Neutrosophic Multicriteria Methods for the Selection of Sustainable Alternative Materials in Concrete Design

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Abstract

Increased awareness of the environmental impacts associated with excessive carbon dioxide emissions generated from cement production has led to great strides in developing technologies and materials aimed at reducing such impacts. A large amount of work has been carried out worldwide related to the design of more sustainable concrete mixes that take advantage of natural elements or those recovered from waste. This work analyzes a set of alternatives for substitutes of concrete mix aggregates that guarantee the best levels of resistance to compression and also comply with the principles of environmental sustainability. To do this, the TOPSIS multi-criteria decision method is used to determine the preferred substitute alternative for aggregates based on certain criteria. The analysis carried out using the TOPSIS method revealed that the alternative with the highest level of proximity to the ideal solution was the use of recycled glass as an additive to the concrete mix. It was observed that the specialists considered the environmental impact and the resistance and durability of the resulting concrete as the most important criteria to assess. A qualitative comparison of the alternatives resulting from the analysis was carried out to verify the results achieved by the method used.

Keywords: alternative aggregates; concrete mix; evaluation of alternatives; sustainable substitutes; neutrosophic TOPSIS

1. Introduction

Nowadays, one of the biggest worldwide problems is caring for the environment. Sustainability and environmental protection are core concepts in the dynamics and development of a globalized world. From 1987 to date, society has evolved towards environmental protection and social responsibility, helping to improve the quality and living conditions of the world's population. The recycling of materials reduces pollution, creates new products with less investment of raw materials, minimizes the exploitation of non-renewable resources, and creates new energy and economic sources. [1]

For modern society, it is not enough to satisfy the current needs of humanity, but it is essential to generate better living conditions without compromising the habitat of future generations. In this sense, the strategic guideline for the protagonists of the construction industry and its value chain is to take on the challenge of generating clean production processes with greater efficiency and performance to contribute to the conservation of the planet. [2]

Concrete is the most used material in the field of construction, and the demand for its production is increasing, which implies the exploitation and use of natural products for its preparation, cement, sand, stone, and water. In

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addition, the process of making cement requires a lot of energy (often from non-renewable sources), which generates the emission of gases that, if not treated, contribute to an increase in the greenhouse effect. [3]

Faced with this problem, numerous studies have been carried out related to the theoretical aspects of the design of concrete mixtures that guarantee the best possible results in construction matters and safeguard the environment's integrity. This way, alternatives are sought in terms of the materials used to prepare concrete that is not aggressive with the environment in terms of their obtaining, preparation, treatment, and other aspects. [4]

This has generated numerous investigations of different natural fibers, which have demonstrated the mechanical properties that they add to concrete and the benefits that the use of natural and renewable resources brings [5]. Thanks to scientific advances in materials science, it has been chosen to study and implement new materials in the construction industry, such as synthetic fibers, metallic fibers, and natural fibers.. The main characteristics of the use of fibers are to reduce the weight of the structures, provide acceptable degrees of resistance, and decrease costs. [7]

In front of so many options to consider, this paper seeks to analyze a set of alternatives for substitutes for concrete mix aggregates that guarantee the best levels of compressive strength and comply with the principles of environmental sustainability. To achieve the proposed objective, firstly, by using multi-criteria decision methods, the preferred alternative substitute for aggregates will be determined for a select group of specialists based on certain pre-selected criteria. In the second part, the analysis of the data and the comparison of the results obtained will be carried out. Finally, the conclusions derived from the analysis carried out are exposed.

2. Method

The TOPSIS method (*Technique for Order Preference by Similarity to Ideal Solution*), allows combining several heterogeneous attributes in a single dimensionless index, and this is because the attributes under evaluation are quite possibly expressed in different units or scales. It is based on the concept that the selected alternative must have the shortest Euclidean distance to an ideal solution and the greatest Euclidean distance to an anti-ideal solution. It is a decision-making technique that was developed by Hwang and Yoon in 1981. [9]

On the other hand, the incorporation of neutrosophic sets to multi-criteria decision methods guarantees that the uncertainty of decision-making is taken into account, including indeterminacies. For this study, we will use the Neutrosophic TOPSIS method to determine the most preferred alternative and the least preferred alternative quantitatively measured, according to certain evaluation criteria. [14]

