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THE IDENTIFICATION OF DESIGN FOR MAINTAINABILITY IMPERATIVES TO ACHIEVE COST EFFECTIVE BUILDING MAINTENANCE: A DELPHI STUDY

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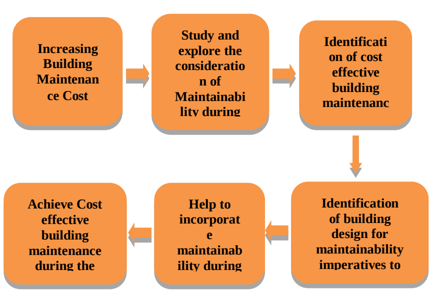
Graphical abstract



Abstract

Incorporating maintainability during the building design is essential to increase overall performance of the building including quality and cost as; the management and operation process of facilities can have a significant impact on cost, health and safety, energy and quality. As a result, a more effective and efficient building facility will be turned over during the post occupancy stage. Literature review reveals that there is a need to implement maintainability during the building design phase; mainly due to the increasing life-cycle cost of the building facilities. A critical review of the literature has been carried out to explore the consideration of maintainability during the building design and subsequently identifies a set of criteria and indicators to be applied during the building design phase to achieve cost effective building maintenance. Thus, this paper opted a four-round Delphi questionnaire survey to identify the relevant design for maintainability criteria and indicators to achieve cost effective building maintenance. 8 designs for maintainability criteria along with the indicators for each of the criterion have been identified. These design for maintainability indicators help the building architects to incorporate maintainability practice during the building design phase and thus help to achieve cost effective maintenance. This paper aims to address the long pending quest of incorporating maintainability during the building design phase and consequently achieve cost effective building maintenance.

Keywords: Facility management, building design, building maintainability, cost effective building maintenance

1.0 INTRODUCTION

Facility management (FM) encompasses multiple disciplinary activities that integrate people, place and technology within the context of built environment. FM is often viewed as representing a field of operational process that lies beyond design, construction and installation. However, FM input especially maintainability is renowned in lack of integration with the building design. This has been seen as one of the major factors contributing to various problems facing the building industry. This is based on the studies conducted by previous researches, whereby, these researchers have found that, many problems faced by building during the maintenance phase are the result of inconsideration of maintainability during the building design[1-2]. Among those problems are namely, building services related defects, early deterioration of building components, inadequate accessibility for repair, replacement and cleaning process and so on [3-5]. These increasing numbers of design deficiencies can be reflected through the lofty maintenance costs [6-9]. This is because, defects arising in a building often exhibit a chain effect, hinder performance, increase maintenance workloads and contribute to increasing maintenance cost [10-13]. Recognizing the increasing building maintenance cost due to inherent maintenance problems, building industry is moving forward on identifying the solution for this situation [14-15]. As a consequence, it is substantiating that; a better building design integrated with maintenance consideration during the building design phase can result in ease of maintenance to offset the soaring maintenance costs. For this statement, previous researchers have supported and stated that 'the incorporation of building maintenance into the building design denotes ease of maintenance through mitigation of defects and consequently contribute to reduce building maintenance cost and time [2, 9, 15-19].

This paper therefore intends to identify and establish the building design for maintainability criteria and indicators to help the building architects or designers to incorporate maintainability during the building design phase and consequently helps to achieve cost effective building maintenance. A four-round Delphi questionnaire survey was carried out with a group of eighteen experts within Malaysia in the field related with architecture, civil engineering, structural engineer, building service engineer, building maintenance or management, facility maintenance or management and quantity surveying in order to identify the relevant design for maintainability indicators to achieve cost effective building maintenance.

2.0 DESIGN FOR MAINTAINABILITY CRITERIA AND INDICATORS TO ACHIEVE COST EFFECTIVE BUILDING MAINTENANCE

Design for maintainability criteria referred to specific design related building maintenance features that are applicable for a building that being developed. These criteria constitute as an input to the building during its design process, with the aim to reduce the maintenance cost by increasing ease of maintenance and minimizing preventive and corrective maintenance. In accordance, the specific building design for maintainability criteria must be identified in order to lead to the fulfilment of maintainability requirements. This section discusses the significant building design for maintainability criteria and indicators which have been drawn from the available literature focusing on causes of problem and building defects occurring during the post occupancy stages. Indicators are viewed as indicating the characteristics of the criteria. Having maintainability criteria solely will create ambiguity in the consideration of maintainability decision during the building design phase. Therefore, the identification of design for maintainability indicators is apparent to form more comprehensive as well as clearly delineated decisive maintainability criteria to achieve cost effective building maintenance (CEBM).

