Article

A Survey-Based Study of Students' Expectations vs. Experience of Sustainability Issues in Architectural Education at Wroclaw University of Science and Technology, Poland

Marcin Brzezicki * and **Agata Jasiolek**

Faculty of Architecture, Wroclaw University of Science and Technology, 50-317 Wroclaw, Poland;
agata.jasiolek@pwr.edu.pl
* Correspondence: marcin.brzezicki@pwr.edu.pl; Tel.: +48-71-320-63-10

Abstract: Sustainability is currently one of the biggest concerns in the field of architecture and civil engineering. The presented study elaborates on the students' expectations vs. experience of sustainable and ecological design in their architectural education. Students were surveyed after the interdisciplinary Hybrid Factory Design (HFD) course carried out at the Faculty of Architecture WUST, Poland. Respondents were asked to anonymously fill in a two-part online questionnaire in the last week of the summer semester of the academic year 2020/2021. The questionnaire was composed of 30 compulsory single-choice questions and 8 optional open questions. The single-choice questions were prepared using a five-point Likert scale, ranging from 1 (negative answer) to 5 (positive answer). Additionally, the Expectation Fulfilment Rate (EFR)—an original tool developed by the authors—was used to assess students' expectations. The conducted survey revealed a significant disproportion between students' expectations and experience regarding sustainable and ecological design aspects. There are also knowledge gaps in certain areas that should be addressed. Topics related to urban planning, green areas design, renovation and adaptation are not sufficiently represented in the curriculum. Moreover, it is essential to provide students with a broad, cross-disciplinary overview of sustainable architecture to deepen their understanding of different design aspects.

Keywords: sustainability; architectural education; teaching methods

1. Introduction

1.1. Sustainable Development and UN 17 Sustainable Development Goals

The term sustainable development started to be used in the 1960s and 1970s; however, it entered a global debate in the 1980s, with increased awareness of the social and environmental cost of economic growth. Although there is no fixed definition of sustainable development, it is usually understood as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [1]. In 2015, the ongoing degradation of the natural environment, population growth, the problem of poverty and social inequality have led the United Nations to adopt the 2030 Agenda for Sustainable Development, including 17 Sustainable Development Goals (SDGs). The document indicates 17 interconnected areas of world development that should be addressed before 2030, to lead to a more sustainable future [2].

1.2. Sustainable Development in the Building Industry and Architecture

Sustainability is currently one of the biggest concerns of the architecture and building industry. Responsible architecture can contribute to reducing environmental pollution, improving biodiversity, reducing social inequalities and increasing quality of life. Each one of the SDGs can and should be reflected in the way the built environment and urban spaces are created, and a deeper understanding of sustainability among future architects is crucial to achieving that. Although the goals are interlinked and should be viewed together, some

areas are more applicable in architecture—Table 1 shows the authors' proposal on how some goals can be implemented, providing examples of application.

Table 1. Examples of implementation of selected SDGs in architecture (author's own work).

	Goal	Examples of Implementation
GOAL 1	No Poverty	• access to education and services • affordable housing
GOAL 3	Good Health and Well-Being	• healthy living environment • non-hazardous building materials • ventilation and daylighting • reduced ambient pollution
GOAL 6	Clean Water and Sanitation	• water-saving systems • rain and greywater use
GOAL 7	Affordable and Clean Energy	• energy-saving systems • renewable energy
GOAL 9	Industry, Innovation and Infrastructure	• new building technologies • sustainable manufacturing and prefabrication
GOAL 11	Sustainable Cities and Communities	• responsible land use • public transport • green areas • public spaces
GOAL 12	Responsible Consumption and Production	• reduced natural resources consumption • green, renewable and local materials • recycling and closed-loop material cycle

One of the most important aspects of sustainable development in the context of architecture is its impact on the natural environment. Although sustainability is not limited to ecology, the exceptionally high environmental impact of the construction industry results in the priority of pro-ecological changes in this area. In 2018, over 976 million tonnes of construction waste were generated in the European Union (UE28), accounting for 37% of all waste generated [3]. At the same time, only 39% of all waste treated in the EU was recycled, and 37% was landfilled [4]. Furthermore, in 2019, the building industry and building operation were responsible for 35% of global energy consumption, 55% of electricity consumption and 38% of energy-related CO_2 emissions [5].

1.3. Sustainability and Ecology in Architectural Education

Considering the increasing demand for environmental awareness and social responsibility among architects, the development of new technologies and changes in legal regulations and modifications to the curriculum of architecture studies are inevitable. Future architects shall have the necessary knowledge and skills to meet the challenges of sustainable design. While all the architecture universities are adjusting their curriculums and reviewing teaching techniques, changes are often not sufficient and do not always meet students' expectations.

1.4. Aim of the Research

Considering the discussed problems and challenges, it is necessary to diagnose current strategies for incorporating sustainability and ecology issues in architectural education and analyze students' needs in order to improve the quality of teaching. The adopted

methodology includes a literature study, students' survey and a case study of an academic course. Therefore, the aims of this paper are (i) to perform an analysis of the results of the conducted surveys; and (ii) to discuss the lessons learned from the answers provided, paving the way towards better integration of sustainability issues into the architectural design curricula. The research focuses on students' expectations and experiences, as effective education has to respond to students' needs. Strengths and weaknesses of the teaching strategies are indicated, resulting in guidelines for more effective sustainability education of future architects.

2. Literature Study

2.1. Method and Eligibility Criteria

The data for the literature review were acquired from international scientific databases (WoS and Scopus—last search 15 July 2021). Studies with similar profiles were used to determine candidate search terms ("keywords"). This was accomplished by examining the words in the titles and abstracts. Search strategy for all databases included the papers with keywords: "architectural", "education" and "sustainability". The review was carried out by two researchers (AJ, MB).

Study selection was a multi-stage process. Potential studies were first identified from screening titles and abstracts. A single researcher (MB) reviewed titles and abstracts of 450 records (published in the years 2017–2021) and—after duplicates removal—the second researcher (AJ) double screened the abstract from the years 2000–2016. Subsequently, 490 records were screened, from which 32 full-text documents were reviewed, and finally 16 (each cited) papers were included in the literature review.

