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Evaluation of the Impact of Sustainable Infrastructure on the Perception of the Community Through the Use of Geocells Made of Recycled Tires in an Educational Environment

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Abstract: The purpose of this study is to evaluate the perceptions of the educational community regarding the use of recycled materials in sustainable road infrastructure. To this end, an 11-question survey was administered to students, teachers, and administrators at the La Sagrada Familia Technical Educational Institution in Ibagué, Colombia. The survey assessed their attitudes, awareness, and acceptance of sustainable materials in dimensions such as knowledge of sustainability, perception of recycled materials, and willingness to recommend sustainable practices. As part of the study, a 17 m-long vehicle platform was constructed using geocells made from recycled tires. This practical implementation served both as a demonstration of the potential of recycled materials in road infrastructure and as an educational tool to engage the community in sustainable practices. The construction process included awareness campaigns to educate participants on the environmental and functional benefits of using recycled materials. Preliminary results indicate a significant shift in perception after participants were educated on the benefits of recycled materials. Teachers and administrators showed high levels of acceptance, with 96.6% of teachers reporting improved perceptions. Students, while enthusiastic, showed more varied levels of satisfaction, reflecting their varied exposure to sustainability concepts. This study underscores the critical role of educational projects in fostering awareness and acceptance of sustainable solutions. It highlights the potential of initiatives such as geocells made of recycled tires to integrate practical applications with educational efforts, thereby advancing the adoption of circular economy principles and promoting long-term social benefits in infrastructure development.

Keywords: sustainable infrastructure; recycled tires; circular economy; community perception; geocells

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1. Introduction

The construction industry generates significant amounts of waste on a daily basis. Much of this waste is disposed of in both legal landfills and inappropriate locations, contributing to global environmental problems [1]. This situation has exacerbated the ecological crisis, as the planet is exceeding its limits in terms of carbon production and accumulation [2]. To mitigate these impacts, it is crucial to adopt strategies aligned with the principles of the circular economy, which promote the implementation of the 3Rs: reduce, reuse, and recycle, enabling more efficient resource management and waste minimization [3].

The circular economy (CE) is emerging as a key response to the environmental challenges posed by the depletion of non-renewable resources and the growing excess of waste. In 2010, approximately 1300 million tons of waste were generated, and this figure is expected to increase to 2200 million tons by 2025 [4]. These figures highlight the urgent need to transform the linear economic model of "extraction, use and disposal" into a more sustainable system. This transition aligns with the principles of the circular economy, which emphasizes efficient resource management and waste reduction [3]. The implementation of these practices is crucial to reducing pressure on natural resources and mitigating the growing generation of waste.

While the original 3Rs laid the foundation for resource efficiency, the concept has evolved into the 7Rs framework. This comprehensive approach addresses broader sustainability challenges by incorporating actions such as redesign, repair, and renewal [3]. These seven actions represent a set of strategies that promote more efficient resource management, with the goal of advancing toward global sustainability. In this context, disciplines such as engineering have a key role, not only in implementing recycling techniques but also in redesigning products using materials previously considered waste. This approach not only reduces dependence on virgin materials but also encourages innovation in resource reuse, optimizes product lifecycles, and helps reduce environmental impact.

The increase in vehicle production has led to a proportional increase in the generation of discarded tires, which is expected to reach 2.67 billion units by 2027 [5]. This massive accumulation represents a serious environmental impact, as particles released from tires contaminate both freshwater ecosystems and coastal estuaries, affecting local flora and fauna [6]. In addition, discarded tires pose a significant fire risk, especially if they are poorly managed or dumped in illegal landfills. In recent years, there has been a growing interest in finding sustainable alternatives for the reuse of these materials, driven by the urgent need to reduce their environmental impact. Among these initiatives, the reuse of tires in road construction and their incorporation in industrial applications stand out [7]. This is driving a shift towards a circular economy and sustainable waste management.

Roads are essential for connecting communities to basic services such as education, commerce, healthcare, and others, and play a critical role in economic and social development [8]. However, from an environmental sustainability perspective, the construction and maintenance of these infrastructures pose significant challenges. This includes the intensive use of non-renewable materials such as aggregates, hydraulic cement, and asphalt cement [9], and the generation of large amounts of waste from excavation and other construction activities. As these infrastructures consume enormous amounts of natural resources, it is essential to research and incorporate sustainable alternatives that minimize the environmental impact without compromising the functionality and durability of the roads [10]. For these reasons, governments are encouraging the use of more sustainable alternatives [11].

Sustainability has gained popularity in various industries, including civil engineering, as a priority in road infrastructure development. However, not all solutions labeled "sustainable" meet the necessary criteria to be considered technically and environmentally viable. In the case of pavements, the choice of materials must be carefully considered. Although recycled materials are often promoted as a greener alternative, their use does not always guarantee an effective reduction in carbon emissions or environmental impact. In many cases, the transportation of these recycled materials over long distances can result in higher CO_2 emissions than if local or virgin materials were used [12].

When analyzing pavement sustainability, it is important to consider all phases of the project life cycle. This includes evaluating the materials used, from extraction to final disposal, to minimize the use of non-renewable resources and ensure the durability of the materials. Energy consumption at each stage—such as production, transportation, and installation of materials—must also be carefully analyzed [1]. The emission of pollutants, especially greenhouse gases (GHG), is another key factor, especially in the production of asphalt or concrete. In addition, it is critical to examine waste generation and the potential for recycling or reuse of these materials, which helps to reduce the environmental footprint. Finally, the durability of the pavement and the cost of maintenance play a key role in influencing the frequency of interventions and the cumulative environmental impact throughout the life cycle of the pavement, including the final stages of recycling or disposal [9].

Studies such as that of H. Lei et al. [13] have shown that the use of geocells significantly reduces deformation and increases soil strength due to their confinement effect. In addition, the use of these materials has gained popularity due to their ability to better distribute stresses, increase soil strength, and minimize deformation under repetitive loads [14]. Geocells offer several variations in height, weld spacing, and manufacturing material that can be optimized based on the specific needs of the project. These features make geocell reinforcement more efficient and effective than other types of geosynthetics, maximizing structural and functional performance in a wide range of infrastructure applications [15].

The construction of geocells using recycled tires is a viable alternative due to the high strength and durability inherent in tires, allowing the production of cells that meet the strength and physical properties required for such structures. Moreover, this technique has a positive impact on the environment by using a hazardous and difficult-to-manage waste product and incorporating it into a new production chain. This not only reduces the amount of tires going to landfills, but also contributes to the creation of more sustainable infrastructures with the use of recycled materials in construction.

