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Designing sustainable furniture: guidelines to promote furniture Life Cycle Design



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Abstract

Given the serious environmental impact of the furniture system, the role of design in innovating furniture products toward sustainability is increasingly recognized as a key leverage, as acknowledged by the European Union's Circular Economy Action Plan in 2020. The need for sustainable design knowledge to address environmental issues caused by the life cycle of furniture products – a fundamental part of the furniture system – has now been prioritized. Despite the fact that Life Cycle Design (LCD) is widely studied as a systematic approach that considers all life cycle stages and engages the objectives of reducing environmental impacts, its application within the furniture system is still very limited. Within this framework, the paper presents furniture-specific LCD guidelines to guide sustainable furniture design. These guidelines were developed through an established methodology involving scholars and specialists on both Design for Sustainability and Furniture Design, and were the results of a research project funded by the Italian Ministry of Education (MIUR), aimed at developing and disseminating innovative design strategies and guidelines to foster a sustainable and circular economy within the furniture industry. In this sense, these guidelines will promote long-term open innovation and technological transformation of furniture products, allowing designers and organizations to support the implementation of sustainable options from the beginning of the design process.

Author keywords

furniture design; Life Cycle Design; design guidelines; sustainable design.

Introduction

Furniture has recently been identified as one of the key sectors that should be addressed and improved to achieve more sustainable development (European Commission, 2020). Estimated by the Centre for Industrial Study (CSIL), total global furniture production in 2019 was US\$490 billion, exportation was US\$160 billion, and consumption was US\$477 billion (CSIL & CNFA, 2020), resulting in huge resource consumption, harmful emissions and waste generation. Each year, 10.5 million tons of furniture are produced in the European Union, with 10 million tons of furniture waste generated, accounting for more than 4% of municipal solid waste in the European Union (EU) (Forrest et al., 2017). These impacts could also be

seen throughout the life cycle of furniture, including pre-production, production, distribution, use and disposal (González-García et al., 2019).

The role of design

The importance of design in innovating furniture products for sustainability is becoming more widely recognized. Up to 80% of a product's environmental impacts are determined during the design phase (European Commission, 2020), emphasizing the importance of sustainable design knowledge in addressing major environmental issues associated with the furniture life cycle. Indeed, addressing environmental concerns early in the design process is more efficient than retroactive actions, as it avoids costly and dangerous operations to reverse or limit the damage. Looking at the overall design scene, although disciplines like environmentally sustainable product design or LCD are widely studied, their application within the furniture sector is still quite limited. Furniture LCD is the design of the furniture life cycle stages that aims to minimize the overall environmental impact of all life cycle processes concerning the functional unit (Vezzoli, 2018). Two major approaches, in particular, must be introduced. The first is the life cycle thinking approach, which means shifting from furniture design to the design of furniture life cycle stages, i.e. considering all processes required to produce, distribute, use and dispose of materials and furniture. The second approach is the functional unit approach, i.e., considering the function of the furniture rather than the physical furniture itself during design and impact evaluation.

The development of furniture-specific LCD guidelines

In this scenario, the paper presents innovative furniture-specific LCD guidelines. The development of furniture-specific guidelines was carried out as part of more than two decades of research of LeNSlab Polimi, a research group within the Design Department of Politecnico di Milano, working on Design and system Innovation for Sustainability (DIS).

In particular, the current contribution is based on the results of the research project *The Circular Economy for the competitiveness of Made in Italy industry - GIOTTO*, which was funded by the Italian Ministry of Education and Research (MIUR) in collaboration with eleven national organizations. The project aimed at developing and disseminating innovative design

guidelines and tools to promote and implement a sustainable and circular economy within competitive value chains of Made in Italy, i.e. furniture, food and fashion. Through a multidisciplinary and complementary research consortium, GIOTTO contributed to empowering small and medium enterprises with innovative approaches to minimizing the environmental impact of their products throughout their entire life cycle. Within this context, LeNSlab Polimi led research activities aimed at defining specific Life Cycle Design strategies and guidelines to guide the development of environmentally sustainable furniture products.

Method: from general to furniture-specific LCD guidelines

The approaches and processes for developing specific LCD guidelines from general ones have well-established roots. Over two decades of research and consultancy activities carried out by LeNS lab Polimi gradually led to the definition of a structured and validated methodology (Vezzoli & Sciama, 2006). This study was carried out with the method as illustrated in figure 1.

