.

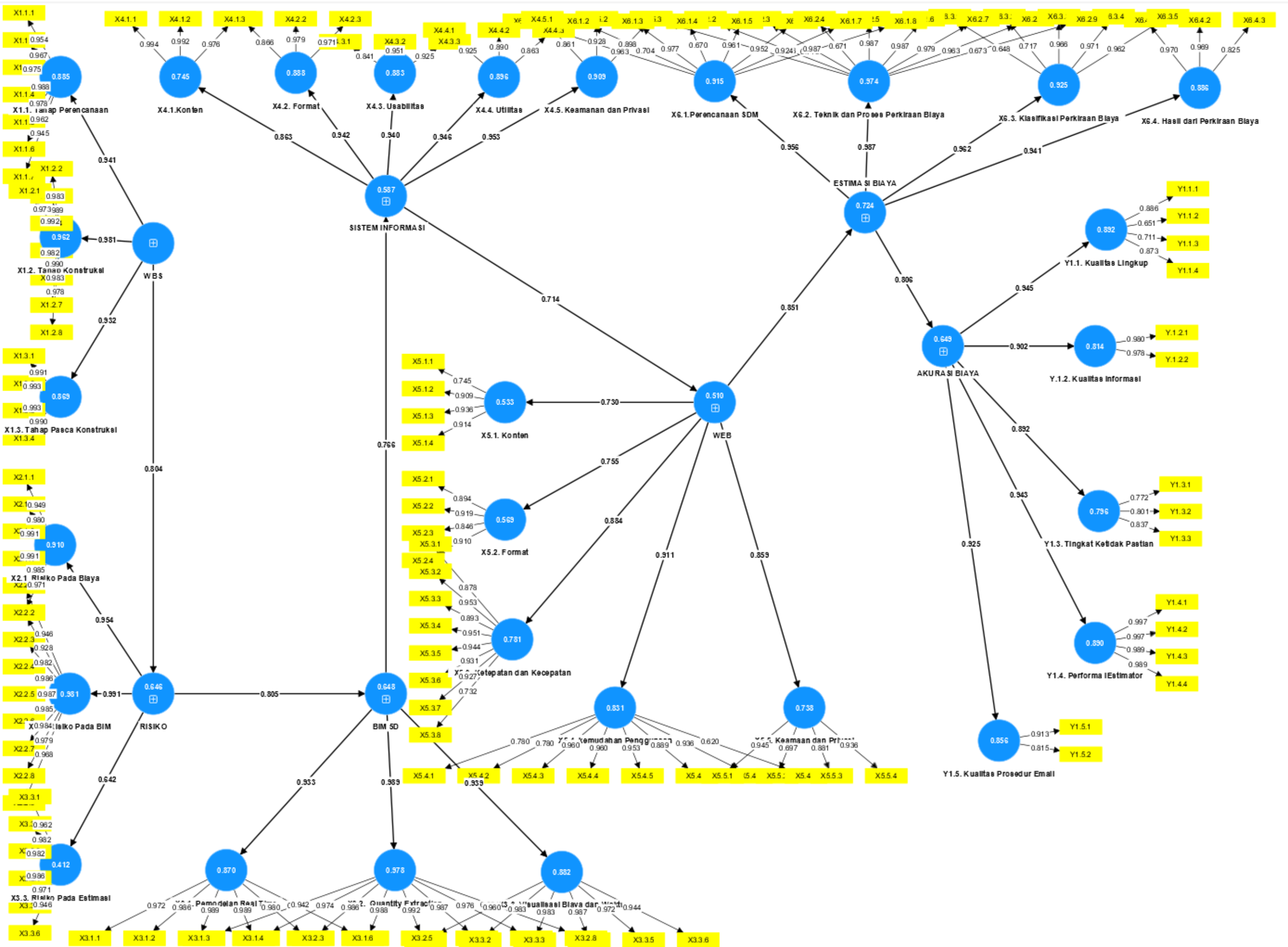


Figure 5. Structural model and correlation path model between latent variables.

