Comparison of AHP and FAHP Techniques in Assessing 21st-Century Skills in the Academic Context of Civil Engineering Students

Comparación de las técnicas AHP y FAHP en la evaluación de las habilidades del siglo XXI en el contexto académico de los estudiantes de ingeniería civil

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Abstract

This research paper explores the assessment of 21st-century skills in civil engineering students using the analytic hierarchy process (AHP) and fuzzy analytic hierarchy process (FAHP) as multi-criteria decision-making (MCDM) tools. The main criteria considered in the MCDM problem were critical thinking, problem solving,

creativity and innovation, communication, and collaboration. The results consistently highlighted the utmost importance of communication and collaboration, as they emerged as the primary criteria in both the AHP and FAHP methodologies. Conversely, creativity and innovation were ranked with the lowest importance in both methodologies. The selection between AHP and FAHP depends on the nature of the decision problem and the decision-makers' preferences. FAHP may be more suitable when the decision problem involves difficult-to-quantify or subjective preferences.

Keywords
AHP, FAHP, education, academy, civil engineering

Resumen

Este artículo de investigación explora la evaluación de las habilidades del siglo XXI en estudiantes de ingeniería civil mediante el Proceso Analítico Jerárquico (AHP, por sus siglas en inglés) y el Proceso Analítico Jerárquico Difuso (FAHP, por sus siglas en inglés) como herramientas de toma de decisiones multicriterio (MCDM, por sus siglas en inglés). Los principales criterios considerados en el problema MCDM fueron el pensamiento crítico, la resolución de problemas, la creatividad y la innovación, la comunicación y la colaboración. Los resultados destacaron de manera consistente la importancia primordial de la comunicación y la colaboración, que emergieron como los criterios principales tanto en la metodología AHP como en la FAHP. Por el contrario, la creatividad y la innovación ocuparon los niveles de menor importancia en ambas metodologías. La elección entre AHP y FAHP depende de la naturaleza del problema de decisión y de las preferencias de quienes toman las decisiones. El FAHP puede ser más adecuado cuando el problema de decisión involucra preferencias difíciles de cuantificar o de carácter subjetivo.

Palabras clave:
AHP, FAHP, educación, academia, ingeniería civil.

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Introduction

Student learning capabilities refer to the ability of a student to absorb, process, retain, recall, and apply knowledge and skills [1]. These capabilities can be influenced by factors such as prior knowledge, motivation, study habits, learning style, and environmental factors [2]. Assessing student learning capabilities can help educators tailor their teaching approach to better meet the needs of their students and improve their outcomes.

Critical thinking, problem solving, creativity and innovation, communication, and collaboration can be grouped together as a set of related competencies known as "21st century skills" [3], [4]. These skills are considered important in today's rapidly changing and highly interconnected world, as they help individuals navigate complex challenges and opportunities, and adapt to new situations [5]. Besides, 21st-century skills are essential for students to succeed in their future careers, as they enable them to adapt to change, think critically, collaborate, and communicate effectively. In the civil engineering context, construction companies now require professionals to have a range of skills that extend beyond traditional academic knowledge, such as working in teams, using technology effectively, and thinking creatively to deal with complex situations.

The role of professors in universities can no longer be limited to knowledge transfer; it must be well-targeted, discussed, and, of course, evaluated based on the progress of students, so that they know when more support is needed [6]. In the same way, it must be considered which skills should be reinforced the most during classes. In this research, a multi-criteria decision-making (MCDM) analysis was conducted to evaluate the importance of 21st-century skills from the perspective of civil engineering students. The application of MCDM helps decision-makers assess different criteria and select the best alternatives among various options, considering multiple criteria or factors that are important to the decision. MCDM has been widely applied in various contexts, including engineering, business, finance, healthcare, environmental management, and social sciences [7], [8]. In the education field, several studies have implemented MCDM techniques. For instance, Ozdemir et al. [9] proposed a measuring tool for sustainable campus universities in higher education using MDCM methods. In another study, Hou et al. [10] applied an integrated MCDM method to measure student residents' perception of the overall performance of residential buildings. Surdez Perez et al. [11] used the analytical hierarchy process (AHP) to assess student satisfaction with university services at a university. A set of questionnaires was completed by students, and the data were analyzed using the AHP method. The results showed that the most important criteria for student satisfaction were faculty members, academic facilities, and administrative services. The authors concluded that the AHP method can be a useful tool for universities to prioritize their efforts in improving student satisfaction with services.