Building with sustainable materials faces significant challenges in several key areas, such as the durability of materials, the proper selection of these materials, the implementation of circular supply chains, the development of sustainable business models, and the formulation of public policies by governments that promote these practices [16]. In particular, the construction of unpaved roads reinforced with tire-derived geocells reflects all these challenges, as it involves overcoming barriers in each of these areas. However, the continuous and systematic application of this alternative helps to reduce the complexity of these challenges over time, promoting the development of practical solutions that strengthen the implementation of this sustainable technology. In this way, the consistent use of tire-derived geocells not only provides environmental benefits, but also promotes improvements in design, supply, and management processes, paving the way for a more efficient and sustainable road infrastructure model that capitalizes on the mechanical properties of tire durability and strength [17]. This is particularly important when you consider that conventional applications only use between 2% and 3% by weight of the granular layers. This is a very limited amount [18].

Nergard [19] identifies five key factors that influence the perception of sustainability: knowledge of issues, knowledge of processes, social incentives, material incentives, and stimuli. Among these factors, the level of public knowledge about sustainable technologies stands out. Therefore, education, awareness, and promotion of sustainable practices in the education system are essential to increase the adoption and understanding of these technologies [20].

Previous studies have shown that public perception plays a crucial role in the adoption of sustainable alternatives, acting as both a driver and a barrier to their consumption [21]. Public acceptance of sustainable products and technologies depends on demographic factors such as education, gender, and age [22]. Recent research suggests that positive perceptions of these alternatives can increase their demand and promote their integration into the market, while negative or limited perceptions can hinder their adoption, even when the alternatives are environmentally and economically beneficial [23]. This finding underscores the importance of understanding and addressing public perceptions to promote the success of sustainable solutions in the marketplace.

In response to increasing environmental degradation, numerous studies highlight environmental education as a critical strategy to mitigate the rapid depletion of natural resources and the increase in pollution. Environmental education in higher education promotes the adoption of pro-environmental behaviors by raising awareness of the urgency of sustainable practices [24,25]. The literature suggests that students generally have a perspective on sustainability that is primarily focused on the environment [25]. Incorporating sustainable strategies into educational institutions not only strengthens the awareness of the student community, but also promotes the integration of systemic approaches aimed at comprehensive sustainability.

In the area of education, institutions play a critical role in shaping the environmental consciousness of new generations [25] Implementing sustainable infrastructure projects, such as using recycled tires in sidewalks and platforms, not only provides practical solutions to waste management issues, but also educates the community about the value of sustainability in everyday life [24,25]. These types of projects promote active learning about circular economy practices and create opportunities for the development of functional and environmentally friendly infrastructure [20].

Inadequate management of hard-to-discompose materials, such as used tires, is a challenge for both the environment and public health [26]. This problem is exacerbated by the lack of sustainable options for reusing these wastes, which contributes to the accumulation of waste in landfills and the emission of pollutants harmful to ecosystems. The circular economy offers a promising alternative to reduce these impacts through the reuse of materials, but its adoption depends largely on community acceptance and understanding [14]. In educational institutions, where new generations are trained, the implementation of sustainable solutions could not only provide environmental benefits, but also promote a culture of sustainability [24,25]. However, the perception and acceptance of these practices by the educational community remain a barrier to their effective implementation, highlighting the need to investigate these attitudes in order to promote a shift towards sustainable practices in infrastructure [25].

This research investigates the educational community's perceptions of the use of recycled materials in road infrastructure, with a focus on scrap tire geocells. By implementing and analyzing a vehicle platform constructed with these innovative materials, the study highlights their dual impact: promoting sustainable practices in infrastructure development and fostering environmental awareness within an educational setting.

2. Methodology

This study was carried out at La Sagrada Familia Educational Technical Institution, located in Ibague (Colombia), and was divided into two main phases: the practical implementation of a sustainable solution in infrastructure and the evaluation of the perception of the educational community regarding this intervention.

In this work, geocells made from waste tires were used as an alternative reinforcement for unpaved roads. Geocells are three-dimensional geosynthetics typically made from polymers and manufactured under strict physical property standards. They work by confining the material within each of the cells of their structure, increasing the material's strength. Their use reinforces the material, allowing for the construction of more durable retaining walls or pavements [13,14,27,28].

In the current case study, geocells were incorporated into a road platform within an educational facility. This alternative was used to assess the educational community's perception of these circular economy solutions. The goal is to expose students and teachers to ideas that promote the use of recycled materials and foster a more open perspective towards sustainable practices. This initiative aims to stimulate interest in green engineering solutions within the educational community [29].

2.1. Implementation of the Vehicle Platform with Recycled Geocells

The first phase consisted of the construction of a 17 m-long by 4 m-wide vehicle platform for parking school bus routes, using geocells made from recycled tires. This material was chosen for its durability and strength, as well as its alignment with the principles of the circular economy. The construction was carried out in modules, using a total of 584 tires, organized into assembled geocells and reinforced with granular material. This approach made it possible to directly observe the impact of the sustainable infrastructure on the mobility and safety of the users, while facilitating the subsequent evaluation of their perception.

This phase served a dual purpose: to provide a practical improvement to the existing infrastructure and to serve as an empirical basis for data collection in the next phase. Figure 1 shows the manual assembly process of the geocell mesh. Figure 1a illustrates the tire cutting process. Figure 1b shows the method used to invert the tires, while Figure 1c displays the arrangement of the eight segments. Finally, Figure 1d presents the completed geocell ready for use.

Figure 1. Manufacturing process of geocells made from recycled tires. (**a**) Sidewall cutting, (**b**) tread flipping, (**c**) assembly of the eights, (**d**) joining of the eights.

2.2. Characterization of the Fill Material for the Vehicle Platform

In this phase, the properties of the subgrade and the reinforcement material for the platform were determined based on the methodology established by SUCS [30]. The properties of the subgrade at the educational center are detailed in Table 1, where its soil was characterized as silty sand with a CBR resistance of 2%.

Table 1. Subgrade soil properties.

Property	Result
LL (%) [31]	36.9
LP (%) [30]	26.2
IP (%)	10.7
Specific gravity	2.66
CBR (%) [32]	2

The geocells were filled with a typical local material known as "recebo". Recebo is a natural granular material, locally sourced and cost-effective, widely utilized by communities in rural road construction. Composed of mixed soils, it does not meet formal technical standards but is favored for its accessibility and low cost, making it a practical alternative to processed or standardized materials. Commonly employed in the construction of low-traffic roads, the specific properties of recebo are provided in Table 2.

Table 2. Properties of the geocell fill material.

