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Articles

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A Value-Based Decision-Making Model for Selecting Sustainable Materials for Buildings

Amirul Afiq Bin Ruslan [a], Ezzaddin Abdullah Al-Atesh [a], Yani Rahmawati [b,*], Christiono Utomo [c], Noor Amila Wan Abdullah Zawawi [d], Mohamad Jahja [e], Raflis [f], Ali Elmansoury [g]

[a] *Department of Civil and Environmental Engineering, Universiti Teknologi PETRONAS, Seri Iskandar 32610, Malaysia*
[b] *Architectural Engingeering, Universitas Gadjah Mada, 55281 Yogyakarta, Indonesia*
[c] *Civil Engineering, Institut Teknologi Sepuluh Nopember, Sukolilo Surabaya 60111, Indonesia*
[d] *Institute of Self Sustainable Building, Universiti Teknologi PETRONAS, 32610 Seri Iskandar, Perak, Malaysia*
[e] *Faculty of Mathematics and Natural Science, Universitas Negeri Gorontalo, Gorontalo 96128, Indonesia*
[f] *Civil Engineering, Universitas Trisakti, Jakarta 11440, Indonesia*
[g] *Architectural Department, College of Engineering, Al-Azhar University, Egypt*

*Corresponding author: *yanirahmawati2012@gmail.com*

***Abstract*— Nowadays, the earth faces problems and challenges from different circumstances due to the dramatic rise of urban modernization. The construction industry is the most contributor to climate change. Achieving sustainability in construction is complicated, but one of the most optimal strategies is selecting building materials with a lower carbon footprint. Therefore, this research aims to investigate the criteria for sustainable materials selection, rank and prioritize sustainable criteria, and developing value-based decision making. A mixed method was used to satisfy the objectives through an extensive literature review, surveys, and interviews with experts. The statistical descriptive was based on a scatter plot of mean and standard deviation, AHP judgment and Value-based decision-making using function over cost. There are two alternatives obtained in this study: Aluminum Composite Panel (ACP) and Stainless Steel. As a result, the suitable alternative for sustainable façade material is ACP based on value-based calculation. The tendency of choosing sustainable material depends on the stakeholders, owner of the building, designers, and others. The research is to show the way in selecting sustainable material by using value-based analysis. This study could expect to give feasibility and useful knowledge in solving problems and increase the use of sustainable materials in building construction. Future research may be conducted with different requirements for sustainable materials. AHP and Value-based analysis are structured technique that solves a complex problem easily using mathematics and psychology approach.**

***Keywords*— Sustainable façade material; materials selection; decision making; building industry.**

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I. Introduction

In sustainable building, various definitions can be seen from various perspectives. For example, a sustainable building can be defined as the lower usage of resources and maximize the function of buildings [1]. The building sector is one of the essential parts of modern society and a vital element of any economy [2]. The building proves to have a significant impact on our environment. This is stated by Ajayi *et al.* [3] in their research; building activities produce a significant impact on resource depletion. The construction industry is having difficulty and remained under pressure to improve environmental sustainability [4]. The buildings have tremendous environmental effects, energy, human health, and productivity [5]. Many illnesses, fatalities, and ultimate environmental harm have been associated with unsustainable building materials [3]. According to Krausmann *et al.* [6], it is estimated that about 60 billion tons of materials are consumed and expected to increase in the future due to rapid population growth rapidly.

From previous studies, non-sustainable building materials could lead to negative impacts both on environmental and human health. Therefore, many building staff has started to track and correct environmental damages due to their operations [7]. Although sustainable building seems like an easy task, the crucial part is deciding to choose building materials. How is it hard? Because it caused difficulties for project stakeholders in selecting the best material. Based on

Hoxha *et al.* [8], it is argued that different stakeholders have different backgrounds in their activities about the criteria for sustainable building materials. Hence, there are no right or wrong criteria to be selected for sustainable building materials. Lastly, criteria for choosing sustainable building material can be categorized into technical, economic, and environmental.

Therefore, this study aims to select suitable sustainable materials for building construction, particularly in façade. To achieve this, a list of criteria in sustainable building material to apply in the decision-making process is investigated and possible alternative materials to achieve sustainability. Analytical Hierarchy Process (AHP) judgment and value-based decision-making are used in developing a decision-making model to identify the suitable sustainable façade material. This research is limited to the selection of the best sustainable façade material for buildings in Malaysia. The result has been validated by interviewing an expert.

II. Materials and Method

The study flow is described in Fig. 1, adapted from Othman *et al.* [9] and Buniya *et al.* [10]. A mixed-method was used to achieve the research objectives [11]. There are two main study surveys and data analysis.

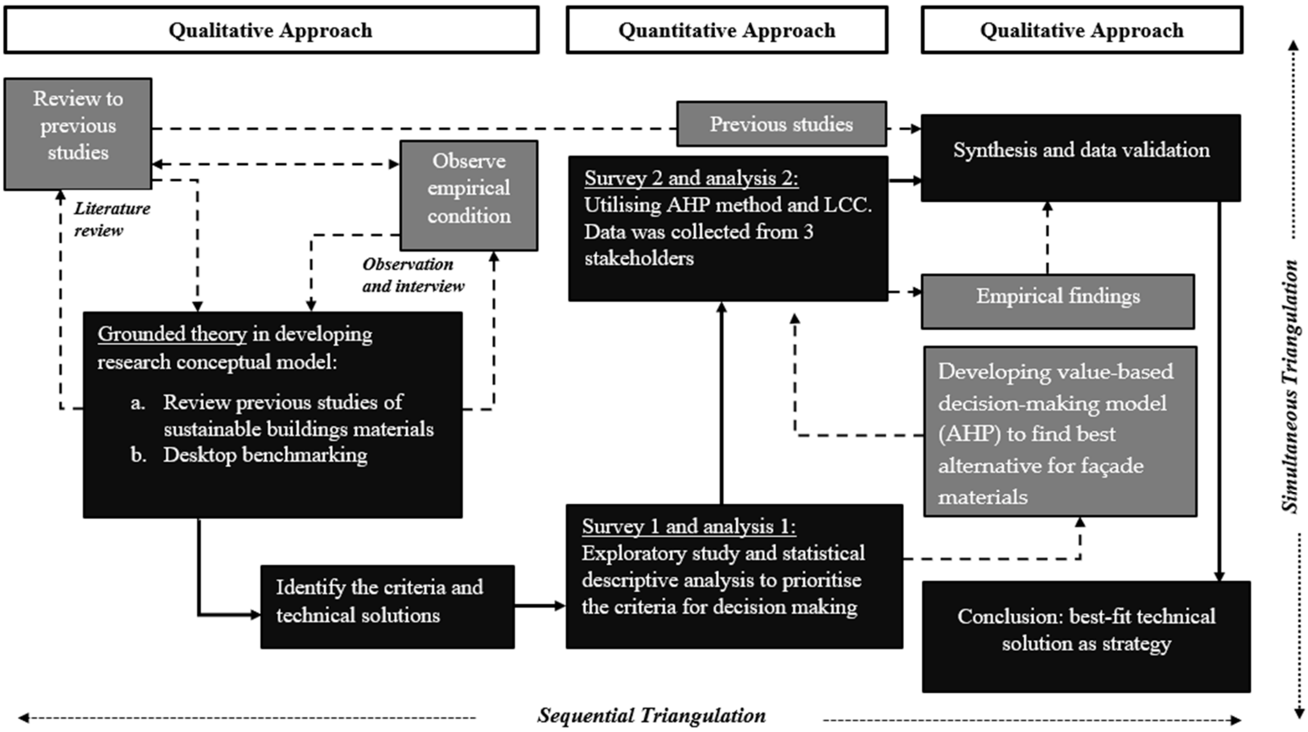

Fig. 1 Research flow chart

At the first stage, the research started with studying the previous studies related to the current sustainable buildings criteria for façade materials selection, followed by an interview with practitioners. The first survey was distributed to rank the importance level of the criteria. For data analysis, a scatter plot of mean and standard deviation scores was performed. In this study, Aluminum Composite Panels (ACP) and stainless steel were chosen to be façade materials alternatives for buildings. AHP method was selected for the second questionnaire with the main purpose of selecting the most suitable material. Three experts were involved from stakeholders. On the other side, the initial cost and operational and maintenance costs for each alternative were obtained through online resources and validated by the expert. The local priorities for the alternatives based on function and cost were derived from the data collected through the AHP. AHP is a structured technique used to organize and simplify complex problems. The first structure is the goal; the second one is the main criteria to attain the goal, and the third one is the sub-criteria for each main criterion and alternatives [12]. AHP was used not only because it is focused on relevant study data and analyses but also because the experts on the subject are involved [13].