AHP is a structured, systematic approach to decision-making developed by Thomas L. Saaty in the 1970s [12]. This technique can be catalogued as a powerful MCDM method since it allows decision-makers to consider both qualitative and quantitative factors in the decision-making process [13]. Besides, AHP decomposes complex problems into smaller, more manageable

sub-problems [14]. The method enables decision-makers to clearly identify and weigh the various factors that influence the decision, thereby facilitating the building of consensus among stakeholders. As the decision-making process may involve discrepancies, the fuzzy analytic hierarchy process (FAHP) was also performed to assess the importance of 21st-century skills among students. FAHP allows the use of fuzzy sets to represent the vagueness and ambiguity of the decision-making criteria [15]. The incorporation of fuzzy logic in the FAHP method can result in more accurate and realistic decision outcomes by capturing the subjective judgments of decision-makers [16]. As a supplementary component of this research, a comparative examination was conducted to analyze the outcomes attained through both methodologies.

Methods

AHP consists of a hierarchical structure of decision criteria and alternatives, with the goal of selecting the best alternative based on a set of decision criteria. It involves constructing a matrix of pairwise comparisons between each criterion and alternative, which is then used to calculate the relative weights of each criterion and the relative priority of each alternative. Details of the algorithm used can be seen in [11], [12], [15], [17], [18]. The method typically involves the steps outlined in Table 1. The definition of the problem involves evaluating the importance of different 21st-century skills from the perspective of civil engineering students.

Table 1. Steps of the AHP Method

Step	Name	Description
1	Define the problem	Clearly state the decision to be made and the criteria that will be used to evaluate the alternatives.
2	Construct a hierarchy	Develop a hierarchy of decision criteria and alternatives. The hierarchy should include the overall goal or objective, main criteria, sub-criteria, and alternatives.
3	Assign numerical values	Assign numerical values to each element in the hierarchy. These values are typically in the form of judgments or ratings, such as pairwise comparisons.
4	Calculate the weights of different criteria	Calculate the relative weights of each criterion and sub-criterion based on the judgments and ratings.
5	Determine priorities	Prioritize the alternatives based on the weights of the criteria.

The five main criteria considered in AHP were critical thinking (CT), problem solving (PS), creativity and innovation (CI), communication (COM), and collaboration (COL). CT is the ability to analyze and evaluate information and arguments in a logical and reflective manner to reach well-supported conclusions. PS involves identifying and resolving complex issues through the

application of critical thinking and decision-making skills. CI involves generating novel and useful ideas or solutions to problems. Creativity involves the production of original and valuable ideas or solutions, while innovation is the process of implementing those ideas to create new or improved products, services, or processes. COM is the exchange of information and ideas through speaking, writing, or other forms of expression. COL refers to the act of working together with others to achieve a common goal.

The study was conducted with a classroom group of 23 students enrolled in the Pavements Course. The study proposed a questionnaire survey to gather the information. Consequently, a set of questionnaires using pairwise comparison was administered to the students to weigh the different criteria based on their experience in project development during the academic course. The students who participated, all undergraduates in the Pavements Course, with an average age between 20 and 22 years old, were taking courses between the seventh and ninth semesters. The survey was administered during the third grading period, as it was considered an appropriate time for students to have completed various group projects over the course of the semester, thereby allowing them to effectively assimilate the 21st-century skills being taught. The paired comparison scale used in the research was proposed by Saaty, as shown in Table 2.

