Enhancing safety and comfort through mechanical component maintenance performance on green building using BIM-based information system

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Abstract. The reliability of functioning mechanical components has major implications not only for the ease of use, lowering maintenance cost, avoiding loss of time and preserving safety factor but also for achieving green buildings mission namely emission and energy reduction. Failure in maintenance phase of mechanical components can adversely affect the achievement of the mission. Problems that occur are fragmented data, undocumented data, slow responses of human resource, and unscheduled maintenance. As a result, the massive budget spent in the green building construction phase is in vain. The purpose of this study is to improve the performance of maintenance of government green buildings in mechanical components by developing an information system that integrated with Building Information System (BIM). The case study studied was the Ministry of Public Works and People’s Housing Republic of Indonesia. The research methods used are literature reviews, case studies, system development and statically analysis. This study uses a Work Breakdown Structure (WBS) in managing data dynamically using BIM, which is integrated with web-based information systems. The result in this study explained that HVAC system, vertical transportation, BIM and information system has proofed that these variables could enhance the performance of mechanical components maintenance in green building which are safety, health and comfort.

1. Introduction
A solution to overcome environmental problems in the construction sector is to build green buildings [1]. As a form of commitment in promoting the construction of green buildings, the Jakarta government set regulations on building green buildings to reduce pollution rates such as reducing emissions, energy and global warming which are very closely related to the mechanical components of a building [2]. Good maintenance of mechanical component will determine how readiness and continuity of operation of the equipment and also its function to achieve green mission [3]. Moreover, lack of maintenance could lead the equipment into catastrophe. According to data from the Recapitulation of Fire Events in Jakarta, at least in the last 1 year there were two fires and 3 elevator damages in the government building due to the failure of maintenance of mechanical and electrical components. This is caused by an inefficient maintenance system that causes losses in terms of time, cost and productivity [4]. To avoid those accidents in future, good maintenance is required, both of preventive and corrective maintenance [5]. Good preventive maintenance requires a sufficient data and information about the building. Lack of data and information, the preventive maintenance could be cured with a wrong treatment. With good
maintenance, it is expected that the life time of an equipment will be longer and can be operated at any time [4].

Execution of building maintenance work is impacted by various aspects. One of them is the aspect of data and information about the building itself. Historical data during the construction phase contained in as-built drawings are crucial in achieving success during the building maintenance phase [6]. Gaps in information and knowledge transfer and sharing between various phases of construction and maintenance phase could lead facility management issues [7]. For example information about architectural components and mechanical components documented in different documents is often brings a mismatch between the documents and impacted to inaccurate data. So that many important data and information needed in the maintenance phase are not recorded and documented [6,7]. Moreover, the system used by facility management requires an accessible way to ease the building user to report any damages occurred. In several cases, government buildings that appear damaged are not maintained as perfected as the elevator, firefighting, the faded paint, the use of personal stability and the way it is formed [8]. Current system used in Jakarta government building which is relied on call-centre system could not covered and recorded all report at the same time. Paper-based information recording also worsened the maintenance system especially for a long term maintenance. This research is improving the initial information system of mechanical component maintenance by developing a new system to enhance the building maintenance performance specifically in mechanical component.

2. Research method

2.1. Validation of mechanical component maintenance WBS

In term of building maintenance, Work Breakdown Structure (WBS) is a breakdown of deliverables and project work into smaller components that can be better managed. Smaller component defines resources which is consist of materials, tools, and manpower [9]. The X1 variable in this study which is maintenance of mechanical components are divided into sub variables to ease the result of the research. WBS level 5 will be used to define the maintenance work and associated it with the building performance. There are 91 alternative designs in total that will be test with normality test to eliminate any variables that does not associated with the green building performance.

2.2. Creating 3D BIM model based on the guideline

As a 3D model tools, the role of BIM potentially used for visualization and coordination [10]. As build drawing of government building are taken as the base of making the model on 3D software followed by any information regarding mechanical component material. Expert validation for developing BIM model is used to generate a proper model that increasing the building performance.

2.3. Integrating BIM model with web-based information system

Computerized maintenance management systems (CMMS) is a tools that bring a lot of benefits to enhance maintenance performance and reduce cost [11]. System Information are used for information, automation, and transformation to reduce and replace human resources [12]. Web-based information system is used to enhance the maintenance system and replacing initial call-centre system. To bridge the communication between BIM model and web-based information system, BIM will be uploaded into the website to provide real time data to ease the facility management. Expert validation of the system developed also used to generate the proper model.

