Maintainability Factors for Robust Maintainance Integrated Design (R-MInD) in Building Design

Neza Ismail[1,a*],Mohamad Ibrahim Mohamad[2,b],

[1]Faculty of Engineering, Nasional Defence University of Malaysia

[2]Faculty of Civil Engineering, Universiti Teknologi Malaysia, Malaysia

[a*]nezalin69@yahoo.com, [b]mibrahim@utm.my

Keywords: Building maintainability consideration, Robust building design, Partial Least Square-Structural Equation Modelling (PLS-SEM).

Abstract. Building maintainability considerations relate to the extent to which the building maintenance tasks could be seen as being achievable. The purposes of incorporating good maintainability considerations into building designs are to achieve high building performance, ease day-to-day housekeeping tasks, make the building adaptable for future needs and maintain a stable usage cost throughout the building's design life. This paper identifies the factors suitable for building maintainability interaction evaluation for a robust building design. The evaluation will be used as a holistic evaluation of variable interaction during operational stage, to reduce future maintenance difficulties and cost. The maintainability interaction evaluation has a multidimensional diagnosis system which consists of controlled and uncontrolled factors. The data collection method in this research includes an expert panel interview using prepared semi-structured interview questions and a questionnaire survey to identify the maintainability factors in fulfilling the maintenance-related needs of the building. This research identifies maintainability factors by applying partial least square structural equation modelling (PLS-SEM) technique. From this research, it is found that the controlled factors are conformance and compliance to regulation and standard; and building services integration while the uncontrolled factors are space planning and, material and equipment selection.

Introduction

Building maintainability considerations relate to the extent to which the building maintenance tasks could be seen as being achievable. The purposes of incorporating good maintainability considerations into building design are to achieve high building performance, ease day-to-day housekeeping tasks, make building adaptable for future needs and maintain a stable usage cost throughout the building's design life [1], [2]. It is important for building design to encompass unforeseen changing conditions created by changing environment or uncontrolled factors [3]. It is argued that building designs are not optimised but they are only set to meet basic needs. Optimising building designs with time constrain considerations such as space planning, and material and equipment selection which are also known as uncontrolled factors in building operation; will produce better design outcomes [4], [5]. The objective of this paper is to identify factors suitable for building maintainability interaction for robust design by applying the multidimensional diagnosis system.

Design considerations are identified as controlled and uncontrolled factors, which interact with one another and affect the performance of the building. Effects of the usage on a building or un control factors change throughout the use of the building, and influence the performance of the building where it is predicted to eventually decrease. A design process must be able to incorporate building maintainability requirements by relying on lessons learned from problems faced during building operation, which maybe categorised as the uncontrolled factors in building design [6]. By identifying the uncontrolled factors and their interaction with the controlled factors, a better building design with optimum performance can be achieved. The uncontrolled factors are the building's day-to-day concerns which affect performance of a building such as space planning, and material and equipment selection. Space planning involves user's environment and the uncontrolled factors include client's usage, temperature, humidity, and surrounding subsystems. Optimising use of space refers to space planning in the building design stage. During this stage, what needs to be taken into account are design of spatial and occupancy requirements, maintenance and logistics route for installation and moving in and out of large equipment, and including but not limited to space layouts and final planning. The main goal of material selection is to minimise cost, while meeting product performance goals. The relationship between the controlled and uncontrolled factors is shown in Figure 1. The controlled factors can be described as important engineering focus, namely compliance to current regulation and cost aspect which encompassed the integration of all buildings services system. On the other hand, the uncontrolled factors can be described as factors that deal with user's preferences and usage conditions. Based on Figure 2, the following hypotheses were developed and tested for their significance.

H_1: Compliance and Conformance to Requirements and Standard (CCRS) has a direct positive effect in Material and Equipment Selection (MES).
H_2: CCRS has a direct positive effect in Space Planning (SP).
H_3: CCRS has a direct positive effect in System Integration (SYSINT).
H_4: MES process has a direct positive effect in Robust Maintainability Integrated Design (RMInD).
H_5: SP has a direct positive effect in Robust Maintainability Integrated Design (RMInD).
H_6: SP has a direct positive effect in MES.
H_7: SYSINT has a direct positive effect in SP.

