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Embracing Artificial Intelligence (AI) in Architectural Education: A Step towards Sustainable Practice?

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Abstract: This study explores the impact of artificial intelligence (AI) on the behavior and knowledge of final-year architectural students in Serbia and Montenegro. It aims to describe how students approach sustainability in architecture and their use of AI tools within this context. The primary objective is to analyze how AI affects students' understanding of sustainable architecture indicators and how sustainability challenges and concerns influence AI applications. Using a comparative analysis approach across the two countries, this research employs surveys to test various hypotheses regarding the effects of AI on students' perceptions of sustainability and their use of AI to achieve sustainable outcomes. The findings highlight a significant relationship between students' knowledge of sustainability and their use of AI, revealing different influencing factors. These insights are essential for predicting future AI usage in architectural practice and provide a theoretical foundation for assumptions about sustainability in architecture. This study's findings offer valuable guidance for refining curricula at the universities involved, aiming to enhance the integration of AI and sustainability in architectural education.

Keywords: artificial intelligence AI; sustainability; architectural studies

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1. Introduction

The rising significance of artificial intelligence has prompted the EU to adopt Regulation (EU) 2024/1689 [1] of the European Parliament and of the Council of 13 June 2024 that more precisely oversees the use of AI. This regulation aims to foster the adoption of human-centric and trustworthy AI and ensures a high level of protection for health, safety, and fundamental rights, including democracy, the rule of law, and environmental protection [1].

Integrating architecture, sustainable development, and artificial intelligence, energy-efficient and environmentally friendly buildings are being created that are tailored to the needs of a sustainable environment. Considering this, the education of future professionals in the field of architecture is gaining greater significance.

Architectural students use artificial intelligence (AI) in designing and urban planning in various innovative ways, leveraging its capabilities to enhance creativity, efficiency, and sustainability. Students use AI-powered tools for designing to explore numerous design alternatives, modeling, zoning, energy analysis, and material optimization. Tools like Tally or Sefaira use AI to evaluate the life cycle of building materials, energy consumption, and carbon footprint [2]. Software like UrbanSim allows them to assess changes in transportation systems and zoning, and also helps in promoting urban sustainability [3]. Tools like AutoCad with AI plug-ins can generate detailed plans efficiently. ChatGpt or SketchUp helps them in suggestions, offering design tips or concepts [4]. Miro and Figma tools integrate AI and help students to work effectively together in complex designing projects [5]. AI integration in Virtual Reality (VR) and Augmented Reality (AR) allows students to immerse themselves in virtual models of their projects. Tools like Enscape and Unreal Engine use AI to enhance realism in a virtual environment [6]. Platforms like Iris.ai help students find and summarize research articles, finding inspiration and new insights for their designs [7].

Digital Twins in architecture are virtual models of physical buildings created from data collected through sensors and Building Information Modeling (BIM). They offer real-time insights into building performance, allowing for simulations and the analysis of factors like energy use, structural health, and occupancy [8,9]. This technology helps architects and engineers make informed decisions, improve building operations, and anticipate maintenance needs, leading to better design, management, and sustainability [10]. The future development of a digital methodology that integrates Digital Twins, BIM, IoT, and AI with lean construction practices is crucial for optimizing the building process, reducing delays and resource waste, creating net-zero buildings and achieving substantial economic and time savings [11,12].

Despite significant advancements in the global design sector's application of AI, there remains a notable gap in understanding how architectural students in Serbia and Montenegro perceive AI and its implications for enhancing sustainability. This gap is crucial because students' and future engineers' attitudes play a significant role in the successful and sustainable integration of AI technology [13].

When exploring the intersection of sustainability and artificial intelligence in architecture, several research paradigms can be considered. Critical realism examines how AI influences sustainable practices within complex social, technological, and ecological systems [14]. Pragmatism focuses on the practical applications of AI in achieving sustainability, assessing the effectiveness of these methods [15]. Systems thinking views sustainability as an interconnected system, where AI optimizes elements like energy efficiency and resource management [16]. Sociotechnical systems theory explores the interaction between technological advancements and social contexts [17], while the eco-centric paradigm considers how AI can align technological innovation with environmental ethics to protect and restore ecological systems [18].

