JOURNAL OF DESIGN FOR RESILIENCE IN ARCHITECTURE & PLANNING

Research Article
Online: www.drarch.org
Volume 7, Issue 2 (434-450), 2026
DOI: 10.47818/DRArch.2026.v7i2222

Sustainability theory and practice in industrial design education: A comparative case study

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Abstract

Sustainability has become a significant part of design education, either as an integrated subject or as a central focus in courses with diverse structures and pedagogical approaches. The necessary approaches, tools, and methods have been developed over the past thirty years and continue to evolve. This study examines how design for sustainability can be taught in undergraduate design education. First, background information is established on the scope of design, design for resilience and sustainability, and design education. While the literature focuses primarily on integrating sustainability into design curricula or studios, theoretical courses on design for sustainability in undergraduate design education have not been sufficiently explored. Therefore, this study examines two consecutive semesters of an elective course on design for sustainability, which has both a theoretical and practical structure, through a comparative case study. Course documents and outcomes from two semesters, before and after the course's time plan and evaluation criteria were updated, were analyzed and compared. The comparison focused on the course process and the themes of the final projects, as well as the sustainability goals they aimed to contribute to. The findings reveal that shifting the focus of the course process and outcome criteria from the design ideation phase to the design development phase altered the course outcomes. Furthermore, examining the results obtained by students participating in an international student design competition on sustainable design, using the projects they developed during the course, indicates that competitions improve the quality of project outcomes and student motivation, while also providing validation of design success and sustainability impact. The study can provide information to researchers, instructors, and practitioners working on design for sustainability and design education.

Keywords: design for resilience, design for sustainability, product design, product-service system design

1. Introduction

The concepts of sustainable development and the circular economy have been integrated into design theories and practices, and the integration is continually evolving (Faludi et al., 2023). Design approaches, tools, and methods for sustainability began to be developed in the 1990s, and their dissemination has been supported by leading organizations such as the United Nations Environment Programme (Brezet & van Hemel, 1997; Crul et al., 2009). This is also relevant for the circular economy, a newer approach to sustainability (UNEP, 2025; EMF, 2016).

While most studies in the literature focus on integrating sustainability into design curricula and design studios at both undergraduate and graduate levels (Bakırlıoğlu & McMahon, 2021; Boks & Diehl, 2006; Calikusu et al., 2023; Lawton & Judd, 2025; Lockrey & Bissett Johnson, 2013; Yavuz Özgür & Çalışkan, 2025; Yilmaz & Kapkin, 2021; Tümtürk et al., 2025; Küçüksayraç & Arıburun Kırca, 2020), some studies focus on how theoretical courses on sustainability support design studios in graduate education (Dhaouadi & Leclercq, 2022) and on developing content and resources for such courses (Faludi et al., 2023). There is a need to share current, in-depth experiences with courses of different structures in undergraduate design education on design for sustainability.

This study examines how design-for-sustainability approaches can be taught in undergraduate industrial design education through a course that includes both theoretical and practical settings.

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Article history: Received 19 April 2026, Revised 21 July 2026, Accepted 21 August 2026, Published 30 August 2026

The research method is a comparative case study, involving two consecutive semesters of a recently updated course on design for sustainability offered over seven semesters in eight years. The study aims to share experiences with researchers and instructors working in the fields of design and sustainability.

This paper is structured as follows: Section 2 provides background information on the scope of industrial design, design for resilience, sustainability, and circularity, and their integration into undergraduate education. Section 3 presents the research method, comparative case study, and background information on the cases. Section 4 presents the findings, focusing on the course process and the projects developed in the course, their themes, and sustainability goals. Section 5 provides a discussion, and Section 6 presents the conclusions.

2. Background

2.1. Industrial Design Scope

The definition of industrial design is dynamic and evolving, broadening its scope from products to services, experiences, and systems. The World Design Organization (WDO, 2015) has updated the definition to "a strategic problem-solving process that drives innovation, enhances business success, and leads to a better quality of life through innovative products, systems, services, and experiences." They list the United Nations Sustainable Development Goals (UN SDGs, 2015), to which designers are primarily expected to contribute, as follows: SDG 3 (Good health and well-being), SDG 6 (Clean water and sanitation), SDG 7 (Affordable and clean energy), SDG 9 (Industry, innovation and infrastructure), SDG 11 (Sustainable cities and communities), SDG 12 (Responsible consumption and production) and SDG 17 (Partnerships for the goals) (WDO, 2015).

Industrial design has been examined across three eras: industrial, service, and digital, which are sequential yet continue to coexist (Calabretta & Kleinsmann, 2017). These eras differ in human-centeredness, collaborative and prototyping practices, value creation mechanisms, and design impact. Moreover, human-centeredness has been defined as the fundamental way designers create value (Norman, 1988). This focus has recently been further developed to shift from people to ecosystems and is referred to as humanity-centered design, with its principles also updated (Norman, 2024).

Over time, the main theories and models related to the design process have remained valid (e.g., Roozenburg & Eekels, 1995). The updated models emphasize the cyclical nature of the design process, highlighting values and needs along with functions at the starting point (Van Boeijen et al., 2013). Design thinking (Design Council, 2003) has also become widespread and even found its place outside the design discipline; it is taught in some engineering and management departments (Sanders, 2017). The steps of design thinking are modeled as the Double Diamond, encompassing the steps: discover, define, develop, and deliver (Design Council, 2003). The Hasso Plattner Institute of Design at Stanfor (2010) proposes a five-step design thinking model consisting of empathize, define, ideate, prototype, and test steps. Here, design ideation refers to the designer generating ideas by combining an understanding of the problem space and the user for whom they are designing.

2.2. Design for Resilience, Sustainability, and Circularity

Design for resilience is defined as “creating a material culture that not only is lasting and has enduring usefulness but also – through its continued presence – can acquire other kinds of meaning” (Walker, 2023). The ten principles defining the qualities of design for resilience are: Beautiful, enduring, restrained, equitable, situated, enabling, trustworthy, farsighted, holistic, and transformational. While the concepts of resilience and sustainability are closely related, they are not the same. For resilience, adaptability, robustness, and endurance are essential, while originality and innovation are approached thoughtfully. In design for sustainability, sustainability is seen as a source of innovation (Thackara, 2005), and promising social and technological innovations should be sustained (Manzini, 2009).

