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Designing Environmentally Sustainable Furniture Products: Furniture-Specific Life Cycle Design Guidelines and a Toolkit to Promote Environmental Performance

Dongfang Yang * and Carlo Vezzoli *

Design Department, Politecnico di Milano, 20158 Milano, Italy
* Correspondence: dongfang.yang@polimi.it (D.Y.); carlo.vezzoli@polimi.it (C.V.)

Abstract: As awareness of the serious environmental impact of the furniture sector increases, design is increasingly recognized as a crucial lever for innovating towards sustainable furniture products. This acknowledgment was emphasized by the European Union in the Circular Economy Action Plan in 2020 and is further emphasized in the forthcoming Ecodesign for Sustainable Products Regulation in 2024. To address the environmental issues stemming from the life cycle of furniture products, which constitute the fundamental part of the furniture system, specific design knowledge and know-how are developed within this study. Although Life Cycle Design (LCD) is a systematic approach to reducing environmental impacts, its application within the furniture system remains limited. This paper adopts a design-based research approach with three research stages and employs various methods including a literature review, case study, workshops, interviews, questionnaires, and a focus group to develop furniture-specific LCD guidelines and a toolkit. As a result, this paper presents furniture-specific LCD guidelines (comprising 7 strategies, 21 sub-strategies, and 154 guidelines), 41 environmentally sustainable furniture case cards, and a toolkit (comprising 4 tools). These guidelines provide comprehensive principles for designers to address environmental impact throughout the furniture's life cycle. The toolkit guides sustainable furniture LCD, promoting low environmental impact and high design efficiency. These outcomes address the existing gaps in knowledge and tools in this field.

Keywords: environmental impact; sustainable furniture; life cycle design; design guidelines

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1. Introduction

1.1. The Environmental Impact of Furniture

As sustainable development becomes an increasingly pressing concern, the furniture industry has been identified as a sector in need of attention and improvement [1]. In 2023, the Joint Research Center of the European Commission assessed 19 product groups, considering their environmental impacts and potential for improvement. The assessment ranked furniture as the second highest-scoring group, after textiles and footwear [2]. Globally, according to estimates from the Centre for Industrial Study, furniture production, exportation, and consumption reached $490 billion, $160 billion, and $477 billion, respectively, in 2019 [3]. The furniture industry has doubled its volume from 2000 to 2021, reaching a worldwide volume of about $500 billion, with projections indicating further growth in the next year [4]. However, these data equate to approximately 58.64 million tons of furniture consumed and 56 million tons discarded each year worldwide (calculated based on data from [4,5]). Such levels of production and consumption result in significant resource utilization, harmful emissions, and waste generation. Data from the Consumption Footprint Platform [6] show that, since 2018, furniture has been the most impacting sector (with 27.79 mpt Consumption Footprint per capita) among all household products (which are furniture, clothes, paper products, detergents, plastic products, footwear, sanitary products, bed mattresses, and personal care). If compared with larger amounts of product groups,

it is still possible to see the importance of furniture in a total of 55 sectors from 5 groups (food, housing, mobility, household goods, and appliances). The furniture sector ranked as the 9th most impacting sector for Consumption Footprint per capita, after meat (food), dairy (food), single-family houses_moderate (housing), passenger cars_gasoline (mobility), passenger cars_diesel (mobility), multi-family houses_moderate (housing), beverages (food), and multi-family house_warm (housing), and as the first most impacting sector among all household sectors. These environmental impacts are also evident throughout the furniture's life cycle, from pre-production to disposal [7]. A profound change in the furniture system is vital for the transition towards sustainability.

1.2. The Role of Design for Sustainable Development

The importance of design in creating sustainable furniture products is increasingly acknowledged. Incorporating environmental considerations at the design stage is more efficient and economical than implementing retroactive solutions to limit damage, which can be costly and risky. The European Commission reports that up to 80% of a product's environmental impact is determined at the design stage, and emphasizes the importance of sustainable design knowledge in addressing environmental issues associated with the product [1].

The focus on design for sustainability has expanded the level of innovation from low-impact material and energy selection to sustainable product design to sustainable system design [8]. In the early level of sustainable design practices, i.e., low-impact materials and energy selection, the primary emphasis is on the redesign of individual qualities of individual products [8], such as materials or components. Typical examples of such practices included reducing the quantity of materials used in a product, utilizing recyclable materials, renewable materials or energy sources, substituting virgin materials with recycled alternatives, and replacing hazardous or toxic materials with non-hazardous ones.

Sustainable product design, such as eco-design, represents a design approach aimed at reducing the environmental impacts of products throughout their entire life cycle while ensuring similar or improved performance for the end customer [9]. Different from materials or energy selection, which improves an individual aspect of a product, eco-design puts emphasis on the whole life cycle of the product, ranging from the extraction of raw materials through manufacturing, distribution, and use to final disposal [10–17]. Eco-design is also referred to as Life Cycle Design (LCD), Circular Design, or Design for the Environment [18–20].

1.3. The Current Situation of Sustainable Furniture Design

While the fields of environmentally sustainable product design are extensively studied, their application in the furniture industry is still scarce. According to findings from the literature review, the furniture industry is currently focusing on the first level of innovation, i.e., the single-indicator innovation, selecting resources with lower environmental impacts [21–25], such as materials choice [26–32], packaging volume or materials content reduction [33,34], labels, certification standards [35], waste management [36], component choice [21], and materials innovation [37], which are insufficient. These design principles are fundamental in the context of furniture, and they remain a central focus in contemporary furniture design practices. However, a common misconception in the furniture sector regarding environmental requirements is the belief that the selection of material with lower environmental impact could be the best leads to a product with a reduced environmental impact [18]. An example is furniture crafted from recycled thermoplastic sourced from used plastic packages. However, it is important to note that in order to meet quality standards and necessary mechanical requirements, additives are often incorporated into such designs, which can hinder further recycling at the end of the product's life cycle. While these innovations are significant steps in the realm of furniture design, they fall short of achieving full sustainability.

While LCD (or eco-design) has been extensively discussed in the literature, the environmental practices related to eco-design have a generic shape and are difficult to fit into specific product projects and industrial processes [38]. In the furniture sector, LCD is quite a relevant topic in the pursuit of sustainability. Although some fragmented attempts at furniture product LCD strategies have been proposed [39], there is still a lack of comprehensive furniture-specific approaches, strategies, and guidelines. Relevant research includes defining the eco-design criteria for Scandinavian wooden furniture industries [40], defining the design strategies for office furniture [41], which is one of the earliest works on furniture LCD that focuses on office furniture, evaluating the energy and economic saving potential of remanufacturing/refurbishing/reusing furniture [42], value chain management in a certain company [43], or a methodology to understand and measure the eco-efficiency in extended supply chains [42]. However, with the ongoing development of design for sustainability and furniture design research, numerous new insights have emerged. These include updated LCD guidelines [20], new furniture cases such as Orangebox [44], and insights from furniture companies, such as Gispen [45]. In light of these developments, there is a pressing need to establish new, comprehensive, and furniture-specific LCD knowledge and tools that are developed to be universally applicable and adaptable for furniture and for practitioners.

1.4. The Research Considerations, Questions, Objectives

Considering the increasing pressure for environmental protection, and the fact that few in the furniture design community possess the comprehensive knowledge base and expertise required for designing sustainable furniture, the research proposed the following research questions: What are the innovation requirements and characteristics of environmentally sustainable furniture products? And what new tools are needed for environmentally sustainable furniture product Life Cycle Design?

This paper aims to bridge this gap and answer the research questions by proposing comprehensive solutions that include design knowledge, in the form of furniture-specific LCD guidelines, accompanied by a practical and innovative digital toolkit. This toolkit integrates these guidelines into a collection of open access tools, designed for application throughout the furniture LCD process.

This article is structured as follows: Section 2 describes the methodology used to develop the furniture-specific guidelines and the Sustainable Concept Ideation (ICS) × Furniture toolkit. Section 3 presents the results of the research activities, including design guidelines, best cases, and tools for furniture LCD. This section also discusses the iterative process of applying, evaluating, and refining the ICS × Furniture toolkit. This paper concludes with Sections 4 and 5, which emphasize the key findings and contributions to both the academic and practical fields, and acknowledge the limitations and directions for future research.

2. Materials and Methods

To develop the furniture LCD guidelines and the supporting toolkit for design practice, a design-based research approach [46] consisting of three research phases was employed, as illustrated in Figure 1. The initial phase involved conducting a literature review and analyzing promising cases to understand the environmental impact of furniture and to obtain valuable design insights that would inform the establishment of furniture-specific LCD strategies, sub-strategies, and guidelines in the next phase. In the development phase, an expert workshop was organized to develop a draft version of furniture-specific LCD guidelines. These guidelines were reviewed by internal and external experts before constructing the final version. A consolidated method [18,47], as illustrated in Figure 2, was applied. The final phase focused on the iterative processes of designing, empirically applying, evaluating by experts, and then updating and refining the ICS × Furniture toolkit. This toolkit, comprising four tools, integrates the guidelines developed in the previous stage, aiming to make these guidelines more actionable and supportive for designers throughout the design process.

Figure 1. The methodology of this research.