Considering that the use of AI tools is in its early stages and its expansion is yet to come, the question arises of whether students of all profiles are using them properly. Undoubtedly, most students use AI tools; however, sustainability, which is an essential component of all contemporary projects, is addressed only in certain fields of study.

Recognizing this, our study aims to fill this gap by providing an in-depth analysis of the attitudes of architecture students in both countries towards the adoption of AI, with a particular focus on its potential sustainability implications in the architectural sector.

To address these identified issues, our study aims to explore the following key questions:

RQ1: What are the understandings of architectural students regarding the main sustainability indicators that are essential in contemporary architectural practice?

RQ2: What are the perceptions of architectural students in Serbia and Montenegro concerning the acceptance and use of AI in architectural practice?

RQ3: To what extent can the adoption of AI in architecture contribute to the achievement of sustainability goals?

The research questions and questionnaire indicators were taken and modified from a systematic review on the use of AI in architecture concerning energy efficiency measures used and studied by students on courses at architectural faculties in Serbia and Montenegro [19].

Furthermore, the extent to which the adoption of AI in architectural students' practice and work contributes to sustainability goals is explored. The motivation for this research is the aim to uncover the under-researched dimensions that influence the adoption of AI in future architectural practice, offering insights that extend beyond the current literature.

Theoretically, this study explores the largely uncharted territory of AI adoption in Serbian and Montenegro architectural studies. Practically, it provides valuable guidance for scholars in developing effective AI architectural strategies in the future introduction of new courses in architectural studies. Our study stands out for its focus on architectural students, its attitudes towards AI, and its exploration of AI's benefits of sustainability. Using empirical research, including detailed statistical analyses, the reliability and validity of the findings are ensured, creating a basic foundation for future research on AI adoption in architectural studies in the context of sustainability.

The subsequent sections unfold as follows: Section 2 introduces the theoretical background of the research. Section 3 delineates the materials and methods, where the research questions, questionnaire design, and hypothesis are explained in detail. Section 4 clarifies the results of the survey. Section 5 gives an overview of the results, and finally, Section 6 concludes the research and gives recommendations for future work.

2. Theoretical Background

The development of sustainability impacts both broader fields and specific areas such as architecture. Analyzing the evolution of sustainable architecture shows that many of the issues architects confront today have been present for a long time, albeit with changing focuses. The author Donovan (2020) [20] provides a brief overview of how terms evolve in response to societal challenges and their relationship with nature [9]. However, there are numerous definitions outlining how architects design while considering the natural environment and limited resources, each with its own subtle nuances. For the purposes of this paper, the generic term "sustainable architecture" will be used.

There is some literature that indicates that designing sustainable architecture can reduce urban vulnerability and lower CO_2 emissions, thereby helping to mitigate climate change and improve both the environmental and financial sustainability of buildings [21–23]. There is also a connection between sustainable water management and urban architectural design that is crucial for ensuring water availability, preventing disasters, promoting health and hygiene, preserving ecosystems, enhancing resilience to climate change, and fostering social equity [24]. Besides this, sustainable architecture enhances health and well-being. This is because human physical, psychosocial, and spiritual well-being are positively affected by built spaces which serve as healthy or therapeutic or medicinal environments to users [25].

Recently, the literature increasingly highlights the importance of circular economy and architecture [26,27].

The application of generative AI technologies in architectural design enhances the design process by improving efficiency and fostering innovation. Additionally, they optimize design processes and enhance decision-making in architecture [28,29]. Artificial intelligence (AI) is transforming the architectural and urban environment by making the design process faster, more efficient, and more sustainable [30]. It facilitates collaboration between architects, data scientists, urban planners, and engineers [31]. AI revolutionizes design by integrating Building Information Modeling (BIM) techniques, allowing for real-time analysis and optimization [32]. There are several applications of AI in urban planning, as predictive analytics for infrastructure need support from data from various sources such as traffic patterns, utility usage, or population growth [33]. Simulation and modeling help urban planners with the prediction of building development and city reaction, using UrbanSim tools to gain insight into the potential impacts of urban development decisions [34,35]. Enhanced with AI, Geographic Information System (GIS) technology can analyze spatial data and optimize land use to aid in the planning and management of urban spaces and predicting environmental impacts [36]. AI integrates with Internet of Things (IoT) as sensors and cameras to manage operations in smart cities [37].