Results of the literature review are presented in the form of a table, comparing the different approaches and conclusions reached by different teams of researchers. The main scientific method for the literature study used was a desk study (PC with an internet connection); no automation tools were used.

2.2. Previous Research, State of the Art

The issues of sustainability in the context of architectural education were recently (2015–2020) extensively studied, mainly in the area of architectural education reports. However, the first reports were published earlier. In 2011, Iulo et al. presented a model for environmentally conscious content of the course based on the curriculum review [6]. Two years later, Khan et al. suggested that sustainability should be seen as an integrative framework, with the design as the most appropriate synthesis of many fields of knowledge [7]. Koszewski in 2014 presented a new curriculum of the English-taught courses at Warsaw University of Technology. The general assumptions of the new curriculum are presented with emphasis on important relevant problems. Particular attention is devoted to the need for conscious critical evaluation of the rapid changes in the discipline, including sustainability [8]. In 2016, Alvarez et al. presented a comparative review of different education curricula of Asian universities, with the conclusion that—in many cases—course content is formulated against the principles of sustainability. They have also noticed that economic aspects are almost totally absent in the curricula [9]. The work by Hassanpour et al., published in 2017, is a large survey-based study with 293 participants [10]. The findings of the study reveal that horizontal and vertical relations between different course types that share similar sustainability objectives are very important. The authors postulate that issues of sustainability should be incorporated as the content of different courses at the same time and that the students should be the subject of constant positive pressure. The problems that have been articulated by Hassanpour et al. were later confirmed by the curriculum review by Ismail et al., who found an absence of an obvious framework of how knowledge of sustainable architecture was integrated into the curriculum [11]. In 2018, Donovan provided the results of a case-study review that revealed that the field of sustainable architecture education needs to address multiple disciplines and actors [12]. This general postulate for the integration of different disciplines is formulated in many

subsequent research papers and reviews. Albareda-Tiana et al. presented a curriculum analysis based on the interviews with deans pointing out the importance of using active teaching-learning strategies and a holistic approach [13]. Regarding the above discoveries, the team of Mahomed and Elias-Ozkan in 2019 presented a course report of an experimental studio that was an attempt at integrating sustainability principles into the architecture design studio [14]. A course report with similar conclusions was also presented by Celadyn regarding the courses of interior architectural design [15].

In 2020, three large survey-based studies were presented by Fernandez-Antolin, Xiang et al. and Grover et al. Papers explore the issues of digital tools used for the integration of the issues of sustainability into the curricula. Xiang et al. presented a model that incorporates sustainable development concepts into digital architectural design teaching [16]. Fernandez-Antolin postulated that Building Performance Simulation software should be present from the earliest stages of architectural education [17]. This observation was earlier shared by the team of Taleghani et al., which postulated offering renewable energy courses in first degrees based on the review of courses taught in Iran and Australia [18]. In 2020, Grover et al. published a survey-based report concluding that the focus on teaching interactions towards sustainable design should be shifted towards architectural studio (classwork with students). The authors also observed that architectural/aesthetic values frequently undermine holistic approaches to sustainability [19].

For the full picture, critical studies should also be presented, which observe serious problems with the implementation of sustainable development issues in the curricula. In 2019, Kowaltowski et al. presented a survey-based (150 participants) study, which states, "novice designers, at the beginning of their professional training, could be overwhelmed by the complexity of a design process" [20], and points out that sustainability as a concept can be overwhelming for early year students. Kowaltowski et al. conclude that care should be taken to avoid this frustration.

To sum up, almost all researchers see the necessity of starting sustainability-based education at the earliest possible stage and integrating many actors and disciplines under a single course. In the published scientific literature there is a limited amount of information related to the students' expectations, very little information about the delivery process of final projects and no information could be found concerning the satisfaction level. Results of the bibliographic survey are presented in Table 2.

Table 2. Results of previously conducted research review on the topic.

No.	Authors	Year	Type of Research [1]	Research Focus	Research Gap
1	Iulo et al. [6]	2011	course review	• A model for environmentally conscious content.	• Conclusions were drawn from the assessment of a limited number of programs. No survey-based study.
2	Taleghani et al. [18]	2011	course review	• Establishing renewable energy courses related to architecture and other engineering fields of study • Providing opportunities for continuing professional education.	• The paper addresses some pioneering efforts in the field. No survey-based study.
3	Khan et al. [7]	2013	curriculum review, pedagogical study	• Sustainability is seen as an integrative framework, and design is the most appropriate (synthesis) field for exploring and dealing with this integrative endeavor.	• The overlapping layers model presented a rather theoretical study. No students' feedback was included.
4	Altomonte et al. [21]	2014	survey-based (not revealed)	• Identified some of the key hindrances to the successful integration of sustainability in teaching.	• Outcomes of a European project EDUCATE after the Bologna unification process are presented. Practitioners were surveyed, not students.