Table 2. Scale of Relative Importance in the Pairwise Comparisons

Importance value	Definition	Explanation
1	Equal importance	Both activities make an equal contribution to the objective.
3	Weak importance	One activity is slightly favored over another based on experience and judgment.
5	Strong importance	One activity is strongly favored over another based on experience and judgment.
7	Very strong importance	Practice strongly demonstrates a preference for one activity over another.
9	Extreme importance	The evidence strongly supports one activity over another, with the highest level of affirmation.
2, 4, 6, 8	Intermediate values	When a compromise is needed between two adjacent judgments.

The consistency ratio (CR), a key metric in AHP, was calculated to assess the consistency of the pairwise comparisons made by decision-makers (see Equation 1).

$$CR = \frac{CI}{RI} \tag{1}$$

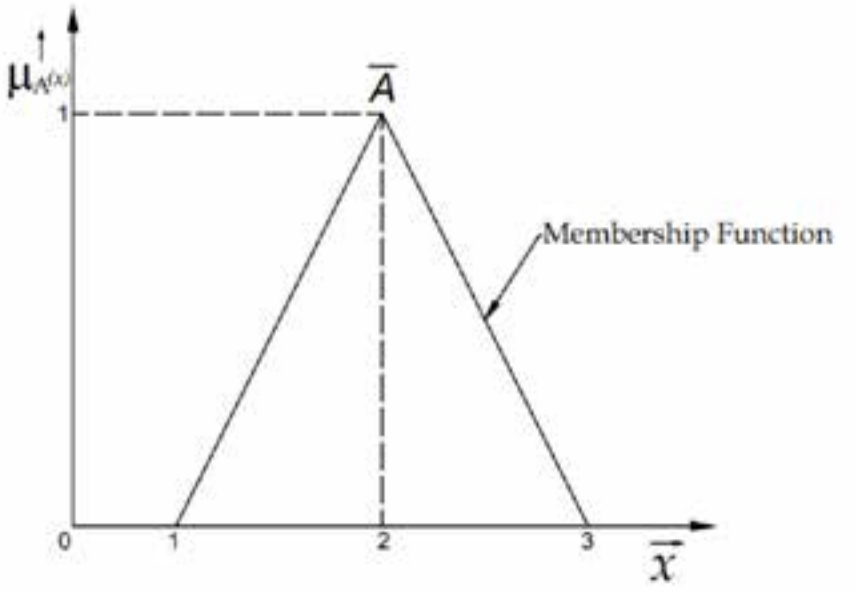
where CI is the consistency index and RI is the random index. The consistency index is calculated as shown in Equation 2:

$$CI = \frac{\lambda_{max}\text{-}n}{n\text{-}1} \tag{2}$$

Where λ_{max} is the maximum eigenvalue of the pairwise comparison matrix, and n is the number of criteria being compared. The random index is a value that depends on the size of the matrix and is used as a benchmark for comparison [12]. In this investigation, the consistency ratio was constrained to a maximum value of 0.5. A consistency ratio greater than 0.5 suggests that the pairwise comparisons are inconsistent and may require revision. This indicator can be used to ensure that the AHP process is reliable and produces accurate results.

