Building Safety Index: Assessment Framework

Muhamad Hafis Bin Jumhat[1,a*], Ahmadon Bin Bakri[1,b]

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

[a*]hafisjumhat@gmail.com, [b]ahmadon@utm.my

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Abstract. The implementation of safety measures on building should be addressed in order to improve the occupants' quality of life. The cases of roof collapse at Sultan Mizan Zainal Abidin Stadium after a year officially opened to host the 2008 Sukma Games concern over the possible dire consequences of building neglect. Review of literatures shows that the design and management systems of building safety contributed to safety performance of existing building. The objective of this paper is to propose a Building Safety Index (BSI) framework for existing buildings in Malaysia as benchmarking tool for classifying buildings in respect of safety of buildings. Through the BSI, occupants and the public will be informed of the safety risk associated with their living environments. In view of the monetary benefits, the building owners will upkeep their properties in serviceable conditions. Prior to it, with reference to the results of the BSI assessment, an alternative strategic solution can be achieved.

Introduction

Background of the Study Ancient people lived in caves because sheltered places could protect them against the changing external environment, notably adverse weather conditions and savage beasts. This is because caves have provided ancient people with basic necessities such as safety and health. Nowadays, with the advance of technology, we live in sophisticated form called buildings. Buildings not only include supporting structures, but also a variety of integrated hardware (e.g. building services) and software (e.g. property management) that enhance our living and working conditions. No matter how many life-enhancing services are provided, buildings must still have at least fundamental requirements which namely safety and health. Nowadays, a number of building-related accidents have occurred recently which leads us to question the extent to which our buildings have fulfilled the basic requirements of health and safety. For example, the cases of roof collapse at Sultan Mizan Zainal Abidin Stadium after a year officially opened to host the 2008 Sukma Games. Moreover, health and safety problems are not confined to building owners, but can also adversely affect users, visitors, and even passers-by. As a result, a better understanding of building performance is needed and actions should be taken immediately for the benefit of the entire society. Regarding to these issues, there was a benchmarking tool for classifying buildings in respect of their safety and physical conditions that have been developed by Faculty of Architecture of the University of Hong Kong and it is called Building Safety and Conditions Index (BSCI). It can be used to indicate the level of achievement of individual buildings in enhancing the safety of both occupants and the general public.

Problem Statement Nowadays, our public is lacked of information on the safety risk related to their living environments. One dilemma identified is that no a uniform standard have been stated for buildings' safety level. Furthermore, there are no unambiguous acceptance criteria to state that the building in serviceable conditions. In fact, safety is a prerequisite for health-state of people because safety is ''a state in which hazards and conditions leading to physical, psychological or material harm are controlled in order to preserve the health and well-being of individuals and the community'' [1]. Besides, entitlement to a habitable environment, which needs to be safe, is a basic human right [2]. Therefore, building safety should be put on the research agenda. [3] Some strategic

building management factors which apply to all safety attributes, namely management organization (e.g. deeds governing common areas, owners' corporations, and property management companies), documentation (e.g. the keeping of building records), emergency preparedness (e.g. plans for emergency situations, the provision of contingency funds), and post-occupancy evaluation systems (e.g. occupant survey), are not included. These factors should not be ignored because building safety is inseparable from building management.

Objectives For this study, the objectives are:

1. To determine the weightage of factor contributing BSI.
2. To formulate formulated score of contribution factor to BSI
3. To develop framework for BSI.

Scope of Study The scope of this study is focusing in aspect of safety performance of existing building by accessing some authorities and agencies such as Department of Public Works (Jabatan Kerja Raya Malaysia), Building & Facilities Management, National Heritage Department, Safety Consultant, Building Surveyor, Architectural Heritage, Quantity Surveyor and Urban Planning & Conservation. Data collection will be conducted by referring to the literature reviews and distributing the questionnaire survey forms to the local authorities, government's agencies and private sector which responsible to monitor the existing buildings in Malaysia. The specific data used for this research is the degree of importance for each of the contribution factors which finally will be interpret in the form of weightage, mean score and ranking as well. All the mechanism used is to get clarification for developing assessment framework BSI.

Previous Studies

Introduction The BSCI was developed by the Faculty of Architecture of the University of Hong Kong, for classifying apartment buildings in respect of their safety and physical conditions. It is a benchmarking tool which serves to indicate the level of achievement of individual buildings in enhancing the safety of both occupants and the general public. Besides, what makes the BSCI distinguishable is that its assessment framework is bespoke for the mass assessment of buildings. On the other hand, the assessment scheme of the BSCI is backed up by rigorous and sound theoretical foundation so its creditability and practicality can be achieved.