Table 2. *Cont.*

No.	Authors	Year	Type of Research [1]	Research Focus	Research Gap
5	Koszewski	2014	curriculum review	● The social context of the discipline with a special focus on the idea of a society of knowledge.	● Interesting course curriculum review. No students' surveys were presented.
6	Alvarez et al. [9]	2016	curriculum review	● Economic aspects are almost totally absent.	● Interesting and exhaustive course curriculum review. Only East Asian universities were reviewed.
7	Hassanpour et al. [10]	2017	survey-based (293)	● Horizontal and vertical relations between different course types that share similar learning objectives are very important. ● The integration of sustainability issues in the architecture curriculum.	● Questions asked respondents to compare the level of sustainability incorporation in design studios. No further expectation study was performed.
8	Ismail et al. [11]	2017	curriculum review	● An absence of an obvious framework of how knowledge of sustainable architecture was integrated into the curriculum.	● A review of integration principles, values and practices at 10 conveniently sampled architecture schools in the UK and USA. Geographically limited.
9	Donovan [12]	2018	case study, direct observation	● Need for full integration of sustainability into architecture education. ● Need to address multiple disciplines and actors.	● Example from Denmark, Aarhus School of Architecture. Geographically limited, no students' opinions included.
10	Albareda-Tiana et al. [13]	2018	curriculum analysis and interviews with deans	● The importance of using active teaching-learning strategies. ● Holistic methodological strategies relate theory to practice.	● Global competencies related to education for sustainable development were not studied.
11	Kowaltowski et al. [20]	2019	survey-based (150)	● Novice designers could be overwhelmed by the complexity of a design process. ● Sustainability as a concept can be overwhelming and care must be taken to avoid frustration.	● Students' feedback included, but some reflections and resulting actions came from the teaching staff.
12	Mohamed & Elias-Ozkan [14]	2019	course report (22), survey-based (not revealed)	● Integrating sustainability principles into the architecture design studio.	● Single course report of "sustainable design studio". Some students' feedback included.
13	Grover et al. [19]	2020	survey-based (20)	● Shifting the focus of teaching interactions towards sustainable design can increase its value within the architectural studio.	● The research adopted a qualitative approach. Lack of quantitative study.
14	Boarin et al. [22]	2020	survey-based (283)	● Sustainability as a critical aspect in architectural education. ● Sustainability education should be delivered within a more fully integrated pedagogical framework.	● The lack of data from individual courses to which the questionnaire was offered. ● Lower response rate.

Table 2. *Cont.*

No.	Authors	Year	Type of Research [1]	Research Focus	Research Gap
15	Celadyn [15]	2020	course report, survey	● Integrative classes as supportive instruments in the transformation of the learning process.	● Integrative classes are discussed in the paper. No survey details revealed.
16	Fernandez-Antolin [17]	2020	survey-based (171)	● Deficiency in Spain in the current training of architecture students at universities in Building Performance Simulation.	●Spain-based study. Geographically limited.
17	Xiang et al. [16]	2020	course review, survey (29)	● The close relationship between the teaching level and the transfer of architectural knowledge. ● Sustainable development concepts into digital architectural design.	● The study focused exclusively on Chinese universities and all the research was conducted in the Chinese education system. Geographically limited.

[1] Number of survey participants is given in the brackets.

2.3. Research Gap, Innovative Nature of the Presented Study

The literature review shows that the issues of sustainability are analyzed from a different perspective by the different authors. Teams consider different aspects of sustainability, formulating different answers to solve the problems they observe in architectural curricula. The closest approach was presented in 2020 by the team of Boarin et al., who provided a survey-based study of students' perception of sustainability in architecture [22]. As a result, Boarin et al. concluded that sustainability subjects tend to be mostly delivered through lecture-based courses and that education should be delivered within a more fully integrated pedagogical framework. However, none of the approaches presented above attempted to analyze the students' expectations vs. experience considering the issues of sustainability. An original data analysis tool of Expectations Fulfilment Rate (EFR) was developed to assess this correlation and analyze what students expect and what they ultimately receive during the studies.

3. Methods

The research was conducted at Wroclaw University of Science and Technology (WUST) in Poland, in the summer semester of the academic year 2020/2021 and consisted of four main stages.

- A bibliographic survey conducted according to the methodology presented in Section 2.1.
- A case study of an innovative Hybrid Factory Design (HFD) course taught for a group of M.Sc. architecture students.
- A survey among students, regarding their experience of sustainability in architectural education and feedback from the HFD course.
- Analysis of the survey results and discussion with a solution proposal.
- The adopted methodology is presented in Figure 1.

3.1. Students' Survey

Students participating in the survey were divided into two groups:

- Group A, composed of students in the third year of Bachelor in architecture (N = 27, age 21–23 years old);
- Group B, composed of students in the first year of Master in architecture (N = 21, age 22–24 years old), who attended the HFD course in the semester preceding the survey.
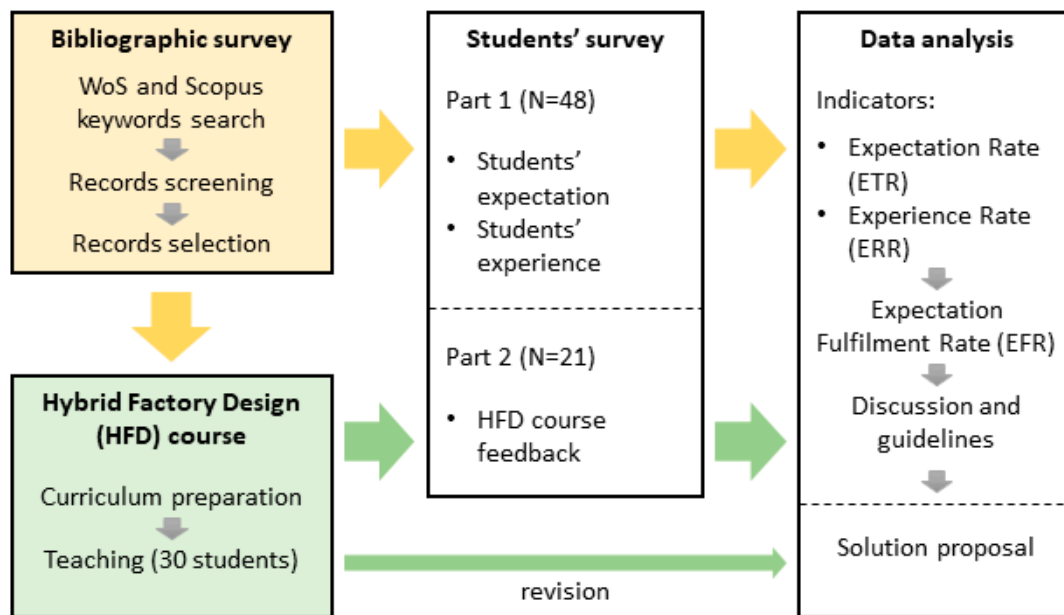
Figure 1. The research methodology.

