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EVALUATING THE SUSTAINABILITY OF BUILDING MATERIALS BASED ON THEIR PERFORMANCE INDICATORS USING AHP METHOD

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Abstract - To complete the building construction projects sustainably, the materials used in the projects should be chosen with a well-defined set of sustainable performance indicators to advance and implement the concept of Sustainable Construction (SC) in developing countries like India. These performance indicator criteria are derived from green building rating systems, previous studies and experts' opinions. The performance indicator criteria of sustainable building materials are evaluated according to the impact they have on the three pillars of sustainability, such as the economic, social and environmental aspects of the building construction project in general. The Analytical Hierarch Process (AHP) method is used to select the most sustainable building material depending on the evaluation of performance indicators. The performance indicators were identified during the pilot survey after getting feedbacks from experts. A total of 18 sub-criteria which are under the triple bottom line (TBL) main criteria of sustainability, and three blocks of sustainable building materials were selected as alternatives for the sake of evaluation of a case study. Then the weights and ranks of the triple bottom lines (TBL) as the main criteria and performance indicators as sub-criteria with the help of the Analytical Hierarchy Process (AHP) MCDM method were done. This study analyzed and chose the right sustainable building material based on the material's performance indicators as criteria under the three pillars of sustainability which are the environment, economic and social, also called TBL, for the Indian construction context by framing a sustainable material performance evaluation framework.

Index Terms – Sustainable Building Materials (SBM), Analytical Hierarchy Process (AHP), triple bottom line (TBL)

I. INTRODUCTION

BACKGROUND AND THEORY

In terms of resource consumption by urban dwellers, today's cities use two-thirds of global energy and account for 70% of Green House Gas (GHG) emissions. The construction and operation of building projects require a substantial amount of natural resources. It accounts for around 40% of global resource usage, 44% of overall energy consumption, and approximately 16% of global annual water use. According to the UN "State of Global Population Report," Indian urbanization will reach 40.8% by the end of 2030. In developing nations such as India, the construction sector contributes an estimated 7.8% of GDP, second only to agriculture, which contributes 16%, and employs 33 million people. The impact that the building construction sector overall has on the economic, social and environmental aspects of a country like India, justifies that the sector plays a critical role in the sustainability of a nation. The building sector emits 15–18% of total carbon dioxide (CO_2) emissions in India. Energy emissions from emerging countries such as China and India will increase at a 3.2% yearly pace by 2020. Moreover, with around 17.5% of the world's population and a fast-developing metropolitan society, India is expected to face a variety of environmental concerns in the next decades if we don't tackle sustainability issues that are caused by the construction sector in general. Assessing and quantifying the sustainability features of buildings becomes critical as a result.

THE NEED FOR SUSTAINABLE CONSTRUCTION IN INDIA

Lately, in India, there are efforts to look into every possible way to accelerate infrastructure development, for instance, in the 12th Five Year Plan (FYP) Government of India has increased the investments in the infrastructure sector to one trillion US $ [1] with an emphasis on urban transformation, such as the creation of the Smart City Mission, the Atal Mission for Rejuvenation and Urban Transformation (AMRUT), and the Heritage Cities Development and Augmentation Yojana (HRIDAY), which can primarily strengthen the industry[2]. Even the Bureau of Indian Standards (BIS) produced the National Building Code of India in 2005 to oversee building construction operations throughout the nation and launch a strategy to promote sustainability through the NBC 2005 Part 11 [3], [4].

The Jawaharlal Nehru National Urban Renewal Mission (JNNURM) and a relationship between fiscal decentralization and local urban authorities' execution of green building rules are two ways that the FYP seeks to speed up the approval and implementation of codes relevant to green construction. The BIS and the Building Materials and Technology Promotion Council (BMTPC), an apex organization, are actively engaged in promoting environmentally friendly and cost-effective housing, sustainable building materials, and the creation and development of regulatory standards for these topics. To increase awareness and lower energy use, the Bureau of Energy Efficiency (BEE) uses standards and labelling. To address the global challenges of global warming, pollution, carbon footprint, depletion of natural resources, etc., all these problems require rapid action on the issue. They also require a well-defined set of indicators.