A good understanding on the CEBM will help identify the design for maintainability criteria that influence the CEBM. CEBM is known as minimum cost of replacing degraded materials and elements, minimum costs of periodic works and repairs as well as minimum costs of reactive maintenance [20]. As refer to El-Haram, to achieve CEBM it is necessary to minimize the number of maintenance tasks [21-22]. Minimizing the maintenance tasks consequently, influence all the costs associated to conduct the maintenance tasks. Therefore, to identify the CEBM attributes is important to study on the types of maintenance tasks and identify the costs associated with maintenance tasks. Figure 1 below illustrates the cost of building maintenance task. Where, MC is the cost of a maintenance task (reactive, preventive or replacement), DMc is the direct maintenance cost, IMc is indirect maintenance cost, Cl is cost of labour, Cm is cost of material and spare parts, Ce is cost of equipment and tools, Ca is cost of administration and management, Co is overheads and Cp is cost of penalties or loss of revenue.

$$\begin{aligned} Mc &= DMc + IMc \\ DMc &= Cl + Cm + Ce \\ IMc &= Ca + Co + Cp \end{aligned}$$

Figure 1 The Cost of building maintenance task (Adopted from: El-Haram & Horner, 2002)

A thorough review of literature led to the identification of major cost effective building maintenance attributes. These attributes comprise of both direct maintenance cost and indirect maintenance cost. These attributes are the indicators, which will contribute to CEBM. Table 1 summarized the CEBM attributes. Eight design for maintainability criteria namely, accessibility, durability, clean ability, availability, standardization, simplicity and flexibility, modularization and identification along with the indicators stated in the Table 2 below.

3.0 RESEARCH METHODS–THE DELPHI SURVEY

The Delphi method was originally developed in 1950 by the Olaf Helmar of the Institute for the Future and Norman Dalkey of the RAND Corporation, to ask the opinion of experts to select and develop "an optimal US industrial target system and to estimate the number of A-bombs required to reduce the munitions output by a prescribed amount" [23]. The Delphi method is known as "a research tool to develop, identify, forecast and validate a wide variety of research areas" [24]. The researcher decided on the Delphi method for two main reasons. First, prior research has not yielded a set of validated design for maintainability criteria with indicators. Therefore, this issue requires gathering reliable data from several individuals with the knowledge or experience in the subject area. Second, Delphi method has the ability to achieve consensus, something that was lacking in literature review. The emergence of recent maintainability studies has brought similar and some particularly related maintainability criteria into view. For instance, Chew *et al*., listed few maintainability criteria to be considered during the building façade design [18]. The list comprises of material selection from the aspects of durability, sustainability, clean ability; accessibility and flexibility. Silva and Ranasinghe, suggested five maintainability criteria to be incorporated during the design stage of a project, which ranging from design for adequate safety, maintenance needs, environment, easy maintenance and efficient access [6]. These show that, there is no consensus on the identification of maintainability criteria and its indicators which may lead to the inadequate maintainability decision to be considered during the design phase and consequently influence poor maintainability.

The Delphi method is designed to obtain the most reliable consensus from a panel of experts by a series of intensive questionnaires interspersed with controlled opinion feedback, and with results of each round being fed into the next round [25]. Therefore, the Delphi method is considered as one of the best-known consensus-reaching methodologies [26].The Delphi method typically involves the selection of suitable experts, development of appropriate questions to be put to them and analysis of their answers [27-28]. The original Delphi procedures have three features namely [29]:

(1) anonymous response;
(2) iteration and controlled feedback; and
(3) statistical group responses.

The features of Delphi method are designed to minimize biasing effects of dominant individuals, irrelevant communications, and group pressure toward conformity. The number of rounds varies between two and seven [29-30]. Too many rounds would waste respondents' time, and stopping the study too soon could yield meaningless results [31]. In order to reach an acceptable and stable degree of consensus, majority of the studies have used two or three iterations [32-33]. While panel composition is important, researchers often struggle with what is considered an acceptable expert panel size for Delphi studies. A review of Delphi studies published in AIS and MIS journals reveals that most studies utilize 10 to 18 expert participants [33-34]. However, panel as small as 4 to 10 expert is appropriate, with a homogeneous group of experts [34-35].