A. Sustainable Criteria for Decision Making (Grounded Theory)

Sustainable development (SD) is today the long-term development strategy designed to address the next generation's needs. SD is a worldwide notion, especially in developed and emerging economies [14]. One of the main sustainable development goals is environmental conservation and climate mitigation. Over the past decades, the international construction sector has been affected by many factors that have increased the energy efficiency of buildings [15]. The oil crisis in the 1970s was the first factor, then sustainable development aim, and more recently, the climate change concerns [16], [17]. In this perspective, Hodges [18] argues that the benefits of environmental sustainability and green building strategies are significantly higher in facility management.

The sustainability imperative would be the energy consumption reduction, productivity increase, and emissions reduction [19]. Furthermore, the advantages of sustainability can be quantified and presented in an organization's leading position in protecting sustainability practices and their bottom-line positive impact. Sustainable building has many economic benefits: savings on energy costs, cuts in water costs, and mechanical equipment downsizing [20]. According to Gan *et al.* [21], using highly energy-efficient materials and optimizing building operation technology will reduce maintenance costs and improve the total life cost control. The previous studies related to the same field and scope of research have been reviewed. Fig. 2 illustrates the similarities and differences of findings from the previous studies.

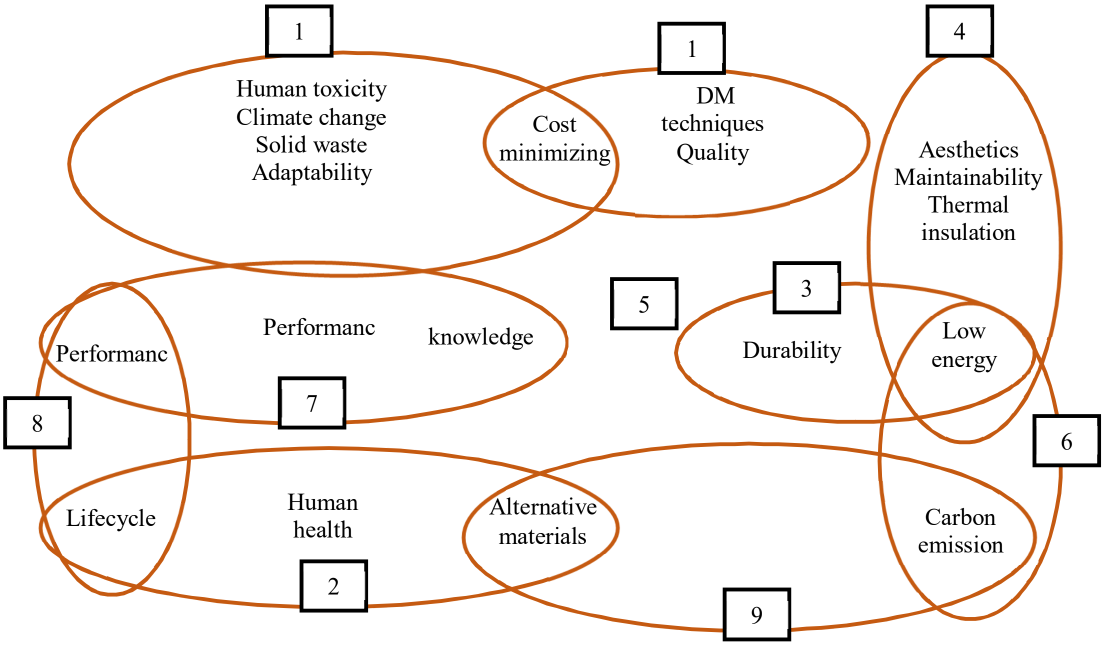

Fig. 2 The similarities of findings from previous studies (Sources: 1 = Abdel-malak, et al. [22]; 2 = Ajayi, et al. [3]; 3 = Hoxha, et al. [8]; 4 = Akadiri and Olomolaiye [23]; 5 = Krueger, et al. [24]; 6 = Hoxha and Shala [25]; 7 = Jailani, et al. [26]; 8 = Oduyemi and Okoroh [27]; 9 = Mahmoudkelaye, et al. [28]; 10 = Danso [29].

One of the best strategies for choosing sustainable building material is selecting the most environmentally friendly material, such as lower carbon emission [28]. Ajayi *et al.* [3] investigated the lifecycle relationship between building sustainability and its environmental health impacts, based on a modeled design using some software to run the research, which is Revit (to model a case study), and ATHENNA (to calculate the human health impact). At the end of the research, lifecycle assessment (LCA) was performed on seven alternatives. The findings show a direct relationship between sustainability and human health impacts, (insulated concrete form) contributes to the highest human health and environmental impacts. While (timber structure) least impact on human health and environmental impacts.

Hoxha *et al.* [8] studied the awareness, perception, and sustainable development of building materials among consumers, the construction industry, and facility managers in Prishtina, Kosovo. One of the highlighted criteria is the durability of building materials, followed by embodied energy and energy consumption. From the study, there are many criteria for sustainable building materials. Different people with different practitioners have different perspectives on choosing sustainability to meet their own needs [30]. Sustainable building constructions benefits and bolding the challenges facing the contractor in Kosovo for achieving sustainable building have been studied by Krueger *et al.* [24]. The findings show that the people of Kosovo are not exposed to sustainable buildings because of a lack of promotion by the practitioners. As a result, construction practitioners are looking for sustainable buildings to achieve the low cost of operations, savings of energy, and reduction of environmental pollution. At the same time, the challenges faced by practitioners are mainly focusing on structural, regulatory, and economical. Apart from the findings, the research benefits society as their research would expose some knowledge in sustainable building and the use of a sustainable building.

Another study has been conducted to investigate the key assessment criteria to use in assessment tools to develop sustainable building materials selection in the UK [23]. It is a crucial step in selecting sustainable building materials in construction buildings [28]. The main challenge is identifying the suitable criteria based on the principles and concepts of sustainable material. The results from the research are listed in three categories: socio-economic, environmental, and technical variables. A total of 24 criteria were identified, 12 criteria were highlighted as high importance level in selecting building materials. The top 3 out of 12 that are high importance level are aesthetics, maintainability, energy-saving, and thermal insulation. This research is only developing a list of criteria in sustainable building material selection. Thus, there is a limitation where the research is unable to utilize the criteria in developing further steps for decision making to choose the best alternatives for sustainable building material.

Lack of knowledge and clarity to use the right alternative materials could create barriers in determining what to choose for sustainable building materials [31]. It is true alternative materials could bring some benefits to the environment and society, but a lack of knowledge in a sustainable building could bring or create barriers to choose materials. Alternatives show a positive impact on the environment, but the selection of material could be hard as it depends on the client's needs and contractor resources [8]. Therefore, a list of criteria for materials selection to develop a decision-making model is identified. A comprehensive list of sustainable criteria for materials selection is identified based on the previous studies, as shown in Table I.