Respondents were asked to anonymously fill in a two-part online questionnaire in the last week of the summer semester of the academic year 2020/2021 (18–23 June 2021). The questionnaire was composed of 30 compulsory single-choice questions and 8 optional open questions. The single-choice questions were prepared using a five-point Likert scale, ranging from 1 (negative answer) to 5 (positive answer).

Part 1, completed by both groups, covered the students' expectations and experiences regarding the sustainable and ecological design aspects in architectural education throughout their studies. Students were asked to rate their expectations for incorporating sustainability-related topics in the whole curriculum, as well as in the eleven areas of architectural education. Secondly, participants assessed the amount of knowledge they actually gained in those topics during the studies. This structure of the questionnaire was intended to allow evaluation of the overall quality of sustainability teaching as well as identification of specific areas for improvement. Part 2 concerned the evaluation of the HFD course and was completed only by group B. The entire questionnaire can be found in the Supplementary Materials.

The reliability of the survey was analyzed using Cronbach's alpha, which is the most common measure of internal consistency. It is usually used when multiple Likert questions in a survey/questionnaire are used. The authors calculated "α" separately for expectations and experience (each for 11 questions that were rated in the Likert scale), and the result is $\alpha = 0.860$ and $\alpha = 0.865$, respectively. Judging from the literature [23], the numbers we have calculated (between 0.80 and 0.90) prove the high consistency of the survey for applied research.

It has to be stated here that behavioral observation of students' reactions was not possible due to COVID restrictions. Online information exchange with students allowed only communication via electronic platforms, which enabled giving design instruction and tutorials but prevented face-to-face interaction. All these abovementioned factors might have affected the results of the survey, and are therefore explicitly communicated; see also Section 6.1.

3.2. Data Analysis

The answers from the survey were analyzed by the authors of the presented paper. Part 1 was analyzed with the distinction between groups A and B, as well as for the whole population. Results from single-choice questions were presented in graphs in percentage form and used to calculate the Expectation Rate (ETR) and Experience Rate (ERR) for each

of the categories. ETR and ERR were obtained by calculating the average of all the answers provided for each question on a Likert scale from 1 (lowest score) to 5 (highest score).

The Expectation Fulfilment Rate (EFR) is an original tool developed and used by the authors to assess the extent to which a curriculum addresses students' expectations in terms of sustainable aspects in various areas of architectural education. EFR, taking values from 0 (lowest level) to 1 (highest level), was calculated according to Equation (1).

$$EFR = ERR/ETR \tag{1}$$

Following the methodology implemented by Grover et al. [19] in a study of the qualitative survey, responses for open questions were scanned for recurring words and themes and presented as a list of themes with representative quotes. Representative, in a sense, meaning expressing the majority of students' opinions shortly and straightforwardly, and simultaneously capturing the essence of a problem.

4. Survey Results

The authors argue that the lessons learned from this survey of 48 student participants will allow determining the steps that should be taken to make the sustainability curricula more effective by improving understanding rather than communicating dry facts and rules. The survey revealed a significant disproportion between students' expectations regarding the sustainable and ecological design aspects in architectural education and the range of knowledge they receive in university courses. Although sustainability aspects are incorporated into the curriculum, there are knowledge gaps in certain areas that should be addressed. Furthermore, the conducted research proved that new teaching techniques with interdisciplinary approaches implemented in M.Sc. studies can deepen students' understanding of sustainable design.

4.1. Reported Students' Expectations

Based on the survey results, architecture students consider sustainable and ecological design a key issue in their academic education—81% of them declared that the topic is very important to them (see Figure 2). Moreover, the vast majority of respondents find the topic interesting and are willing to deepen their knowledge. This attitude creates optimal conditions for integrating sustainable design into architectural education. Besides preparing future architects to design responsibly in an era of climate crisis, it can increase their engagement and satisfaction from studying. Students have high expectations regarding sustainability in their education; however, they often gain their knowledge outside the classroom. More than half of respondents declared that studies should not be the main source of knowledge regarding sustainability in architecture. Students pointed out the role of individual research, internet resources and social media in their education.

In all the discussed categories, a high level of students' expectations was observed—the average scores are between the answers 4 (rather important) and 5 (very important), with the standard deviation from 0.71 to 1.26, for the whole population (see Table 3). Differences between B.Sc. and M.Sc. students are noticeable; however, they do not exceed 0.41 scale points. The highest students' expectations are associated with the following categories:

- Renewable energy (4.67);
- Rehabilitation and adaptation of damaged areas (4.63);
- Eco-friendly and bio-based building materials (4.59);
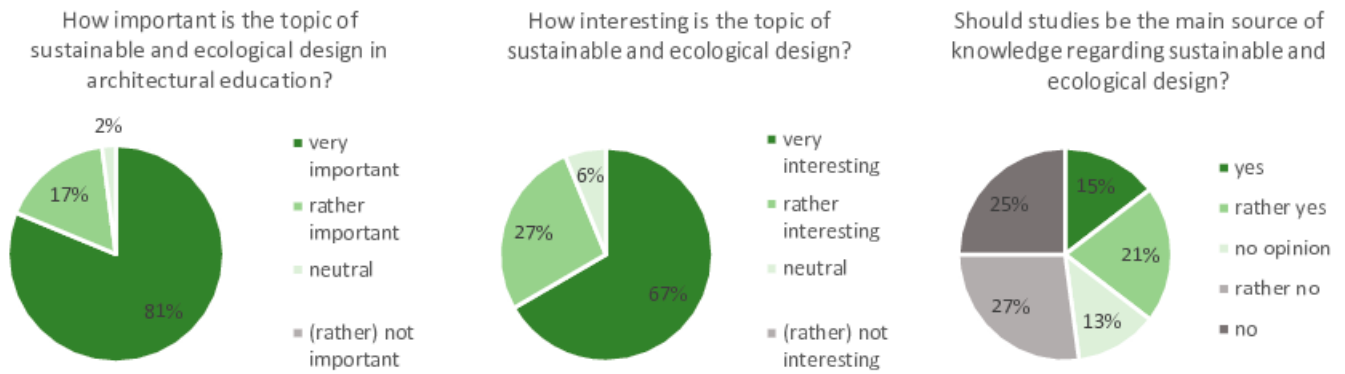- Architectural design (4.58).

