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FAÇADE MATERIAL SELECTION CRITERIA FOR OPTIMISING BUILDING MAINTAINABILITY

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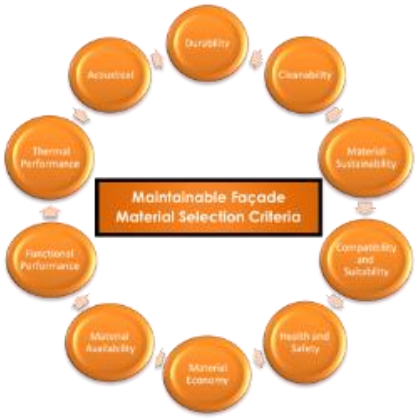
Graphical abstract



Abstract

Maintainability of building facilities partially relies on the materials selection as their potential to resist defects from common deterioration, ease maintenance, and minimise maintenance cost can be improved throughout their designed life. Therefore, it is highly critical that during the design stage, scores of material options are identified and analysed for their suitability to achieve maintainability during post construction occupancy. This article identify a set of criteria to evaluate facade materials as to their potential contribution to post construction maintainability in built environment. Ten maintainable façade material selection criteria which is durability, cleanability, material sustainability, compatibility and suitability, health and safety, material economy, material availability, functional performance, thermal performance and acoustical had been identified by using NVIVO and content analysis on 40 selected articles. This initial findings will provide a review on the maintainability attributes that needed during selecting façade material to ensure successful implementation of design maintainability.

Keywords: Building material, maintainability, design, facade, facility management, NVIVO, content analysis

Abstrak

Penyelenggaraan fasiliti bangunan adalah sebahagiannya bergantung kepada pemilihan bahan binaan bangunan sebagai potensi untuk mengelakkan kemerosotan bangunan, memudahkan penyenggaraan bangunan dan mengurangkan kos penyelenggaraan sepanjang hayat bangunan. Oleh itu, ia adalah sangat penting bahawa dalam peringkat reka bentuk, skor pilihan bahan bangunan yang telah dikenal pasti dan dianalisis untuk kesesuaian bahan tersebut untuk mencapai kemudahan penyelenggaraan semasa bangunan tersebut dihuni. Artikel ini mengenalpasti satu set kriteria untuk menilai bahan-bahan binaan fasad supaya berpotensi untuk memudahkan penyelenggaraan selepas bangunan dibina. Sepuluh kriteria untuk pemilihan bahan binaan fasad yang boleh diselenggara iaitu ketahanan, keupayaan bersih, bahan binaan berkelanjutan, kesesuaian, kesihatan dan keselamatan, ekonomi bahan binaan, ketersediaan bahan binaan, fungsi dan akustik telah dikenalpasti dengan menggunakan NVIVO dan analisis kandungan terhadap 40 artikel terpilih. Hasil penemuan awal ini akan menyediakan kajian mengenai sifat-sifat kebolehsenggaraan yang diperlukan semasa memilih bahan binaan fasad bagi memastikan kejayaan pelaksanaan penyelenggaraan dalam reka bentuk.

Kata kunci: Bahan binaan bangunan, penyelenggaraan, reka bentuk, fasad, pengurusan fasiliti, NVIVO, analisis kandungan

1.0 INTRODUCTION

The issue of building maintainability is considered highly critical in recent days as they largely influence durability of building facilities. Maintainability is a wider scope where it is not only addresses reparability but also increases ease of restoring a defective item to its same function as in design stage. Therefore, maintainability should be considered right from the early stage of design and construction. Maintainability is defined as 'the ability of an item, under conditions of use, to be retained in or restored to a state in which it can perform its required functions, when maintenance is performed under stated conditions and using prescribed procedures and resources' [1]. Furthermore, maintainability of buildings can be defined as attaining the optimum performance throughout the lifespan of a building within a minimum life cycle cost [2]. To make right decisions, building consultants need to evaluate and select suitable building material to optimize building maintainability.

Building material plays an important role throughout the life cycle of a building. Selection of materials for constructing the building is one of the most important design decisions in the early phase. Building materials or subsystems consist of civil-architectural and mechanical-electrical system. Civil-architectural system comprises basement, facade, wet area and roof. Mechanical-electrical system consists of sanitary-plumbing; elevator; HVAC/ heating, ventilation, air-conditioning; electrical and fire protection. Based on previous study, civil-architectural subsystems have higher emphasise on design compared to M&E subsystems and facade was selected as the most important contributing civil-architectural system in maintainability [3].

