Analysis of building and its components condition assessment case study of dormitory buildings

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Abstract. Condition Assessment of assets is one of stages in assets management system that supports effective and efficient improvement and maintenance strategy. The objective of this paper is to develop a condition assessment model based on important components that build an asset. A building asset hierarchy is proposed in which four main categories that build spaces inside building is the principle element of evaluation. The Physical component in which selected as the variable of this research, based on Regulation of the Minister of Public Works of Indonesia no.24 in 2008 about building maintenance guidelines. Data are collected via questionnaires from experts to ranking and assign relative weights as model's attribute using Confirmatory Factor Analysis (CFA) in Structural Equation Modeling (SEM) techniques. Multi attribute utility theory (MAUT) is used to calculate entire building condition based on rank and relative weight of selected components. This research model is applied to a case study dormitory of Universitas Gadjah Mada, located in Yogyakarta. Result of the research is condition of the entire building based on components that build spaces inside that building. This result of this research will assist owners and facility managers in select effective and efficient improvement and maintenance strategy for the building.

1 Introduction

Building is a major physical asset within every facility [1]. There are three primary functions of a building which is related to space, as a shelter from weather; and provides safety and privacy to the users or occupiers. Buildings degraded during its service life. Douglas (1996) compares the performance of buildings that degraded during time, with the required performance by users that increase during time [1]. Maintenance is required to restore the quality and performance of degraded buildings. Effectively and efficiently Maintenance of buildings will provide optimal results, both quality and economy.

Dormitory buildings in Universitas Gadjah Mada area, play important roles to supports every user's activity. Maintenance by dormitory managers inclined to accidental action, will be done if only severe damage happened to the buildings. Of course it is ineffective and inefficient. Assessment of conditions is the key to develop an effective and efficient maintenance strategic plan. Condition assessment becomes first point in a process to develop the guideline of decision making in the future planning and implementation of maintenance. Finally, the results of periodic condition assessments are used to predict the extent of damage that will occur in the future. Therefore, the preparation of the condition assessment model is the first step to realize effective and efficient maintenance. The purpose of this research is to develop a model of buildings condition assessment based on building's physical components.

2 Background

2.1 Building Performance

Building performance used to denote the physical performance characteristics of a building as a whole and of its parts [2]. Building performance relates to a building's ability to contribute to fulfilling the functions of its intended use [3]. Building performance is very important both in terms of inter-building (inter-building) and intra-building (in buildings) [1]. An inter-building evaluation is where the performance of a building is compared with other building performance, while intra-building evaluation is the performance evaluation of the building by self-assessed without any other reference. The goal is to ensure how well the building can serve the needs of the users or to identify any damage to the overall performance. Performance of buildings related to the ability of the building or building products [4]. The needs of users and the achievement of the function of the building becomes the target of building implementation. Building performance can be achieved by a building through the management of facilities that have been targeted at the implementation process of a building

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2.2 Condition Assessment and Building Performance

Building performance and condition assessment could not be separated as condition of a building is the typical way to measure the building performance [5]. The ability of the building can be seen through the physical condition of the building [6]. The reason why the condition of a building becomes one of the signs that can be used to determine the performance of the building. Therefore, the condition of the building becomes the most effective way to know the performance of the building. The assessment of the condition also shows the maintenance program that must be done to keep the building remains in the original condition on the components.