Figure 2. Students' attitude to sustainable and ecological design in architecture education.

Table 3. Students' answers regarding their expectations and experiences in different aspects of sustainable and ecological design in architectural education. Answers on a scale from 1 (definitely not) to 5 (definitely yes).

Questions: Are the issues related to sustainable and ecological design in the following areas important? Should they be a part of architectural education? (ETR)
Were the issues related to sustainable and ecological design in the following areas included in the curriculum? Did you get enough information in these areas? (ERR)

Category	Parameter	Group A		Group B		All Students	
		Average Response	Standard Deviation	Average Response	Standard Deviation	Average Response	Standard Deviation
Urban design	ETR	4.56	0.63	4.33	0.94	4.46	0.79
	ERR	2.78	0.99	2.43	0.85	2.63	0.95
Spatial planning and ecosystem protection	ETR	4.56	0.79	4.57	0.66	4.56	0.73
	ERR	2.15	1.15	2.62	1.09	2.35	1.15
Architectural design	ETR	4.48	0.63	4.71	0.45	4.58	0.57
	ERR	3.67	0.67	3.86	0.89	3.75	0.78
Design of green spaces	ETR	4.37	0.82	4.57	0.58	4.46	0.73
	ERR	2.70	1.27	3.10	1.06	2.88	1.20
Rehabilitation and adaptation of damaged areas	ETR	4.67	0.67	4.57	0.79	4.63	0.73
	ERR	1.96	1.07	2.33	1.28	2.13	1.18
Restoration and adaptation of monuments	ETR	3.96	1.04	3.86	1.49	3.92	1.26
	ERR	2.07	0.94	2.38	1.05	2.21	1.00
Eco-friendly and natural building materials	ETR	4.62	0.68	4.55	0.74	4.59	0.71
	ERR	3.15	0.85	2.86	0.99	3.02	0.92
Energy-saving systems and technologies	ETR	4.59	0.62	4.43	1.05	4.52	0.84
	ERR	3.19	1.09	3.33	0.84	3.25	0.99
Renewable energy	ETR	4.81	0.39	4.48	0.79	4.67	0.62
	ERR	3.67	0.72	3.71	0.82	3.69	0.77
Water-saving systems and technologies	ETR	4.74	0.44	4.33	1.08	4.56	0.81
	ERR	3.00	1.05	3.10	0.97	3.04	1.02
Closed-loop material cycle	ETR	4.41	0.73	4.33	0.89	4.38	0.81
	ERR	2.26	1.07	2.71	0.93	2.46	1.04

Clearly, renovation and adaptation of monuments is the subject of least interest, with a score of 3.92 points and 17% of negative responses (not important or rather not important).

Additional categories, suggested by the students to be included in the curriculum, were responsible use of the buildings and extending the life of the building.

4.2. Reported Students' Experience

Despite the systematic implementation of sustainable design elements in the architecture studies curriculum, the range, amount and quality of knowledge provided by tutors is still not sufficient. Only 13% of respondents feel rather satisfied with the range of knowledge they gained during studies, and 41% assessed it as not sufficient (see Figure 3). However, it should be noticed that the average level of satisfaction increases from 2.37 among B.Sc. students to 2.90 among M.Sc. students. Furthermore, 67% of students declared that the knowledge they received was up to date, while 15% considered it outdated. Students pointed out that tutors often focus on tried and tested conventional solutions instead of innovative technologies (see Table 4).
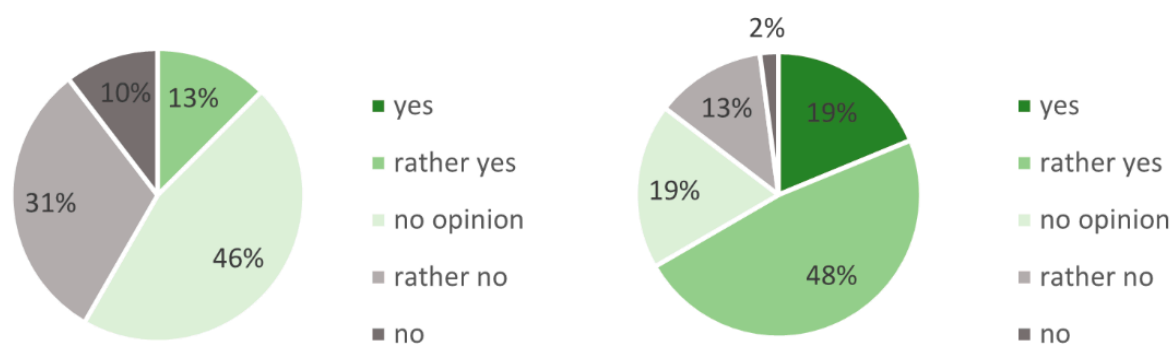
Figure 3. Students' assessment of the quality of the knowledge in sustainable and ecological design received during their studies.

Table 4. Representative quotations and key topics on students' experience.

Topic	Representative Quotes
Learning outside the classroom	*"I gained most of my practical knowledge about ecological design reading about them on my own."* *"Studies should be one of the main sources of knowledge on the subject but social media also play an important role here."* *"Tutors are not able to present all the issues in detail, but only to indicate the right direction. It is important to study this topic outside the classroom."*
Sustainable design in elective classes	*"'Most of the positively assessed topics were elaborated on in elective classes."*
Outdated knowledge	*"Very little information is up to date and most of it is typical greenwashing."* *"In classes, design suggestions are often based on tested, safe solutions."*
Importance of the topic	*"Sustainable and ecological design is important and should be a key component of architectural studies."* *"These are very important issues considering the current climate situation."*
Lack of knowledge provided in the courses	*"Few tutors talk about it (sustainable design), and even fewer provide practical knowledge on the subject."* *"It (sustainable technology) is definitely in the background and could have been explained to the students more."* *"Knowledge on specific topics (regarding sustainable design) was required but not always clearly presented during the classes."*
Superficial approach to the problem	*"It (sustainable design) is often limited to theory and very basic aspects such as the installation of photovoltaic panels."*

In all the discussed areas related to sustainable and ecological design, students' experience was significantly lower than their expectations. The average score is between the answers 2 (rather not) and 4 (rather yes), with the standard deviation from 0.77 to 1.20 (see

Table 3). Differences between B.Sc. and M.Sc. students are noticeable; however, they do not exceed 0.48 scale points. The best experience was declared in the following categories:

- Architectural design (3.75);
- Renewable energy (3.69);
- Energy-saving systems (3.25).