Design for sustainability aims to balance environmental, social, and economic aspects in design processes and encompasses various approaches with different focuses (Crul et al., 2009). Ceschin and Gaziulusoy (2019) map design-for-sustainability approaches across different levels of innovation, describing each level and approach and how they have evolved over time and in relation to one another. They propose five levels of innovation: (1) The material / component, (2) Product, (3) Product-service system, (4) Spatio-social, and (5) socio-technical system. The authors also state that all approaches are important and useful, and that several design-for-sustainability approaches should be applied in an integrated manner to address sustainability.

According to Ceschin and Gaziulusoy's (2019) classification, the product innovation level includes approaches such as eco-design (e.g., Brezet & van Hemel, 1997), design for sustainable behavior (e.g., Lilley, 2009), cradle-to-cradle design (e.g., McDonough & Braungart, 2002), and design for the base of the pyramid (e.g., Kandachar & Halme, 2008). Circular product design (e.g., Den Hollander et al., 2017; EMF, 2016) is not included directly in the classification, but its relationship with design for sustainability is discussed separately. Compared with other approaches, circular design strategies place greater emphasis on user engagement and business models. Furthermore, they help create new contexts grounded in emerging social and technological paradigms, revitalizing sustainability and industrial ecology research for the next generation of researchers and designers (Bakker et al., 2021).

Methods for assessing product sustainability have been developed, starting with the eco-design approach. Based on life cycle assessment and management, eco-design offers the eco-design strategy wheel as a tool (Brezet & Van Hemel, 1997; Van Boeijen et al., 2013). It aims to evaluate products according to eight criteria: new concept development, selection of low-impact materials, reduction of material usage, optimization of production techniques, optimization of the distribution system, reduction of impact during use, optimization of initial lifetime, and optimization of the end-of-life system. The tool relies on data interpretation and is often used to compare the sustainability of old and new product versions in a radar chart when products are redesigned (Van Boeijen et al., 2013). While more advanced life cycle analysis tools and software are primarily used by environmental engineers, they are also taught in some design engineering programs specializing in design for sustainability, and their graduates apply them in the industry (Küçüksayraç et al., 2015).

Manufactured products and product concepts are primarily evaluated by third-party certification organizations and design competitions. Cradle to Cradle Products Innovation Institute, one of the organizations providing product certification, evaluates manufactured products according to five criteria: material health, product circularity requirements, clean air & climate protection requirements, water & soil stewardship requirements, and social fairness requirements (C2C, 2026). Sustainability is also a criterion in design competitions today, both for manufactured products and design concepts (e.g., iF Design, 2026). Green Product Award is one such example, focusing particularly on sustainability. Its criteria include seven titles that place the highest weight on sustainability (GP-Award, 2026).

The sustainable product-service system approach (and innovation level) is defined as “the result of an innovative strategy that shifts the center of business from the design and sale of (physical) products alone, to the offer of product and service systems that are together able to satisfy a particular demand” (Manzini & Vezzoli, 2002). When designing sustainable product-service systems, it is important to identify and illustrate the relationships between the various stakeholders that constitute the actors or support systems using flows. With the Stakeholder System Map tool, Vezzoli et al. (2014) define four types of flows: information, material, labor, and financial.

Product-service systems are categorized along a spectrum of product and service orientation: product-oriented, use-oriented, and results-oriented. Product-oriented services include product-related services, advice, and consultancy. Use-oriented services include product leasing, renting, sharing, and pooling. Result-oriented services include activity management, pay-per-service unit,

and functional result (Tukker, 2004). Software was later added to this categorization, spanning all types of product-service systems (VentureWell, 2022).

2.3. Design Education and Sustainability

The backbone of design education is the design studio course and the critique (Uluoğlu, 2020), which require distinctive pedagogical approaches (Süner-Pla-Cerdà et al., 2025) and are supported by other theoretical and elective courses (Demirbaş & Demirkan, 2003). Experiential learning (Kolb, 2015) and project-based learning (Larmer et al., 2015) are common learning theories applied in design studio courses. Furthermore, collaboration, teamwork, and group work are effective pedagogies in design studios (Anteet & Binabid, 2025).

To categorize the outcomes of design studios, the Structure of Observed Learning Outcomes (SOLO) taxonomy can be used (Biggs & Collis, 1982; Biggs & Tang, 2011). According to this taxonomy, intended learning outcomes are categorized under five headings in an increasing hierarchy, and a pool of verbs is created for each category. It starts with the prestructural (1) category for failed outcomes. The next categories (and three example verbs) are: (2) Unistructural (memorize, draw, write), (3) Multistructural (describe, discuss, illustrate), (4) Relational (integrate, differentiate, solve a problem), (5) Extended abstract (reflect, generate, create). Teaching and learning activities, intended learning outcomes, and assessment tasks should be constructively aligned. Undergraduate courses are usually graded using norm-based assessment, in which grades are determined by comparisons among students, as opposed to criterion-based assessment, in which criteria or standards are established before the assessment. Biggs and Tang (2011) also identify four types of motivation to enhance the value of the task for students: (1) extrinsic (what the outcome produces), (2) social (what other people value), (3) achievement (the opportunity for ego enhancement), and (4) intrinsic (the process of doing it).

In architecture, design, and planning, it is common to apply to competitions with projects developed during courses. While some competitions have special, free-to-apply categories for students (e.g., iF Design, 2026; GP-Award, 2025), some are specifically designed for graduation projects (e.g., Archiprix, 2021). Awards primarily contribute to reputation and are listed among the categories used to measure design value (Lockwood, 2007). The ten categories used to measure design value are: (1) Purchase influence / emotion, (2) Enable strategy / enter new markets, (3) Build brand image and corporate reputation, (4) Improve time to market and development processes, (5) Design return on investment / cost savings, (6) Enable product and service innovation, (7) Increase customer satisfaction / develop communities of customers, (8) Design patents and trademarks / create intellectual property, (9) Improve usability, (10) Improve sustainability.

A study on the changing design education in the 21st century (Meyer & Norman, 2020) lists eleven challenges, grouped under four main themes: Performance, systemic, contextual, and global. Sustainability is the only challenge listed under global challenges, and three of the contextual challenges relate to the complex systems of projects, products, and services that designers must address. These complex systems often transcend the boundaries of organizations, stakeholders, producers, and user groups, and must meet demands and expectations at every level of production, distribution, reception, and control.