To ensure that the data population is accurately targeted, determining the population is not solely based on population size but also involves validation from experts. This was done to ensure that the targeted population was aligned with the research objectives. After data collection, the collected data was examined and categorized based on variables such as education, job position, and project experience. This was crucial to appropriately direct the questionnaires to the relevant respondents, thereby obtaining valid data.

SEM-PLS to analyze Convergent Validity which assesses how well a measure correlates with other measures of the same construct. Composite Reliability and Cronbach's Alpha are the tools used for this assessment. Composite reliability values that fall within the range of 0.6–0.7 are indicative of good reliability. Cronbach's alpha values were used to measure the internal consistency and reliability of the scales. For all variables, reliability values exceeding 0.6 were determined for the overall scale used.

In this research project, the questionnaire data collected by the researchers will undergo processing and analysis using "structural equation modeling" (SEM). The p-values of the loading factors and path coefficients, along with the diagram corresponding to **Figure 4**, can show the relationship between *p*-values and path coefficients.

The validity test is considered valid if the Average Variance Extracted (AVE) value exceeds 0.5. An AVE value above 0.5 indicates that the latent variable construct accounts for more than half of the variance in the indicator. In terms of reliability, variables are considered reliable if Cronbach's Alpha exceeds 0.7 and Composite Reliability is greater than 0.7, which is a widely accepted standard for research instrument reliability. All indicators with outer loading values greater than 0.5, as per the outer loading validity criteria, confirm that all indicators have convergent validity, as illustrated in **Table 3** below.

Table 3. AVE test and composite reliability results.

Variable	**Cronbach's alpha**	**Composite reliability (rho_a)**	**Composite reliability (rho_c)**	**Average variance extracted (AVE)**
	(> 0.7)	**(> 0.7)**	**(> 0.7)**	**(> 0.5)**
X1 (WBS INTEGRATION)	0.992	0.993	0.993	0.876
X1.1 (Planning Stage)	0.988	0.989	0.990	0.935
X1.2 (Implementation Stage)	0.995	0.995	0.996	0.968
X1.3 (Post-implementation Stage)	0.995	0.995	0.996	0.984
X2 (RISKS)	0.993	0.994	0.994	0.900
X2.1 (Risk in Cost)	0.991	0.991	0.992	0.956
X2.2 (Risks in BIM)	0.993	0.993	0.994	0.945
X2.3 (Risk in WBS)	0.988	0.988	0.992	0.977
X3 (5D BIM QTO)	0.992	0.992	0.993	0.872
X3.1 (Real Time Modeling)	0.991	0.991	0.992	0.956
X3.2 (Quantity Extraction)	0.993	0.993	0.994	0.952
X3.3 (Visualization of Cost and Time Estimation)	0.988	0.988	0.990	0.944
X4 (INFORMATION SYSTEMS)	0.974	0.975	0.976	0.735
X4.1 (Content)	0.987	0.987	0.991	0.974
X4.2 (Format)	0.934	0.953	0.958	0.884
X4.3 (Usability)	0.891	0.893	0.933	0.823

Table 3. (*Continued*).