The Delphi method used in this research was composed of four rounds with 18 experts. In first round of the Delphi survey, respondents were requested to review the generated CEBM attributes and choose the relevant CEBM attributes by selecting Yes or No option. The respondents also encouraged to submit as many as extra missing CEBM attributes as possible. Following it, a list of design for maintainability criteria and indicators influencing CEBM were listed and respondents again requested to use CEBM attributes as a needle to choose and identify relevant design for maintainability criteria for achieving CEBM. Again, the respondents were encouraged to submit as many as extra missing design for maintainability criteria or indicators that applicable to achieve CEBM. In round 2 of the Delphi questionnaire survey, the respondents were asked to determine the finalized design for maintainability criteria associated with each building elements (basement, facade, floor, roof, lighting system, HVAC, lift, sanitary plumbing and fire-protection). In round 4 of Delphi questionnaire survey, the respondents were provided with the consolidated results from round 3 and were asked reconsider the answer given in round 3.

Table 1 The cost effective building maintenance attributes

Attributes of Labor Cost	Description	Authors
Maintenance/Technical Personnel Availability	The availability of high and special maintenance personnel/ labour to conduct the maintenance tasks.	[36].
Consultation/Technical Personnel Professional Fees	The fees required to pay for professional maintenance or technical personnel to conduct the maintenance tasks.	[36].
Access Delay	Delay in accessing or reaching the parts or elements of a building, its facilities or components quickly and without barriers as; and when required to maintenance tasks (repair or replacement works).	[11];[37]; [38];[39];[21]; [14].
Working Condition	Working condition here refer to similar or dissimilar tasks carried out/ the position where the tasks need to be carried out (height) by maintenance personnel.	[40].
Working Duration	The time when maintenance personnel service required (working/ outside working hours).	[40].
Preparing & Clearing up routines	Commence maintenance tasks immediately without any clearing up & when completed the tasks they can move straight to next job without clearing up.	[40].

Attributes of Material & Spare Parts Cost	Description	Authors
Select suitable materials from market	Selecting the most appropriate materials/ spare parts with respect to several factors such as cost, quality, performance, availability & etc.	[41].
Standardized materials and spare parts	The attainment of maximum practical uniformity, & concerned with restricting to a minimum the variety of parts & components that can be used to meet the equipment requirements.	[42];[43];[19]; [44].
Durable/ Quality materials	The totality of features& characteristics of a product/ service that bears its ability to satisfy stated needs& being free from defects, deficiencies &significant variations.	[41]; [8]; [7].
Easily obtainable materials	Easily obtainable building material refers to the availability of material, whereby it can be easily acquire with minimal cost.	[45]; [4]; [46].
Attributes of Equipment & Tools Cost	**Description**	**Authors**
Ensure critical building equipment/ systems divided into many modular parts/ units.	Modularization is the division of a product into functionally and physically distinct units.	[41];[47]; [48].
Ease of disconnect, disassembly & assembly.	Ease of dismantle the associated parts or component of a building system that requires repair or replacement.	[41]; [47].
Ability to easily clean.	The ability to clean easily the systems or components of the building over its life-cylce to be able to meet aesthetical and functional performance requirements.	[7]; [45]; [8].
Ability for easy diagnose.	The ability to trace the building components that are being malfunction & requiring replacement or repairing.	[50]; [36]
Attributes of Administration & Management Cost	**Description**	**Authors**
Availability of knowledgeable administrative & clerical staff	The availability of administrative & clerical staff that have the knowledge regarding administration jobs.	[41].
De-layering	De-layering refers to a planned reduction in the number of layers of a management hierarchy.	[51].
Optimization on the number of staffs	Optimize the number of workforce with the most cost effective or highest achievable performance under the given constraints.	[41]; [51].
Budgeted and justified cost	Plan on budgeting and justify the budget made in order to achieve cost effectiveness.	[51].
Attributes of Penalties and Loss of Revenue Cost	**Description**	**Authors**
Easily cleaned & maintained building components/ equipment's	The ability to easily clean any components of equipment's of building without any barrier or difficulties.	[10].
Easy access for cleaning purpose	Ease of accessing or reaching any parts or elements of a building and its facilities for cleaning services.	[10].
Safe environment	A safe environment is one where the risk of harm is minimized and occupants feel secure.	[10]; [40].
Comfort environment	Comfortable & friendly environment from the aspect of indoor air quality/circulation, humidity control, heat loss/ gain, lighting, human traffic, vertical transportation, & noise protection.	[10]; [40].
Design Quality	Quality in the design of a building which includes functional layout, choice of equipment, and choice of materials.	[10].