Development of an Assessment Framework The assessment framework of the BSCI is divided into three levels. First level is a vision, which sets the assessment principles and delimits the scope of the assessment. Second level assumes a strategic role, which defines the safety attributes that contribute to building safety and conditions. Third level deals with operational issues by transforming the safety attributes into a hierarchy of building factors for devising a location and time-specific assessment scheme.

The assessment framework is intended for the first-tier screening of building safety and physical conditions. For this purpose, it must allow for a wide coverage of buildings within a short period of time at a reasonable low cost. The framework is designed with respect to the principles of generality, objectivity, practicability, and relevance to safety. In order to achieve the objective, the factors to be assessed should be measurable and verifiable. The assessment methods should be practicable and simple, and the factors to be assessed should be easily acquired. A site visit may be required, but generally is confined to common areas and the external environment only. In general, only characteristics of buildings easily assessable by the public are acquired, measured, and assessed. Furthermore, the factors to be considered should be directly related to building safety and conditions that pose hazards to occupants and the public.

Based on the above principles, a number of safety attributes that affect the safety of occupants and the public have been identified through literature reviews and workshops with relevant

professionals and experts. Intuitively, fire hazard is regarded as the most threatening to the occupants of a building. [4] developed a fire safety ranking system apt for Hong Kong's situation, and the findings are valuable guidance for identifying fire safety attributes. Yet, building safety embraces not only fire safety, but also many other factors. Structural integrity and external finishes are also problematic areas identified [5]. For the BSCI, several key safety attributes, namely fire resistant construction, means of escape, means of access for fire-fighting, fire services installations, internal defects, external defects, density, and special hazards, are identified.

The relationship between the safety attributes and various aspects of building factors is then mapped together to develop a hierarchy of building factors. Study [6] has stipulated that there were different categories of architectural elements, each of which was involved in accidents in a particular way. Previous study [7] has confirmed the role of architectural features in the causation of accidents in the built environment. Therefore, building design should play an important role in building safety. Apart from misuse and the lack of maintenance, poor design is one of the causes of building-related accidents [8]. Building factors are grouped into two main categories as show in Figure 1.

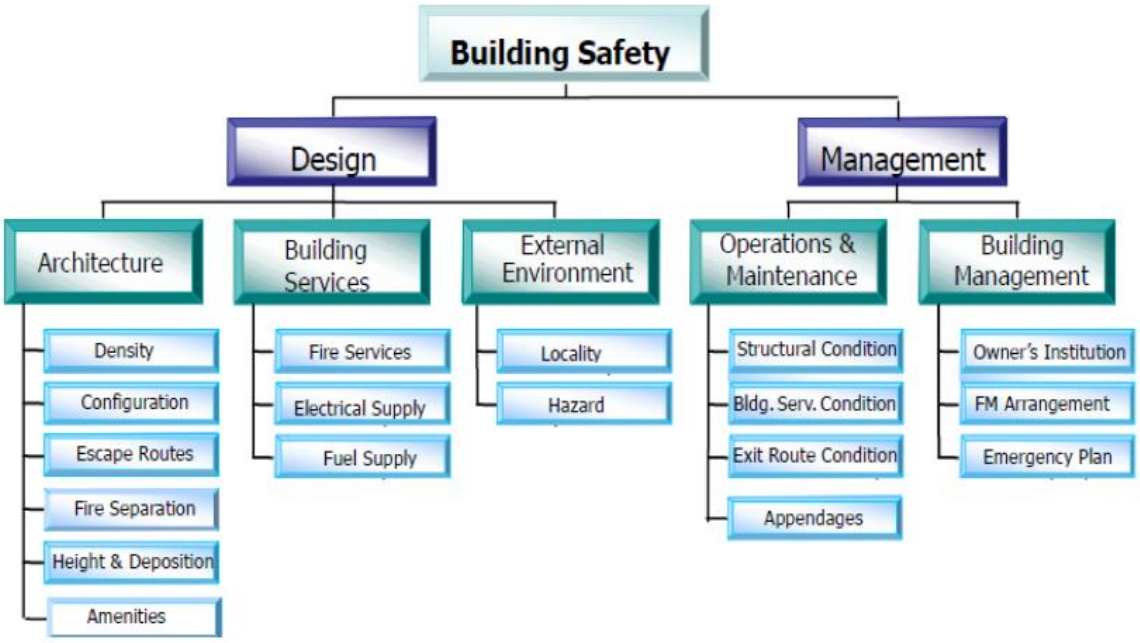

Figure 1: Hierarchies of Building Factors for Safety and Conditions Assessment [3], [4]