2.1 Neutrosophic Preliminaries

Definition 1. Let X be a space of points (objects) with generic elements in X denoted by x. A single-valued neutrosophic set (SVNS) A in X is characterized by truth-membership function T_A (x), indeterminacy-membership function I_A (x), and falsehood membership function F_A (x). Then, an SVNS A can be denoted by $A = \{x, T_A(x), I_A(x), F_A(x)\ x \in X\}$, where $T_A (x), I_A (x), F_A (x) \in [0,1]$ for each point x in X. Therefore, the sum of T_A (x), I_A (x) and F_A (x) satisfies the condition $0 \leq T_A (x) + I_A(x) + F_A(x) \leq 3$. [15]

For convenience, a SVN number is denoted by $A = (a\ b\ c)$, where a, b, c $\in [0,1]$ and $a + b + c \leq 3$

Definition 2. Let $A_1 = A_1 = (a_1,b_1,c_1)$ and $A_2 = (a_2,b_2,c_2)$ be two SVN numbers, then addition between A_1 y A_2 is defined as follows:

$$A_1 + A_2 = (a_1 + a_2 - a_1a_2, b_1b_2, c_1c_2) \quad (1)$$

Definition 3. Let $A_1 = (a_1, b_1, c_1)$ and $A_2 = (a_2,b_2,c_2)$ be two SVN numbers, then multiplication between A_1 y A_2 is defined as follows:

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$$A_1 * A_2 = (a_1a_2,, b_1 + b_2 - b_1b_2, c_1 + c_2 - c_1c_2) \quad (2)$$

Definition 4. Let A = (a,b,c) be a SVN number and $\lambda \in \mathbb{R}$ an arbitrary positive real number, then:

$$\lambda A = \left(1 - (1 - a)^{\lambda}, b^{\lambda}, c^{\lambda}\right), \lambda > 0 \quad (3)$$

Definition 5. Let $A = \{A_1, A_2, \ldots, A_n\}$ be a set of n SVN numbers, where $A_j = (a_j,b_j,c_j)$ (j= 1,2,…,n). The single value neutrosophic weighted average operator on them is defined by

$$\sum_{j=1}^{n} \lambda_j A_j = \left(1 - \prod_{j=1}^{n}(1 - a_j)^{\lambda_j}, \prod_{j=1}^{n} b_j^{\lambda_j}, \prod_{j=1}^{n} c_j^{\lambda_j}\right) \quad (4)$$

Where λ_j is the weight of A_j (j= 1,2,…,n), $\lambda_j \in [0,1]$ and $\sum_{j=1}^{n} \lambda_j = 1$

Definition 6. Let $A^* = \{A_1{}^*, A_2{}^*, \ldots, A_n{}^*\}$ be a vector of n SVN numbers, such that $A_j^* = (a_j^*,b_j^*,c_j^*)$ (j= 1,2,…,n), and $B_i = \{B_{i1}, B_{i2}, \ldots, B_{im}\}$ (i= 1,2,…,m), (j= 1,2,…,n). Then the separation measure between B_i and A^* based on Euclidian distance is defined as follows:

$$s_i = \left(\frac{1}{3}\sum_{j=1}^{n}\left(|a_{ij} - a_j^*|\right)^2 + \left(|b_{ij} - b_j^*|\right)^2 + \left(|c_{ij} - c_j^*|\right)^2\right)^{\frac{1}{2}} \quad (5)$$

(i= 1,2,…,m)

Next, we proposed a score function for ranking SVN numbers as follows:

Definition 8. Let A = (a,b,c) be a single-valued neutrosophic number, a score function S of a single-valued neutrosophic value, based on the truth-membership degree, indeterminacy-membership degree, and falsehood membership degree is defined by

$$S(A) = \frac{1+a-2b-c}{2} \quad (6)$$

where $S(A) \in [-1,1]$

The score function S is reduced according to the score function proposed by Li (2005) if b = 0 and $a + b \leq 1$.

