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APPLYING SUSTAINABILITY PRINCIPLES IN THE SELECTION OF BUILDING MATERIALS FOR BUILDINGS CONSTRUCTION

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Abstract: The research main object was to determine factors that affect the selection of building materials according to sustainability principles. The research objective was achieved through two stages; the first stage included a theoretical study about sustainable building materials and their characteristics, while the second stage included a practical study to determine the relative importance of the factors that affect the selection of building materials. The results of practical study showed that environmental criteria got a high importance after economic criteria among the identified factors while social criteria got the last priority in the selection of building materials. Deepening on the results of practical study a methodology for applying sustainability principles in the selection of building materials was proposed. The proposed methodology included the use of multi-criteria decision making methods like goal achievement matrix and analytical hierarchy process in the selection of building materials.

Keywords: *sustainable materials, building materials, sustainable buildings, sustainability principles*

تطبيق مبادئ الاستدامة في اختيار مواد البناء لتشييد المباني

الخلاصة: يهدف البحث الى تحديد العوامل المؤثرة في اختيار مواد البناء وفق مفهوم الاستدامة وقد تم تحقيق ذلك من خلال مرحلتين تضمنت المرحلة الاولى دراسة نظرية للتعريف بمواد البناء المستدامة و خصائصها اما المرحلة الثانية فتضمنت الدراسة العملية التي شملت القيام باستبيان ميداني مفتوح واخر مغلق لتحديد مدى تاثير العوامل المحددة سابقا في عملية اختيار مواد البناء . اظهرت نتائج الدراسة الميدانية ان العوامل البيئية حصلت على نسبة عالية من الاهمية بعد العوامل الاقتصادية في اختيار مواد البناء في حين احتلت العوامل الاجتماعية المرتبة الاخيرة في اختيار مواد البناء . تم التوصل الى اقتراح منهجية لتطبيق مبادئ الاستدامة في اختيار مواد البناء اعتمادا على نتائج الدراسة الميدانية. تضمنت المنهجية المقترحة استخدام طرق اسناد القرار المتعدد المعايير مثل طريقة مصفوفة تحقيق الاهداف وطريقة التحليل الهرمي وتهدف المنهجية المقترحة الى مساعدة المصممين في اختيار مواد البناء وفق معايير الاستدامة .

1. Introduction

The selection of building Materials for used to be based on economic and technical considerations, beside the planned life span of a facility and the requirements and codes it must meet.

With the rapid development in the field of construction industry and the continuing need to use modern technologies in the construction of buildings, there is a need for a new way for selecting building materials depends on sustainability criteria to ensure

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optimal use of available resources. Hence the importance of this research to propose a new direction in the selection of building materials based on gathering the environmental, technical, economic, and social criteria into an index used to compare between material alternatives.

2. The importance of building material for a construction project

Materials constitute a considerable proportion of a project total cost. It is ranged between (20-50%) according to some studies. Others indicated that materials proportion of a project total cost can increase up to (60%) sometimes. [1]

In Iraq building and construction sector considered one of the most important sectors to the national economy. It plays a major role in the preparation of GDP (gross domestic product) and employment and providing the key indicators of national accounts. According to Central Statistical Organization in Iraq (CSO) , the value of building materials that was actually used in building and construction during 2013 accounted (69.7%) from the total cost of building and construction projects.[2]

Materials are pivotal in any type of industries .building materials can affect a construction project in two ways:

1. Shortage or unavailability of materials can interrupt or even stop the work in the project which will cause extra costs due to the delay.
2. Too much quantities of materials can cause serious problems, thus it increases the cost of storing and handling materials.

3. Materials life cycle

Materials affect the environment severely through its life cycle from "extraction of row materials through processing, manufacturing, using and demolition" [3].