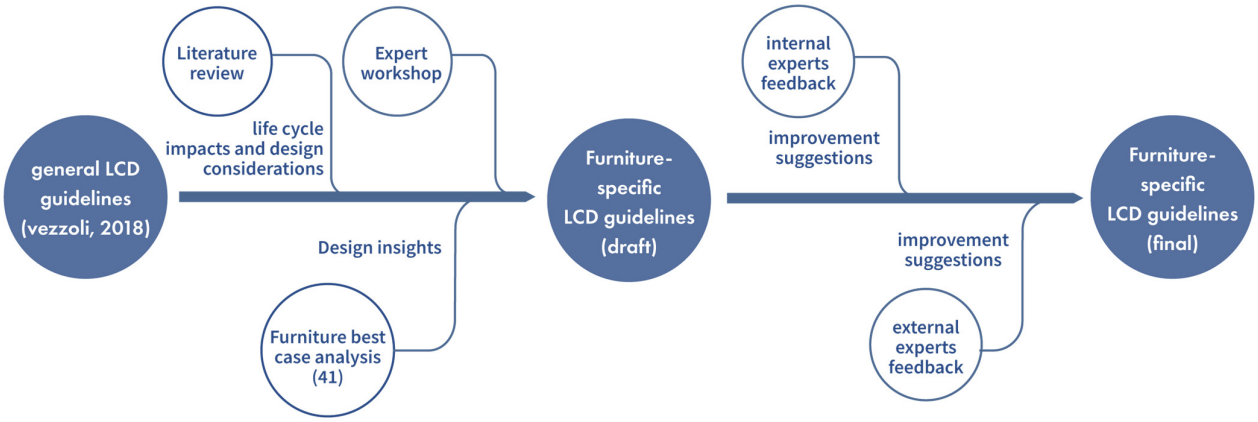

Figure 2. Prior knowledge and steps to develop furniture-specific product LCD strategies/sub-strategies/guidelines, adapted from [18,47].

2.1. Preliminary Research Phase: Analysis of the (Un)sustainable Characteristics of Furniture

The main objectives of this stage were to identify the environmental challenges associated with furniture and uncover insights into sustainable furniture design. Methods used in this stage were the literature review and case studies.

Step 1: A literature review was initiated to thoroughly examine the environmental impacts associated with furniture throughout its life cycle, andto explore furniture LCD insights as potential avenues toward environmental sustainability. For this analysis, a total of 165 articles and books, published from 2000 onwards, were found in Scopus and Google Scholar. Among these, 60 articles were identified as highly relevant to this study, with an additional 12 articles considered to be of moderate relevance. These articles covered a broad range of subjects, including various furniture types, materials, and manufacturing processes. Consequently, these 72 articles, exploring Life Cycle Assessments (LCAs) from 28 different countries, were analyzed to identify the environmental impacts and uncover valuable design insights.

Step 2: In addition to the literature review, a comprehensive analysis of best furniture design practices from an environmental perspective was carried out to understand the characteristics, environmental benefits, and design interventions. The selection of cases was guided by the maximum variation strategy. To ensure the robustness and reliability of the case study information, the triangulation method was employed. This involves using multiple data collection methods and sources to converge on a comprehensive understanding of each case. Data collection for this research was primarily through a literature review and desk research, relying on secondary data sources. These sources included scientific papers such as case studies conducted by other researchers, reports from international organizations like the European Commission, company reports, and information available on websites. A total of 41 sustainable furniture products cases were gathered and analyzed through a pre-defined case study format.

The insights gained from this analysis of the literature review and sustainable furniture product cases served as valuable input for the subsequent stage of the research, which focused on the development of furniture-specific LCD guidelines.

2.2. Development: The Development of Furniture-Specific LCD Guidelines and a Toolkit

The outcomes derived from research conducted in broad contexts often result in findings that are overly general and abstract, thereby limiting their practical applicability in diverse settings [48–50]. Although such general outcomes may not be effective in specific settings, they provide a foundation that can be adjusted, replaced, or adapted to meet the needs of different scenarios. In response to this challenge, this stage of the research focused on the development of furniture-specific LCD guidelines, building upon the general guidelines that have been refined through over two decades of research projects and industry consultancy by LeNS Lab Polimi [20]. The process of creating sector/company/product-specific LCD guidelines from general ones is rooted in a well-established methodology which is visually depicted in Figure 2 [18,47]. The methodology is organized into several key steps, as follows: With the design insights derived from the literature review and case study in the initial stage, a collaborative workshop was subsequently organized with a total of 6 scholars and experts specializing in furniture design and Design for Sustainability. The aim was to generate a preliminary draft of furniture-specific LCD guidelines. Furniture-specific guidelines consist of three levels of detail, namely strategies, sub-strategies, and guidelines. Each strategy encompasses multiple sub-strategies, and each sub-strategy consists of several guidelines. In this paper, when referring to guidelines in general, we are referring to all three levels of detail, including strategies, sub-strategies, and guidelines. The development process finished with the following activities:

Step 1: Before the workshop, a report was sent to all participants to collect their opinions on whether the general guidelines are clear and relevant to furniture and facilitate the generation of furniture-specific LCD guidelines.

Step 2: At the initial stage of the workshop, results from the preliminary research stage (environmental impacts and design insights from practical LCAs and academic literature review, sustainable furniture product characteristics from case studies) were presented to participants. The process to be followed for the workshop was also presented to participants.

Step 3: During the workshop, each of the general guidelines was presented, and all participants' comments before/during the workshop were recapped/recorded, discussed, and polished. During this phase, a structured process was implemented for each general guideline, allowing participants to perform a variety of specification actions, such as integrating a general guideline related to furniture products or typology; adding a new guideline that deals with a certain environmental impact related to furniture products or typology; adding notes related to particular furniture product or typology; and erasing a guideline if irrelevant; see examples in Table 1. The outcome of the workshop was a draft of furniture-specific guidelines, which was further reviewed and refined for final improvements. The workshop's main activity, the guidelines specification, was then completed.

Table 1. Examples of developing furniture-specific guidelines from general ones.

General Guidelines	Actions/Insights Sources	Furniture-Specific LCD Guidelines
Design modular and dynamically configured products to facilitate their *adaptability for changing environments*	Adding characteristics relevant to specific furniture products or types/Insightples from case study	Design reconfigurable furniture that can *adapt to different spaces and situations, such as modular desks and storage* that can be used for both transforming a given office space or *accommodating new function (e.g., an individual working station that can be transformed into a collective one, and that can also be rearranged if the office moves to a new location).*
Design products that can be upgraded and adapted *on-site*	Adding characteristics relevant to specific furniture products or types/Insights from case study and expert knowledge	[Office seats] Design modular and on-site upgradable seats, *allowing the user to substitute (with standard tools) fixed feet with wheels and/or fixed components with adjustable ones.*
	Adding new guidelines/Insights from experts' knowledge or case study	*Design a family of furniture instead of single ones, with different properties and functions that enable adaptation.*
Enable and facilitate software upgrade	Erase if irrelevant	

Note: The characteristics listed in blue/orange italics and underlined on the left column are updated through actions indicated in the middle column (with the middle column also denoting the source of the insights). The corresponding furniture-specified characteristic is listed in the right column with the same font and color style.

Step 4: After the workshop, each guideline was polished considering participants' comments. The draft version of furniture-specific LCD guidelines was developed.

Step 5: The draft version of the furniture-specific LCD guidelines was sent to 3 internal experts from LeNSLab POLIMI for improvement and finalization.

Step 6: Then, the new draft version was sent to external experts further improvement and finalization to form the final version of furniture-specific LCD guidelines.

2.3. Design and Iterative Evaluation and Improvement of the ICS × Furniture Toolkit

2.3.1. The Design of Furniture LCD Tools

This stage started with the conceptualization of the toolkit, aimed at determining the functions and structures of furniture LCD tools. An analysis was conducted on Design for Sustainability tools to identify the potential application of these general tools for furniture, while another aim was to identify gaps in tools for furniture LCD. The results revealed that there are tools for complete or simplified LCA, dedicated tools for specific environmental

performance (such as materials selection), and tools for description. However, there is a lack of qualitative evaluation tools and design tools for furniture Life Cycle Design. The general ICS toolkit [20] can be a good reference for the development of furniture-specific LCD tools for several reasons:

- The general ICS toolkit was developed as part of European Union-funded projects and the Lens Network. They have undergone verification by collaborators from approximately 150 universities.
- The general ICS toolkit integrates functions crucial for qualitative assessment, sustainability design orientation, and improvement comparison. These functionalities are significant in the development of sustainable projects and can support the entire design process from strategic analysis to concept design, detailed design, and communication.
- The new knowledge developed within this research, including the environmental impact, the developed guidelines, and the cases, can be seamlessly integrated into the toolkit to support furniture LCD.

Actually, the prototyping of furniture-specific tools follows the structures and functions of the general ICS Toolkit. New efforts encompass the specification of knowledge (achieved in former research stages) integrated into the tools for furniture, the optimization of functions of general ones, the sequence of operation, using steps, and the layouts.

2.3.2. The Iterative Improvement of These Furniture Tools

Following the design of furniture-specific LCD tools, an iterative cycle of evaluation and improvement took place. This cycle involved the empirical application of the tools, followed by evaluation, updating, and further redesign or improvement of the ICS × furniture toolkit, with the goal of enhancing its comprehensibility, usability, and usefulness. The primary methods employed during this stage included a workshop, interviews, a focus group, and questionnaires.

The strategy to involve participants was purposive sampling, where individuals were selected and invited specifically because they either were the end-users or had substantial experience as such. The developed toolkit was subjected to an iterative process of testing and refinement involving 70 furniture designers and experts in furniture design and/or design for sustainability.