Based on literature review condition assessment is the main function of assets management. Condition assessment is first point of assets management and maintenance process, as described in Fig. 1 [7]. Ahluwalia (2008) explains that the assessment of conditions is initial step to support the next step, that is selecting or predicting maintenance and improvement strategies that match the physical components and conditions of the assessed buildings. Conditions after building repaired should be reviewed to find out the results of improvements that have been made, then the cost can be calculated. Therefore, the assessment of the condition has a relationship with the performance of the building. Assessment of many conditions helps in the preparation of maintenance strategy and also prepares budget for the future. Building performance increases if maintenance costs and maintenance programs can be predicted with the same deterioration assumption.
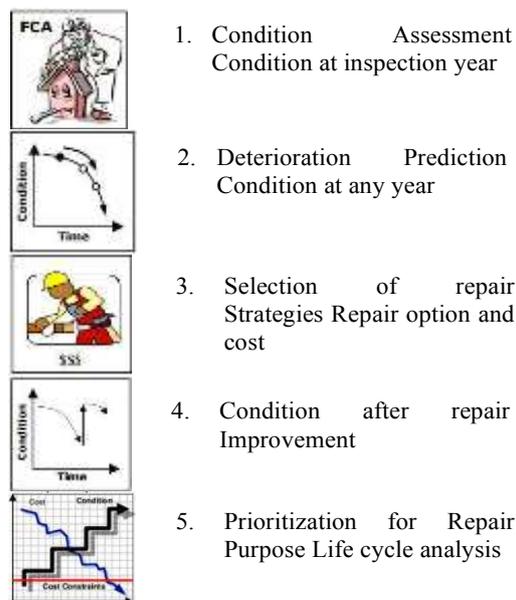

1. Condition Assessment Condition at inspection year

2. Deterioration Prediction Condition at any year

3. Selection of repair Strategies Repair option and cost

4. Condition after repair Improvement

5. Prioritization for Repair Purpose Life cycle analysis

Fig.1. Main function of an Asset Management System [7]

2.3 Condition Assessment

A tool for assessing the technical performance or the properties to underpin long-term maintenance expectation [12]. Condition assessment as vehicle for producing a complete inventory of deficiencies in a facility by thoroughly assessing the existing physical conditions and functional performance of buildings, equipment, utilities, and grounds [13]. Ahluwalia (2008), explains that conditions assessment taken by consultants, or contractors, or facility staff. Inspector should be skilled and trained in the inspection and assessment of conditions, supported by certification related to building inspection experts [8]. This is important because the assessment team must fully understand the operational maintenance of the assessed facility. Ahluwalia explained that assessor becomes the main constraint, for example for small or remote areas it is not possible to provide specialists in the field of assessment.

The condition assessment has been defined in different ways in literature. Condition assessment as "a process of systematically evaluating an organization's capital assets in order to project repair, renewal, or replacement needs that will preserve their ability to support the mission or activities they were assigned to serve" [9]. It was found that condition assessment systems have been developed for each type of infrastructure asset considering each asset's particularities. For example, PAVER was developed for pavement management [10], RAILER for railroads, and BUILDER for buildings [11], which were all developed by the U.S. Army Corps of Engineers

Based on literature review condition assessment requires series of process to supporting future decision-making regarding maintenance planning [6]. Condition assessment consist of 4 main step as described in Fig.2 [7].
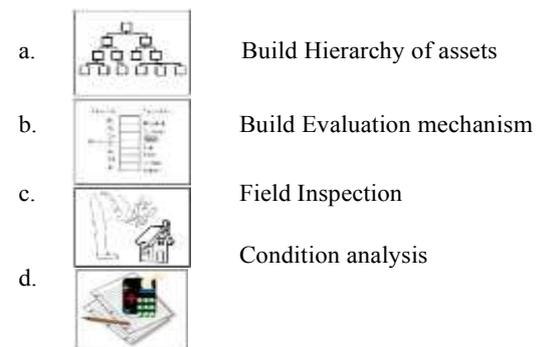

a.   Build Hierarchy of assets

b.   Build Evaluation mechanism

c.   Field Inspection

        Condition analysis

d.