An ideal life cycle of a material is explained in Figure (1). At each step of the life cycle there is energy and resources consumption, and waste and pollutants generation to the environment. Yet, transporting materials require transport during their life cycle require more energy and produces more emission to the atmosphere. Environmental impacts of materials can be reduced through the recycling and reusing of materials which will reduce the need for manufacturing new materials [4], [5]

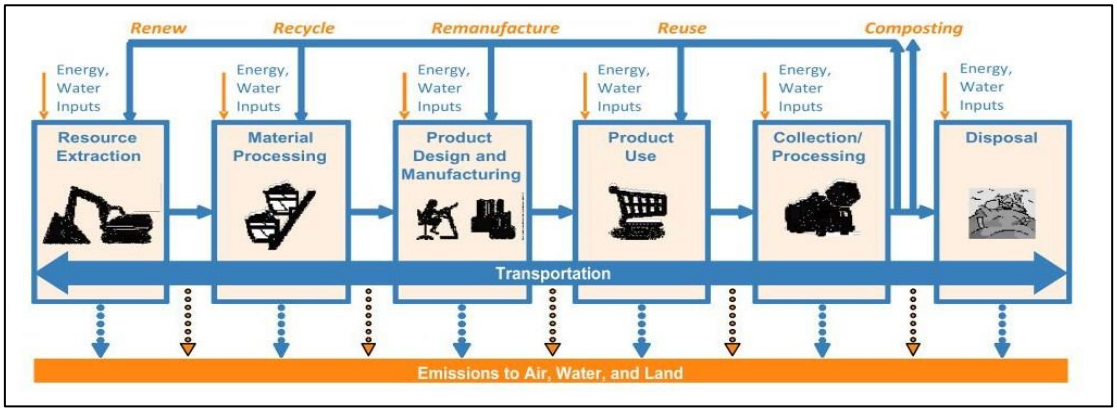

Figure (1): the life cycle of materials [5]

4. Building materials and sustainability

Building materials have a basic role in achieving sustainability in buildings and participate in the economic growth. The use of construction materials affects the environment in many ways, basically due to the big consumption of the non-renewable resources and the amount of waste and pollutants that are generated through the life cycle of materials [6].

In general construction stakeholders began to recognize the importance of controlling the environmental impacts that caused from construction industry. Selecting construction materials has got a big attention to be improved so that considering the sustainability suitability of materials while in pact factors like cost ,availability and appearance more effector in the selecting process of materials. [7]

Huberman stated that sustainable building materials are materials that "respect the limitations of non-renewable resources, work within the pattern of nature's cycles and inter-relationships of ecosystems, are non-toxic, are energy and water efficient, are made from recycled materials and are themselves recyclable".[8]

Kibert stated that "Sustainable products may not necessarily be manufactured from sustainable materials. For example low-e glass is considered a sustainable product because it reduces building heat gain. However, float glass is considered a sustainable material because it is highly recyclable unlike low-e glass, which is not, or is poorly, recyclable". [9]

Another opinion supposes that "sustainability represents a system not a material or product and there are no sustainable materials but materials used sustainably. We may create outstanding environmentally preferable materials, but if we do not use them in a way that supports their use in line with sustainability principles (if wastes cannot become food for future materials for example), we fail". [10]

4.1 Characteristics of Sustainable Building materials

Many attributes distinguish sustainable building materials depending on materials life cycle. Materials or products can be considered sustainable if they have one or more of the following attributes: [11], [12]

1. Enhance the quality of indoor air by reducing emissions of VOCs.
2. Durability and low maintenance requirements
3. Having recycled content "which is partially or entirely produced from post-industrial or post-consumer waste".
4. They are manufactured from renewable resources
5. Having low "embodied energy" which is "the energy required for materials production and transportation"
6. Free of ozone depleting substances such as CFCs, HCFCs
7. Having less toxic compounds.
8. They are local materials
9. They have the ability to be reused
10. They have the ability to be recycled "preferably in a closed-loop recycling system"

11. They are biodegradable
12. Reduce waste generation during manufacturing or construction process
13. They are energy efficient "contribute in reducing the operation energy during building occupancy"
14. They contribute in water conservation.