(1) Tools Evaluation within the Course

Initially, the ICS × Furniture toolkit underwent empirical testing with 30 international furniture designers, graduates enrolled in a specializing master's program in "Furniture Design" offered by POLI Design (Politecnico Di Milano). This testing session took place during the "sustainable furniture design" course, organized in February 2022, which encompassed both theoretical sessions and practical activities centered around furniture LCD. Following an introductory session on LCD concepts, the designers were tasked with the challenge of designing a sustainable workstation for home use within a span of two days. The primary objective of this workshop was to evaluate the toolkit's usability, comprehensibility, and success/usefulness in the design process.

On the first day of the workshop, the author presented the strategic analysis results of an existing workstation, highlighting the LCD strategy priorities determined by the checklist for existing furniture evaluation. The designers were then tasked with utilizing the ECO-idea boards to generate a wide range of promising new design ideas. Following this creative process, these furniture designers engaged in discussions to select the most promising ideas, which were then put on the radar map adjacent to the corresponding design strategies.

On the second day, the designers developed new concepts based on the promising ideas generated and grouped on the first day. They were given the freedom to use sketches or 3D modeling software to visualize their concepts. Each group then presented their concepts, showcasing an overview, images, and the sustainable design characteristics of

their work. Despite the time constraints that prevented the completion of all projects, every group managed to consider key aspects of furniture LCD.

At the conclusion of the exercise, the participants were asked to complete questionnaires assessing the comprehensibility, usability, and success of the ICS × Furniture toolkit, which includes 5 tools (then, one tool called ESPI form was erased, and its functions were integrated into other tools). The quantitative data are presented in the Results section and, at the same time, some qualitative responses are discussed.

(2) Tools Evaluation with Experts

Following this initial testing and subsequent updates and refinements, the toolkit was evaluated by 19 participants, including furniture designers from design studios, experts, researchers, and professors from the Learning Network on Sustainability (LeNS) to obtain further insights for improvement. This evaluation involved three rounds, including interviews with furniture designers, a post-doc, and a professor with a background in furniture design; interviews with experts on design for sustainability/furniture design from the LeNS Network; and a focus group at DESIS China_Hunan University. The process of interviews and the focus group finished with the following activities (see Figure 3):

- The process initiated with the distribution of the toolkit to designers or experts participating in the process;
- At the outset of each interview/focus group, the facilitator provided background information and introduced the ICS × Furniture toolkit;
- Following the presentation, the facilitator guided the evaluation by proposing questions as needed, while designers or experts utilized the toolkit and offered feedback.

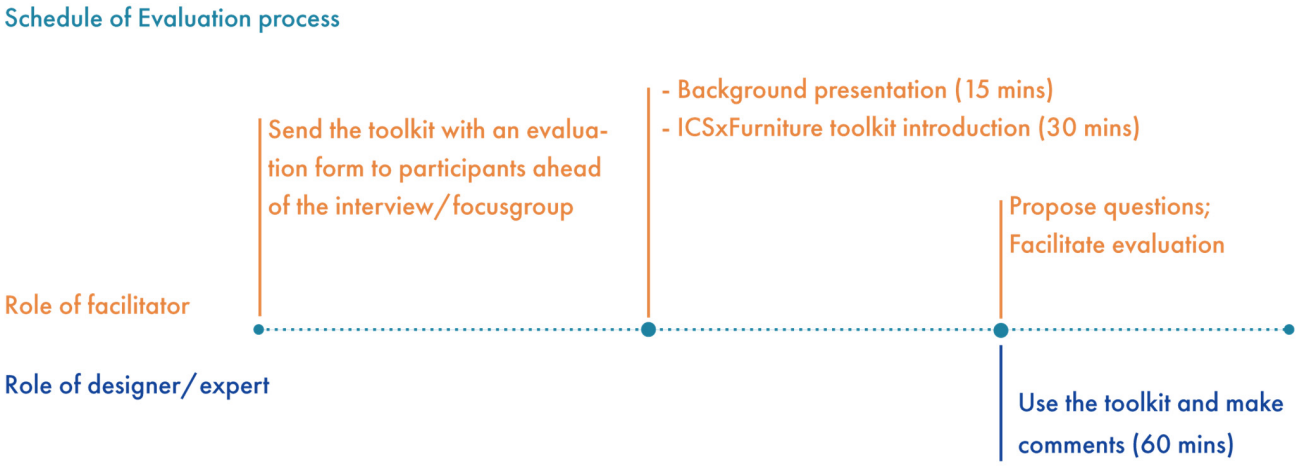

Figure 3. The process of interviews and focus group.

(3) Online questionnaire

At last, an online questionnaire was distributed to 21 LeNS members who were interested but did not have time for face-to-face tests.

In parallel with the in-person evaluations, online questionnaires were distributed among 21 LeNS Network members who were interested but were unable to participate in the focus groups or interviews. Each questionnaire was accompanied by a video presentation of the toolkit and a link for free download, ensuring that respondents had a clear understanding of its features and functionalities.

The continuous application and evaluation process of the toolkit brought opportunities to reflect and define the ICS × Furniture toolkit that designers need.

3. Results

3.1. Furniture's Environmental Impact and Innovation Approaches

The environmental impact of furniture has been extensively discussed by various authors. The primary outcome of the first research stage focused on the design insights proposed by authors following the conduct of LCAs. These design insights can be categorized as follows:

Material reduction: When designing furniture, it is critical to identify the components with the greatest environmental impact, such as the seatback of a chair, and to aim for dimension reduction [51], for example, by decreasing thickness through Finite Element Analysis [52]. Implementing advanced technology in production processes can enhance eco-efficiency by reducing the use of raw materials [34]. Nonetheless, new technologies are not universally the optimal solution; designers are recommended to select the most appropriate technological options based on site-specific and context-dependent evaluations [53]. In addition to considering the materials used in furniture, the reduction of packaging materials is also worth attention [54].

Material life extension represents another crucial strategy, focusing on extending the lifespan of materials through recycling or reuse [55]. This approach reduces the demand for new raw material extraction and mitigates disposal impacts associated with landfills or incineration. Research indicates a significant reduction in Global Warming Potential impact when chairs are recycled instead of being sent to landfills, particularly in a market with growing demand for recycled materials [56]. From an environmental perspective, recycling wood waste to manufacture particleboard is more favorable than generating energy through incineration [56]. Furthermore, employing a cascading approach to avoid waste throughout the product life cycle results in lower environmental impacts [57], such as reusing wood waste residue compared to using primary wood.

Energy reduction is essential throughout the furniture life cycle, with improving production efficiency being a common approach. Specifically, in the production of wood components, the milling saw step has a higher potential for reducing energy consumption than plantation, felling, finger joints, and lamination [58]. Therefore, focusing on enhancing efficiency during this phase is particularly worthwhile. Transportation plays a crucial role in reducing energy consumption.

Choosing a shorter supply chain is advantageous for reducing the environmental impacts linked to transportation [53]. Furthermore, oceanic shipping has lower environmental impacts compared to truck transportation [55]. Prioritizing the use of Euro 5 vehicles over the traditional Euro 4 for all transportation activities can result in substantial energy savings and diminished environmental impacts [54].

Resource conservation and renewability involve utilizing renewable materials and energy throughout the furniture life cycle. Renewable materials are those that do not surpass their natural regeneration rates, such as wood, bamboo, or natural fibers [59]. Additionally, advancements in technology have led to the development of biodegradable materials, like those made from hemp fiber and polylactide [60]. Utilizing energy from renewable and biogenic sources can significantly reduce greenhouse gas emissions [61]. For instance, energy harnessed from photovoltaic cells or biofuels (e.g., wood residues) offers a sustainable alternative to traditional diesel, aligning with environmental conservation efforts [59,62].

Extending the life of the furniture or intensifying its use can significantly reduce the life cycle impacts per functional unit. Designers and engineers can contribute by selecting materials that are highly resistant to wear and damage. For instance, densified hardwood represents a suitable choice for areas requiring high compressive or tensile strength [63]. Minimizing the production of defective products, particularly at the finishing stage, is crucial for enhancing the reliability of furniture products [64]. Moreover, multifunctional furniture, which can serve various purposes, is an avenue to intensify the use of furniture [65], making it a valuable consideration. Additionally, strategies such as reuse, refurbishment, and remanufacturing present viable options for extending the life

of furniture, and, at the same time, conserving the energy and raw materials required for producing new products [42,66]. Adaptive remanufacturing, which involves updating, reconfiguring, and customizing products that were previously considered obsolete to meet current market demands, offers a way to extend the product life cycle beyond traditional methods. This approach is not only environmentally beneficial but also economically sustainable, presenting a viable business strategy [39].

3.2. Furniture Best Practice Analysis

This study revealed a variety of sustainable benefits across 41 cases, each presenting unique environmental advantages through different design strategies. Significantly, 31% of the cases pointed to the potential for extending or intensifying the use of furniture, while 20% demonstrated benefits in terms of energy consumption reduction. Additionally, 17% of the cases were notable for their ability to prolong the lifespan of materials. About 15% of the cases showed advantages related to resource conservation and biocompatibility. Moreover, 14% of the cases focused on the benefits of reducing material consumption, and a smaller portion, 3%, highlighted the potential for reducing toxicity.

All 41 cases were coded with the label "#case number". These strategies are further broken down into primary design approaches (denoted as "A*") as derived from the case studies. Each primary design approach encompasses specific sub-approaches (denoted as "B*"), which are detailed in Table 2.

Table 2. Design approaches obtained from case study.