Fig.2. Main steps in the Condition Assessment Process [7]

a.   Build Hierarchy of assets
     Asset hierarchy is categorized the components of the assets or buildings that will be assessed. Buildings usually divide and composed of many systems and components Asset hierarchy will help to determine level of inspection

b. Build Evaluation mechanism

Evaluation mechanism as standard to assess buildings. In this step inspector develop a condition scale, require data and analysis to assess the assets.

c. Field Inspection

Objective of this step is detect damage and measure severities on physical components by inspector in field investigation.

d. Condition analysis

The conditions of a component can be evaluated using two approaches, namely the distress survey and the direct-condition rating survey [14]. Distress method is an evaluation mechanism based on a list of criteria for evaluation of component damage that has been prepared. Inspector will evaluate by checklist on the list of damage criteria. This method is more suitable for some cases because it provides a better understanding of the real problem. Distress method in some cases can indeed show more detailed results, more accurate and minimal subjectivity. The direct-condition rating approach is less accurate but easier to develop and faster in implementation. The decision to use a distress survey or a direct-condition rating should be tailored to the needs and objectives of the assessment. If the purpose is to identify the condition of the component, then the direct-condition rating is the right approach. If the goal is to identify the problem that occurred then the distress survey would be more suitable [14].

3 Methodology Of Model Development

The main objective of this paper is to develop a condition assessment model for buildings. In this research, dormitory buildings around Universitas Gadjah Mada are chosen to be condition assessment model validation. Generally dormitory buildings around Universitas Gadjah Mada are storey building type, that consist of many floor level (1st floor, 2nd floor, 3rd floor, etc.). Survey dormitory building are useful to determine physical component and its parts inside the building.

The physical component in which selected as the variable of this research, based on Regulation of the Minister of Public Works of Indonesia no.24 in 2008 about building maintenance guidelines. Based on Regulation of the Minister of Public Works of Indonesia no.24 in 2008, building are classified into 6 categories: architectural, structural, mechanical, electrical, and outdoor. Each category consists of physical elements. Based on that, physical components in this research describe in table 1.

The model methodology is based on managing a storey building according to its floor level (1st floor, 2nd floor, 3rd floor, etc.); where level of floor is the principal element to be evaluated, according to its internal physical elements. Those physical elements are categorized into five main categories: architectural, mechanical, structural, electrical, and outdoor category. Each building category has some building systems that belong to it, named as element. The methodology a physical condition assessment for the entire building in

the final output described as Fig.3. Fig. 3 illustrates the model methodology and shows its main components.

Table 1. Research's Categories and physical elements

Categories	Physical elements

Architectural	a. Walls
	  Instances : brick wall, glass wall, partition wall (Gypsum), ceramic wall
	b. Ceiling
	  Instances : plywood, gypsum, plasterboard, GRC
	c. Floors finishing
	  Instances : ceramic, tiles, marble, wooden
	d. Doors and Window
	  Wooden, metal, glass, plastic doors and window.
	e. Sills
	  Instances : aluminium sills, wooden sills

Structural	a. Columns b. Beams c. Foundation d. Slabs e. Shear wall f. Stairs
Mechanical	a. Clean water network b. Dirty water network c. Floor drain d. Roof and Ground tank e. Freight elevator f. Fire protection network g. Septic tank
Electrical	a. Lamps b. Cable network distribution c. Socket and switch d. Fire alarm system e. Lightning rod
Outdoor	a. Outside Paint b. Roof c. Canopy

Relative weight of all categories and its elements evaluated by questionnaire. The objective of the questionnaire is to determine rank and priority of all categories and element in maintenance implementation. Data result from questionnaire analyzed by Confirmatory Factor Analysis (CFA), and will be explained further in next chapter. The output of analysis is a loading factor similar to the regression coefficient which represents the importance of all categories and elements. Questionnaire using Likert scale to determine categories and elements. Value 1 represent very not important, value 2 represent not important, value 3 represent moderate, level 4 represent important, and level 5 represent very important. A survey questionnaire was sent to expert in maintenance and buildings. data was verified for reliability before used in model development.