Variable	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
	(> 0.7)	**(> 0.7)**	**(> 0.7)**	**(> 0.5)**
X4.4 (Utility)	0.873	0.881	0.922	0.798
X4.5 (Security and Privacy)	0.877	0.877	0.924	0.803
X5 (WEB)	0.970	0.971	0.972	0.560
X5.1 (Content)	0.899	0.899	0.931	0.773
X5.2 (Format)	0.915	0.915	0.940	0.797
X5.3 (Accuracy and Speed)	0.967	0.968	0.973	0.817
X5.4 (Ease of Use)	0.950	0.954	0.960	0.752
X5.5 (Security and Privacy)	0.888	0.886	0.925	0.758
X6 (COST ESTIMATION)	0.985	0.988	0.986	0.747
X6.1 (Resource Planning)	0.949	0.963	0.960	0.753
X6.2 (Cost Estimation Techniques and Process)	0.975	0.985	0.980	0.849
X6.3 (Cost Estimate Classification)	0.907	0.934	0.935	0.747
X6.4 (Result of Cost Estimation)	0.912	0.923	0.946	0.854
Y1 (COST ACCURACY)	0.962	0.972	0.967	0.667
Y1.1 (Environmental Quality)	0.799	0.843	0.865	0.620
Y1.2 (Information Quality)	0.956	0.957	0.978	0.958
Y1.3 (Level of Uncertainty)	0.735	0.742	0.846	0.647
Y1.4 (Estimator Performance)	0.995	0.995	0.997	0.986
Y1.5 (Quality of Estimation Procedures)	0.673	0.730	0.856	0.749

The AVE value showed that the latent and median variables were >0.5, so the convergent variable was valid and adequate. The value of Composite Reliability and Cronbach's alpha were > 0.7, so the reliability of the instrument could be trusted and accepted.

3.2. Structural model evaluation (Inner Loading—Bootstrapping)

The size indicator of external structure to explain endogenous construction was the coefficient of determination (R2). The coefficient of determination (R2) was estimated between 0 and 1. Models were classified as strong, moderate, and weak indicated by R2 values of 0.75, 0.50, and 0.25. The classification of R2 criteria into strong, moderate, and weak with values of 0.67, 0.33, and 0.19 respectively (Chin, 1998).

The value of R-square is the independent variable to explain the variance of the dependent variable. The result of R-square to Y = cost was 0.840 which meant that all latent and median variables were able to explain the dependent variable or affect the cost by 84%.

Table 4 below shows the results of the PLS-SEM analysis for R-square.

Table 4. R2 Result.

Variable	R-square	R-square adjusted
X1.1 (Planning Stage)	0.885	0.884
X1.2 (Implementation Stage)	0.962	0.961
X1.3 (Post-implementation Stage)	0.869	0.867
X2 (RISKS)	0.645	0.642
X2.1 (Risk in Cost)	0.909	0.908
X2.2 (Risks in BIM)	0.982	0.982
X2.3 (Risk in WBS)	0.905	0.904
X3 (5D BIM QTO)	0.649	0.646
X3.1 (Real Time Modeling)	0.870	0.869
X3.2 (Quantity Extraction)	0.978	0.978
X3.3 (Visualization of Cost & Time Estimation)	0.882	0.881
X4 (INFORMATION SYSTEMS)	0.587	0.583
X4.1 (Content)	0.745	0.743
X4.2 (Format)	0.888	0.887
X4.3 (Usability)	0.883	0.882
X4.4 (Utility)	0.896	0.895
X4.5 (Security and Privacy)	0.909	0.908
X5 (WEB)	0.510	0.505
X5.1 (Content)	0.533	0.529
X5.2 (Format)	0.569	0.566
X5.3 (Accuracy and Speed)	0.781	0.780
X5.4 (Ease of Use)	0.831	0.829
X5.5 (Security and Privacy)	0.738	0.736
X6 (COST ESTIMATION)	0.724	0.722
X6.1 (Resource Planning)	0.915	0.914
X6.2 (Cost Estimation Techniques and Process)	0.974	0.974
X6.3 (Cost Estimate Classification)	0.925	0.924
X6.4 (Result of Cost Estimation)	0.886	0.885
Y1 (COST ACCURACY)	0.892	0.894
Y1.1 (Environmental Quality)	0.643	0.646
Y1.2 (Information Quality)	0.814	0.813
Y1.3 (Level of Uncertainty)	0.796	0.794
Y1.4 (Estimator Performance)	0.890	0.889
Y1.5 (Quality of Estimation Procedure)	0.856	0.854