A comprehensive study (Faludi et al., 2023) offers recommendations for integrating sustainability into the design education curriculum at three levels of student specialization: all design students, students expecting to practice design for sustainability, and students pursuing elective or advanced studies. The study lists sustainability topics under six headings: (1) Fundamentals of sustainability, (2) circular economy, (3) whole systems thinking, (4) sustainable innovation strategies, (5) impact assessment, and laws and standards, and (6) communication, collaboration, and leadership. According to the classification, product and product-service-systems-focused strategies are primarily grouped under the headings of circular economy and sustainable innovation strategies. While all students should be taught that sustainable innovation tools and

methods exist, specific strategies should be taught to the second type of students who will be practicing in sustainable design. Furthermore, the product-service system approach should be taught to all students, external stakeholder management to the second type of students, and systems mapping to the third type of students pursuing elective or advanced studies.

3. Research Method

The research method of this study is a comparative case study (Yin, 2018). The case is "Sustainable Product Design", an elective course on design for sustainability offered at the Department of Industrial Design at Istanbul Technical University, which awards a B.Sc. degree after four years of undergraduate education. The comparative case study examines two semesters of the course: Fall 2024/2025 and Fall 2025/2026 (hereafter abbreviated as 2024 and 2025, respectively). The primary reason for selecting these two semesters is that the course plan was updated in the latter semester; the content remained the same, but the time plan, number of assignments, and evaluation criteria were updated.

Furthermore, in 2025, four projects developed individually and as a team by students were selected as finalists in the international competition, the Green Product Concept Award (GP-Award, 2025), among 183 projects from around the world across 13 categories. The jury of the competition consists of 24 experts in sustainability and design, from leading companies, universities, research organizations, public institutions, and publishers.

The data analyzed in this study consisted of archival materials, course documents, and course outputs. In 2024, 54 projects were submitted by 27 students; in 2025, 34 projects were submitted individually or in teams by 26 students, resulting in a total of 87 projects analyzed. During the analysis, the focus was on the design process, how each project was developed, and the themes and UN SDGs the projects aim to contribute to.

3.1. Background Information on the Case Course

The course content was developed by the author, and the course was first offered in the 2017 / 2018 Spring Semester. The developed course curriculum was tested through a workshop with students (Küçüksayraç & Arıburun Kırca, 2020). The course aims to provide in-depth knowledge of design for sustainability and its approaches at the product and product-service-system innovation levels. The course is a fourth-year elective course with four ECTS credits. When the course was first offered, it consisted of two theoretical and two practical hours, and three local credits. In the 2021 / 2022 Fall Semester, a new second-year compulsory course on sustainability was added to the undergraduate program, which focuses on society and sustainability. The same year, all elective courses in the program were set at two local credits and three weekly hours. Therefore, the weekly hours of the case course were also reduced to three hours, consisting of one theoretical and two practical hours. Following these updates to the undergraduate program and the course, its content was also updated.

In recent years, the student quota has been set at 30, consistent with most program electives. This course is offered to industrial design students; however, Erasmus+ Programme students enrolled in other programs may also take it. The course has been offered to 186 students over seven semesters. Furthermore, the course instructor teaches a course on environmental sustainability in the master's program in the same department and has also been one of the instructors in a first-year interdisciplinary elective course on sustainability offered by the Department of Urban and Regional Planning to all five programs in the Faculty of Architecture at Istanbul Technical University.

The course description in the course catalog includes the following topics and approaches to design for sustainability: Sustainability concept, design for sustainability and its approaches, eco-design strategies, eco-friendly materials and production techniques, sustainable energy technologies, life cycle assessment (LCA), design for sustainable behavior and lifestyles, design for the base of the pyramid, cradle to cradle, and sustainable product-service system. Circular product

design was not included in the initial course description but was later added to the course content because it is a more recently developed approach (see Bakker et al., 2021; Charter, 2018).

The course outcomes consist of two projects: one at the product level and the other at the product-service system innovation level. Additionally, students must submit a sketchbook containing assignments completed during the practical hours of the course. Assignments are determined according to the course content and the topics covered in the theoretical hours and are structured as design-idea-generation exercises. They serve as assessment tasks and usually include the verbs design, analyze, illustrate, apply, as well as list, make a plan, research, answer, select, compare, redesign, review, and rewrite.

Since it started, the course content has been improved each year, while the core of the process described above has remained the same. Observations made during the course and improvements made to the course content over the years are summarized in Table 1. In addition to observations, students complete an anonymous satisfaction survey developed by the Rectorate each semester, which is then shared with the course instructors. This feedback has also been considered and contributed to improvements.

Table 1 Observations and Improvements for Improving the Course Content

Observation	Improvement
Students' questions	Elaboration of theoretical content and sharing best practice examples
Themes frequently chosen by students for their projects	Adding best practice examples related to these themes to the course content, aiming to improve final projects beyond existing solutions
Quality of students' assignments	Balancing course content and outcomes by increasing or decreasing the complexity and requirements
The use of AI tools by students	Aiming to develop AI-resistant assignments, if possible; otherwise, explaining how to use AI responsibly and efficiently

4. Findings

The course plan followed a similar theoretical and practical flow until 2025; preliminary and final juries were held on sustainable product design and sustainable product-service system projects. In 2025, the course schedule was revised to include a condensed theoretical section in the first five classes. Following the theoretical hours, assignments were briefly introduced to the students, and time was given for them to begin their work and ask questions. Following these first five weeks, a preliminary jury was held on sustainable product design. Then, three practical classes focusing on project development were conducted. Separating theoretical and practical hours of a course into different classes, rather than implementing them within the same class, was used in hybrid (online and in-person) education during the COVID-19 pandemic. The reason for the update was to limit the number of assignments, encourage students to develop their projects in depth, and allow for more detailed design critique. Assignments were revised to offer students options of design-for-sustainability approaches to choose from, or to combine closely related approaches, such as eco-design and LCA, or cradle-to-cradle and circular product design. This way, the number of assignments students had to complete was reduced, while the scope of the content remained the same.

In 2025, the course's final submission requirements were revised to require students to enter the sustainable product design project they developed during the course in a design competition. Students were required to submit proof of participation in a design competition in addition to the project. This was not compulsory, but it affected the grading. In previous years of the course, the Green Product Concept Award had been introduced to students in the theoretical part on certifications, laws, and standards, but their participation was not tracked.

