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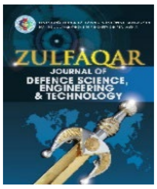

ENABLERS FOR BUILDING DESIGN OUTCOME WITH HIGH MAINTAINABILITY CONSIDERATION FROM DESIGN ENGINEERS PERSPECTIVES

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ABSTRACT

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 enablers that enhance building maintainability considerations in building design by applying structural equation modelling with the partial least square estimation (PLS-SEM) technique. The data collection methods in this research include 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. This study identifies five significant enablers that could improve building design outcome by enhancing building maintainability considerations in Malaysia. The most significant enablers are developing efficient design tools that utilize information and analysis focusing on the user's usage behaviour.

1.0 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 consideration into building design 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. There is a need to identify the enablers that influence a building's maintainability. This study identifies enablers that improve building maintainability in building design by applying structural equation modelling with the partial least square estimation (PLS-SEM) technique. PLS-SEM was developed by Joreskog and Wold [1-2]. PLS-SEM analysis was employed to test the model developed in Figure 1.

Many studies of the construction industry's productivity concluded that improving the maintainability of buildings will yield significant impacts in the long-term use of buildings [3-7]. In Singapore, for example, the Construction 21 Report identified improving maintainability as the core strategic method in situations where resources are limited. The report outlined eight enablers that have high impact to improve building maintainability: life-cycle cost (LCC), rating individual devices for maintainability, a longer defect liability period, designers and suppliers' role in providing information of construction methods and materials, use of a Design and Build (D&B) procurement system, the availability of LCC data, developing guidelines, and improving training programmes. Silva et al. (2004) conducted a study and survey of these eight enablers in Singapore's construction industry [9]. The eight enablers fall into three main areas: Competencies Development, Method and Database Development and Procurement Strategy. In concluding their findings two main enablers that are important to improve the level of maintainability of buildings are: 1) knowledge of maintainability: and 2) setting a benchmark for maintainability. This

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finding reflects the importance of ensuring designer's competencies 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 needs.

Arditi and Nawakorawit (1998, 1999) also stressed the importance of designer competency along with efficient methods and guidelines to enable informed decisions during the design stage [10]. An inherent maintenance problem in buildings is attributed to the lack of consideration in the code of practice [1, 9-18]. Lack of attention to maintainability considerations at the design stage may lead to difficult and costly operation to users; users' expectation may be unachievable. Because most building designers focus on meeting statutory and safety requirements, maintainability needs are considered as a trade-off and deemed less important [19-21]. The above discussion leads the author to formulate the following hypotheses:

Hypothesis 1: A collaborative team approach in building design has a direct positive effect in improving designer competency development.

Hypothesis 2: A collaborative team approach in building design has a direct positive effect in producing designs with improved building maintainability.

Hypothesis 3: A collaborative team approach in building design has a direct positive effect in the efficient use of information and effective design method.

Hypothesis 4: Designer competency development has a direct positive effect in improve building maintainability at the design stage.

Maintainability describes how easily a system can be maintained while optimising the use of space and equipment with minimum interruption to users of a building [22]. BS 3811:1984 define maintenance as: "The combination of all technical and associated administrative actions intended to retain an item in, or restore it to, a state in which it can perform its required function". A design that does not consider building maintenance has a significant deleterious effect on building performance. Current building designs rely on the experience of the designers and the lessons learned from previous projects [17, 23-24]. To improve designs, a structured approach that focuses on meeting users' expectation in terms of maintenance-related considerations is highlighted. The approach must be efficient in using project information and effective in analysis that focus on high engineered quality and good product performance. The above discussion leads to the following hypotheses:

Hypothesis 5: 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.

Hypothesis 6: An integrated procurement system has a direct and positive impact on improving building maintainability.

Hypothesis 7: Product performance evaluation has a direct and positive impact on improving building maintainability.