II. METHODOLOGY

The methods used in this research project to complete the task is introduced in this chapter. Data were gathered through a questionnaire. There are two primary sections to the questionnaire. General information for the responder is covered in the first section. Questions on their expertise in the building sector and their perspectives regarding the performance indicators for sustainable building materials were posed to the contractors, architects, site engineers, and consultants. Section two discusses, based on the respondents' suggestion, we identified out the criteria that would be considered as performance indicators for the selection of sustainable building materials.

CRITERIA FRAMEWORK

Based on the data collected from past research work and discussions with experts for identifying criteria for the selection of sustainable building materials and framing the performance indicators, this study is structured into three main criteria(the triple bottom lines 3TBs') and 18 sub-criteria the 3TBs'.

DATA ANALYSIS USING ANALYTICAL HIERARCHY PROCESS

In this study, the analytic hierarchy process (AHP) method of the MADM branch of MCDM is used to develop a sustainability performance indicators assessment framework for the selection of sustainable building mater

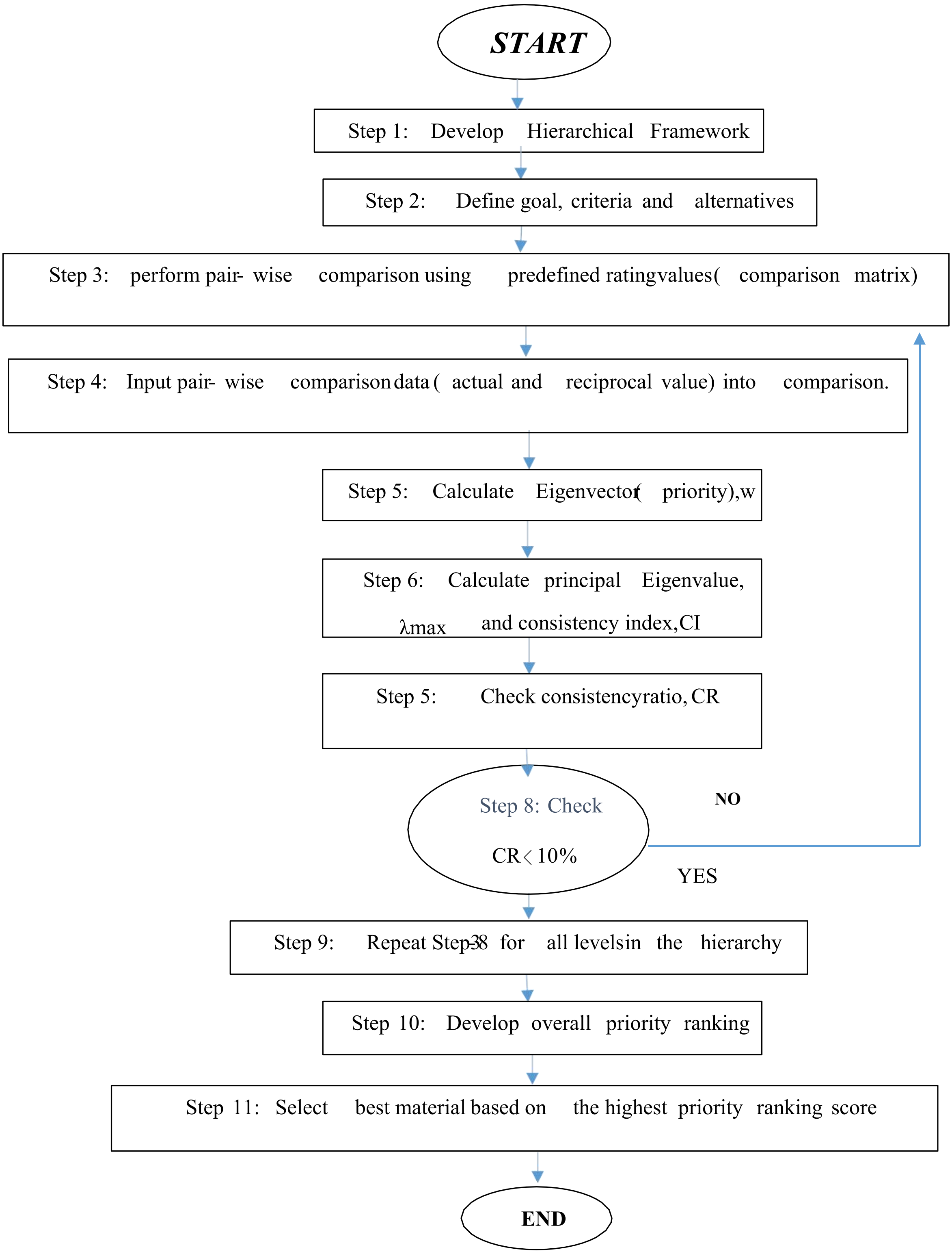

Figure: *Analytic hierarchy process (AHP) methodology for material selection*

III. RESULTS AND DISCUSSIONS

In this chapter, the data obtained from the previous section is analyzed with the assistance of the Analytical Hierarchy Process (AHP) method for selecting and ranking building materials with the notion of the three pillars (3Ps) of sustainability, and to evaluate their value based on performance indicators for the Decision-Maker to select the right material. During the questionnaire survey data collection process, we contacted some sustainable building material manufacturers who are producing in Gujarat state. Amongst the sustainable building materials these companies produce, we use three building blocks randomly for the method we are going to apply for our case. And these materials are:

1) NuEarth Hallow Block, which is manufactured in AEPP Ahmedabad City
2) Silica Plastic Block, which is manufactured in Rhino Machines, Anand City
3) C+D Block, which is manufactured in SGPPL, Surat City

These three different sustainable building materials are going to be used for their various qualitative and quantitative dimensions of performance indicators they have. And they are going to be used for the worthiness of applying AHP in the selection process of sustainable building materials based on their performance.