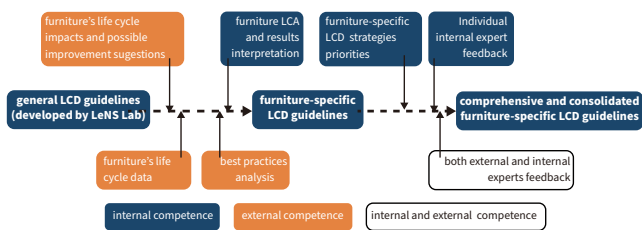


Figure 1. Prior knowledge and steps to develop furniture-specific LCD strategies/sub-strategies/guidelines, adapted from (Vezzoli & Sciama, 2006).

The project started with a preliminary phase of desk research to uncover the most updated knowledge about the environmental impact of the furniture life cycle. On one side, a critical review of available literature was conducted to analyze previous evaluations of furniture's environmental impact, i.e. Life Cycle Assessment.

On the other hand, a detailed analysis of best practices from an environmental standpoint was conducted to provide inspiration for subsequent collaborative sessions when elaborating on furniture-specific LCD guidelines. The first stage produced an overview of the environmental impact of furniture's life cycle stages and best practices representing promising designs. Results from these research actions represented the framework to facilitate the successive step within the GIOTTO project, aimed at moving from general LCD strategies and guidelines toward the definition of furniture-specific version to reduce the overall environmental impact along furniture's life cycle.

The specification process was carried out through a collaborative workshop that involved scholars and experts on Design for Sustainability and Furniture Design, with the goal of generating a preliminary draft of furniture-specific LCD guidelines. The findings of the literature review and case study were presented as a context introduction. The workshop's main activity, the guidelines specification, was then completed. 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 particular furniture products or typology; adding a

new guideline that deals with a certain environmental impact related to particular furniture products or typology; adding notes related to particular furniture product or typology; and erasing a guideline if irrelevant. The outcome of the workshop was a draft of furniture-specific guidelines, which was further reviewed and refined to integrate final improvements. Please see table 1 for a more specific example of the shift from general to furniture-specific Life Cycle Design guidelines.

Table 1. An example of generating furniture-specific strategy, sub-strategy and guideline from general ones

General strategy, sub-strategy and guideline	Furniture-specific strategy, sub-strategy and guideline
Strategy: Product lifespan optimization	Specific strategy: Furniture use extension and intensification
Sub-strategy: Facilitate repairs	Specific sub-strategy: Facilitate/enable furniture re-use and remanufacturing
Guideline: Arrange and facilitate disassembly and re-attachment of easily damageable components.	Specific guideline: Facilitate disassembly, especially for parts that are easy to wear out, such as task chair wheels and back, upholstery and desk surfaces, using reversible connections or a two-way snap-fits system.

Furthermore, proper identification of LCD strategy priorities (the degree of relevance of various strategies) that take function into account is crucial for guiding design efforts. It is assumed that some strategies have greater priorities than others for each product, whether a car, a piece of furniture or something else. For furniture, for example, extending the lifespan is more important than reducing resource consumption, whereas reducing the resource consumption is more important for a car which consumes energy while in use. As a next step, a priority indicator was defined for each of the 6 design strategies based on their potential for environmental improvement (compared to the other strategies), based on the life cycle environmental impact of furniture defined in the first stage.

Results

Furniture's environmental impact along the life cycle

The **Pre-production** stage incorporates the impact associated with the acquisition of resources, delivery to the production area and raw materials preparation. If take wooden furniture, which has a significant proportion of total furniture consumption (Forrest et al., 2017), as an example, an average production of 1 m³ particle board consumes a total of 759 kg of materials and 507 MJ energy (González-García et al. 2019). The overuse of resources may cause resource depletion or deforestation. Chemical use is a critical source of hazardous emissions. For example, formaldehyde is a sensory irritant that, depending on the concentration in the environment and exposure time, can cause health problems for workers and users, such as eye, skin and respiratory allergic reactions (Liu et al., 2012). The **Production** stage includes all activities such as raw materials processing, components and package production, furniture assembly and other finishing processes, like polishing and painting of solid wood-made furniture. The cutting, punching and sanding processes generate solid waste such as sawdust, metal and plastic residues. The assembly, finishing and coating processes use adhesives and coatings which consist of resins, pigments, sol-