Design Strategies	Design Approaches	Detailed Design Sub-Approaches	Case Number
Furniture Use Extension or intensification	A6 modular system	B10 modularity with different functions	#5, #13
		B35 modularity with different sizes	#16
		B36 changeable shapes (e.g., bed, sofa)	#15
	A7 disassemble and assembly connections	B11 embedded nuts	#6
		B14 zipper connections	#8, #12, #19
		B15 reduction in the number of components/connections	#8, #9, #10
		B18 tupperware-like connections	#17
		B19 wedge dowel connections	#20
		B31 buckle connections	#30
		B34 special brackets and cut-outs	#41
	A8 multi-functions	B12 changeable dimensions (e.g., beds)	#7
		B36 changeable shapes (e.g., beds, closets)	#11
	A9 standardization	B13 universal components	#8
	A15 uses strong materials	B9 incorporation of metal as raw materials	#37
Reducing energy consumption of the furniture system	A2 reduced packaging volume	B3 stackable design	#3, #21
		B22 flat packaging	#23, #30, #42
		B25 vacuum packaging	#25
		B32 inflation assembly/disassembly	#31
	A3 distributed economy	B4 use of local raw materials	#3, #4
		B17 on-site assembly	#16, #39
	A12 enhancing environmental benefits rather than reducing impacts	B24 integration of energy generation mechanisms	#24
	A14 lightweight		#31

Table 2. *Cont.*

Design Strategies	Design Approaches	Detailed Design Sub-Approaches	Case Number
Furniture materials life extension	A5 use of low-impact materials_renewable/non-exhaustible/biocompatible materials	B8 use of recyclable materials	#4
	A7 disassemble and assembly connections	B14 zipper connections	#19
		B18 tupperware-like connections	#17
		B19 wedge dowel connections	#20
		B31 buckle connections	#18, #30
		B11 embedded nuts	#6
		B15 reduction in the number of components/connections	#8, #9, #10
		B34 special brackets and cut-outs	#41
	A10 mono-materials	B7 3D printing technology	#4
		B20 plastic molding processes	#18, #30
		B37 aluminium extrusion	#21
	A11 easier recycling	B21 materials marking	#22
Resources conservation/ biocompatibility for furniture	A5 use of low-impact materials_renewable/non-exhaustible/biocompatible materials	B6 utilization of waste plastic from other sectors	#4
		B8 use of recyclable materials	#4
		B16 utilization of waste components from other furniture within the same sector	#35, #42
		B23 use of sustainably sourced materials	#23, #38
		B33 utilization of renewable materials (e.g., bamboo, palm leaves, rattan)	#36, #39
Reduce material consumption of furniture system	A1 reinforced structure	B1 corrugated plywood	#1
		B2 ribbed structure	#2, #29
		B27 cross inset structure	#27
	A4 one-piece molding	B5 incorporation of bent wood craft	#3
		B7 3D printing technology	#4
		B30 compression molding	#30
	A13 avoids packaging waste	B28 packaging as component(s)	#28
Reducing toxicity	A5 use of low-impact materials_renewable/non-exhaustible/biocompatible materials	B23 use of sustainably sourced materials	#32
		B29 water-based glues	#38

A total of 41 case cards were developed in a designed format and are accessible with an open access ethos, as seen in File S1_Case cards_41 furniture products. These cards are designed to be a valuable resource for brainstorming and have been linked to the design guidelines, seamlessly integrating into the ICS × Furniture toolkit, as elaborated in the third research stage.

Each case featured on these cards demonstrates environmentally sustainable benefits and employs innovative design approaches. Notably, only seven of these cases adopt a Life Cycle approach, considering sustainable opportunities across the entire furniture life cycle. For example, the task chair from 'Orange Box' (case #17, depicted in Figure 4) illustrates efforts towards both furniture life extension and material life extension. Conversely, most cases focus on specific design approaches targeting particular indicators, such as 'Emeco' (case #37, shown in Figure 5), which primarily highlights the use of recycled materials.

Figure 4. A case card of a sustainable furniture product with Life Cycle Design consideration.

Figure 5. A case card of a sustainable furniture product with a single design indicator.

The case study facilitated the identification of 15 design approaches and 36 design sub-approaches, with the coding details documented in File S2_Case study innovation intervention coding. These design insights have been incorporated into the formulation of furniture-specific LCD guidelines during the second stage of research.

3.3. Furniture-Specific LCD Strategies, Sub-Strategies and Guidelines

This research led to the creation of a comprehensive set of furniture-specific LCD guidelines, featuring 7 strategies, 21 sub-strategies, and 154 guidelines, all aimed at fostering the development of environmentally sustainable furniture ideas.

The seven strategies identified are as follows:

- Furniture Use Extension/Intensification: focuses on reducing the environmental impact of furniture and its components by extending or intensifying its lifespan.
- Reducing Material Consumption of Furniture: aims to minimize material use throughout its life cycle, from extraction and processing to transportation and disposal.
- Furniture Materials Life Extension: seeks to prolong the lifespan of furniture materials through recycling or composting.
- Resources Conservation/Bio-compatibility: emphasizes the use of renewable or inexhaustible resources, including both energy and materials.
- Reducing Toxicity of the Furniture System: focuses on selecting materials or processes that minimize the emission of harmful substances throughout the furniture's life cycle.
- Reducing Energy Consumption of the Furniture System: aims to decrease energy use across all stages of the furniture's life cycle.
- Design for Furniture Disassembly: encourages designing furniture that is easily disassembly, promoting materials recycling and furniture reuse.

Table 3 offers an example that shows the hierarchical structure of these strategies, with relevant sub-strategies and specific guidelines for each. For a comprehensive understanding and access to the full list of furniture-specific strategies, sub-strategies, and guidelines, interested individuals can visit the LeNSLab Polimi 'Learning Resources' section on the official website.

Table 3. A furniture-specific strategy with sub-strategies and guidelines.

Strategy: 1. Furniture Use Extension/Intensification
Sub-strategies 1.1: Facilitate furniture maintenance; 1.2: Facilitate furniture upgrading and adaptation; 1.3: Design furniture for reliability; 1.4: Facilitate/enable furniture re-use and remanufacturing; 1.5: Intensify furniture use.
Guidelines_1.2: Facilitate furniture upgrading and adaptation. 1.2.1: Design reconfigurable furniture that is able to adapt to different spaces/situations, such as modular desk and storage structures that can be used for both the transformation of a given office space or for a new function (e.g., an individual working station that can be transformed into a collective one, and that can also be rearranged if the office moves to a new location). 1.2.2: Design a family of products instead of single ones, with different properties and functions that enable adaptation. 1.2.3: Include add-on parts to transform and/or upgrade the function and properties of the furniture. 1.2.4: Design for changeable ergonomic positions, e.g., a height-adjustable desk and chairs. 1.2.5: Avoid premature aesthetic obsolescence by designing furniture that can be customized (e.g., exchangeable seat covers) or personalized with a corporate identity via software to avoid add-on brand identification operations (printing, adhesive plates, etc.). 1.2.6: Consider designing multi-functional products that can adapt to the user's development (physical and cultural). 1.2.7: [Office seats] Design modular and on-site upgradable seats, allowing the user to substitute (with standard tools) fixed feet with wheels and/or fixed components with adjustable ones. 1.2.8: [Office desks] Design modular and on-site upgradable desks, allowing the user to add (with standard tools) drawers, change drawer typology, add inner cabling cabinets, etc. 1.2.9: [Office storage] Design modular and on-site upgradable storage, allowing the user to add (with standard tools) shells, change drawer typology, etc. 1.2.10: Co-design furniture and connection platforms such as flooring, ceilings, and walls. 1.2.11: Include multiple connection possibilities on tables and storages, e.g., electricity cables, joints to combine table surfaces, etc. 1.2.12: Provide website and/or app with instructions and tools to enable maintenance and repair by the user, such as periodic maintenance procedures, e.g., cleaning of hard surfaces (desk, storage), inspection, repair, and lubrification (height-adjustable mechanism for office chairs or wheels). 1.2.13: [Office desks] If related to tech devices, enable upgrading and design reconfigurable desks according to forecastable technology development, e.g., Wi-Fi system/wireless system of automated desks.

Note: The whole list of developed furniture-specific LCD guidelines can be found at https://www.lenslab.polimi.it/learning-resources/ (accessed on 21 february 2024), within the title of "furniture product environmental sustainability".

3.4. The ICS × Furniture Toolkit: Objectives, Functions and Integration in the Design Process

The furniture-specific LCD guidelines, hierarchically structured into 7 strategies, 21 sub-strategies, and 154 guidelines, as detailed in Section 3.3, along with the analysis of 41 sustainable furniture product best cases in Section 3.2, have been integrated into the ICS × Furniture toolkit. This toolkit is designed with the primary goal of guiding designers and companies towards the creation of environmentally sustainable furniture products. It aims to facilitate the application of LCD principles in furniture product design and innovation, thereby promoting more sustainable practices within the industry. The ICS × Furniture toolkit can be found in File S3.

The ICS × Furniture toolkit is built upon a spreadsheet that integrates four interconnected tools, facilitating effortless navigation between them, as illustrated in Figure 6. The toolkit comprises:

1. Checklist for Existing Furniture Evaluation: this consists of six checklists, one tailored to each strategy, designed to assess the design priorities for the existing furniture items.
2. ECO-Idea Boards: there are six sets of boards, again, one for each strategy, intended to foster the generation and visualization of eco-friendly design concepts.
3. Checklist for Concept Improvement/Furniture LCD Strategy Pursuit Evaluation: this tool is divided into three levels of detail for evaluating and enhancing design concepts according to LCD strategies—simplified (strategy level), normal (sub-strategy level), and deep (guideline level).
4. Multi-Strategy Radar: a visual tool that depicts how a furniture design or concept aligns with various LCD strategies, providing a holistic view of its sustainability aspects.