2.4. Relationship test to calculate green building performance

The hypothesis of the study will be tested using regression test to find the answer of the last research question and to develop mathematical model between proposed maintenance information systems with green building maintenance performance. Data sufficiency, normality, reliability and validity test also will be tested before entering the regression. This research conducted a survey of 50 respondents with specialty in green building, mechanical components, or building maintenance system background. In
brought, the operational model used and research methodology in this study is briefly shown in the figure 1 below.

![Operational Model of Research and Research Methodology](image)

**Figure 1.** Operational Model of Research (left) and Research Methodology (right).

From figure 1 above, there are two X variables that will be associated to achieve the Y variable which is the building performance. Building performance is divided into 4 categories: safety, comfort, convenience, and healthy based on Ministry of Public Works Regulation No. 24, 2008.

### 3. Results and discussion

#### 3.1. Mechanical components that enhance the maintenance performance

The result of RQ 1 is expert approval of alternatives design variables that associated with the Y variable. Using normality test, it shown that only 69 variables from 91 variables that associated with Y variable, therefore the rest will be eliminated. This test used $\alpha = 0.1$ Shapiro-Wilk method. Hypotheses testing: if $H_0: P \geq 0.1$ Data is normally distributed and if $H_a: P < 0.1$ Data may not normally distributed.

Validity test is performed as correlation analysis where it's used to measure strength of the association (linear relationship) between two variables. Usually, variables that has $r$ above than ±0.5 has high coefficient of determination ($R$) to perform regression. So from the table above we seek variables which has $r$ above than ±0.5. To perform correlation analysis, Hypotheses testing must be done as: if $H_0: \rho = 0$ (no correlation) and if $H_a: \rho \neq 0$ (correlation exists). From the test given, only 9 variables that correlated with Y variables, therefore only these variables will continue to the regression test as shown below:

| WBS Level 3 (Sub-work Section) | WBS Level 4 (Work Package) | WBS Level 5 (Alternative Design) |
|--------------------------------|---------------------------|----------------------------------|
| HVAC System                    |                           |                                  |
| Unit AC                        | X1.3                      | Ceiling Cassette                 |
| Unit Fan                       | X1.7                      | Ceiling Fan                      |
| Chiller                        | X1.11                     | Water Cooled Chiller             |
| Metering Device                | X1.16                     | Metering Device                  |
| Pump                           | X1.20                     | Condenser Water Pump             |
| Grill                          | X1.29                     | Intake Air Grill                 |
| Vertical Transportation        |                           |                                  |
| Passenger Elevator             | X1.35                     | Passenger Elevator               |
| Escalator                      | X1.37                     | Escalator                        |
| Information System             |                           |                                  |
| Information Technology         | X2.2.1                     | Information                       |
| BIM                            | X2.1.3                     | Visualization                    |

#### 3.2. Development of 3D BIM model integrated with web-based information system

BIM model is drawn using Autodesk Revit 3D based on as build drawing data from case study building followed by any related information about the mechanical components. All combined together as basis data and framework to be used at maintenance phase.
Findings from expert shows that BIM is best for visualization and coordination. Further, BIM also offers possibility for energy efficiency calculation that built-in to its software to help the facility management for green building periodic assessment. Specifically, during post construction phase, BIM is high potentially used as a basis of information system for building maintenance. After BIM model is developed, the study continues to integrate the BIM model into web-based information system that shown as below.

From the figure below, there are 2 pages that differentiate between building management page and building user page. The building management page will be functioning as; notified by reported damage from building user, notified by daily maintenance work, documented any action given in maintenance, reporting work to building owner, accessing BIM for any related information for maintenance and updating energy efficiency of the related components. Besides, the building user page will have a different function as: notifying any damage of building components and receiving feedback from every report given. After the two proposed solution have been tested with validity test with expert validation, the final result shows that the web-based information system that integrated with BIM model is associated with the increase of green building maintenance performance.