Ranking and relative weight determined based on loading factor obtained through the CFA. Ranking is useful to know the categories, elements, and instances of

priority in maintenance. Relative weighting is used to calculate the condition values of categories, elements, and instances that proposed using Multi Attribute Utility Theory. Multi Attribute Utility Theory (MAUT) will be explained further in next chapter.
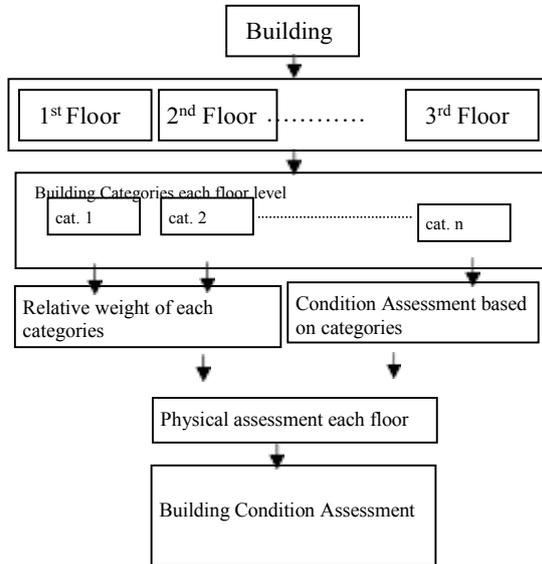

Fig.3. Methodology of model development

4 Model Development

4.1 Proposed Asset Hierarchy of Condition Assessment

To assess the physical condition of a building space, both the identification of the different building categories in each space and the asset hierarchy must be determined. As discussed in the introduction part, there are some drawbacks in the existing asset hierarchies. Based on their pros and cons, a new asset hierarchy that considers their benefits and aims to fix their drawbacks is proposed. The new asset hierarchy is structured on six levels, starting with the building at the upper level and ending with the instance level. Fig. 4 illustrates the proposed asset hierarchy.

    a. Building Level: the top level of asset hierarchy represents the building type where it is different from one building type to another

    b. Floor level: Includes all the floor level inside the building.

    c. Category level: includes five main building category represent each floor level (architectural, mechanical, structural, electrical, and outdoor category)

    d. Element level: includes all element in the same category that have similar characteristic (walls, flooring, ceiling, doors and window, etc.)

    e. Instances level: includes all properties each element (brick wall, glasses wall, partition wall, etc.)
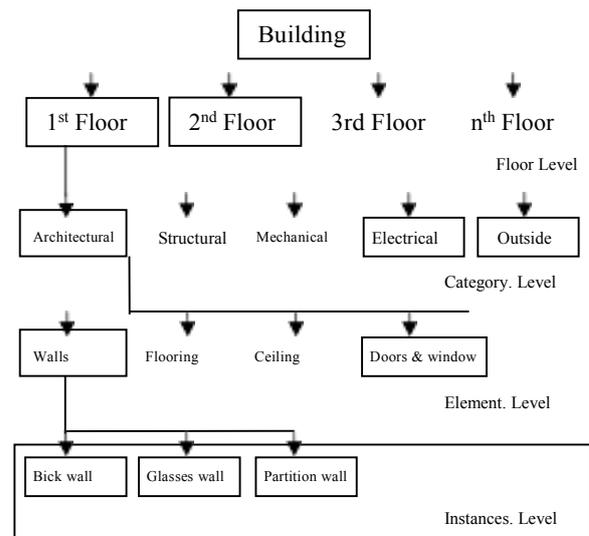

Fig. 4. Proposed Asset Hierarchy

4.2 Evaluation Mechanism of Condition Assessment

The conditions of a component can be evaluated using two approaches, namely the distress survey and the direct-condition rating survey [14]. Distress method is an evaluation mechanism based on a list of criteria for evaluation of component damage that has been prepared. Inspector will evaluate by checklist on the list of damage criteria. This method is more suitable for some cases because it provides a better understanding of the real problem. Distress method in some cases can indeed show more detailed results, more accurate and minimal subjectivity. The direct-condition rating approach is less accurate but easier to develop and faster in implementation. The decision to use a distress survey or a direct-condition rating should depend on objectives of the assessment. If the purpose is to identify the condition of the component, then the direct-condition rating is the right approach. If the goal is to identify the problem that occurred then the distress survey would be more suitable [14].