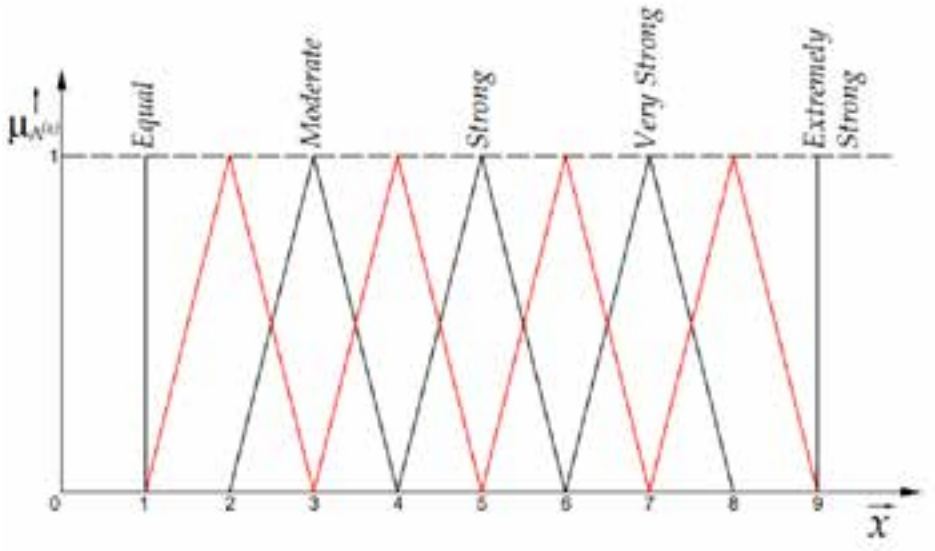
To deal with the vagueness and uncertainty in the decision-making process, the FAHP was also implemented as an MCDM analysis. Instead of the AHP method, which uses crisp numbers to represent preferences, the FAHP method uses fuzzy numbers to represent the judgments of decision-makers regarding the relative importance of criteria, allowing for a more nuanced and realistic representation of their preferences. Membership functions are used to represent fuzzy numbers, which are a way of expressing imprecise or uncertain values. A membership function is a mathematical function that assigns a degree of membership to a fuzzy set. Membership functions can take different forms, depending on the type of fuzzy number being used. For example, triangular, trapezoidal, and Gaussian membership functions are commonly used in FAHP [19]. In this study, a triangular membership function was employed, as illustrated in Figure 1.

Figure 1. Triangular Membership Function



A triangular membership function is defined by three main parameters: a lower limit, a peak value, and an upper limit. The membership function is shaped like a triangle, with the peak value corresponding to the maximum degree of membership. Decision-makers can use linguistic terms to describe the different parameters of the membership function, making it easier to communicate their preferences and judgments to others. Figure 2 illustrates the fuzzy triangular membership function for linguistic terms.

Figure 2. Fuzzy Triangular Membership Function for Linguistic Terms

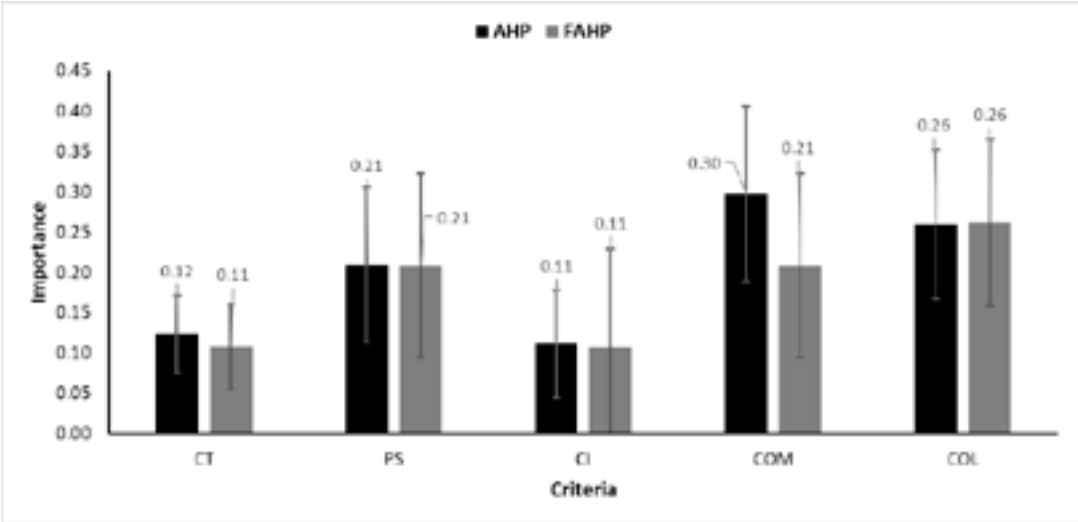


Other researchers suggest that FAHP offers a more sophisticated and nuanced decision-making approach than AHP, which can lead to more accurate, robust, and effective decision-making in a variety of contexts [20]. In this study, the results obtained from both techniques are also compared as another contribution of this research.