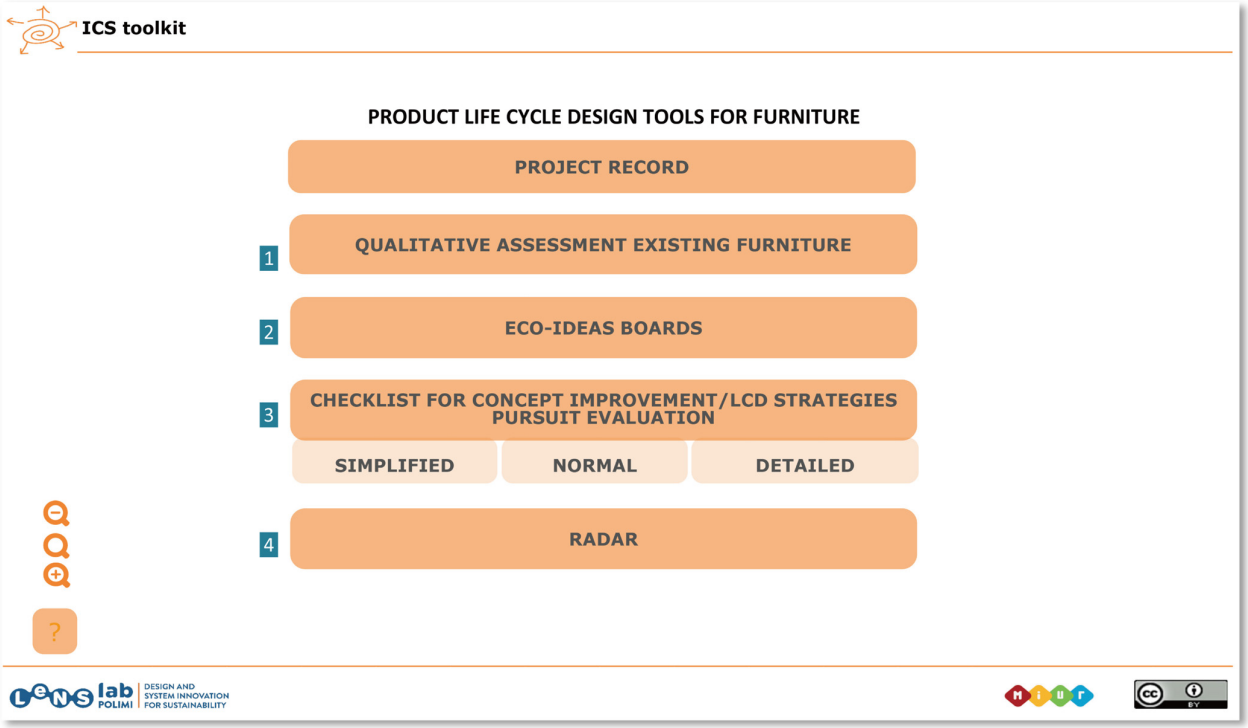

Figure 6. The ICS × furniture toolkit homepage. All 4 tools are linked to homepage for easy navigation.

These tools in the ICS × Furniture toolkit, while varied in their individual functionalities, are collectively engineered to aid in the creation of sustainable furniture products. The toolkit encompasses a range of tools, each designed for specific stages of design, offering users the flexibility to choose and utilize the tools that best suit their project's specific needs. The following detailed descriptions provide insights into the goals, components, usage instructions, and how each tool can be effectively incorporated into the design process.

3.4.1. Checklist for the Existing Furniture Evaluation

The primary purpose of this tool is to perform a qualitative assessment of the environmental impact of existing furniture, with the goal of identifying the priority levels for each of the six furniture product LCD strategies based on their potential for environmental improvement. This tool, as depicted in Figure 7, includes the following:

1. Six checklists, each one related to one specific furniture LCD strategy;
2. A navigator to move between different checklists;
3. A list of environmentally focused questions associated with each strategy;
4. Space for environmental analysis results for reference furniture;
5. A drop-down menu for users to assign priority levels to each strategy;
6. Visual representation of assigned priorities assigned to each design strategy.

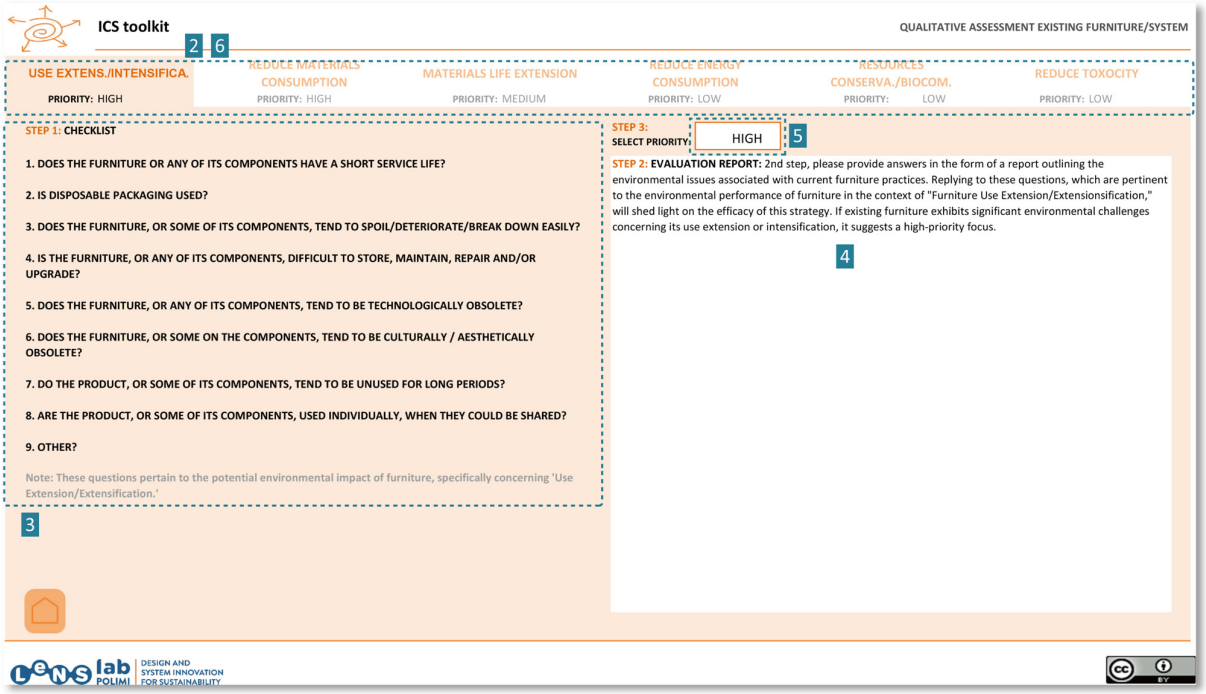

Figure 7. The components for checklist for the existing furniture evaluation.

This checklist is intended to be incorporated into the 'furniture product strategic analysis' phase of the design process. It helps evaluate the environmental impact of reference furniture and, subsequently, prioritize environmental design strategies effectively.

3.4.2. ECO-Idea Boards (Integrating Furniture Product LCD Guidelines and Cases)

The ECO-idea boards are designed to support the generation and collection of ideas that enhance the environmental sustainability of furniture products. This tool is comprised of seven sets of boards, each linked to a specific LCD strategy, equipped with previously established priorities along with detailed guidelines and best cases associated with specific guidelines. These elements are aimed at stimulating and guiding the generation of eco-friendly design ideas. This tool, as depicted in Figure 8, includes the following:

1. Eleven idea boards for 7 furniture LCD strategies;
2. A navigator enables seamless transition between different idea boards;
3. A list of design guidelines for each strategy;
4. e-post-its allow users to write down promising new ideas during brainstorm;
5. Best practices linked to certain guidelines, to illustrate successful implementations and inspire new ideas;
6. Visualization of priorities for each strategy to indicate where to start and the importance of each strategy for the project.