2.0 METHODS

SEM is a second-generation multivariate data analysis method. Multivariate analysis involves the use of statistical methods simultaneously examining the relationship between various exogenous (independent) and endogenous (dependent) latent variables in a model. A latent variable (LV) is responsible for the correlation between certain measured variables. The SEM approach seeks to explain the relationship between a set of variables in which it examines the "structure" of each set in a series of equations: this is like a series of multiple regression equations. In Figure 1, the straight arrow displays the hypothesised relationships between independent and dependent LVs. The values that can be seen in Figure 1 (e.g., 0.700, 0.324, 0.457, 0.356, -0.023, 0.123 and 0.103) are like the path coefficients in path analysis. The items in rectangular boxes represent observed variables or the item's measurements according to the answers from the questionnaire (see Table 1). In Figure 1, the latent variable "CDesign - Collaborative Design Team" is measured with a three-item measurement (i.e., the rectangular box), "DComp - Designer Competency Development" is measured by a four-item measurement; "InfoMethod - Information and

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Method of Use", "Integrated - Integrated Acquisition System" and "PP - Product Performance" are measured by a two- item measurement: and "HMB- Improve Building Maintainability" is measured by a five-item measurement. The line with one arrowhead linking the measurement item to the LVs represents the relationship between each of the measurement items and the LV it measures. The relationship on the line (i.e., (0.748, 0.829, 0.893 for CDesign), (0.746, 0.918 for Info Method), (0.601, 0.815, 0.546, 0.795, 0.780 for HMB)) is the loading of each item to the construct.

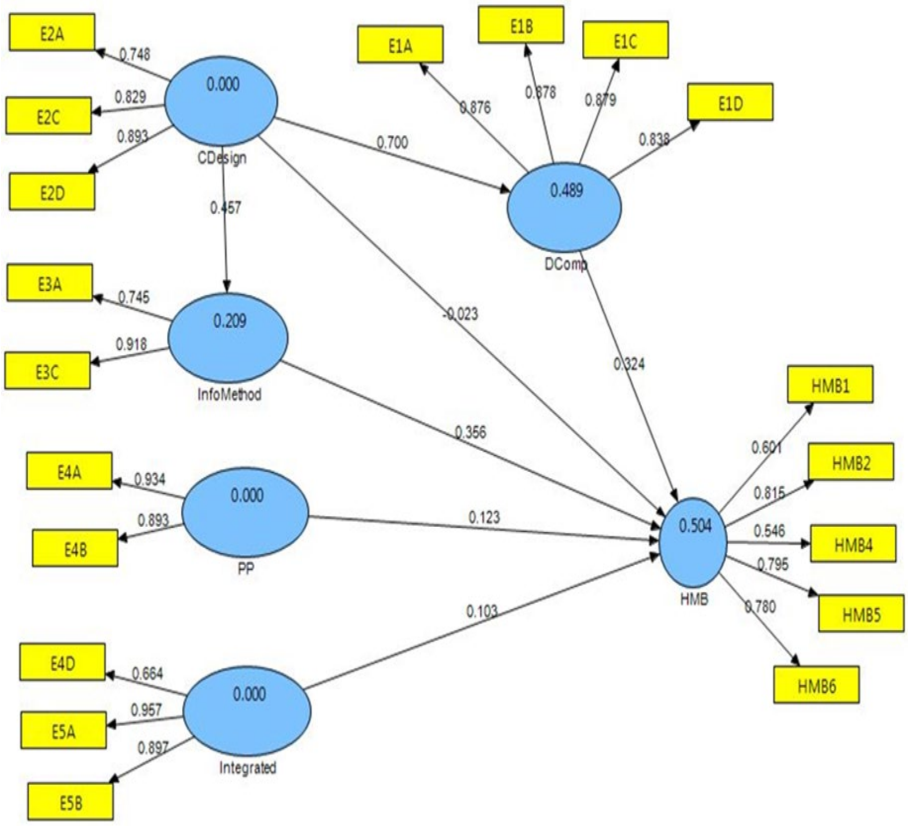

Figure 1. Structural model of the factors to improve building maintainability in the design stage

The systematic procedures for applying the PLS-SEM are shown in Figure 2. The process starts with the specification of structural and measurement models, followed by the collection and examination of data in terms of reliability and validity. When the data are considered reliable and valid the evaluation of structural model is done using the bootstrapping method with 500 re-samplings was used to determine the significance levels of loadings, weights, and path coefficients.