SEM allows for a thorough examination of latent variables, factors, and procedural issues, which can be analyzed as subfactors of observed or latent variables. **Figure 3** shows that the R-square value of the collective effect on the Cost Accuracy variable (Y) is 0.649, with an adjusted R-square value of 0.646. This shows that all independent variables collectively influence the Accuracy variable (Y) by 0.649 or 64.9%. Since the adjusted R-square value of 64.9% is greater than 50%, it can be concluded that the influence of all independent variables on the Cost Accuracy (Y) variable is considered strong. Based on the analysis conducted on 140 factors, it is found that 10 factors in **Table 5** have the most significant influence in improving the cost accuracy of retrofitting High-Rise Office Buildings.

Table 5. The most influential main factors.

No.	Factor	R-square
1	X2.2. Risks on BIM	0.981
2	X3.2. Quantity Extraction	0.978
3	X6.2. Cost Estimation Techniques and Processes	0.974
4	X1.2. Construction Phase	0.962
5	X6.3. Cost Estimate Classification	0.925
6	X6.1.HR Planning	0.915
7	X2.1. Risk At Cost	0.910
8	X4.5. Security and Privacy	0.909
9	X4.4. Utility	0.896
10	Y1.1. Quality Scope	0.892

3.3. Path coefficient and interpretation

The correlation results between WBS Integration, Risks, BIM-5D, Information Systems, Web, and Cost Estimation have a significant effect on the cost accuracy of green retrofitting high-rise office buildings, which is 6.501 (0.000) with a positive original sample value of 0.643. This shows that the hypotheses are accepted.

Evaluating the structural model involves testing for collinearity between constructs and assessing the predictive power of the model. Furthermore, various criteria such as coefficient of determination (R2), cross-validation redundancy (Q2), effect size (f2), and path coefficient are used. Q2 > 0 indicates that the model exhibits strong predictive relevance, and Q2 < 0 indicates a lack of predictive relevance in the model. The estimated values of the path coefficients in the structural model were assessed for strength and significance, with *p*-values < 5% and t-statistic > 1.96 considered significant. Next, a detailed analysis was conducted to examine the direct and indirect effects of each factor using the SEM model as shown in **Table 6**.

Table 6. Influencing factors.

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (O/STDEV)	p-values	Information
COST ACCURACY → Y.1.2. Quality of Information	0.902	0.905	0.020	44,496	0.000	Significant
COST ACCURACY → Y1.1. Scope Quality	0.945	0.945	0.010	90,183	0.000	Significant
COST ACCURACY → Y1.3. Level of Uncertainty	0.892	0.895	0.021	42,622	0.000	Significant
COST ACCURACY → Y1.4. Estimator Performance	0.943	0.944	0.013	71,724	0.000	Significant
COST ACCURACY → Y1.5. Quality of Email Procedures	0.925	0.926	0.013	71,864	0.000	Significant

Table 6. (*Continued*).