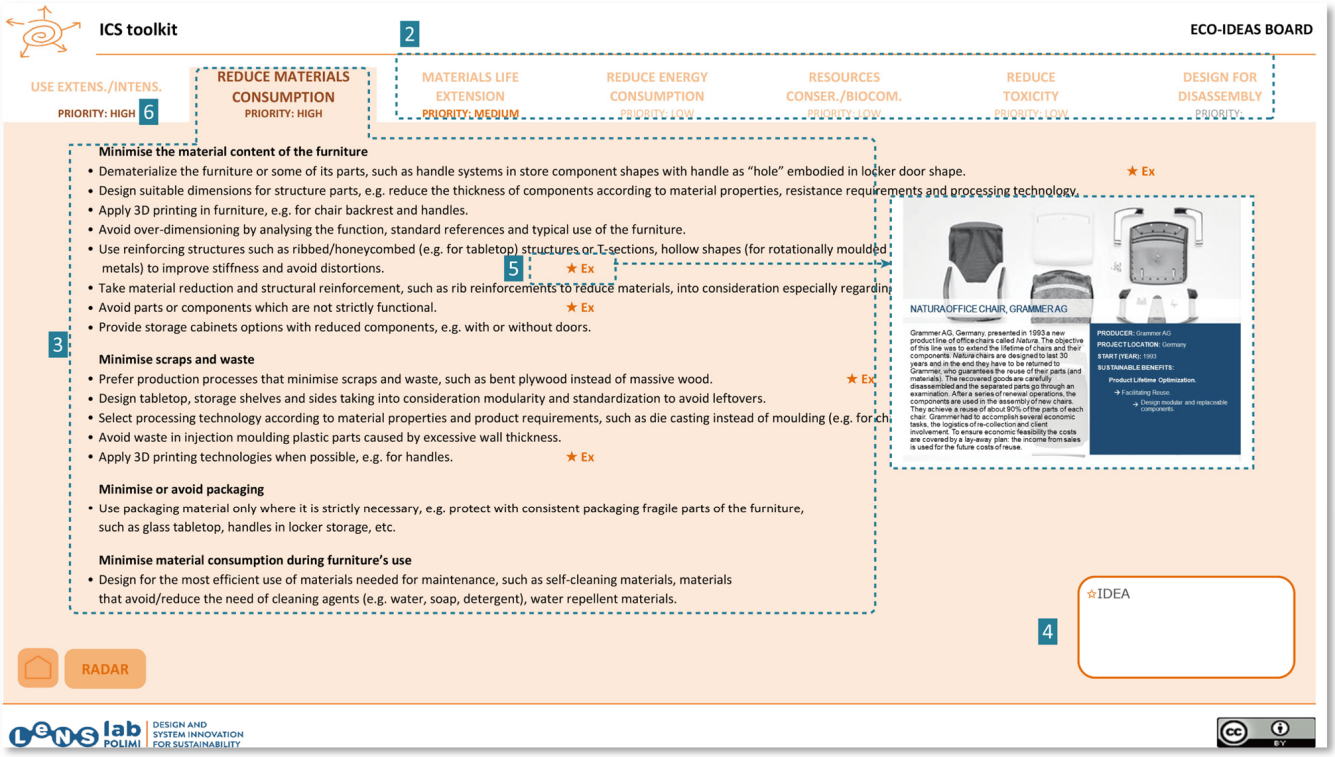

Figure 8. ECO-idea boards for 7 furniture product LCD strategies linked to 41 case cards.

The ECO-idea boards are supposed to be applied in the 'furniture product concept design' stage to facilitate environmental sustainability-focused ideas generation, selection, and clustering.

3.4.3. Checklist for Concept Improvement/LCD Strategies Pursuit Evaluation

The checklist for concept improvement, available in both simplified (on the strategy level) and normal versions (on the sub-strategy level), is designed to provide a qualitative assessment of the extent to which a new concept represents an improvement over existing furniture. Meanwhile, the checklist for LCD pursuit evaluation, detailed at a deep level, seeks to offer a qualitative measure of how thoroughly the new furniture concept adheres to furniture-specific LCD guidelines.

This tool (normal version), as depicted in Figure 9, includes the following:

1. A Drop-down List: This component allows users to assess the level of improvement achieved for each sub-strategy. The options available range from "worse" to "no improvement", "incremental improvement", and "radical improvement";
2. Identified Priority for Each Strategy;
3. A Score and Level of Improvement for the Pursuit of Sub-strategies;
4. A Final Score and Level of Improvement for the Pursuit of Strategies.

The Checklist for LCD Strategies Pursuit Evaluation is designed to be incorporated into the 'furniture product concept design' stage to facilitate the environmental sustainability evaluation of furniture product concepts, comparing them against a standard product. During the 'furniture product communication' stage, the results of this evaluation and comparison can be utilized effectively as key content for communication.

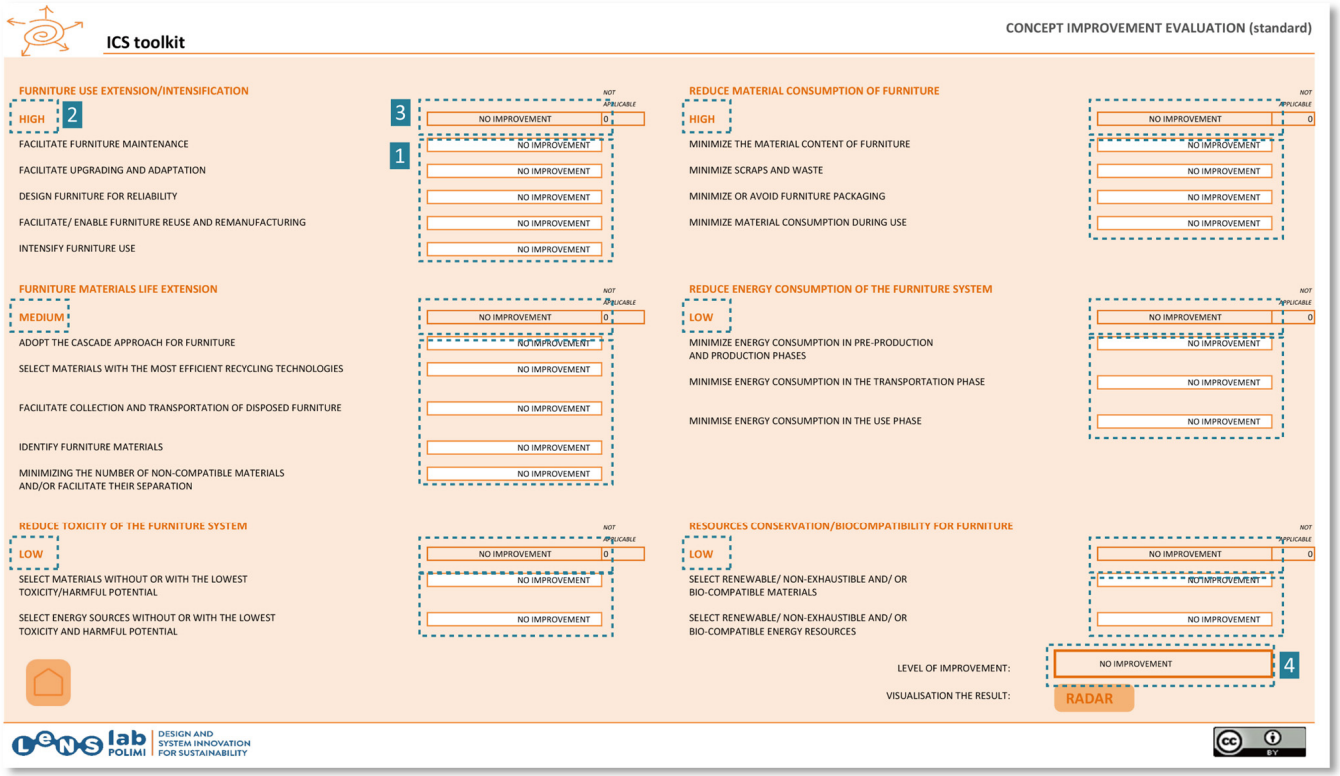

Figure 9. The components for the checklist for furniture product LCD strategies pursuit evaluation (normal).

3.4.4. Multi-Strategy Radar

The radar is a visual tool designed to summarize evaluations and ideas developed with the idea boards. Specifically, the radar can be employed to illustrate the allocation of intervention priorities for each LCD strategy, visualize the potential improvement level determined by the concept—whether it is radical, incremental, none, or worsened—and highlight the main characteristics contributing to these improvements in the furniture concept. Furthermore, the radar also acts as an effective tool for collecting the most promising ECO-ideas generated during the ideation phase. This tool, as depicted in Figure 10, includes:

1. A radar map to visualize the potential improvement of the furniture product concept over the existing furniture product for each of six strategies;
2. A space for each strategy to summarize and highlight the promising ideas identified for the new concept;
3. Text to keep users informed about the level of priorities and the degree of improvement for each strategy.

The multi-strategy radar, due to its multifunction, can be effectively integrated at various stages of the design process. Its applications include:

During the Strategic Analysis Phase: The radar can be employed to visually report the identified environmental priorities for each strategy. During the furniture product concept design stage: In conjunction with ECO-idea boards, the radar facilitates the transfer and clear visualization of the best ideas. It serves as a visual synthesis, illustrating the overall potential environmental benefits of the concept. During the furniture product communication stage: The tool can be utilized to present the environmental comparison results with reference products.

