FACTORS IN BUILDING DESIGN THAT IMPROVE BUILDING MAINTAINABILITY IN MALAYSIA

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A building designed with good maintainability considerations not only functions as intended, but is also adaptable to current and future use. The purposes of incorporating good maintainability considerations into the design of a building 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 study identifies factors that improve building maintainability in building design by applying structural equation modelling with partial least square estimation (PLS-SEM) technique. Data collection method in this study includes an expert panel interview using prepared semi-structured interview questions and a questionnaire survey to identify the influencing factors to improve the maintenance-related needs of the building. Based on hypotheses derived from the expert panel interview, a structural model is developed using systematic procedures in the application of PLS-SEM technique. The population of interest is defined as building designers, including architects, civil, mechanical and electrical engineers, quantity surveyors, and client's technical and maintenance engineers. This study identifies five significant factors or variables that can enhance building designs, and in turn improve building maintainability in Malaysia. The most significant variable is developing efficient design tools that utilise information and analysis focusing on the user's usage behaviour.

Keywords: building maintainability consideration, building performance, design management, structural equation modelling, partial least square.

INTRODUCTION

A building designed with good maintainability considerations, not only functions as intended but is also adaptable to current and future use. 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 to future needs and maintain a stable usage cost throughout the building's design life. Lack of attention to maintainability considerations at the design stage may lead to difficult and costly operation to users; hence users' expectation may not be achieved (Nicolella 2014; Wood 2012; Williamson *et al*. 2010; Ikpo 2009). As a result of fragmented work processes coupled with building designers' focus on meeting statutory and safety requirements; maintainability needs are considered as a trade-off and deemed less important (Neza and Mohamad 2014).

Current building designs rely on the designers' experiences and lessons learned from previous projects (Omigbodun 2001; Kartam 1996; Stewart 1994). To improve designs, a structured approach that focuses on meeting users' expectation in terms of

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maintenance-related considerations is highlighted. Many studies on construction industry's productivity concluded that improving the maintainability of buildings will yield significant impacts in long-term use of the buildings (Egan 1998, 2010; Fairclough 2002; Construction 21 Report 1999; Latham 1994). In Singapore, for example, the Construction 21 Report (1999) identified improving maintainability as the core strategic method in situations where resources are limited. The report outlined eight potential factors that improve building maintainability. The factors are life-cycle cost (LCC), rating individual devices for maintainability, longer defect liability period, designers' and suppliers' role in providing information on construction methods and materials, use of Design and Build (D&B) procurement system, the availability of LCC data, developing guidelines, and improving training programmes. The eight factors fall into three main areas, which are: Competencies Development, Method and Database Development and Procurement Strategy.

A study by Silva (2004) using the same factors or variables reflected the importance of ensuring designer's competency through basic knowledge, continuous training and formulating a holistic method that focuses on building performance while in use rather than focusing on satisfying the current code of practice and client's needs. Arditi and Nawakorawit (1999) also stressed the importance of designer's competency along with efficient and effective methods; to enable informed decisions during the design stage. The approach in building design must be efficient in using project information and, effective in analysis that focuses on high engineered quality and good product performance. Procument strategy must take into account the need to include a reliable design team from the beginning until operation stage, to ensure high maintainability building. The above discussion and interview with experts lead to the following hypotheses:

> H1, a collaborative team approach in building design has a direct positive effect in improving designer's competency development.
> H2, a collaborative team approach in building design has a direct positive effect in producing designs with improved building maintainability.
> H3, a collaborative team approach in building design has a direct positive effect in the efficient use of information and effective design method.
> H4, designer's competency development has a direct positive effect in improving building maintainability at the design stage.
> H5, efficient use of information and effective analysis in building design has a direct positive effect in producing designs with improved building maintainability at the design stage.
> H6, an integrated procurement system has a direct and positive impact on improving building maintainability.
> H7, product performance evaluation has a direct and positive impact on improving building maintainability.

The above relationships given in the hypotheses are presented in a structural model in Figure 1. The items in rectangular boxes represent observed variables or the item's measurements according to the answers from the questionnaire (see Table 1). The latent variable (LV) *"Collaborative Design Team (CDesign)"* is measured by a three-item measurement (i.e., the rectangular box), *"Designer Competency Development (DComp)"* is measured by a four-item measurement, *" Information and Method of Use (InfoMethod)", " Integrated Acquisition System (Integrated)"* and *" Product Performance (PP)"* are measured by a two- item measurement; and *" Improve Building Maintainability (HMB)"* is measured by a five-item measurement.