In this case the evaluation mechanism of component conditions in the field adapts the evaluation mechanisms proposed by Mckay et al. [15] [16]. The evaluation mechanism is based on discussion with Facility Managers (FM) and experts in the field of building condition assessment. Assessors will be given the level of condition of the physical condition of the component to be in value. Levels start at 0 (zero) which is the worst condition that has failed and 100 (one hundred) represents the perfect condition. The evaluation index is divided into six (6) levels and multiple scales. The index of evaluation mechanisms developed by Mckay et al. (1999) (adopted by Elhakeem (2005)) is modeled as in the foundation chapter of theory Fig. 5. This assessment mechanism is chosen because it is easier to implement in the field. Index scales that are used are also easier to understand and have a relatively good level of accuracy.
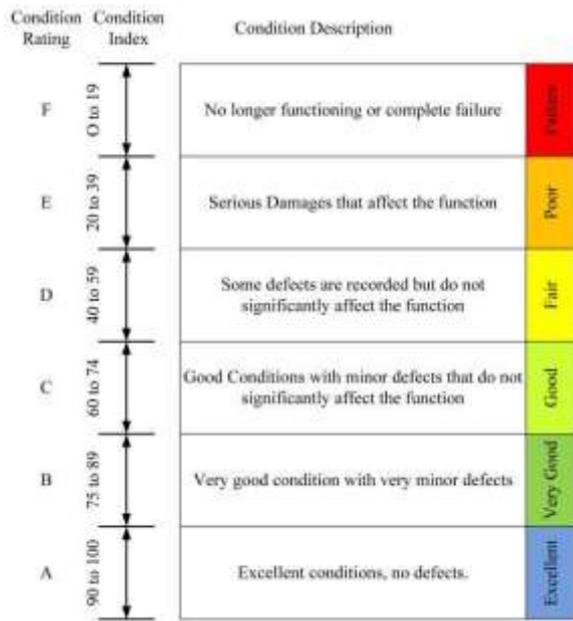
Fig. 5. Proposed Condition index scale [15] [16]

The other method is the distresses method in which the inspector is asked to evaluate the physical components according to a list of evaluation criteria. This method may be more suitable in some cases because it gives a better understanding of the exact problem. it is more suitable in cases where more details are required, and finally it is more accurate and less subjective. Another capability of this method is to give an idea about the location of the problem; hence, it will be used in the other phases of managing the asset. As mentioned before that BUILDER uses its 23 generic distress types in the evaluation process, the inspector evaluates each subcomponent against these 23 distress types [17] The inspector should provide judgment on two measurements (density and extent) for each distress. It was found that using these 23 distress types requires a lot of time and may also not be cost effective. This is because the inspector is asked to answer 23 questions and give his judgment on two measurements (density and extent) for each element inside the building. A better and more effective method is required, and there is a requirement of maintaining the aim of reducing subjectivity and saving time. The 23 published distress types in the BUILDER condition assessment manual were analyzed and grouped to only three evaluation criteria in order to evaluate physical elements. Some criteria were concerned with damages that happen to the components such as cracks and deterioration; some others were concerned with whether the component is performing properly or not such as leakages and operationally impaired; and others are concerned with the appearance of the components itself such as patched and displaced.

4.3 Confirmatory Factor Analysis for Identifying Relative Weight Category & Element of Building

Confirmatory Factor Analysis (CFA) is an analytical technique to identify relationship between a variable and

its indicators by examining the correlation. CFA calculate the coefficients of indicators that similar to the regression coefficient between indicators X with variable Y. The coefficient called loading factor, that the value between 0 (poor) and 1 (perfect fit). If the value getting closer to point 1 that means indicators is important. CFA actually one of stages in Structural Equation Modeling (SEM). CFA is used to determine the significance of a constituent indicator of a variable. Ghozali (2013) states that an significant indicator or has an important influence if it has a loading factor above 0.5.