Construction of the BSCI The BSCI is defined and it is essentially an aggregate figure of ratings and weightings of all building factors directly related to safety and conditions of a particular building. Mathematically,

$$\text{BSCI} = g\,(w1,2,,\ \ldots,\ wn;\ F1,\ F2,\ \ldots,\ Fn\ )$$

where wi (i=1, 2, …, n) denotes the relative importance (weighting) of the ith building factor in affecting the safety and conditions of that building; Fi denotes the rating of the ith building factor collected using the above assessment framework; n is the total number of building factors; and g is a function that combines all wi's and Fi's. The simplest form is the weighted arithmetic mean; with all wi's summed to unity:

$$\text{BSCI} = \Sigma \text{wi Fini=1}$$

Methodology

Literature Review This study started with a comprehensive review of literature from various sources such as government publications, books, academic and professional journals and conference papers to retrieve information related to building safety, schemes for assessing building safety

performance, and factors affecting the state of repairs and management quality of a building. The literature review would facilitate the development of the assessment framework for this study.

Questionnaire A questionnaire is a research instrument consists of a series of question for the purpose of gathering information based on the findings from the preceding literature reviews. The general of questionnaire was formulated in order to determine score of each factor contribute to BSI.

Determination of Weightage After the survey, let the result for the survey as shown in table below:

5	Very important
4	Important
3	Moderately important
2	Less important
1	Not important

Table 1: Example Ranking by Respondents

Critical Factor	Indicator	Frequency				
		5	**4**	**3**	**2**	**1**
Factor$_1$	Indicator$_1$	3	1	3	1	2
	Indicator$_2$	2	3	2	2	1
	Indicator$_3$	2	2	2	2	2

The degree of membership of the indicator is calculated as below:

Table 2: Degree of Membership

Frequency	Degree
5	0.9
4	0.7
3	0.5
2	0.3
1	0.1

$$\text{Indicator} = \frac{\Sigma\text{Number of respondent X Degree of Membership}}{\text{Total number of respondent}}$$

Consistent with fuzzy set's theory [9], property F is defined as a fuzzy set in Y.
Y= {Indicator$_1$, Indicator$_2$, Indicator$_3$, Indicator$_4$, Indicator$_5$}
F= {Important},

By adopting [10], the weightage is calculated as such:

Step 1:

$$r = \frac{\Sigma\text{Count (F)}}{\Sigma\text{Count (y)}}$$

Step 2:
Truth (QY's are F) = $\mu \boldsymbol{Q}(r)$ with the formula as below:

$$\mu \text{ 'most'}(r) = \begin{cases} 1 \text{ for } r > 0.8 \\ 2r - 0.6 \text{ for } 0.3 \leq r \leq 0.8 \\ 0 \text{ for } r < 0.3 \end{cases}$$

Data Analysis

Weightage of Factor Contribute BSI

Table 3: Ranking of Sub-factors Maintenance Management

Sub-factors	Weightage	Mean	Rank
The Professional Skill	1.00	0.81	1
Factor of Safety (The Professional Skill)	1.00	0.80	2
Procedure of the Maintenance Works	0.99	0.79	3
Comfort of Occupants (The Professional Skill)	0.98	0.79	4
Regular Building Inspections	0.98	0.79	5
Maintenance Workers	0.97	0.78	6
Control the Increased Maintenance Costs (The Professional Skill)	0.97	0.78	7
Management Organization Chart	0.96	0.78	8
Basic Strategies of Maintenance Management	0.96	0.78	9
Information Management	0.95	0.78	10
Maintenance Staff Training and Expertise	0.94	0.77	11
The Existing Material (Replacement)	0.93	0.77	12
Budget Allocation	0.91	0.76	13

From the analysis carried out, the professional skill contributes highest weightage and mean to the safety performance of the building which is 1.00 and 0.81 respectively. It means existing building should have an adequate skills and idea in conducting maintenance work. Moreover, the professionals should be responsible in any situation during maintenance works. They capable to give directions to the technician involved during maintenance works and ensure satisfactory outcome to the building occupants.

Table 3 shows that least contribution of sub-factor maintenance management to the safety performance is budget allocation. The weightage and means of budget allocation are 0.91 and 0.76 respectively. Due to lack of budget, owner of the building will ignore the issues of building maintenance's criteria. Other than that, they need to establish accurate strategy for estimate maintenance cost for aging existing building because it will cause more expenditure. Figure 2 is representing the weightage and means for sub-factor maintenance management contribute to BSI.