	Original sample (O)	**Sample mean (M)**	**Standard deviation (STDEV)**	**T statistics (O/STDEV)**	**p-values**	**Information**
BIM-5D → INFORMATION SYSTEMS	0.766	0.765	0.055	14,039	0.000	Significant
BIM-5D → X3.1. Real-Time Modeling	0.933	0.932	0.024	38,898	0.000	Significant
BIM-5D → X3.2. Quantity Extraction	0.989	0.989	0.003	297,976	0.000	Significant
BIM-5D → X3.3. Cost and Time Visualization	0.939	0.939	0.019	49,013	0.000	Significant
COST ESTIMATION → COST ACCURACY	0.806	0.805	0.048	16,678	0.000	Significant
COST ESTIMATION → X6.1.HR Planning	0.956	0.956	0.013	76,138	0.000	Significant
COST ESTIMATION → X6.2. Cost Estimation Techniques & Processes	0.987	0.987	0.003	317,836	0.000	Significant
COST ESTIMATION → X6.3. Cost Estimate Classification	0.962	0.962	0.014	69,836	0.000	Significant
COST ESTIMATION → X6.4. Results of Cost Estimates	0.941	0.941	0.018	50,957	0.000	Significant
RISK → BIM-5D	0.805	0.804	0.043	18,860	0.000	Significant
RISK → X2.1. Risks to Costs	0.954	0.953	0.014	69,479	0.000	Significant
RISK → X2.2. Risks in BIM	0.991	0.990	0.003	353,088	0.000	Significant
RISK → X3.3. Risks in Estimates	0.642	0.641	0.069	9,331	0.000	Significant
INFORMATION SYSTEMS → WEB	0.714	0.711	0.049	14,643	0.000	Significant
INFORMATION SYSTEMS → X4.1. Content	0.863	0.863	0.041	20,823	0.000	Significant
INFORMATION SYSTEMS → X4.2. Format	0.942	0.943	0.012	81,156	0.000	Significant
INFORMATION SYSTEMS → X4.3. Usability	0.940	0.941	0.015	64,776	0.000	Significant
INFORMATION SYSTEMS → X4.4. Utility	0.946	0.947	0.014	65,915	0.000	Significant
INFORMATION SYSTEMS → X4.5. Security and Privacy	0.953	0.953	0.013	75,987	0.000	Significant
WBS → RISK	0.804	0.802	0.038	21,032	0.000	Significant
WBS → X1.1. Planning Stage	0.941	0.940	0.017	54,907	0.000	Significant
WBS → X1.2. Construction Phase	0.981	0.980	0.005	190,755	0.000	Significant
WBS → X1.3. Post-Construction Phase	0.932	0.931	0.013	69,537	0.000	Significant
WEB → COST ESTIMATION	0.851	0.850	0.030	28,719	0.000	Significant
WEB → X5.1. Content	0.730	0.727	0.054	13,641	0.000	Significant
WEB → X5.2. Format	0.755	0.751	0.050	15,222	0.000	Significant
WEB → X5.3. Accuracy and Speed	0.884	0.885	0.023	39,058	0.000	Significant
WEB → X5.4. Ease of Use	0.911	0.912	0.018	51,974	0.000	Significant
WEB → X5.5. Security and Privacy	0.859	0.859	0.027	31,265	0.000	Significant

4. Conclusion

SEM-PLS uses path coefficients to determine the strength and significance of hypothesized relationships among latent constructs. These path coefficients can be thought of as standardized beta coefficients. In PLS-SEM, bootstrapping techniques are commonly used to analyze t-values for path coefficients, assessing the significance of hypothesized connections. Path coefficient values typically range between −1 and +1 when standardized. Path coefficients near +1 indicate a strong positive linear relationship, while negative values indicate the opposite. In practice, p-values are a consistent measure of evidence but are often dichotomized into highly significant, marginally significant, and statistically insignificant at conventional levels, with thresholds at $p \leq 0.01$, $p \leq 0.05$, and $p > 0.10$.

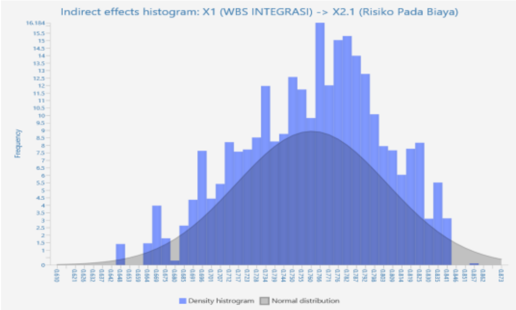
Table 7 shows the significant relationship between X1; X2; X3; and Y is t-statistics 6.403 > 1.96 and *p*-value 0.000 < 0.01, that the relationship between the factors is highly significant.

Table 7. Research self-assessment recapitulation.