4.2 Benefits of using sustainable building materials

Kibert stated that selecting sustainable material can be one of the most difficult duties to be done in a construction project. Partially, this can be because: [9]

1) A Construction project involves various products that needed to be evaluated
2) Assessment parameters can vary according to material categories and manufactured countries
3) Lack of sufficient information about Manufacturing processes
4) There is no agreed method to evaluate materials and products universally

Despite that, using sustainable products for buildings can be useful to the triple bottom (TBL) for many reasons: [13]

1. In environmental term, using sustainable materials can reduce the environmental impacts of construction industry
2. Economically , the use of sustainable products can reduce the operation costs
3. Socially, using sustainable products and materials can improve the well-being of building occupiers and protect the natural environment

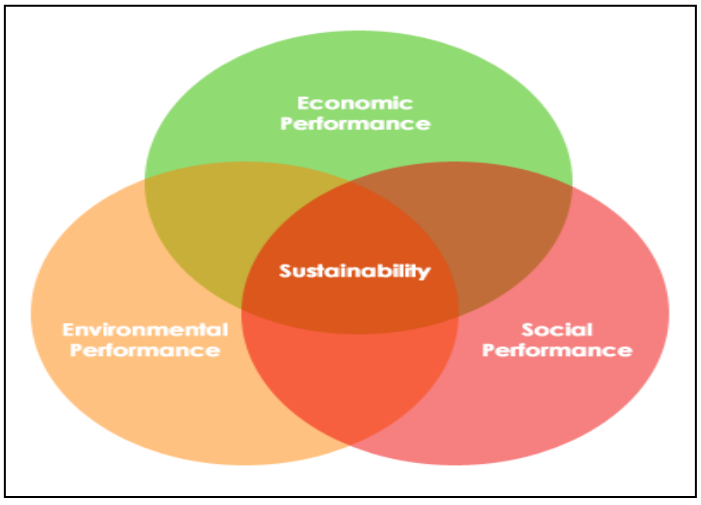

Figure (3-2): TBL description

5. Principals of selecting materials

In general, selecting a product can be done through three steps which are explained below : [14]

a. Research process

It involves collecting all information about technical performance and environmental impacts related to the product in order to identify available

b. The Evaluation process

It involves verification of the gathered information about the product then evaluating it according to that information. Evaluation may be difficult when comparing various materials for the same function

c. The Selection process

It involves using an assessment method like "assessment matrix" to accumulate the scores of each environmental criterion for each alternative. The alternative which gets high score will get the high priority to be selected.

6. Practical study

Practical study included the following stages:

1. Personal interviews and open questionnaire
2. Closed questionnaire: included two parts:
    - Examining the content validity and Pilot study
    - Main survey

6.1 Personal interviews and open questionnaire

This phase included personal interviews with engineers having experience in the field of buildings design in order to determine the outline of the research path. These engineers were top managers, architect engineers, civil engineers, electrical engineers, and environmental engineers; they all have more than ten years' experience in the design of buildings and the process of selecting building materials.

6.2 Closed questionnaire

Depending on the results obtained from personal interviews and open questionnaire process and literature review, the researcher developed a closed questionnaire. The closed questionnaire was designed to investigate the reality of applying sustainability principles in the design of buildings and selecting building materials and develop sustainability criteria to be used in selecting building materials. The sample was taken were engineers who had experience in buildings designs

6.2.1 Examining the content validity and Pilot study

In order to ensure the validity of the questionnaire content, it was presented to a group of (10) experts in the design of buildings and sustainable buildings issues. They were asked to review the questionnaire whether its content was comprehensible in studying the research problem.

The experts agreed with the questionnaire items. Minor changes were taken place to improve the questionnaire and make it clear and adequate in investigating the research problem.

A pilot study was made by randomly selecting a convenient sample of (10) engineers concerned with the studied problem .The objectives of the pilot study were as follows:

- Determining the researcher dependency and the respondents reliability
- Identifying the time needed for data collection through each single interview
- Identifying the difficulties that might be faced through the questionnaire process.

Table (1) explains reliability of the pilot study where the reliability of respondents "intra examiners" , and the reliability of researcher dependency "inter examiner" recorded high and adequate in the pilot study. Reliability Coefficient for the pilot study were calculated by equation (1): [15]

$$\text{Actual value} = \left(1 - \frac{\text{no. of non coincidences items}}{\text{no.of all items} * \text{sample size of pilot study}}\right) * 100\% \quad (1)$$

Table (1) : Reliability Coefficients of the Pilot Study

Groups	Reliability Coefficients	Actual values %
Students	Inter Examiners	93.23 (63:930)
	Intra Examiner	91.94 (75:930)

6.2.2 Main survey

The questionnaire form was designed according to the theoretical literature review and personal interviews carried out by the researcher with engineers having expertise and practice in designing building and selecting of materials. (45) Questionnaire forms were distributed while (39) were filled and analyzed.