Property	Result
Specific gravity	2.75
CBR (%) [32]	86
Los Ángeles test (%) [33]	54
Maximum density (t/m^3) [34]	1.94
Optimun moisture content (%) [34]	6.5

2.3. Design and Planning of the Vehicle Platform Construction

For this stage, the dimensions of the platform were set as follows: width a = 4 m, length l = 17 m, and thickness e = 0.30 m. This was done to ensure the stability of the ground. Figure 2 shows a sectional view of the platform.

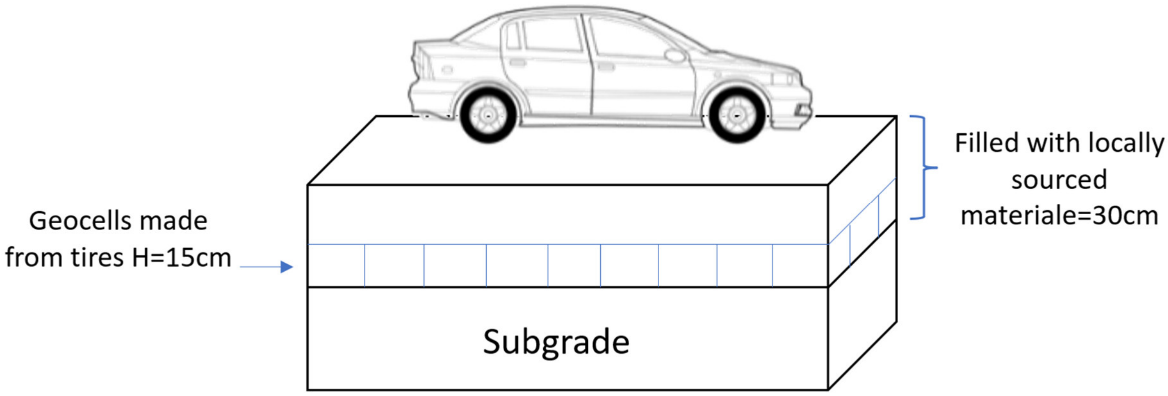

Figure 2. General layout of the vehicle platform.

2.4. Construction of the Roadway Platform and Dissemination of the Construction Process

Two types of mechanical equipment, an excavator, and a vibratory compactor, commonly used in road construction, were used in this phase. First, the excess material was excavated and leveled. Then the 2 m × 1 m tire geocell modules were placed, filled with granular material, and compacted to ensure stability. Figure 3 shows the construction process of the platform, highlighting the main activities carried out during this phase. The process began with the excavation and grading of the soil for proper preparation. Next, the tire geocells were installed, followed by the filling and compaction of the granular material to ensure proper stability and functionality of the structure.

Once the construction was completed, an awareness campaign was organized to inform the educational community about the intervention carried out and the benefits associated with the use of sustainable materials. This phase included presentations to students, teachers, and administrative staff on, the project details, the construction process, and the use of recycled tires as a sustainable solution.

Figure 3. Vehicle platform construction process. (**a**) Excavation and levelling of the subgrade, (**b**) placement of the tire geocells, (**c**) filling and compaction.

The purpose of this phase was not only to educate about the newly built infrastructure but also to raise awareness of the positive impact that sustainable solutions can have in the school environment. To complement these activities, graphic and visual materials were distributed to facilitate the understanding of the technical and environmental aspects of the project.

Regarding the characterization of the educational institution's population, the selected population of the educational institution included high school students, teachers, administrators, and management. This characterization provided a clear overview of the total number of personnel within the institution, which was essential to properly structure the analysis and ensure that the perceptions of all relevant groups were included. Table 3 shows the distribution of the total population of the educational center.

Table 3. Characterization of the educational population.

Role	Quantity	Percentage
Administrators and school leadership	13	3.07
Students	350	82.74
Teachers	60	14.18
Total	423	100

Each of the roles of individuals in this study is essential, as they provide a unique perspective on the sustainable alternatives implemented. Senior high school students were selected due to their daily use of the vehicle platform, as they rely on school bus routes. Their inclusion is key to assessing their level of awareness and understanding of sustainability, which is particularly relevant given that they are future decision-makers on environmental issues.

Teachers, on the other hand, provide a perspective focused on the safety and functionality of the infrastructure, as their priority is to ensure a suitable environment for the education and well-being of the students. Finally, administrative and management staff contribute a more technical and organizational perspective, as they are involved in managing the institution's facilities, which allow them to evaluate the infrastructure from an efficiency and maintenance perspective.

2.5. Sample Size Calculation

To calculate the sample size, the stratified random sampling method was used to ensure the representativeness of each role within the educational center. This approach ensures both the representativeness and the heterogeneity of sustainability perceptions within the institution.

The sample size calculation was calculated using the finite population formula, based on a confidence of 95% and a margin of error of 5%, which guarantees a high level of precision in the results obtained. The formula used was:

$$n = \frac{N * Z^2 * p * q}{e^2 * (N-1) + Z^2 * p * q} \quad (1)$$

where:

n is the sample size.
N is the total population size (in this case, 423 people).
Z is the critical value corresponding to the desired confidence level (for a 95% confidence level, Z = 1.96).
p is the estimated proportion of the population that has the characteristic of interest (in this case, assumed to be 0.5, which maximizes variability).
q is the complementary proportion (1 − p).
e is the desired margin of error (in this case, 0.05 or 5%).

With the above, the representative sample for the study is calculated to be 202 individuals, divided as shown in Table 4.

Table 4. Distribution of the sample according to the roles existing in the educational center.

Role	Quantity	Percentage
Students	167	82.67
Teachers	29	14.36
Total	202	100

2.6. Design of Perception Measurement Instrument

The instrument used for data collection was a survey consisting of 11 questions designed to address different key aspects related to the perception of the use of sustainable technologies in road infrastructure. The questions were grouped into five main thematic sections in order to cover different dimensions of the study topic.

- Characterization of the sample by gender, education, and age—4 questions
- Knowledge about sustainability—1 question
- Perception of the use of recycled materials in road infrastructure—2 questions
- Acceptance of the vehicle platform built with recycled geocells—2 questions
- Perceived impact on environmental sustainability—2 questions

The questionnaire was developed based on established frameworks for assessing perceptions of sustainability in infrastructure projects to ensure comprehensive coverage of demographic factors, sustainability awareness, and attitudes towards recycled materials. The number of questions was carefully optimized to balance response burden and data reliability, increasing participant engagement while capturing statistically relevant insights.

To validate its effectiveness, a pilot test was conducted with a subset of respondents to confirm the clarity, coherence, and reliability of the instrument prior to full deployment. While the results are specific to this institution, they provide valuable insights into perceptions of sustainable infrastructure in educational environments.