There were no changes in the final requirements for the sustainable product-service system design. The sketchbook content was revised to include fewer assignments. The weekly course plan and content for 2024 and 2025 are shown in Figure 1. It should also be noted that in both semesters,

one class was suspended due to public holidays, resulting in 13 classes in the standard 14-week semester. Final projects were submitted on the exam date officially announced by the Registrar's Office (usually one or two weeks after the last class).

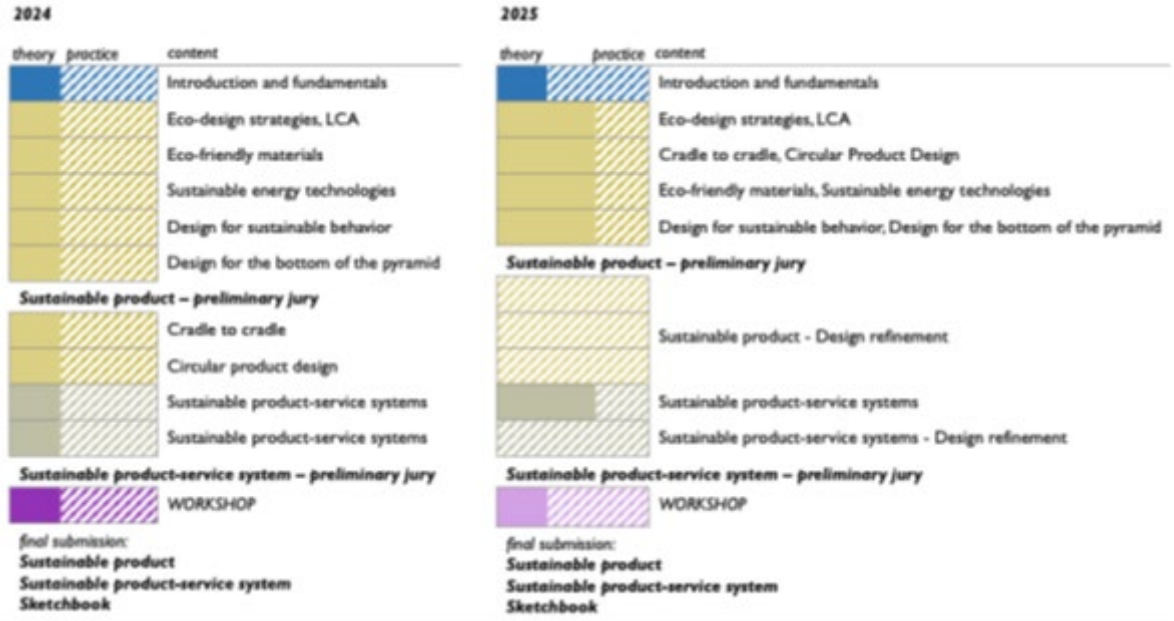

Figure 1 The course plan and contents in 2024 and 2025

In both 2024 and 2025, the last class was dedicated to two separate workshops on eco-friendly materials, conducted by graduate students and supervised by the instructor. Both workshops received ethical approval from the Istanbul Technical University Social and Human Sciences Scientific Research and Publication Ethics Board. Student participation was voluntary and confirmed by written consent from the participating students. The specific theme of the 2024 workshop was the use of generative artificial intelligence in material research and selection in design, while the theme of the 2025 workshop was material tinkering with living organisms in design (Karaca & Küçüksayraç, 2026). The workshops helped students expand their knowledge of materials, provided them with hands-on experience, and gave them insight into the content of graduate studies in industrial design.

In 2024, 28 students took the course, and 27 of them completed their submissions and passed. In 2025, 26 students took the course, and all of them completed their submissions and passed. Two Erasmus+ Program students from Germany took the course in 2024, while four students from Italy, the Netherlands, and Germany took the course in 2025. In 2024, all students were required to present individual projects. However, in 2025, teamwork was encouraged in project submissions. Sketchbooks were still required to be completed and submitted individually by the students. As a result, eight teams were formed, seven of which consisted of two students each. The only team of three students consisted of three Erasmus+ Programme students from Italy and the Netherlands. In total, 26 students submitted 17 sustainable product design projects, 17 sustainable product-service system projects, and 26 sketchbooks.

The task assessment type of the course is criterion-referenced, in which individual submissions are graded based on predetermined criteria. While norm-referenced assessment and bell curves are commonly used in undergraduate education and are mandatory for courses with more than 30 students at Istanbul Technical University, a criterion-referenced assessment was chosen to ensure that students who meet the criteria could receive a good grade. In 2024, one student failed the course for not completing assignments, while another student completed assignments at a satisfactory level. In 2025, all submissions were at least good, and the number of students demonstrating excellent performance increased from five to nine compared with the previous year.

Student feedback was not collected for research purposes; it was collected and reported solely through the survey conducted by the Rectorate. Since completing the online survey is not mandatory for students, no students completed it in 2024, and only one student completed it in 2025. For all Likert scale items, the student chose the most positive response category. In the only open-ended item regarding opinions and suggestions about the course, the student wrote: "…Our instructor effectively taught me different methods from a sustainable design perspective and, through hands-on activities, enabled me to reflect these principles in my own designs. Furthermore, the instructor truly encouraged me to participate in competitions, providing a significant contribution to my professional growth." The anonymous survey results are shared with faculty members through the online Student Information System.

4.1. The Projects Developed in the Course

When developing the sustainable product design project, students are expected to present two alternative design concepts, either selected from their assignment outcomes or by proposing a new concept based on the design-for-sustainability approaches at the product level. In both cases, they are expected to apply multiple design-for-sustainability approaches to increase the sustainability impact. During and after the preliminary jury, students select a sustainable product design concept to continue developing, taking into account the instructor's critiques and their peers' feedback. The second project on the sustainable product-service system was developed by students in response to the assignment given after the theoretical part. Students are also given the option to work on these two projects at separate levels in a compatible way; this means they can develop a product-service system starting from a product idea they developed during the course. Similarly, after the preliminary jury of the product-service system design project, students are given the option to develop a product that is necessary for or complements the product-service system they have presented and submit it as the final sustainable product design project. The aim is to equip students with the ability to build relations among various design-for-sustainability approaches across different levels of innovation, iterate by applying multiple approaches, and thus deeply examine user needs and sustainability goals to obtain a more impactful sustainable solution. The course process in 2024 and the flows of design ideas between the two projects are shown in Figure 2.