A linguistic variable is a variable whose values are characterized with words or sentences instead of numbers in a natural or artificial language. The value of a linguistic variable is expressed as an element of its term set. The concept of a linguistic variable is very useful for solving decision-making problems with complex content. For example, we can express the performance ratings of alternatives on qualitative attributes by linguistic variables such as very important, important, medium, unimportant, very unimportant, etc. Such linguistic values can be represented using single-valued neutrosophic numbers.

In the method, there are k-decision makers, m-alternatives, and n-criteria. k-decision makers evaluate the importance of the m-alternatives under n-criteria and rank the performance of the n-criteria with respect to linguistic statements converted into single-valued neutrosophic numbers. Here, the decision makers utilize often a set of weights such that W ={very important, important, medium, unimportant, very unimportant} and the importance weights based on single-valued neutrosophic values of the linguistic terms are given as Table 1.

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Table 1: Linguistic variable and SVNS. Source: [17]

Definition	**SVNS**
Extremely preferred (EXP)	(1,0,0)
Very very preferred (VVP)	(0.9, 0.1, 0.1)
Very preferred (VP)	(0.8,0,15,0.20)
Preferred (P)	(0.70,0.25,0.30)
Equally preferred (EP)	(0.50,0.50,0.50)
Not preferred (NP)	(0.35,0.75,0.80)
Very not preferred (VNP)	(0.20,0.85,0.80)
Very very not preferred (VVNP)	(0.10,0.90,0.90)
Extremely not preferred (ENP)	(0,1,1)

2.2 Methodology

The TOPSIS method for SVNS used consists of the following: Assuming A = $\{\rho_1, \rho_2, \dots, \rho_m\}$ is a set of alternatives and G = $\{\beta_1, \beta_2, \dots, \beta_n\}$ is a set of criteria, the following steps will be carried out:

Step 1: Determine the relative importance of the experts.

For this, the specialists evaluate according to the linguistic scale shown in Table 1, and the calculations are made with its associated SVNN. Let's call A_t = (at, bt, ct) the SVNS corresponding to the t-th decision-maker (t = 1, 2 , ..., k). The weight is calculated through the following formula:

$$\delta_t = \frac{a_t + b_t\left(\frac{a_t}{a_t+c_t}\right)}{\sum_{t=1}^{k} a_t + b_t\left(\frac{a_t}{a_t+c_t}\right)} \qquad (7)$$

$$\delta_t \geq 0 \; and \; \sum_{t=1}^{k} \delta_t = 1$$

Step 2: Construction of the neutrosophic decision matrix of aggregated single values.

This matrix is defined by $D = \sum_{t=1}^{k} \lambda_t D^t$, where d_{ij} = (u_{ij}, r_{ij}, v_{ij}) and it is used to aggregate all individual assessments. d_{ij} is calculated as the aggregation of the evaluations given by each expert $\left(u_{ij}^t, r_{ij}^t, v_{ij}^t\right)$, using the weights λ_t of each one using Equation 4. In this way, a matrix D = $(d_{ij})_{ij}$ is obtained, where each d_{ij} is a SVNN (i = 1,2, .., m; j = 1,2,…, n).

Step 3: Determination of the Weight of the Criteria.

Suppose that the weight of each criterion is given by W = (w_1, w_2,…, w_n), where w_j denotes the relative importance of the criterion $\lambda_t w_j^t = (a_j^t, b_j^t, c_j^t)$. If it is the evaluation of the criterion λ_t by the t-th expert. Then Equation 5 is used to aggregate the w_j^t with the weights λ_t.

Step 4: Construction of the neutrosophic decision matrix from the single-valued weighted mean with respect to the criteria.

$$D^* = D * W, \qquad (8)$$

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$where\ d_{ij} = (a_{ij}, b_{ij}, c_{ij})$

Step 5: Calculation of the ideal positive and negative SVNN solutions.