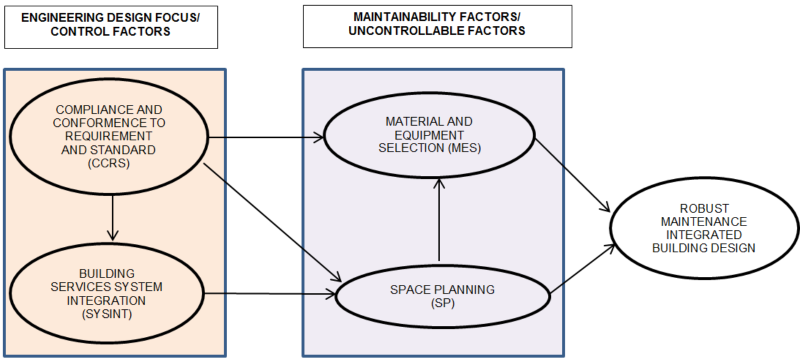

Figure 1. Research Model for Engineering Design Focus (Controlled factors) and Maintainability Factors (Uncontrolled factors) Interaction for Robust Maintenance Integrated Design

Methodology

To identify the relationship between engineering design focus and maintainability factors for Robust Maintainability Integrated Design (RMInD) in building design, the flow of the processes conducted in this study are as follows,

1. Gather the measurement item of factors in Figure 1.
2. Design the questionnaire and input responses.
3. Analyse the responses using smart PLS software.
4. Run the measurement and structural model analysis.
5. Develop the relationship for RMInD.

The data collection method in this research includes a questionnaire survey to identify the key variables in improving maintenance integrated needs of the building. In this study, Structural Equation Modelling Partial Least Square (PLS-SEM) analysis was employed to test the model developed in Figure 1. PLS-SEM was developed by Joreskog and Wold [7], [8]. It has the capability of working with unobservable latent variables and can account for measurement error in the development of LVs [9]. The structural model of the influencing factors is shown in Figure 2 while the questions or indicators of the five latent variables are shown in Table 1.

Table 1. Operationalisation of independent Latent Variables

Latent Variable (LV)	Item Code	Description of measurement item (indicator)
Compliance and Conformance to Requirement and Standards	CCRS2	The design is approved by the authorities and existing statutory requirements.
	CCRS6	Constructability and safety aspect.
Building Services Integration	SYSINT1F	The proposed system must be compatible with each system and subsystem.
	SYSINT5MC	Flexibility of components to be replaced in the future.
	SYSINT6MC	Performance data from previous project.
	SYSINT7MC	Familiarity of client to the system in terms of usage.
Robust Maintainability Integrated Design (RMInD)	RMInD2	Minimise down time of equipment.
	RMInD5	Ease of procurement of spare parts and components.
	RMInD6	Predictable maintenance cost.
Space Planning	SP4F	Availability of land area for footprint and building orientation.
	SP5C	Whole life cycle assessment of the building usage.
Material and Equipment Selection	MES5C	Consideration of the whole life cycle issues of the material.
	MES9MC	Ensuring the effective use of material.
	MES10MC	Ease of cleaning, replacing and repairing buildings.
	MES11MC	Ease of replacing.
	MES12MC	Ease of repair.