The typology and concepts of CFA suitable with the building's asset hierarchy. Transformation of the asset hierarchy form into CFA can be done, example Architectural as variables in CFA and elements such as ceilings, glass walls, ceramic walls, as indicators. The hierarchy of assets tested by CFA will show the importance of each indicator through loading factor. Through loading factor ranking process to each category and elements that important in condition assessment can be done. Another advantage is relative weighting of each indicator also can be done. Relative weighting useful for synchronizing category or elements of different types. The relationship between constituent indicators and factors is modeled in Figure 6. The variable or construct Ω is formed by the indicators X1, X2, and X3 with each loading factor of $\beta1$, $\beta2$, and $\beta3$. Individual indicators are also influenced by the residual variables $\varepsilon1$, $\varepsilon2$, and $\varepsilon3$. The equation of construct Ω describe in equation 1.

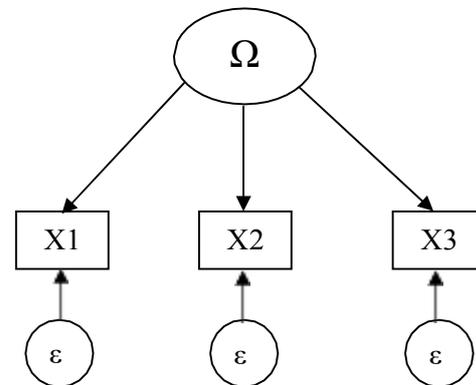**Fig. 6**. CFA model

$$X = \beta.\Omega + \varepsilon \qquad (1)$$

where X = indicators of each variable; β = Loading factor each indicators; Ω = variable/ construct; ε = error term.

Goodness-of-fit criteria is conducted to assess the feasibility and validity of the CFA model. The goodness-of-fit criteria that used are Likelihood-Ratio Chi-Square Statistic, goodness of fit index, Cmin / Df, root mean square error of approximation, Adjusted goodness of fit, Tucker-Lewis Index, comparative fit index. The CFA test is performed using the software of Analysis of Moment Structure (AMOS) ver.21 which is a IBM enterprise product.

Based on recap data of questionnaire, level categories and level element in asset hierarchy analyzed by CFA to

determine loading factor of all categories and elements. CFA for categories level in asset hierarchy with AMOS Graphic interface give results as shown in Figure 7. Through CFA results, rank and priority of all categories and elements represent with loading factor. Relative weights are calculated by comparing the loading factor of each categories or elements with the accumulation of loading factor categories or elements. CFA not performed in floor level because in this research, assumed that each floor has same priority in maintenance implementation. Priority in maintenance implementation and relative weight in category level showed in Table 2.
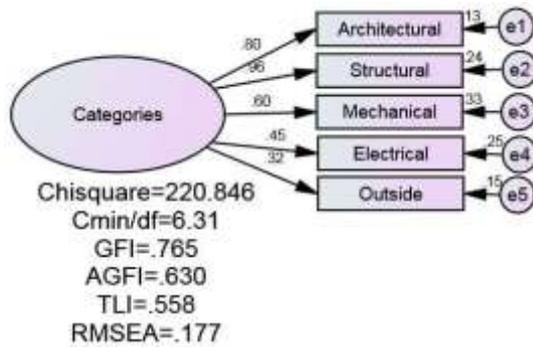

Fig. 7. CFA categories level result with AMOS graphic

Table 2. Priority and relative weight of categories

Components	Loading Factor	Ranking	Relative weight
Architectural	0.80	2	0.26
Structural	0.96	1	0.31
Mechanical	0.60	3	0.19
Electrical	0.45	4	0.14
Outside	0.32	5	0.10

CFA also performed for elements level. CFA for elements level in asset hierarchy with AMOS Graphic interface give results as shown in Figure 8, Figure 9, Figure 10, Figure 11, Figure 12. Priority in maintenance implementation and relative weight in elements level showed in Table 3.
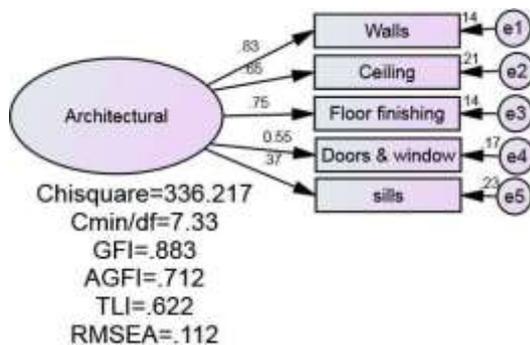