AI is profoundly transforming architecture and interior design, offering innovative approaches that enhance both the design process and building functionalities [38,39]. The integration of AI in architecture spans several dimensions, each contributing significantly to the field's evolution [40].

Firstly, AI optimizes the design process [41]. Advanced algorithms and machine learning models enable architects to generate and evaluate numerous design iterations swiftly [42]. This rapid prototyping allows for the exploration of complex forms and structures that were previously unattainable or too time-consuming to develop manually [43]. AI-driven generative design tools, like Autodesk's Fusion 360, allow architects to define parameters like material size and weight and at the same time analyze vast datasets to suggest optimal design solutions, considering factors like esthetics, structural integrity, and environmental impact [44]. This iterative feedback loop enhances creativity while ensuring precision and efficiency.

Moreover, AI enhances building functionality and sustainability through predictive analytics and smart systems [45]. By leveraging data from sensors and IoT devices, AI can monitor and manage building operations in real-time, optimizing energy consumption, climate control, and maintenance schedules [46]. Predictive models anticipate potential issues before they arise, facilitating proactive maintenance and reducing operational costs [47]. This integration fosters intelligent buildings that adapt to occupants' needs and changing environmental conditions, promoting comfort and sustainability [48].

In urban planning, AI aids in analyzing and synthesizing complex urban data, enabling more informed decision-making [49]. AI algorithms simulate various urban development scenarios, assessing their impact on traffic patterns, energy usage, and socio-economic factors [50]. This holistic approach allows urban planners to design cities that are not only more efficient but also more resilient to future challenges [51].

Furthermore, AI contributes to construction by automating tasks and improving construction management [52]. Robotics and AI-powered machinery in the Architecture, Engineering, and Construction (AEC) industry perform repetitive or hazardous tasks, enhancing safety and efficiency on construction sites [53]. AI-driven project management tools streamline workflows, optimize resource allocation, and ensure timely project completion, reducing costs, risks, and minimizing delays [54].

The real benefit of the efficient usage of AI does not lie in merely reducing the intensities of energy, water, and land usage that society may engage in, but rather in facilitating and promoting environmental governance at a higher level [55]. Sustainable AI seeks to create AI systems that align with environmental resources, economic frameworks, and societal values, while maintaining a balance between innovation and fairness [56].

Rapid changes in the environment also pose challenges to traditional educational concepts. Several studies emphasize the role of energy literacy and the integration of energy-efficient practices within schools, highlighting the active participation of students in managing energy efficiency. Architectural education, a key element of sustainable development in higher education, faces the challenge of students' professional knowledge and many skills becoming obsolete after graduation due to rapid advances in AI. Architectural education needs to rethink its approach to develop students' skills to flexibly use AI for problem analysis, information gathering, and creative design, equipping them for future challenges in the field of architecture [57].

In academic discourse, integrating AI in architecture signifies a paradigm shift, challenging traditional practices and proposing new methodologies for the built environment. The synergy between AI and architecture promotes a more adaptive, data-driven approach, leading to buildings and urban spaces that better respond to users' needs and environmental conditions [58].

In conclusion, AI is revolutionizing architecture by enhancing the design process, improving building functionality, and optimizing urban planning and construction. This integration represents a significant advancement, driving innovation and efficiency while addressing contemporary challenges in sustainability and urbanization. Students' use of AI can lead to the opposite of sustainability.

The existing literature on AI within the context of sustainable architecture mostly examines various aspects of sustainability. Additionally, many researchers analyze the benefits of using AI in architecture, particularly concerning sustainability. However, there is a relative lack of empirical research on the practical application of AI in architecture toward sustainability, especially in terms of facilitating AI in architecture and further exploring its benefits and challenges. This study also incorporates an additional component, education, highlighting the importance of AI adoption for students in the two observed countries. Additionally, comparing these countries adds value to this research. This research presents a comprehensive approach to addressing AI in architectural education across different educational systems, but systems with many similarities.