3.3. Relationship model of building performance
Regression analysis is used to predict the value of a dependent variable -which is green building maintenance performance- based on the value of 10 independent variables and explain the impact of changes in an independent variable on the dependent variable. From the correlation test, it shows that
the HVAC system has the strongest association with the green building maintenance, further detail of calculation are shown below:

Table 2. Regression output.

| Regression Statistics          |
|-------------------------------|
| Multiple R | 0.626049 |
| R Square   | 0.591938 |
| Adjusted R Square | 0.436024 |
| Standard Error | 0.688866 |
| Observations | 50      |

Table 3. Anova.

| df | SS  | MS  | F   | Significance F |
|----|-----|-----|-----|----------------|
| Regression | 10.00 | 11.92 | 1.19 | 2.51 | 0.02 |
| Residual   | 39.00 | 18.50 | 0.47 |    |     |
| Total      | 49.00 | 30.42 |      |    |     |

Table 4. Coefficients of Y1 variable.

| Coefficients | Standard Error | t Stat | P-value | Lower 95% | Upper 95% | Lower 90.0% | Upper 90.0% |
|--------------|----------------|--------|---------|-----------|-----------|-------------|-------------|
| Intercept    | 1.219          | 0.857  | 1.424   | -0.513    | 2.952     | -0.224      | 2.663       |
| X1.3         | 1.278          | 0.995  | 1.285   | -0.734    | 3.291     | -0.398      | 2.955       |
| X1.7         | -0.313         | 1.065  | -0.294  | -2.466    | 1.841     | -2.107      | 1.481       |
| X1.16        | 0.826          | 1.032  | 0.800   | -1.261    | 2.912     | -0.913      | 2.564       |
| X1.20        | -0.748         | 1.116  | -0.670  | -3.006    | 1.510     | -2.629      | 1.133       |
| X1.24        | 0.031          | 0.572  | 0.054   | -0.957    | 1.189     | -0.933      | 0.996       |
| X1.29        | -0.250         | 0.864  | -0.289  | -1.998    | 1.499     | -1.706      | 1.207       |
| X1.35        | 0.484          | 0.530  | 0.914   | -0.588    | 1.556     | -0.409      | 1.377       |
| X1.37        | -0.047         | 0.898  | -0.052  | -1.864    | 1.770     | -1.560      | 1.466       |
| X2.2.3       | -0.294         | 0.881  | -0.334  | -2.075    | 1.487     | -1.777      | 1.190       |
| X2.1.1       | -0.219         | 0.404  | -0.541  | -1.037    | 0.599     | -0.900      | 0.462       |

The coefficients on table above shows the population slope coefficient of independent variables while population Y intercept is 1.219 for Y1 variable and so on for the other Y variable, since there are four Y variables consist of; safety, healthy, comfort, and convenience. From the result, only three variables that has strong association with X variables which are: safety and comfort. To ease the model, the Y population regression model is as shown below:

\[
Y_1 = 1.219 + 1.278X1.13 - 0.312X1.7 + 0.031X1.11 + 0.825X1.16 - 0.747X1.20 - 0.249X1.29 + 0.484X1.35 - 0.046X1.37 - 0.293X2.2.1 + 0.218X2.1.3
\]  

\[
Y_3 = 1.112 + 1.131X1.13 - 0.347X1.7 + 0.561X1.11 - 0.054X1.16 - 0.019X1.20 - 0.775X1.29 + 0.324X1.35 - 0.236X1.37 + 0.064X2.2.2 + 0.125X2.1.3
\]  

Finally, after the mathematics model has been done, observation of predicted Y is conducted to explain a significant portion of the variation in performance using 50 observations and the test shows that the F value = 1.762 and F statistic = 2.513, therefore the regression model of decision = 0.1 does explain a significant portion of the variation in performance (there is evidence that at least one independent variable affects Y) and so on with the rest Y variables. The result also conformed to other literature saying that maintain the components would increase the performance. HVAC systems are important to provide health and comfort condition. It can operate for long-term usage to fulfill people’s requirements. The use of metering device also increasing convenience performance because it would ease the facility management by skipping unnecessary procedure without affecting power consumptions for HVAC system and also as a component in assisting energy displays that could notify building owner in their
energy utilization [13]. The most powerful for rotating machines such as pumps, it is logical that well-aligned and smoother running machines should use less energy and in general will also cost less to maintain [14]. In chiller -which is the most energy user- a decrease in evaporator pressure and an increase in leaving chilled water temperature would indicate a loss of refrigerant or dirty evaporator tubes [15], that leads to uncomforting and unsafe condition. Beside of HVAC system, vertical transportation has been one of the dominant factor in energy efficiency and conservation [16], moreover a good maintenance of these equipment could provide safe and effective service to occupant [17]. Other than that, the maintenance of plumbing has great impact on the supply of water that brings health and comfort to building user [18], but from the study it shown that plumbing is having small correlation to green building maintenance. Good maintenance of mechanical component will certainly improve the safety and comfort of the building user. From the study, it has been proofed that BIM and information system would enhance the maintenance performance which are safety and comfort.