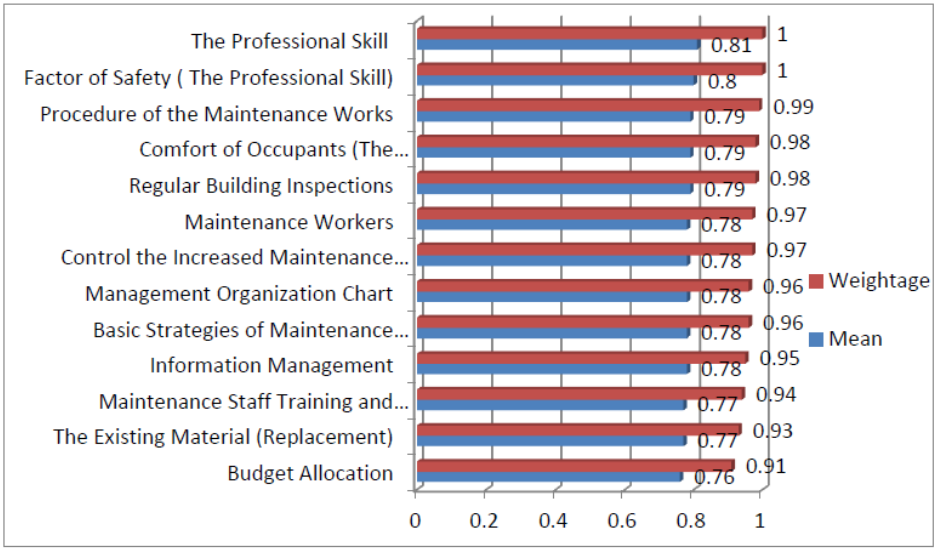

Figure 2: Weightage of Sub-Factor Maintenance Management Contribute BSI

Table 4: Ranking of Sub-factors Building Management

Sub-factors	Weightage	Mean	Rank
Exit Routes Condition	1.00	0.80	1
Fire-fighting Appearances	1.00	0.80	2
Knowledge of Emergency Preparedness	1.00	0.80	3
Opinions on the Emergency Evacuation Behaviors	0.98	0.79	4
Stairway Condition	0.96	0.78	5
Fire Drill Session	0.96	0.78	6
Post Occupancy Evaluation (POE)	0.95	0.77	7
Building Condition	0.92	0.76	8

From the analysis carried out, exit routes condition, fire-fighting appearances and knowledge of emergency preparedness contribute highest weightage and mean to the safety performance of the building which is 1.00 and 0.80 respectively. Each existing building should manage well their exit routes condition. Sufficient numbers of exit route can increase the safety performance of the existing building. Exit routes should be clear, unobstructed and unlocked exits. Other than that, exit routes need to be clearly marked in order to prevent confusion. For fire-fighting appearances, the existing buildings need to have an adequate portable fire extinguisher. Warning system must be available in each building for a better safety performance.

Each building's occupant should have knowledge about fire exits location and alternative exits. Sufficient evacuation and location of pull stations need to be considered for each existing building. From Table 4, it shows that building condition contribute the least weightage and means to building management which is 0.92 and 0.76 respectively. Figure 3 is representing the weightage and means for sub-factor building management contribute to BSI.

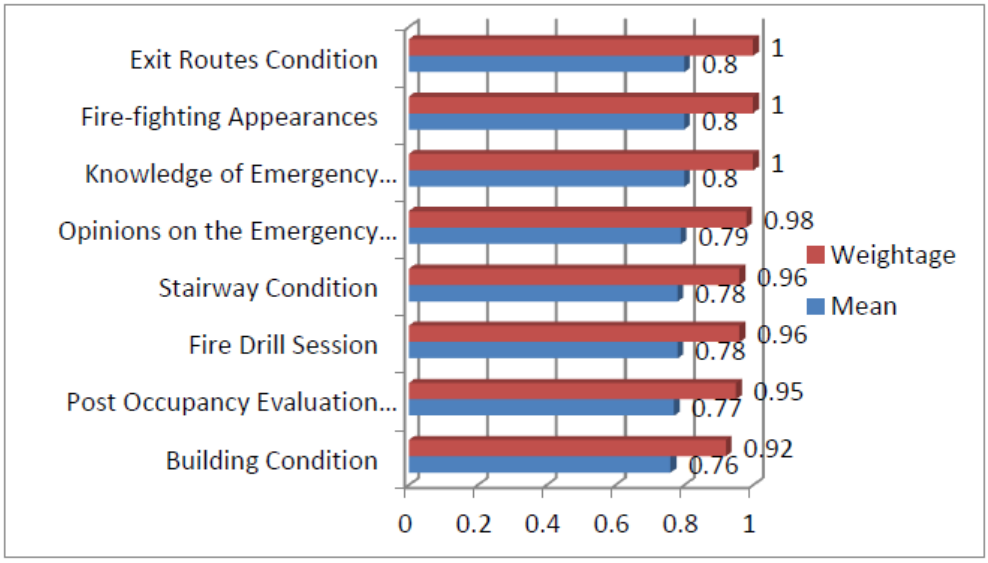

Figure 3: Weightage of Sub-Factor Building Management Contribute BSI

Table 5: Weightage Prioritize For Management Factor Contribute BSI

Sub-factors	Weightage	Weightage Prioritize
The Professional Skill	1.00	0.049237
Factor of Safety (The Professional Skill)	1.00	0.049237
Exit Routes Condition	1.00	0.049237
Fire-fighting Appearances	1.00	0.049237
Knowledge of Emergency Preparedness	1.00	0.049237