As this research was part of other study, the part of the questionnaire concerning the research subject was designed to comprise two major parts as represented in the following:

Part one: contains general information about the respondents

Part two: development of material selection criteria. This axis contains a set of criteria for the selection of building materials depending on sustainability, the selection criteria were divided into four main categories as following:

- Environmental criteria
- Technical criteria
- Social criteria
- Economic criteria

Each category contains a number of sub-criteria

6.3 Statistical Analysis

The following statistical data analysis approaches were used in order to analyze and assess the results of the study under application of the statistical package (SPSS) version. (14.0):

a- Tables (Frequencies, and Percent).

b- Summary Statistics tables including: Frequencies, percentages, Mean of score (MS),Standard Deviation (SD), Relative R Sufficiency RS%, as well as primarily assessment degree (A.D.) throughout selected specific categories of

responding of different five measurement scales of Lekirt score, as illustrated in table (2):

Table (2): Different Scoring Scales of the studied Questionnaire's items with Assessment Degrees

Scores	*Scales*	*Interval*	*A.D.* (*)
Not important	1	20 -	TL
2	2	36 -	L
3	3	52 -	M
4	4	68 -	H
Extremely important	5	84 - 100	TH

(*) TL: too Low; L: Low; M: Moderate; H: High; TH: too High

Where Relative Sufficiency (RS%) are calculated by equation (2): (15)

$$\text{R.S.}\% = \frac{Mean\ of\ Score}{no.\ of\ Scoring\ Scales} * 100\% \qquad (2)$$

6.4 Reliability of the questionnaire

In order to determine the accuracy of the questionnaire , the reliability of the questionnaire was determined by using the major statistical parameter :Alpha Cronbach, as shown in table (3), where the results showed a very high level of stability and high consistency of the main axis of the questionnaire .that results meant that the questionnaire was successful and valid in studying the problem of selecting building materials according to sustainability criteria on the same population at any time in the future under assumption of stationary conditions of the studied population.

Table (3) : Reliability Coefficients of the Studied Questionnaire's

Reliability Coefficients of the studied Questionnaire	Standard lower bound	Actual values	Assessment
Alpha (Cronbach - α)	0.70	0.9130	Pass

Alpha Cronbach (α) for the reliability of questionnaire (Internal consistency)

Where Alpha Cronbach (α) was determined by the following equation (3):

$$\alpha = \frac{K}{K-1}\left[1 - \frac{\sum_{i=1}^{K} \sigma_{ii}}{\sum_{i=1}^{K}\sum_{j=1}^{K} \sigma_{ij}}\right] \qquad (3)$$

Where K is the number of items (questions) and σ_{ij} is the estimated co-variance between items i and j. Note that σ_{ii} is the variance (not standard deviation) of item i.

7. Results discussion

Questionnaire analysis and results will be explained in the following paragraphs:

Part 1: distribution of socio-demographical characteristics variables

Table (4) shows distribution of studied sample concerning "Socio-Demographical Characteristics" variables (SDCv.), with comparisons significant. The results has indicated that there has been a highly significant differences at P<0.01 among different levels of studied (SDCv).

Table (4): Distribution of the studied sample according to Socio-Demographical Characteristics variables (SDCv.) with significant comparisons

SDCv.	*Groups*	*No.*	*Percent*	*C.S. P-value*
Educational Degree	B.Sc.	26	66.7	K-S= 0.333
	M.Sc.	9	23.0	P<0.01
	Ph.D.	4	10.3	(HS)
	Total	39	100	
Years of Experience	5 - 10 years	9	23.1	P=0.000
	more than 10 years	30	76.9	(HS)
	Total	39	100	
Specialist	Architect	19	48.7	K-S= 0.287
	Civil	10	25.6	P<0.01
	Mechanical	4	10.3	(HS)
	Electrical	4	10.3	
	Environmental	2	5.1	
	Total	39	100	

(*) HS: Highly Sig. at P<0.01; The Statistical Hypotheses are Based on one sample Kolmogorov-Smirnov and Binomial tests.

Part 2: Development of Material Selection Criteria

Table (5) shows summary statistics and basis assessments for the "Basic Criteria", which consists of (4) items, and they are accounted high assessments, except (social criteria with RS=63.1%) has reported a moderate assessment.