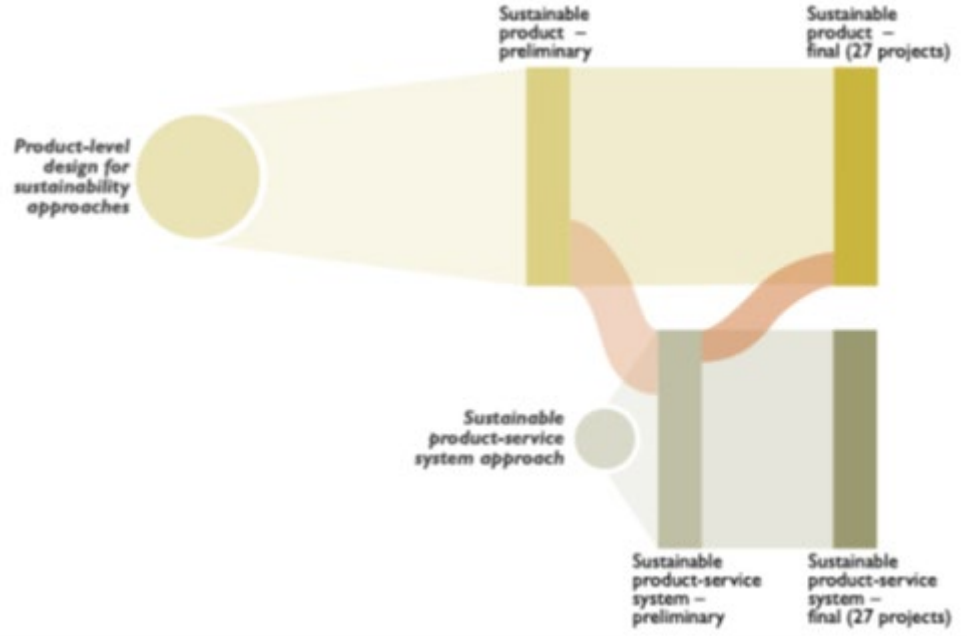

Figure 2 The course process in 2024 and the flow between the projects

In 2025, students went through a similar presentation and jury process to previous years; however, the timeline was changed, and the submission of a competition entry certificate was added to the grading, as previously mentioned. The course process in 2025 and the flow of design ideas between the two projects are shown in Figure 3.

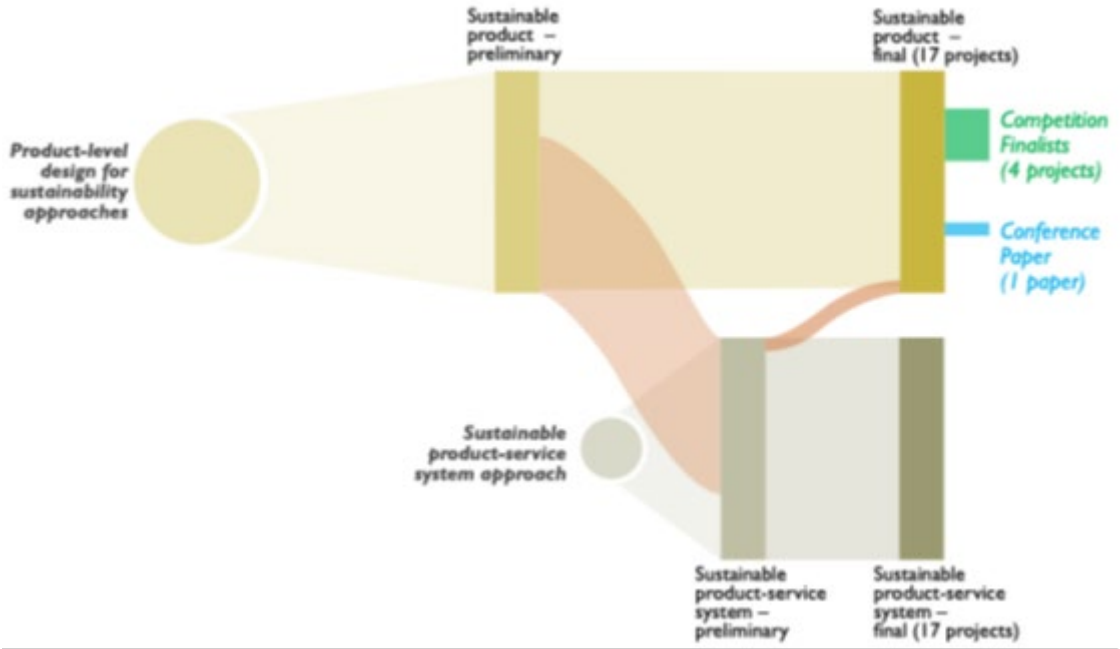

Figure 3 The course process in 2025 and the flow between the projects

As a result of the competitions in which students participated with projects they developed during the course, four projects were selected as finalists in the Green Product Concept Award. The product and product service system dimensions of the finalist products are shown in Table 2, and selected visuals of the finalist projects are shown in Figure 4. These projects belonged to two individual students and two teams, one of which consisted of three Erasmus+ Program students. However, the Green Product Concept Award was not the only competition students were encouraged to enter; the Istanbul Mining and Metals Exporters Association (IMMIB) (2025), Industrial Design Competition was also offered as an option. Unlike the Green Product Concept Award, this competition had four sub-categories under the specific theme of "Creative Solutions and Designs for Unforeseen Situations": (1) Disasters and emergencies, (2) Unforeseen, sudden crises in daily life, (3) Sudden situations arising from individual needs, and (4) Small, preventive and interventional solutions. The projects were evaluated in two main categories: Metal and plastic products. Also, the winners were announced at the end of the competition, but not the finalists.