Discussion

Figure 3 depicts the outcomes derived from the AHP and FAHP techniques. The results show that COM and COL were the most significant criteria in both methodologies. COM obtained a higher weight than COL in AHP, whereas in FAHP, COL attained the highest score, followed by COM. PS was ranked as the third most important criterion, while CT and CI were ranked the least important, with very similar scores.

Figure 3. Results Obtained from AHP and FAHP



The study results were discussed with the students to gather their insights into the possible causes of the findings. According to their opinions, it is possible that they prioritized COM and COL because they recognized the importance of these skills in their future careers as civil engineers. Team-based projects in the subject of study may have also emphasized the significance of these skills. Additionally, COM and COL skills are essential in many professional settings, leading students to assign higher weights to these criteria based on their perception of their future career needs. It is worth mentioning that the classroom environment and teaching methods may have influenced students' perceptions of the importance of COM and COL. If the teacher placed a strong emphasis on group work and encouraged open communication and collaboration among students, this may have influenced their weighting of these criteria.

With respect to PS criteria, students viewed it as a more tangible skill that can be applied in specific situations. In addition, the classroom activities and projects may have emphasized PS skills more than the other skills, which may have led students to prioritize them higher. During the discussion with students, it was also challenging to identify the specific reasons why CT and CI had similar scores and were ranked in the last positions. However, students ranked CI in the last position, and possible reasons could be that civil engineering is a highly technical field that involves the application of scientific and mathematical principles to solve real-world problems. Students in this field may believe that CI could not be as important as technical skills and knowledge. Similarly, students may have misconceptions about what CI means. They may believe that creativity is only about artistic expression or that innovation is only about creating new technologies. As a result, they may not fully appreciate the importance of these skills in their field. Finally, students may perceive that technical skills and knowledge are more valued by employers than CI. They may believe that having strong technical skills will make them more employable than having strong creative and innovative skills. Finally, students suggest that the projects may not emphasize CI as much as other skills, and they may not have been exposed to activities that encourage them to think creatively or innovatively.