4. Conclusion

- There are 10 variables that highly associated with mechanical component in green building maintenance performance especially for HVAC system, building vertical transportation and BIM based-information system.
- Implication of BIM on web based information system in mechanical component maintenance has been proofed that it is associated with the increasing of green building maintenance performance by its function to develop an integrated information, automation and communication system not only for the facility management but also the building user.
- BIM offers possibility for energy efficiency calculation to ease the facility management for preserve their periodic assessment of green building. The use of BIM and information system would ease the facility management and building user in terms of documentation and transformation
- Mathemetic model of building performance can be produced using variables that has association with the dependent variables which are HVAC system and vertical transportation that has been reinforced with various study says that maintaining those systems would be increasing maintenance safety and comfort performance.

References

[1] Ervianto W I 2012 Save the Earth Through the Green Construction (Yogyakarta: Andi Offset)
[2] Hu Z Z 2018 BIM-based integrated delivery technologies for intelligent MEP management in the operation and maintenance phase (Advances in Engineering Software 115/Elsevier) p 1
[3] Zaino and Nadiah N, et al. 2014 Critical Factors That Lead to Green Building Operations and Maintenance Problems in Malaysia: A Preliminary Study Advanced Materials Research Trans Tech Publications, Ltd 935 23–26
[4] Ministry of Public Works Republic of Indonesia 2008 Ministry of Public Works Regulation Regarding Guidelines for Building Maintenance (24)
[5] Ruparathna R et al. 2017 Multi-Period Maintenance Planning For Public Buildings A Risk Based Approach for Climate Conscious Operation Journal of Cleaner Production 170 1338
[6] Park J 2017 WBS-Based Dynamic Multi-Dimensional BIM Database for Total Construction As-Built Documentation Automation in Construction 15-23
[7] Tan A Z T, et al 2018 Enabling an Effective Knowledge and Information Flow Between the Phase of Building Construction and Facilities Management Facilities 36 (3/4) 151-170
[8] Latief Y, Machfudiyanto R A, et al 2018 The Development of Quality Management Systems in Maintenance and Monitoring the Process of Risk-Based Repair Work in Government Buildings MATEC Web of Conferences 195
[9] PMBOK 2018 Project Management Body of Knowledge (USA: Project Management Institute)
[10] Habibi S 2017 The Promise Of BIM For Improving Building Performance (Energy of Building 153) pp 525-548

[11] Lee P, et al 2018 An Integrated System Framework of Building Information Modelling and Geographical Information System for Utility Tunnel Maintenance Management (Tunnelling and Underground Space Technology 79) pp 263-273

[12] Alaraifi A, et al 2011 Information Systems for Data Centres Description and Operational Characteristic Proceedings of Pacific Asia Conference on Information Systems

[13] Ma’arof M I N, et al Smart Metering Device for HVAC System International Journal of Mechanical Engineering and Technology 9(8) 397–403

[14] Beebe R S 2004 Predictive Maintenance of Pumps Using Condition Monitoring (Elsevier Science & Technology Books) p 8

[15] Ziffer F E 2009 Chiller Maintenance For Reciprocating, Absorption, Screw, And Centrifugal Machines Service Application Manual SAM Chapter 630-103 p 1

[16] Berawi M A, et al 2019 Stakeholders' perspectives on green building rating: A case study in Indonesia Heliyon Volume 5(3)

[17] Au-Yong C P, et al 2018 Maintenance of lift systems affecting resident satisfaction in low-cost high-rise residential buildings Journal of Facilities Management 16(1) p 17-25

[18] Mwanza B G, Mbohwa C 2016 The Impact of Maintenance Systems on Water Supply: A case Study of a Utility Company Proceedings of the 2016 International Conference on Industrial Engineering and Operations Management