3. Materials and Methods

3.1. Research Questions and Hypothesis

Building on the literature review and empirical research, this paper addresses the following research objectives: explore understandings of architectural students regarding the main sustainability indicators that are essential in contemporary architectural practice; analyze the perceptions of architectural students in Serbia and Montenegro concerning the acceptance and use of AI in architectural practice. And finally, investigate to what extent the adoption of AI in architecture can contribute to the achievement of sustainability goals.

In order to elaborate further upon the presented topics, the following hypotheses were formulated:

H1: *The use of AI has a positive influence on the values of sustainability indicators in architecture.*

H2: *The perceived benefits of using AI in architecture influence the acceptance of AI tools by architecture students.*

H3: *The perceived concerns and challenges of using AI influence the acceptance of AI tools among architecture students.*

H4: *There are no significant differences between Serbian and Montenegrin architecture students in terms of the evaluation of sustainability indicators, the use of AI, and the perceived benefits and challenges of AI use.*

3.2. Research and Questionnaire Design

The methodology had several components that, besides conceptualization, include creation of a questionnaire, data collection, and statistical analysis. In order to obtain answers to the hypotheses put forward, a questionnaire was drawn up for architecture students. The questionnaire was designed for architectural students in Serbia and Montenegro and was logically divided into three sections. The students were enrolled in the final years of undergraduate and master's degree programs in general studies of architecture and urban planning at both state universities, with similar curricula. The study included an equal number of participants from both observed countries, ensuring balanced representation in our dataset.

In addition to general information about the students, including geographical location, gender, etc. [59,60], the first section asked about the students' knowledge of sustainability indicators in architecture, such as reducing carbon emissions, improving water quality, occupant health and well-being, applying life cycle thinking for responsible design, and using smart technologies to achieve sustainability [61].

The second part of the questionnaire was dedicated to AI and its use in architecture. The use of AI in architectural education has evolved significantly over time. Initially, AI served mainly as a support tool, improving efficiency through tasks like extensive data analysis and accurate simulation assessments. As technology has advanced, AI's role in architectural design has become more proactive. AI not only helps address complex design challenges but also provides tailored learning experiences based on individual student needs, thereby improving the specificity and effectiveness of architectural education [57]. Students learn about AI applications and tasks that can be performed in project design, urban planning, or interior design. The questions were created and modified based on the research in ref. [62] on energy efficiency measures used in students' existing portfolios.

In the third part, the following benefits of using AI in architecture were asked about: increased efficiency, innovative design solutions, and improved sustainability. Challenges and concerns such as ethical or legal issues and the displacement of jobs were also asked about in the questionnaire.

All these constructs were created based on the understanding of sustainability indicators and suggested factors impacting the use of AI in courses for architecture students in Serbia and Montenegro. It is important to note that AI usage behavior reflects students' actual patterns of AI usage, with a focus on sustainability. On the other hand, intention describes students' willingness to use and knowledge of AI in the future with the aim of achieving sustainability as a must in contemporary architecture.

Students rated five statements about sustainability indicators in architecture, six statements about the use of AI in architecture, three statements about the perceived benefits of using AI in architecture, and four statements about the perceived challenges of using AI in architecture. The statements were rated on a five-point Likert scale (1—not at all; 5—extremely). The collected data were processed and analyzed using SPSS software, version 23. The statistical analysis included descriptive statistics, reliability analysis, correlation analysis, and non-parametric tests to compare the differences between the groups.

4. Results

The students rated the level of importance of selected factors for sustainability in architecture (1—not at all important; 5—extremely important). These sources provide a comprehensive overview of the different elements of sustainability in architecture.

Table 1 shows the percentage structure of the students' evaluations together with the mean value and the standard deviation of the answers. The elements in Table 1 represent a framework for a comprehensive analysis of how the students assessed these elements within the context of sustainable architecture [63–66]

Table 1. The percentage structure of respondents' ratings.

Sustainability in Architecture	M	SD	1	2	3	4	5
Reducing/excluding carbon emissions in buildings	3.82	1.16	5%	9%	20%	31%	35%
Enhance water efficiency by techniques (cutting back on use, upping recycling, using alternate water sources)	3.96	1.12	5%	6%	16%	34%	39%
Enhance health and well-being through effective building design, construction, use, accessibility, operations, maintenance, etc.	4.19	1.10	5%	3%	13%	26%	53%
Use life cycle thinking to reduce, reuse, recover, and recycle for responsible design, production, purchasing, and consuming	4.07	1.07	4%	5%	14%	34%	43%
Using smart buildings and other technology for sustainability, health, and resilience goals	4.08	1.12	4%	6%	16%	26%	48%
Cronbach's Alpha				0.91			

Source: author's research.