Procedure of the Maintenance Works	0.99	0.048744
Comfort of Occupants (The Professional Skill)	0.98	0.048252
Regular Building Inspections	0.98	0.048252
Opinions on the Emergency Evacuation Behaviors	0.98	0.048252
Maintenance Workers	0.97	0.047760
Control the Increased Maintenance Costs (The Professional Skill)	0.97	0.047760
Management Organization Chart	0.96	0.047267
Basic Strategies of Maintenance Management	0.96	0.047267
Stairway Condition	0.96	0.047267
Fire Drill Session	0.96	0.047267
Information Management	0.95	0.046775
Post Occupancy Evaluation (POE)	0.95	0.046775
Maintenance Staff Training and Expertise	0.94	0.046283
The Existing Material (Replacement)	0.93	0.045790
Building Condition	0.92	0.045298
Budget Allocation	0.91	0.044806

Table 6: Ranking of Sub-factors Architecture Approach

Sub-factors	Weightage	Mean	Rank
Provision of Emergency Access Into the Building	0.90	0.75	1
Proper Selection of Fire Resistant	0.90	0.75	2
Provision of Emergency Escape	0.89	0.75	3
Space Functionality For Emergency Purpose	0.88	0.74	4
Proper Selection of Material For Structural Integrity	0.77	0.68	5
Proper Selection of Structural System	0.72	0.66	6

From the analysis carried out, provision of emergency access into the building and proper selection of fire resistant contribute highest weightage and mean to the safety performance of the building which is 0.90 and 0.75 respectively. Each existing building should have adequate width of exit routes, geometry of exit routes, exit signs, length of escape routes, locking system at exit routes and number of exit routes. Prior to proper fire resistance, existing building should have adequate of fire rated door, fire rated protection, adequate column fire resistance and adequate view panels in order to increase safety performance. Sub-factor proper selection of structural system have the least contribution to the safety performance. The weightage and means of are 0.72 and 0.66 respectively. It shows that completed information describe parameters of the building such as material used, shape and building parts is enough to select proper structural system. Figure 4 is representing the weightage and means for sub-factor architect approach contribute to BSI

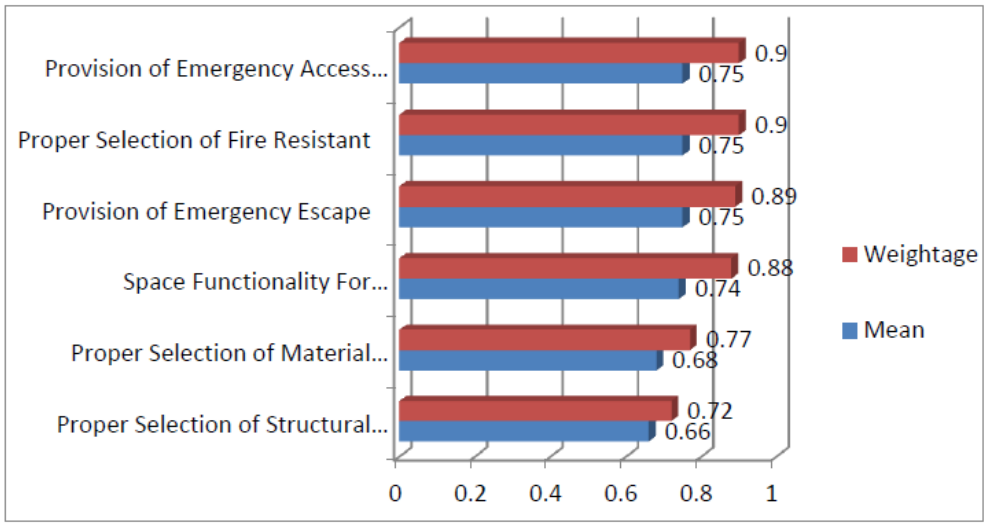

Figure 4: Weightage of Sub-Factor Architecture Approach Contribute BSI

Table 7: Ranking of Sub-factors Building Services Approach

Sub-factors	Weightage	Mean	Rank
Provision of Lifts	0.92	0.76	1
Provision of Fire Protection System	0.90	0.75	2
Proper Electric Installation	0.86	0.73	3
Controlled of Indoor Air Quality	0.76	0.68	4
Provision of Plumbing & Sanitary Services	0.75	0.68	5
Provision of Emergency Lighting	0.72	0.66	6

From the analysis carried out, provision of lifts contribute highest weightage and mean to the safety performance of the building which is 0.92 and 0.76 respectively. Each lift should provide visual warning sign in elevator cabs. Furthermore, open onto access lobbies must have safe staging area. Other than that, elevator emergency operation should have recall system. In order to have high safety performance lift, it must consist hardened shaft enclosures, water infiltration protection and prohibition on sprinklers in the hoistway. The weightage and mean of provision of emergency lighting is 0.72 and 0.66 respectively. It shows least contribution to safety performance as well as existing building fulfill light level requirement. Figure 5 is representing the weightage and means for sub-factor building services approach contribute to BSI.