Table 5, the perception measure, is designed to comprehensively assess the education community's acceptance, understanding, and attitudes toward sustainable infrastructure solutions. It is divided into key dimensions: General Characterization, which examines demographic factors such as gender, age, role, and education level; Knowledge of Sustainability, which assesses conceptual understanding of the issue; Perception of Recycled

Materials, which focuses on initial preferences and changes after receiving information; Acceptance of the Intervention, which measures satisfaction and willingness to adopt these technologies; and Perceived Impact, which explores how the experience influences perceptions of recycling. This approach ensures clear and relevant results for identifying trends and opportunities.

Table 5. Design of data collection instrument.

Dimension	Item	Measurement Scale	Purpose
General Characterization	1. What is your gender?	Male/Female/Prefer not to say	Identify basic demographic characteristics.
	2. What is your level of education?	High school/University/Postgraduate	Evaluate the level of educational background to correlate with perception.
	3. What is your age group?	Age range (e.g., 15–20, 21–30, etc.)	Group responses according to generations.
	4. What is your role in the organization?	Teacher/Student/Administrators and school leadership	Identify the role within the educational community.
Knowledge of Sustainability	5. What is your understanding of sustainability?	"Not sure" or "I've heard the term, but I don't know what it means"	Evaluate basic understanding of the concept.
Perception of Recycled Materials Acceptance of the Intervention	6. What material would you have preferred to see used on the road in question?	Hydraulic concrete, asphalt concrete, pavers, recycled materials	Identify initial preferences.
	7. After reading this paragraph: "The use of recycled materials, such as used tires, in the construction of infrastructure. . .", what material would you have preferred to see used for the road in question?	Hydraulic concrete, asphalt concrete, pavers, recycled materials	Identify preferences after information about benefits.
Perceived Impact Knowledge of Sustainability	8. How do you feel about the use of environmentally friendly solutions in your work or study environment?	Very satisfied—Very dissatisfied	Evaluate emotional acceptance of the implemented solution.
	9. Do you agree with the implementation of alternatives using recycled materials in the educational institution?	Completely agree—Completely disagree	Identify perception of the project's execution.
Perception of Recycled Materials	10. Would you recommend the use of these alternatives for future infrastructures in your work or study environment?	Likert scale	Measure willingness to promote the technology.
	11. How did your perception of recycling change when you learned that the road was made of used tires?	Improved/No change/Worsened	Analyze how perception changes after experiencing the technology.

Finally, in phase 5, various statistical techniques were used to analyze respondents' perceptions of the use of recycled tires in road construction. Percentages were used to represent the distribution of responses and identify the proportion of respondents who reported changes in their perceptions, such as "much improved" or "no change". Additionally, the chi-square test was used to assess the relationship between categorical variables, such as the perceptions of different groups (teachers, students, administrators) and their responses regarding changes in their perceptions of recycling. This statistical test helps determine whether the observed differences between the groups are statistically significant or if they could be due to chance.

2.7. Data Collection

Data collection was carried out through the application of digital surveys, using platforms accessible to all participants through their mobile devices. The process was divided into two modalities, depending on the target group.

For high school students, the survey was administered in person by gathering them in a designated space within the educational institution. Each student accessed the digital questionnaire through his or her personal mobile phone. This method allowed for simultaneous data collection, maximized the response rate, and ensured that participants could complete the survey under the supervision of the research team.

For teachers, administrators, and staff, the survey was sent individually via digital message, allowing access from any location and at a convenient time for each participant. The link to the digital questionnaire was directly sent to the mobile phones of the respondents, ensuring their participation in a flexible manner without interfering with their work responsibilities.

This digital data collection method was selected for its practicality and the high penetration of mobile devices among the target population, enabling broad coverage and a high response rate. Additionally, the digital format facilitated the immediate collection of data into a centralized database, optimizing the subsequent analysis process.

3. Analysis of Results and Discussion

In this chapter, the results of the analysis of the surveys conducted at the Technical Institution La Sagrada Familia in the city of Ibague (Colombia) are presented. The analysis is divided into the thematic blocks of the survey.

3.1. General Characterization of the Sample

Table 4 shows that students are the largest group in the educational institution, representing 82.67% of the sample. Teachers represent 14.36%, while administrative and managerial staff represent 2.97%.

The gender classification, shown in Table 6, shows a predominance of females within the institution, representing 66% of the participants. A more detailed analysis by role, shown, highlights that female representation exceeds 75% in administrative, managerial, and teaching positions, underscoring a significant gender majority in these categories. This high representation of females in these key roles highlights their predominance in the organizational structure of the institution and may have implications for perceptions of issues such as sustainability and environmental impact.

Table 6. Gender distribution within each role of the educational institution.

Role	Men	Men (%)	Women	Women (%)	Total
Administrators and school leadership	1	16.67	5	83.33	6
Students	61	36.53	106	63.47	167
Teachers	7	24.14	22	75.86	29
Total	69		133		202

The education level analysis focused on teachers, administrators, and managers, as the students were all in their final year of high school. The results show that none of the respondents in these roles have a level of education lower than a university degree. Among the administrative and managerial groups, the majority have university degrees, while 100% of the teachers have postgraduate degree. This factor is significant because a higher level of education is directly related to greater exposure to technical knowledge and experience related to sustainability. Therefore, it is expected that individuals with postgraduate or university education will have a more critical and informed perception of environmental issues, which could positively influence their openness to the implementation of sustainable technologies such as geocells made from recycled tires. See Figure 4.

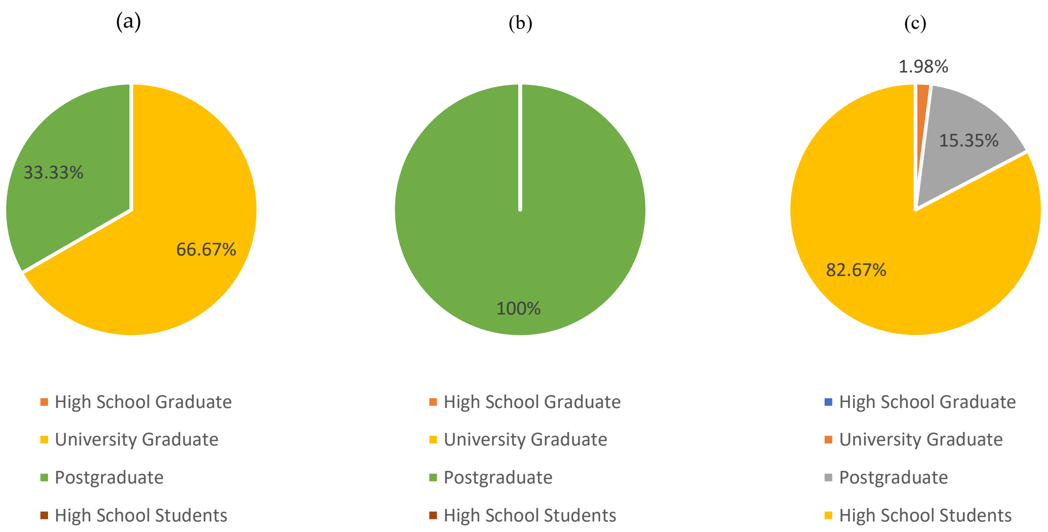

Figure 4. Distribution of academic level by role and in the total sample. (**a**) Administrative staff and managers, (**b**) teachers, (**c**) total.