The criteria can be classified as cost type or benefit type. Let G_1 be the set of benefit-type criteria and G_2 the cost-type criteria. The ideal alternatives will be defined as follows:

The ideal positive solution, corresponding to G1.

$$\rho^+ = a_{\rho+w}(\beta_j), b_{\rho+w}(\beta_j), ac_{\rho+w}(\beta_j) \tag{9}$$

The ideal negative solution, corresponding to G2.

$$\rho^- = (a_{\rho-w}(\beta_j), b_{\rho-w}(\beta_j), ac_{\rho-w}(\beta_j)) \tag{10}$$

Where:

$$a_{\rho+w}(\beta_j) = \begin{cases} max_i a_{\rho iw}(\beta_j), si\ j\epsilon G_1 \\ min_i a_{\rho iw}(\beta_j), si\ j\epsilon G_2, \end{cases} \qquad a_{\rho-w}(\beta_j) = \begin{cases} min_i a_{\rho iw}(\beta_j), si\ j\epsilon G_1 \\ max_i a_{\rho iw}(\beta_j), si\ j\epsilon G_2, \end{cases}$$

$$b_{\rho+w}(\beta_j) = \begin{cases} max_i b_{\rho iw}(\beta_j), si\ j\epsilon G_1 \\ min_i b_{\rho iw}(\beta_j), si\ j\epsilon G_2, \end{cases} \qquad b_{\rho-w}(\beta_j) = \begin{cases} min_i b_{\rho iw}(\beta_j), si\ j\epsilon G_1 \\ max_i b_{\rho iw}(\beta_j), si\ j\epsilon G_2, \end{cases}$$

$$c_{\rho+w}(\beta_j) = \begin{cases} max_i c_{\rho iw}(\beta_j), si\ j\epsilon G_1 \\ min_i c_{\rho iw}(\beta_j), si\ j\epsilon G_2, \end{cases} \qquad c_{\rho-w}(\beta_j) = \begin{cases} min_i c_{\rho iw}(\beta_j), si\ j\epsilon G_1 \\ max_i c_{\rho iw}(\beta_j), si\ j\epsilon G_2, \end{cases}$$

Step 6: Calculate the distances to the ideal positive and negative SVNN solutions.

With the help of Equation 5, the following Equations are calculated:

$$d_i^+ = \left(\frac{1}{3}\sum_{j=1}^{n}\left\{(a_{ij} - a_j^+)^2 + (b_{ij} - b_j^+)^2 + (c_{ij} - c_j^+)^2\right\}\right)^{\frac{1}{2}} \tag{11}$$

$$d_i^- = \left(\frac{1}{3}\sum_{j=1}^{n}\left\{(a_{ij} - a_j^-)^2 + (b_{ij} - b_j^-)^2 + (c_{ij} - c_j^-)^2\right\}\right)^{\frac{1}{2}} \tag{12}$$

Step 7: Calculation of the Coefficient of Proximity (CP).

The CP of each alternative is calculated with respect to the positive and negative ideal solutions.

$$\widetilde{\rho_J} = \frac{s^-}{s^+ + s^-} \tag{13}$$

Where $0 \leq . \widetilde{\rho_J} \leq 1$

Step 8: Determine the order of the alternatives.

They are ordered according to what was achieved by $\widetilde{\rho_J}$. The alternatives are ordered from highest to lowest, provided that $\widetilde{\rho_J} \rightarrow 1$ is the optimal solution.

3. Results and discussion

There are several investigations carried out on the addition of more sustainable alternative materials that at the same time guarantee certain parameters of quality and durability over time. When talking about the sustainability of alternative materials, it is essential to consider not only those materials that we can find and obtain from nature; but rather consider, from the point of view of recycling and reuse, the wastes of productive and industrial processes so that industrialization with 0 wastes is achieved. In this sense, the specialists have determined the comparison of three alternative materials, products of the reuse of industrial waste (plastic, glass, tetra pack containers) and, on the other hand, three natural fiber materials are selected (rice husk ash, fique fiber, and coconut tow fibers).

For the evaluation of the alternatives, the following criteria are considered:

C1. Manageability: It is important that the concrete obtained has adequate manageability for its placement or application. This depends mainly on the properties and characteristics of the aggregates and the quality of the cement.