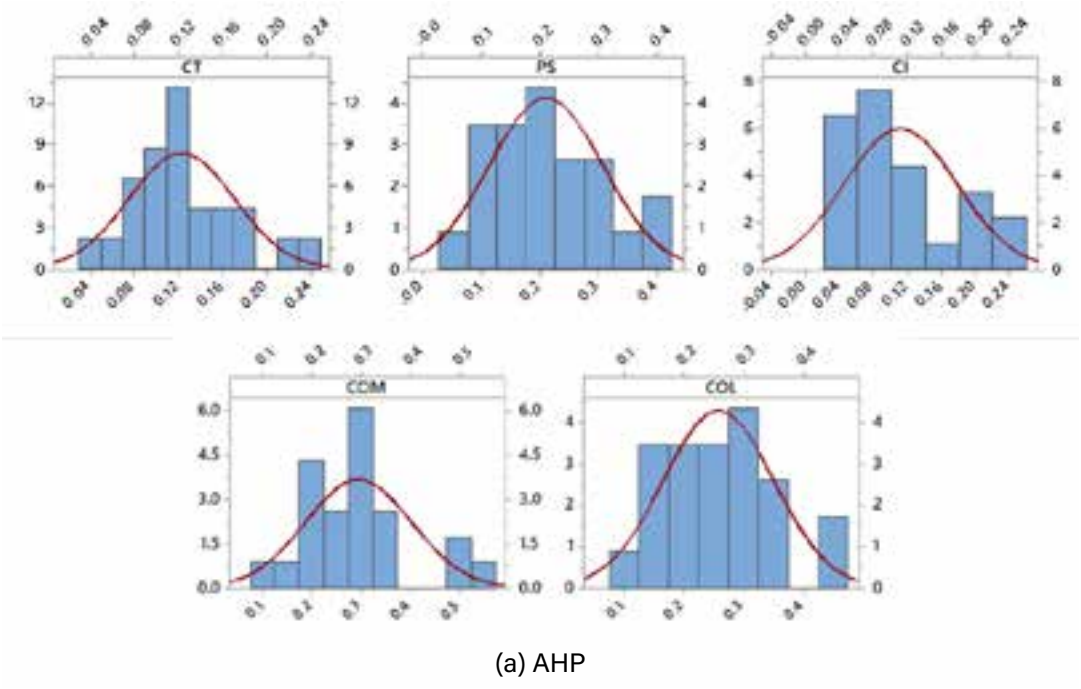
A series of histograms was also generated to visualize the weights obtained from the AHP and FAHP analysis, respectively (see Figure 4). To determine whether the data are normally distributed, an Anderson-Darling normality test was conducted (see Table 3). The *p*-value obtained from the test indicates whether the data follow a normal distribution. Typically, a *p*-value greater than 0.05 indicates that the data are normally distributed, while a *p*-value less than 0.05 suggests non-normality. Based on the results obtained, it was found that CI and COM exhibited p-values less than 0.05, indicating a non-normal distribution of the data. Therefore, non-parametric Mann-Whitney tests were employed to determine statistical differences for these criteria. In contrast, for the remaining criteria, parametric two-sample t-tests were utilized to observe any potential statistical differences.

Table 3. Statistical Analysis of Both Methods

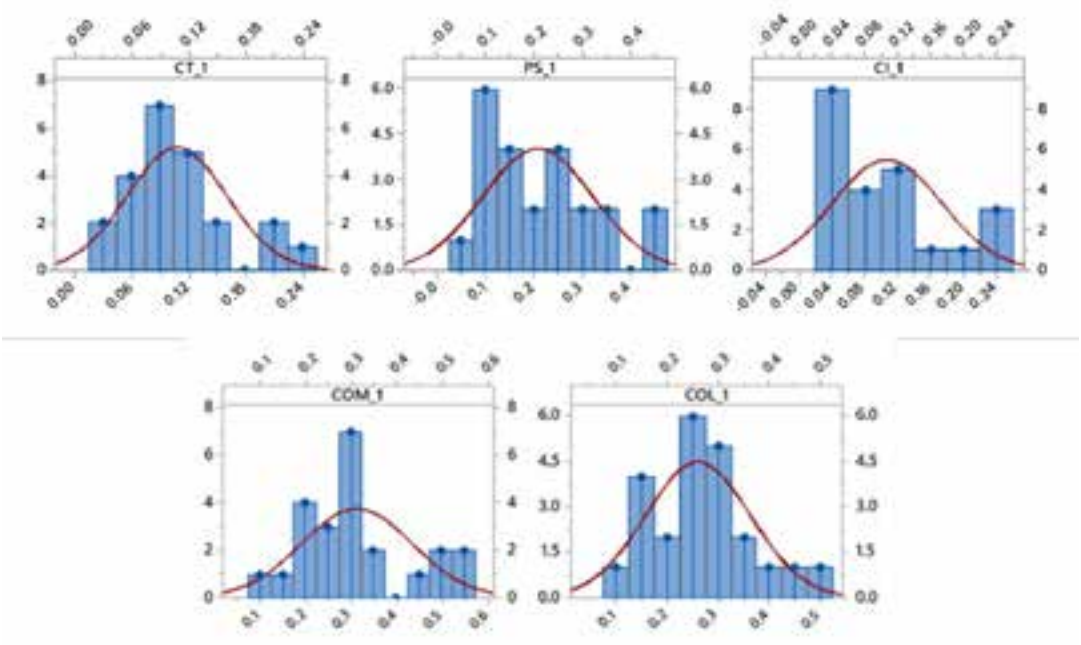
Criteria	AHP			FAHP			T-test	Mann-Whitney
	P-value	Mean	SD	P-value	Mean	SD		
CT	0.354	0.12	0.05	0.072	0.11	0.05	0.303	-
PS	0.554	0.21	0.10	0.118	0.21	0.11	0.973	-
CI	0.042	0.11	0.07	0.021	0.11	0.12	-	0.809