From the data in Table 1, it can be concluded that the vast majority of the students rated sustainability factors as very important (4) or extremely important (5). In particular, reducing carbon emissions (for 66% of the respondents), improving water efficiency (for 73% of the respondents), improving health and well-being (for 79% of the respondents), using life cycle thinking (for 77% of the respondents) and using smart buildings (for 74% of the respondents) are considered very or extremely important. Such responses from the participants are not surprising given that they are in line with theoretical and empirical findings from the literature [21–23].

In Table 2, the students rated the extent to which they use AI in their work for selected purposes (1—not at all; 5—extremely). The percentage structure of the students' ratings together with the mean and standard deviation of the responses are shown in the table. The elements in Table 2 provide a comprehensive overview of how AI is being integrated into architectural practices in order to enhance sustainability, efficiency, and innovation [67].

Table 2. The percentage structure of respondents' ratings.

Facilitating AI in Architecture	M	SD	1	2	3	4	5
Performance-based (energy-saving, benefit from daylight, passive design solutions)	2.73	1.38	28%	16%	23%	21%	12%
Form finding (building envelope design, parametric designs, modular architecture)	2.91	1.36	22%	15%	28%	20%	15%
Spatial planning (site plan suggestions, plan solution suggestions, mass settlements proposals on an urban scale)	2.88	1.36	23%	14%	30%	18%	15%
Multi-objective (applications of active and passive systems, mass and façade recommendation for maximum benefits)	2.91	1.44	27%	9%	28%	18%	18%
Restoration (completing the missing part of structures, transferring important structures to digital platforms)	2.82	1.45	26%	18%	22%	16%	18%
Design tool development (designing, urban planning, interior) that solve various design problems	3.02	1.44	21%	18%	19%	22%	20%
Cronbach's Alpha				0.96			

Source: author's research.

It can be concluded from this that less than half of the students surveyed use AI in their work. Specifically, 33% use AI (very or extremely) to enhance their performance, 35% for form finding, 33% for spatial planning, 36% for multi-objective applications, 34% for restoration, and 42% for developing design tools. The results of this study reveal that the architecture students in both countries under examination demonstrate a lower-than-average utilization of artificial intelligence (AI) in their academic and design work. This observation suggests that there may be a significant gap between the potential applications of AI in architectural practice and its actual adoption within the educational context.

In Table 3, the students ranked the perceived benefits of AI use in architecture (1—not at all; 5—extremely). The percentage structure of the students' ratings together with the mean and standard deviation of the responses are shown in the table.

Table 3. The percentage structure of respondents' ratings.

Benefits of Using AI in Architecture	M	SD	1	2	3	4	5
Increased efficiency	3.52	1.11	6%	10%	31%	32%	21%
Innovative design solutions (designing, urban planning, and interior)	3.45	1.24	9%	14%	23%	31%	23%
Improved sustainability	3.17	1.24	10%	21%	29%	22%	18%
Cronbach's Alpha				0.80			

Source: author's research.

As can be noticed, the perceived benefits of using AI in architecture are increased efficiency for 53% of the respondents (ratings 4—very and 5—extremely), innovative design solutions for 54% of the respondents, and improved sustainability for 40% of the respondents. Based on these responses, it is observed that the students in Serbia and Montenegro have not yet recognized the benefits of using AI in their work.

In Table 4, the students rated the perceived challenges or concerns regarding the use of AI in architecture (1—very low; 5—very high). The perceived challenges of using AI in architecture are ethical issues (for 43% of the respondents), legal issues (for 42% of the respondents), job displacement (for 51% of the respondents) and reliability (for 42% of the respondents). The responses of the respondents in this table are consistent with the answers in Table 3.

Table 4. The percentage structure of respondents' ratings.