Table 2 Product and system sustainability aspects of the finalist projects (based on GP-Award, 2025)

Project title (category) and short description	**Product aspect**	**Product-Service System aspect**	**The UN-SDG targets primarily contributed**
Coffee Pur (workspace) Coffee waste-to–carbon cartridge system	Design supports sustainable material cycles	Product-oriented: Cafés and hotels convert their own coffee waste into carbon cartridges to be used for water purification	SDG 12.4; environmentally sound management of chemicals and all wastes throughout their life cycle
Cook A Pack (packaging) The packaging that makes you want to play	Mono-material recycled solid cardboard and eco-friendly inks	Product-oriented: Packaging becomes a creative kit for children, extending the play experience beyond the product through a digital tutorial	SDG 12.5; substantially reduce waste generation through prevention, reduction, recycling and reuse
HUSK (consumer goods) Turkish coffee cup made by coffee ground	Bio-composite exterior manufactured from coffee waste and ceramic interior	Product-oriented: Local production through coffee-waste collection from users	SDG 12.4; environmentally sound management of chemicals and all wastes throughout their life cycle
Mico-Guard (kitchen) Circular fire Safety integrated with insurance	Steel body, magnetic mounting detail, and refillable cartridge	Result-oriented: Fire safety service integrated with home insurance, products owned by the service provider	SDG 7.1; universal access to affordable, reliable and modern energy services

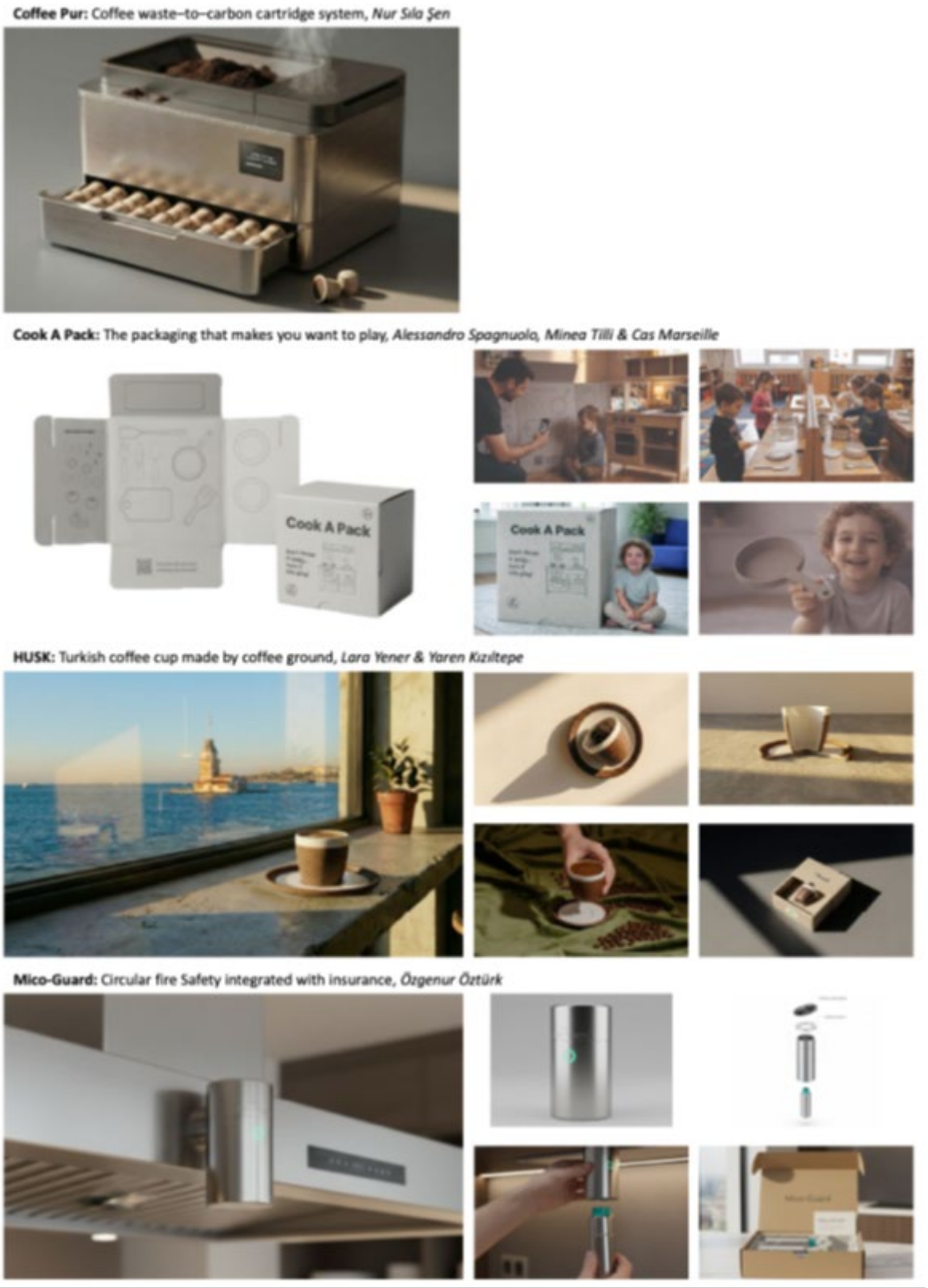

Figure 4 The projects that were developed in the course and were selected among finalist in the Green Product Concept Award (GP-Award, 2025)

According to the submitted competition entry documents, nine students participated in the Green Product Concept Award, six students and a team participated in IMMIB, and one team participated in a different competition. One student did not participate in any competition; this will be explained below. Given that the Green Product Concept Award is an international competition

and that nine projects were submitted, the number of finalists can be considered a success in terms of design, sustainability, and innovation.

Another difference from previous courses was that, in 2025, a student requested to focus on design research rather than product development for the first project and to submit a draft research paper. Since the student was already formally involved in a research project at another university, she aimed to enhance her research skills and experience. While presenting a paper at an academic conference is a requirement for completing graduate studies at Istanbul Technical University, writing a research paper is uncommon and not an evaluation criterion in the industrial design undergraduate program, especially in courses with a practical part. The instructor supported this request by informing all students in the course. Instead of a sustainable product design project, the student developed and presented a draft of a research paper. After the course was completed, she continued to develop the draft with the instructor's supervision. The paper was completed in the following semester, submitted to a national design research conference, and was accepted. The student also developed and presented a sustainable product-service system project with a product component, based on her research, like the other students. Therefore, the project was included among the sustainable product design projects shown in Figure 3 and was linked to the sustainable product-service system project.

The specific design-for-sustainability approach, which is the starting point for sustainable product design projects, is not included in Figure 2 and Figure 3 due to the submission process. Assignments were submitted as a compilation in a sketchbook, rather than as weekly submissions. Furthermore, students were able to work on the same product in multiple assignments. Therefore, it is not possible to fully define the design-for-sustainability approach that served as the starting point for each project.

4.2. The Project Themes and UN SDGs Targeted

The theme list for grouping student projects is based on the categories of the Green Product Concept Award (GP-Award, 2025). It is arranged alphabetically as follows: (1) Architecture, (2) Building design, (3) Consumer goods, (4) Fashion, (5) Startups, (6) Interior and lifestyle, (7) Children, (8) Kitchen, (9) Mobility, (10) New materials, (11) Packaging, (12) Personal care and (13) Workspace. As additional information, the sports category has been added to the competition in 2026. The ratios of themes covered in the projects in 2024 and 2025 are shown in Figure 5.