Criteria	AHP			FAHP			T-test	Mann-Whitney
	P-value	Mean	SD	P-value	Mean	SD		
COM	0.029	0.30	0.11	0.046	0.21	0.11	-	0.6445
COL	0.611	0.26	0.09	0.398	0.26	0.10	0.930	-

Figure 4. Histograms Obtained from (a) AHP and (b) FAHP Techniques.



(a) AHP



(b) FAHP

Based on the 2-sample t-test and Mann-Whitney test, no statistical differences were found in this study between the AHP and FAHP methods. Since AHP and FAHP have similar results, it can be concluded that the weighting of criteria is consistent regardless of the method used. This suggests that the criteria are perceived similarly by the participants and that the decision-making process is stable [21]. It also provides evidence of the validity and reliability of the methods, as they produce similar results.

To evaluate the relationships between the different criteria obtained from AHP and FAHP, the coefficient of determination R^2, as well as Pearson's and Spearman's correlation coefficients, were calculated (Figure 5 and Table 4).

The coefficient of determination R^2 measures the proportion of the variance in one variable that can be explained by another variable. Pearson's correlation coefficient is used to assess the strength and direction of the linear relationship between two normally distributed variables, while Spearman's correlation coefficient measures the monotonic relationship between two variables, which can be non-linear and non-normally distributed. By examining these correlation coefficients, the authors were able to determine the extent to which the different criteria are related to each other and identify any potential patterns or trends.

Figure 5. R-squared (R^2) Value Obtained between AHP and FAHP: (a) CT; (b) PS; (c) CI; (d) COM; (e) COL