TABLE I
CRITERIA FOR SUSTAINABLE MATERIALS SELECTION

Main criteria	Sub-criteria	Studies
Technical	S1: Durability of the material due to the external environment	[8]
	S2: The ability of material in reducing a building's energy, particularly for the tropical climate	[25]
	S3: Capability of the materials to secure the building from air leakage	[32]
Economical	S4: The easiness of material to be maintained during their life cycle	[29]
	S5: The ability to reduce operational and maintenance cost of building	[23]
Environmental	S6: The ability of a material to reduce greenhouse gas emission	[28]
	S7: The ability to reduce construction waste	[33]
	S8: The ability to reduce or prevent environmental impacts	[3]

III. RESULTS AND DISCUSSIONS

A. Ranking of Sustainable Criteria for Materials Selection

An interview to develop and verify the criteria was conducted. The questionnaire surveys were distributed to 30 participants to evaluate and develop the importance level of the criteria for buildings projects. The participants' background is presented in Fig. 3.

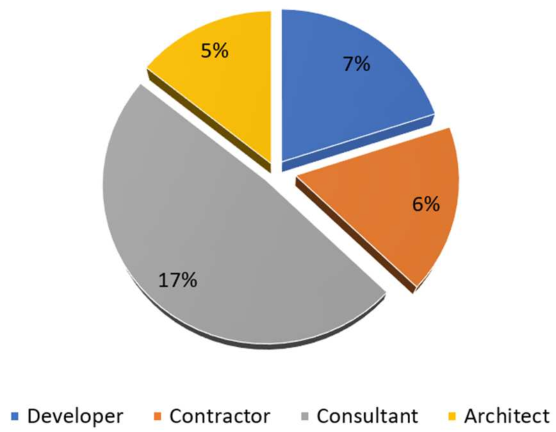

Fig. 3 Profile of respondents

The criteria are classified into three categories, which are technical, economical, and environmental. Moreover, the participants were requested to rank the criteria for all mentioned main categories to achieve sustainability in buildings projects. Table II presents the ranking analysis for each criterion based on its level of importance in achieving sustainability.

TABLE II
THE RANK OF THE SUSTAINABLE CRITERIA FROM THE SCATTER PLOT OF MEAN AND SD

Main criteria	Sub-criteria	Mean	SD	Rank
Technical	S1	4.25	0.67	1
	S2	4.24	0.82	5
	S3	3.30	1.18	8
Economical	S4	3.50	0.84	7
	S5	3.95	0.70	2
Environmental	S6	4.11	0.82	6
	S7	3.90	0.80	4
	S8	4.23	0.78	3

The analysis was performed by a scatter plot of mean and standard deviation. From the analysis, the durability of material (S1) was found to be ranked by participants as the priority criteria, followed by the ability of materials to reduce operational and maintenance costs of building (S5). Also, participants in this study showed the importance of reducing construction waste and reducing the environmental impacts by ranking criteria (S7) and (S8) as the third and fourth influencing criteria while selecting materials, respectively. The ability of the material to reduce the energy (S2) and to reduce the GHG emission (S6) was ranked as the fifth and sixth importance level among all criteria. It is followed by the easiness of material to be maintained during their life cycle (S4) and the capability of the material to secure the building from air leakage (S3), respectively.

B. Alternatives Evaluation Using AHP

In the last section of the first survey, there is a section asking for potential sustainable façade material, and most of the respondents recommended Aluminum Composite Panel (ACP) and Stainless-Steel materials. So, ACP and Stainless Steel were chosen to be the potential alternatives in this study. To evaluate the recommended alternative materials, a second survey was designed based on the AHP tool. The AHP questionnaire surveys have been distributed to building stakeholders in the Malaysian building industry. Based on three stakeholders' preferences, weight was created for each assessment criterion, and a score was appointed following each alternative. The good performance of the alternative shows a higher score. Three main criteria and eight sub-criteria were used to select the best alternative material. Fig. 4 presents four levels of decision hierarchy.

The top level represents the study's goal, the second level presents the main criteria, the third level shows sub-criteria, and the last level provides materials alternatives. After the decision hierarchy was built, the judgment and synthesis were stated using AHP. A decision and a synthesis are conducting to evaluate the best alternatives among stakeholders.

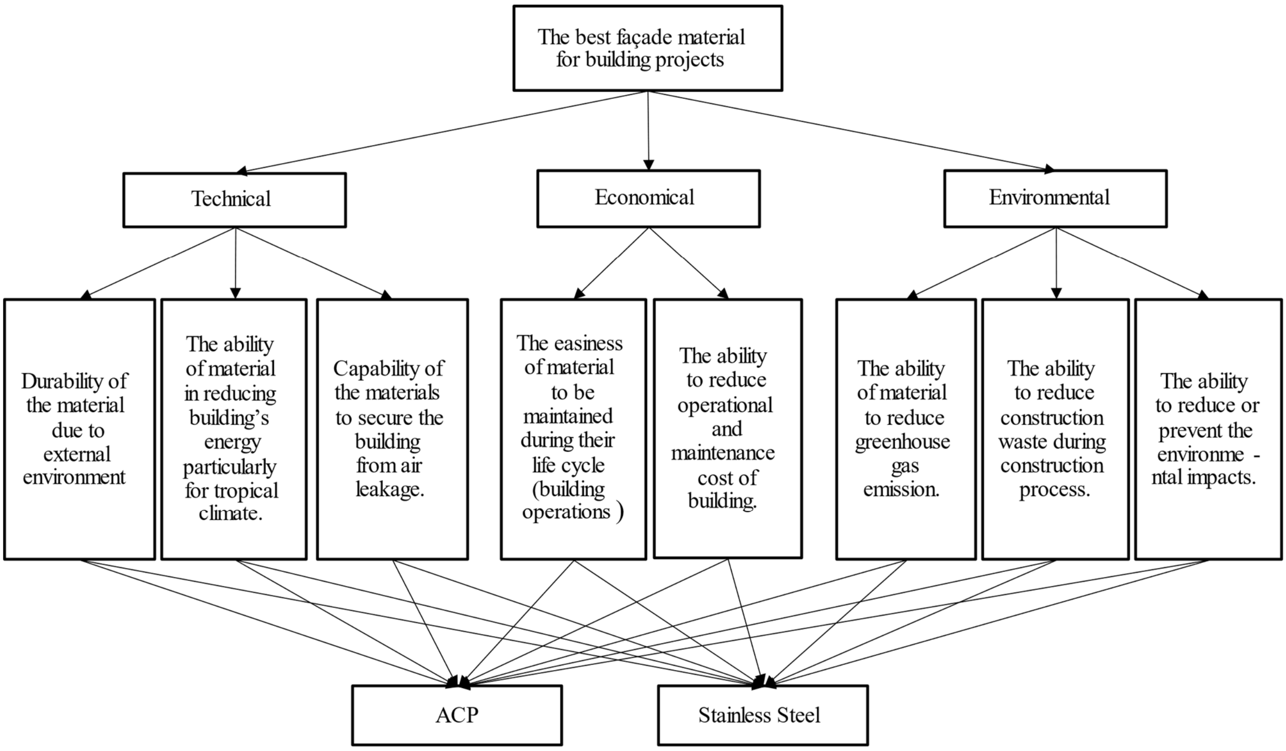

Fig. 4 Decision hierarchy for sustainable building materials selection

Sequentially, three steps must be taken. Firstly, each stakeholder's weighting factor (weight of preferences) of each main criterion is determined (Fig. 5). The second is weight determination for each stakeholder in each sub-criterion (Fig. 6), and the third is grading the weight values of the provided alternatives for each stakeholder and their aggregation score (Fig. 7).