Table 2 The Building Design for Maintainability Criteria and Indicators to achieve CEBM

Accessibility - The ability of accessing or reaching the parts or elements of a building, its facilities or components quickly and without barriers as; and when required.	Authors
Accessibility Indicators	
Less complexity of building shape & features.	[52]; [53].
High tech approach for not readily accessible elements/ systems of building.	[39].
Direct access to system/components after dissembling one/more entities.	[54].
Prior access to critical systems/parts.	[37]; [38].
Easy access provision for regular cleaning/inspection of building elements.	[18]; [55].
Safety access for maintenance personnel to provide maintenance services.	[35]; 56].

Durability - The ability of the building materials to serve their intended function not only when newly installed but also for some acceptable length of time.	Authors
Durability Indicators	
Ensure the fulfilment of technical benchmark & ability to stand against various consequences.	[8].
Ensure material compatibility.	[18]; [57].
Material that have the ability to resist extreme weather.	[57]; [58].
High standard workmanship.	[18].
Clean-ability - The ability to easily clean, repairs, and make replacements of, the building systems/ components to be able to meet aesthetical and functional performance requirements.	Authors
Clean-ability Indicators	
Proper Selection of Paint Colour.	[8]; [14]; [46].
Proper Selection of Flooring.	[8]; [14]; [46].
Proper selection of Wall finishes.	[8]; [14]; [46].
Self-Cleaning Capability (for system prone to rapid build-up of dust).	[37]; [59].
Availability - refers any types of building objects or instruments that is easily obtainable during the building repair and replacement work.	Authors
Availability Indicators	
Availability of materials (spares & repair parts, finishes (flooring, wall finishes, and ceiling finishes).	[35].
Availability of finishes (flooring, wall/ ceiling finishes).	[35].
Availability of maintenance support equipment's (equipment to support maintenance activities).	[35]; [6].
Availability of high skill maintenance personnel.	[35].
Standardization - the attainment of maximum practical uniformity.	Authors
Standardization Indicators	
The usage of properly tested & approved materials.	[44]; [19]; [55].
Apply interchange ability features.	[38]; [35].
Encourage the use of standard parts on similar system or elements.	[38];[35].
Minimize the use of different models or systems.	[38]; [49]; [50].
Simplicity & Flexibility - Designing a building without complexity, with reduced fundamental parts & in flexible way.	Authors
Simplicity & Flexibility Indicators	
Minimize building complexity (Height and Size).	[39]; [60].
Minimize the selection of critical materials, processes, the use of proprietary items & etc.	[50]; [47].
Make certain every part, equipment's & elements installed have an absolute function & needs.	[35].
Ensure the maintenance procedures; adjustments & etc. are minimized.	[35].
Modularization - Division building system or elements into functionally and physically distinct units to allow easy removal and replacement.	Authors
Modularization Indicators	
Ensure critical building equipment or systems to be divided into many modular parts/ units.	[47]; [50].
Ensure to design of systems/ equipment parts for ease of opening, assemblies, installation & fixing.	[47]; [50].
Design the modules for greatest ease of operational testing when they are removed from the equipment.	[47]; [50].
Design equipment so that a single person can replace any malfunctioning component.	[47]; [50].
Can built modular parts such as walls, frames, doors, ceilings, & windows especially in office building, retail space, conference hall & other applicable buildings.	[47]; [50].
Identification – Ability to readily identify the building parts, systems or control need services, repair or replacement.	Authors
Identification Indicators	
Provide adequate labelling or marking on building equipment and system.	[35]; [50].
Provide adequate labelling/ marking on building system parts.	
Install diagnose ability features.	[35].
Assure fault isolation facets.	[35].

4.0 FOUR ROUNDS OF DELPHI QUESTIONNAIRE SURVEY: RESULTS AND ANALYSIS

4.1 Selection of Experts Panels

One of the most important considerations when carrying out Delphi study is the identification and selection of potential members to constitute the panel of experts [61]. The selection of members or panellists is important because the validity of the study is directly related to this selection process. Regarding any set standards of selecting Delphi panel of experts, there is, in fact, no exact criterion currently listed in the literature concerning the selection of Delphi panellists [62]. In this Delphi survey, the researchers attempted to identify panellists who meet all the following selection criteria: knowledge (interest) and experience with the issues under investigation [63-66], hierarchy or position [66-67], publications (academicians) [66,68] or involvement in projects (practitioners) [69-71] and their capacity and willingness to participate [65, 69].

Finally, 18 experts met all the selection requirements and were willing to participate in the Delphi survey. A list of the panel members and their affiliations are shown in Table 3. The selected experts represent a wide spectrum of professionals in the field of building industry of Malaysia and thus provide a balanced view for the Delphi study. All the experts have sufficient experience, position and expertise in building industry. Table 4 depicts the frequency of the respondent's number of years working in the building industry, position or hierarchy and number of projects involved. The knowledge and area of expert, sufficient working experience, senior job positions and projects involved by the selected experts ensure the validity of this Delphi research.