Table (5): Distribution of studied responding concerning Development of Material Selection of Basic Criteria

Statements	*Responding*	*No.*	*%*	*MS*	*SD*	*RS %*	*A.D.*
Axis Three: Development of Material Selection Criteria							
Basic Criteria .A							
Environmental criteria	Not important	1	2.6	4.41	0.82	88.2	TH
	2	0	0.0				
	3	2	5.1				
	4	15	38.5				
	Extremely important	21	53.8				
Technical criteria	Not important	0	0.0	4.26	0.77	85.2	TH
	2	0	0.0				

	3	8	20.5				
	4	13	33.3				
	Extremely important	18	46.2				
Social criteria	Not important	4	10.3	3.15	1.01	63	M
	2	2	5.1				
	3	20	51.3				
	4	10	25.6				
	Extremely important	3	7.7				
Economic criteria	Not important	0	0.0	4.66	0.54	92.8	TH
	2	0	0.0				
	3	1	2.6				
	4	12	30.8				
	Extremely important	26	66.7				

8. Selecting building materials according to sustainability criteria

It is well known that the choice of construction materials are usually on the basis of selecting the most appropriate in terms of material cost. The concept of sustainability, supposes that the selection of materials should be according to a four set of key criteria and, which are environmental, functional, economic and social. Each key criterion includes a set of sub-criteria which their importance may vary according to many factors like: the type of association, the type and objectives of their projects like Water Resources, Residential, Roads and bridges Public buildings and commercial buildings. The association has to identify the headlines of sustainability criteria for their projects then the design team for each project has to determine the detailed criteria appropriate to their project, and prioritize them according to their importance to the project.

Sustainability criteria that affect the selection of building materials were identified by the researcher from the results of the literature review. They were classified-based on sustainability aspects- into four basic criteria which are (environmental, technical, economic, and social). Each basic criterion involved a set of sub-criteria .the relative weight of each criterion and prioritization of the identified criteria was found from the results of the questionnaire. Tables (6), (7), (8), (9), and (10) show the identified criteria and their relative weights.

Table (6): Sustainability main criteria and their relative weights

Main criteria	*Average weight*	*Relative weight*
Economic criteria	4.64	28
Environmental criteria	4.41	27
Technical criteria	4.26	26
Social criteria	3.15	19
Total	16.50	100

Table (7): Economic sub-criteria relative weights

economic sub-criteria	*Symbol*	*Average weight*	*Relative weight*
Initial cost	C1	4.41	36
Maintenance cost	C2	4.21	34
Disposal cost	C3	3.62	30
Total		12.24	100

Table (8): Environmental sub-criteria relative weights

Environmental sub-criteria	*symbol*	*Average weight*	*Relative weight*
Environment pollution (water, soil, and air)	E1	4.44	11.4
Impact on the indoor air quality of the building	E2	4.38	11.3
Less productive (or do not produce) of toxic emissions	E3	4.36	11.2
Ozone depletion potential	E4	4.08	10.5
Environmentally sound disposal at the end of material's life cycle (recycling or reusing)	E5	4.03	10.4
Availability of material in the local market	E6	3.94	10.1
Amount of waste generated from material use in the construction process	E7	3.87	9.9
Recycled Content	E8	3.56	9.2
Closeness to the project area	E9	3.12	8.0
Embodied energy	E10	3.10	8.0
Total		38.90	100

Table (9): Technical sub-criteria relative weights

technical sub-criteria	*symbol*	*Average weight*	*Relative weight*
thermal insulation and contribution in saving operational energy	T1	4.51	13.0
Maintainability	T2	4.46	12.8
Durability	T3	4.46	12.8
Suitability to climatic conditions	T4	4.38	12.6
Fire resistance	T5	4.28	12.3
Moisture resistance	T6	4.28	12.3
Ease of use in construction operations	T7	4.23	12.2
Sound insulation	T8	4.15	12.0
Total		34.80	100

Table (10): Social sub-criteria relative weights

social sub-criteria	*symbol*	*Average weight*	*Relative weight*
Health and safety when manufactured and used in construction	S1	4.44	38
Aesthetically	S2	3.92	33
Local materials	S3	3.46	29
Total social performance weight		11.82	100

8.1 The process of selecting building material

Figure (2) shows a flow chart for the proposed methodology for the selection of building materials according to sustainability criteria which were identified previously.