The highest rate of positive answers was observed in the area of architectural design, where 69% of respondents declared that they gained enough knowledge on this topic. A positive answer was also given by 65% of students in the category of renewable energy.

On the contrary, lower scores were obtained in the following areas:

- Rehabilitation and adaptation of damaged areas (2.13);
- Renovation and adaptation of monuments (2.21);
- Spatial planning and ecosystem protection (2.35);
- Closed-loop material cycle (2.46).

The biggest knowledge gap can be identified in the categories of rehabilitation and adaptation of damaged areas, where 66% of respondents declared that they gained no or almost no knowledge on the topic, and restoration and adaptation of monuments, 65%. For spatial planning and ecosystem protection, this answer was given by 46%, for the design of green spaces, 42%.

The Expectation Fulfilment Rate shows that there is a gap between students' expectations and the level of knowledge they are provided with during the studies in each of the analyzed categories (see Table 5, which is based on answers from Table 3). The highest level of expectations fulfilment was achieved in the areas of:

- Architectural design (0.82);
- Renewable energy (0.79);
- Energy-saving systems and technologies (0.72).

Table 5. Students' expectation fulfilment rate.

Category	Expectation Fulfilment Rate		
	Group A	Group B	All Students
Urban design	0.61	0.56	0.59
Spatial planning and ecosystem protection	0.47	0.57	0.52
Architectural design	0.82	0.82	0.82
Design of green spaces	0.62	0.68	0.64
Rehabilitation and adaptation of damaged areas	0.42	0.51	0.46
Restoration and adaptation of monuments	0.52	0.62	0.56
Eco-friendly and natural building materials	0.68	0.63	0.66
Energy-saving systems and technologies	0.69	0.75	0.72
Renewable energy	0.76	0.83	0.79
Water-saving systems and technologies	0.63	0.71	0.67
Closed-loop material cycle	0.51	0.63	0.56

On the contrary, the lowest level can be associated with:

- Rehabilitation and adaptation of damaged areas (0.46);
- Spatial planning and ecosystem protection (0.52);
- Closed-loop material cycle (0.56);
- Restoration and adaptation of monuments (0.56).

In most of the categories, there is a significant increase between the rate declared by B.Sc. and M.Sc. students; the only exceptions are urban design and eco-friendly and

natural materials. This result indicates an overall increase in the quality of sustainable design education in the later years of studies.

Furthermore, an imbalance between the level of sustainable education in different analyzed categories can be observed. Sustainable and ecological design issues are, according to the students, relatively well integrated into the teaching of architectural design; students also receive knowledge about the energy efficiency of a building. At the same time, significant deficiencies are noticeable in areas related to urban and green area design, as well as the reuse and adaptation of land and buildings.

5. Solution Proposal

Diagnosis of the status quo is crucial, although it also seems important to formulate proposals for improvement. The authors' proposal is based on the experiences learned from the block of design courses that were conducted in the summer semester of the academic year 2020/2021 at the Faculty of Architecture Wroclaw University of Science and Technology, Poland. The new faculty's curriculum followed the fundamental change in governmental architect education standards, which were advertised in July 2019 and implemented in the following year. The new standard called for significantly more design hours. The faculty's answer for the challenge was the introduction of so-called integrated design courses, which were meant to provide students with more comprehensive knowledge of design issues including sustainability.

5.1. Course Description

The course titled Hybrid Factory Design (HFD) was taught in Polish and English (for Erasmus students), for 2 cohorts of 15 students at the M.Sc. level, each totaling 105 hours (7 h per week, for 15 weeks). The adopted educational approach was blended learning (BL), combining various didactic forms: group work, lectures, design tutorials, presentations and case-study analysis. Those different forms of learning were coordinated through a Moodle-based platform, used for the provision of course materials, design briefs and lectures. An important part of the platform was a reflective diary that was private for the student and the tutor. This tool, as described by other researchers [24] enabled a more intimate relationship to be built and allowed problems to be diagnosed in advance.

Not only urban planners, structural engineers and greenery designers, but also specialists in the application of new renewable energy sources—PV, solar collectors and heat pumps—participated in the classes (the team of WUST Faculty of Mechanical and Power Engineering). The online form of teaching allowed for much easier sourcing of external experts whose participation in the class did not require physical relocation. In the context of sustainability, we dedicated 7 h to classes with renewable energy specialists, 7 h for greenery designers and 7 h for urban eco-planners. Classes were divided into two parts: (i) the first consisted of lectures (3 h), after which students could ask questions; (ii) the second part consisted of project tutorials, during which the specialists commented on the students' projects (4 h)—the structure of the course is presented in Figure 4. This method proved to be very beneficial, as students could obtain direct feedback on the sustainable solutions adopted in their designs.