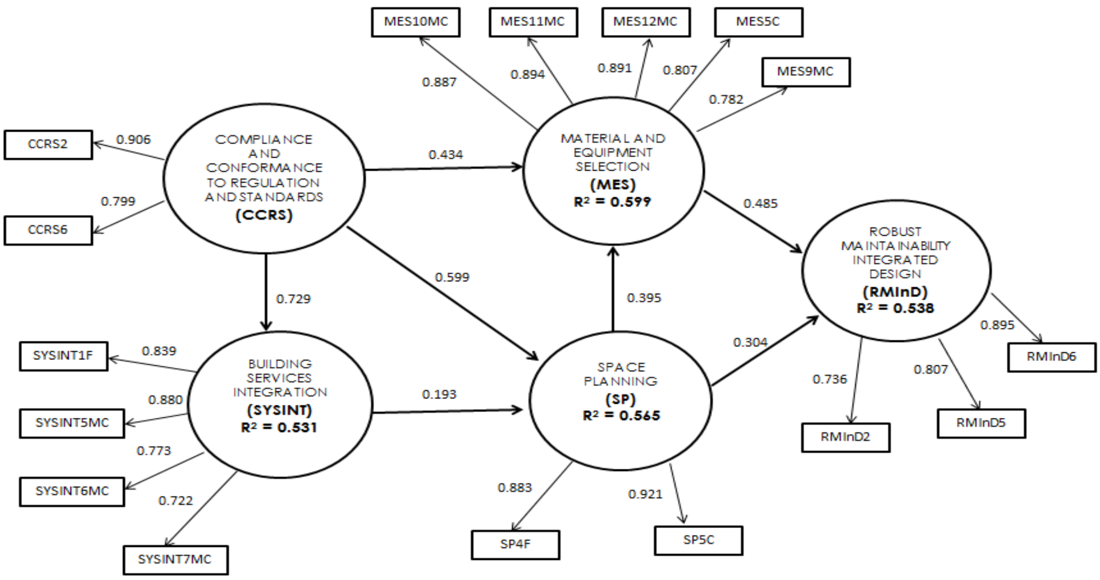

Figure 2. Structural Model for Engineering Design Focus and Maintainability Factors Interaction for Robust Maintainability Integrated Design in smart PLS software with measurement item

Data Analysis and Results

Data collection was conducted from early April, to end of May, 2013. The questionnaires were handed out to design engineers and collected immediately after they were completed. Of the 250 questionnaires handed out, 111 questionnaires were returned representing an overall rate of 44.4%. The responses were checked for completeness and coded for data analysis. The public sector represented 54.1% of responses while private sector represented 45.9% of responses. All respondents were involved in design tasks with 67% of respondents rated themselves as being competent in building maintenance. In terms of work experience, 5.4% have less than five years of work experience; 15.3% have 6 to 10 years of experience; 20.7 % have 11 to 15 years of experience, and 24.3% have more than 21 years of experience. The first criterion to be evaluated is typically internal consistency reliability [10]. Composite reliability (CR) values of 0.6 to 0.7 are acceptable in exploratory research, while in a more advanced stage of research; values between 0.7 and 0.9 can be regarded as satisfactory [11]. Table 2 below shows that the composite reliability, with a value range of 0.827 to 0.935 is considered acceptable. The value for loading with 0.5 as the significant value, was used [12]. All loadings were higher than 0.5, which can be regarded as satisfactory.

Table 2. Result of the measurement model

Construct	Measurement item	Loading	AVE[b]	CR[a]
Compliance and Conformance to Requirement and Standards	CCRS2	0.906		
	CCRS6	0.799	0.730	0.843
Building Services Integration	SYSINT1F	0.839	0.649	0.880
	SYSINT5MC	0.880		
	SYSINT6MC	0.773		
	SYSINT7MC	0.722		
Robust Maintainability Integrated Design (RMInD)	RMInD2	0.736	0.664	0.855
	RMInD5	0.807		
	RMInD6	0.895		
Space Planning	SP4F	0.883	0.814	0.897
	SP5C	0.921		
Material and Equipment Selection	MES5C	0.807		
	MES9MC	0.782	0.729	0.931
	MES10MC	0.887		
	MES11MC	0.894		
	MES12MC	0.891		

[a] Composite reliability (CR) = (Square of the summation of the factor loadings)/{(square of the summation of the factors loadings) + (square of the summation of the error variances)}
[b] Average variance extracted (AVE) = (summation of the square of the factor loadings)/{(summation of the square of the factor loadings)+(summation of the error variances)}