The building façade is an important element of a building's exterior envelope that is certainly subjected to the worsening effects from weathering agents such as rainfall, ultra-violet emission, oxygen and heat. The maintenance of facades has become very expensive caused by numerous issues such as unusual massing, height, space constraint and exotic finishes [4]. From the past researches that carried out with 59 building managers, it is revealed that 34% of facades defects were caused by design faulty, wrong material selection was accounted for 24%, 19% due to construction erroneous, environment was accounted for 16% and defects due to maintenance practices are around 7%. Generally, design and material have contributed more to the facades deficiencies.

Empirical researches validates that studies on facade system have established within the past 35 years. Researches on consideration of maintenance requirement right from the selecting material or building subsystems are rare. Based on past 35 years studies, Holmes argued that economy factors should be considered during selecting the facade system [5]. Further Flanagan cited in the BPG Building Fabric Component Life Manual, that the demands of cost-effective maintenance would only be met when design team, maintenance team, facilities manager and clients knew how components and building elements performed and deteriorates over the lifetime [6]. El-Haram and Horner supported the statement of Holmes and Flanagan and recommended the conceptualisation of whole life costing at the design stage of new buildings and develop current maintenance strategies [7]. Next, Huang presented a decision-support tool to rank the maintenance strategies for facade from an economic standpoint [8]. This analytical tool has incorporated a deterioration model and LCC analysis. Layzell discussed the failure modes and causes of cladding failure in general and mostly focused on water tightness of cladding [9]. Furthermore Chew has study and compiled common facade failures and causes of the facade failure [10]. Layzell and Chew did not emphasise and suggest the specific way of preventing the failures. However, this gap has been bridge by Kang who studied on the common facade failures, causes of the facade failure and set benchmarks for design, construction and maintenance practices for façade system [11]. He also included the intangible performance during the assessment of facade.

From the past studies, it can be concluded that there are insufficient attention given to the evaluation and selection of facade system during design stage. The past studies mostly concentrate on the existing facade system which the failure already exist. However, there are some studies that emphasise on facade system selection but using simple criteria. This clearly indicates that the aforesaid facade material selection criteria were so generic, which largely ignore the maintainability features. This aspect is the most significant factor that has been identified in previous research that causing the facade to be failure in post occupancy. Research on this element is highly desirable to complement the present trend of sustainable development.

The materials selection process should yield desirable materials, which have the potential to resist defects from common deterioration and maintain the building to achieve their proposed function throughout their life span. Facades that is able to satisfy aesthetical and functional performance necessities at minimum intervals for cleaning and inspections for defects can be considered as "maintainable" [10, 12]. Thus, the material component in facade design plays an important role in maintainability since a material that is suitable with its adjoining materials and needs little maintenance during its lifespan will acquire a minimum maintenance cost [10, 12].

This article identify a set of criteria to evaluate facade materials as to their potential contribution to post construction maintainability in built environment.

2.0 ISSUES OF FAÇADE MATERIAL SELECTION IN RESPECT TO POST CONSTRUCTION MAINTAINABILITY OF BUILDINGS

Considering suitability of facade materials during the design stage of a building ensures minimisation of maintenance requirements in the future. This means that the facade system is easy to maintain at less time, less cost and with less effort. Unfortunately, architects and designers often overlook this most important factor, which has the potential to carry out future maintenance tasks. Building maintainability and maintenance costs have been rather ignored at the design and construction phases resulting in difficulties and costly in maintaining buildings [13]. It was revealed that many countries were experiencing enormous maintenance workloads throughout the post construction phase; increasing the problems in maintenance. The main causes for such circumstances are varied from inadequate design and planning with respect to maintainability at the initial design phase, inefficient maintenance planning at the post construction phase and ineffective construction techniques during the construction phase of a building [14]. Therefore, maintainability today is considered as an important aspect that should be considered right from the early phase of design and construction.