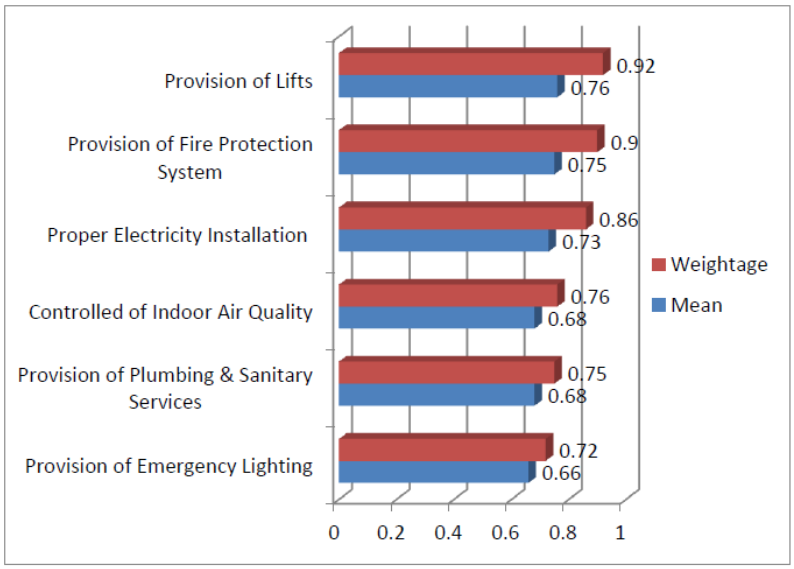

Figure 5: Weightage of Sub-Factor Building Services Approach Contribute BSI

Table 8: Ranking of Sub-factors External Environment Approach

Sub-factors	Weightage	Mean	Rank
Building Near Emergency Services Area	0.82	0.71	1
Density of the Population in the Building	0.77	0.68	2
Location of Building Far From Hazardous Area	0.74	0.67	3
Free From External Hazard	0.73	0.67	4
Fresh Quality & Peaceful Environment	0.69	0.65	5

From the analysis carried out, building near emergency services area contributes highest weightage and mean to the safety performance of the building which is 0.82 and 0.71 respectively. It means existing building have adequate time for ambulance response for medical emergency, adequate time for Fire Services Department response for emergency and adequate time for Police Station response for emergency.

Table 8 shows that least contribution of sub-factor external environment approach to the safety performance is fresh quality and peaceful environment. The weightage and means of fresh quality and peaceful environment are 0.69 and 0.65 respectively. Distance landfill areas normally located far from existing building. Appropriate size, adequate space for buildings and convenient parking normally have considered during design stage. Figure 6 is representing the weightage and means for sub-factor external environment approach contribute to BSI.