Specific indirect effects	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	*P* values
RISIKO → BIM 5D → SISTEM INFORMASI → WEB → ESTIMASI BIAYA → X6.3. Klasifikasi Perkiraan Biaya	0.360	0.359	0.055	6.502	0.000
RISIKO → BIM 5D → SISTEM INFORMASI → X4.4. Utilitas	0.584	0.583	0.055	10.618	0.000
WBS → RISIKO → BIM 5D → SISTEM INFORMASI → WEB → X5.1. Konten	0.258	0.258	0.053	4.918	0.000
WEB → ESTIMASI BIAYA → X6.3. Klasifikasi Perkiraan Biaya	0.819	0.818	0.032	25.567	0.000
ESTIMASI BIAYA → AKURASI BIAYA → Y1.1. Kualitas Lingkup	0.761	0.761	0.048	15.703	0.000
RISIKO → BIM 5D → SISTEM INFORMASI → WEB → ESTIMASI BIAYA → AKURASI BIAYA → Y1.5. Kualitas Prosedur Email	0.279	0.279	0.050	5.532	0.000
BIM 5D → SISTEM INFORMASI → WEB → ESTIMASI BIAYA → AKURASI BIAYA → Y1.1. Kualitas Lingkup	0.354	0.353	0.057	6.231	0.000
RISIKO → BIM 5D → SISTEM INFORMASI → WEB → ESTIMASI BIAYA → AKURASI BIAYA	0.302	0.301	0.053	5.667	0.000
RISIKO → BIM 5D → SISTEM INFORMASI → X4.1.Konten	0.532	0.532	0.064	8.327	0.000
RISIKO → BIM 5D → SISTEM INFORMASI → WEB → X5.5. Keamaan dan Privasi	0.378	0.377	0.056	6.740	0.000
RISIKO → BIM 5D → SISTEM INFORMASI → WEB → ESTIMASI BIAYA → X6.2. Teknik dan Proses Perkiraan Biaya	0.370	0.369	0.051	6.649	0.000
SISTEM INFORMASI → WEB → X5.5. Keamaan dan Privasi	0.613	0.611	0.043	11.965	0.000
WBS → RISIKO → BIM 5D → SISTEM INFORMASI → WEB → ESTIMASI BIAYA → AKURASI BIAYA → Y.1.2. Kualitas Informasi	0.219	0.219	0.052	5.066	0.000
WBS → RISIKO → BIM 5D → SISTEM INFORMASI → WEB → X5.2. Format	0.267	0.266	0.055	5.093	0.000
BIM 5D → SISTEM INFORMASI → X4.3. Usabilitas	0.720	0.720	0.056	13.066	0.000
BIM 5D → SISTEM INFORMASI → WEB → ESTIMASI BIAYA → AKURASI BIAYA → Y1.4. Performa IEstimator	0.354	0.353	0.059	6.299	0.000
BIM 5D → SISTEM INFORMASI → WEB → ESTIMASI BIAYA → AKURASI BIAYA	0.375	0.374	0.054	6.403	0.000

Based on the results of the SEM-PLS 4 analysis, of the 14 hypotheses, all hypotheses with t-statistic values (significance values) above 1.96 are acceptable. Thus, the relationship model based on the results of the SEM-PLS analysis is as follows in **Figure 6**:

