Evaluation of Material Sustainability Using Analytical Hierarchy Process

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Abstract –Sustainability and sustainable construction became integral part in reducing impact on social, economic and environmental aspects in developed and developing countries. To achieve sustainability in construction, selection of material plays an important role. As construction industry largely depends on resources and hence material selected should follow all the principles of sustainability. Comprehensive review of methods for selecting construction material is carried out and found that very few studies are available for deciding the alternatives for binder material, fine aggregate and coarse aggregate for sustainability. The sustainable score is then taken as an input to Analytical Hierarchy Process and statistical analysis is carried out to determine the best material among the available alternatives for the three ingredients of concrete.

Keywords: Sustainability, Sustainable construction, Material life cycle, Concrete ingredients, Analytic Hierarchy Process (AHP).

I. INTRODUCTION

Sustainability is one among those fields which has greatest potential to bring change. As construction industry largely depend on consumption of non-renewable resources and hence it produces waste in huge amount. Many operations in construction project are responsible for generation of large amount of CO_2 gas emissions. Therefore, challenging job for construction firm is to construct a structure which should help in enhancing user's quality of life and at the same time it should reduce the impact on social, environmental and economic parameters.

One of the important parameter to sustainable development is selection of sustainable material because materials are major consumers of resources and structural materials are fundamental in construction and selection of good material is integral part of good design, therefore there arises a necessity of sustainability evaluation methodologies for selection of sustainable materials.

It is widely accepted that construction sector is main contributors to sustainable development because it is focusing more on social advancement, encouraging environmental protection and economic growth.

Environmental sustainability: Utilizing natural resources carefully and taking care of environment from damages resulting from emission of harmful gases and waste generation. Social sustainability: understanding the needs of everyone including construction workers and users of construction products from starting of construction till end phase of destruction. Economic sustainability: this can be achieved by using resources like men, material, equipment's, energy, water efficiently and hence making more profits.

A] Problem Statement &Scope of the Study

There are good number of research works that have been done for identifying key performance sustainable parameters and assessment indicators for the sustainability of construction projects, but no definite research has been done to measure the sustainability of routine and regularly used ingredient materials of concrete. Therefore, research has to be done to know the sustainability of different ingredients of concrete and their different alternatives. There are three phases namely preconstruction phase, construction phase and post construction phase. The responses of all the professionals can be analysed using multi criteria decision methods and materials will be ranked with their sustainability performance.

B] Objectives of Study

As discussed in the above paragraph, the paper study is limited to following objectives:

- Facilitate selection of material considering its sustainability through material life cycle.
- To develop methodology for the selection of Sustainable materials by considering Economic sustainability, Environmental sustainability, Technological sustainability and Social sustainability.
- To select the alternative for fine aggregates and coarse aggregate for ensuring sustainability in concrete through multi criteria decision support system.

II. Literature Survey

Gholamreza Heravi, Medya Fathi, Shiva Faeghi (2015): Has mentioned in research that the concept of increasing the quality of life by providing a healthy environment, while promoting societal and economic qualities, not only for present but also the future generations is sustainability.

Liyin Shen, Yuzhe Wu, and Xiaoling Zhang (2011). Has done research on key assessment indicator for the sustainability of infrastructure projects. This research consist of introduction to various sustainable indicators, the study methodology consist of formulating questionnaire survey and sending questionnaires to three expert groups including professionals, government officials and clients involved in construction industry. And analysis of collected data using fuzzy set theory. Also one case study discussed which consist of metro project in Hangzhou, one among the major infrastructure projects.

Neha Bhatia (2014): Has done research on life cycle assessment as a tool for material selection- a comparison for autoclaved aerated concrete and brick wall assembly. In this research work energy consumption of autoclaved aerated concrete is compared with brick wall assembly and its environmental impact is studied. Both the materials are evaluated with respect to embodied energy, environmental impact in terms of health safety, cost, CO_2 emissions. energy and resource consumption.

Rajiv Bhatt and J.E.M.Macwan (2015): Has done research on Fuzzy logic and Analytical Hierarchy Process-based conceptual model for sustainable commercial building assessment for India. In this literature author covered hundred sustainable criteria, and a conceptual tool for assessment of commercial building through these sustainable criteria is done. Global weights of criteria is evaluated using Analytic Hierarchy Process and performance score of criteria determined using Fuzzy logic approach.