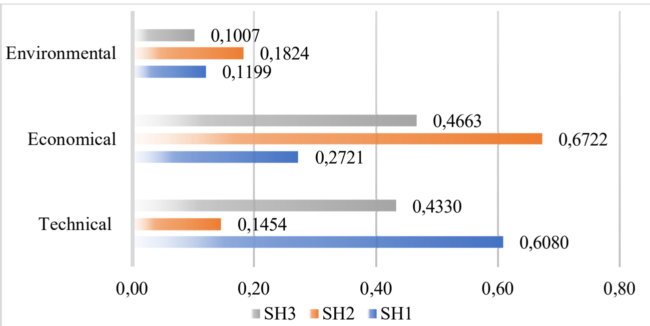

Fig. 5 The priority of main criteria of façade building materials for each stakeholder

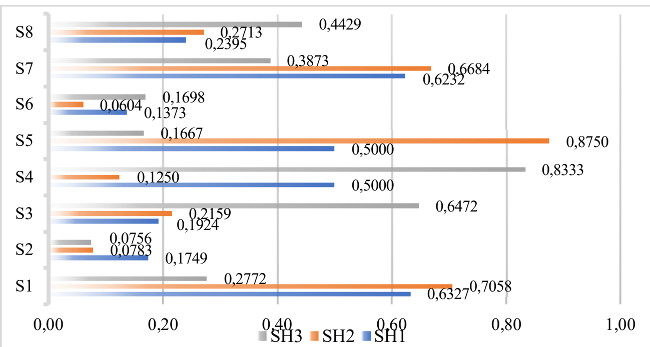

Fig. 6 The priority of sub-criteria of façade building materials for each stakeholder

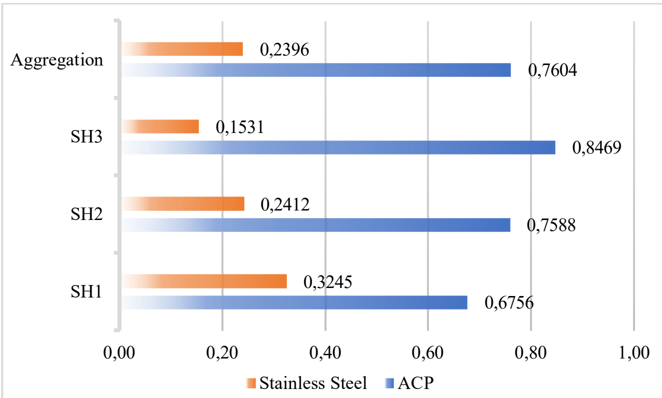

Fig. 7 The priority of alternative for each stakeholder and the value of aggregation

This decision comprises three decisions, the first is the main criteria judgment for each decision-maker, the second is a sub-criteria judgment for each creation, and the third is the alternatives judgment from each stakeholder. The first step is presented in Fig. 5; it can observe that stakeholder 1 (SH1) considered technical criteria the most priority among other criteria in selecting sustainable materials with a weightage of 0.6080. Meanwhile, stakeholders 2 (SH2) and stakeholders 3 (SH3) agreed that economics is the most important criterion in choosing sustainable materials. This differentiation is a natural decision-making character. This is due to the disparity in interest background. These factors distinguish the alternatives choices. The results from the second step are shown in Fig. 6. From SH1, the most important sub-criteria are the durability of the material due to the external environment (S1) with the weightage of 0.6327, the ability to reduce construction waste during the construction process (S7), followed by the easiness of material to be maintained during their life cycle (S4) and the ability to reduce operational and maintenance cost of building (S5), has a similar weightage of 0.5. According to SH2, the top 3 most important sub-criteria are (S5), (S1), and (S7). Lastly, SH3 stated that the top three sub-criteria chosen are (S4), (S3), and (S8), with weight values of 0.8333, 0.6472, and 0.4429, respectively. Fig. 7 indicates the third step or the final step to decide the best choice. Each stakeholder has numerous choices.

The aggregate of the value of the three players also appears in Fig. 7. All stakeholders in this study selected the ACP alternative to meet sustainable buildings by façade materials. In other words, the respondents choose ACP among stainless steel. Several methods are available to evaluate mutual preference, first with aggregated value, second by coalition algorithm negotiation, based on the optimal payroll for every player. A joint option with aggregated values is performed in this study.

C. Value-based Analysis (Function/Cost)

The most valuable alternative for sustainable façade material of the building is selected by considering the criteria of function and cost. There are two different attributes to calculate the value: one represents a function, and another attribute represents cost [34]. The value equation used in the calculation is function/cost. The higher the value, the greater the alternatives and vice versa. The alternative will only be accepted when the value is more than 1, while the alternative with a value of less than one will be rejected. In utility of cost, three factors are taken into consideration, which is the initial cost of the materials (c_1), operational and maintenance cost (c_2), and replacement cost (c_3). Loss is calculated using the highest total cost of material added by the lowest total cost of material and is subtracted with the total cost of the material. Based on Table III, the ACP alternative has the highest loss of 2.226. Hence, the other alternative will be more potential by considering the cost criteria only.

TABLE III
THE PRIORITY OF ALTERNATIVES BASED ON COST CRITERIA

	c_1	c_2	c_3	Sum	Loss	Rank
ACP	0.255	0.255	0.265	0.774	2.226	2nd
Stainless Steel	0.745	0.745	0.735	2.226	0.774	1st

Referring to Table IV, the ACP alternative is selected as the most valuable alternative with the greatest value of 1.148 as compared to the stainless-steel alternative.

TABLE IV
THE PRIORITY OF ALTERNATIVES BASED ON COST AND FUNCTION CRITERIA

	Cost	Function	Value	Rank
ACP	0.742	0.852	1.148	1st
Stainless Steel	0.258	0.148	0.575	2nd

On the other hand, based on the result shown in Table 3, the stainless-steel material is ranked before the ACP material when considering the criteria of cost only. However, when the function is considered, ACP will be more valuable to be used as a façade material for buildings than other alternative materials. Hence, the stainless-steel material is rejected as the value is lower than 1. Fig. 8 shows the value of the alternatives based on the scatters plot analysis. It shows that the alternatives located above the baseline are valuable for façade material.

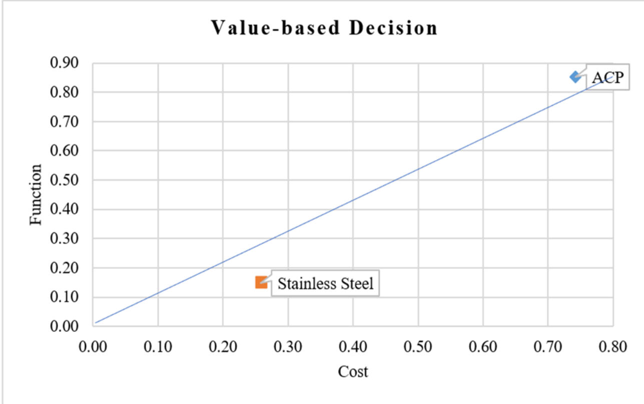

Fig. 8 Scatter plot for value-based decision-making

D. Empirical Validation

The most valuable alternative for building material to improve its economic, operational performance, and sustainability was identified based on value-based decision making. The empirical validation is necessary for this research to validate the acceptance of the value-based decision-making in the industry based on the result obtained. Thus, the validation is conducted by an interview with an expert who has a wide experience in construction project management [35], [36]. According to the expert, the result of the ACP as the most valuable alternative for façade building material is accepted. The reason behind that is that the ACP material is much cheaper than stainless steel as both materials would give the same function, and ACP is much lighter; hence the workability is much higher than stainless steel.

Furthermore, technical criteria are ranked the first level. The respondents might choose stainless steel to compare to ACP material. It is because stainless steel is higher in strength and its steel integrity is double the ACP. In short, value-based decision-making model is accepted to be adopted in the construction industry to help stakeholders make a decision based on the value of the properties.