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 the maintainability needs of the building.
	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

Latent Variable (LV)	Item Code	Description of measurement item (indicator)
		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 user 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 just the 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

The data collection methods in this research include an expert panel interview using prepared semi-structured interview questions and a 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. In the questionnaire survey, two groups comprising the public sector and private consulting firms were selected. The selected public sector group was based on the nature of the organisation's core tasks, which include executing building design and building maintenance operations. The private sector group that was chosen are primarily design firms, which have extensive experience in building design. The population of interest is defined as building designers, including architects, civil, mechanical and electrical engineers, quantity surveyors, and client technical and maintenance engineers. The first part of the questionnaire was designed to reflect the profiles of the organisations and respondents. The second part was aimed at evaluating the engineers' views on current incorporation of maintenance consideration and needs in building design. The third part was to identify important maintenance related needs in the design process to increase the maintainability of buildings. The fourth part focused on this study's objective to identify the influencing factors to increase buildings' maintainability at the design stage. The structural model of the influencing factors is shown in Figure 1 while the questions or indicators of the six latent variables are shown in Table 1. Smart PLS M2, Version 2.0 software was used to analyse the data [25]. Following the suggestions of some researchers, the bootstrapping method with 500 re-samplings was used to determine the significance levels of loadings, weights, and path coefficients [26-28].

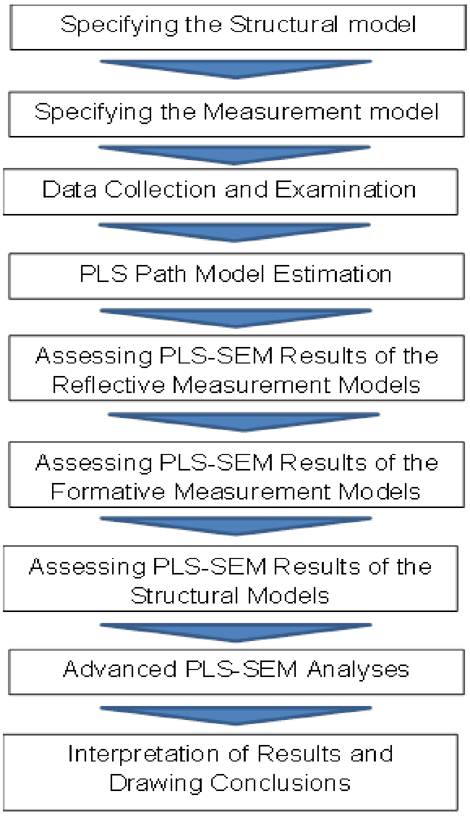

Figure 2. A systematic procedure for applying PLS-SEM [29]

3.0 RESULTS AND DISCUSSIONS

3.1 Measurement Model Testing

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 concept it is intended to measure [30]. The adequacy of the model was evaluated using individual item reliability analysis, convergent validity and discriminant validity.

The questionnaires were handed out to the design engineers and collected immediately after they were completed. Of the 250 questionnaires sent, 111 responses 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 were involved in design tasks with 67% of respondents rating themselves as competent in building maintenance. In terms of work experience, 9.0% have less than five years of experience; 18.9% have 6 to 10 years of experience; 20.7 % have 11 to 15 years of experience, 28.8% have 16 to 20 years of experience and 22.5% have more than 21 years of experience. The field of discipline included architects (1.8%), civil engineer (31.5%), mechanical engineer (33.3%), electrical engineer (32.4%) and others, which included project managers and quantity surveyor (0.9%). The services that the respondents' organisations provide included - architectural design (25.2%), civil engineering design (61.3%), mechanical engineering design (69.4%), electrical engineering design (73.9%), building equipment design (50.5%), infrastructure design (71.2%), and project management (13.5%).