Figure 5 The project themes in 2024 and 2025, according to the Green Product Concept Award (GP-Award, 2025) categories

Although a single category was chosen for each project, some concepts could be evaluated under more than one category. For example, a wearable product that supports people's well-being was considered a consumer good, rather than a fashion product. If the business model of product-service systems predominantly encompassed businesses or public institutions, it was classified in the initiative category. Nevertheless, by comparing the number of themes in 2024 and 2025, it can be observed that the 2024 projects have greater category diversity. This can be explained by the

difference in the number of projects and the decrease in the number of assignments. In addition, in both 2024 and 2025, students did not work in the architecture and building design categories, which is expected, given that they are mostly industrial design students.

Figure 6 shows the UN SDG to which each project can contribute the most. Considering all projects, the SDGs to which the greatest contribution can be made are, in order: SDG 12, SDG 3, SDG 11, SDG 7, SDG 6, and SDG 15. While the number of sustainable product design and sustainable product-service system projects is the same for each goal for 2025, the goals are not the same for each student or team's projects, but the total numbers are the same. In terms of themes, a project can generally contribute to more than one SDG, but a single selection is made for each project. For example, projects aiming to change existing materials and production techniques with more sustainable ones are grouped under SDG 12, while products primarily aimed at improving health, well-being, and lifestyles are grouped under SDG 3. Projects that aim to contribute to sustainable cities and disaster resilience and to build communities through sustainable product-service systems and platforms are grouped under SDG 11. Furthermore, projects related to stray and wild animals are evaluated under SDG 15, while projects related to domestic animals are evaluated under SDG 3.

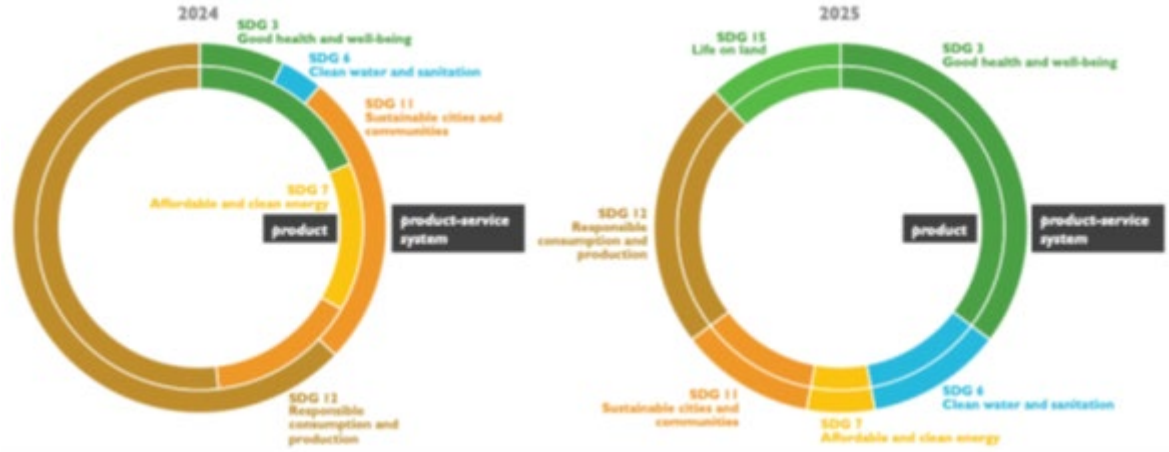

Figure 6 The UN SDG that each project aims to contribute to in 2024 and 2025

5. Discussion

The course examined in this study, an elective in undergraduate industrial design education with both theoretical and practical components, primarily aims to develop students' skills in applying design strategies for sustainability at the levels of product and product-service system innovation. While the course briefly addresses the fundamentals of sustainability, it primarily focuses on sustainable innovation strategies. In this respect, it is consistent with the topics suggested by Faludi et al. (2023) for elective or advanced studies. A workshop conducted to develop the course content showed that the biggest challenge students faced in applying design-for-sustainability strategies was deciding which strategy to focus on (Küçüksayraç & Arıburun Kırca, 2020). Furthermore, the literature emphasizes that, although their effects differ, all approaches are important for achieving sustainability and should be applied together (Crul et al., 2009; Ceschin & Gaziulusoy, 2019). Figure 2 and Figure 3 show that students were able to explore different design approaches for sustainability, even at different innovation levels, and apply more than one approach in a single project.

The assessment tasks and verbs used for the intended learning outcomes of the course are listed in Table 3 and classified according to the SOLO taxonomy levels (Biggs & Collins, 1982; Biggs & Tang, 2011) and the list of sustainability topics (Faludi et al., 2023). All sub-topics listed as necessary for sustainability-specific programs are covered in the course. The first class begins with an introduction to the course content and a summary of sustainability fundamentals, followed by an assignment on students' daily sustainability-related habits. This assignment and its revision in the

last week can be assessed within the relational category of the SOLO taxonomy. In subsequent weeks, design-for-sustainability approaches are taught, and students begin working on related assignments. Among these assignments, only the first assignment, which focuses on eco-design strategies, can be categorized as relational, as students are asked to redesign a product, analyze and compare it, illustrate the eco-design strategy wheel, and answer eco-design checklist questions. The following assignments and the two projects can be assessed in the extended abstract category.