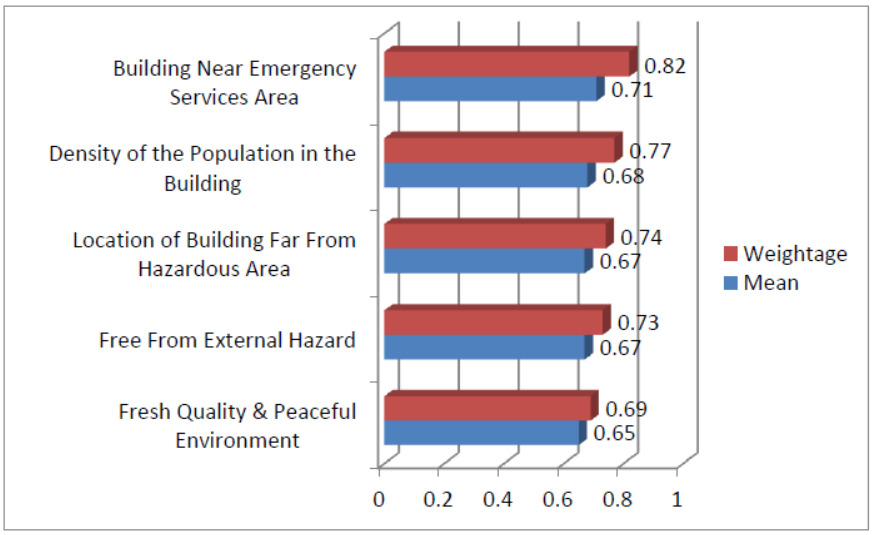

Figure 6: Weightage of Sub-Factor External Environment Approach Contribute BSI

Table 9: Weightage Prioritize For Design Factor Contribute BSI

Sub-factors	Weightage	Weightage Prioritize
Provision of Lifts	0.92	0.067055
Provision of Emergency Access Into the Building	0.90	0.065598
Proper Selection of Fire Resistant	0.90	0.065598
Provision of Fire Protection System	0.90	0.065598
Provision of Emergency Escape	0.89	0.064869
Space Functionality For Emergency Purpose	0.88	0.064140
Proper Electricity Installation	0.86	0.062682
Building Near Emergency Services Area	0.82	0.059767
Proper Selection of Material Integrity	0.77	0.056122
Density of the Population in the Building	0.77	0.056122
Controlled of Indoor Air Quality	0.76	0.055394
Provision of Plumbing & Sanitary Services	0.75	0.054665
Location of Building Far From Hazardous Area	0.74	0.053936
Free From External Hazard	0.73	0.053207
Proper Selection of Structural System	0.72	0.052478
Provision of Emergency Lighting	0.72	0.052478
Fresh Quality & Peaceful Environment	0.69	0.050292

Formulate Score of Contribution Factor to BSI Based on the findings from the preceding literature reviews, the implementation of safety measures should be addressed in the management and design factors. Prior to it, a number of safety attributes each factor affect safety performance of existing building have been identified. Factor of management can be divided to two major factors which is maintenance management and building management. For maintenance management, there are seven sub-factors have been considered as mention below:

1. Budget Allocation
2. The Existing Material (Replacement)
3. Maintenance Workers
4. Management Organization Chart
5. Procedure of The Maintenance Works

6. The Professional Skill
    - Factor of Safety
    - Comfort of Occupants
    - Control the Increased Maintenance Costs
7. Basic Strategies of Maintenance Management
    - Maintenance Staff Training and Expertise
    - Regular Building Inspections
    - Information Management

For the building management, there three sub-factors regarding safety performance of existing building:

1. Arrangements of Facilities Management
    - Exit Route Condition
    - Stairway Condition
    - Building Condition
    - Fire-fighting Appearances
2. Emergency Plan and Preparedness
    - Fire Drill Session
    - Knowledge of Emergency Preparedness
    - Opinions on the Emergency Evacuation Behaviors

Factor of design can be divided into three major factors. Each factor consist own sub-factor which contribute to BSI. They are the following:

1. Architectures Approach
    - Provision of Emergency Escape
    - Provision of Emergency Access Into The Building
    - Proper Selection of Structural System
    - Proper Selection of Fire Resistant
    - Proper Selection of Material for Structural Integrity
    - Space Functionality for Emergency Purpose
2. Building Services Approach
    - Proper Electricity Installation
    - Provision of Emergency Lighting
    - Controlled of Indoor Air Quality
    - Provision of Plumbing and Sanitary Services
    - Provision of Fire Protection System
    - Provision lifts
3. External Environment Approach
    - Building Near To Emergency Services Area
    - Free From External Hazard
    - Fresh Quality and Peaceful Environment
    - Location of Building Far From Hazardous Area
    - Density of The Population in The Building

Therefore, the general of questionnaire was formulated in order to determine score of each factor contribute to BSI. Figure 7 is representing flow chart to formulate score contribution factor to BSI.

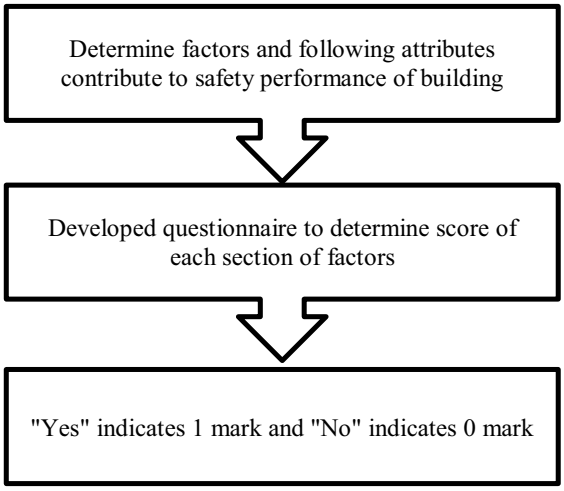

Figure 7: Flow Charts to Formulate Score of Contribution Factor

Construction of BSI The BSI is essentially an aggregate figure of scores and weightings of contribution factor which are design and management design. Design factor and Management factor will use formula as mentioned below in order to determine BSI:

$$BSI = (\Sigma WiSini=1) \text{ x}100\%$$

Where Wi (i= 1, 2, …, n) denotes the weightage prioritize of contribution factor in affecting safety performance of existing building; Si denotes the score of each section of design or management factor collected using above questionnaire and n is the total number of factor.