A matrix for each main and sub-criteria is prepared and after going through all the steps of the AHP method, the Consistency Ratio value of each matrix is also checked. In the final results shown below in the tables and graphs, the performance indicators of sustainable building materials are ranked accordingly to align with the three pillars (3Ps) of sustainability. The three sustainability pillars of social, economic, and environmental sustainability were used as the basis for ranking and weighting the SBMs criterion in the final findings.

PAIRWISE COMPARISON MATRIX

The steps of the analytical hierarchy method are followed to analyze the following varied survey respondent data. The overall data can be summarized in an average format, and the respondents' data can be analyzed in one matrix. This is how the example calculation is carried out:

PAIRWISE COMPARISON MATRIX FOR THE MAIN CRITERIA AND ITS ANALYSIS

Table: Pair-wise comparison matrix for the main criteria

Main Criteria	Environmental	Economic	Social
Environmental	1	2	3
Economic	0.5	1	2

Social	0.3333	0.5	1
Summation of Column =	1.8333	3.5	6

Table: Priorities and Rankings of Main Criteria

Main Criteria	Environmental	Economic	Social	Priorities	Ranking
Environmental	1	2	3	0.539	1
Economic	0.5	1	2	0.297	2
Social	0.333	0.5	1	0.164	3

The above table shows a pairwise comparison of the main criteria against each other with relative importance values given to them in each cell of the matrix. At the bottom, the summation of each cell value under that column would be calculated,

Table : Weighted Average values in percentage showing priorities

Main Criteria	**Environmental**	**Economic**	**Social**	**Weighted Values/Priorities**
Environmental	0.5454	0.5714	0.5	53.9%
Economic	0.2727	0.2857	0.3333	29.7%
Social	0.1818	0.1428	0.1666	16.4%
Summation of Column =	1	1	1	100%

Following the same comparison procedure for the main criteria such as Environmental, Economic and Social Performance Indicators eigenvalues (weighted average values) of each and sub-criterion, the corresponding ranking of each criterion under the economic, social and environmental main criteria and sub-criteria under the main -criteria been found positive results.

Depending on the eigenvalues (weighted average values) of each criterion, the corresponding ranking of each criterion after analysis shows that most respondents give more priority to the environmental main criteria with 53.9% compared to the others such as economic with 29.7% and at last the social with 16.4% of all 55 respondents, the C.R. value for the main criteria is 0.0079 is good enough, which satisfies the essential criteria of CR value, which must be < 0.1. From the value we computed, we can conclude that the pairwise comparison matrix is consistent.