C2. Strength and durability of concrete: This resistance specification may have some limitations when it is specified with a maximum water-cement ratio and the amount of cementing material is conditioned. It is important to ensure that the requirements are not mutually incompatible. In some cases, the water/cementing material ratio becomes the most important characteristic due to durability.

In some specifications, the concrete may be required to meet certain durability requirements related to freezing and thawing, chemical attack, or chloride attack, cases in which the water-cement ratio, the minimum cement content, and the use of additives become a fundamental piece for the design of a concrete mix.

C3. Economy: The cost of making a concrete mix is made up of the cost of materials, equipment, and labor. The variation in the cost of the materials is because the price of cement per kilo is higher than that of the aggregates and, hence, that the proportion of the latter minimizes the amount of cement without sacrificing the strength and other properties of the concrete. The difference in cost between the aggregates may be sufficient to influence selection and dosing. The cost of water usually has no influence, while that of additives can be important because of their potential effect on the dosage of cement and aggregates.

C4. Environmental impact: When considering alternative materials for the addition to the concrete mix, it is sought to find ways that allow guaranteeing optimal levels of construction quality but also less impact on the environment. The use of natural materials minimizes industrial processes that in most cases have a negative impact on the environment. On the other hand, the incorporation of waste materials or materials considered pollutants to the environment to concrete mixtures helps to clean the natural environment, allows the optimization of production cycles, and contributes to the reduction of production costs.

C5. Constructive versatility: The proportions of the concrete mixture that meet the characteristics necessary for each construction system, with the materials available, is achieved through trial and error or the adjustment and readjustment system. However, finding mixtures that achieve enough versatility to adapt to different environments and manage to remain within the quality parameters established by international organizations is the goal of every designer.

For the evaluation of the different alternatives, five specialists in concrete mix design with several years of experience are selected. Decision-makers use a set of linguistic weights given by the data shown in Table 1 to determine the performance of each alternative based on the evaluation criteria. Table 2 presents the information from the evaluations carried out by the five specialists

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Table 2: Evaluation of the alternatives according to decision criteria by the k decision-makers. Source: Own elaboration

<table>
<tr><th colspan="6">Manageability</th></tr>
<tr><th>Alternatives</th><th>K1</th><th>K2</th><th>K3</th><th>K4</th><th>K5</th></tr>
<tr><td>Coconut bast</td><td>(0.35,0.75,0.80)</td><td>(0.75,0.25,0.20)</td><td>(0.35,0.75,0.80)</td><td>(0.10,0.90,0.90)</td><td>(0.35,0.75,0.80)</td></tr>
<tr><td>Fique Fiber</td><td>(0.9,0.1,0.1)</td><td>(0.75,0.25,0.20)</td><td>(0.9,0.1,0.1)</td><td>(0.75,0.25,0.20)</td><td>(0.75,0.25,0.20)</td></tr>
<tr><td>Tetra Pack</td><td>(0.50,0.5,0.50)</td><td>(0.75,0.25,0.20)</td><td>(0.50,0.5,0.50)</td><td>(0.50,0.5,0.50)</td><td>(0.75,0.25,0.20)</td></tr>
<tr><td>Plastic</td><td>(0.10,0.90,0.90)</td><td>(0.50,0.5,0.50)</td><td>(0.50,0.5,0.50)</td><td>(0.75,0.25,0.20)</td><td>(0.50,0.5,0.50)</td></tr>
<tr><td>Glass</td><td>(0.9,0.1,0.1)</td><td>(0.9,0.1,0.1)</td><td>(0.75,0.25,0.20)</td><td>(0.75,0.25,0.20)</td><td>(0.9,0.1,0.1)</td></tr>
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<tr><th colspan="6">Strength and durability of concrete</th></tr>
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<tr><th colspan="6">Economy</th></tr>
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<tr><th colspan="6">Environmental impact</th></tr>
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<tr><td>Fique Fiber</td><td>(0.75,0.25,0.20)</td><td>(0.75,0.25,0.20)</td><td>(0.75,0.25,0.20)</td><td>(0.75,0.25,0.20)</td><td>(0.75,0.25,0.20)</td></tr>
<tr><td>Tetra Pack</td><td>(0.50,0.5,0.50)</td><td>(0.75,0.25,0.20)</td><td>(0.75,0.25,0.20)</td><td>(0.75,0.25,0.20)</td><td>(0.50,0.5,0.50)</td></tr>
<tr><td>Plastic</td><td>(0.75,0.25,0.20)</td><td>(0.75,0.25,0.20)</td><td>(0.50,0.5,0.50)</td><td>(0.75,0.25,0.20)</td><td>(0.50,0.5,0.50)</td></tr>
<tr><td>Glass</td><td>(0.9,0.1,0.1)</td><td>(0.9,0.1,0.1)</td><td>(0.9,0.1,0.1)</td><td>(0.9,0.1,0.1)</td><td>(0.9,0.1,0.1)</td></tr>
</table>