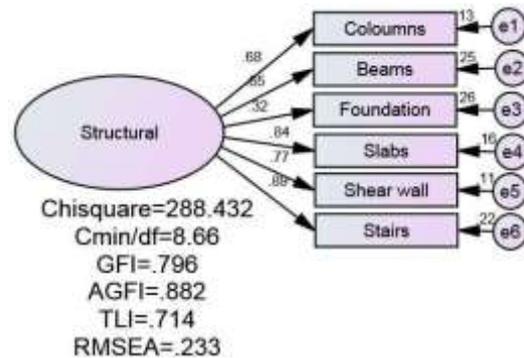**Fig. 8.** CFA Architectural and its element with amos graphic

Fig. 9. CFA Structural and its element with amos graphic
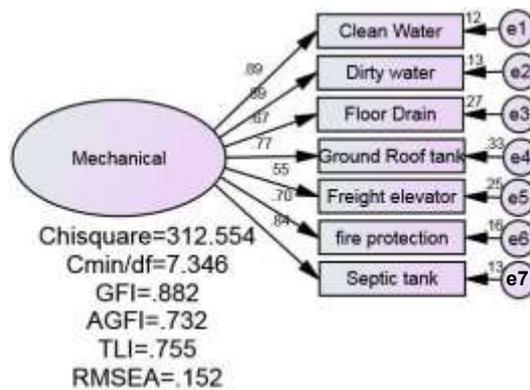

Fig. 10. CFA Mechanical and its element with amos graphic
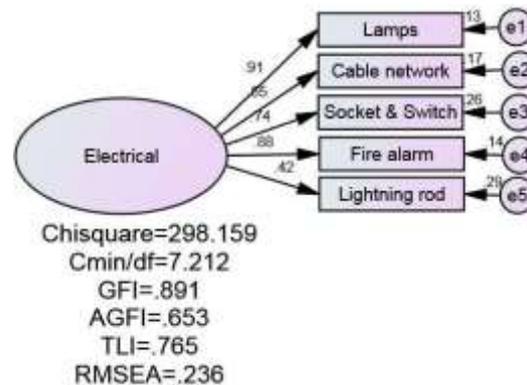

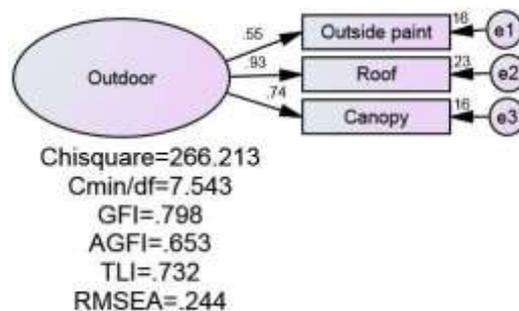**Fig. 11.** CFA Electrical and its element with amos graphic

Fig. 12. CFA Outdoor and its element with amos graphic

Table 3. Priority and relative weights of elements for each categories

Elements	Loading Factor	Ranking (each categories)	Relative weigth
Architectural			
Walls	0.83	1	0.26
Ceiling	0.65	3	0.21
Floor finishing	0.75	2	0.24
Doors and window	0.55	4	0.17
Sills	0.37	5	0.12
Structural			
Coloumns	0.68	4	0.16
Beams	0.65	5	0.16
Foundation	0.32	6	0.08
Slabs	0.84	2	0.20
Shear wall	0.77	3	0.19
Stairs	0.89	1	0.21
Mechanical			
Clean water network	0.89	1	0.17
Dirty water network	0.89	2	0.17
Floor drain	0.67	6	0.13
Roof and Ground tank	0.77	4	0.15
Freight elevator	0.55	7	0.10
Fire protection network	0.70	5	0.13
Septic tank	0.84	3	0.16
Electrical			
Lamps	0.91	1	0.26
Cable network distribution	0.55	4	0.16
Socket and switch	0.74	3	0.21
Fire alarm system	0.88	2	0.25
Lightning rod	0.42	5	0.12
Outdoor			
Outside Paint	0.55	3	0.25
Roof	0.93	1	0.42
Canopy	0.74	2	0.33