Challenges of Using AI in Architecture	M	SD	1	2	3	4	5
Ethical issues	3.34	1.13	7%	13%	37%	25%	18%
Legal issues	3.24	1.19	9%	17%	32%	25%	17%
Job displacement	3.57	1.10	4%	11%	34%	26%	25%
Reliability	3.30	1.19	6%	21%	31%	21%	21%
Cronbach's Alpha				0.84			

Source: author's research.

A correlation analysis is used to test the first hypothesis about the positive influence of the use of AI on the values of sustainability indicators in architecture. Table 5 shows the Spearman correlation coefficients between the following constructs: sustainability in architecture, facilitating AI in architecture, benefits of using AI in architecture, challenges of using AI in architecture. Each construct represents an arithmetic mean of the evaluations of the statements that make up this construct. Cronbach's Alphas for all four constructs (shown in Tables 1–4) are above the threshold value of 0.7, which indicates the good reliability of the measurement instruments.

Table 5. Spearman's correlation coefficients.

Spearman's Rho		Sustainability in Architecture	Facilitating AI in Architecture	Benefits of Using AI in Architecture	Challenges of Using AI in Architecture
Sustainability in architecture	Correlation coefficient	1.00	0.10	0.26	0.13
	Sig. (2-tailed)		0.34	0.01	0.19
Facilitating AI in architecture	Correlation coefficient	0.10	1.00	0.49	0.31
	Sig. (2-tailed)	0.34		0.00	0.00
Benefits of using AI in architecture	Correlation coefficient	0.26	0.49	1.00	0.42
	Sig. (2-tailed)	0.01	0.00		0.00
Challenges of using AI in architecture	Correlation coefficient	0.13	0.31	0.42	1.00
	Sig. (2-tailed)	0.19	0.00	0.00	

Correlation is significant at the 0.05 level (two-tailed). Source: author's research.

The Spearman correlation coefficient between the construct "sustainability in architecture" and the construct "facilitating AI in architecture" ($\rho = 0.10$) is not statistically significant ($p = 0.34$), suggesting that the use of AI in architecture and the indicators of sustainability in architecture are not correlated. To investigate this relationship further, the students surveyed were divided into two groups (subsamples) depending on whether they had used AI tools in any of their project designs. Table 6 shows how each group rated indicators of sustainability in architecture.

Table 6. Descriptive statistics with the test of normality of AI tools used in project design.

Sustainability in Architecture	N	M	SD	Shapiro–Wilk Statistic	Sig.
AI tools used in project design—YES	45	3.96	0.98	0.86	0.00
AI tools used in project design—NO	55	4.08	0.94	0.83	0.00

The results are significant at the 0.05 level. Source: author's research.

The Shapiro–Wilk test for normality is significant for both subsamples ($p < 0.01$), which means that the data are not normally distributed. Since the normality assumption is required for parametric tests, the non-parametric Mann–Whitney test is used to determine whether there are significant differences between the students who used AI tools in their project designs (M = 3.96) and those who never used such tools (M = 4.08) in terms of their ratings of the sustainability indicators.

The result of the Mann–Whitney test ($Z = -0.743$; $p = 0.46$) is not significant, indicating that there are no differences in the assessment of sustainability indicators between students who used AI tools in their project designs and those who never used such tools. Hypothesis H1, which states that the use of AI has a positive influence on the values of sustainability indicators in architecture, is not confirmed.

The second hypothesis on the influence of the perceived benefits of using AI in architecture on the acceptance of AI tools by architecture students is tested using the correlation analysis shown in Table 5. There is a statistically significant ($p < 0.01$) positive moderate correlation ($\rho = 0.49$) between the construct "facilitating AI in architecture" and the construct "benefits of using AI in architecture", indicating that hypothesis H2, which states that the perceived benefits of using AI in architecture influence the acceptance of AI tools by architecture students, is confirmed.

The third hypothesis, on the influence of perceived concerns and challenges in the use of AI in architecture on the acceptance of AI tools by architecture students, is also tested using the correlation analysis presented in Table 5. There is a statistically significant ($p < 0.01$) positive moderate correlation ($\rho = 0.31$) between the construct "facilitating AI in architecture" and the construct "challenges of using AI in architecture", indicating that hypothesis H3, which states that the perceived concerns and challenges of using AI influence the acceptance of AI tools among architecture students, is confirmed.