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Rice husk ash	(0.75,0.25,0.20)	(0.75,0.25,0.20)	(0.9,0.1,0.1)	(0.75,0.25,0.20)	(0.9,0.1,0.1)

For the analysis, it is considered that each of the specialists has an evaluation (VVP), according to the linguistic values provided in Table 1. Once the individual evaluation of each decision-maker is obtained, the single values matrix is determined, by applying equation 4. See table 3

Table 3: SVNS aggregate decision matrix. Note: Source: Own elaboration

Alternatives	**Manageability**	**Strength and durability of concrete**	**Economy**	**Environmental impact**	**Versatility**
Coconut bast	(0.42696,0.62441,0.62074)	(0.38323,0.69158, 0.72823)	(0.80963,0.19037, 0.19037)	(0.8096,0.1904, 0.1904)	(0.9,0.1,0.1)
Fique Fiber	(0.82671,0.17329,0.15157)	(0.85573,0.14427, 0.13195)	(0.85573,0.14427, 0.13195)	(0.6496,0.371,0.3641)	(0.75,0.25,0.2)
Tetra Pack	(0.62107,0.37893,0.34657)	(0.5,0.5,0.5)	(0.67012,0.32988, 0.28854)	(0.5975,0.4262, 0.4373)	(0.6701,0.3299,0.2885)
Plastic	(0.51043,0.48957,0.46821)	(0.5,0.5,0.5)	(0.62107,0.37893, 0.34657)	(0.7254,0.2746, 0.2512)	(0.6701,0.3299,0.2885)
Glass	(0.85573,0.14427,0.13195)	(0.82671,0.17329, 0.15157)	(0.62107,0.37893, 0.34657)	(0.7232,0.2848, 0.2885)	(0.9,0.1,0.1)
Rice husk ash	(0.67012,0.32988,0.28854)	(0.67012,0.32988, 0.28854)	(0.72536,0.27464, 0.25119)	(0.7254,0.2746, 0.2512)	(0.8267,0.1733,0.1516)

To obtain the weighted decision matrix (see Table 5), the specialists determine the weights of the criteria according to the values provided in Table 1. Linguistic language is used as it is the most natural for human beings. The vector of weights of the criteria obtained according to the evaluations carried out is shown below:

Table 4: Vector of weights of the criteria. Source: Own elaboration

Criterion	**Criterion weight**
Manageability	(0.82671; 0.17329; 0.15157)
Strength and durability of concrete	(0.87989; 0.12011; 0.11487)
Economy	(0.85573; 0.14427; 0.13195)
Environmental impact	(0.87989; 0.12011; 0.11487)
Versatility	(0.85573; 0.14427; 0.13195)

Table 5: Weighted decision matrix. Source: Own elaboration

Alternatives	**Manageability**	**Strength and durability of concrete**	**Economy**	**Environmental impact**	**Versatility**
Coconut bast	(0.35297; 0.6895; 0.67822)	(0.3372; 0.72862; 0.75945)	(0.69282; 0.30718; 0.2972)	(0.71236; 0.28764; 0.2834)	(0.77016; 0.22984; 0.21876)
Fique Fiber	(0.68345; 0.31655;	(0.75295; 0.24705; 0.23166)	(0.73227; 0.26773;	(0.57158; 0.44655;	(0.6418; 0.3582; 0.30556)