The first criterion to be evaluated is typically the internal consistency reliability [30]. The main criterion used for internal consistency is Cronbach's alpha, which provides an estimate of the reliability based on the interrelations of the observed indicator variable. Due to the limitations of Cronbach's alpha in the population, it is more appropriate to use a composite reliability (ρc) to measure the internal consistency reliability. 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 [31]. Table 2 below shows that the composite reliability has a value of between 0.821 and 0.924, which is acceptable. The loading of all items is tabulated in Table 2. The value for a loading of 0.5 is

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considered significant [32]. All loadings are shown to be higher than 0.5, which can thus be regarded as satisfactory. Out of the 26 total items used to measure the latent variables, seven (27%) were deleted as they were found to be below 0.5.

Table 2. Result of reliability test

Constructs	Measurement items	CR	Loading range	Number of items*
Collaborative Design Effort	E2A, E2C, E2D	0.865	0.748-0.893	3(4)
Designer Competency Development	E1A, E1B, E1C, E1D	0.924	0.838-0.879	4(4)
Improve Building Maintainability	HMB1, HMB2, HMB4, HMB5, HMB6	0.837	0.546-0.815	5(6)
Effective information and efficient method	E3A, E3C	0.821	0.745-0.918	2(5)
Integrated procurement system	E4D, E5A, E5B	0.883	0.890-0.965	3(3)
Product Performance	E4A, E4B	0.910	0.893-0.934	2(4)

*final item (initial item)

Construct validity describes how well the result obtained from the measurement fits the theories around which the test is designed [30]. The instrument must measure the concepts as theorised. This can be assessed through convergent and discriminant validity. The loadings of all items are tabulated in Table 3. A loading of 0.5 is considered significant [32]; the 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 3: Loadings and cross loadings

	CDesign	DComp	HMB	Info/ Method	Integrated	PP
E1A	0.483	**0.876**	0.685	0.718	0.485	0.323
E1B	0.669	**0.878**	0.506	0.459	0.313	0.357
E1C	0.768	**0.879**	0.505	0.537	0.160	0.314
E1D	0.466	**0.838**	0.471	0.570	0.427	0.253
E2A	**0.748**	0.371	0.235	0.291	-0.203	0.430
E2C	**0.829**	0.565	0.352	0.268	0.389	0.155
E2D	**0.893**	0.717	0.443	0.515	0.141	0.446
E3A	0.237	0.478	0.411	**0.745**	0.498	0.222
E3C	0.481	0.607	0.636	**0.918**	-0.061	0.660
E4A	0.384	0.324	0.432	0.503	-0.037	**0.934**
E4B	0.378	0.341	0.343	0.571	-0.150	**0.893**
E4D	0.050	0.267	0.047	0.066	**0.664**	-0.005
E5A	0.068	0.390	0.308	0.221	**0.957**	-0.088
E5B	0.296	0.317	0.210	0.083	**0.897**	-0.101
HMB1	0.169	0.416	**0.601**	0.332	0.398	0.273
HMB2	0.367	0.602	**0.815**	0.500	0.297	0.168
HMB4	0.383	0.405	**0.546**	0.344	0.142	0.088
HMB5	0.048	0.272	**0.795**	0.521	0.211	0.399
HMB6	0.546	0.509	**0.780**	0.576	-0.026	0.546

Convergent validity is the degree to which multiple items that measure the same concept agree. As suggested by Hair et al. (2010), the factor loadings, composite reliability and the average variance extracted were used to assess convergent validity [32]. The loadings for all items exceeded the recommended value of 0.5. Composite reliability (CR) (see Table 2) that depicts the degree to which the construct indicators indicate the latent, construct range from 0.821 to 0.924, which exceeded the recommended value of 0.7 [32]. 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 [33]. The average variance shown is in the range of 0.513 to 0.835. The results in Table 4 demonstrate convergent validity and good internal consistency within the measurement model. This implies that the measurement items of each latent variable are measuring as intended and not measuring other latent variables in the model.