Table 3 Assessment Tasks, Verbs of the Intended Learning Outcomes, and Their Analysis

Assessment Tasks	**Verbs of the Intended learning outcomes**	**SOLO taxonomy levels (Biggs & Tang, 2011)**	**Sustainability Topics (Faludi et al., 2023)**
Assignment 1: Daily habits and plans	List, make a plan	Relational	Fundamentals of sustainability
Assignment 2: Eco-design strategies, checklist, and wheel	Redesign; select, analyze, compare, illustrate, answer	Relational	Sustainable innovation strategies Impact assessment and laws and standards
Assignment 3: Cradle to cradle, circular product design	Design; apply, analyze, illustrate	Extended abstract	Sustainable innovation strategies Circular economy
Assignment 4: Eco-friendly materials, sustainable energy technologies	Design; select, research	Extended abstract	Sustainable innovation strategies
Assignment 5: Design for sustainable behavior, design for the bottom of the pyramid	Design; apply, illustrate	Extended abstract	Sustainable innovation strategies
Assignment 6: Sustainable product-service systems	Design; analyze, illustrate	Extended abstract	Sustainable innovation strategies Whole systems thinking
Assignment 7: Revision of Assignment 1	Review and rewrite	Relational	Communication, collaboration, and leadership
Project 1: Sustainable product design	Design, apply, analyze	Extended abstract	Sustainable innovation strategies Circular economy
Project 2: Sustainable product-service systems	Design, analyze, illustrate	Extended abstract	Whole systems thinking

The assignments students must complete after each theoretical section aim to support the development of design ideas based on the design-for-sustainability approaches taught. Reducing the number of assignments has helped students focus on developing sustainable product design ideas further in terms of user scenarios, materials and production techniques, product technical drawings, CAD models and renders, and presentations, as well as the design-for-sustainability approaches applied. If a course aims to have students generate design ideas rather than focus on product detailing and development, increasing the number of assignments may lead to broader coverage of themes. However, as in this study, if the course aims to enhance students' product detailing and development and the rigorous application of design-for-sustainability approaches, limiting the number of assignments may be preferable.

Examining Figure 2 and Figure 3, it can be observed that in 2025, the starting points for most sustainable product-service system design projects are sustainable product design projects. This may be due to the increased emphasis on sustainable product design projects, as students were encouraged to submit these projects to competitions. Furthermore, when comparing the number of flows for each project type in both 2024 and 2025, it can be observed that sustainable product design projects serve as the starting point for sustainable product-service system design projects more than the other way around. This situation may stem from differences in the complexity of the projects' innovation levels and in the timeline and flow of the course structure. In any case, it can be concluded that students can establish relationships among design-for-sustainability approaches at different levels of innovation.

As an additional observation, the concentration of theoretical content in fewer classes creates a disadvantage for students who miss these courses. This situation is intended to be addressed by having the instructor repeat important theoretical parts when necessary, or by students reviewing course materials and engaging in peer learning. It should also be noted that students take an eight-

hour design studio course each semester in addition to other compulsory and elective courses; therefore, the time they can dedicate to electives is limited. Nevertheless, students can complete their projects according to the specified criteria.

The number of projects developed within the scope of the course and selected as finalists in the 2025 Green Product Concept Award can be considered an indicator of success in design, sustainability, and innovation. Several factors were observed to be important in this process. First, instructors need to select and suggest the right competitions for student participation. The application requirements and schedule of the Green Product Concept Award competition were well-aligned with the course's project outcome criteria, timeline, and deadlines. Furthermore, its international nature motivated the students. Second, the Green Product Concept Award announced the finalist projects, while IMMIB announced only the winners, who are fewer in number, although only Turkish citizens can apply. Identifying and announcing finalists before the winners in a two-stage evaluation is a common strategy, also observed in other international design student awards. This can both motivate more students and provide transparency for all participants and those following the competition results. Although more data are needed, based on limited formal student feedback on the courses, participating in competitions may provide students with social and achievement motivation in addition to extrinsic and intrinsic motivation, as defined by Biggs and Tang (2011).

The UN SDGs targeted by the students in their projects largely overlap with the goals that the design field can contribute to, as defined by the WDO (2015), although there are also projects developed targeting SDG 15 (Life on Land) in the course. In contrast, SDG 9 (Industry, Innovation and Infrastructure) was not considered as most relevant for the projects in this paper, as the projects focused more on people, ecosystems, and communities. Thus, it can be stated that the projects embrace the definition of humanity-centered design proposed by Norman (2024). However, innovation is one of the criteria for both outcome projects in this course; therefore, SDG 9 is also relevant for all projects. Furthermore, the sustainability aspects of the finalist projects are presented in detail in Table 2, including the type of product-service system (Tukker, 2004; VentureWell, 2022), and the specific targets they can primarily contribute to in relation to the UN SDGs (2015). In the future, this can be added as a task for students to analyze and report on the intended contribution of the projects.

As a final point of discussion, the sustainable products and product-service systems developed in the scope of the course, their target themes and SDGs, and the finalist projects exemplify the complexity in terms of the number of sectors in which industrial design education operates, the stakeholders it must consider or interact with, and therefore the knowledge that needs to be integrated into the curriculum. These challenges have also been addressed in the literature (e.g., Faludi et al., 2023; Meyer & Norman, 2020). In design studios, complexity is often limited by problems, categories, or themes defined in design briefs. This study exemplifies a course with theoretical and practical content that is primarily concerned with design for sustainability, encompasses the complexity of both sustainability and design, and therefore presents unique challenges. In this course, complexity is intended to be navigated by integrating theoretical and practical parts across assignments and project outcome criteria.

6. Conclusions

This study aimed to exemplify a specific type of undergraduate course in design for sustainability and to share findings and experiences from the course. The case course is a fourth-year undergraduate elective with both theoretical and practical parts. The study aimed to inform researchers, lecturers, and practitioners working in the fields of design for sustainability and design education. Data from two semesters, before and after the course update, were compared in terms of course content, processes, outcomes, themes arising from these outcomes, and alignment with the UN SDGs. The findings showed that although the theoretical content remained unchanged, changes to the course schedule and assignments were reflected in the scope and quality of the

course outcomes. Furthermore, encouraging student participation in design competitions that aligned with the course content and schedule improved the quality of course outcomes. Such recognition of achievements beyond the course grade is important for students' professional development and can motivate them to succeed in real-world situations.

One limitation of the study is that the data are limited to archival materials, course documents, and course outcomes and do not focus on student feedback. Furthermore, it is a comparative case study covering two semesters of a single course. Future studies could focus on courses with different structures and pedagogies in industrial design, architecture, and planning that aim to contribute to the sustainability and continuous improvement of design education.

Acknowledgements

The author thanks the anonymous reviewers and the editor for their constructive comments and suggestions.

CRediT Authorship Contribution Statement

Elif Küçüksayraç: Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The author declares no conflict of interest or competing interests.

Data Availability

Data will be made available on request.

Ethics Committee Approval

Ethics committee approval was not required for this study as it relied on archival data and did not involve human participants. No active data collection methods, such as surveys, interviews, or focus groups, were utilized. The product and product-service system descriptions and visuals presented in Table 2 and Figure 4 are based on the cited GP-Awards (2025).

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Resume

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