Education level has a significant impact on perceptions of sustainability. Studies show that people with higher levels of education tend to have a more developed awareness of environmental issues and a positive attitude toward sustainability [35].

Finally, as part of the characterization of the sample, a classification by age was conducted, recognizing the importance of this factor in the perception of sustainability. Age influences how sustainability is valued in everyday life and in the adoption of new technologies. Younger people have grown up in a context where the need to be more environmentally friendly is evident due to the frequency and intensity of environmental disasters such as wildfires, floods, and other effects of climate change. These experiences have made younger generations to become more aware of the urgency of changing traditional habits. On the other hand, older people have also been influenced by their experiences, observing changes in climate and natural resource availability over the years. It is expected that, regardless of age, the impact of using sustainable alternatives will be perceived positively, as sustainable technologies can benefit both younger and more experienced generations. Figure 5 shows the age distribution of the role groups in the educational institution.

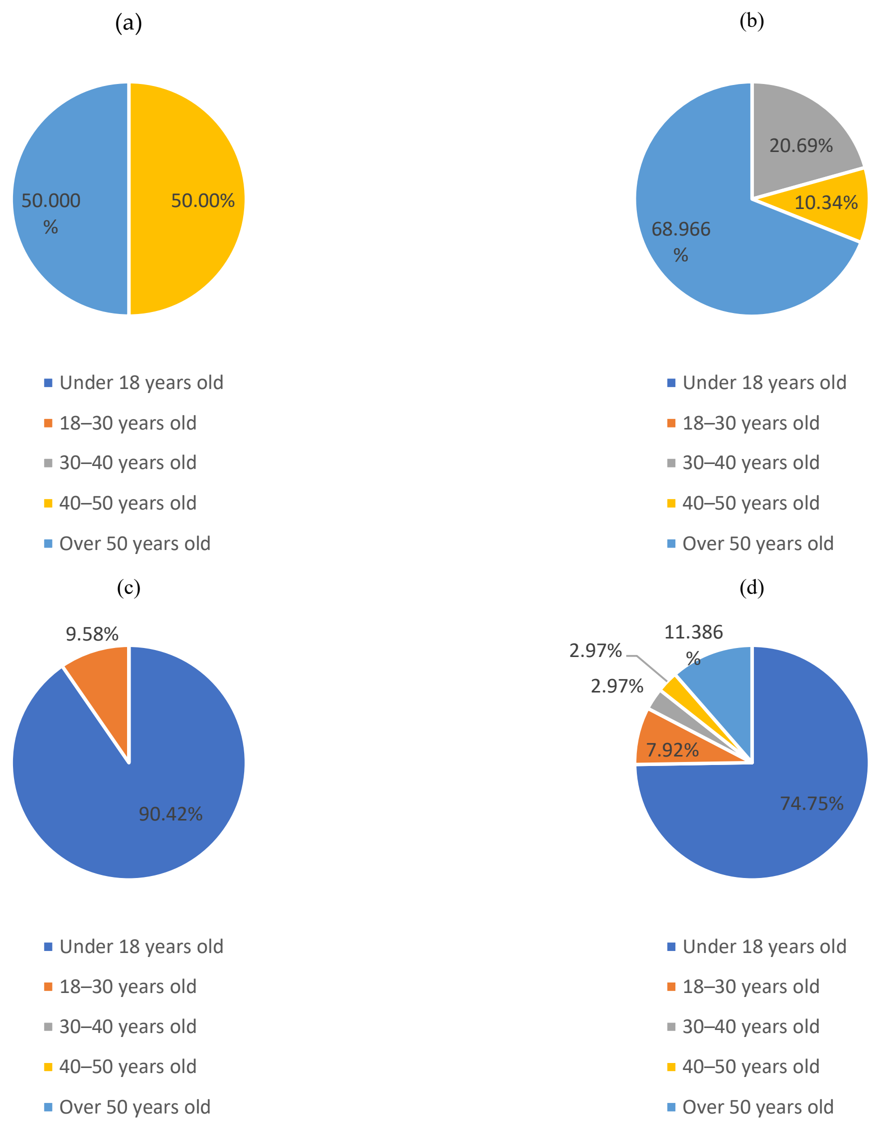

Figure 5. Age distribution among the survey respondents. (**a**) Administrators and directors, (**b**) teachers (**c**), students, (**d**) total sample.

The analysis of the groups according to their role in the school reveals specific characteristics. In the group of administrators and directors, 33% have a postgraduate degree and 67% have a university degree. In addition, this group is evenly divided into two age groups: 50% are between 40 and 50 years old, and the other 50% are over 50 years old. On the other hand, the group of teachers shows a greater homogeneity in terms of educational level, as 100% have postgraduate studies. In terms of age, the group is divided into three ranges: 69% are over 50 years old, 31% are between 30 and 40 years old, and only 10% are between 40 to 50 years old. The student group, on the other hand, is very homogeneous, as 90% are minors. These differences in age structure and educational level between the groups could influence their perception and understanding of concepts such as sustainability.

Perception can be approached from two main perspectives: one that holds that perceptions are socially constructed in a collective manner, and another that emphasizes that they are individually influenced by personal experiences and demographic, cultural, and socioeconomic factors [36]. In this sense, the characterization of the sample in terms of age range, gender, role, and educational level provides a solid foundation for conducting a thorough analysis of perceptions regarding sustainability. This classification allows us to understand how different demographic and educational factors influence the adoption of sustainable technologies and the evaluation of implemented environmental initiatives.

3.2. Knowledge of the Concept of Sustainability

In terms of sustainability knowledge, 84.16% of respondents accurately defined it as the balanced and responsible use of resources, reflecting a solid understanding among the sample population. However, 15.84% of respondents showed uncertainty or limited understanding, selecting responses such as "I'm not sure" or "I've heard the term but don't know what it means". This suggests that while the majority have a clear understanding of sustainability, there is still a section of the population that needs greater awareness and education on the subject. An analysis of responses by role and educational level revealed that teachers and administrators had a higher level of understanding of the concept, while students had more varied levels of knowledge. These findings highlight the importance of continuing to promote sustainability education within the institution.