4.4 Multi Attribute Utility Theory Implementation for Building Condition Assessment

Multi Attribute Utility Theory (MAUT) is a systematic approach to quantify various objects. MAUT is used to

rescale numerical value on objects that have different types. MAUT compare different types of objects into a new general scale that can be used to assess the various types of objects. Example in the case of buildings we can create a universal scale that used to equalize the conditions of structural components such as beams, columns, and architectural components such as walls and ceramics into a similar scale. MAUT equations are generally written down in equation 2. V (x) is the value of the accumulated objects being assessed. Wj is the relative weights of each valued object. xij is the utility value of each object being judged.

$$V(x) = \sum_{i=1}^{n} w_j \times x_{ij} \qquad (2)$$

Implementation MAUT for building condition assessment adopt Eweda, et. al.(2015) [. Physical condition entire building is accumulation of physical condition each floor inside the building. In this case we assume that each floor has same relative weight. Each floor has same priority in maintenance. So CFA test begin at categories level in asset hierarchy.

After relative weights determined based number of floors, MAUT can be applied to calculate physical condition condition entire building (Physical Condition Building). Based on MAUT logic, condition of whole building is the accumulation of the Physical Condition (PC) of all floors level. Implementation MAUT to calculate the overall condition of the building as shown in equation 3 and 4.

$$PCB = \sum_{i=1}^{n} PC.floor_i \times W.floor \qquad (3)$$

where

$$W.floor = \frac{1}{number.of.floor.inside.the.building} \qquad (4)$$

PCB is Physical Condition Entire Building; $PC.floor_i$ is Physical Condition each floor; and W.floor is relative weights floor.

With the same logic, Physical Condition each floor level is accumulation of physical condition categories. After relative weights of each categories determined based on CFA , MAUT can be applied to calculate physical condition each floor level. implementation MAUT to calculate the physical condition of each floor as shown in equation 5.

$$PC.floor_i = \sum_{j=1}^{n} PC.Category_{ij} \times w.category_{ij} \qquad (5)$$

Where $PC.floor_i$ is physical condition each floor inside building; PC. category is physical condition each category; w. category is relative weight each category based on CFA test.

With the same logic, Physical Condition each category is accumulation of element's utility value. After relative weights of each elements determined based on CFA , MAUT can be applied to calculate physical condition condition each category. Implementation MAUT to calculate the physical condition of each floor as shown in equation 6.

$$PC.Cat_j = \sum_{k}^{n} U.element_{jk} \times w.element_{jk} \qquad (6)$$

5 Conclusion

The condition assessment model is developed based on physical components inside building. A new building asset hierarchy is proposed in which number of floors inside building is the principle element that will be evaluated. A condition index scale proposed to provide facility manager evaluation mechanism condition assessment.

CFA result has showed loading factor of all categories and elements inside building. Loading factor is used to determined priority of categories and elements in maintenance implementation. Loading factor then used to calculate relative weights of all categories and elements. Based on relative weight, finally MAUT was

selected to calculate the physical condition of the buildings.

Dormitory building type is used to be a model validation, help on determined buildings component and develop a asset hierarchy. In this case, it is possible to assume that each floor inside dormitory has same priority in maintenance implementation because mostly each floor in dormitory has same function. Condition assessment model in this research is expected to be used for another building in other place that has same type. This model is expected to helps facility manager in case of building maintenance decision-making process. For another type of building, different review must be done. Probably another type of building has different criteria and function.

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