Table 3 List of the panel experts for the Delphi study

Area of Expert	Number
Architecture	4
Civil Engineering	7
Building Services Engineering	2
Building Maintenance	1
Facility/Property Management	2
Building Surveying	2
Total	18

Table 4 Respondent classifications by years working, position and number of projects involved in the building industry

Years of Experience	No	Project Involved	No	Position	No
0-5	2	0-5	1	Deputy Director	1
6-10	3	6-10	5	Vice Director	1
11-15	6	11-15	2	Engineer	5
16-20	1	16-20	2	Architect	4
20-25	3	21-25	3	Maintenance Supervisor	2
26-30	1	26-30	-	Facility/ Property Manager	2
30+	2	30+	5	Maintenance Executive	3

4.2 Round 1: Delphi Questionnaire Survey: Identifying the relevant CEBM attributes and identifying the Design for Maintainability indicators influencing CEBM

The first round of the Delphi questionnaire survey was conducted as the exploration process and was of crucial importance. Round one divided into two sections. In first section, every expert was required to identify relevant CEBM attributes as well as list additional CEBM attributes if relevant. In section two, experts were requested to identify the relevant design for maintainability indicators which influence CEBM. In addition, experts were also encouraged to list additional designs for maintainability indicators. The findings in the literature review were also provided for their reference. All the 18 experts returned their responses. After the completion of first round survey, answers suggested by the 18 experts were carefully analysed and a list of CEBM attributes was formed for further survey. Similar to Gracht, certain level agreement (CLA) analysis have been selected to analyse the obtained data and determine the level of consensus [72]. In keeping with most other nominal scaled Delphi studies, more than 67% agreement was considered cut off level of consensus for this survey. The result of first round survey is shown in Table 5 and Table 6.

4.3 Round 2: Delphi Questionnaire Survey: Re-assessing the Ratings of Round 1 of Delphi Survey

The purpose of the second round Delphi survey was to begin the process of building the consensus among the panellists regarding the identification of relevant CEBM attributes and design for maintainability indicators that influence CEBM. In the round 2 Delphi survey, the experts were asked to re-assess their answers in the light of the consolidated results obtained in round 1. Finally, 15 experts retuned the questionnaire. Researcher tried contact the left three experts through ordinary phone calls as the experts failed to return the questionnaire. However, because of few circumstances researcher failed to contact and receives response from the experts. Considering that the experts decline from the Delphi study, researcher proceeds and analyzed the completed questionnaire received from the 15 experts. The results show that, most experts had reconsidered their ratings and had made adjustments to their answers. Table 7 and Table 8 manifest the result obtained through second round of Delphi survey.

To reach consensus, a cut-off level of two-thirds (67%) of agreement (for positive or negative answers) was required. Finally, consensus among panels was achieved within two rounds of survey. The indicators that score below 67% are excluded from the survey. Those indicators score 67% and more were included and concluded upon reached consensus.

4.4 Round 3: Delphi questionnaire survey: Determine the finalized Design for Maintainability criteria associated with each Building Elements

The third round of the Delphi questionnaire survey was conducted to identify the design for maintainability criteria associated with each building elements (basement, facade, floor, roof, lighting system, HVAC, lift, sanitary plumbing and fire-protection). Therefore, experts were requested to identify the relevant design for maintainability criteria for applied for the associated building elements. Further, experts were also encouraged to add additional designs for maintainability criteria using the provided list of design for maintainability criteria. Thus, experts were provided with the finalized list of design for maintainability criteria with the explanation for their reference. All the 15 experts returned their responses. After the completion of first round survey, measures suggested by the 15 experts were carefully analysed and a list of design for maintainability criteria with associated building elements were identified. Similar to first and second round Delphi survey, certain level agreement (67%) analysis have been selected to analyse the obtained data and determine the level of consensus. The result of first round survey is shown in Table 9.