The costs, incurred from the maintainability issues, have caused significant problems in many countries around the world. In some revealed circumstances, the building maintenance costs have reached around 50% of their original construction cost [14]. A defective façade system would have a large financial impact on the building's total maintenance cost. The expenditure on maintenance work is nearly 50% of total construction output in UK [10, 12]. Maintenance costs analysis in buildings having life less than 25 years old unveiled fair wear and tear at 56%, design specification errors at 20%, and repairs caused by defective materials at 12.5%; the remaining 11.5 per cent was specific to additional causes [15]. The cost of rehabilitating a building could be as high as new construction [16].

An important issue to be considered in achieving design maintainability churning the design stage of a building project is selecting suitable building materials. The use of defective and poor quality materials and/or design details are common incidents in numerous building projects, creating major defects during in post construction service. Consequently, this has led to short service lives of many buildings. Such circumstances seek additional maintenance as caused by the inadequacies in the design and quality of construction [16].

During the design phase, the designer should always identify materials that can withstand current climate conditions. Using facility harshly, aggressive environmental and climate circumstances lead to early deterioration to building materials [15]. Designers should investigate the features of the materials before they specify them. A material, proven to function well in one location or country, might not function well in another location caused by changes in climatic circumstances. Ineffective designs identify materials in common without exclusive specifications. This may allow the contractor to offer materials which fulfil only the general guidelines, where it will not serve the work appropriately.

It is important for designers to study the specifications, information and data about the performance of materials. However, such an effort would be complicated if there is a lack of knowledge of the functions of the materials [13]. It is vital that designers should identify the ineffectiveness of materials and systems to function as preferred. Further, Silva explains that the selection of materials, in a certain location, is affected by the climate, availability, building technique and economy [13]. Thus, the material availability must be considered at the construction phase and when replacements are required.

The most significant cause that influences badly the process of selecting materials is unsystematic and not up-to-date information [17]. It is proven that the quality assurance mechanism is not working effectively if the reliability and accuracy of some data specified on the catalogues and brochures is not audited by any laboratory or institute [17]. Therefore, it is essential to document the performances of various types of materials in order to improve or prevent using materials which have been observed not to function satisfactorily [16]. Such data would be beneficial when approximating the long term cost of a specific material. It is worth stating that a material with a high initial cost, but requiring little or no maintenance for a long period, could be more appropriate than one which has a low initial cost but would require regular maintenance work.

Material manual is a benchmark that needs to be utilised. It must include detailed maintainability guidelines for effective material selection process to make sure that the decisions influencing maintenance budgets are prepared at the beginning of design phase [13]. Material manual without suitable technology wouldn't improve maintainability [18].

Research on non-monetary methods has been conducted to search for alternate methods so that material selection for the maintainability potentials can be determined and analysed in an appropriate manner. Ikpo explained how maintainability analysis could be undertaken before construction; however, it does not emphasise on the common indices [18]. A gap therefore exists between material selection and the integration of maintainability principles in the decision-making process. This article focuses on identifying criteria for selecting maintainable facade materials.

3.0 RESEARCH METHODOLOGY

This article is precisely assigned to search and review the literature on the criteria for selecting maintainable façade materials. The primary data was produced through qualitative content analysis. Content analysis is a systematic and objective means of describing and quantifying phenomena [19-21]. It is also known as a method of analysing documents. Content analysis allows the researcher to test theoretical issues to enhance understanding of the data. Through content analysis, it is possible to filter words into fewer content related categories.