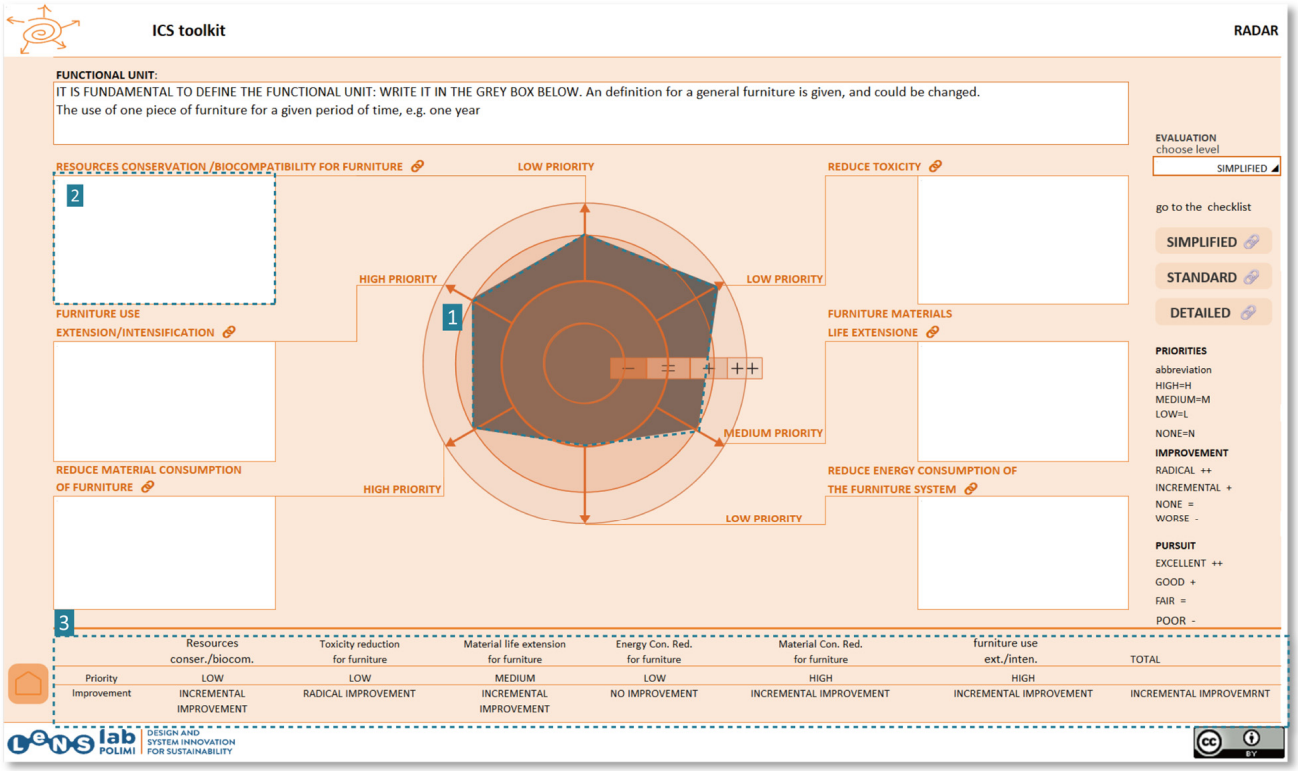

Figure 10. Muti-strategic radar.

3.5. The ICS × Furniture Toolkit: Evaluation

3.5.1. The Result of Tools Evaluation within the Course

Through the utilization of the toolkit, each group generated many sustainability-oriented design ideas, as shown in Table 4. Although not all work was finalized due to time constraints, all groups managed to address some key aspects of furniture LCD. For example, the concept of group 1 is characterized by a universal joint that facilitates easy assembly and disassembly for repair and upgrade. Additionally, by incorporating a QR code, transparent information such as the source of materials and recycling methods is displayed (see Figure 11). Differently, the concept of group 4 is characterized by reduced material content and a simplified structure (see Figure 12).

Table 4. New ideas generated by furniture designers in the workshop.

Group	Result of Using the ECO-Idea Boards
1	32 new ideas
2	16 new ideas
3	20 new ideas
4	18 new ideas

The questionnaire also provided valuable feedback. The quantitative evaluation results are presented in Table 5, at the same time some qualitative responses were collected. Regarding comprehensibility, most participants (67–73%) rated as very comprehensible or completely comprehensible with the toolkit. Regarding usability, most participants (67–73%) rated these tools as more than very satisfied. Most participants highly rated the success of the toolkit, with 80% being more than very satisfied with the ECO-idea boards. This can also be confirmed by the richness of the new ideas generated after using the tool. As a general comment, 93.3% of students would like to use ECO-idea boards in future projects, 66.7% of students would like to use the checklist for existing furniture evaluation,

53.3% would like to use the checklist for furniture LCD strategies pursuit evaluation, and 40% would like to use ESPI form and radar.

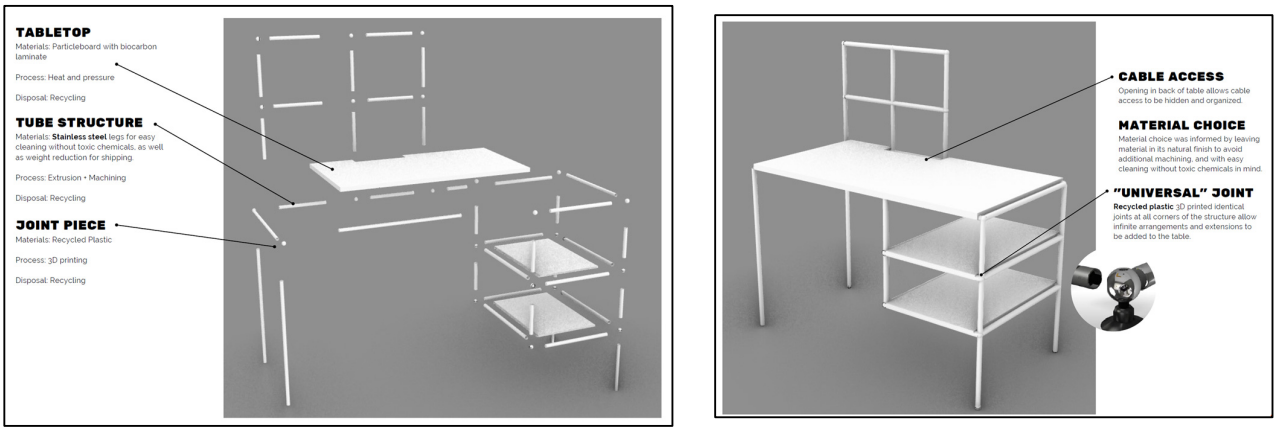

Figure 11. The concept of group 1.

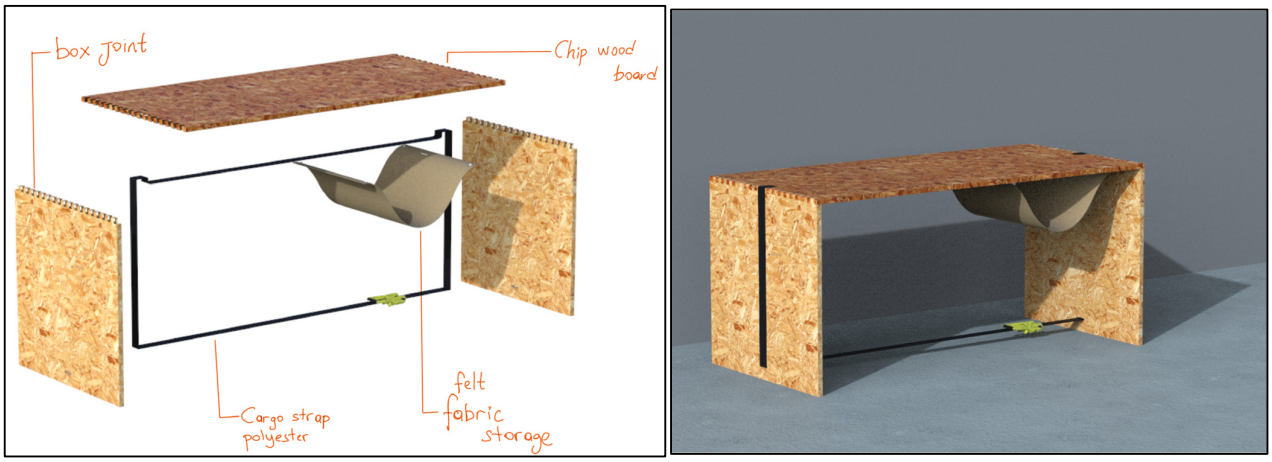

Figure 12. The concept of group 4.

Table 5. Questionnaire results from the workshop at Poli Design.

Rating: 1 = very unsatisfied; 2 = unsatisfied; 3 = moderately satisfied; 4 = satisfied; 5 = very satisfied						
Tool	1	2	3	4	5	4 + 5
Comprehensibility: Do you clearly understand the aim of the tool?						
ECO-idea boards	0%	0%	27%	40%	33%	73%
Multi-strategy radar	13%	7%	7%	53%	20%	73%
Checklist for existing furniture evaluation	0%	13%	13%	20%	53%	73%
ESPI form	7%	7%	20%	27%	40%	67%
Checklist for LCD strategies pursuit evaluation	0%	7%	27%	27%	40%	67%
Usability: is it easy to understand how to use the tool						
ECO-idea boards	0%	0%	27%	27%	47%	73%
Multi-strategy radar	0%	7%	20%	33%	40%	73%
Checklist for existing furniture evaluation	0%	0%	27%	27%	47%	73%
ESPI form	0%	7%	27%	27%	40%	67%
Checklist for LCD strategies pursuit evaluation	0%	0%	33%	60%	7%	67%

Table 5. *Cont.*

Success/Usefulness: do you think the tool is helpful to achieve its aim?						
ECO-idea boards	0%	13%	7%	20%	60%	80%
Multi-strategy radar	0%	7%	33%	47%	13%	60%
Checklist for existing furniture evaluation	0%	13%	53%	20%	13%	33%
ESPI form	0%	0%	21%	43%	36%	79%
Checklist for LCD strategies pursuit evaluation	0%	0%	27%	53%	20%	73%

Drawing conclusions from the feedback collected, it can be stated that the tool required some improvements from the function point of view to improve its usability and comprehensibility. Some efforts have been made to address the following aspects and develop the second version of the ICS × Furniture toolkit:

- A tool guide video presentation has been made for users to understand the function of each tool and how to use each tool.
- Since the ECO-idea boards and the Checklist for Existing Furniture Evaluation contain many pages, we redeveloped the title bar for better navigation to avoid missing some strategies.
- Color differentiation was used to guide the operation of tools.

3.5.2. Tools Evaluation with Experts

Within the second series of evaluations, all feedback, encompassing a total of 102 comments, was collected and coded. The majority of designers and experts acknowledged the toolkits as successful in fulfilling their objectives, with the overall usage experience being positive. Participants praised the tools for being inspirational, opening up new opportunities, and expressed their interest in utilizing them in future projects. The logical flow of the application steps and sequences of the tools was noted for its clarity, and the smooth integration between these tools was highlighted. The toolkit was recognized for its logical structure and expertise in achieving its intended purpose.