Table 4. Result of the measurement model

Construct	Item	Loading	AVE	CR
Designer 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
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 the Fornell and Larcker's (1981) method [34]. Discriminant validity is the degree to which items differentiate between constructs or measure distinct concepts. The criterion used to assess this compared the AVE with the squared correlations or the square root of the AVE with the correlations. The items should load more strongly 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 [35-36]. The square root of the AVE of each latent variable should be larger than the correlation between the two variables. As shown in Table 5, the second method was utilised which compared the square root of the AVE with the correlations. The criteria used stated that if the square root of the AVE, which is shown on the diagonals, is greater than the values in the row and columns on that construct, then it can be concluded that the measures are discriminant. From Table 5, 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. Consequently, the results presented in Tables 4 and 5 demonstrate an adequate discriminant and convergent validity. This shows that the discriminant validity test does not reveal any serious problems and all latent variables are different from each other.

Table 5. 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 (in bold) value represents the square root of the AVE and the off diagonals represent the correlations

3.2 Structural Model Testing

With satisfactory reliability and validity of the measurement model, the structural model is assessed to determine the explanatory power of the model and is used to test the above hypotheses. Figure 1 shows

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the path coefficients and R^2 while Figure 3 shows the bootstrapping results generated by the SmartPLS software. The value of R^2 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). DComp has one predictor (CDesign) with 48.9% of the variance being explained by CDesign. InfoMethod has one predictor, namely CDesign with an R^2 value of 0.209, suggesting that 20.9% of the variance can be explained by CDesign.

Validation of the structural model is conducted using path analysis of the model. Each path (see Figure 1) corresponds to a hypothesis. Using a bootstrapping technique with a re-sampling of 500, the path estimates, and t-statistics were calculated for the hypothesised relationships. Tests of the hypotheses were achieved by comparing the path coefficients (β) between each latent variable: 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 6. The hypothesis is considered upheld based on the conventional significance level of 0.10. Table 6 shows that only H2 path is not significant while the others are shown to be significant. CDesign effort is shown to have a positive influence on designer competency development. However, CDesign was not a significant predictor to improve building maintainability. This shows that DComp has a mediating effect against CDesign.