Qualitative content analysis was used for reviewing published articles related to maintainable façade material's criteria. Based on the method used by [22-24], a three stage method was carried out to extract, analyse and report the literature-based findings. The first stage comprised identifying the articles to be included in this review. The second stage comprised designing and executing detailed rules of conduct that prescribed how to capture and analyse the literature. The third stage involved synthesising the analysed details and developing the research findings. In identifying the articles to be included in this review, leading construction and building materials journals, academic conferences and books were considered. The construction and building materials journals included in the search consists of International Journals on Architectural Science, Journal of Performance of Constructed Facilities, Journal of Architectural Engineering, Construction Management and Economics, Structural Survey, Building and Environment, Journal of Financial Management of Property and Construction, Journal of Quality in Maintenance Engineering, Construction and Building Material, Construction and Architectural Management, Architectural Science Review, Journal of Building Appraisal, International Journal of Project Management and Journal of Strategic Property Management. The literature sample comprises peer-reviewed papers; journals, books and proceedings from academic conferences on criteria for maintainable façade material selection, covering the thirty five-year-period from 1977 to 2012. Literature sample was collected by conducting a literature search according to relevant keywords such as "building maintainability", "façade material", "building material", "building maintenance" and "building design". The keywords search was carried out in major databases subscribed by the UTM library: Sage Journals, Emerald, Scopus, ScienceDirect, Elsevier, Wiley, Taylor & Francis and Springer. A total of 40 qualitative research articles related to maintainable façade material selection were identified through these processes. Therefore, the 40 articles are referred as the 'primary' set of articles. NVIVO 9.0 software was employed to code and analyse the literature in a single repository and this software had been effectively used in this way by few authors previously [22-23]. A comprehensive rule of conduct was developed to store, code and analyse the extracted papers in the NVIVO database. All 40 articles were saved and arranged as 'documents' and 'nodes'. The maintainable façade material selection criteria were plotted at a high level in main tree-level nodes in NVIVO. A tree-level node is a logical location within NVIVO, where during the coding process; one can capture and store content and ideas that are logically grouped together. The tree-level node represents a logical location within NVIVO. This allows one to plot and store the content that are logically grouped together, during the coding process. Based on the rule of conduct, each article was manually scanned in NVIVO to inductively identify the maintainable façade material selection criteria. The coding process was carried out by mapping relevant statements to the nodes. Any suggestion of a benefit either implicit or explicit was mapped to the node. The result from the first analysis (the coded content) was examined to inductively derive actual maintainable façade material selection criteria. To group the statements that described similar criteria, subfolders were created. This process headed to the identification of a set of maintainable façade material selection criteria from the coded literature. The research findings were analysed and interpreted in the following section.

4.0 DATA ANALYSIS AND FINDINGS

Content analysis was carried out to identify the maintainable façade material selection criteria. Table 1 presents the criteria identified through this effort.

Table 1 Summary of results from the content analysis

No.	Maintainable Façade Material Selection Criteria	Number of Coding References	Number of Sources	List of Sources
1.	Durability	12	7	2, 10, 12, 14, 16, 26, 47
2.	Cleanability	3	3	10, 12, 47
3.	Material Sustainability	6	3	2, 47, 50
4.	Compatibility and Suitability	8	5	10, 12, 14, 16, 29
5.	Health and Safety	7	4	16, 46, 49, 50
6.	Materials Economy	18	6	12, 13, 16, 46, 48, 50
7.	Material Availability	5	3	13, 16, 47
8.	Functional Performance	6	5	10, 12, 14, 15, 28
9.	Thermal Performance	12	12	12, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43
10.	Acoustical	9	9	33, 34, 35, 38, 40, 42, 43, 44, 45

5.0 DISCUSSION

There are 10 maintainable façade material selection criteria identified from this study. Figure 1 shows 10 maintainable façade material selection criteria. The criteria are briefly discussed in the following subsections.

5.1 Durability

The durability of façade materials is the capability of a material to perform its necessary functions and it's doesn't require to be replaced with a new material throughout its life span [25]. These criteria play a significant role in selection of maintainable façade materials since durable materials require less maintenance during its lifespan and consequently will acquire a minimum maintenance cost [10, 12]. Hence, the durability of materials is critical criteria to be considered during the selection of facade materials to enhance the building maintainability [2, 10, 12, 14, 16, 26, 47]. Durability is defined as follows:

Durability: Durability is the capability of buildings and their elements to execute their necessary functions throughout their life cycle with minimal regular maintenance work.

5.2 Cleanability

The cleanability of material is the ability to clean easily the materials or its adjacent components so that it will be able to meet aesthetical and functional performance requirements [26]. The cleanability criteria emphasise the frequency and the method of cleaning and maintenance of different type of materials which attribute to longer life span of a building [14]. Hence, the greater the maintainability, the lower the cleaning required to keep the material functional [47]. Cleanability is one of the significant criteria that must be evaluated when selecting façade materials [10, 12, 47]. Cleanability is defined as follows:

Cleanability: Cleanability is the capability of the building to be easily dirt-free easily and/or without damage.