For the easy consumption of ordinary people, the index can be presented in forms of grades A, B, and C and D. Based on the index or grade, the general public can be better informed of the performance of buildings in respect of safety performance.

Decision Making Tools The BSI can be used as a priority setting tool for decision making and budget planning, providing a basis for allocating and directing funding to specific building-related problems. The value of the BSI becomes more apparent when the number of problematic buildings in Malaysia is so large and must be spread out over extended periods. Needless to say, the grade or numeric figure of the BSI can tell how a building performs on safety aspects. Using the scores obtained, it can be for contribution of management factor and design factor to safety performance of existing building. The pair of scores can be mapped in a 2-dimensional matrix, as illustrated in Figure 8.

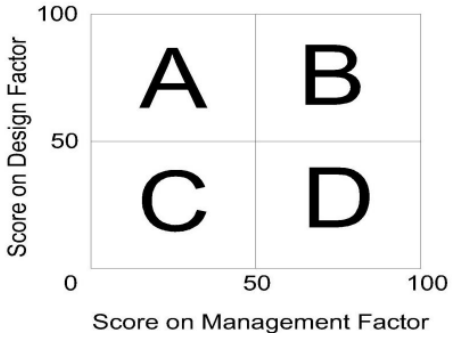

Figure 8: Connections between Design Factor and Management Factor

Quadrant A shows that existing building have poor management approaches either in building management or maintenance management but good in design quality. According to [11], facilities operations and maintenance encompasses all that broad spectrum of services required to assure the

built environment will perform the functions for which a facility was designed and constructed. He suggested that operation and maintenance includes preventive and predictive (planned) maintenance and corrective (repair) maintenance. Preventive Maintenance (PM) consists of a series of time-based maintenance requirements that provide a basis for planning, scheduling, and executing scheduled (planned versus corrective) maintenance. While, corrective maintenance is a repair necessary to return the equipment to properly functioning condition or service and may be both planned and un-planned. On the other hand, Quadrant B shows that the building has good design quality and management approaches.

Poor design quality either in term of architecture, building services or external environment and lack of management approach shown in quadrant C. It means score of each design factor and management factor is less than 50 %. 47% of defects were caused by design defects, 17% from materials, 15% from construction, 18% from misuses of facilities, 15% from poor maintenance and 5% from vandalism [12]. The majority of the defects identified were architectural works, followed by electrical works, and civil and structural defects [13]. These suggested that defects could have been prevented if consideration were made on the architectural building elements. Previous study [13] also proposed building best maintenance criteria in order for future sustainable building maintenance management works as follows:

1. Clear maintenance policy.
2. Systematic maintenance programmers and priority.
3. Produce an accurate building assessment and condition.
4. Updated information and data integration system.

Lastly, quadrant D stated that the building has quality in management approaches and maintenance but lack in design quality. Previous study [14] proved that physical housing condition such as plumbing, heating, cooling and building security contribute to mental health dysfunction such as being depressed, feeling worried, feeling sad, feeling helpless, and feeling emotionally. Thus, it can be summarized that housing could have a significant impact on safety, health, education and behavior of resident. Therefore, proper provision of plumbing and sanitary services will increase safety performance of the building.

Conclusion

From the study, developing weighting for each factor contributes to BSI is a necessary stage for developing assessment tools. The data have been analyzed by evaluating the weightage score and mean of all contribution's factors. Finally, the ranking of the contribution's factors have been sorted according to weightage score and mean respectively. The ranking of each sub-factors as below:

1. Management Factor
   - Highest Ranking: The Professional Skill
   - Lowest Ranking: Budget Allocation
2. Design Factor
   - Highest Ranking: Provision of Lifts
   - Lowest Ranking: Fresh Quality and Peaceful Environment

Other than that, the literature review has identified two majors factor contributing safety performance of existing building which is management and design. For the purposes of the BSI, a number of safety attributes have been first made out. From the attributes, a questionnaire was developed in order to determine score of each sub-factor. It will contribute to the construction of BSI. Therefore, the BSI can provide a useful tool for evaluating safety aspects of a building that are not easily observable. According to such previously hidden information provided by the index on how each building performs in terms of safety, the public can distinguish buildings of similar ages with different safety performances. At the same time, the BSI can serve as a useful performance evaluation tool for the owner building or building's occupant to maintain safety performance. Prior to it, BSI can be used for the relevant buildings in order to evaluate the level of safety.

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