III. RESEARCH METHODOLOGY

In this research, it is proposed to determine the best sustainable material among different available alternatives which are being used as ingredients of concrete in construction industry. The evaluation method considered in the present study follows a specific Multi Criteria Analysis (MCA) approach.

Considering the environmental, economic, social and technological aspects of sustainability and also through literature reviews a list of 10 sustainable factor is developed. These main 10 factors are again subdivided into sub indicators which are used for analysing the material in selection of one best sustainable material among available alternatives.

These main sustainable factors includes climate change, pollution potential, solid waste generation capability, resource consumption, cost, recyclability, local economic development, human health safety, human satisfaction and practicability.

Table1: Sustainable factors and criteria

Sr.no	Factors/criteria	Environmental	Economical	Social	Technological
1	Climate change	*			
2	Pollution potential	*			
3	Solid waste	*			
4	Resource consumption	*	*		
5	Cost		*		
6	Recyclability	*	*		*
7	Local economic development		*	*	
8	Human health safety			*	
9	Human satisfaction	*		*	
10	Practicability		*		*
Total no of factor related to criteria		6	5	3	2

A] FACTORS

1. Climate change

Climate change is one of serious subject of discussion in present scenario. It is now more certain than ever, human's activities are changing Earth's climate which is going to results in increase in atmospheric temperature, sea warming and increase in sea level for future generation.

1.1 Global warming potential

Greenhouse gases such as carbon dioxide has potential to absorb infrared radiation emitted from earth surface, but increase in concentration of these gases results in increase in temperature of earth because trapping more heat results in warming. Increased concentration of these gases further will cause climate change. Therefore material used in construction should be such that it should not emit more CO2 during its manufacturing to demolition stage.

Material with low global warming potential should be preferred compared to material which is prone to produce more carbon dioxide.

1.2 Ozone depletion

Chlorofluorocarbons are trace gases that are of concern, because reaction of these gases and their breakdown in atmosphere results in generation of radicals of chlorine (Cl) which in turn destroy ozone in upper layer of atmosphere. Shortage of ozone in stratosphere leads to the biosphere being exposed to higher level of ultraviolet radiations.

Therefore material used in construction should be such that it should not emit more chlorofluorocarbons during its manufacturing to demolition stage.

2. Pollution

Pollution is defined as addition of undesirable material into the environment as a result of human activities. The substance which is being added in environment is called as pollutant. Pollutant is harmful substance which may be biological, chemical or of physical origin.

Human activities directly or indirectly affect the environment.

2.1 Air pollution

Air pollution is result of manmade and natural activities, manmade activities involves manufacturing industry, increased use of fossil fuel in power plants ,automobile, construction industry etc.

Air pollution is defined as presence of any matter like solid, liquid, or gaseous substance in the atmosphere which is injurious to living organisms and plants.

Therefore material used in construction should be such that it should not be responsible for air pollution during its manufacturing to demolition stage.

Material with low air pollution potential should be preferred compared to material with having more potential to cause air pollution.

2.2 Water pollution

Water is universal solvent, anything which enters in water cause change in water properties. Water pollution is one of most serious problem to environment, water pollution is major source of water borne diseases and other health problems.

Material used in construction should be such that it should not be responsible for water pollution during its manufacturing to demolition stage. Material with low water pollution potential should be preferred compared to material with having more potential to cause water pollution.

3. Solid waste

Construction industry is major consumer of resources also it generate huge amount of waste, the waste may solid, liquid or gases. Solid waste are of two type, hazards solid waste and residual solid waste.

3.1 Hazardous solid waste

Hazards solid waste are generated in construction industry during all the phases of manufacturing, construction and demolition. Hazardous solid waste are the waste which are toxic to human being and to environment.

Therefore material used in construction should be such that it should not be responsible for generation of more hazards solid waste during its manufacturing to demolition stage.

Material which generate less hazards waste should be preferred compared to material with produce more hazards waste.

3.2 Residual solid waste

Residual solid waste are those which will not disintegrate easily, these waste last longer. These waste are also generated during manufacturing to demolition phases of construction industry.