The analysis of the results shows a significant correlation between the level of education and the understanding of the concept of sustainability. Of the group of administrators, consisting of four graduates and two postgraduates, 16.67% expressed uncertainty about the concept of sustainability. In contrast, 100% of the teachers, all with postgraduate degrees, confidently identified the responsible use of resources as the core of the concept. Higher education may provide a stronger conceptual foundation, but workplace context and personal experience may also play a crucial role in shaping a broader understanding of sustainability.

Figure 6 shows the distribution of knowledge about the concept of sustainability for all respondents and by roles.

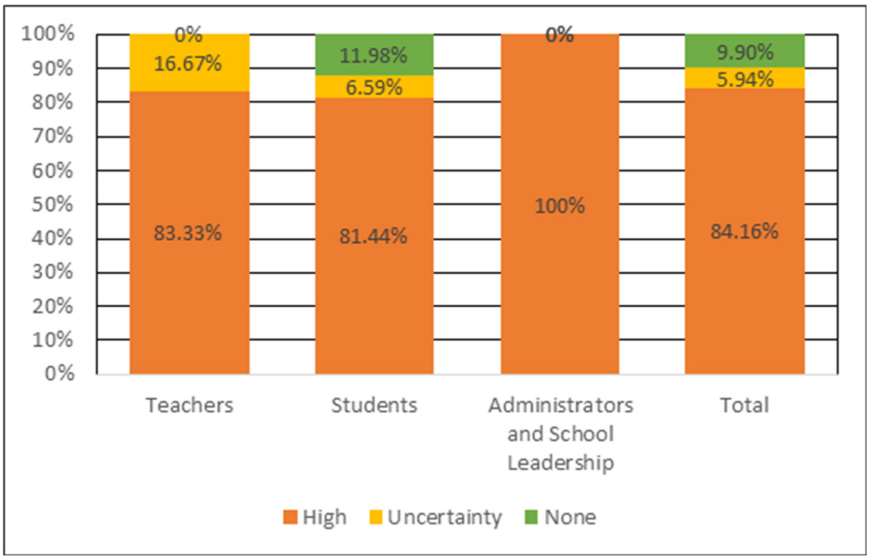

Figure 6. Level of knowledge about the concept of sustainability for the total sample and groups by role.

To determine whether the level of education influences the understanding of the concept of sustainability, a chi-square test is performed. This method is widely used to test the relationship between categorical variables by assessing whether there is a significant relationship between them. The chi-square test [37] compares the observed frequencies in the data with those expected under the hypothesis that there is no relationship between the variables. In this case, it examines whether the distribution of responses by education level matches the expected proportions in the total sample.

For the calculation, a null hypothesis and an alternative hypothesis are established:

- Null hypothesis (H_0): There is no significant relationship between education level and knowledge of the concept of sustainability.
- Alternative hypothesis (H_1): There is a significant relationship between the level of education and knowledge of the concept of sustainability.

Table 7 presents the calculations performed for the test, and it is determined that the null hypothesis is not rejected, as there is insufficient evidence to assert a relationship between knowledge of the concept of sustainability and the level of education.

Table 7. χ^2 Calculation to determine how education level affects sustainability knowledge.

Expected Data				
Educational Level	**Level of Knowledge about the Concept of Sustainability**			
	High	**Uncertain**	**None**	**Total**
High school student	136	11	20	167
University student	3	0	1	4
Postgrad	31	0	0	31
Total	170	11	21	202
Total sample	202			
Percentage distribution	84.16	5.45	10.40	100.00
Expected Data				
Educational level	**Level of knowledge about the concept of sustainability**			
	High	**Uncertain**	**None**	**Total**
High school student	140.54	9.09	17.36	167
University student	3.37	0.22	0.42	4
Postgrad	26.09	1.69	3.22	31
Total	170	11	21	202
Total sample	202			
χ^2 calculation	0.15	0.40	0.40	
	0.04	0.22	0.82	7.86
	0.92	1.69	3.22	
Freedom degrees	4.00			
Significance level	0.05 (5%)			
Valor χ^2 table	9.49			
Result	The calculated χ^2 value is less than the critical χ^2 value			

3.3. Perception of the Use of Recycled Materials in Road Infrastructure

The study first assessed respondents' preferences for conventional materials, including asphalt concrete, hydraulic concrete, and cobblestone. Participants were then informed about the concept of sustainability and the benefits of using alternatives such as tire-derived geocells for road reinforcement. This step was designed to assess whether knowledge of these benefits could change their perceptions and preferences.

The results, shown in Figure 7, show a significant shift toward sustainable building materials after participants were informed about the benefits of recycled materials and innovative technologies through a brief reading within the survey.