To test the fourth hypothesis, the respondents were divided into two groups: the students from Serbia and the students from Montenegro. Table 7 shows how each group rated the indicators of sustainability in architecture, the extent to which they use AI in their work, the perceived benefits of using AI, and the perceived challenges or concerns regarding the use of AI in architecture.

Table 7. Descriptive statistics with the test of normality of the constructs.

	Country	N	M	SD	Shapiro–Wilk Statistic	Shapiro–Wilk Sig.
Sustainability in architecture	Serbia	51	3.98	1.10	0.82	0.00
	Montenegro	49	4.07	0.79	0.89	0.00
Facilitating AI in architecture	Serbia	51	3.13	1.25	0.93	0.00
	Montenegro	49	2.62	1.28	0.92	0.00
Benefits of using AI in architecture	Serbia	51	3.48	0.95	0.94	0.01
	Montenegro	49	3.28	1.08	0.96	0.08
Challenges of using AI in architecture	Serbia	51	3.28	0.93	0.97	0.19
	Montenegro	49	3.44	0.96	0.95	0.06

The results are significant at the 0.05 level. Source: author's research.

The Shapiro–Wilk test for normality is significant ($p < 0.05$) for all constructs (except for the construct "challenges of using AI in architecture"), which means that the non-parametric Mann–Whitney test must be used to determine whether there are significant differences between the students from Serbia and those from Montenegro. The results of the Mann–Whitney test are presented in Table 8.

As can be seen, the results of the test for all the constructs are not significant ($p > 0.05$), except for the construct "facilitating AI in architecture" ($p = 0.05$), which indicates that there are no significant differences between the Serbian and Montenegrin architecture students in terms of their ratings of sustainability indicators, perceived benefits of AI use, and perceived challenges of AI use. However, in terms of the extent to which students use AI tools in their work, the differences are significant. The Serbian students (M = 3.13) use AI tools to a greater extent than the Montenegrin students do (M = 2.62). For all these reasons, it can be stated that hypothesis H4, which states that there are no significant differences between Serbian and Montenegrin architecture students in terms of the evaluation of sustainability indicators, the use of AI, and the perceived benefits and challenges of AI use, is partially confirmed.

Table 8. Mann–Whitney test.

	Sustainability in Architecture	Facilitating AI in Architecture	Benefits of Using AI in Architecture	Challenges of Using AI in Architecture
Mann–Whitney U	1190.00	971.50	1091.50	1131.00
Wilcoxon W	2415.00	2196.50	2316.50	2457.00
Z	−0.41	−1.92	−1.10	−0.82
Asymp. Sig. (2-tailed)	0.68	0.05	0.27	0.41

Grouping variable: country. The results are significant at the 0.05 level. Source: author's research.

5. Discussion

The results of this study reveal that architecture students in both countries under examination demonstrate a lower-than-average utilization of artificial intelligence (AI) in their academic and design work. This observation suggests that there may be a significant gap between the potential applications of AI in architectural practice and its actual adoption within the educational context.

Hypothesis H1, which states that the use of AI has a positive influence on the values of sustainability indicators in architecture, is not confirmed.

In terms of the response to the question concerning the architectural students' understanding of the main sustainability indicators that are essential in contemporary architectural practice, the vast majority of the students rated sustainability factors as very important. In particular, reducing carbon emissions (for 66% of the respondents), improving water efficiency (for 73% of the respondents), improving health and well-being (for 79% of the respondents), using life cycle thinking (for 77% of the respondents) and using smart buildings (for 74% of the respondents) are considered very or extremely important, that is, according to the theoretical and empirical literature findings [23,68].

The acknowledgement of the research question regarding the perceptions of architectural students in Serbia and Montenegro concerning the acceptance and use of AI in architectural practice showed that the benefits of using AI in architecture influence the acceptance of AI tools by architectural students.

Despite the results in Table 2 showing that AI is insufficiently accepted in the work of students, the students are aware of the benefits of using AI in architecture. As shown, the architecture students in both countries insufficiently use AI in their work, even though they are aware of its benefits. However, challenges and concerns such as ethical issues, legal issues, job displacement, and reliability limit their usage.