Table 5 The result of 1st round Delphi Survey (Certain Level of Agreement (67%))

Attributes of Labour Cost	**YES**	**NO**	**CLA (67%)**	**Decision**
Maintenance & Technical Personnel Availability	12	6	67%	Included
Travelling Cost & Time	18	-	100%	Included
Easy access for maintenance/cleaning purposes	18	-	100%	Included
Acceptable Working Condition	18	-	100%	Included
Less Duration of Maintenance	18	-	100%	Included
Preparing & Clearing up routines	10	8	56%	**Excluded**
Additional: Emergency Works	2/18			
Attributes of Material & Spare Parts Cost				
Usage of suitable materials/ spare parts	13	5	72%	Included
Standardized material & spare parts usage	18	-	100%	Included
Durable/ Quality material usage	18	-	100%	Included
The usage of easily acquirable materials/spare parts	12	6	67%	Included
Attributes of Equipment & Tools Cost				
Ensure critical building equipment divided into many modular	14	4	78%	Included
Ease of disconnect, disassembly & assembly	18	-	100%	Included
Ease of cleaning/ maintaining building components	14	4	78%	Included
Ability for easy diagnose problems	15	3	83%	Included
Attributes of Administration & Management Cost				
Availability of knowledgeable administrative & clerical staff	11	7	61%	**Excluded**
De-layering	10	8	56%	**Excluded**
Optimization on the number of staffs	12	6	67%	Included
Budgeted and justified cost	13	5	72%	Included
Additional: Maintenance Support Documentation	4/18			
Additional: Storage Cost	2/18			
Attributes of Penalties & Loss of Revenue Cost				
Easily cleaned & maintained building components/equipment's	18	-	100%	Included
Easy access for cleaning purpose	18	-	100%	Included
Safe environment	14	4	78%	Included
Comfort environment	18	-	100%	Included
Design quality	13	5	72%	Included

Table 6 The result of section 2 of 1st round Delphi Survey (Certain Level of Agreement (67%))

Accessibility Parameters	**YES**	**NO**	**CLA (67%)**	**Decision**
Less complexity of building shape & features (Design Simplification).	11	7	61%	**Excluded**
Provision for access building elements, system & components for regular cleaning/maintenance.	18	-	100%	Included
High tech approach for not readily accessible elements/ systems of building.	18	-	100%	Included
Direct accessible to system/components after dissembling one/more entities.	18	-	100%	Included
Prior access to critical system/components.	18	-	100%	Included
Safety access for maintenance personnel to provide maintenance services.	18	-	100%	Included
Durability Parameters				
Ensure technical benchmark of materials.	18	-	100%	Included
Ensure material compatibility.	13	5	72%	Included
Material that have the ability to resist extreme weather.	13	5	72%	Included
High standard workmanship.	12	6	67%	Included
Clean ability Parameters				
Proper Selection of Paint Colour.	11	7	61%	**Excluded**
Proper Selection of Flooring.	18	-	100%	Included
Proper selection of Wall finishes.	14	4	78%	Included
Self-Cleaning Capability (for system prone to rapid build-up of dust).	8	8	50%	**Excluded**
Additional: Design for easy Cleaning Capabilities	2 /18			
Availability Parameters				
Availability of materials (spare & repair parts, finishes (flooring, wall finishes, ceiling finishes).	18	-	100%	Included
Availability of finishes (flooring, wall finishes, ceiling finishes).	13	5	72%	Included
Availability of maintenance support equipment's (tools or equipment require supporting associated maintenance actions).	18	-	100%	Included
Availability of maintenance personnel (high personnel skills).	11	7	61%	**Excluded**
Additional: Availability of easy access features for maintenance works	1 /18			
Standardization Parameters				
Properly tested and approved materials.	18	-	100%	Included
Use standard interchangeable parts.	11	7	61%	**Excluded**
Encourage the use of standard parts on similar system or elements.	18	-	100%	Included
Minimize the use of different models or systems.	13	5	72%	Included
Simplicity & Flexibility Parameters				
Minimization in Height and Size.	9	9	50%	**Excluded**
Minimize the selection of critical materials, critical processes, the use of proprietary items, & the use of special production tooling	12	6	67%	Included
Make certain every part, equipment's and elements used and installed have an absolute function and needs.	18	-	100%	Included
Ensure the maintenance procedures; adjustments and etc. are minimized.	12	6	67%	Included
Additional: Flexibility to handle maintenance works/processes and conduct in regular basis	3 /18			
Modularization Parameters				
Ensure critical building equipment or systems to be divided into many modular parts or units.	18	-	100%	Included
Ensure to design of systems or equipment parts for ease of opening, assemblies, installation and fixing.	18	-	100%	Included
Design the modules for greatest ease of operational testing when they are removed from the equipment.	18	-	100%	Included
Aim to design equipment so that a single person can replace any malfunctioning component.	13	5	72%	Included
Can built modular parts such as walls, frames, doors, ceilings, & windows especially in office building, retail space and conference hall & other applicable buildings.	12	6	67%	Included