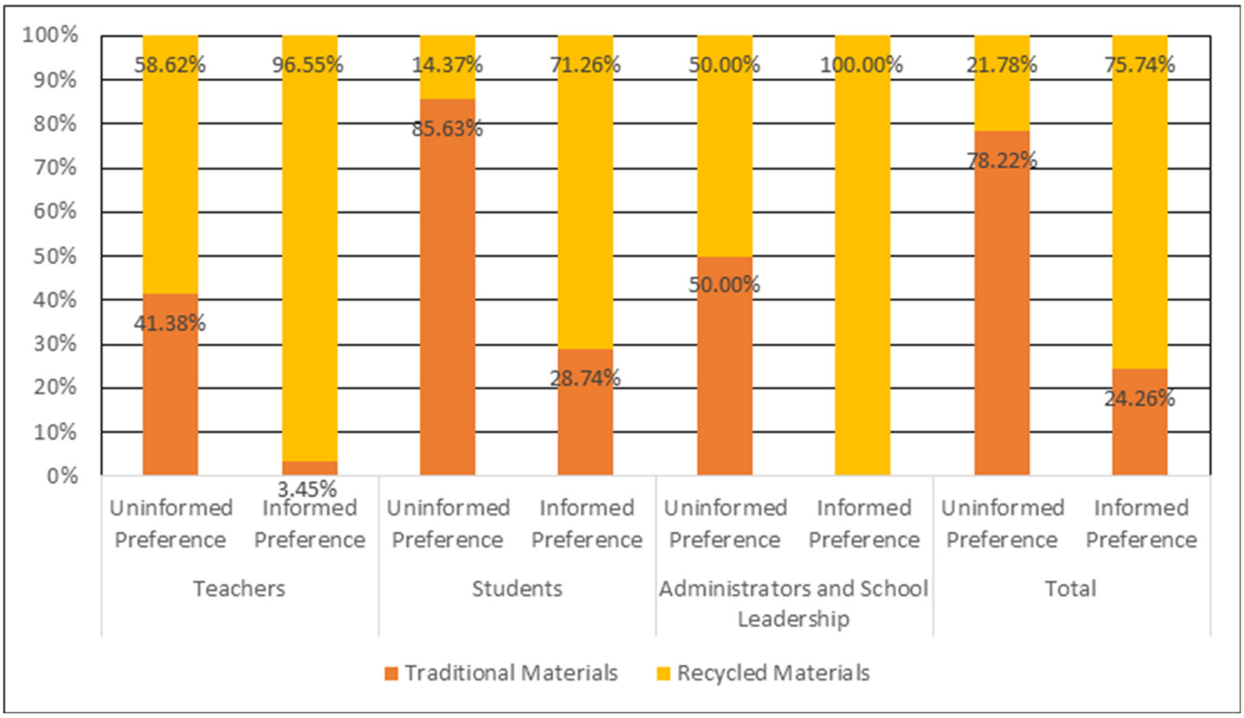

Figure 7. Distribution of choice between traditional or recycled materials.

After assessing participants' preferences, respondents were asked about their satisfaction with the intervention at the education center. Among teachers, 60% reported being "very satisfied", representing a strong majority. Similarly, 50% of administrative staff selected "very satisfied", with only marginal responses in the "satisfied" or "neutral" categories, indicating overall approval of the methodology. In contrast, students showed a broader distribution, with approximately 60% reporting "satisfied" and 30% selecting "very satisfied", reflecting a moderate but positive level of satisfaction". The greater dispersion in students' responses, as reflected by the larger standard deviation compared to the other groups, suggests that while the majority accept the methodology, their level of satisfaction is more moderate, possibly due to different levels of exposure or experience with the interventions.

3.4. Intervention Acceptance

In general, Figure 8 shows strong evidence of widespread acceptance of the methodology within the educational community, with an average satisfaction rate of 70% and a clear preference for recycled materials. The lowest variance observed in the Teacher and Administrative groups reinforces the idea of a positive consensus towards these strategies. These results suggest that as technologies based on recycled materials and circular economy practices become more widespread, the acceptance and use of these sustainable interventions could increase even further. The current level of satisfaction, with a high mean and a distribution concentrated in the positive categories, indicates a favorable environment for the implementation of new sustainable strategies in educational infrastructures. This highlights the importance of continued dissemination and education in these technologies to further increase acceptance and satisfaction across all segments of the educational community.

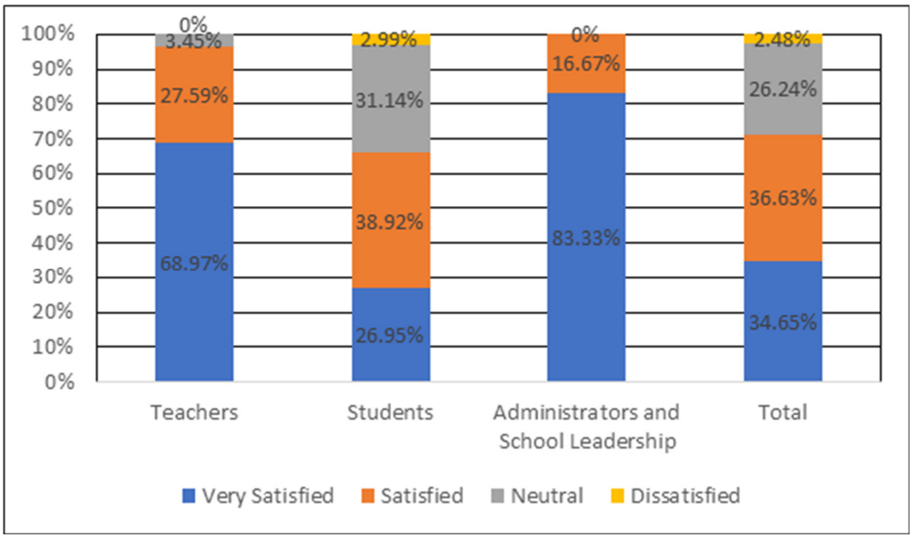

Figure 8. Distribution of satisfaction with intervention.

3.5. Impact Perceived

Figure 9 illustrates a notable positive change in participants' perceptions of recycling after the intervention. Overall, 66.3% reported improved perceptions, with 27.7% reporting "much improved" and 38.6% reporting "improved" perceptions". Teachers reported a high level of positive change, with 96.6% reporting an improvement in their perceptions, including 69.0% who said it was "improved greatly". Students, while more varied in their responses, also showed a significant change: 59.9% perceived an improvement, with 18.6% saying it was "improved greatly". Administrative staff reflected the greatest impact, with 100% of respondents indicating that their perceptions were "improved" or "improved greatly".

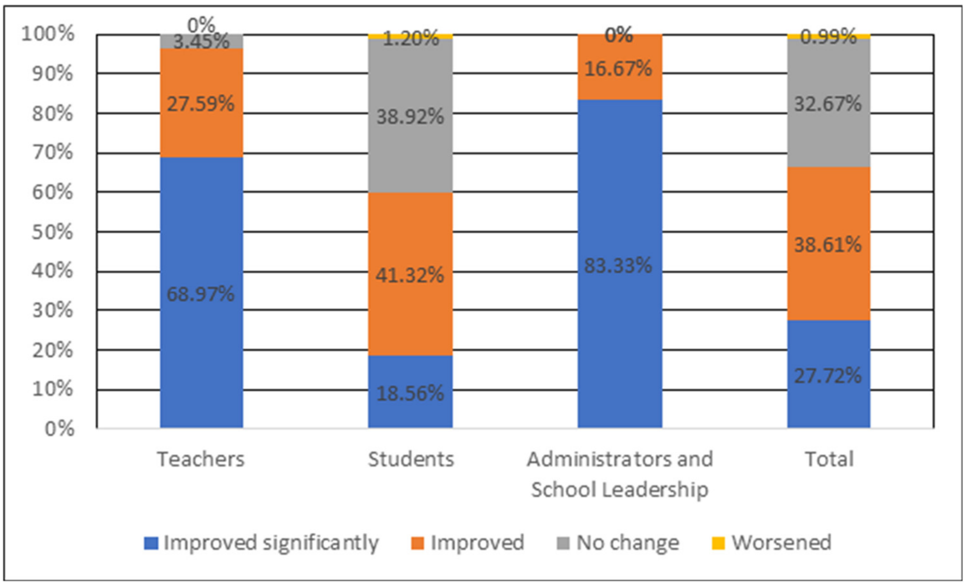

Figure 9. Evaluation of the impact of sustainable solutions on participants' perceptions by role.