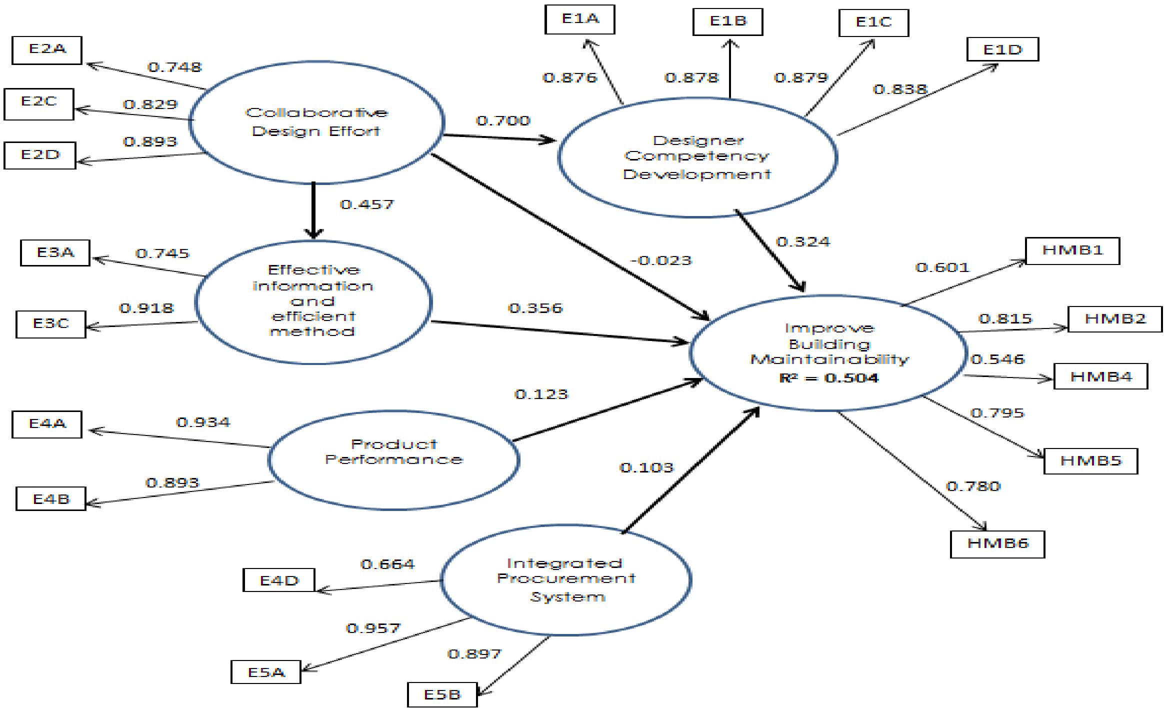

Figure 1: Structural model of the factors to improve building maintainability in the design stage

RESEARCH METHOD

Structure Equation Modelling Partial Least Square (PLS-SEM)

PLS-SEM is a second generation multivariate technique (Fornell and Cha 1994) which can simultaneously evaluate a measurement model (the relationships between constructs and their corresponding indicators), and a structural model with the aim of minimising error variance (Chin 1998). PLS-SEM was developed by Joreskog and Wold (1982), and Wold (1980). It has the capability of working with unobservable LVs and can account for measurement error in the development of LVs (Chin 1998). The estimation procedures in PLS-SEM use the ordinary least - square regression-based method, which estimates the path relationships with the objective of minimising the error term while maximising the R square value to achieve the predicted objectives (Hair *et al*. 2014). PLS-SEM works efficiently with small sample size and complex model while making practically no assumption about the underlying data in terms of data distribution. PLS-SEM makes use of resampling methods to determine the confidence interval of the model parameters by using a random subset of data such as bootstrapping. Bootstrapping is a robust alternative to statistical inference based on parametric assumptions such as normality when the assumptions are in doubt (Mooney and Duval 1993). When the research has an interactive character as in the case of incremental study, which is based on new measures and structural path, PLS-SEM is deemed more appropriate. In this respect, these statements are confirmed by Reinartz *et al*. (2009) that, PLS-SEM is the preferable approach when researchers focus on prediction and theory development.