E. Discussion

Based on the data analyzed, the weightage of the main criteria, sub-criteria, and alternatives for sustainable façade materials were obtained from 3 respondents with different backgrounds. All the involved participants have extensive experience in construction, particularly high-rise buildings. This data analysis will help make or develop a decision-making model for selecting sustainable façade materials, with the help of a mathematical equation from the Analytical Hierarchy Process.

Thus, (SH 1) selected the technical criteria (Fig. 5) and sub-criteria the durability of the material due to the external environment (S1) (Fig. 6) as the most priority in selecting sustainable material for façade. This criterion was agreed by Hoxha *et al.* [8] as mentioned that improve the durability of the materials is the efficient way in construction to sustain sustainability. Akadiri and Olomolaiye [23] support the statement that technical properties such as strength and durability are important when choosing sustainable materials. Meanwhile, SH2 and SH3 agreed that economics is the most important criteria in choosing sustainable materials (Fig. 5). Danso [29] supported the statement, which stated that the economic aspect should be one of the important criteria in sustainable constructions today and in the future. The reason is the sustainable construction materials should save in the long run while reducing maintenance costs and operational costs. Tam *et al.* [37] mentioned that sustainability and cost significantly impact building construction because designers should consider life cycle cost when building façade. Thus, the economic aspect should be the priority when choosing sustainable façade material. As mentioned earlier, this differentiation of the results is a natural decision-making character. This is due to the disparity in the interesting background of the stakeholders. However, all stakeholders have been chosen ACP instead of stainless steel as the most appropriate alternative materials. One reason is that ACP is cheaper while stainless steel is almost three times higher than ACP cost. ACP provides a much lower cost in the long run, but both alternatives' maintenance cost and operational cost are almost the same [37]. Aluminum is widely used in construction and is the second most frequently used apart from steel. In building sustainable façade material, the aluminum composite panel chose by each respondent from a different background (consultant, contractor, and architect) because they know aluminum can achieve more with its versatility.

According to stakeholders with architect backgrounds, aluminum can come in a wide range of colors, and it is environmentally friendly and can easily be recycled. Next, according to the respondent with the consultant background, which experiences in doing high-rise building mentioned aluminum is easy to fabricate during installation, and its strength to weight ratio is different or no like other metals. Thus, make the ACP the popular choice. Lastly, a respondent with a contractor background also mentioned that aluminum provides a long lifespan and is maintenance-friendly, reducing the cost of operation and maintenance. Naqash *et al.* [38] suggested using aluminum for curtain walls due to its lightweight compared to other steel materials. Furthermore, aluminum provides a high strength-to-weight ratio despite the ability to form to any shapes hassles. Hence, ACP would be a suitable sustainable material for the façade.

IV. Conclusion

In conclusion, it is important to develop value-based decision-making that could help and support stakeholders during materials selection to achieve sustainability. This study was conducted to develop a decision-making model for selecting the best sustainable building material using Analytical Hierarchy Process (AHP). The value-based decision is performed to choose the best façade alternatives. Aluminum Composite Panel (ACP) is chosen at the end of the research. Much previous research only focusing on developing decision-making using a traditional way. However, this research used a value-based decision where desirable and considerable is the primary consideration with given attributes. Criteria and alternatives are transformed into numerical using mathematical logic, and then the best alternative is chosen based on the highest value (Value ≥ 1).

As a result, the economic criteria are considered the top priority to stakeholders in choosing sustainable façade material, followed by the technical criteria and environmental criteria. The best alternative calculated from function over cost is the Aluminum Composite Panel (ACP) with a value of 1.149, greater or equal to 1.

Finally, the research and decision model mainly focused on local experts in Malaysia, considering the existing situation and most common building in Malaysia. However, the research can be extended based on any given requirement or element of façade from a different site. Other than that, the study partially uses value-based decisions as a form of cost analysis to find the alternatives for sustainable façade material. There is another detailed step in determining the result accurately but beyond the researcher's knowledge. Next, more respondents should be considered in determining the accuracy of the research. Choosing the best alternatives material for building is important in construction nowadays. Hence, it is recommendable for future research to be conducted to improve the construction industry's quality.

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A Value-Based Decision-Making Model for Selecting Sustainable Materials for Buildings

Amirul Afiq Bin Ruslan[a], Ezzaddin Abdullah Al-Atesh[a], Yani Rahmawati[b,*], Christiono Utomo[c], Noor Amila Wan Abdullah Zawawi[d], Mohamad Jahja[e], Raflis[f], Ali Elmansoury[g]

[a] Department of Civil and Environmental Engineering, Universiti Teknologi PETRONAS, Seri Iskandar 32610, Malaysia
[b] Architectural Enggineering, Universitas Gadjah Mada, 55281 Yogyakarta, Indonesia
[c] Civil Engineering, Institut Teknologi Sepuluh Nopember, Sukolilo Surabaya 60111, Indonesia
[d] Institute of Self Sustainable Building, Universiti Teknologi PETRONAS, 32610 Seri Iskandar, Perak, Malaysia
[e] Faculty of Mathematics and Natural Science, Universitas Negeri Gorontalo, Gorontalo 96128, Indonesia
[f] Civil Engineering, Universitas Trisakti, Jakarta 11440, Indonesia
[g] Architectural Department, College of Engineering, Al-Azhar University, Egypt

Corresponding author: *yanirahmawati2012@gmail.com

Abstract*— Nowadays, the earth faces problems and challenges from different circumstances due to the dramatic rise of urban modernization. The construction industry is the most contributor to climate change. Achieving sustainability in construction is complicated, but one of the most optimal strategies is selecting building materials with a lower carbon footprint. Therefore, this research aims to investigate the criteria for sustainable materials selection, rank and prioritize sustainable criteria, and developing value-based decision making. A mixed method was used to satisfy the objectives through an extensive literature review, surveys, and interviews with experts. The statistical descriptive was based on a scatter plot of mean and standard deviation, AHP judgment and Value-based decision-making using function over cost. There are two alternatives obtained in this study: Aluminum Composite Panel (ACP) and Stainless Steel. As a result, the suitable alternative for sustainable façade material is ACP based on value-based calculation. The tendency of choosing sustainable material depends on the stakeholders, owner of the building, designers, and others. The research is to show the way in selecting sustainable material by using value-based analysis. This study could expect to give feasibility and useful knowledge in solving problems and increase the use of sustainable materials in building construction. Future research may be conducted with different requirements for sustainable materials. AHP and Value-based analysis are structured technique that solves a complex problem easily using mathematics and psychology approach.

***Keywords*— Sustainable façade material; materials selection; decision making; building industry.**

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I. Introduction

In sustainable building, various definitions can be seen from various perspectives. For example, a sustainable building can be defined as the lower usage of resources and maximize the function of buildings [1]. The building sector is one of the essential parts of modern society and a vital element of any economy [2]. The building proves to have a significant impact on our environment. This is stated by Ajayi *et al.* [3] in their research; building activities produce a significant impact on resource depletion. The construction industry is having difficulty and remained under pressure to improve environmental sustainability [4]. The buildings have tremendous environmental effects, energy, human health, and productivity [5]. Many illnesses, fatalities, and ultimate environmental harm have been associated with unsustainable building materials [3]. According to Krausmann *et al.* [6], it is estimated that about 60 billion tons of materials are consumed and expected to increase in the future due to rapid population growth rapidly.

From previous studies, non-sustainable building materials could lead to negative impacts both on environmental and human health. Therefore, many building staff has started to track and correct environmental damages due to their operations [7]. Although sustainable building seems like an easy task, the crucial part is deciding to choose building materials. How is it hard? Because it caused difficulties for project stakeholders in selecting the best material. Based on

Hoxha *et al.* [8], it is argued that different stakeholders have different backgrounds in their activities about the criteria for sustainable building materials. Hence, there are no right or wrong criteria to be selected for sustainable building materials. Lastly, criteria for choosing sustainable building material can be categorized into technical, economic, and environmental.