H1

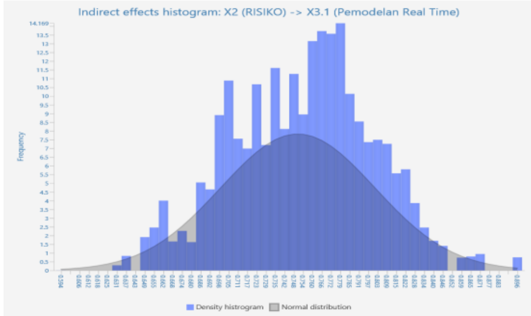


Result: WBS → Risk

T Statistics (> 1.96; $p < 0.05$): **20.60**

Inter-Variable Relationship: Significant

H2

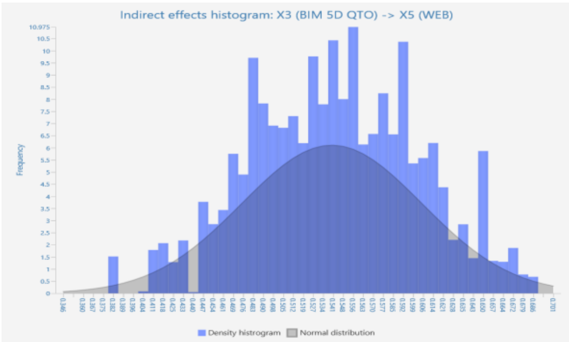


Result: Risk → BIM

T Statistics (> 1.96; $p < 0.05$): **19.89**

Inter-Variable Relationship: Significant

H3

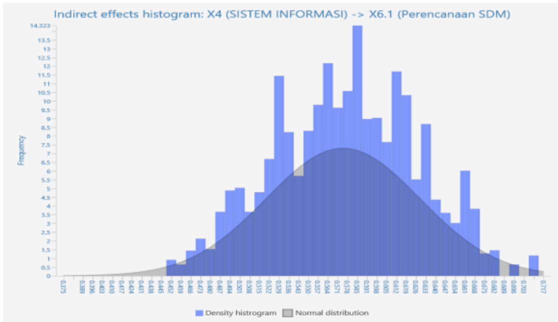


Result: BIM → Information Systems

T Statistics (> 1.96; $p < 0.05$): **13.42**

Inter-Variable Relationship: significant

H4

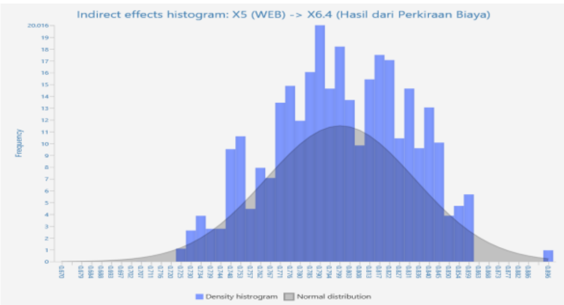


Results: Information System → Web

T Statistics (> 1.96; $p < 0.05$): **14.67**

Inter-Variable Relationship: significant

H5

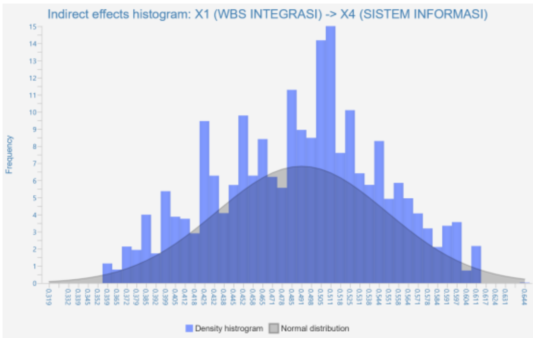


Result: Web → Cost Estimation

T Statistics (> 1.96; $p < 0.05$): **26.43**

Inter-Variable Relationship: significant

H6



Result: Cost Estimation → Cost Accuracy

T Statistics (> 1.96; $p < 0.05$): **16.07**

Inter-Variable Relationship: significant

Figure 6. The relationship model based on the results of the SEM-PLS 4 analysis, of the 14 hypotheses.

The results of the SEM-PLS 4 analysis show that the relationship between independent variables has a t-statistic value of more than 1.96 which is considered 'significant' because it is higher than 1.96. These results are in line with expert opinion.

Based on the R-square value table and path coefficient analysis show that the magnitude of the influence of the Latent Variable on Cost performance = 64.9%.

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