These results highlight a significant educational impact, demonstrating that the intervention positively influenced perceptions of recycling among different groups. The significant proportion of positive responses highlights the effectiveness of disseminating sustainability practices and providing direct experience with recycled materials, such as scrap tires, in fostering acceptance and appreciation of these initiatives. The fact that only

1.4% (2 people) considered that their perception had "worsened" reinforces the effectiveness of the educational methodology used, emphasizing the importance of educational strategies in promoting sustainability.

Table 8 shows the analysis of the results, revealing significant differences in the consistency of perceptions among the different groups. The group of teachers shows more consistent opinions, with a mean of 2.655 and a variance of 0.305, presents more consistent opinions, indicating a clear trend towards a positive perception of the project. On the other hand, the group of students shows the greatest dispersion, with a mean of 1.898 and a variance of 0.694, indicating a greater diversity of opinions spread over different levels of satisfaction. Meanwhile, the administrative group, with a mean of 2.364 and a variance of 0.455, shows an intermediate consensus, mostly positive, although with some variability in responses. The overall variance of 0.710 indicates that there is significant dispersion in perceptions across all groups, influenced primarily by student responses. These results suggest that, although the general perception of the project is positive, it is necessary to design differentiated communication and follow-up strategies that address the concerns and diversity of opinions present in the different groups, especially among students, in order to achieve greater convergence of perceptions.

Table 8. Variance of perception change by group.

Group	Very Satisfied (3)	Satisfied (2)	Neutral (1)	Slightly Dissatisfied (0)	Mean	Variance
Teachers	20	8	1	0	2.655	0.305
Students	45	65	52	5	1.898	0.694
Administrators and School Leadership	5	5	1	0	2.364	0.455
Total	70	74	53	5	2.035	0.710

Analysis of the overall mean of 2.035 indicates that while the overall perception is positive, there are significant differences in the acceptance of sustainable materials among teachers, administrators, and students. While teachers are the most receptive group, students show more uncertainty and variability in their responses.

The results (Figure 10) show a high level of acceptance of sustainable alternatives for future infrastructure within the educational community, with 85.64% of all respondents recommending their use. Teachers led this support with 96.55%, reflecting their confidence in these technologies, possibly due to their understanding of the benefits of sustainability. Students also showed significant support (83.23%), although with a lower percentage, which could indicate doubts about their effectiveness or familiarity with the concepts. On the other hand, administrators and directors stand out with 100% positive responses, highlighting their positive perception and strategic vision towards these initiatives. These results confirm the potential of sustainable solutions in educational contexts.

The success of this project underscores the need for public policies that encourage the use of recycled materials in infrastructure, particularly in educational and rural contexts. Incentives such as tax benefits, grants, and subsidies can encourage the adoption of sustainable technologies such as recycled tire geocellulose. By prioritizing such initiatives, policymakers can reduce environmental impacts, foster community engagement, and build capacity for sustainability, creating long-term benefits for both local communities and broader societal goals.

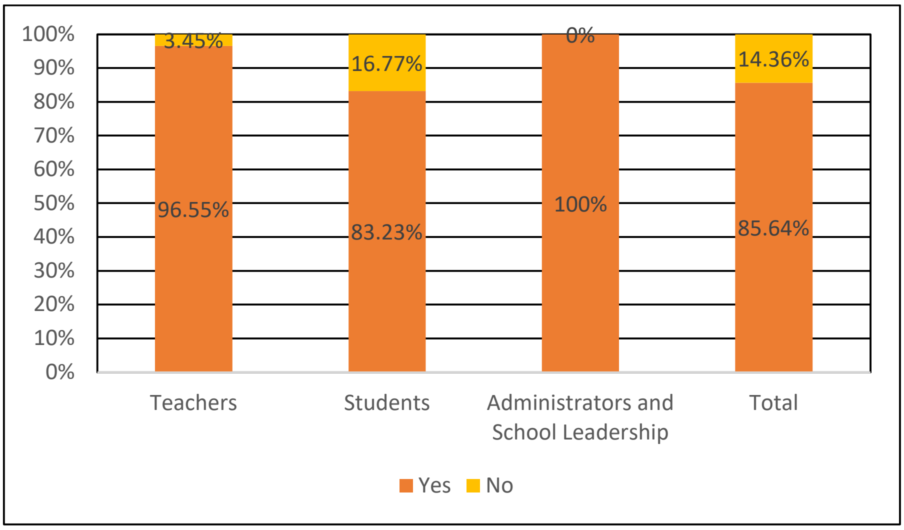

Figure 10. Willingness of educators to recommend and promote sustainable technologies.

The results of this study provide strong evidence of how information influences perceptions of sustainability in an educational setting, specifically the acceptance of recycled materials in infrastructure. The quantitative approach, supported by statistical analyses, allowed the identification of patterns of perception before and after the information intervention. However, there are limitations, such as the fact that the study was limited to a single institution, which may limit generalizability. In addition, the study did not explore emotional or cultural factors that may influence the adoption of sustainable practices. Future research could use a mixed-methods approach and assess the long-term maintenance of perceptual changes.

4. Conclusions

This study assessed the perceptions of the educational community regarding the use of recycled materials in road infrastructure, specifically scrap tire geosynthetics as a sustainable solution. The results indicate a significant shift in perception after participants were informed about the benefits of these materials, highlighting the role of education and awareness in promoting sustainability adoption. The results also suggest that sustainability knowledge is not solely determined by formal education, but is influenced by external factors such as work environment and personal experiences.

The research underscores the importance of integrating theoretical education with practical experience to enhance understanding and long-term adoption of sustainable technologies. While teachers and administrators showed high levels of acceptance, students showed more heterogeneous perceptions, highlighting the need for targeted awareness strategies within educational institutions. Encouraging hands-on learning and direct engagement with sustainable solutions can help bridge the perception gap and strengthen acceptance of circular economy practices.

Future research should focus on evaluating the long-term performance of recycled tire geocells under different conditions to validate their applicability in infrastructure projects. Educational institutions can contribute to this transition by incorporating sustainability principles into academic curricula and conducting awareness campaigns. In addition, collaboration with policymakers and private organizations will be essential to scale up these initiatives and promote the widespread use of recycled materials in public infrastructure, thereby fostering a more sustainable and environmentally responsible construction sector.

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Informed Consent Statement: In this study, the educational institution provided formal authorization for conducting the research. All surveys were conducted anonymously, and no sensitive data were collected. For this reason, only the institution's authorization was required, and individual informed consent was not necessary.

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