Therefore material used in construction should be such that it should not be responsible for generation of more residual solid waste during its manufacturing to demolition stage.

Material which generate less residual waste should be preferred compared to material with produce more residual waste.

4. Resource consumption

Construction industry depend only upon resources it may be man material machinery etc. but efficient use of resources results in gain in profit to investor, society and helps in maintaining environmental balance. Here resources consumption are discussed with consumption in terms of raw material, water and energy.

4.1 Raw material consumption

Raw material consumption means more material requirement for production of final product. Therefore material used in construction should be such that it should not consume more raw material for its generation during its manufacturing stage.

Material which consume less raw material should be preferred compared to material which need more raw material extraction.

4.2 Water consumption

Consumption of more water for generation of final product is not feasible, more water consumption leads to shortage of water for regular needs of living organisms and plants.

Therefore material used in construction should be such that it should not consume more water for its generation during its manufacturing stage and also it should not demand more water during its maintenance stage.

Material which consume less water and also demand less water for maintenance should be preferred compared to material which need more water.

4.3 Energy consumption

Global energy consumption has about doubled in the last three decades. The future of energy is uncertain, the uncertainty is not about scarcity of energy reserves, rather it is about which mix of resources will be used to meet the demand. Energy is consumed in in all stages of material lifetime starting from its manufacturing, transportation, construction, maintenance and demolition. Energy consumption is expressed in three different forms like initial embodied energy deals with material acquisition, processing, manufacturing and transportation. Induced energy deals with energy consumed in construction phase, whereas Recurring energy is deals with maintenance and restore. Therefore material used in construction should be such that it should consume less energy during its life cycle. Material which consume less energy should be preferred compared to material which need more energy.

5. Cost

Life cycle cost is the sum of the total of all costs associated with expenditure during the time it is in use. These expenditure include its research development cost, manufacturing cost, processing cost, transportation cost, construction cost, operation cost, maintenance cost and demolition cost.

Therefore material used in construction should be such that it should possess less expenditure throughout its life cycle so that life cycle cost will be less. Material with low life cycle cost should be preferred compared to material with having more life cycle cost.

6 Recyclability

As a nation we are utilizing more resources and hence generating more waste without knowing what is to be done with that waste. Improper disposal of this waste can pollute the environment and pose a public health risk. Current disposal methods threaten our health, safety, and environment, and pose additional indirect costs to society.

6.1 Recyclability

Material once used and when it's time to discard that waste, finding the ways to recycle it instead of letting it throw to fill the land is called recyclability.

Recyclability can be measured as percentage of time material recycled again and again. Higher the recycling value more will be material economy. Therefore material used in construction should be such that it should possess more recyclability. Material with more recyclability should be preferred compared to material with having less recyclability.

6.2 Reusability

Utilizing the same material again and again with or without any refurbishment is called reusability. More the material reused cost will be saved in purchasing the material and hence overall project cost will be minimised. Therefore material used in construction should be such that it should possess more reusability. Material with more reusability should be preferred compared to material with having less reusability.

7. Local economic development

Local Economic Development is process through partnerships between local government, the business community and NGOs to stimulate investments that will promote sustained high growth in a local community.

7.1 Locality

Local economic development focuses on regions potential and identifies what local stakeholders need. Degree of contribution in adding local income by selecting the locally available material. If material is available locally then its results in reducing transportation cost, also project duration can be minimised by reducing the time of waiting the material arrival from far places.

Therefore material used in construction should be such that it should easily available in local area. Material which available locally in abundant amount should be preferred compared to material which is not available locally.

7.2 Employment

Employment is related with job opportunity which will be available by selecting particular material. More the locally available material more will be the job opportunity to local people to work there in their respective local areas.

Therefore material used in construction should be such that its manufacturing and related process should produce good employment to local people. Material which provide more job opportunity should be preferred compared to material which doesn't provide enough employment.

8 Human health and safety

Human health safety comes under Occupational Safety and Health (OSH) or Workplace Health and Safety (WHS), is a multidisciplinary field concerned with the safety, health, and welfare of people at work.