The proposed methodology can be summarized in the following steps:

1. The design team will Identify the intended use of martial such as selecting sustainable material for windows or roofs or floors
2. Identify selection criteria which will be chosen from table (6) because that criteria were supposed to be general and they affect the selection of materials in different ways such that factors affecting the selection of internal finishes are not the same as the factors affecting the selection of floors
3. Client can play a major role in selecting building material some times , the proposed methodology supposed the client agreement on the proposed selection criteria and material alternatives .
4. Comparing between material alternatives will be by using multi-criteria decision method such as AHP or GAM
5. Material alternatives will be selected according to its sustainability after prioritizing them as a result to the two methods as it will be detailed later.

8.2 The Goal Achievement Matrix

The Goal Achievement Matrix (G.A.M) is the trying to determine the feasibility of alternatives to reach a set General targets (Goals) and detailed targets (Objectives) which are determined previously. It is the degree of achievement of planned targets chosen by the planner by each of the plans put forward to solve a specific problem. [16]

There are several stages to implement goals achievement matrix:

a. Determine the stage of detailed and general goals
b. Determine the style of measuring all of the goals set according to their nature (economic, social, environmental)
c. Giving weights for goals and this represents the foundation stone weights in the application of the matrix to achieve goals
d. Assess the achievement of each of the alternatives proposed targets set
e. Choose the best alternative based on the total weight
f. Some studies rely a sensitivity analysis to check the stability of results Model