vents, additives and diluents, may emit Volatile Organic Compounds (VOCs) such as alcohols, olefins, ethers, alkanes and aldehydes, as well as wastewater containing sulfide, chlorine, alcohols, olefins, alkane (Cheung et al., 2017). VOCs will harm the environment and human health (Berríos et al., 2005). The **distribution** stage is concerned with furniture packaging and transportation to a warehouse or end users' location via truck, train, ship or even plane. These activities necessitate not only the use of energy for transportation but also the use of resources to manufacture and store the means of transportation. The **use** phase, which may consume water, detergent and electricity, has low environmental impacts (Donatello et al., 2017). However, it is still an important stage that must be considered because it has the potential to extend the lifespan, reducing the environmental impacts per functional unit in the long term. The **Disposal** stage includes different scenarios. In the EU, 80–90% of furniture waste is incinerated or disposed of in landfills, with 10% recycled (Donatello et al., 2014). Many furniture products become obsolete before the actual end of their functional lifetime. This is due to various factors such as relocation, furniture inadequacy after renovation, expansion of premises or new staff, and changes in the interior or corporate design – the latter resulting in perfectly functional furniture being disposed of for aesthetic reasons. Frequent office furniture replacement contributes to increased solid waste production, requiring more landfill space (Besch, 2005). Landfill disposal may generate methane and groundwater pollutants, while incineration generates toxic ash and causes air pollution (Ulrich & Eppinger, 2012).

Last but not least, consumption of non-renewable fossil fuels such as coal, natural gas and diesel oil occurs throughout furniture's life cycle for raw materials production, transportation or electricity generation releases CO₂, CH₄, CF₄, C₂F₆, SO₂, HF, NO_x, CO, particulate matter, etc., may contribute to Global Warming (CO₂, CH₄, CF₄, C₂F₆), Acidification (SO₂, HF, NO_x), Photochemical Ozone Creation (SO₂, CO, NO_x), human toxicity (NO_x).

Many furniture LCAs (scientific papers and company Environmental Product Declarations) compares the environmental impact of furniture's life cycle stages (Wenker et al., 2018; Babarenda Gamage et al., 2008; Plaschke, 2019). Results indicate that the highest environmental impacts occur during the pre-production stage; The production stage is the second one, followed by the distribution, disposal and use stages; the pre-production stage has more significant impacts than all the other stages.

Furniture best practice analysis

Sustainable furniture best practices were investigated to discover innovative design interventions and long-term sustainable benefits and characteristics. 41 case cards (from 32 brands) were created. These case cards were used directly for brainstorming or as examples of design guidelines developed in the following stages. See an example in figure 2.

Furniture-specific LCD strategies (with priority), sub-strategies and guidelines

As a result of the research, furniture-specific LCD guidelines were developed, which include 6 strategies, 21 sub-strategies and 141 guidelines to stimulate and guide the generation of environmentally sustainable ideas. Table 2 shows an example of the hierarchical structure of each strategy, which contains several sub-strategies and additional specific guidelines.

Each of these 6 strategies was assigned a priority indicator – very high, high, medium, low and very low – which refers to the potential environmental burden reduction associated with each LCD strategy. **Furniture use extension/intensification** (very high priority) is to reduce the environmental impact of furniture and components by extending or intensifying the lifespan. **Reduce material consumption of furniture** (high priority) aims to reduce material use throughout the life cycle by avoiding extraction, processing, transportation and disposal. **Furniture materials life extension** (middle priority) seeks to extend the lifespan of furniture materials through recycling or composting. **Resources conservation/bio-compatibility** (low priority) aims to use renewable or inexhaustible resources (energy and materials). **Reduce toxicity of the furniture system** (very low priority) aims to choose materials or processes that minimize harmful substances emissions throughout the life cycle. **Reduce energy consumption of the furniture system** (very low priority) means reducing energy use throughout the life cycle.

Table 2. A furniture-specific strategy with sub-strategies and guidelines.

Strategy: 1. furniture use extension/intensification

ARA Chair - Orangebox

The design of the Cradle to Cradle certified chair ARA from Orangebox has a tongue and groove assembly feature with an attachable back support to the seatback frame. Usually seats are made out of PU foam but ARA seat is made out of a flexible elastomer, supported by a structural frame made of Long Glass Fibre Reinforced Polypropylene. The back rest can be easily disassembled due to a special mechanism which is inspired by the closing mechanism used in Tupperware and eliminates the need for fasteners at this part of the chair. Consequently, no tools are needed for exchanging or disassembling the seatback.