8.1 Human health

Material toxicity has several effect on workplace people it may be in terms of illness or death. Therefore material used in construction should be such that it should not have any toxicity which will make workplace people such as labour, staff, and user of building to suffer from illness or death. Material which affect less on human heath due to its toxicity should be preferred compared to material having more toxicity.

8.2 Safety

Improvement and special care about workplace safety is becoming a top priority in construction industry. Safety is concern with material handling. Therefore material used in construction should be such that it should not require more safety during its handling, as majority of workplace people will me uneducated apart from regular training development and guidance for material handling few people will do the mistakes, in such case the selected material should be such that it should not cause severe damage. Material which needs less safety during handling should be preferred compared to material which need more attention for safety.

9. Human satisfaction

Human satisfaction is concerned with liveability, habitability, hygiene and comfort. Material selected should give mental and physical satisfaction to user of the building. Selected material should not produce bad smell, or should not produce too much heat or should not allow easy water leakage, should satisfy the basic need for which it is manufactured.

Therefore material used in construction should be such that it should have capability to satisfy needs of user of building. Material which poses more human satisfaction characteristics should be preferred compared to material which has less human satisfaction properties.

10. Practicability

Practicability is concerned with constructability, material flexibility, user friendliness and compatibility. Constructability includes easy transportation of material to site, easy storage of material, easy handling and at the end of its life easy demolition. Material flexibility concerned with ease of use and repair whereas compatibility is concerned with material ability to withstand reaction with surrounding material.

Therefore material used in construction should be such that it should have more practicability features. Material which poses more practicability features should be preferred compared to material which has less practicability.

B]PHASES

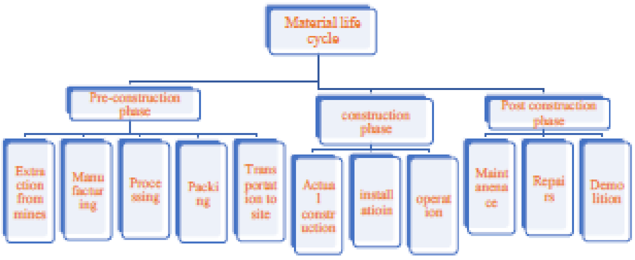

FIG 1: Three phases of material life cycle

1. Pre- construction phase

In preconstruction phase the behaviour of from material extraction, material manufacturing, material processing, material packing, to material transportation till site is studied.

This phase of material life cycle has potential to cause environmental impact by generation of pollutants, also it cause ecological impact by doing loss of habitat.

2. Construction phase

When material is transported from extraction place to actual work place this construction phase starts, in this phase material energy is consumed and waste is generated. This phase represents useful life of material product. This phase includes actual construction, or installation and operation.

3. Post construction phase

Once construction and installation work finished, the occupant is ready to take possession then this phase of material life cycle starts. This phase tells that material usefulness has finished. In this phase it is needed to determine structures reusability, recyclability potential. This phase is associated with maintenance, repair and demolition, recycling and disposal.

IV.Analytical Hierarchy Process

Thomas saaty (1980) invented tool for dealing with complex decision making problem that tool is named as Analytic hierarchy process. It will help the decision maker to make best decision.

AHP considers alternatives and set of criteria, among which best decision has to be made.

Weight for each evaluation criteria is generated according to decision maker's pairwise comparison of criteria. If weight is higher then that criteria is more important, also higher the score for particular alternative then performance of that alternative is better with respect to considered criteria. AHP considers option score and criteria weight to finally determine the score for each alternative and gives subsequent ranking. Implementation of AHP is a 4 step process which is in detail explained below.

Computing the vector of criteria weight

Decompose the problem into hierarchy of criteria, sub criteria and alternative.

For computation of weight for different criteria, pairwise comparison matrix is used.

Consider the matrix A which is m x m real matrix, where m stands for no of evaluation criteria, each entry aij in matrix A shows importance of ith criteria relative to jth criteria.

If aij > 1 ……….then ith criteria is more important than jth criteria

If aij < 1 ……….then ith criteria is less important than jth criteria.

If aij=1 …………then two criteria are equal

aij . aji =1

Relative importance is measured on 1 to 9 scale, where it is assumed that ith criteria is equally or more important than jth criteria.