	0.28017)		0.24649)	0.43715)	
Tetra Pack	(0.51344; 0.48656; 0.44561)	(0.43995; 0.56006; 0.55744)	(0.57344; 0.42656; 0.38242)	(0.52573; 0.49512; 0.50194)	(0.57342; 0.42658; 0.38238)
Plastic	(0.42198; 0.57802; 0.54881)	(0.43995; 0.56006; 0.55744)	(0.53147; 0.46853; 0.43279)	(0.63827; 0.36173; 0.33721)	(0.57342; 0.42658; 0.38238)
Glass	(0.70744; 0.29256; 0.26352)	(0.72741; 0.27259; 0.24903)	(0.53147; 0.46853; 0.43279)	(0.63634; 0.3707; 0.37023)	(0.77016; 0.22984; 0.21876)
Rice husk ash	(0.55399; 0.44601; 0.39638)	(0.58963; 0.41037; 0.37027)	(0.62071; 0.37929; 0.35)	(0.63827; 0.36173; 0.33721)	(0.70743; 0.29257; 0.26355)

Finally, the order of the alternatives is shown in table 6, according to the proximity coefficient calculated.

Table 6: Positive and negative ideal values and distances. Source: Own elaboration

Alternatives	d +	d-	CP	Order
Coconut bast	0.66209	0.33963	0.339048	6
Fique Fiber	0.34679	0.67892	0.661899	2
Tetra Pack	0.58224	0.38429	0.3976	4
Plastic	0.60211	0.36854	0.379687	5
Glass	0.32046	0.65089	0.67009	1
Rice husk ash	0.36984	0.49303	0.571381	3

As can be seen, the analysis carried out shows that the alternative that has greater proximity to the ideal solution of the method is the alternative that considers glass as an additive. Very close to this alternative is the use of fique fiber, and the next closest alternative to these is the use of rice husk ash. All the other substitute alternatives have proximity levels lower than 0.5, so it is not considered necessary to analyze them in greater depth.

Table 7 shows the approximate results obtained in the experimentation of the compressive strength of concrete mixtures using each of the alternatives analyzed. [18] - [20]

Table 7: Compressive strength. Curing time 28 days. Source: Own elaboration.

Alternatives	**Kgf / cm2**
Fique Fiber	406.5
Glass	266.5
Rice husk ash	234.0

It is interesting to note that although the mixture with fiber additives has a greater resistance to compression, the results achieved tend towards the selection of glass as the one closest to the ideal solution. In this sense, the criteria of greatest impact in the selection of these alternatives according to the specialists were the *environmental impact* and the *resistance and durability* of the resulting concrete. According to the classification made at first, it is interesting to note that of the resulting alternatives, the majority correspond to natural fibers, while glass is the only alternative selected from those corresponding to waste elements.

In this sense, we consider that although the fique fiber and the rice husk ash are natural elements and therefore their use is not aggressive to the environment, the dependence on the sowing cycles, climatic factors, as well as the

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exploitation of the soils, among other elements, could hinder a constant production to supply large projects. On the other hand, recycled glass is an interesting option as a substitute for aggregates. In this way, the discharge of recycled glass into the environment is avoided, production costs are reduced, etc.

4. Conclusions

The creation and use of concrete mixs with recycled and/or environmentally friendly additives, far from being an extravagant novelty, is practically a necessity these days to optimize processes and guarantee a sustainable future. The addition of natural fibers or waste materials from other production processes can offer interesting alternatives for the creation of concretes with characteristics similar to those that already exist and with environmental, economic, social, and other advantages. The analysis carried out using the TOPSIS method revealed that the alternative with the highest level of proximity to the ideal solution was the use of recycled glass as an additive to the concrete mix. It was observed that the specialists considered the environmental impact and the resistance and durability of the resulting concrete as the most important criteria to assess. A qualitative comparison of the alternatives resulting from the analysis was carried out to verify the results achieved by the method used.

The use of the TOPSIS method in its neutrosophic variant allowed to consider the uncertainty and indeterminacies of the real world for the development of the study. The use of the neutrosophic single value sets to develop the method, as well as the linguistic values used for the evaluation of the alternatives and criteria, allowed to verify the effectiveness of the method used.

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