Therefore, this study aims to select suitable sustainable materials for building construction, particularly in façade. To achieve this, a list of criteria in sustainable building material to apply in the decision-making process is investigated and possible alternative materials to achieve sustainability. Analytical Hierarchy Process (AHP) judgment and value-based decision-making are used in developing a decision-making model to identify the suitable sustainable façade material. This research is limited to the selection of the best sustainable façade material for buildings in Malaysia. The result has been validated by interviewing an expert.

II. Materials and Method

The study flow is described in Fig. 1, adapted from Othman *et al.* [9] and Buniya *et al.* [10]. A mixed-method was used to achieve the research objectives [11]. There are two main study surveys and data analysis.

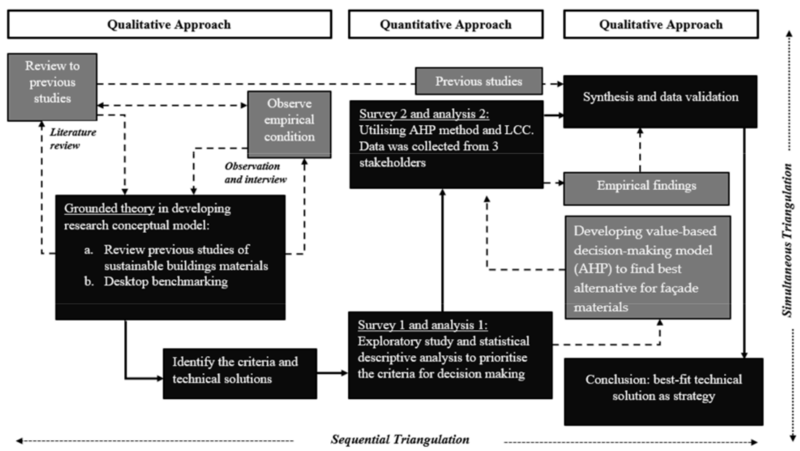

Fig. 1 Research flow chart

At the first stage, the research started with studying the previous studies related to the current sustainable buildings criteria for façade materials selection, followed by an interview with practitioners. The first survey was distributed to rank the importance level of the criteria. For data analysis, a scatter plot of mean and standard deviation scores was performed. In this study, Aluminum Composite Panels (ACP) and stainless steel were chosen to be façade materials alternatives for buildings. AHP method was selected for the second questionnaire with the main purpose of selecting the most suitable material. Three experts were involved from stakeholders. On the other side, the initial cost and operational and maintenance costs for each alternative were obtained through online resources and validated by the expert. The local priorities for the alternatives based on function and cost were derived from the data collected through the AHP. AHP is a structured technique used to organize and simplify complex problems. The first structure is the goal; the second one is the main criteria to attain the goal, and the third one is the sub-criteria for each main criterion and alternatives [12]. AHP was used not only because it is focused on relevant study data and analyses but also because the experts on the subject are involved [13].

A. Sustainable Criteria for Decision Making (Grounded Theory)

Sustainable development (SD) is today the long-term development strategy designed to address the next generation's needs. SD is a worldwide notion, especially in developed and emerging economies [14]. One of the main sustainable development goals is environmental conservation and climate mitigation. Over the past decades, the international construction sector has been affected by many factors that have increased the energy efficiency of buildings [15]. The oil crisis in the 1970s was the first factor, then sustainable development aim, and more recently, the climate change concerns [16], [17]. In this perspective, Hodges [18] argues that the benefits of environmental sustainability and green building strategies are significantly higher in facility management.

The sustainability imperative would be the energy consumption reduction, productivity increase, and emissions reduction [19]. Furthermore, the advantages of sustainability can be quantified and presented in an organization's leading position in protecting sustainability practices and their bottom-line positive impact. Sustainable building has many economic benefits: savings on energy costs, cuts in water costs, and mechanical equipment downsizing [20]. According to Gan *et al.* [21], using highly energy-efficient materials and optimizing building operation technology will reduce maintenance costs and improve the total life cost control. The previous studies related to the same field and scope of research have been reviewed. Fig. 2 illustrates the similarities and differences of findings from the previous studies.

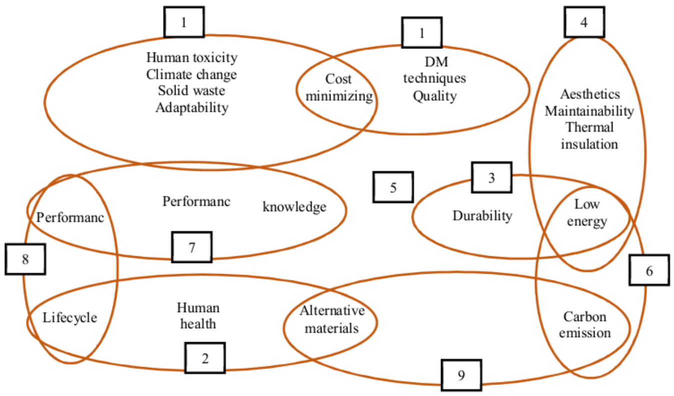

Fig. 2 The similarities of findings from previous studies (Sources: 1 = Abdel-malak, et al. [22]; 2 = Ajayi, et al. [3]; 3 = Hoxha, et al. [8]; 4 = Akadiri and Olomolaiye [23]; 5 = Krueger, et al. [24]; 6 = Hoxha and Shala [25]; 7 = Jailani, et al. [26]; 8 = Oduyemi and Okoroh [27]; 9 = Mahmoudkelaye, et al. [28]; 10 = Danso [29].

One of the best strategies for choosing sustainable building material is selecting the most environmentally friendly material, such as lower carbon emission [28]. Ajayi *et al.* [3] investigated the lifecycle relationship between building sustainability and its environmental health impacts, based on a modeled design using some software to run the research, which is Revit (to model a case study), and ATHENNA (to calculate the human health impact). At the end of the research, lifecycle assessment (LCA) was performed on seven alternatives. The findings show a direct relationship between sustainability and human health impacts, (insulated concrete form) contributes to the highest human health and environmental impacts. While (timber structure) least impact on human health and environmental impacts.

Hoxha *et al.* [8] studied the awareness, perception, and sustainable development of building materials among consumers, the construction industry, and facility managers in Prishtina, Kosovo. One of the highlighted criteria is the durability of building materials, followed by embodied energy and energy consumption. From the study, there are many criteria for sustainable building materials. Different people with different practitioners have different perspectives on choosing sustainability to meet their own needs [30]. Sustainable building constructions benefits and bolding the challenges facing the contractor in Kosovo for achieving sustainable building have been studied by Krueger *et al.* [24]. The findings show that the people of Kosovo are not exposed to sustainable buildings because of a lack of promotion by the practitioners. As a result, construction practitioners are looking for sustainable buildings to achieve the low cost of operations, savings of energy, and reduction of environmental pollution. At the same time, the challenges faced by practitioners are mainly focusing on structural, regulatory, and economical. Apart from the findings, the research benefits society as their research would expose some knowledge in sustainable building and the use of a sustainable building.

Another study has been conducted to investigate the key assessment criteria to use in assessment tools to develop sustainable building materials selection in the UK [23]. It is a crucial step in selecting sustainable building materials in construction buildings [28]. The main challenge is identifying the suitable criteria based on the principles and concepts of sustainable material. The results from the research are listed in three categories: socio-economic, environmental, and technical variables. A total of 24 criteria were identified, 12 criteria were highlighted as high importance level in selecting building materials. The top 3 out of 12 that are high importance level are aesthetics, maintainability, energy-saving, and thermal insulation. This research is only developing a list of criteria in sustainable building material selection. Thus, there is a limitation where the research is unable to utilize the criteria in developing further steps for decision making to choose the best alternatives for sustainable building material.