5.3 Material Sustainability

Sustainable material addresses energy conservation in manufacturing and performance of the material, reduces health hazards to all users, reduces global environmental hazards, and it is recyclable [27]. The designer should always identify materials that are able to tolerate local weather conditions. An early deterioration of materials is caused by aggressive environmental and weather conditions [15]. Based on previous research, sustainable material is one of the most important fundamental parameters in controlling the maintainability of building [2]. Hence, it is obviously shown that the sustainability criteria is an important criteria to select facade material in order to optimise building maintainability [2, 47, 50]. Sustainability with respect to use of materials is defined as follows:

Material Sustainability: Material sustainability can be described as those materials that are drawn from renewable sources that do not adversely affect the natural environment, in terms of both the materials themselves and their immediate surroundings.

5.4 Compatibility and Suitability

Compatibility and suitability of material is any material that can integrate with its adjacent materials with less modification and requires less maintenance throughout its lifespan. Technology provides solutions for the difficulties faced in combining compatible and incompatible materials in building design [18]. The designer needs to consider material properties and design guideline before selecting suitable materials in building design [28]. The unsuitability and incompatibility of materials have posed great maintenance problems and

subsequently increase the maintenance costs [10, 12, 48]. Therefore, optimum maintainability can be achieved through the combination of material components with respect to compatibility and suitability to fulfil its intended functions [29]. Hence, compatibility and suitability of materials are the critical criteria in selecting facade materials [10, 12, 14, 16, 29]. The criteria, compatibility and suitability are defined as follows:

Compatibility and Suitability: Compatibility and suitability can be defined as ability of materials to integrate orderly and efficiently with other materials in a system with less modifications or conversions.

5.5 Health and Safety

Health and safety are two main critical issues in quantifying and grading the maintainability parameters in the facade material selection process [49]. However, nowadays, residential buildings contain a large amount of heavy metals and chemicals that cause several health related problems such as nose and throat irritation, asthma, headaches, nausea, cancer and immune system suppression [30]. A research conducted in Britain noted that relative humidity of indoor air must be between 40% and 60% and this is the most suitable range for human health purpose. If the relative humidity is below 40%, it should be considered as 'sick buildings' syndrome [30]. Based on the above discussion, health and safety criteria must be taken into consideration during the facade material selection process (16, 46, 49, 50]. The 'health and safety' is defined as follows:

Health and Safety: Health and safety aspects of facade materials can be described as the amount and combination of ingredients in a material that is known not to cause any injury, illness, disease, damage or pharmacological effect in human beings.

5.6 Material Economy

Material economy is the materials which give the maximum performance with minimum initial cost and life costs of materials. According to Chew, most of the designers and clients will consider the initial cost to specify the economic acceptability of the project; however, it has been proved that the initial cost may not be the most economical solution as low cost materials often require more frequent maintenance [10, 12, 48]. On the other hand, the economic considerations must be included in the initial cost of purchase and the life costs of materials to get more reasonable value. Materials that give the maximum performance with minimum cost can be determined by short listing them. It is obvious that, materials economics criteria must be considered during the material selection process (12, 13, 16, 46, 48, 5]. Materials economy is defined as follows:

Material Economy: Materials economy can be defined as minimal usage of resources and costs that the materials would incur in the long run in achieving their functional performance.

5.7 Material Availability

Material availability is a material that is available locally and easy to obtain during repair and replacement work. Material availability may influence the decisions being made on facade material selections because long delivery of material may cause the project to hold up and increase the costs. Locally available materials are more easily to get and cheaper than materials procured from long distance. The aforesaid discussion indicates that the availability criteria must be considered during the selection of facade materials [13, 16, 47]. Availability is defined as follows:

Material Availability: Material availability can be defined as a measure of the percentage of the total inventory of a material which is operationally capable of performing an assigned mission at an indefinite random point in time.

5.8 Functional Performance

Functional performance of material is the behaviour of materials to perform up to the best of their capability with minimum defects. It is necessary to document the performances of various materials so as to enhance or avoid using materials that are found not performing satisfactorily [16]. However, selecting materials with best performances might not essentially resulting in the most effective building, since the efficiency of such constructions rely on how the materials are placed together to form a building [16]. On the other hand, Soronis, mentioned that most maintainability failures rely on the actual fact that knowledge of the performance of certain elements or materials is merely available in the literature [46]. In reality, designers don't have the time needed to review these documents. It is vital that the professionals within the field of maintainability assist designers by providing information on the behaviour of materials and on their interaction with the surroundings. Thus, inspection of defects of facade material that are capable to meet functional performance at regular intervals could also be considered as "maintainable" [10, 12, 47]. Based on the foregoing discussion, it is observed that functional performance criteria are important criteria that need to be considered during the facade material selection process [10, 12, 14, 15, 28]. 'Functional performance' is defined as follows:

Functional Performance: Functional performance is the effective performance of the materials to the best of their abilities and in efficient manner with minimum downtime of repair and reduced maintenance costs.