Following the same procedure that we tried to illustrate for the main criteria, we can find the value shown below. Based on Table 3.3, eigenvalues (weighted average values) of each criterion, the corresponding ranking of each criterion under the environmental main criteria after analysis shows that most respondents give the most priority to the G.W.P.(Global Warming Potential) sub-criteria with 34.8% placed at the first spot compared to the others such as P.E.(Pollution and Emission) with 27.9% at the second place and the R.R.(Recyclability and Reusability) with 14.4 at third place % of all 55 respondents, the C.R. value for the main criteria is 0.0553 is good enough, which satisfies the essential criteria of CR value, which must be < 0.1. From the value we computed, we can conclude that the pairwise comparison matrix is consistent which can be shown in table 6.7.

The Consistency Ratio is calculated as: 0.0553

Following the same comparison procedure for Economic Performance Indicators eigenvalues (weighted average values) of each criterion, the corresponding ranking of each criterion under the economic main criteria after analysis shows that most respondents give the most priority to

Based on the final weight of the ranked SBM criteria that are shown in the tables:

- The Environmental main criterion is given the first priority in order to evaluate building materials for their sustainability. The Global Warming Potential sub-criteria under Environmental is given the first priority with 34.8 % amongst other sub-criteria.
- The Economic main criterion is given the second priority, under which Meeting Users Needs is given the first priority with 34.22 % amongst other sub-criteria.
- The Social main criterion is given the third position, under which the Resistance against Natural Contamination and Habitat Disasters (R.N.C.H.D.) is given the most priority with 31.4 % amongst other sub-criteria.
- Based on the overall evaluation process, NuEarth Hallow Block is found to be the best SBM, followed by C+D Block and Silica Plastic Block last.

IV. CONCLUSION

To achieve sustainable building, it is very crucial to promote, put into practice, and defend the sustainability concept through evaluation of the sustainability of building materials based on their performance criteria. Since environmental legislation and other rules and regulations for the protection of the building construction sector becoming more and more prevalent, the concept of sustainable development is in high demand in the construction industry today. As the population that results from building construction projects grows daily, so does global warming, the consumption of natural resources, and the level of environmental degradation also grows at the same time. Considering only the environmental aspects and ignoring the social and economic impacts of construction is not adequate to achieve sustainability. In the case of companies producing building materials and using materials in the construction industry, additional environmental, social, and economic factors are added to the growing competition among these companies. The building construction sector, which includes building construction companies and industries manufacturing building materials is constantly looking for new technologies and materials, which results in a high level of sustainability for buildings and material usability in construction processes.

A systematic approach to the evaluation of the sustainability of materials is required to choose the most appropriate material from the available options. Therefore, with the concept of sustainable development, a two-phase methodology is proposed in this study to evaluate the sustainability of suitable materials in the construction industry based on the Indian context. The first phase, which involved identification of the criteria for evaluating the sustainability of the building materials selection process; that we got from expert opinion during the questionnaire survey and literature review; a total of three main criteria and 18 sub-criteria were selected for the study. The second phase involved the application of the Analytical Hierarchy Process methodology to calculate weights and rankings of the main criteria as well as sub-criteria. To show the practicality of the Analytical Hierarchy Process (AHP) methodology in this particular study, we have computed a practical example. As a case study, the data that we gathered from a questionnaire survey from building materials manufacturing industries that are located in different parts of Gujarat State are taken and used as criteria. Merging these criteria with the three pillars of sustainable development, which are the environmental, economic and social dimensions of the building construction sector, we identified and used the main and sub-criteria for the evaluation process. Based on the criteria weights and rankings obtained using AHP, NuEarth Hallow Block is given priority as the best material alternative among all the three blocks taken up for analysis. Therefore, this study offers evaluation techniques for determining the long-term sustainability of building materials for use in the construction sector.

FUTURE SCOPE OF WORK

Additionally, there are several restrictions on this study. This study uses AHP methodology for evaluating the sustainability of material selection, other MCDM techniques like BWM, VIKOR, FUZZY AHP, or the combination of BWM and ELECTRE can also be applied for this study. By the building material manufacturer's performance priorities, the sub-criteria performance indicators can also be refined for the selection of materials with future new advancements to produce the best outcome for the situations under consideration. Future research can examine different materials other than building blocks as well as other sectors of the construction industry from all around India.

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