Validation of the structural model was conducted using path analysis of the model. Using bootstrapping technique with a re-sampling of 5000, the path estimates and t-statistics were calculated for the hypothesised relationships. Test of the hypotheses was achieved by comparing the path coefficient (β), between each latent variable. It was noted that the higher the path coefficient, the stronger the effect of the predictor latent variable on the dependent variable. A summary of the hypothesis testing is shown in Table 3. The hypotheses are considered as supported based on the conventional significance level of 0.01. Table 3 shows all paths are significant. A closer look at the result shows that CCRS has a positive influence on SYSINT and MES. SYSINT has a positive influence on SP. CCRS and SYSINT are considered as the controlling factors or design space as building required safety for occupants and cost limitation for building owners. Two user parameters in the design are the SP and MES. The two are hypothesised as having positive influence on RMInD. It can be seen that MES has a positive influence on RMInD, and SP has a positive influence on RMInD. SP also has a positive influence on MES.

Table 3. Result of structural model

Hypothesis	Relationship	Std Beta	SE	t value	Decision
H1	CCRS ----> MES	0.434	0.107	4.022	Supported
H2	CCRS ----> SP	0.599	0.082	7.224	Supported
H3	CCRS ----> SYSINT	0.729	0.042	17.613	Supported
H4	MES ----> RMInD	0.485	0.078	6.230	Supported
H5	SP ----> MES	0.395	0.103	3.830	Supported
H6	SP ----> RMInD	0.304	0.087	3.513	Supported
H7	SYSINT ----> SP	0.193	0.082	2.350	Supported

Cut off value for significant level $p < 0.01$, one tail = 2.33

The structural model shows that about 53.8% of Robust Maintainability Integrated Design are due to the four latent variables in the model. All the paths are significant. This study shows that "conformance and compliance to regulation and standard" is the most important influencing factor, followed by “materials and equipment selection", “space planning” and “system integration". In order to better evaluate the interaction between factors, the use of a multidimensional diagnosis system as in Figure 3 is recommended. The controlled variables are closely related to the design space where all the controlling variables are identified as controlling the design. The uncontrolled factors or the user space comprises of space planning, and material and equipment selection. Achieving robustness is to take advantage of the interaction between the design and user space, in the design space.