Lack of knowledge and clarity to use the right alternative materials could create barriers in determining what to choose for sustainable building materials [31]. It is true alternative materials could bring some benefits to the environment and society, but a lack of knowledge in a sustainable building could bring or create barriers to choose materials. Alternatives show a positive impact on the environment, but the selection of material could be hard as it depends on the client's needs and contractor resources [8]. Therefore, a list of criteria for materials selection to develop a decision-making model is identified. A comprehensive list of sustainable criteria for materials selection is identified based on the previous studies, as shown in Table I.

TABLE I
CRITERIA FOR SUSTAINABLE MATERIALS SELECTION

Main criteria	Sub-criteria	Studies
Technical	S1: Durability of the material due to the external environment	[8]
	S2: The ability of material in reducing a building's energy, particularly for the tropical climate	[25]
	S3: Capability of the materials to secure the building from air leakage	[32]
Economical	S4: The easiness of material to be maintained during their life cycle	[29]
	S5: The ability to reduce operational and maintenance cost of building	[23]
Environmental	S6: The ability of a material to reduce greenhouse gas emission	[28]
	S7: The ability to reduce construction waste	[33]
	S8: The ability to reduce or prevent environmental impacts	[3]

III. RESULTS AND DISCUSSIONS

A. *Ranking of Sustainable Criteria for Materials Selection*

An interview to develop and verify the criteria was conducted. The questionnaire surveys were distributed to 30 participants to evaluate and develop the importance level of the criteria for buildings projects. The participants' background is presented in Fig. 3.

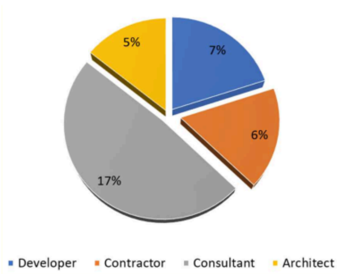

Fig. 3 Profile of respondents

The criteria are classified into three categories, which are technical, economical, and environmental. Moreover, the participants were requested to rank the criteria for all mentioned main categories to achieve sustainability in buildings projects. Table II presents the ranking analysis for each criterion based on its level of importance in achieving sustainability.

TABLE II
THE RANK OF THE SUSTAINABLE CRITERIA FROM THE SCATTER PLOT OF MEAN AND SD

Main criteria	Sub-criteria	Mean	SD	Rank
Technical	S1	4.25	0.67	1
	S2	4.24	0.82	5
	S3	3.30	1.18	8
Economical	S4	3.50	0.84	7
	S5	3.95	0.70	2
Environmental	S6	4.11	0.82	6
	S7	3.90	0.80	4
	S8	4.23	0.78	3

The analysis was performed by a scatter plot of mean and standard deviation. From the analysis, the durability of material (S1) was found to be ranked by participants as the priority criteria, followed by the ability of materials to reduce operational and maintenance costs of building (S5). Also, participants in this study showed the importance of reducing construction waste and reducing the environmental impacts by ranking criteria (S7) and (S8) as the third and fourth influencing criteria while selecting materials, respectively. The ability of the material to reduce the energy (S2) and to reduce the GHG emission (S6) was ranked as the fifth and sixth importance level among all criteria. It is followed by the easiness of material to be maintained during their life cycle (S4) and the capability of the material to secure the building from air leakage (S3), respectively.

B. *Alternatives Evaluation Using AHP*

In the last section of the first survey, there is a section asking for potential sustainable façade material, and most of the respondents recommended Aluminum Composite Panel (ACP) and Stainless-Steel materials. So, ACP and Stainless Steel were chosen to be the potential alternatives in this study. To evaluate the recommended alternative materials, a second survey was designed based on the AHP tool. The AHP questionnaire surveys have been distributed to building stakeholders in the Malaysian building industry. Based on three stakeholders' preferences, weight was created for each assessment criterion, and a score was appointed following each alternative. The good performance of the alternative shows a higher score. Three main criteria and eight sub-criteria were used to select the best alternative material. Fig. 4 presents four levels of decision hierarchy.

The top level represents the study's goal, the second level presents the main criteria, the third level shows sub-criteria, and the last level provides materials alternatives. After the decision hierarchy was built, the judgment and synthesis were stated using AHP. A decision and a synthesis are conducting to evaluate the best alternatives among stakeholders.

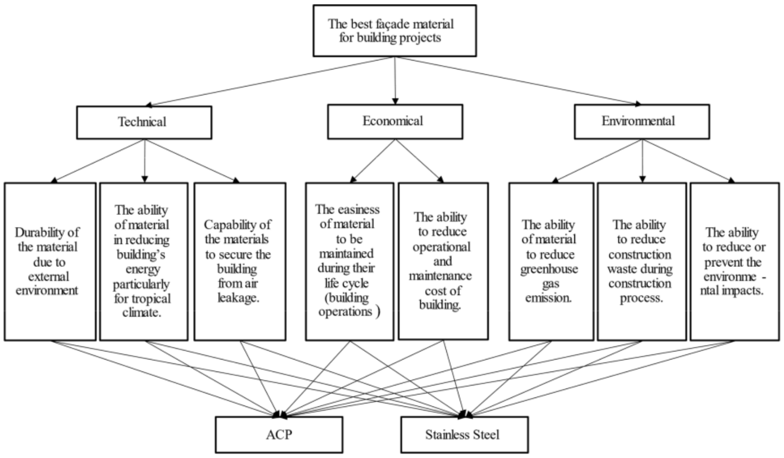

Fig. 4 Decision hierarchy for sustainable building materials selection

Sequentially, three steps must be taken. Firstly, each stakeholder's weighting factor (weight of preferences) of each main criterion is determined (Fig. 5). The second is weight determination for each stakeholder in each sub-criterion (Fig. 6), and the third is grading the weight values of the provided alternatives for each stakeholder and their aggregation score (Fig. 7).

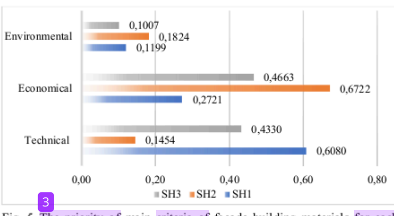

Fig. 5 The priority of main criteria of façade building materials for each stakeholder

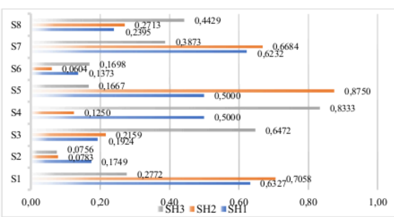

Fig. 6 The priority of sub-criteria of façade building materials for each stakeholder

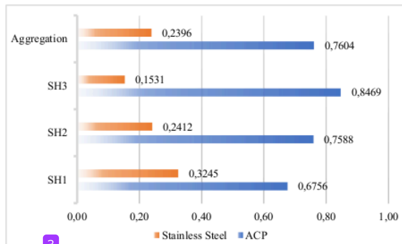

Fig. 7 The priority of alternative for each stakeholder and the value of aggregation

This decision comprises three decisions, the first is the main criteria judgment for each decision-maker, the second is a sub-criteria judgment for each creation, and the third is the alternatives judgment from each stakeholder. The first step is presented in Fig. 5; it can observe that stakeholder 1 (SH1) considered technical criteria the most priority among other criteria in selecting sustainable materials with a weightage of 0.6080. Meanwhile, stakeholders 2 (SH2) and stakeholders 3 (SH3) agreed that economics is the most important criterion in choosing sustainable materials. This differentiation is a natural decision-making character. This is due to the disparity in interest background. These factors distinguish the alternatives choices. The results from the second step are shown in Fig. 6. From SH1, the most important sub-criteria are the durability of the material due to the external environment (S1) with the weightage of 0.6327, the ability to reduce construction waste during the construction process (S7), followed by the easiness of material to be maintained during their life cycle (S4) and the ability to reduce operational and maintenance cost of building (S5), has a similar weightage of 0.5. According to SH2, the top 3 most important sub-criteria are (S5), (S1), and (S7). Lastly, SH3 stated that the top three sub-criteria chosen are (S4), (S3), and (S8), with weight values of 0.8333, 0.6472, and 0.4429, respectively. Fig. 7 indicates the third step or the final step to decide the best choice. Each stakeholder has numerous choices.