Identification Parameters				
Provide adequate labelling or marking on building equipment.	18	-	100%	Included
Provide adequate labelling or marking on building parts/ components.	18	-	100%	Included
Install diagnose ability features.	14	4	78%	Included
Assure fault isolation facets.	16	2	89%	Included
Additional: Inventory on building space and equipment's/ fittings	1/18			

Table 7 The result of section 1 of 2nd round delphi survey (Certain Level Agreement (67%))

Attributes of Labour Cost	YES	NO	CLA (67%)	Decision
Maintenance & Technical Personnel Availability	9	6	60%	**Excluded**
Preparing & Clearing up routines	9	6	60%	**Excluded**
Emergency Works	10	5	67%	Included
Attributes of Material & Spare Parts Cost				
Usage of suitable materials/ spare parts	12	3	80%	Included
The usage of easily acquirable materials/spare parts	12	3	80%	Included
Attributes of Equipment & Tools Cost				
Ensure critical building equipment divided into many modular	12	3	80%	Included
Ease of cleaning/ maintaining building components	12	3	80%	Included
Ability for easy diagnose problems	11	4	73%	Included
Attributes of Administration & Management Cost				
Availability of knowledgeable administrative & clerical staff	8	7	53%	**Excluded**
De-layering	7	8	47%	**Excluded**
Optimization on the number of staffs	10	5	67%	Included
Budgeted and justified cost	10	5	67%	Included
Maintenance Support Documentation	9	6	60%	**Excluded**
Storage Cost	10	5	67%	Included
Attributes of Penalties & Loss of Revenue Cost				
Safe environment	12	3	80%	Included
Design quality	11	4	73%	Included

Table 8 The Result of section 2 of 2nd round delphi survey (Certain Level of Agreement (67%))

Accessibility Parameters	YES	NO	CLA (67%)	Decision
Less complexity of building shape & features (Design Simplification).	9	6	56%	**Excluded**
Durability Parameters				
Ensure material compatibility.	11	4	73%	Included
Material that have the ability to resist extreme weather.	11	4	73%	Included
High standard workmanship.	10	5	67%	Included
Clean ability Parameters				
Proper Selection of Paint Colour.	9	6	60%	**Excluded**
Proper selection of Wall finishes.	12	3	80%	Included
Self-Cleaning Capability (for system prone to rapid build-up of dust).	7	8	47%	**Excluded**
Additional: Design for easy Cleaning Capabilities	10	5	67%	Included
Availability Parameters				
Availability of finishes (flooring, wall finishes, ceiling finishes).	11	4	73%	Included
Availability of maintenance personnel (high personnel skills).	9	6	60%	**Excluded**
Additional: Availability of easy access features for maintenance works	5	10	33%	**Excluded**
Standardization Parameters				
Use standard interchangeable parts.	9	6	60%	**Excluded**
Minimize the use of different models or systems.	11	4	73%	Included
Simplicity and Flexibility Parameters				
Minimization in Height and Size.	7	8	47%	**Excluded**
Minimize the selection of critical materials, critical processes, the use of proprietary items, & special production tooling	11	4	73%	Included
Ensure the maintenance procedures; adjustments and etc. are minimized.	10	5	67%	Included
Additional: Flexibility to handle maintenance works/processes and conduct	11	4	73%	Included

in regular basis				
Modularization Parameters				
Aim to design equipment so that a single person can replace any malfunctioning component.	12	3	80%	Included
Can built modular parts such as walls, frames, doors, ceilings, & windows especially in office building, retail space and conference hall & other applicable buildings.	10	5	67%	Included
Identification Parameters				
Install diagnose ability features.	12	3	80%	Included
Assure fault isolation facets.	14	1	93%	Included
Additional: Inventory on building space/equipment's/ fittings	7	8	47%	**Excluded**

Table 9 The result of 3rd round delphi survey (certain level agreement (67%))