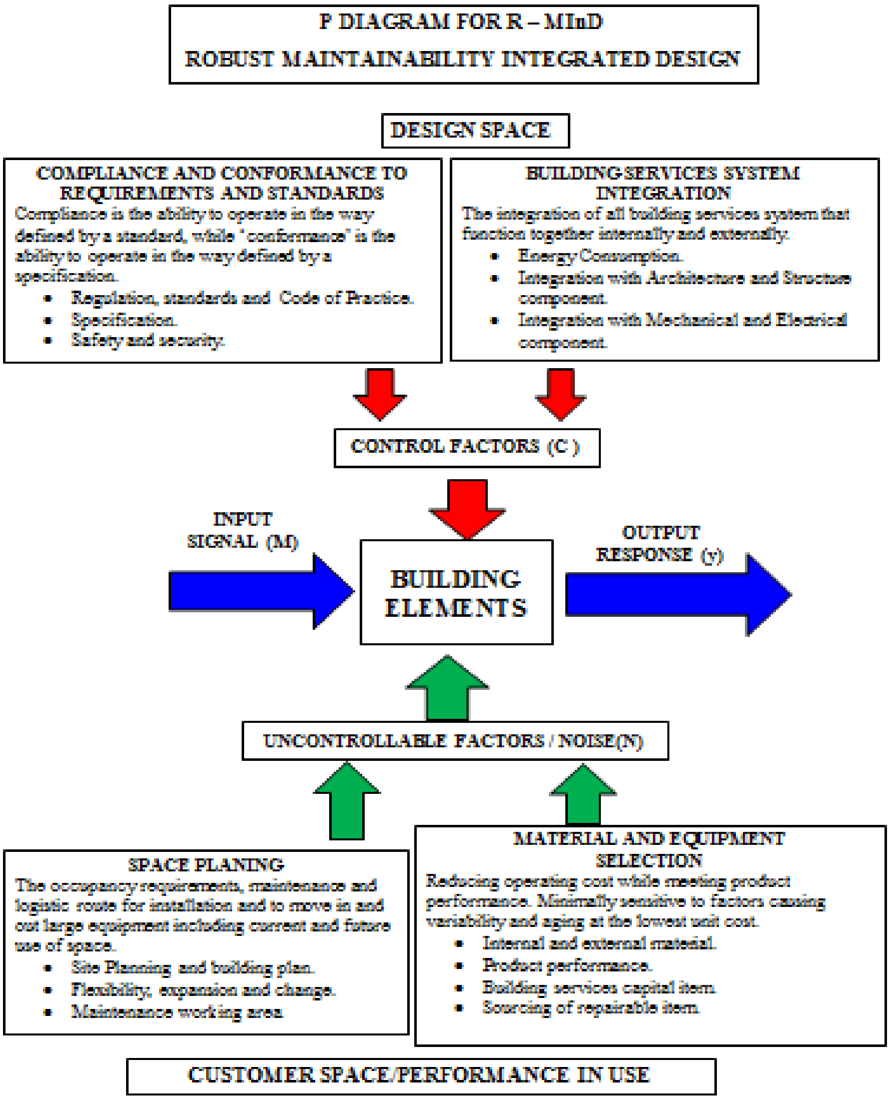

Figure 3. Multidimensional diagnosis system for Robust Maintainability Integrated Design (R-MInD) for building design

Conclusion

To improve building designs, a structured approach that focuses on meeting users’ expectation in terms of maintenance related considerations; is being highlighted. An efficient and effective approach that takes into consideration important elements in design will enhance design outcome. Better building design requires designers’ interactions at design stage to facilitate designers in using information for their designs. The finding of this study suggests that the engineering focus factors and maintainability factors influence a Robust Maintainability Integrated Building Design.

References

[1] B. Wood, Maintenance Integrated Design and Manufacture of Buildings: Toward a Sustainable Model,Journal of Architectural Engineering, 18 2012 192–197.

[2] I. J. Ikpo,Maintainability indices for public building design, Journal of Building Appraisal, 4 2009 321–327.

[3] B. Stewart, How Buildings Learn: What happens after they're built. New York, USA, Penguin Books, 1994.

[4] I. Neza and M. I. Mohamad, Identification of Maintenance Related Issues as Noise Strategy in Building Design, Jurnul Teknologi, 68(4) 2014 61–67.

[5] I. Neza and M. I. Mohamad, The Potential Application of Robust Engineering Principle to Capture Building Maintainability Requirements at Design Stage, in International Conference on Robust Quality Engineering, April 24-25, 2013 84–87.

[6] N. A. Kartam, Making Effective Use of Construction Lessons Learned in Project Life Cycle, Journal of Construction Engineering Management., 122(1) 1996 14–21.

[7] K. . Joreskog and H. Wold, The ML and PLS techniques for modeling with latent variables:historical and comparative aspects, in *System under indirect observation: causality, structure,prediction*, K. . Joreskog and H. Wold, Eds. Amsterdam, 1982 263–270.

[8] H. Wold, Model construction and evaluation when theretical knowledge is scace-theory and application of partial least square, in *Evaluation of Econometric Models*, J. Kmenta and J. . Ramsey, Eds. New York: Academy Press, 1980 47–74.

[9] W. W. Chin, The partial least squares approach to structural equation modeling, in *Modern methods for business research*, G. . Marcoulides, Ed. NJ: Erlbaum, 1998 295–336.

[10] J. F. Hair, G. T. Hult. M, C. M. Ringle, and M. Sarstedt, A primer on partial least squares structural equation modeling(PLS-SEM). California, USA: SAGE Publication Inc., 2014.

[11] J. Nunnally and I. Berstein, Psychometric theory. New York: McGraw Hill, 1994.

[12] J. F. Hair, W. C. Black, B. J. Babin, and R. E. Anderson, Multivariate Data Analysis, 7th ed. Upper Saddle River: Prentice Hall, 2010.