Data Collection

The systematic procedures for applying the PLS-SEM are shown in Figure 2. The data collection method in this research includes an expert panel interview using a prepared semi-structured interview questions and questionnaire survey to identify the current design focus, the main problems during building operations and the key variables to improving the maintenance-related needs of a building. The population of interest is defined as building designers, including architects, civil, mechanical and electrical engineers, quantity surveyors, and client's technical and maintenance engineers. Data collection was conducted from early April 2013 to the end of May 2013. The questionnaires were handed out to the design engineers and collected immediately after they were completed. Of the 250 questionnaires sent, 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 the private sector represented 45.9% of responses. All respondents are involved in design tasks with 67% of respondents rated themselves as being competent in building maintenance.

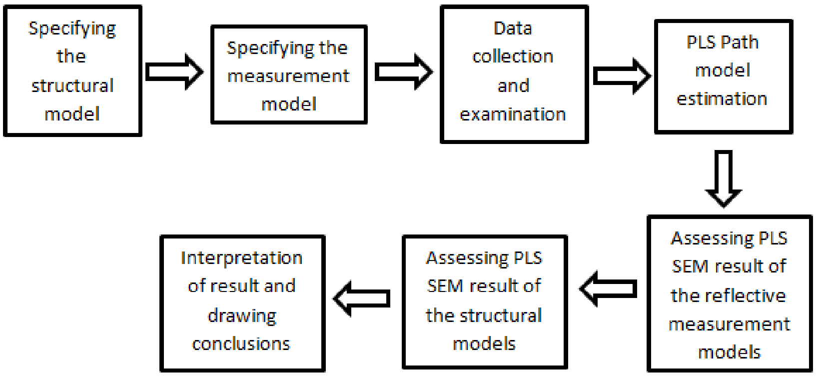

Figure 2. A Systematic Procedure for applying PLS-SEM (Adapted from Hair et al. 2014)

MODEL TESTING AND RESULTS

Measurement model testing

Smart PLS M2, Version 2.0 (Ringle *et al*. 2005) software was used to analyse the data. The two main criteria used for testing the goodness of measures are validity and reliability. Reliability is a test of how consistently an instrument measures a concept while validity is a test of how well an instrument measures the particular concept it is intended to measure (Sekaran and Bougie 2010). The adequacy of the model was evaluated using individual item reliability analysis, convergent validity and discriminant validity. The first criterion to be evaluated is typically the internal consistency reliability (Hair *et al*. 2014). 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 would be regarded as satisfactory (Nunnally and Berstein 1994). Table 2 shows that the composite reliability has a value of between 0.821 and 0.924, which is acceptable. The value for a loading of 0.5 is considered significant (Hair *et al*. 2010). All loadings are shown to be higher than 0.5, which can thus be regarded as satisfactory. Construct validity describes how well the result obtained from the measurement fits the theories around which the test is designed (Sekaran and Bougie 2010). This can be assessed through convergent and discriminant validity. A loading of 0.5 is considered significant (Hair *et al*. 2010) and individual reliability of the item can be assessed by observing the loading. All items measuring a particular construct were highly loaded on that construct and loaded less on the other constructs, thus confirming the construct validity.

Table 1. Operationalisation of independent latent variables

Latent Variable (LV)	Item Code	Description of measurement item (indicator)
Collaborative Design Effort	E2A	Design team consists of multidisciplinary members and future building maintenance team assembled at the planning stage to help develop the project brief.
	E2C	Translating of needs statement of clients into design information with which the building maintenance team will produce a clearly defined project needs statement in terms of building maintainability needs.
	E2D	The multidisciplinary design team must include a building manager in the design stage to identify building maintainability needs.
Designer Competency Development	E1A	Provide training and development programmes on building maintainability needs for building designers.
	E1B	Provide building maintenance curriculum at universities and for all technical institutions.
	E1C	The construction industry to promote an accredited professional design review on maintainability of the building.
	E1D	Building designers must evaluate the performance of the buildings they designed.
Improve Building Maintainability	HMB1	Low unplanned maintenance.
	HMB2	Minimum downtime of equipment.
	HMB4	Minimum downtime of building system and subsystem.
	HMB5	Ease of procurement of spare parts and components.
	HMB6	Predictable maintenance cost.
Effective information and efficient method	E3A	Make available enough performance and cost data.
	E3C	The design team identifies important information to carry out products that meet users' needs at once.
Integrated Procurement System	E4D	Extend the defects liability period of buildings or beyond the current period.
	E5A	The client chooses a successful tender based on whole life cycle cost rather than just initial cost.
	E5B	Value analysis and Life Cycle Cost analysis for material and equipment selection.
Product Performance	E4A	The design team focuses on products which are minimally sensitive by selecting material, equipment and integration.
	E4B	Many design arrangements tried or tested under a few users' conditions to reduce rework, defect and unplanned maintenance instance.