A presented solution proposal also took advantage of the experience of other universities. A number of similarities can be found between the HFD course and the teaching approach described by Donovan. Although Donovan's course was more theory-based, it featured a multi-disciplinary approach, workshop elements, group work and incorporation of different tools and forms of learning [12]. Furthermore, Grover et al. presented a case study of a holistic design studio course composed of both theory and design modules. Sustainability knowledge was provided by specialist consultant tutorials, as it was performed in the HFD course [19].
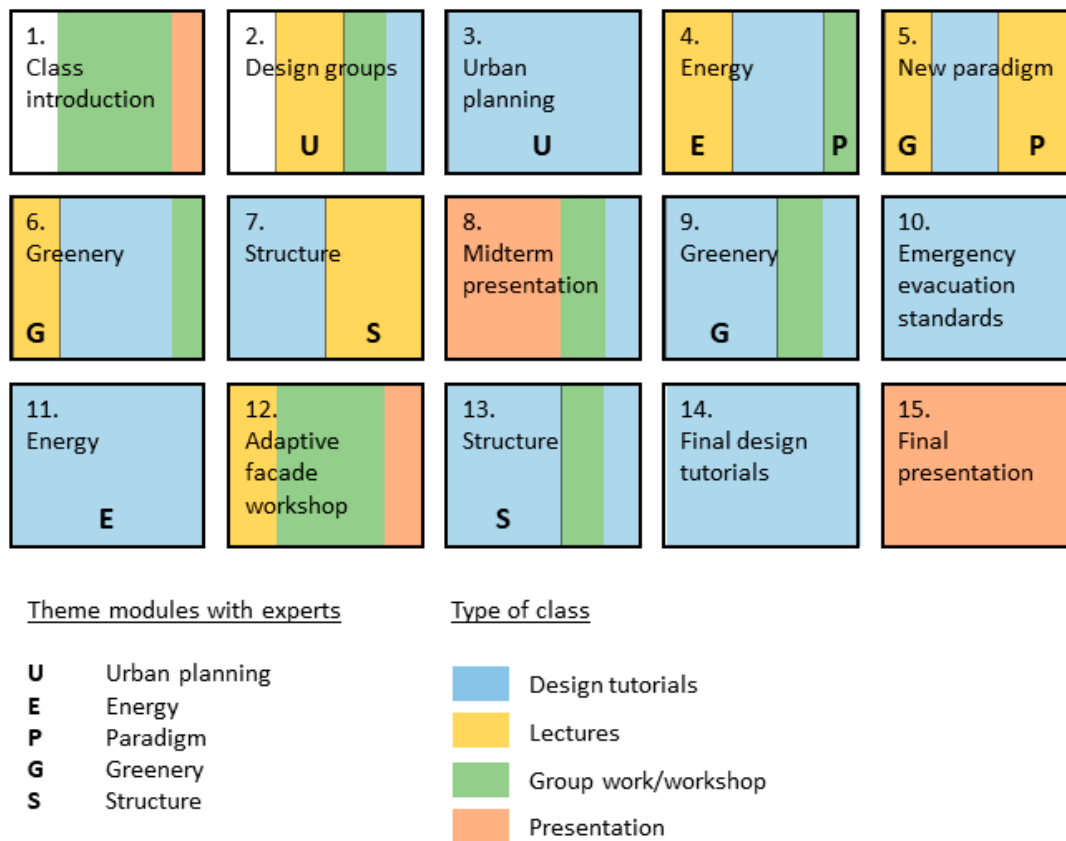
Figure 4. Structure of Hybrid Factory Design course, each rectangle representing a 7-hour working session.

5.2. Course Feedback

The overall student feedback on the course was very positive, although some short-comings were also identified. It is important to note that all students assessed the course as interesting—this result supports the previous hypothesis that the integration of sustainable design elements in architectural education can increase students' interest and satisfaction with the learning process. Moreover, 67% of students found the course to be an adequate contribution to the knowledge of sustainable and ecological design they had already acquired in their course of study (see Figure 5). Owing to the large variety of topics covered, 91% of the respondents declared that they had acquired new knowledge during the course. Among the knowledge-broadening topics listed were:

- Use of natural environmental conditions in the designing process;
- Energy-saving technologies and renewable energy;
- Adaptive facades;
- Vertical farms and hydroponics;
- Water-saving systems.

Students valued the interdisciplinary approach of the classes and the integration of workshop elements, which helped to deepen their understanding of the project and organize knowledge from different areas. On the other hand, lack of time and differences in the way the different modules were conducted, the level of preparation of the tutors and the quality of the knowledge they provided were identified as the main shortcomings of the course (see Table 6).
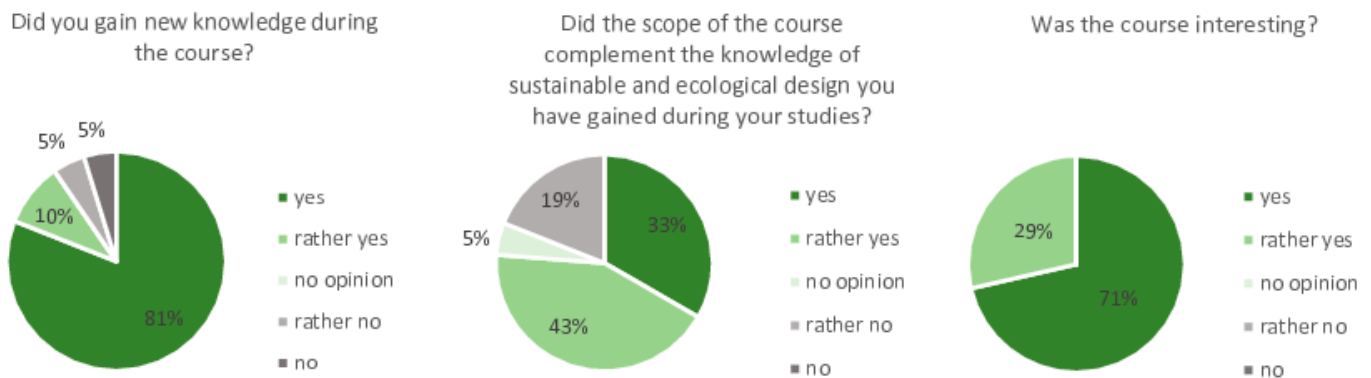
Figure 5. Students' feedback on the Hybrid Factory Design course.

Table 6. Representative quotations and key topics on students' feedback on the course.