Intensity of importance	Definition
1	Equal importance
2	Weak
3	Moderate importance
4	Moderate plus
5	Strong importance
6	Strong plus
7	Very strong
8	Very, very strong
9	Extreme importance

Table 2:Scale of Relative importance according to SAATY (1980)

3.9.1.2 Normalise the matrix

Consider each entry divide by column sum

aij = aij /Σ$a$lj ………………………….. (1)

Take overall row average which will determine ranking priority

wj=Σaml= 1 ij / m……………………………(2)

3.9.1.4 Check for consistency

To check how consistent judgments are we have to check consistency:

Consistency Ratio = Consistency Index (C.I) / Random Index (R.I) ……………(3)

Consistency Index= Max Eigen Value-Size of Matrix

/Size of Matrix - 1 ………………(4)

Size of matrix	2	3	4	5	6	7	8	9	10
R.I	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.51

TABLE 3: Scale of random index according to SAATY

If consistency Ratio (C.R) < 0.1 Judgment is consistence

If consistency Ratio (C.R) > 0.1 Judgment is inconsistence, Revise pairwise comparison matrix

IV. DATA COLLECTION AND ANALYSIS

In this chapter the data collected from survey is summarised and analysis has been carried out on received responses. Questionnaire development was through online google form sheet, and the link was sent out by means of emails, professional networks and social media for distant people and for people who are available in nearby area, hard copy of questionnaire was distributed.

For present work data was collected on sustainable indicator and behaviour of material in its complete life cycle. Three ingredients of concrete i.e. binder material, fine aggregate and coarse aggregate were given with five alternative each and respondent were asked to give rating to the each alternative with respect to each sustainable indicator considering pre- construction, construction and post construction phase.

The main purpose of this data collection was to know perception of respondents on evaluating the sustainability of each material alternative throughout life cycle of that material .and this data is used to rank the alternative using Analytic Hierarchy Process.

4.3 Analysis

For calculation of sustainability of all the material alternative and for ranking those material with respect to their sustainable score analysis is carried out using Analytic Hierarchy Process.

The following step are carried out while analysing the problem and to calculate score of material.

Step 1-Summarised all responses given by respondent for each of the nineteen sustainable indicators.

Step 2- As material life cycle is considered therefore responses are given in three phase of life cycle, therefore to get a one value for an indicator, take average of responses given in three phase.

Step 3- Now arrange these indicators according to their respective factor and take the average of those indicator to find final value of response for each factors.

Step 4- Rearrange the responses for each factor to bring responses of all the respondent together for analysis purpose.

Step 5- Convert all the entries in above table on the common scale for analysing through analytic hierarchy process. In this study conversion is done considering table given by saaty (1977, 1980) for relative importance scale.

Step 6- Formulate comparison matrix for each factor according to response given by each respondent.

Step 7- Formulate normalised comparison matrix for each factor according to response given by each respondent.

Step 8- Check for consistency to know how consistent the judgment are and how much data is reliable.

V. RESULT

The sustainable factors evaluation process is done to calculate final score for each factor for each alternative to form a sustainable scoring system. These scores are then normalised according to saaty (1980) scale of relative importance and finally normalisation is done for generating rank for each alternative.

To select best option among given alternative, all alternatives are given priority as per importance scale and the responses of respondents whereas the sustainable factors being common criteria for comparison kept with uniform importance level as 1, because material to be fully sustainable it should follow all the criteria and aspects of sustainable principles.

Considering all the values corresponding to the sustainable factors such as Climate change, Pollution, Solid waste, Resource consumption, Cost, Human health safety, Local economic development, Recyclability, Human satisfaction and Practicability and adding all these values together the final score of each alternative is calculated below in Table 5.1 for Binder alternatives, which consist of alternative such as ordinary Portland cement, Portland pozollana cement fly ash based, PPC slag based, Geopolymer, and Composite cement.