Note : All Response options 1-5: 1=Least Important to 5= Extremely Important

Convergent validity is the degree to which multiple items that measure the same concept are in agreement. As suggested by Hair *et al.* (2010), the factor loadings, composite reliability and the average variance extracted were used to assess convergent validity. The loadings for all items exceeded the recommended value of 0.5 (Hair *et al.* 2010). Composite reliability (CR) (see Table 2) that depicts the degree to which the construct indicators indicates the latent construct, ranged from 0.821 to

0.924, which exceeded the recommended value of 0.7 (Hair *et al*. 2010). The average variance extracted (AVE) measures the variance captured by the indicators relative to the measurement error and should be greater than 0.5 to justify using a construct (Barclay *et al*. 1995). The average variance shown is in the range of 0.513 to 0.835. The results in Table 2 demonstrate convergent validity and good internal consistency within the measurement model.

Table 2. Result of the measurement model

Construct	Item	Loading	AVE	CR
Designer's Competency	E1A	0.876	0.753	0.924
	E1B	0.878		
	E1C	0.879		
	E1D	0.838		
Collaborative Design Effort	E2A	0.748	0.681	0.865
	E2C	0.829		
	E2D	0.893		
Effective information and Efficient Method	E3A	0.745	0.699	0.821
	E3C	0.918		
Integrated Procurement System	E4D	0.664	0.720	0.883
	E5A	0.957		
	E5B	0.897		
Product Performance	E4A	0.934	0.835	0.910
	E4B	0.893		
Improved Building Maintainability	HMB1	0.601	0.513	0.837
	HMB2	0.815		
	HMB4	0.546		
	HMB5	0.795		
	HMB6	0.780		

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)}

After confirming the convergent validity, the discriminant validity was assessed using Fornell and Larcker (1981) method. Discriminant validity is the degree to which items differentiate between constructs or measure distinct concepts. The items should load stronger on their own construct in the model and the average variance shared between each construct and its measures should be greater than the variance shared between the construct and other constructs (Compeau *et al*. 1999). The square root of the AVE of each LV should be larger than the correlation between the two variables. As shown in Table 3, square root of the AVE, which is shown on the diagonals, is greater than the values in the row and columns on that particular construct, then it can be concluded that the measures are discriminant. From Table 3, it is shown that the values in the diagonals are greater than the values in their respective row and column, thus indicating the measures used in this study are distinct.

Table 3. Discriminant validity of constructs

	CDesign	DComp	HMB	Info/ Method	Integrated	PP
Cdesign	0.825					
Dcomp	0.700	0.868				
HMB	0.435	0.625	0.716			
Info/ Method	0.457	0.655	0.647	0.836		
Integrated	0.166	0.387	0.274	0.172	0.849	
PP	0.416	0.362	0.428	0.582	0.095	0.914

Note: Diagonals value represents the square root of the AVE and the off-diagonals value represents the correlations

Structural model testing

Figure 1 shows the path coefficients and R square, The value of R square of the Improving Building Maintainability construct was 0.504, suggesting that 50.4% of the variance can be explained by the five predictors, namely Collaborative Design Effort (CDesign), Designer Competency Development (DComp), Effective Information and Efficient Method (InfoMethod), Integrated Procurement System (Integrated) and Product Performance (PP).