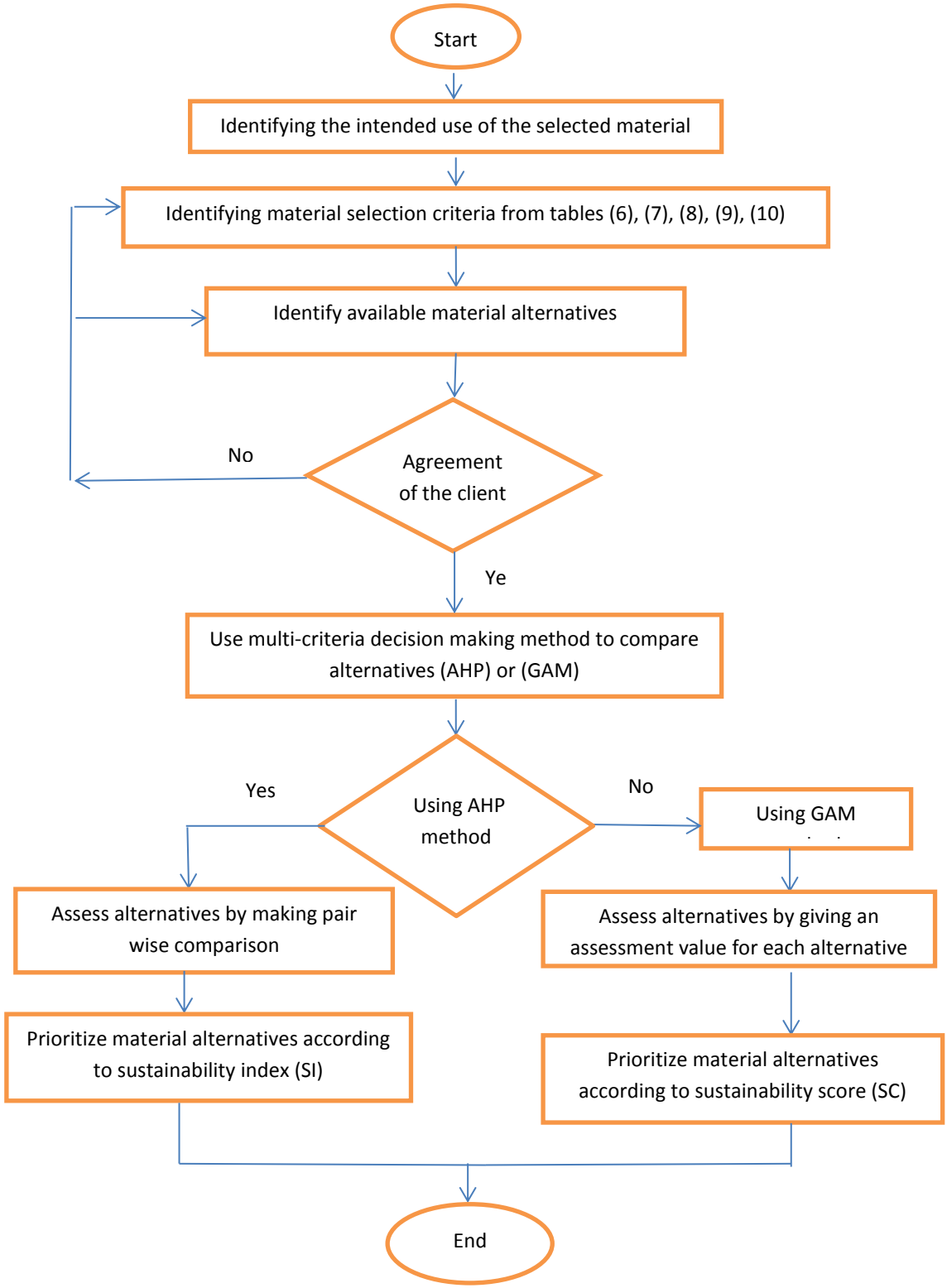

Figure (2): The proposed methodology for material selection

Figure (3) shows a flow chart for using the G.A.M. method. The most important feature in the way of setting goals is that it has taken into account unquantifiable factors such as social benefits and costs.

The main criticism directed to this method is that: some of the weights may be set based on the provisions of personal judgment; therefor the process of setting goals and weights of these goals should be based on an accurate basis as possible

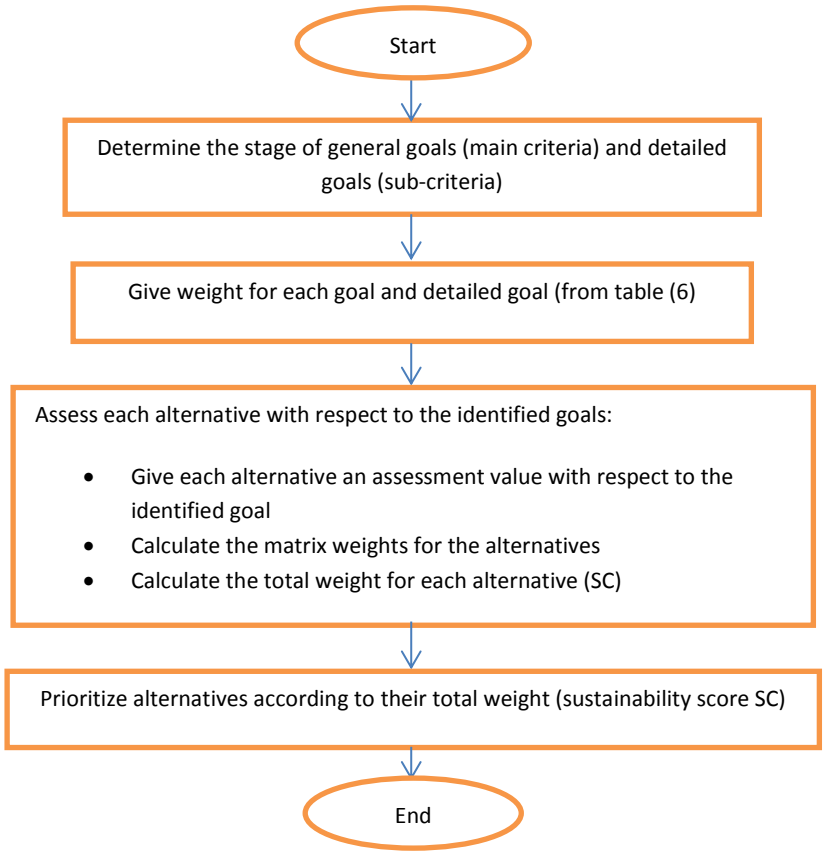

Figure (3): The Goal Achievement Matrix

8.3 The Analytical Hierarchy Process (AHP)

The AHP model offered a logical and representative way of structuring the decision problem and deriving priorities. The method is a theoretically sound and practicable approach for selecting, weighting، standardizing and aggregating individual criteria into a composite index [17].