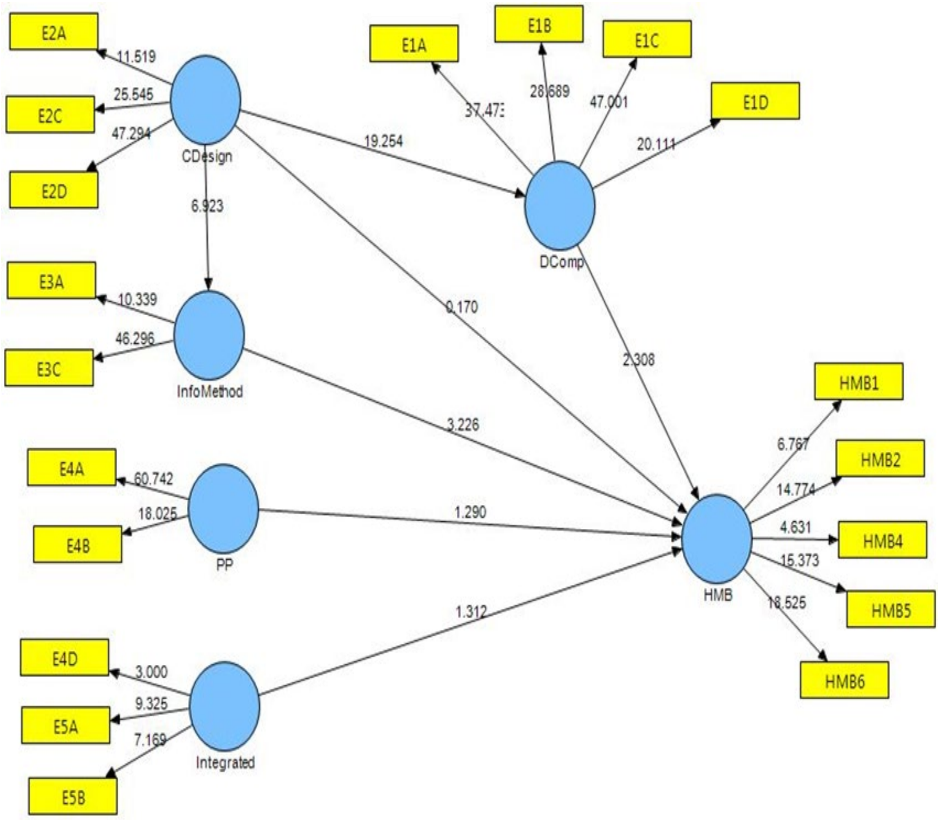

Figure 3. Result of bootstrapping procedure using smartPLS software

Table 6. Result of structural model

Hypotheses	Relationship	Std Beta	SE	t value	Decision
Hypothesis 1	CDesign -> DComp	0.700	0.039	19.254*	Supported
Hypothesis 2	CDesign -> HMB	-0.023	0.129	0.170	Not Supported
Hypothesis 3	CDesign -> InfoMethod	0.457	0.064	6.923*	Supported
Hypothesis 4	DComp -> HMB	0.324	0.130	2.308**	Supported
Hypothesis 5	InfoMethod -> HMB	0.356	0.105	3.228*	Supported
Hypothesis 6	Integrated -> HMB	0.103	0.090	1.312***	Supported
Hypothesis 7	PP -> HMB	0.123	0.088	1.290***	Supported

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

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3.3 Measurement Model

Building with high maintainability were described using five measurement items. The loading of the individual measurement items in order of decreasing influence are “low unplanned maintenance” (0.815), “ease of procurement” (0.795), “predictable maintenance cost” (0.78), “ease of cleaning, replacing and repair” (0.601) and “minimum system downtime” (0.546). Designer competency development was measured by four survey questions and in order of decreasing influence are “accredited professional” (0.879), “incorporating new curricular in university” (0.878), “continuous competency development” (0.876) and “design evaluation at post construction stage” (0.838). Collaborative design effort was measured by three aspects, which were “design team is part of the maintenance team” (0.893), “design focused on maintenance needs” (0.829) and “design in multidisciplinary setting” (0.748).

Two items were used to measure the efficient use of information and the method, namely “the use of product information and cost” and “focus on critical product information". Of the two, “focus on critical product information” carried the most influence (0.918) compared to “use of product performance and cost data” (0.745). “Focus on product performance in use” was also measured with two items, namely “minimally affected by user environment” and “test under user condition". Of the two, the former had the most influence (0.934) compared to the latter (0.893). Integrated procurement systems were measured by three survey questions: in order of decreasing influence, the results show that “based on whole life cycle” had the most influence (0.957), followed by “value analysis” (0.897) and “extended defect liability period” (0.664).

3.4 Structural Model

The structural model shows that a 50.4% improvement in building maintainability can be attributed to the five latent variables in the model. All paths are shown to be significant except for the collaborative design team. This study shows that “efficient use of information and method” is the most important influencing factor, followed by “designer’s competency development", “integrated procurement system” and “focus on product performance". It also shows that a collaborative design team influences the development of designer competency and the efficient use of information and method.

4.0 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 overlooked. Most of the design activities produced workable designs that integrate every discipline’s requirement 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 competency.

Current building designs rely on the experience of the designers and lessons learned from previous projects. Often, there are no specific guideline and procedures to incorporate the maintenance requirements of a building. Maintainability-related needs are based on the experience of the designer, 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 competency and the use of efficient information and methods. Better building designs require interactions of designer at the design stage to facilitate how the designers 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 area (i.e., whether it will create a complication between the structure and ventilation). Therefore, collaborative design will facilitate the translation of clients' 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; this can help develop the project to identify 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 can 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 to 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 client also expects 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 utilizing 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. Among 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 to the construction industry as it has the manufacturing industry.

This study identifies five significant variables that could improve building design by improving building maintainability needs. The most significant variable is shown to be developing efficient design tools that utilise information and analysis that focus on user usage. The need to enhance designer competency through collaborative team effort is also vital to improve building maintainability needs.

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