PRODUCER: Orangebox
NATIONALITY: UK
Website: www.orangebox.com
Year: 2019
SECTOR: Furniture/ task chair
LCD STRATEGY/IES:
Strategy: Furniture use extension
Sub-strategy: Facilitate/enhance re-use and remanufacturing
Guidelines: Facilitate the replacement of external parts, such as castors, sofa covers (clothes), upholstered chair.
Strategy: Design for furniture disassembly
Sub-strategy: Reducing and facilitating operations of furniture disassembly and separation
Guidelines: Construct the product into easily separable and manipulatable sub-assemblies

Figure 2. A case card of sustainable furniture product (own elaboration)

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 desks and storage structures that can be used for both the transformation of a given space or for a new function.
 - 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 functions and properties.
 - 1.2.4 Avoid premature aesthetic obsolescence by designing furniture that can be customized (e.g. exchangeable seat covers).
 - 1.2.5 Consider designing multi-functional products that can adapt to the user's development (physical and cultural).
 - 1.2.6 Design modular and on-site upgradable furniture, allowing the user to substitute with standard tools, for example, fixed feet with wheels or fixed components to adjustable ones.
 - 1.2.7 Include multiple connection possibilities on tables and storages, e.g. electricity cables, joints to combine table surfaces, etc.
- ... a total of 13 sub-guidelines...

All furniture-specific LCD guidelines were eventually integrated into one of the main outcomes of the GIOTTO project - the MIUR manual "Handbook for sustainable furniture system design", which was conceived as an operative tool to enhance the application of the furniture Life Cycle Design, specifically aimed at guiding designers and companies toward environmentally sustainable furniture design and innovation. The handbook is available and open access on LeNS International's 'tools' section (<http://www.lens-international.org/>).

Conclusion: furniture-specific LCD strategies and open innovation

The primary contribution of this research is a set of furniture-specific product LCD strategies, sub-strategies and guidelines with best practices. The main innovation are the development of 21 furniture-specific sub-strategies and 141 guidelines that will significantly contribute to reducing environmental impact along the furniture's life cycle.

A second innovation lies in the priority assigned to each strategy, i.e. the level of environmental impact reduction achieved by implementing the strategy, which is crucial to improve the efficiency during the design process.

A handbook that integrates all these outcomes is currently being distributed worldwide through the Learning Network on Sustainability (LeNS), an international network that connects over 150 higher education institutions and organizations, with the goal of developing and disseminating the Design for Sustainability (DfS) discipline in worldwide curricula with a multipolar, open and copyleft ethos. Moreover, the handbook is being used in international master courses, as well as subjected to implementations and improvements to foster a collaborative and open innovation logic in the furniture sector.

Indeed, even though the phenomenon of open innovation is now well-established and widespread in several disciplines (Gassmann, Enkel, & Chesbrough, 2010), the same cannot be said for the majority of sustainable furniture knowledge innovation. The handbook can represent a key resource for designers and organizations to support the implementation of sustainable choices at the early stages of the design process.

Reflection

These strategies, sub-strategies and guidelines have been developed for general furniture, but specific guidelines tailored to each type of furniture may be necessary for optimal effectiveness in real design practice. Since the outcomes of this research are open access, other groups of researchers and companies can develop more specific guidelines for individual furniture types.

The research contributes to 'Design for transformation' in the scope of the furniture sector. The design guidelines facilitate 'systemic & strategic problem solving' by supporting the furniture LCD at early stages to reduce the environmental impact throughout the life cycle.

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This book contains academic papers and posters of the Cumulus Antwerp conference, held in Antwerp on 12-15 April 2023. The Cumulus community, designers, artists, and educators were invited to submit contributions on how culture and creative industry can offer resilience, consolation, and innovation models on human scale, in line with the conference theme 'Connectivity and Creativity in times of Conflict'.

The contributions were double blind reviewed in the tracks

- 1) Nature positive/Design for transformation,
- 2) Digital futures/Hybrid reality,
- 3) Handle with care/Inclusivity, and
- 4) PhD network.

Editors: Kristof Vaes & Jouke Verlinden