AHP model is based on four basic principles which are: [18]

1. The stakeholders should be able to provide a pair-wise comparison between any two evaluation elements
2. The stake holders should never decide that one indicator is infinitely excellent than another
3. The evaluation must be formulated as hierarchy
4. All elements must be represented in the hierarchy

Figure (4) shows a flow chart for using AHP method in the selection of building materials

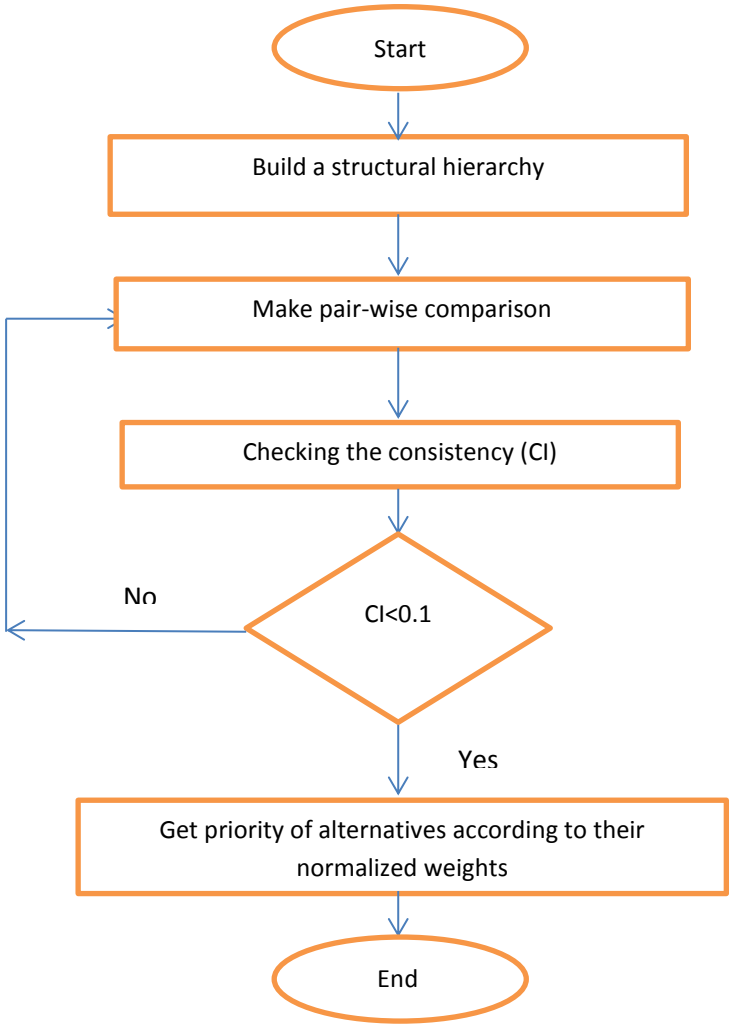

Figure (4): The Analytical Hierarchy Process (AHP)

9. Conclusions

1) It was noticed from the practical study that economic criteria got the highest relative sufficiency (RS=92.8%) in the selection of building materials.
2) Environmental criteria got relative sufficiency (RS=88.2%) which reflects the reorganization of research sample to the importance of considering environmental impacts of building materials
3) Among environmental criteria, material with Less environment pollution (water, air, and soil) got the highest priority with average weight (4.44), while factor of less embodied energy got the last priority with average weight (3.1)
4) Among technical criteria, factor of thermal insulation and contribution to the operational energy saving got the highest priority with average weight (4.51), while sound insulation got the last priority with average weight (4.15)
5) Among social criteria using material which has less impacts on Health and safety when manufactured and used in construction got the highest priority with

average weight (4.44) wile among economic criteria material with less initial cost got the highest priority with average weight (4.41)

10. Recommendations

1) The selection of building materials have to be based on environmental and technical criteria as well as the life cycle cost of material.
2) Using multi –criteria decision making method like goal achievement matrix or AHP can be useful in the selection of building materials when considering sustainability principles.
3) Handling the reasons that prevent from using green building material in constructing building
4) Creating databases for building materials within each construction company containing all features of materials and their prices
5) Creating databases for material suppliers from in and outside the country

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