The adoption of AI in architecture can substantially advance sustainability goals by optimizing resource use, enhancing energy efficiency, and enabling innovative design solutions. AI facilitates the creation of energy-efficient buildings, supports predictive maintenance, and improves urban planning through data-driven insights. Additionally, AI aids in designing structures that are resilient to climate change and aligns with circular economy principles, ultimately contributing to more sustainable and efficient architectural practices.

As rapid environmental changes challenge traditional education, the proper use of AI in architectural education is important. Prior to this, it is crucial for students to develop flexible skills for problem-solving and design, preparing them for increased efficiency, innovative design solutions, and improved sustainability [69].

6. Conclusions

This study examines whether the use of AI tools in project designs by architecture students in Serbia and Montenegro influences their ratings of sustainability indicators. It offers a comprehensive exploration of AI in architectural study programs in two observed countries and addresses the existing gap in feedback on AI applications in architectural education. Long-established traditional teaching models do not incorporate AI in the learning phases in both countries. Integrating AI in architectural education can leverage new technologies while maintaining the foundational principles of the design of urban spaces, buildings, and interiors with sustainability practices such as reducing carbon emissions in buildings and enhancing water efficiency and health and well-being, addressing the principles of circular economy. It is crucial to address the level of knowledge concerning the mentioned issues prior to the use of AI for the same purposes.

The findings indicate that:

(1) while the hypothesis that AI usage positively influences sustainability ratings was not confirmed, the findings open up new avenues for research and educational focus; understanding the broader context of how AI integrates with traditional architectural practices remains a key area for future exploration.
(2) The perceived benefits of using AI in architecture influence the acceptance of AI tools by architecture students. These findings have significant implications for educational strategies and the implementation of AI tools in architecture programs. Educators and policymakers should emphasize the benefits of AI to foster greater acceptance among students. However, it is also crucial to address students' concerns and challenges proactively, perhaps through targeted support, resources, and training to mitigate these issues.
(3) The perceived concerns and challenges of using AI influence the acceptance of AI tools among architecture students.

The confirmed hypotheses underline the complexity of technology adoption, where both the perceived benefits and challenges contribute to shaping users' attitudes. Future research could further explore the specific benefits and challenges that most strongly impact acceptance, enabling more tailored approaches to encourage the adoption of AI in architecture education.

Overall, the analysis demonstrates a balanced view, showing that both positive and negative perceptions play roles in the acceptance of AI tools, with the benefits having a slightly stronger influence. This insight can help guide efforts to integrate AI into educational curricula and professional practices within the field of architecture.

(4) There are no significant differences between the Serbian and Montenegrin architecture students in terms of the evaluation of sustainability indicators, the use of AI, and the perceived benefits and challenges of AI use.

This study's findings highlight that while Serbian and Montenegrin architecture students share similar perceptions regarding sustainability and AI, their actual use of AI tools differs significantly. This partial confirmation of hypothesis H4 underscores the importance of considering both perceptions and practical applications when assessing the integration of AI in education. Addressing the identified differences could lead to the more balanced and effective use of AI tools in architectural education in both countries.

This study focused on the use of AI in architectural education in Serbia and Montenegro, which have experienced the same context of transitioning educational paradigms as other Western Balkan countries. This implicates that this research could be conducted in these countries in order to utilize a larger sample and conduct benchmarking analysis.

To enhance AI integration concerning sustainability in architectural education in Serbia, Montenegro, and other Western Balkan countries, it is recommended to develop targeted AI training programs that address both theoretical understanding and practical application. Facilitating collaborative workshops between architecture schools in Serbia and Montenegro can help share knowledge and harmonize educational practices. Aligning and standardizing curricula across the region will ensure consistent AI integration and facilitate effective benchmarking. Increasing accessibility to AI tools and resources is crucial for providing students with hands-on experience. Extending research to include other Balkan countries and conducting ongoing assessments will refine AI integration strategies. Incorporating AI tools into assessment methods will encourage practical application, while promoting interdisciplinary projects that combine AI, sustainability, and architecture will prepare students for the complexities of modern architectural practice. Implementing these steps will help balance AI tool usage and perceptions, leading to more effective architectural education in the region.

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