The aggregate of the value of the three players also appears in Fig. 7. All stakeholders in this study selected the ACP alternative to meet sustainable buildings by façade materials. In other words, the respondents choose ACP among stainless steel. Several methods are available to evaluate mutual preference, first with aggregated value, second by coalition algorithm negotiation, based on the optimal payroll for every player. A joint option with aggregated values is performed in this study.

C. Value-based Analysis (Function/Cost)

The most valuable alternative for sustainable façade material of the building is selected by considering the criteria of function and cost. There are two different attributes to calculate the value: one represents a function, and another attribute represents cost [34]. The value equation used in the calculation is function/cost. The higher the value, the greater the alternatives and vice versa. The alternative will only be accepted when the value is more than 1, while the alternative with a value of less than one will be rejected. In utility of cost, three factors are taken into consideration, which is the initial cost of the materials (c_1), operational and maintenance cost (c_2), and replacement cost (c_3). Loss is calculated using the highest total cost of material added by the lowest total cost of material and is subtracted with the total cost of the material. Based on Table III, the ACP alternative has the highest loss of 2.226. Hence, the other alternative will be more potential by considering the cost criteria only.

TABLE III
THE PRIORITY OF ALTERNATIVES BASED ON COST CRITERIA

	c_1	c_2	c_3	Sum	Loss	Rank
ACP	0.255	0.255	0.265	0.774	2.226	2nd
Stainless Steel	0.745	0.745	0.735	2.226	0.774	1st

Referring to Table IV, the ACP alternative is selected as the most valuable alternative with the greatest value of 1.148 as compared to the stainless-steel alternative.

TABLE IV
THE PRIORITY OF ALTERNATIVES BASED ON COST AND FUNCTION CRITERIA

	Cost	Function	Value	Rank
ACP	0.742	0.852	1.148	1st
Stainless Steel	0.258	0.148	0.575	2nd

On the other hand, based on the result shown in Table 3, the stainless-steel material is ranked before the ACP material when considering the criteria of cost only. However, when the function is considered, ACP will be more valuable to be used as a façade material for buildings than other alternative materials. Hence, the stainless-steel material is rejected as the value is lower than 1. Fig. 8 shows the value of the alternatives based on the scatters plot analysis. It shows that the alternatives located above the baseline are valuable for façade material.

Fig. 8 Scatter plot for value-based decision-making

D. Empirical Validation

The most valuable alternative for building material to improve its economic, operational performance, and sustainability was identified based on value-based decision making. The empirical validation is necessary for this research to validate the acceptance of the value-based decision-making in the industry based on the result obtained. Thus, the validation is conducted by an interview with an expert who has a wide experience in construction project management [35], [36]. According to the expert, the result of the ACP as the most valuable alternative for façade building material is accepted. The reason behind that is that the ACP material is much cheaper than stainless steel as both materials would give the same function, and ACP is much lighter; hence the workability is much higher than stainless steel.

Furthermore, technical criteria are ranked the first level. The respondents might choose stainless steel to compare to ACP material. It is because stainless steel is higher in strength and its steel integrity is double the ACP. In short, value-based decision-making model is accepted to be adopted in the construction industry to help stakeholders make a decision based on the value of the properties.

E. Discussion

Based on the data analyzed, the weightage of the main criteria, sub-criteria, and alternatives for sustainable façade materials were obtained from 3 respondents with different backgrounds. All the involved participants have extensive experience in construction, particularly high-rise buildings. This data analysis will help make or develop a decision-making model for selecting sustainable façade materials, with the help of a mathematical equation from the Analytical Hierarchy Process.

Thus, (SH 1) selected the technical criteria (Fig. 5) and sub-criteria the durability of the material due to the external environment (S1) (Fig. 6) as the most priority in selecting sustainable material for façade. This criterion was agreed by Hoxha *et al.* [8] as mentioned that improve the durability of the materials is the efficient way in construction to sustain sustainability. Akadiri and Olomolaiye [23] support the statement that technical properties such as strength and durability are important when choosing sustainable materials. Meanwhile, SH2 and SH3 agreed that economics is the most important criteria in choosing sustainable materials (Fig. 5). Danso [29] supported the statement, which stated that the economic aspect should be one of the important criteria in sustainable constructions today and in the future. The reason is the sustainable construction materials should save in the long run while reducing maintenance costs and operational costs. Tam *et al.* [37] mentioned that sustainability and cost significantly impact building construction because designers should consider life cycle cost when building façade. Thus, the economic aspect should be the priority when choosing sustainable façade material. As mentioned earlier, this differentiation of the results is a natural decision-making character. This is due to the disparity in the interesting background of the stakeholders. However, all stakeholders have been chosen ACP instead of stainless steel as the most appropriate alternative materials. One reason is that ACP is cheaper while stainless steel is almost three times higher than ACP cost. ACP provides a much lower cost in the long run, but both alternatives' maintenance cost and operational cost are almost the same [37]. Aluminum is widely used in construction and is the second most frequently used apart from steel. In building sustainable façade material, the aluminum composite panel chose by each respondent from a different background (consultant, contractor, and architect) because they know aluminum can achieve more with its versatility.

According to stakeholders with architect backgrounds, aluminum can come in a wide range of colors, and it is environmentally friendly and can easily be recycled. Next, according to the respondent with the consultant background, which experiences in doing high-rise building mentioned aluminum is easy to fabricate during installation, and its strength to weight ratio is different or no like other metals. Thus, make the ACP the popular choice. Lastly, a respondent with a contractor background also mentioned that aluminum provides a long lifespan and is maintenance-friendly, reducing the cost of operation and maintenance. Naqash *et al.* [38] suggested using aluminum for curtain walls due to its lightweight compared to other steel materials. Furthermore, aluminum provides a high strength-to-weight ratio despite the ability to form to any shapes hassles. Hence, ACP would be a suitable sustainable material for the façade.

IV. Conclusion

In conclusion, it is important to develop value-based decision-making that could help and support stakeholders during materials selection to achieve sustainability. This study was conducted to develop a decision-making model for selecting the best sustainable building material using Analytical Hierarchy Process (AHP). The value-based decision is performed to choose the best façade alternatives. Aluminum Composite Panel (ACP) is chosen at the end of the research. Much previous research only focusing on developing decision-making using a traditional way. However, this research used a value-based decision where desirable and considerable is the primary consideration with given attributes. Criteria and alternatives are transformed into numerical using mathematical logic, and then the best alternative is chosen based on the highest value (Value ≥ 1).

As a result, the economic criteria are considered the top priority to stakeholders in choosing sustainable façade material, followed by the technical criteria and environmental criteria. The best alternative calculated from function over cost is the Aluminum Composite Panel (ACP) with a value of 1.149, greater or equal to 1.

Finally, the research and decision model mainly focused on local experts in Malaysia, considering the existing situation and most common building in Malaysia. However, the research can be extended based on any given requirement or element of façade from a different site. Other than that, the study partially uses value-based decisions as a form of cost analysis to find the alternatives for sustainable façade material. There is another detailed step in determining the result accurately but beyond the researcher's knowledge. Next, more respondents should be considered in determining the accuracy of the research. Choosing the best alternatives material for building is important in construction nowadays. Hence, it is recommendable for future research to be conducted to improve the construction industry's quality.

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