Despite the positive feedback, participants also shared their expectations for further improvements to the toolkit. Taking into account the feedback received, a total of 30 enhancements were implemented to refine the ICS × Furniture toolkit, resulting in the creation of its third version. However, one significant area of concern was its development on the Excel platform, which some found to be less user friendly compared to online platforms, particularly regarding collaboration functions. Although various platforms recommended by designers, such as board mix, Fabire, Feishu, Tencent form, and Miro, were explored, and advice was sought from computer programmers, there was no alternative platform identified at the time that could support a comprehensive set of functions like formula calculation, table creation, collaboration, and open access coding and updating, all of which are currently facilitated by Excel.

3.5.3. Online Questionnaire

A total of 21 LeNS network members provided feedback through the questionnaire, offering positive responses in terms of comprehensibility, usability, and the overall usefulness/success of the tools, marking a significant improvement over the assessments for the toolkit's first version. These members are from the field of Design for Sustainability, spanning across disciplines including product and furniture design.

In regard to the four tools within the ICS × Furniture toolkit, a substantial majority of respondents—ranging from 71% to 76%—rated them as easily understandable. The toolkit's usability and effectiveness received even higher values, with scores between 71 and 90% for usability and 76–90% for effectiveness, as detailed in Table 6.

Table 6. The evaluation result of the questionnaire.

Rating: 1 = very unsatisfied; 2 = unsatisfied; 3 = moderately satisfied; 4 = satisfied; 5 = very satisfied						
Tool	1	2	3	4	5	4 + 5
Comprehensibility: Are the ICS × Furniture toolkit (and integrated tools) easily understandable (for the function and aim)?						
Checklist for existing furniture evaluation	0%	0%	24%	62%	14%	76%
ECO-idea board	0%	0%	24%	57%	19%	76%
Checklist for furniture product LCD strategies pursuit evaluation	0%	0%	29%	52%	19%	71%
Multi-strategic radar	0%	5%	24%	43%	29%	72%
Usability: Are the ICS × Furniture toolkit (and integrated tools) easily used?						
Checklist for existing furniture evaluation	0%	0%	24%	48%	29%	76%
ECO-idea board	0%	5%	24%	52%	19%	71%
Checklist for furniture product LCD strategies pursuit evaluation	0%	5%	14%	52%	29%	81%
Multi-strategic radar	0%	0%	10%	62%	29%	90%
Success/Usefulness: To what extent do you think the ICS × Furniture toolkit is useful to fulfill its aims?						
Checklist for existing furniture evaluation	0%	0%	24%	38%	38%	76%
ECO-idea board	0%	0%	24%	29%	48%	76%
Checklist for furniture product LCD strategies pursuit evaluation	0%	0%	10%	57%	33%	90%
Multi-strategic radar	0%	0%	14%	24%	62%	86%

4. Discussion

In the furniture industry, several sustainable design strategies have been proposed, such as minimizing material usage [34] and choosing resources with lower environmental impacts [21]. However, these strategies often target single indicators, falling short of addressing the complex challenges of sustainability along the furniture's life cycle. There is some fragmented research on specific aspects of furniture LCD, and a pressing need to establish new, comprehensive, and furniture-specific LCD knowledge and tools is appearing.

To fill this gap, this research defines the characteristics of sustainable furniture products by introducing a comprehensive framework of furniture-specific LCD strategies, 21 sub-strategies, and 154 guidelines, alongside best practices. The primary innovation lies in these 21 furniture-specific sub-strategies and 154 guidelines developed to effectively reduce the environmental impact of furniture across its entire life cycle. Another notable innovation is filling the gap of lacking tools for furniture LCD by developing the ICS × Furniture toolkit, which integrates these guidelines and best practices, thereby making the furniture LCD process transparent and straightforward to implement. This toolkit facilitates the entire furniture LCD process, from strategic analysis and concept design to product design, engineering, and communication (as illustrated in Figure 13), playing a crucial role in improving design efficiency.

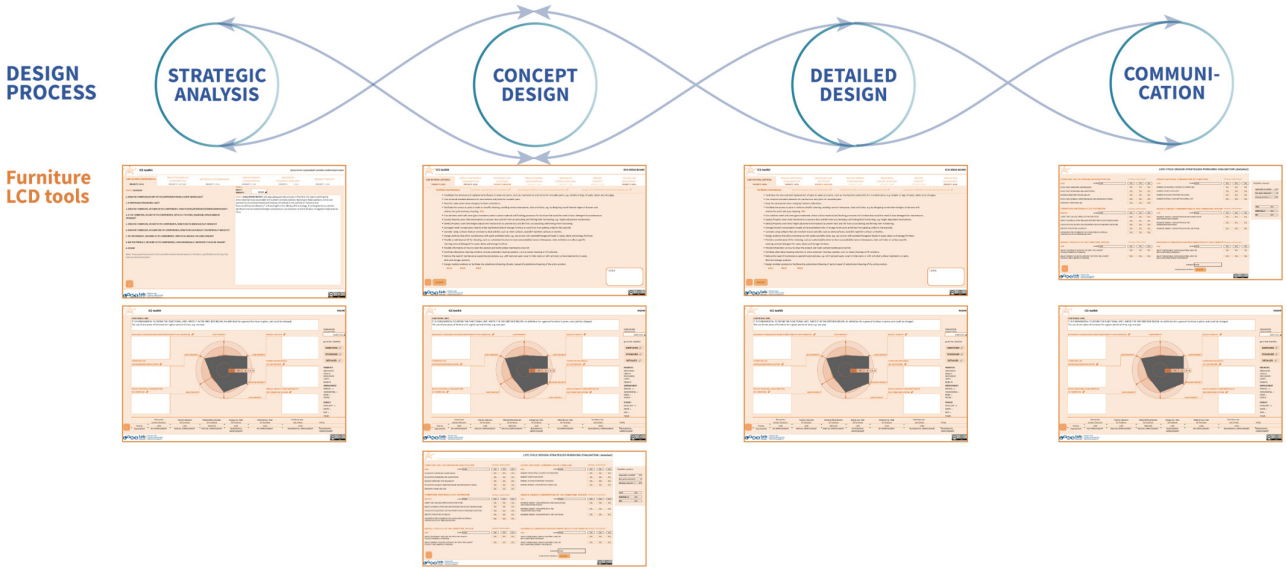

Figure 13. The integration of ICS × Furniture toolkit (and each tool) into sustainable furniture product design process.

5. Conclusions

The development of these furniture-specific LCD strategies, sub-strategies, and guidelines, along with the toolkit, represents a significant advancement. These resources aim to support various stakeholders involved in furniture LCD, including researchers, teachers, students, designers, design studios, furniture companies, NGOs, and other interested organizations. Researchers engaged in furniture LCD projects can tailor these guidelines to their specific contexts and objectives, whether focusing on a particular country, industry area, typology, furniture company, design studio, etc. For educational purposes, the guidelines, cases, and toolkit can provide valuable support for students seeking a deeper understanding of furniture LCD. Likewise, for designers involved in furniture LCD projects, the toolkit offers comprehensive guidance throughout the entire design process, from strategic analysis to communication, and can seamlessly integrate into the overall design process to enhance sustainability.

The ICS × Furniture toolkit is distributed through the LeNS Network, which links over 150 universities and institutions dedicated to promoting the Design for Sustainability discipline into curricula worldwide, using a multipolar, open, and copyleft ethos. Furthermore, the toolkit is being applied in international master's courses and is subject to ongoing improvement to foster a culture of collaborative and open innovation within the furniture industry. While open innovation is a well-established and widely embraced concept across various sectors [67], the adoption of sustainable furniture design knowledge is limited. Nevertheless, the furniture-specific LCD guidelines and toolkit presented in this research can act as valuable knowledge for designers and organizations, supporting the integration of sustainability from the initial design phases.

Despite the progress made, certain limitations remain that need to be addressed in the near future. The demand for enhanced collaboration or co-creation capabilities with the ICS × Furniture toolkit was mentioned repeatedly during the assessment. Despite a lot of trials across various platforms, fulfilling all functions (formula calculation, automation, table creation, open access coding, and updating, as well as collaboration) has proven challenging. Further improvement should be pursued as new opportunities arise. Furthermore, additional application and quantitative evaluation activities involving furniture companies in real projects would be beneficial. On the other hand, there is recognition that guidelines tailored for specific types of furniture (such as task chairs or customized pieces) or tailored to meet the requirements of individual furniture companies may yield the greatest environmental benefits in real-world design practices. With the research outcomes accessible on

an open access basis, it creates opportunities for other research groups and companies to develop more detailed and specific knowledge and expertise in particular contexts.

This research is trying to address fundamental issues within the furniture industry, particularly concerning the environmental impact of furniture products. Additionally, there is a need to delve deeper into product-service system innovation and business model transformation.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su16072628/s1, File S1: case cards_41 furniture products; File S2: case study innovation intervention coding; File S3_ICS × Frutnirue toolkit. The newly developed furniture-specific LCD guidelines can be found at https://www.lenslab.polimi.it/learning-resources (accessed on 21 February 2024), in the section guidelines and cases section. The collected cases and the coding are attached in File S1 and File S2, the ICS × Furniture toolkit is provided in File S3.

Author Contributions: Conceptualization, D.Y. and C.V.; methodology, D.Y. and C.V.; software, D.Y.; validation, D.Y. and C.V.; formal analysis, D.Y.; investigation, D.Y.; resources, D.Y. and C.V.; data curation, D.Y.; writing—original draft preparation, D.Y.; writing—review and editing, D.Y. and C.V.; visualization, D.Y.; supervision, C.V.; project administration, C.V. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflicts of interest.

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