Table 4. Result of structural model

Hypothesis	Relationship	Std Beta	SE	t value	Decision
H1	CDesign --> DComp	0.700	0.039	19.254	Supported
H2	CDesign --> HMB	-0.023	0.129	0.170	Not Supported
H3	CDesign --> InfoMethod	0.457	0.064	6.923	Supported
H4	DComp --> HMB	0.324	0.130	2.308	Supported
H5	InfoMethod --> HMB	0.356	0.105	3.228	Supported
H6	Integrated --> HMB	0.103	0.090	1.312	Supported
H7	PP --> HMB	0.123	0.088	1.290	Supported

Cutoff value for significant level $p < 0.10$, one tail = 1.28

Using a bootstrapping technique with a re-sampling of 500, the path estimates and t-statistics were calculated for the hypothesised relationships. Hypothesis testing was achieved by comparing the path coefficients (β) between each LV: the higher the path coefficient, the stronger the effect of the predictor LV on the dependent variable. A summary of the hypothesis testing is shown in Table 4. The hypothesis is considered upheld based on the conventional significance level of 0.10. Table 4 shows that only H2 path is not significant while the others are shown to be significant.

FINDINGS AND CONCLUSION

The findings of this study present some useful insights for improving building maintainability during the building design stage. First, the fragmented nature of the building design process is clearly illustrated in the analysis, for respondents do not believe that a collaborative design team will enhance building maintainability. Current design activities are executed independently by each discipline and the coordination is usually made during several technical meetings. This typically leads to significant rework of the design to suit each discipline's needs, often leaving maintenance-related needs to be overlooked. Most of the design activities produced workable designs that integrate every discipline's requirements and as a result, the building maintainability element is left to the facility operator to manage and mitigate the setbacks of the design at the operational stage. The focus is on building design for delivery only and typically does not address ease of usage, maintenance-related considerations and building adaptability in the operational stage. The typically fragmented nature of the building design team will significantly improve design results when the design is executed in a collaborative setting, particularly when communication is efficient and experience is shared, improving designer's competency.

Current building designs rely on the experience of the designers and lessons learned from previous projects. Often, there are no specific guidelines and procedures to incorporate the maintenance requirements of a building. Maintainability-related needs are based on the experience of the designers, and it is assumed that all designers have the experience of producing building designs that consider maintenance issues fully. Respondents in this study strongly agreed that a collaborative design team would influence the development of designer's competency and the use of efficient information and methods. Better building designs require designers' interactions at the design stage to facilitate how they use information for their design. For example, a structural engineer may use floor area to calculate the loading (i.e., a structure element), while a mechanical engineer may use the floor area for the computation of heat, ventilation and air conditioning requirement (i.e., user comfort). An electrical engineer may use the area to consider the lighting requirement in his or her design (i.e., another aspect of the user comfort), while the architect is concerned with the form and function of the area (i.e., whether it will create a complication between the structure and ventilation). Therefore, collaborative design will facilitate the translation of client's needs into design information, producing a clearly defined project needs in terms of the maintainability of the building. A design team consists of multidisciplinary members and future building maintenance team assembled at the planning stage; can help develop a project to identify its construction and building maintainability needs.

In the measurement model, *"focus on critical product information"* is shown to have the most influence (0.918) compared to *"use of product performance and cost data"* (0.745). A holistic approach and design tools that focus on product performance are needed to improve building maintainability. The conservative view of building design ensures compliance with the law for safety and meeting the cost agreed with the clients. It also satisfies the basic needs of the building. While pressure to speed up production in terms of design and construction increases, the clients also expect high-quality designs, ease of building maintenance, and stable cost of operations. Therefore, a more efficient design method is needed. A design with low maintenance-related consideration significantly lowers building performance.

The current design approach in construction is seen as inefficient in producing building designs with high operational performance. The building design result also typically lacks performance evaluation, which is typically the ease of building operation and maintenance. In manufacturing, improvement in terms of product design, construction and assembly have been realised by utilising an improved production philosophy. The manufacturing product development approach has gained improvement in terms of product design and has become the main reference to learn from and apply to in the construction industry. A method such as the Robust Engineering (RE) approach in manufacturing has been shown to improve the product's engineered quality and performance. One of the most important considerations in design is ensuring product performance, which is the ability to identify the problems affecting a product while in operation. Adapting this manufacturing approach to building design could espouse the same benefits for the construction industry as it has for the manufacturing industry.

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