Building Elements & Design for Maintainability Criteria	YES	NO	CLA (67%)	Decision
Basement				
Accessibility	15	-	100%	Included
Availability	9	6	60%	**Excluded**
Clean ability	15	-	100%	Included
Facade				
Accessibility	15	-	100%	Included
Clean ability	15	-	100%	Included
Availability	12	3	80%	Included
Simplicity	9	6	60%	**Excluded**
Floor				
Durability	15	-	100%	Included
Clean ability	15	-	100%	Included
Availability	15	-	100%	Included
Roof				
Accessibility	15	-	100%	Included
Durability	12	3	80%	Included
Clean ability	12	3	80%	Included
Availability	13	2	87%	Included
Simplicity	9	6	60%	**Excluded**
Electricity Systems				
Durability	15	-	100%	Included
Clean ability	9	6	60%	**Excluded**
Availability	12	3	80%	Included
Standardization	15	-	100%	Included
Modularization	14	1	93%	Included
Identification/ diagnose ability	15	-	100%	Included
Heat, Ventilation and Air Conditioning System (HVAC System)				
Accessibility	13	2	87%	Included
Durability	15	-	100%	Included
Clean ability	11	4	73%	Included
Availability	8	7	53%	**Excluded**
Modularization	13	2	87%	Included
Identification/ diagnose ability	15	-	100%	Included
Additional: Standardization	2/15			
Lift				
Accessibility	15	-	100%	Included
Durability	15	-	100%	Included
Clean ability	12	3	80%	Included
Availability	11	4	73%	Included
Simplicity	7	8	47%	**Excluded**
Modularization	14	1	93%	Included
Identification/ diagnose ability	14	1	93%	Included

Sanitary Plumbing				
Accessibility	12	3	80%	Included
Durability	13	2	87%	Included
Clean ability	14	1	93%	Included
Availability	9	6	60%	**Excluded**
Additional: Standardization	3/15			
Fire Protection System				
Accessibility	15	-	100%	Included
Durability	15	-	100%	Included
Clean ability	9	6	60%	**Excluded**
Availability	14	1	93%	Included
Standardization	12	3	80%	Included
Identification/ diagnose ability	14	1	93%	Included

4.5 Round 4: Delphi Questionnaire Survey: Re-assessing the Ratings of Round 3 Delphi Survey

The purpose of the round four Delphi survey was to begin the process of building the consensus among the panellists on design for maintainability criteria associated with each building elements. Therefore, in the round 4 Delphi survey, the experts were asked to re-assess their answers in the light of the consolidated results obtained in round 3. Among the 15 experts, 14 experts retuned the questionnaire. Balance one expert couldn't participate in final round as the expert was in medical leave on the final round week. Round four results depicts that few experts had reconsidered their ratings and had made adjustments to their answers. However, the answers of all the building elements remain unchanged when compared with the consolidated results in Round 3. Table 10 manifests the result obtained through fourth round of Delphi survey.

Table 10 The result of 4th round Delphi Survey (certain level agreement (67%))

Building Elements & Design for Maintainability Criteria	YES	NO	CLA (67%)	Decision
Basement				
Availability	9	5	64%	**Excluded**
Facade				
Availability	11	3	79%	Included
Simplicity	9	5	64%	**Excluded**
Roof				
Durability	11	3	79%	Included
Clean ability	11	3	79%	Included
Availability	12	2	86%	Included
Simplicity	9	5	64%	**Excluded**
Electricity Systems				
Clean ability	9	5	64%	**Excluded**
Availability	11	3	79%	Included
Modularization	13	1	93%	Included
Heat, Ventilation and Air Conditioning System (HVAC System)				
Accessibility	13	1	93%	Included
Clean ability	11	3	79%	Included
Availability	8	6	57%	**Excluded**
Modularization	12	2	86%	Included
Additional: Standardization	10	4	71%	Included
Lift				
Clean ability	12	2	86%	Included
Availability	11	3	79%	Included
Simplicity	7	7	50%	**Excluded**
Modularization	13	1	93%	Included
Identification/ diagnose ability	13	1	93%	Included
Sanitary Plumbing				
Accessibility	12	2	86%	Included
Durability	13	1	93%	Included

Clean ability	13	1	93%	Included
Availability	8	6	57%	**Excluded**
Standardization	10	4	71%	Included
Fire Protection System				
Clean ability	9	5	64%	**Excluded**
Availability	13	1	93%	Included
Standardization	11	3	79%	Included
Identification/ diagnose ability	13	1	93%	Included

4.0 CONCLUSION

A four-round of Delphi survey has been conducted to identify the relevant CEBM attributes and the design for maintainability indicators that influence CEBM. In addition, the building design for maintainability criteria that suitable for each building elements were also identified. The findings help develop a composite of comprehensive (or important) building maintainability criteria and indicators to be considered during the building design. A comprehensive building design for maintainability criteria and indicators can provides maintainable building which will subsequently influence CEBM. Consequently, this will lead to an improved future building designs, construction quality, maintenance management, and etc. Hence the author find, it is necessary to study more broadly on the term 'maintainability' and its associated criteria with indicators to open up a possible path for the practitioners, particularly Malaysia's construction industry to apply those indicators during the building design phase. The findings of this study will deepen the current body of knowledge in term of building design for maintainability of the Malaysia's building industry.

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