Topics	Representative Quotes
Interdisciplinary approach	*"By dividing the whole process into individual stages and areas, each area could be properly considered and contributed to the design."* *"The visits of the interdisciplinary guests were a great advantage of this course"*
Opportunity to organize the knowledge	*"Presentations during the energy module finally allowed me to systematize my knowledge"*
Lack of time to cover all the aspects	*"Due to the large scope of the architectural and spatial concept itself, there is no more time for green area design."* *"Far too little time has been spent on the surrounding of the building, which I consider to be very important."*
Differences in quality of modules	*"The urban planning and green areas modules were not well prepared. While the lectures on green areas were interesting, there was a lack of in-depth revision of projects in this aspect."*

5.3. Future Courses Suggestions

Following this experience, it is suggested that sustainability issues should be addressed at the earliest possible stage of architectural education. Moreover, topic-specific lecture series are less effective for architects than design-based classes. In the solution that has been applied and later surveyed, students gain theoretical background first and then directly implement sustainable technologies and solutions in their designs. This knowledge transfer happens within a single Moodle-coordinated course, with the same course leader; students have limited time and have to act according to the schedule. Due to this, students tend to adjust and modify their designs at a very early stage and are more environmentally aware and keener to see the association of their actions with the future of the planet. The effectiveness of the adopted didactic forms was proven by the results of the conducted survey. The didactic recommendations are grouped and explained in Table 7.

Table 7. Didactic recommendations resulting from the analysis of the survey.

Components of the Educational Process	Traditional Method	Innovation
Learning objectives	• Providing students with the skill and competencies to execute an architectural design.	• Providing students with knowledge and rapid execution in the design phase. • Formation of competence to work in the group, leadership skills and self-reliance. • Increasing the ability to work within the schedule.
Course content	• Design brief, site layout.	• Digitalized lectures. • Digitalized case studies. • Urban, greenery and sustainability modules. • Additional study materials (regulations, building codes).
Study methods	• Reproductive, explanatory, illustrative. • Oral methods of knowledge transfer. • Hand notes during lectures.	• Problem-based research. • Direct application of knowledge. • Blended learning. • Flipped classroom. • Upload of all phases of the design.
Study means	• Traditional visual: books, papers, hand sketches. • Traditional oral, word transfer.	• Hypertext. • Multimedia training facilities. • Videoconferencing (Microsoft Teams). • Creation of Moodle-based online teaching environment. • Students' immersion in new media. • Reflective diary for better rapport and instant personal problem solving.

General outline of the table is inspired by the work of Spivakovskiy et al. [25].

6. Conclusions

The conducted survey revealed a significant disproportion between students' expectations and experience regarding the sustainable and ecological design aspects. The results have shown that there are knowledge gaps in certain areas that should be addressed despite the incorporation of the sustainability aspects into the curriculum. Research proved, that based on new teaching techniques with interdisciplinary approaches implemented on M.Sc. studies, students build up the competencies to work in the group, leadership skills and self-reliance; they are more environmentally aware and keener to see the association of their actions with the future of the planet.

With ongoing climate change, population growth and urbanization, a shift towards sustainable and ecological architecture is inevitable. The change in the way that architecture is designed must also be reflected in the way that architecture students are taught, to provide them with the best possible foundation for responsible work in the future. Remarkably, students themselves are very aware of this problem; they consider sustainability and ecology a key aspect of their education and develop their knowledge on the subject themselves. With this attitude, introducing elements of sustainable and ecological design into the curriculum can have a positive effect on student engagement and satisfaction, which was shown by the course feedback.

As a solution, it is essential to provide students with a broad, cross-disciplinary overview of sustainable architecture to deepen their understanding of different design aspects. However, this is often an organizational challenge, which requires high engagement of tutors and, due to a large number of topics included, also the students' own work. It is important to maintain a balance between the different aspects of sustainable architecture in order to present the complexity of the topic. The conducted research showed that topics related to urban planning, green areas design, renovation and adaptation of old sites and buildings are not sufficiently represented in the curriculum. Furthermore, sustainable design knowledge should not be limited to lectures—students should be encouraged to

use their theoretical knowledge in design classes. Incorporating workshop elements into the courses can increase students' engagement, quality of their designs and understanding of the topic.

Despite the abovementioned shortcomings, the teaching of sustainable and ecological design is being implemented in architectural education, both as elements of standard classes and as innovative, interdisciplinary courses. Ongoing observation of the results, including students' expectations and experiences, can help to improve teaching and should be an integral part of its evaluation. Tools presented in this paper, especially Expectation Fulfilment Rate, can be used to assess the effectiveness of these curriculum changes.

6.1. Limitation of the Study

However, the presented study has some limitations, which should be noted. First, there is a limited number of surveyed students (N = 48), which is, in general, the result of the number of the cohorts (2 B.Sc. of 15 students and 2 M.Sc. of 15 students). It has to be stated that student participation was a success anyway, as 80% of the students completed the survey. However, it cannot be forgotten that the results are based on one course at one faculty. Second, due to the COVID restrictions, the online information exchange with students did not allow for behavioral observation. Communicating via electronic platforms enabled instruction but prevented face-to-face interaction between students. Those who worked in groups had difficulty communicating with each other, adequately assigning tasks inside the group and verifying contribution. Yet, this aspect is not suspected to distort the results significantly. Moreover, the supervision of students' work was even easier than in the case of the classes in the classroom, thanks to the records of all students' activities in the Moodle-based platform. Third, educational research deals with individuals. Impaired observation of human behavior is more subjective and thus is more difficult to replicate. The readers should be aware that the same didactic method, implemented in a different course, might not produce the same results.

6.2. Future Research

Future studies should aim to replicate results in larger cohorts in order to verify whether similar results are possible. It will also be important for future research to investigate the issues of sustainability education in architecture using methods other than surveys, e.g., in-person participant observation typically used in qualitative research. Crits and reviews might also be very beneficial at the final stage of the design. Future studies could investigate the association between the content of the course and the output, meaning the technical correctness of the application of sustainable solutions. Potential effects of online communication on architectural design education should also be analyzed more carefully, for example by the comparison of two cohorts: one in class, and the other online.

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