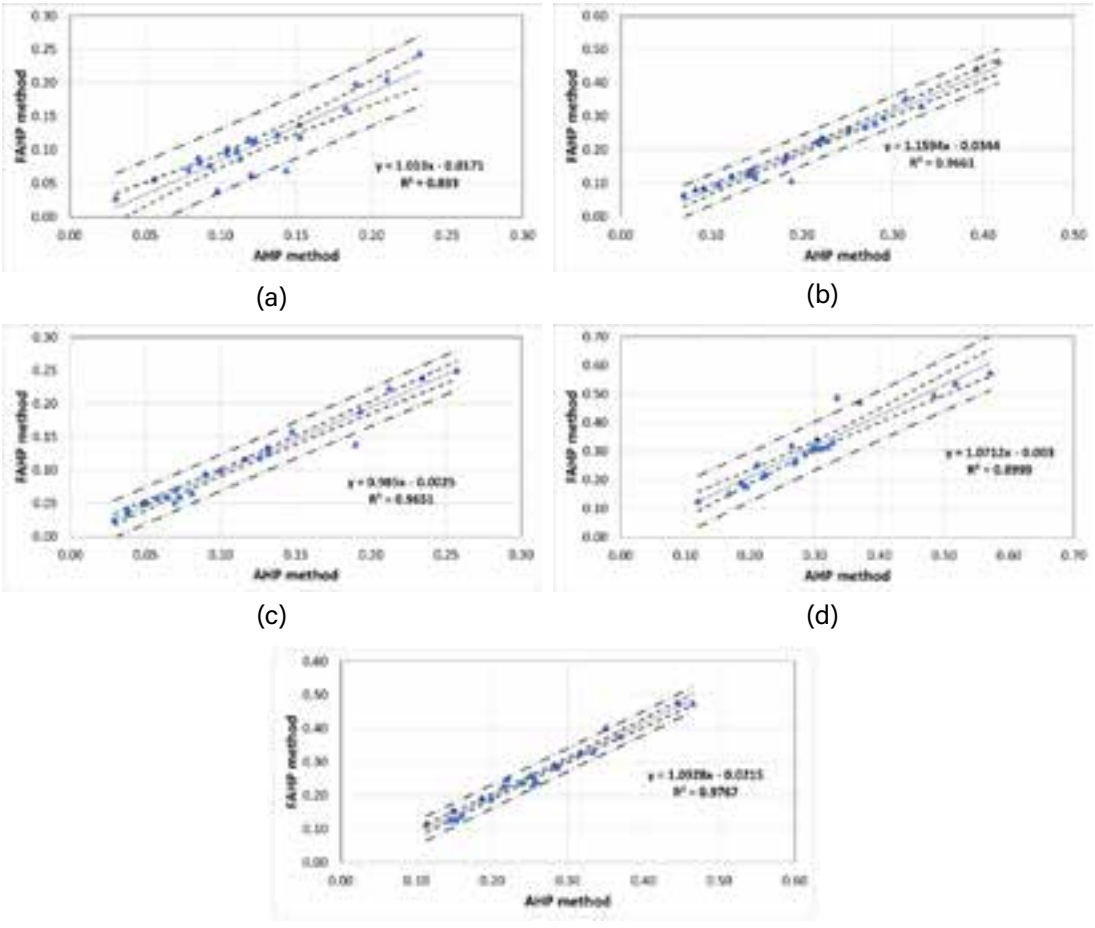


Table 4. Regression and Correlation Values Derived from the Criteria

Criteria	*CT*	*PS*	*CI*	*COM*	*COL*
R^2	0.83	0.97	0.97	0.90	0.98
Pearson's	0.91	0.98	-	-	0.99
Spearman's	-	-	0.985	0.942	-

Based on the study's findings, the determination coefficients for all criteria were above 90 %, except for CT, which had a determination coefficient of 80 %. The obtained p-values for all criteria were less than 0.05, indicating strong evidence against the null hypothesis and supporting the statistical significance of the regression model. The linear model adequately represents the relationship between FAHP and AHP for each criterion, explaining the proportion of variance between the two methods quite well.

Furthermore, the correlation coefficients for all criteria were above 90 %, with PS, CI, and COL exhibiting the highest correlation coefficients. This suggests a strong positive association between FAHP and AHP rankings for these criteria. Overall, the results obtained for all criteria were reliable and consistent, indicating a high level of agreement between the two methodologies.

Conclusions

In this research, 21st-century skills were assessed in the academic context of civil engineering students using a multi-criteria decision-making analysis. A total of 23 students participated in the criteria elicitation process, and the AHP method was used for weighting criteria. Since there may be vagueness and uncertainty in the decision-making process, fuzzy sets were also incorporated. A comparison between AHP and FAHP results was analyzed through descriptive and inferential statistics.

The results demonstrated that communication and collaboration were consistently identified as the most significant criteria in both methodologies, highlighting their crucial role in the evaluation process. The study's findings emphasize the need to reinforce communication and collaboration skills in the classroom, aligning educational practices with the expectations and demands of the professional world.

Creativity and innovation were ranked the lowest in the scale of relative importance of both methodologies. The study findings suggest that students in the civil engineering field may perceive technical skills and knowledge as more crucial to their future careers, potentially undervaluing the importance of creativity and innovation.

Overall, the choice between AHP and FAHP depends on the nature of the decision problem and the preferences of the decision-makers. If the decision problem involves preferences that are difficult to quantify or are subjective, FAHP may be a better choice. If the decision problem involves preferences that can be easily quantified, the AHP method may be a more straightforward and reliable approach.

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