5.9 Thermal Performance

Thermal properties of facade system related to a specific material in spite of its dimensions and location, and properties that relate to the material in a specified design as it is used in a building. During tropics, the temperature degrees are greater and façade are exposed to higher heat loadings and thermal shocks. Consequently, their overall performance and level of deterioration may differ tremendously under the temperate circumstances [10, 12]. The purpose of thermal design of facades is to control and handle heat gain and heat loss. Due to this fact, the facades need to be carefully designed to reduce solar heat gains [31]. Enhancing thermal performance of facades is vital to minimise energy consumption in building, better thermal resistance, reduce thermal bridges and improve the air tightness [32]. Based on the foregoing discussion, it is observed that thermal performance criteria are important criteria that need to be considered during the facade material selection process [12, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43]. 'Thermal performance' is defined as follows:

Thermal Performance: Thermal Performance describes how well a structure reacts to changes in external temperature during the daily and seasonal cycles.

5.10 Acoustical

The recent environmental sound pollution doubts the development in construction of building in noisy urban spots. It is recommended that acoustic requirements have grown to be more widespread in the design of building envelopes. Noise inconvenience by road traffic in urbanized areas is a major problem. The acoustical façade load that concern the sound pressure level at the outside of the building and the façade insulation are the fundamental key to assess the interior sound pressure levels. Façade sound insulation could be improved by using high performance elements or by customizing the shape of the façade. The aforesaid discussion indicates that the acoustical criteria must be considered during the selection of facade materials [33, 34, 35, 38, 40, 42, 43, 44, 45]. Acoustical is defined as follows:

Acoustical: Acoustical façade defined as a façade that designed to absorb or control exterior sound. The final finding is illustrated in the following diagram.

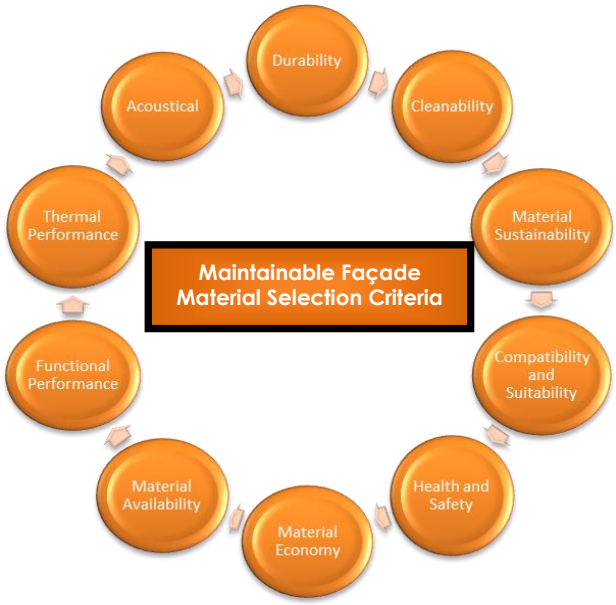


Figure 1 Maintainable façade material selection criteria

6.0 CONCLUSION

The use of materials for achieving future maintainability depends on selecting materials which have the potential to resist defects from common deterioration so that they would continue to achieve their potential function throughout their lifespan. Selection of facade materials for a building construction is one of the most important design decisions in the early phase. Partially, the building defects arise from inappropriate selection of materials with respect to maintainability during the design stage. It is vital to know the preventive measures to be taken to improve maintainability of the buildings. This article has presented the results of the qualitative content analysis on the criteria for selecting maintainable facade materials during the design phase from a widespread literature review.

The findings in this paper suggest that Durability', 'Material Economy' and 'Thermal Performance' are the significant criteria that demand attention for the successful selection of maintainable façade material for optimising building maintainability. The failure of incorporating maintainability attributes in façade material selection in the past had led to various maintenance problem in post occupancy stage and this may cease to persist if the maintainable façade material selection criteria are considered in future building projects.

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