FACTORS	OPC CEMENT	PPC (FLY ASH BASED)	PPC (SLAG BASED)	GEOPOLYMER	COMPOSITE CEMENT
Climate change	0.09	0.17	0.18	0.31	0.25
Pollution	0.10	0.16	0.16	0.34	0.24
Solid waste	0.13	0.21	0.22	0.25	0.19
Resource consumption	0.10	0.20	0.19	0.30	0.21
Cost	0.13	0.27	0.26	0.15	0.19
Human health safety	0.15	0.23	0.22	0.20	0.20
Local economic development	0.17	0.21	0.19	0.20	0.23
Recyclability	0.20	0.20	0.22	0.18	0.20
Human satisfaction	0.25	0.25	0.20	0.15	0.15
Practicability	0.24	0.24	0.20	0.14	0.18

TABLE 4 : Summarised table for Binder aggregate

Below shows summarised table for fine aggregate alternatives, which consist of alternative such as Natural sand, manufactured sand, quarry stone dust, granulated blast slag and foundry sand. Considering all the values corresponding to the sustainable factors such as Climate change, Pollution, Resource consumption, Cost, Human health safety, Recyclability, Local economic development, Human satisfaction and Practicability and adding all these values together the final score of each alternative is calculated.

FACTORS	NATUARAL SAND	MANUFACTURED SAND	QUARRY STONE DUST	GBS	FOUNDRY SAND
Climate change	0.28	0.18	0.15	0.19	0.19
Pollution	0.24	0.20	0.13	0.20	0.22
Resource consumption	0.33	0.17	0.16	0.16	0.18
Cost	0.17	0.14	0.28	0.19	0.22
Human health safety	0.35	0.18	0.13	0.15	0.19
Recyclability	0.34	0.21	0.16	0.14	0.15
Local economic development	0.20	0.23	0.23	0.17	0.17
Human satisfaction	0.32	0.20	0.20	0.14	0.14
Practicability	0.32	0.21	0.21	0.14	0.12

TABLE 5 : Summarised table for Fine aggregate

Below shows summarised table for coarse aggregate alternatives, which consist of alternative such as Crushed gravel, Recycled from demolition waste, bloated clay, Granulated blast slag and sintered fly ash aggregate. Considering all the values corresponding to the sustainable factors such as Climate change, Pollution, Resource consumption, Cost, Human health safety, Recyclability, Local economic development, Human satisfaction and Practicability and adding all these values together the final score of each alternative is calculated.

FACTORS	CRUSHED GRAVEL	RECYCLED FROM DEMOLITION	BLOATED CLAY	GBS	SINTERED FLY ASH AGGREGATE
Climate change	0.24	0.22	0.19	0.16	0.19
Pollution	0.29	0.20	0.21	0.15	0.15
Resource consumption	0.20	0.26	0.17	0.19	0.18
Cost	0.26	0.20	0.19	0.16	0.19
Human health safety	0.28	0.24	0.16	0.14	0.17
Recyclability	0.35	0.18	0.17	0.15	0.15
Local economic development	0.20	0.22	0.22	0.17	0.19
Human satisfaction	0.34	0.21	0.17	0.13	0.14
Practicability	0.33	0.20	0.16	0.15	0.17

TABLE 6 : Summarised table for Coarse aggregate

VI. CONCLUSIONS

The methodology deals with material sustainability measurement by considering material behavior through three phases of material life cycle using Analytic Hierarchy Process for selecting highly sustainable material with highest sustainable score among given alternative.

In this research main focus was given on sustainable aspect of material and its behaviour through its complete life cycle. All the sustainable criteria has been taken into consideration such as environmental aspect, social aspect, economic aspect and technological aspects which made users to select material directly among maintained alternative when it's time to select best sustainable alternative for three ingredients of concrete like binder material, fine aggregate, and coarse aggregate. After collecting responses from respondent's perception and with application highly effective multi criteria decision making statistic tool such as Analytical Hierarchy Process, highly sustainable alternative for binder material as a geopolymer, for fine aggregate material natural sand and for coarse aggregate crushed gravel is determined.

Sustainability level of different alternative of three ingredients of concrete can be come to know through this research results and hence it will be easy to select required alternative by comparing required sustainable factor, more the sustainable factor score for particular alternative that material to be preferred for achieving sustainability in particular construction works.

The AHP is time consuming method of analysis and can be used efficiently when large number of criteria and alternatives need to be evaluate.

One can prepare a concrete mix design for achieving higher sustainability by selecting the three ingredients of concrete with higher sustainable scores and also through permutation combination.

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